Automatic reconstruction of Building Information Models

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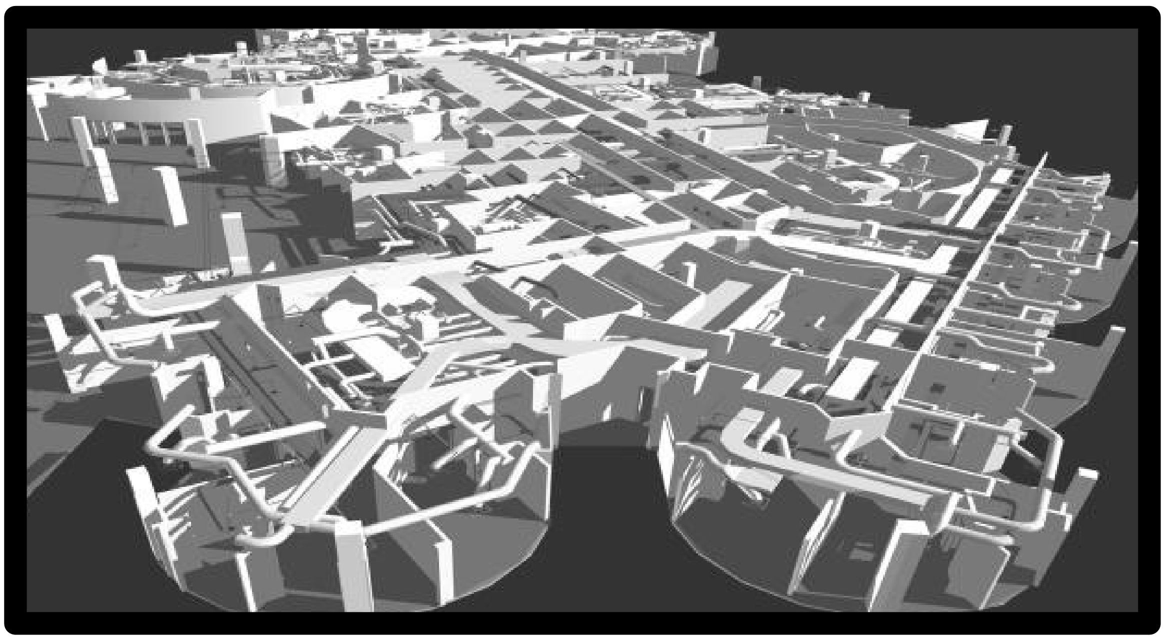
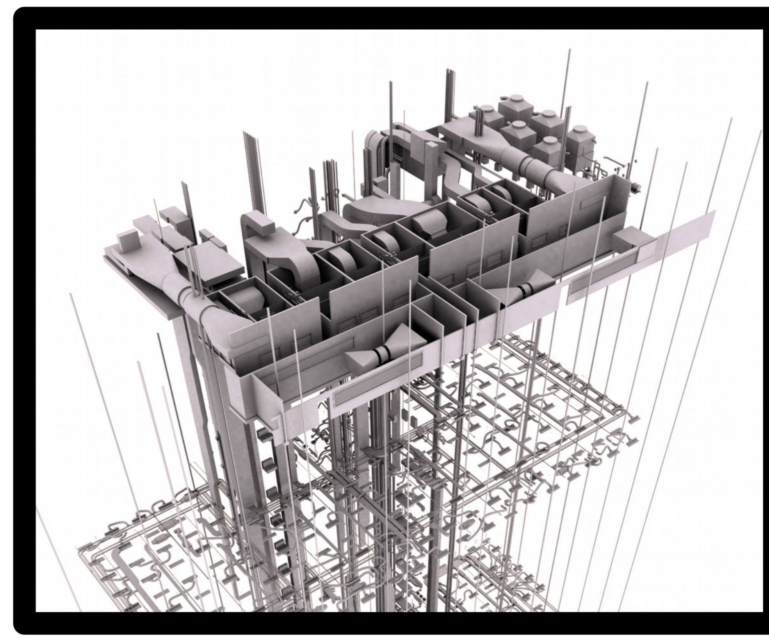
Building Information Models

The BIM is a digital representation of a building



Building Information Modeling (BIM): Benefits, Risks and Challenges
Salman Azhar et al. (2008)



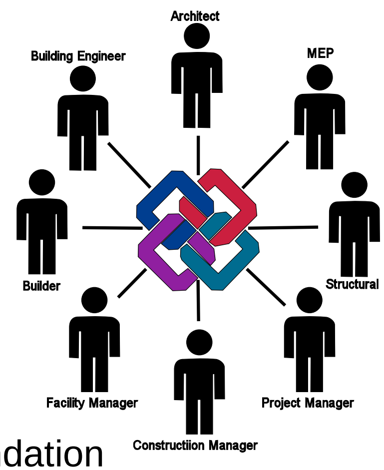
Model interoperability in building information modeling
Steel, James et al. (2010)

Building Information Model

BIM

Building Information Model

Participants Coordination

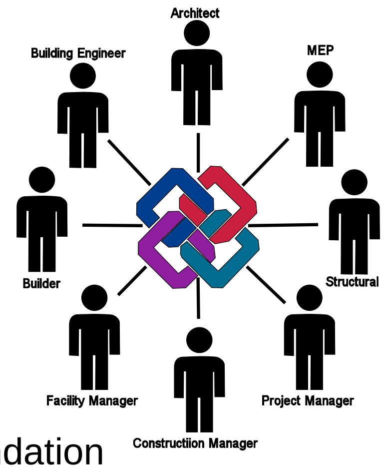


Ifc foundation

BIM

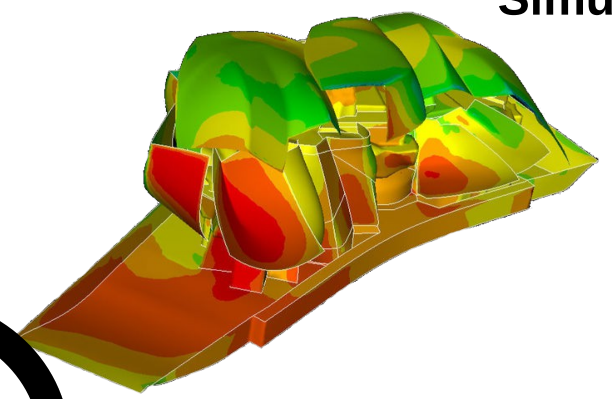
Building Information Model

Participants Coordination



Ifc foundation

Simulation

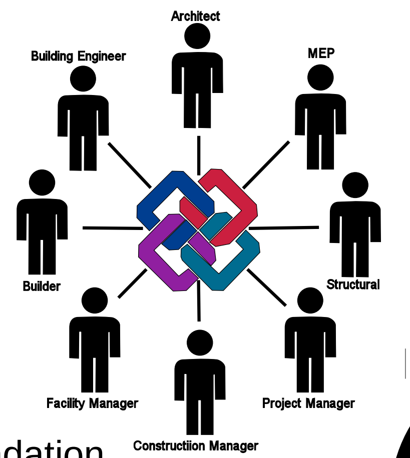


Louis Vuitton Fundation (CSTB)

BIM

Building Information Model

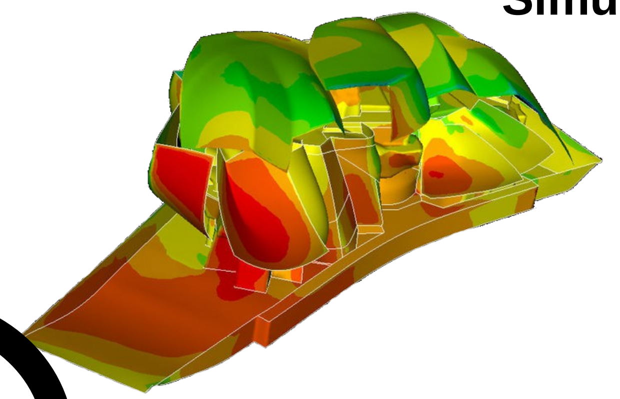
Participants Coordination



Ifc foundation

BIM

Simulation

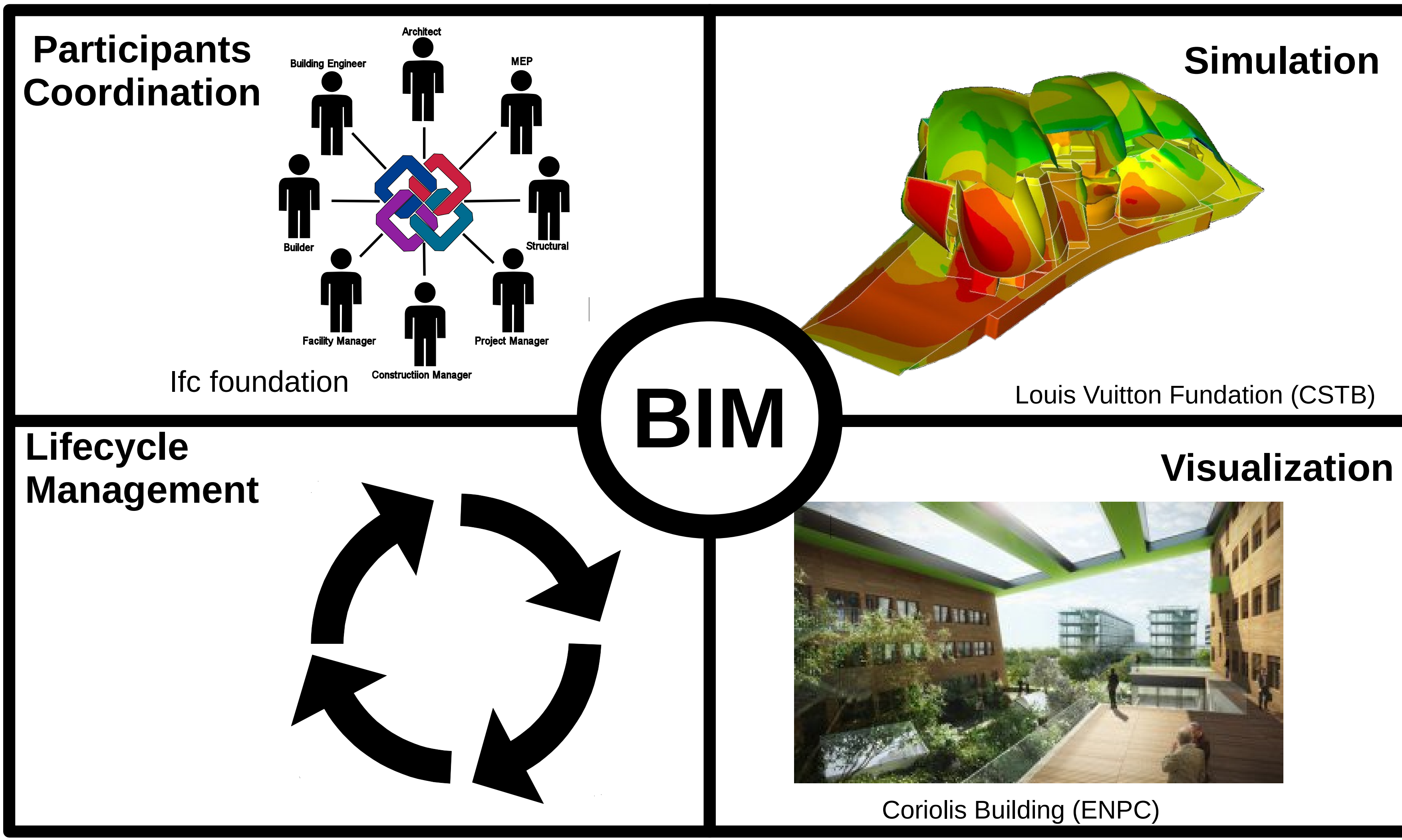


Louis Vuitton Fundation (CSTB)

Visualization

Coriolis Building (ENPC)

Building Information Model



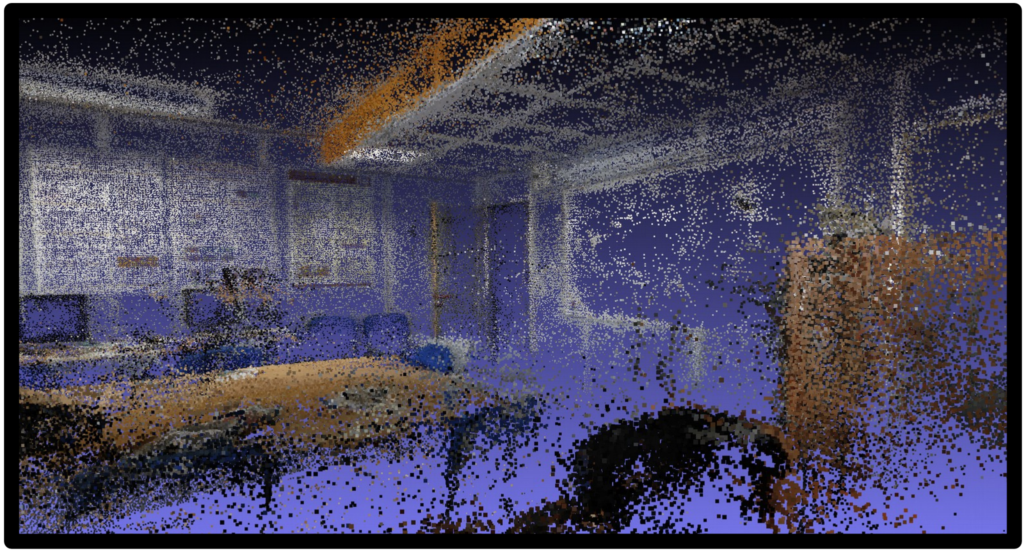
Renovation of old buildings

- Huge market (e.g., improvement of thermal performance)
- No digital model
- Wrong or inexisting blueprints

http://www.agrconstruction.fr/

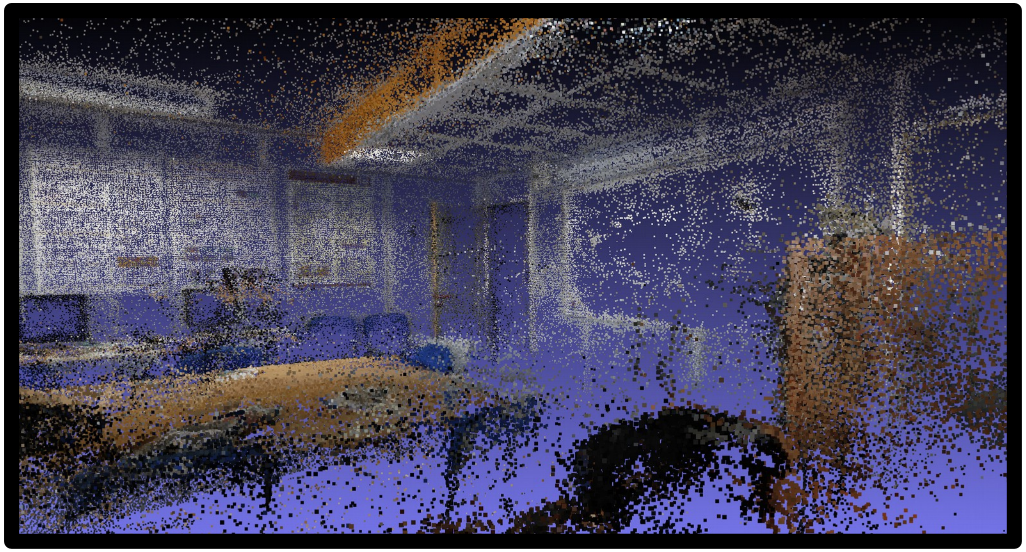
Data

- Photogrammetry



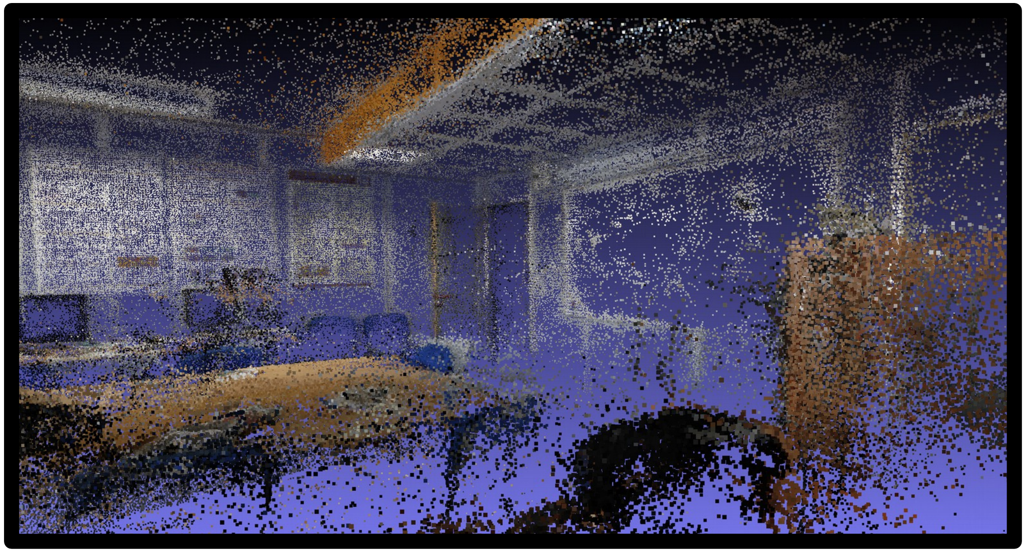
Data

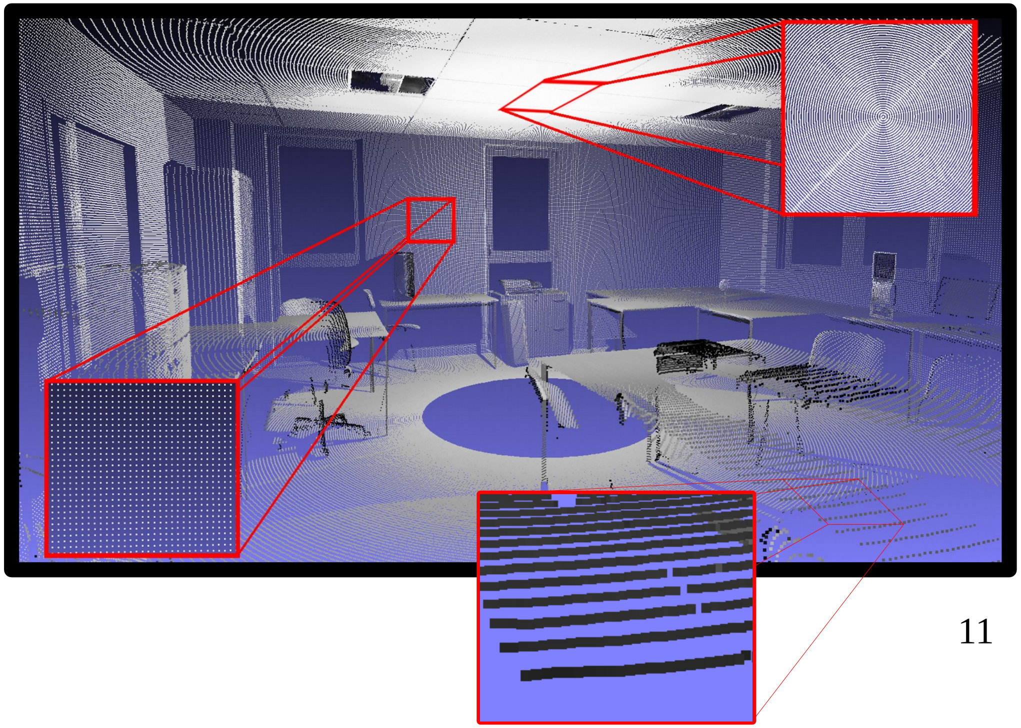
- Photogrammetry
- Depth sensors



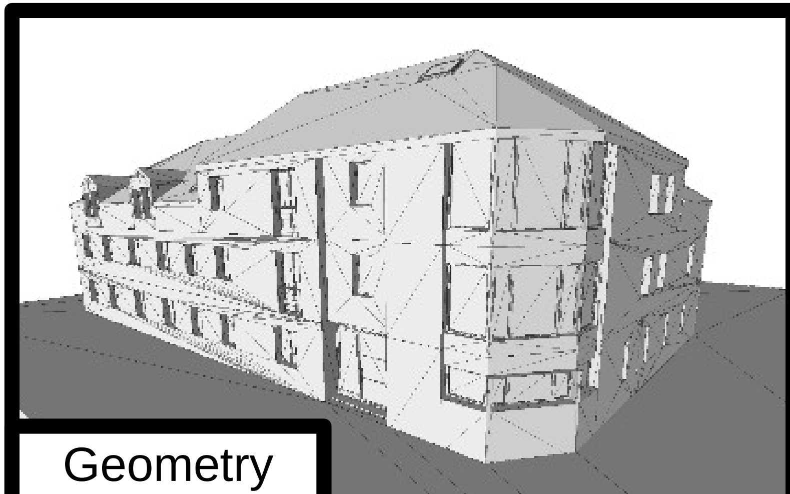
Data

- Photogrammetry
- Depth sensors
- Lasers





Reconstruct and semantize surfaces



Geometry

Building materials:

- Wall: aerated concrete
- Window: double glazing
- Window frame: aluminium
- Door: wood
- ...

Heat capacity:

- ...

Semantics

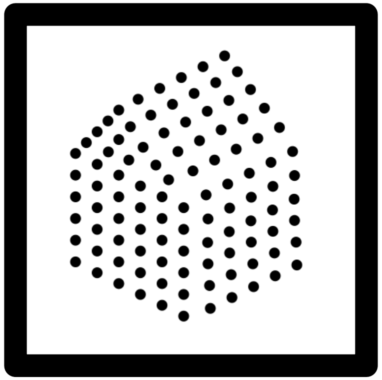
External wall
Thickness: 0.3m
Material:
aerated concrete
...

Bay window
Size: 2.30m x 2.10m
3 panels
Frame: aluminium
Double glazing
...

Door
Size: 2.60m x 2.50m
Materail: wood
...

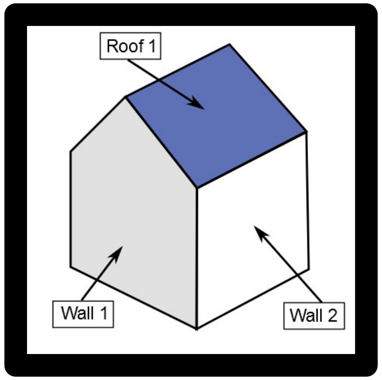
Pipeline

Point cloud



Structure and information enrichment

Digital model

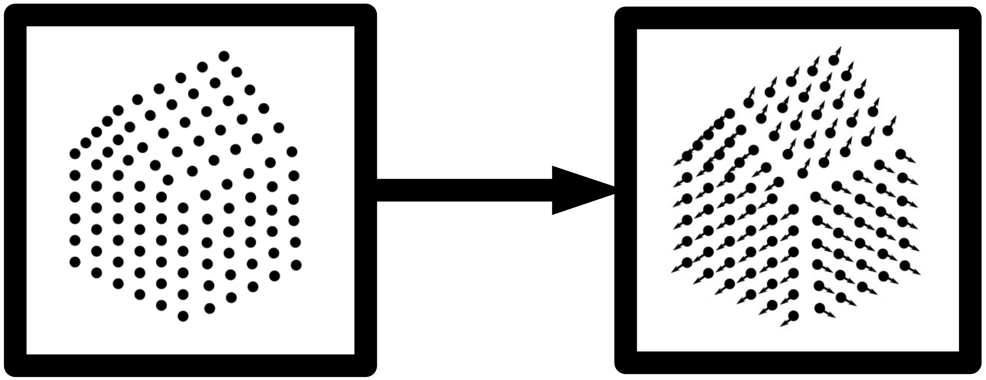


Pipeline

Pipeline

Normal estimation

Local information



Point cloud

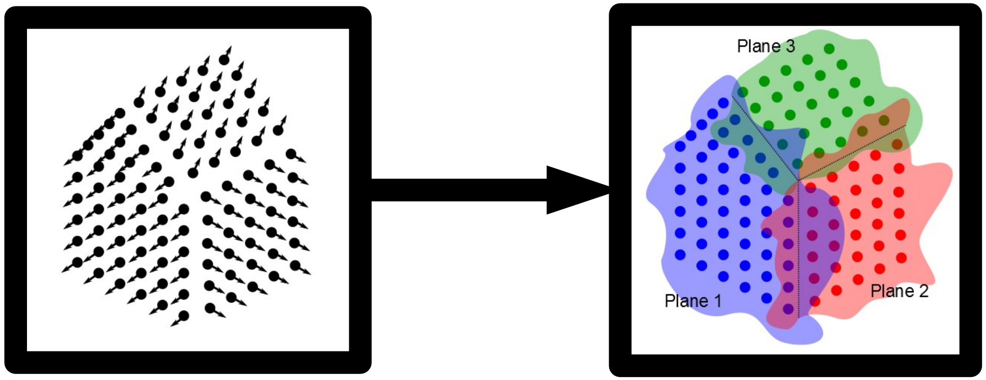
Point cloud + Normals

Pipeline

Normal estimation

Primitive detection

Cluster-level information



Point cloud + Normals

Primitives

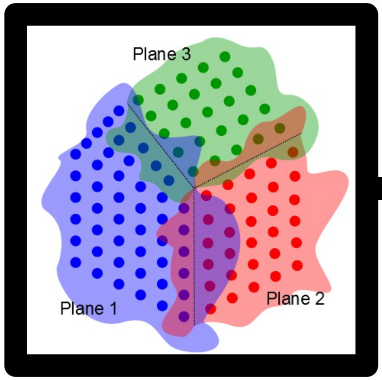
Pipeline

Normal estimation

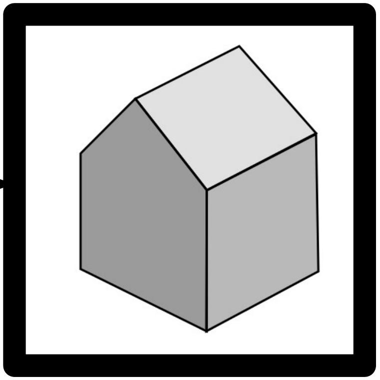
Primitive detection

Surface extraction

Global geometric information



Primitives



Surface

Pipeline

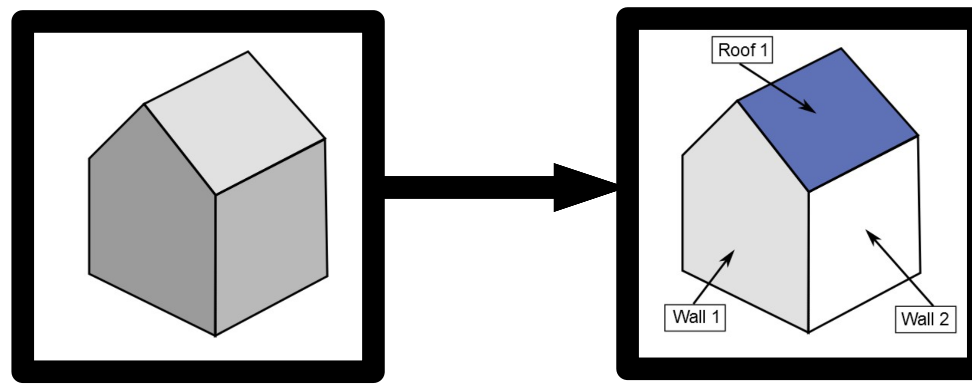
Normal estimation

Primitive detection

Surface extraction

Surface semantization

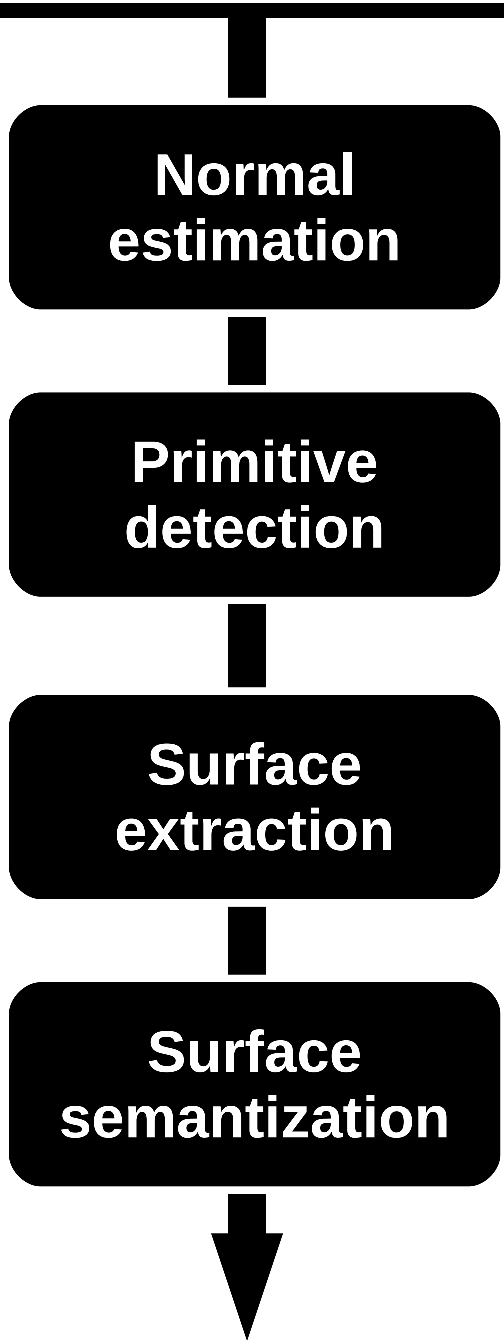
Global semantic information



Surface

Digital model

Pipeline


Normal estimation
Primitive detection
Surface extraction
Surface semantization

Pipeline

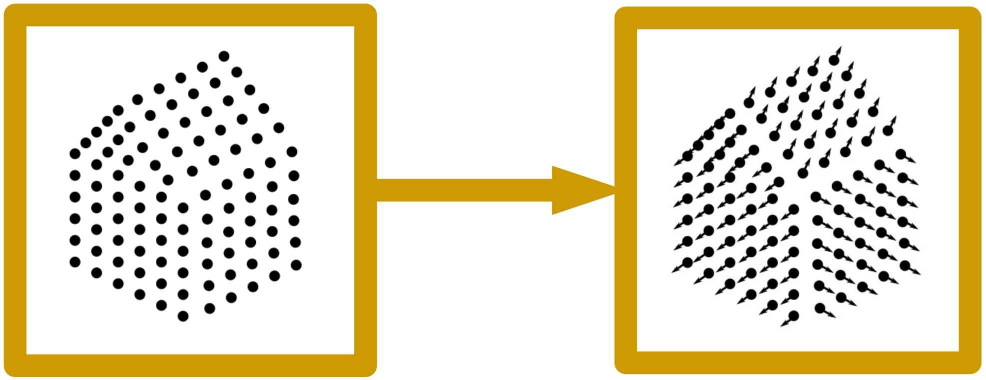
Normal estimation

Local information

Primitive detection

Surface extraction

Surface semantization



Point cloud

Point cloud + Normals

Introduction

- Local estimation of the surface orientation

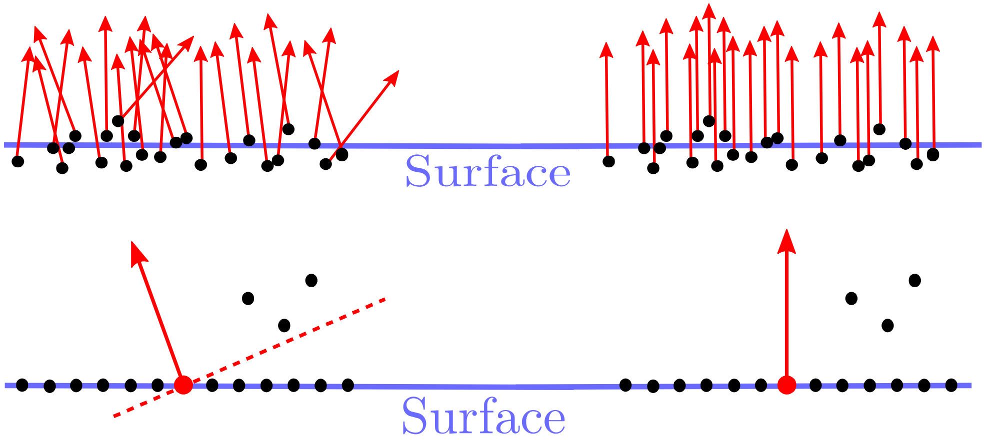
Normal estimation

Introduction

- Local estimation of the surface orientation
- Robustness to
  - noise

Introduction

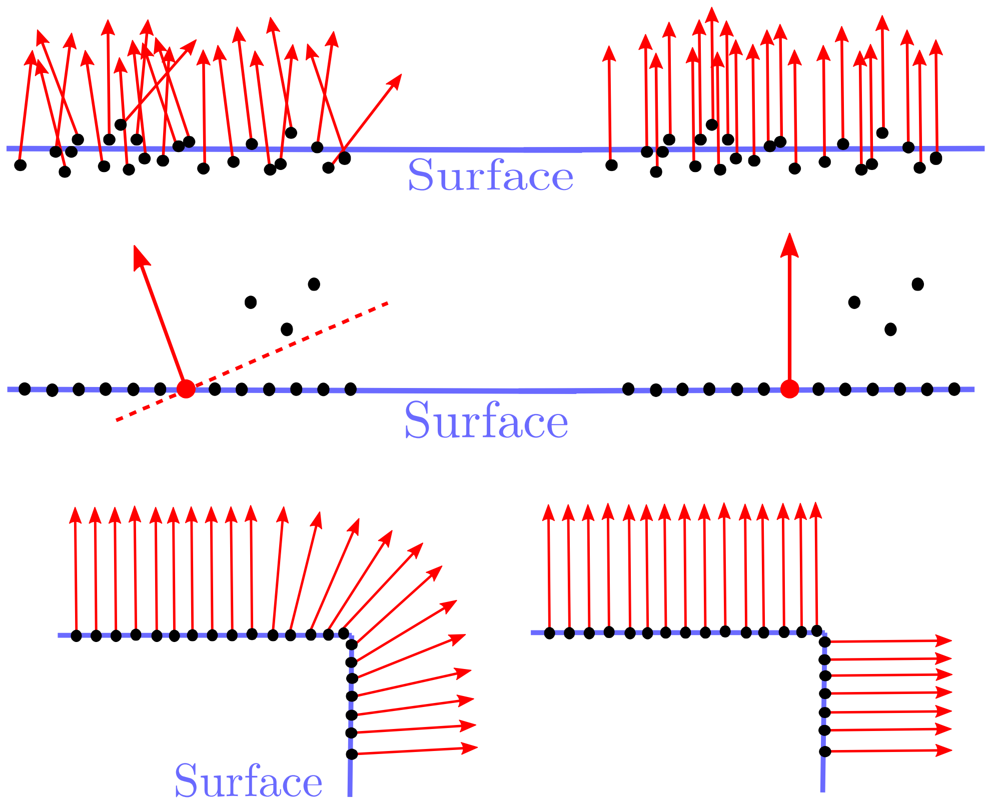
- Local estimation of the surface orientation
- Robustness to
  - noise
  - outliers



Normal estimation

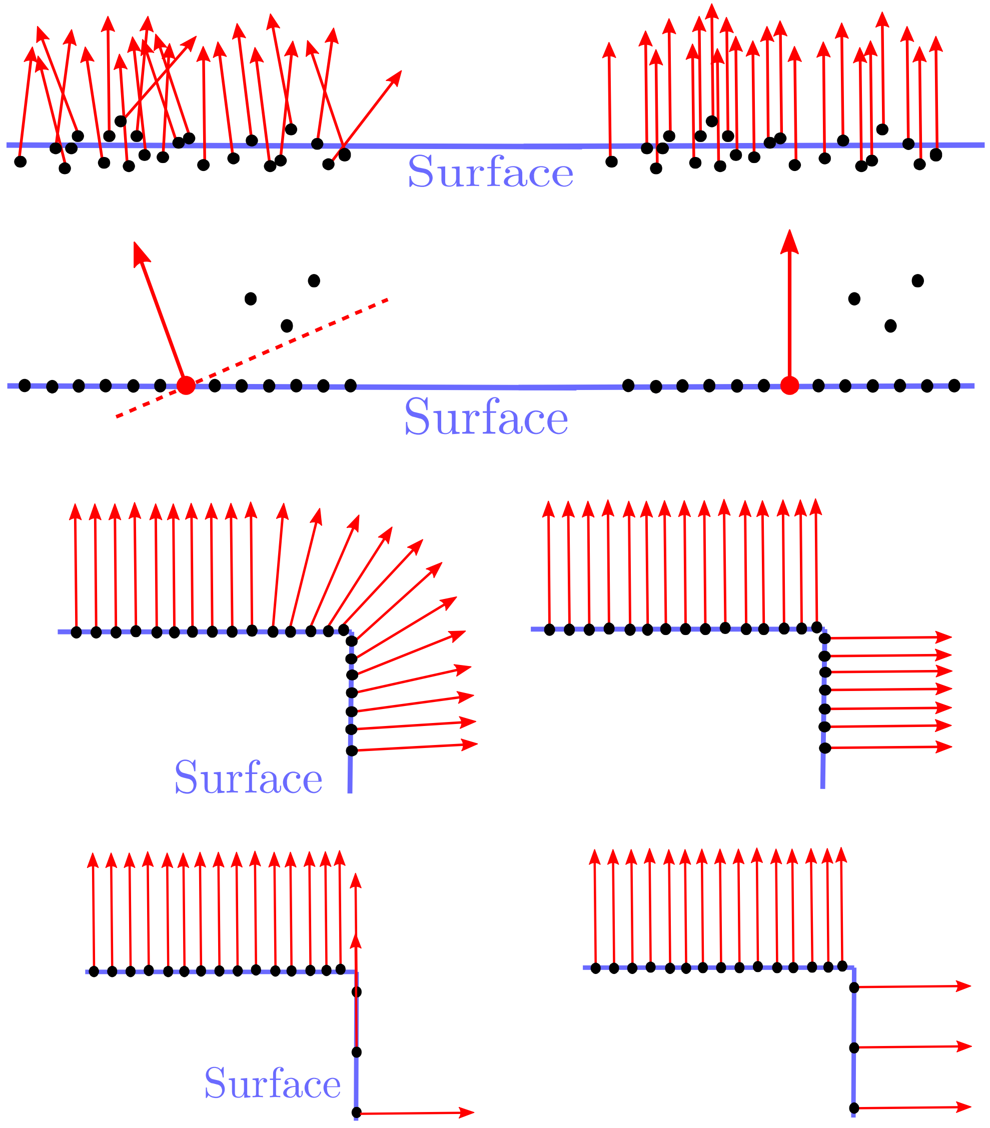
Introduction

- Local estimation of the surface orientation
- Robustness to
  - noise
  - outliers
  - sharp edges



Introduction

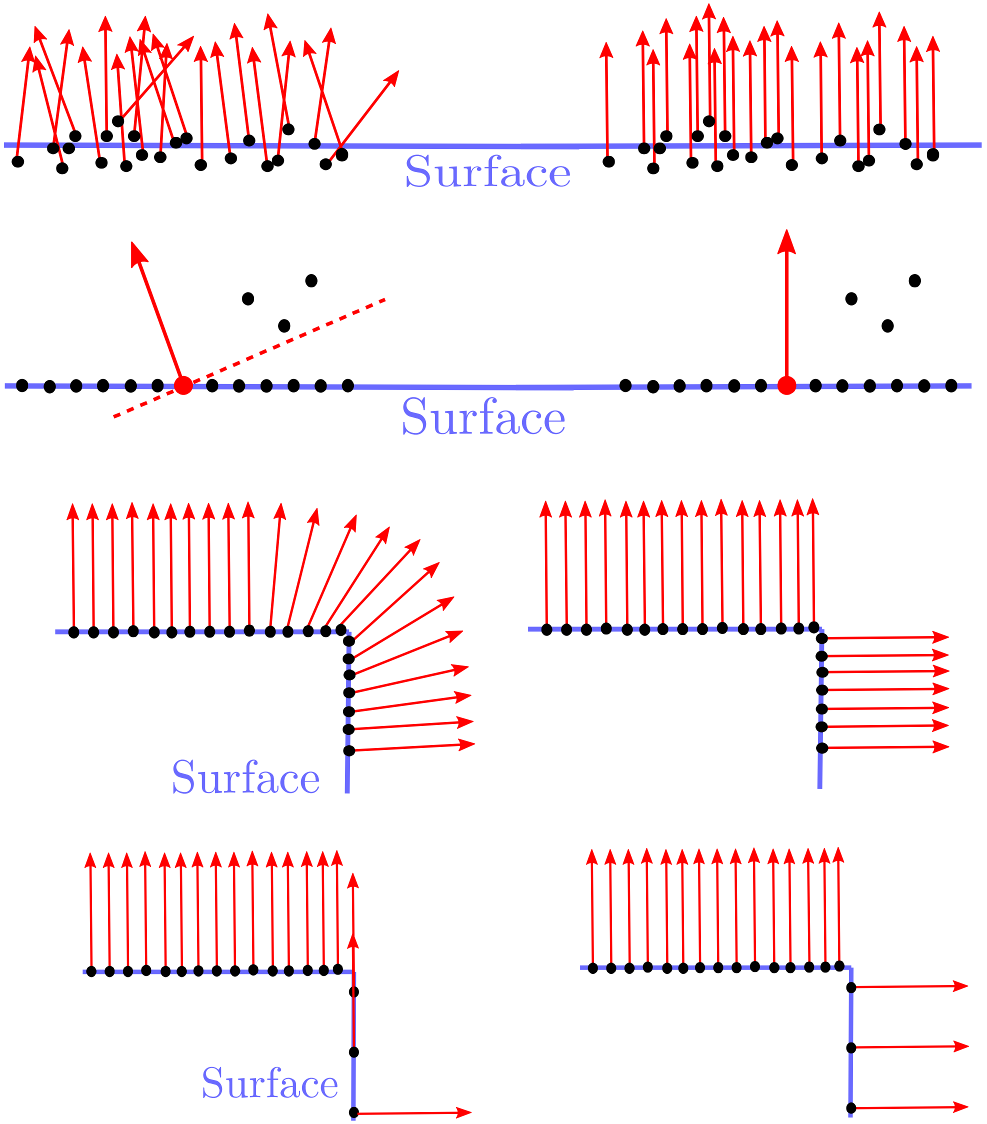
- Local estimation of the surface orientation
- Robustness to
  - noise
  - outliers
  - sharp edges
  - anisotropy



Normal estimation

Introduction

- Local estimation of the surface orientation
- Robustness to
  - noise
  - outliers
  - sharp edges
  - anisotropy
- Speed



Previous work

- Regression
  - Planes: **Hoppe et al**. *Surface reconstruction from unorganized points*. SIGGRAPH, 1992.
  - Jets: **Cazals & Pouget**. *Estimating Differential Quantities using Polynomial fitting of Osculating Jets*. Symposium on Geometry Processing, 2003.
- Voronoï diagrams
  - **Dey and Goswami**. *Provable surface reconstruction from noisy samples*. Comput. Geometry, 2006.
- RANSAC
  - **Li et al**. *Robust normal estimation for point clouds with sharp features*. Computers & Graphics, 2010.

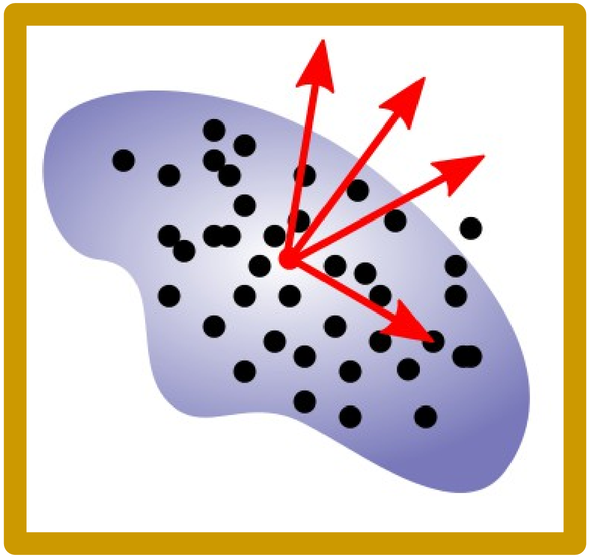
Previous work

	Regression Planes	Regression Jets	Voronoï diagrams	RANSAC
Noise	X	X		X
Outliers				X
Sharp features			X	X
Anisotropy			X	
Speed	X	X	X	

Normal estimation

Randomized Hough transform

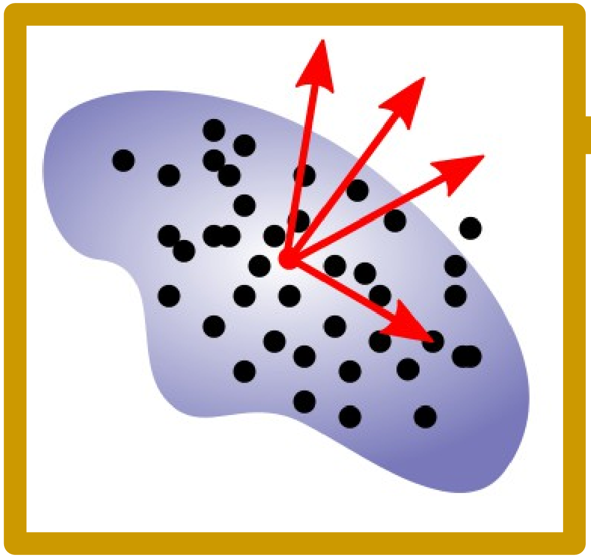
Generate hypotheses: pick triplets of points



Normal estimation

Randomized Hough transform

Generate hypotheses: pick triplets of points

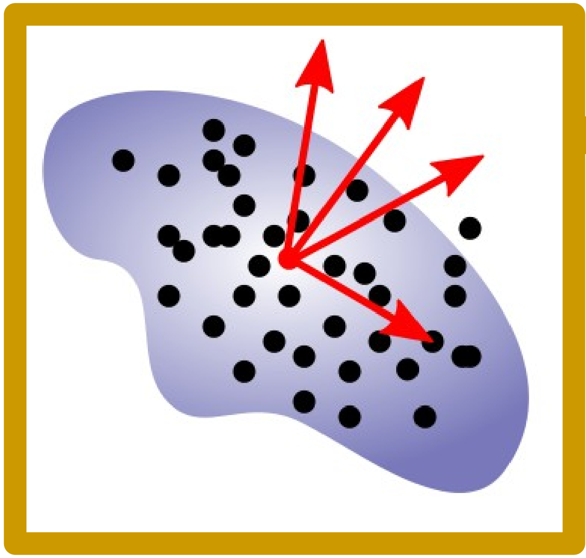


Space change

Normal estimation

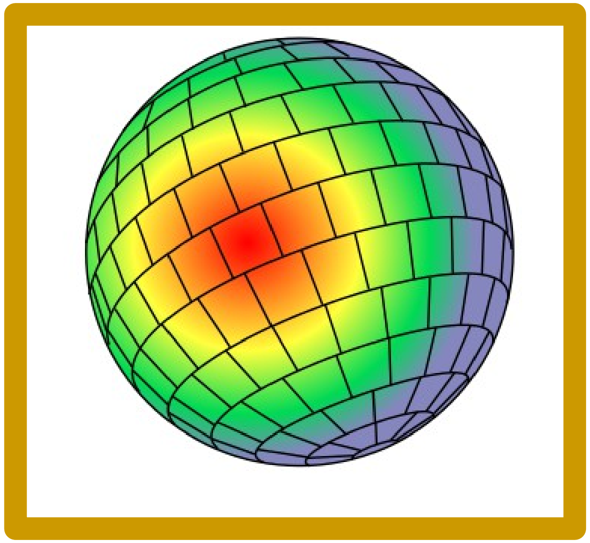
Randomized Hough transform

Generate hypotheses:
pick triplets of points



Space change

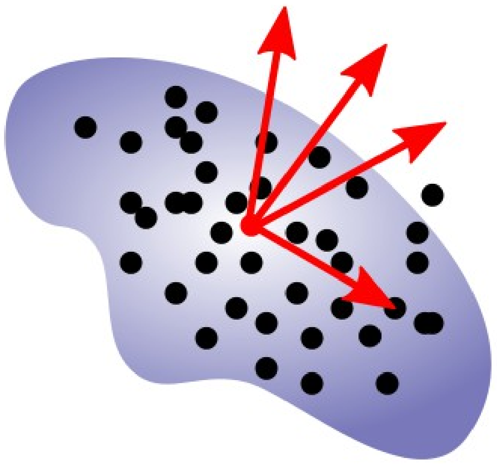
Vote in a spherical
accumulator



Normal estimation

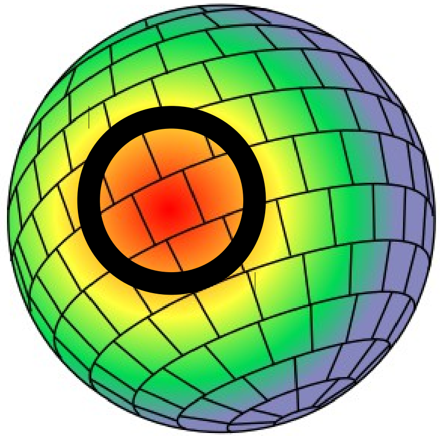
Randomized Hough transform

Generate hypotheses: pick triplets of points



Space change

Vote in a spherical accumulator

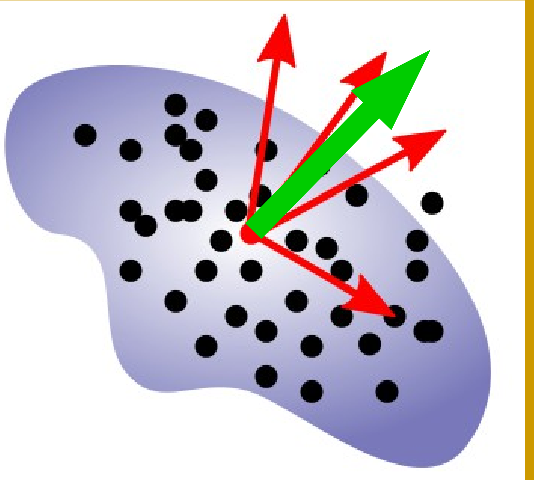


Select the most probable bin

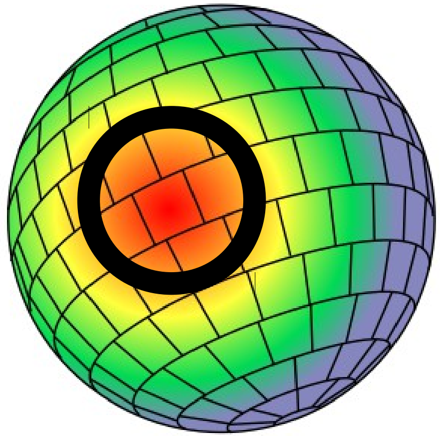
Randomized Hough transform

Generate hypotheses: pick triplets of points

Vote in a spherical accumulator



Space change



Generate normal

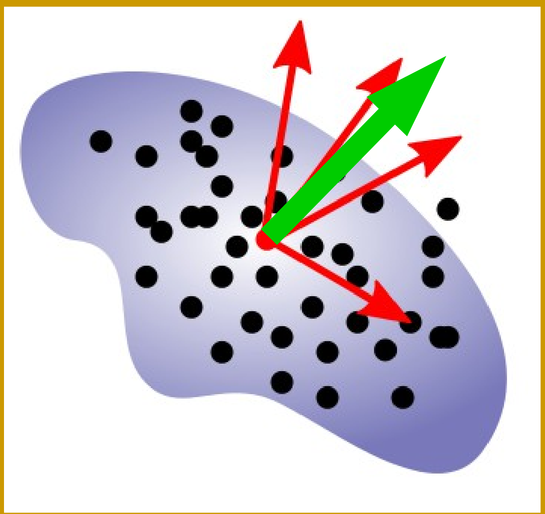
Select the most probable bin

Normal estimation

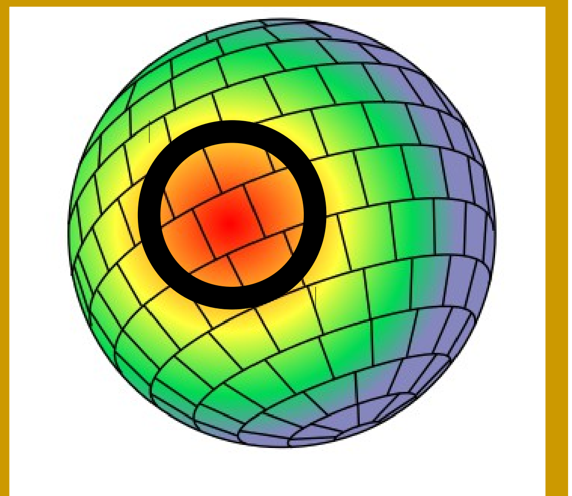
Randomized Hough transform

Generate hypotheses: pick triplets of points

Vote in a spherical accumulator



Space change



Generate normal

How many hypotheses must be generated ?

Select the most probable bin

Normal estimation

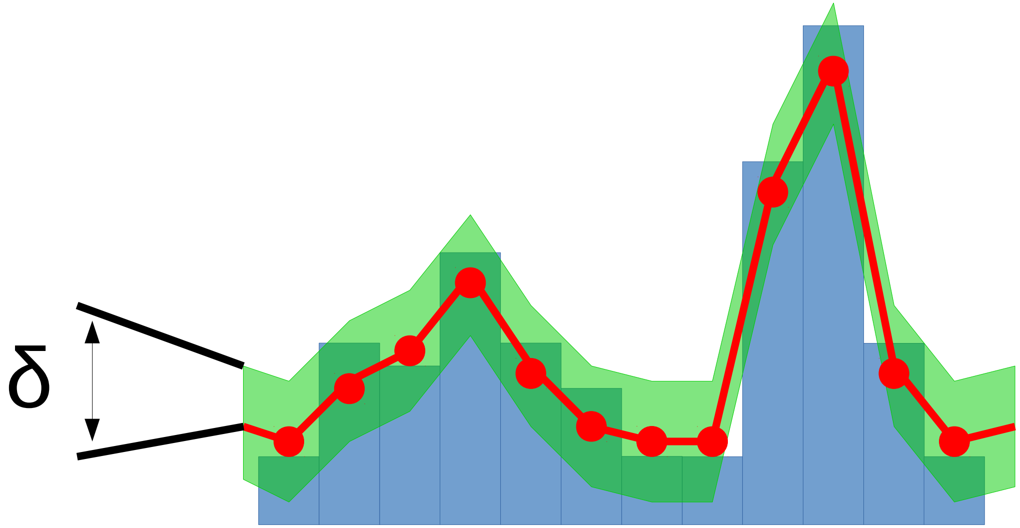
Robust lower bound

- Filled accumulator of M bins:
  empirical approximation of a probability distribution
- Estimate the quality of the approximation.

  T^*, minimum number of triplets to pick such that :

$$\mathbb{P}(\max_{m\in\{1,\ldots,M\}} |\hat{p}_m - p_m| < \delta) \geq \alpha$$

δ: deviation tolerance
α: confidence level



Robust lower bound

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- Estimate the quality of the approximation.

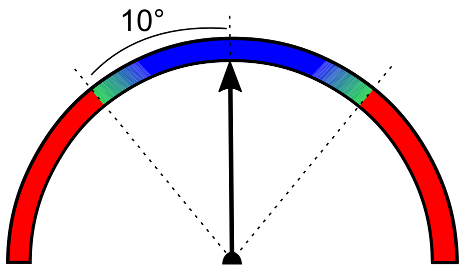
  T^*, minimum number of triplets to pick such that :

$$\mathbb{P}(\max_{m \in \{1,\ldots,M\}} |\hat{p}_m - p_m| < \delta) \geq \alpha$$

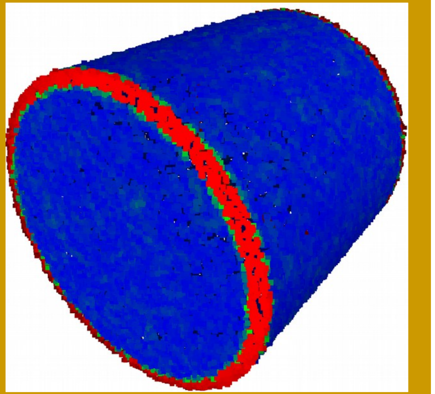
- From Hoeffding inequality:

$$T^* = \left\lceil \frac{1}{2\delta^2} \log\left(\frac{2M}{1-\alpha}\right) \right\rceil$$

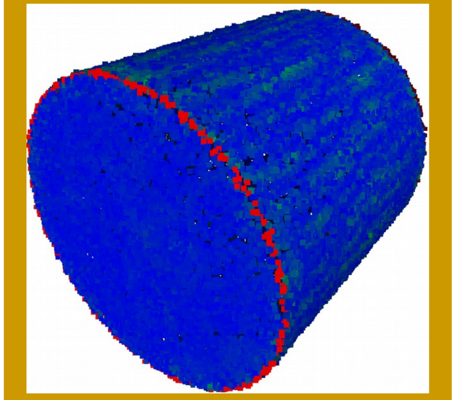
Results



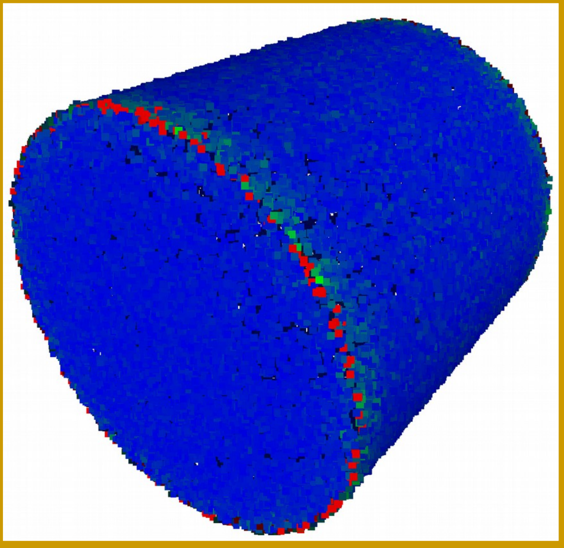
Color code



Cazal & Pouget (2003)



Li & al (2010)

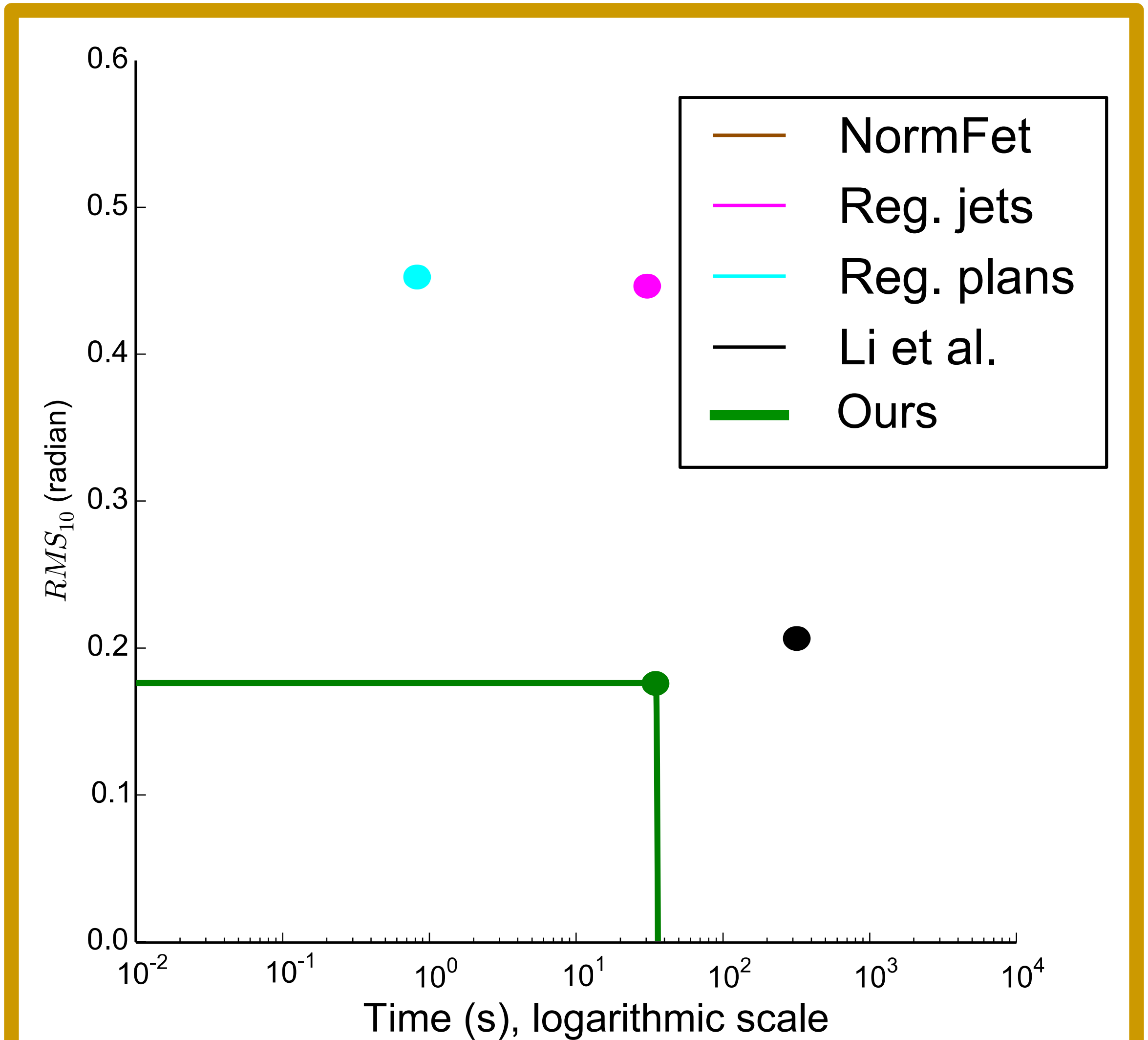


Ours

Normal estimation

Speed and accuracy

- Same complexity
- As accurate and faster than [Li et al. 2010]

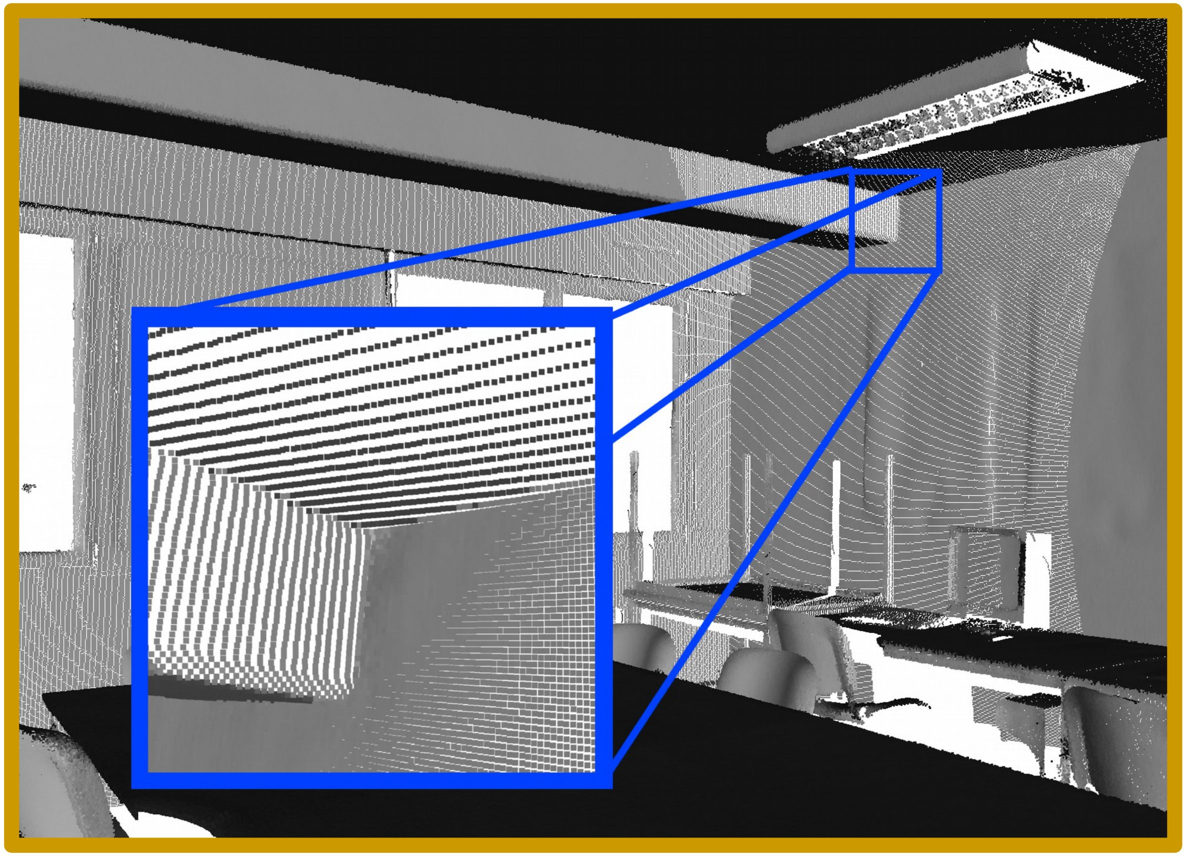


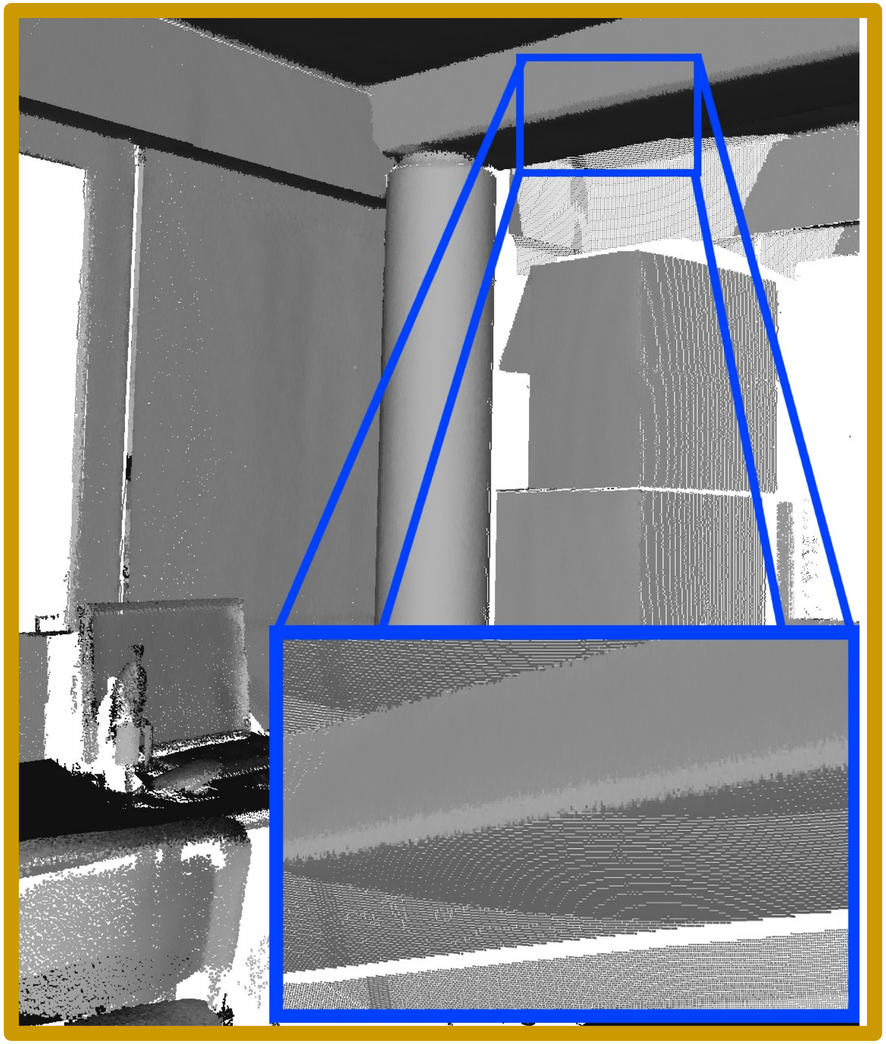
Cylinder, 0.2% noise, 200k points

Note: [Dey & Goswany 2006] does not appear on the graphic, because the method is not robust to noise

Normal estimation

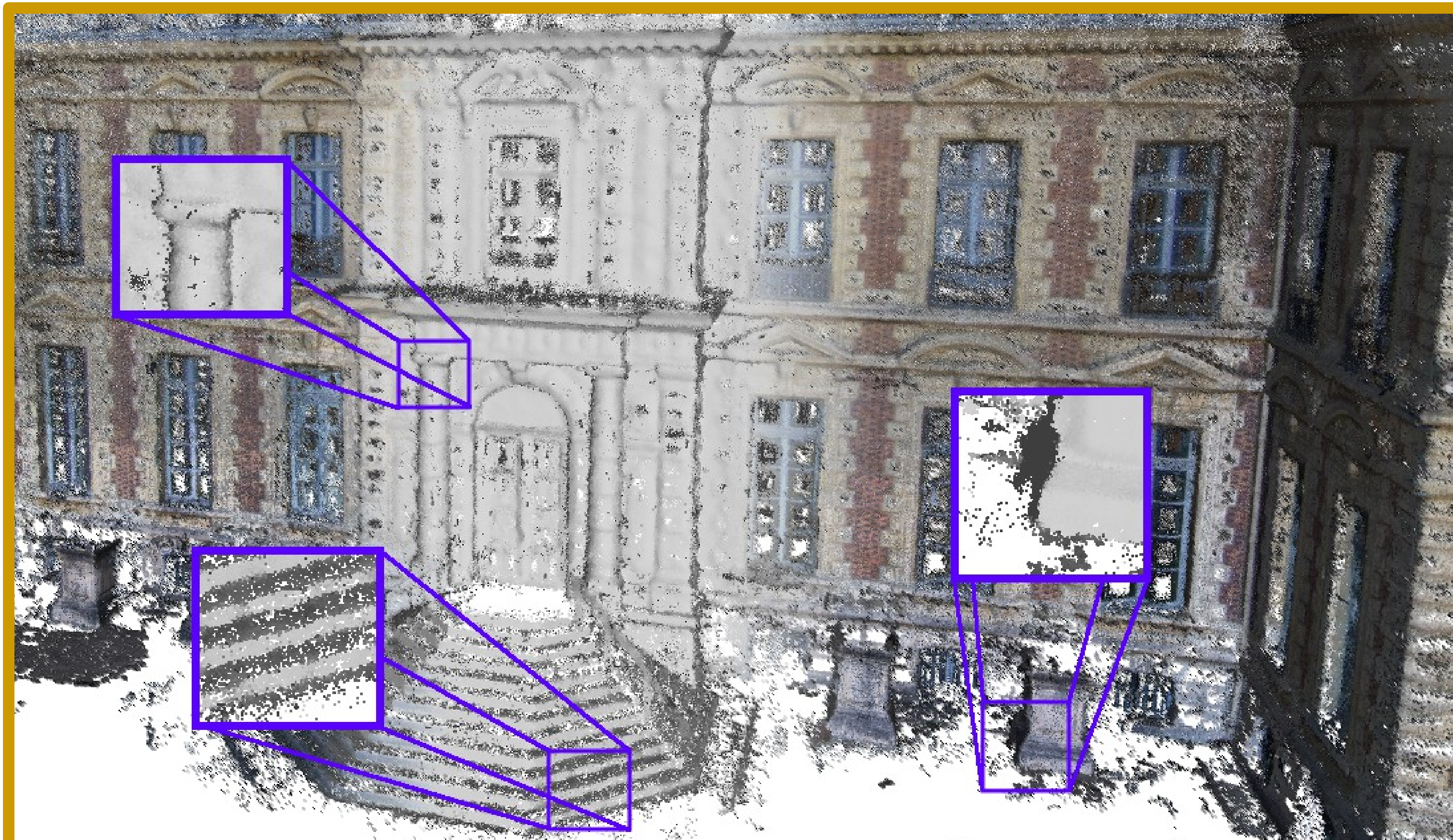
Visuals results: laser scans





Normal estimation

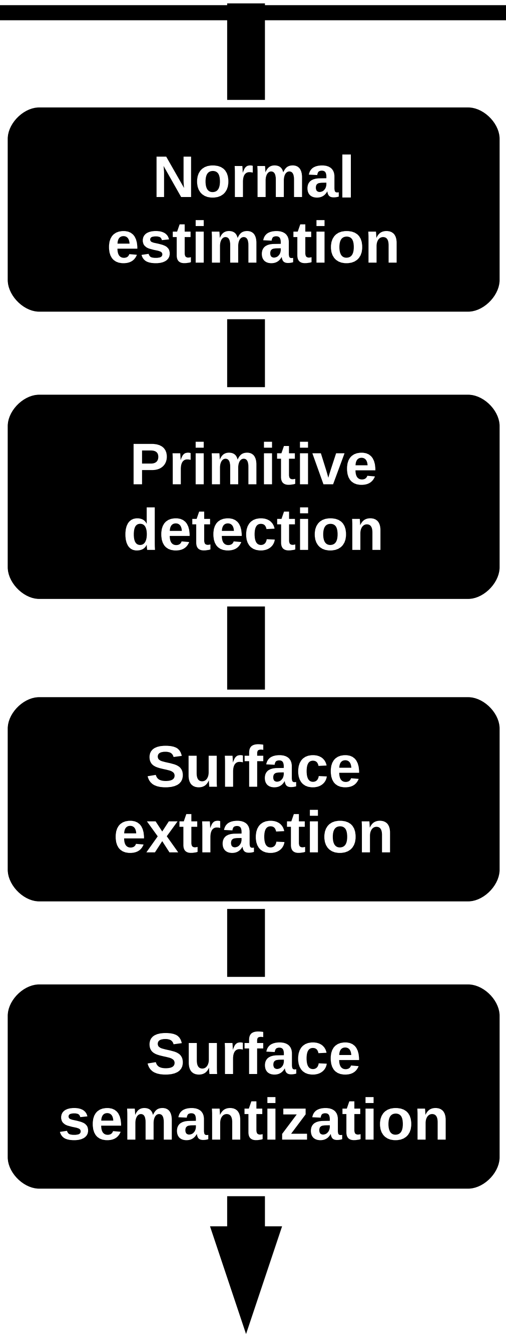
Visual results: photogrammetric data



Conclusion

- Robust normal estimator based on Hough Transform
  - accurate
  - robust to noise, outliers, sharp edges and anisotropy
  - fast
- Limitations
  - smooth normals on wide angles

Pipeline


Normal estimation
Primitive detection
Surface extraction
Surface semantization

Pipeline

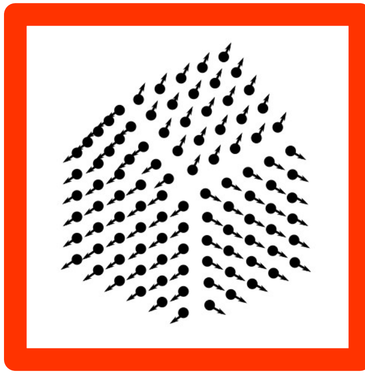
Normal estimation

Primitive detection

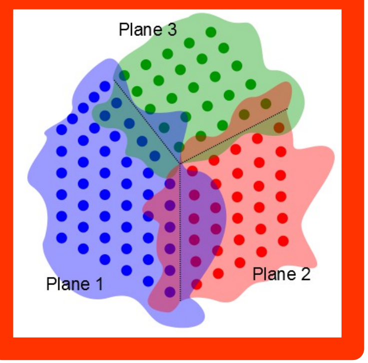
Surface extraction

Surface semantization

Cluster level information



Point cloud + Normals



Primitives

Primitive detection

Extraction

Fusion

RANSAC

Region growing

Schnabel & al (2007)

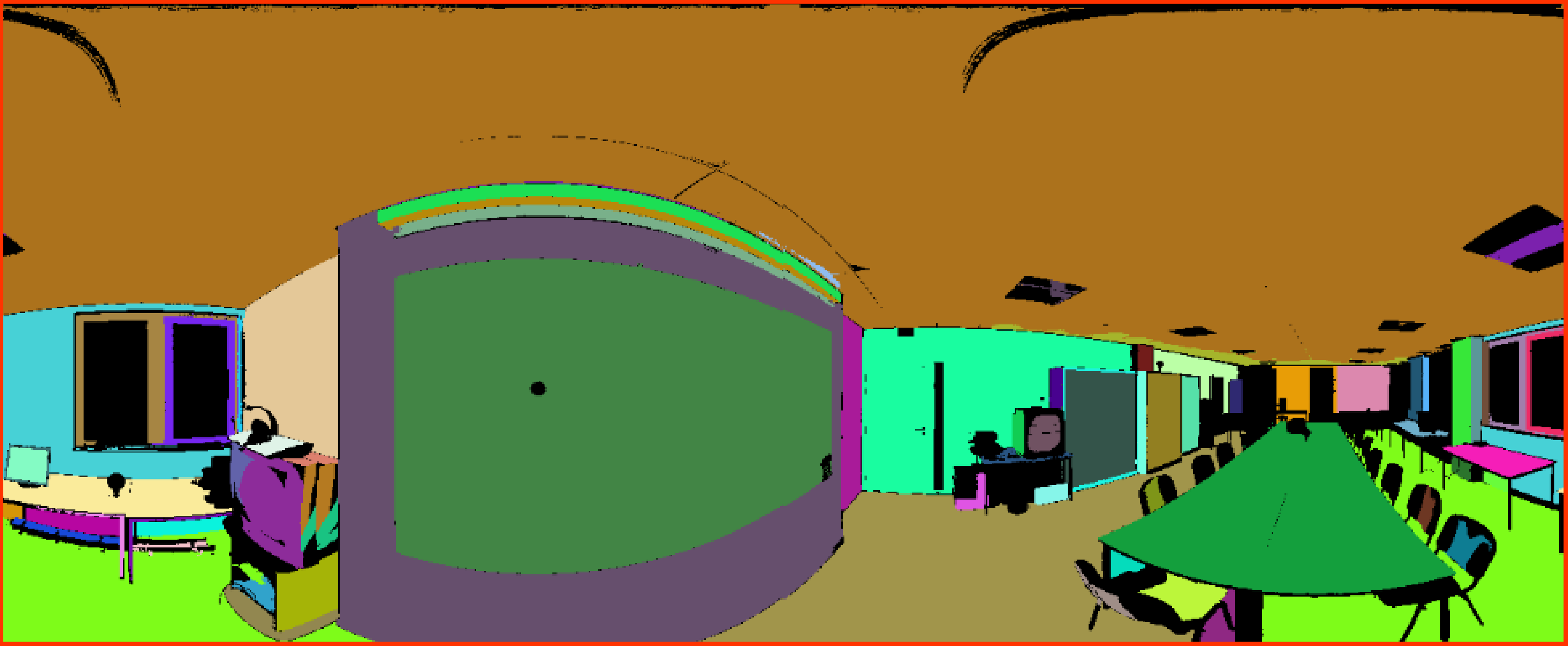
Primitive fusion

Practical example

Over-segmentation

Primitive fusion

Practical example



Over-segmentation

Primitive fusion

Practical example

Over-segmentation

Existing methods

- Tolerance on parameters
  - 3 for a plane (2 for orientation, 1 for distance)
  - 4 for a sphere (3 for position, 1 for radius)
  - …
- A contrario criterion only for planes in depth maps [**Bughin, E.** 2010.]

Primitive fusion

Existing methods

- Tolerance on parameters :
  - 3 for a plane (2 for orientation, 1 for distance)
  - 4 for a sphere (3 for position, 1 for radius)
  - …
- A contrario criterion only for planes in depth maps [**Bughin, E.** 2010.]

Our method:

- One single indicator: distribution of distances to primitive

Primitive fusion

Criterion for fusion

- Two surfaces $\mathcal{S}_1$ and $\mathcal{S}_2$, associated with point sets P_1 and P_2
- Distance function from point to primitives
- Define two sets:

$$X = \{d(p_1, \mathcal{S}_1),\ p_1 \in P_1\} \cup \{d(p_2, \mathcal{S}_2),\ p_2 \in P_2\}$$
$$Y = \{d(p_1, \mathcal{S}_2),\ p_1 \in P_1\} \cup \{d(p_2, \mathcal{S}_1),\ p_2 \in P_2\}$$

- If $\mathcal{S}_1 = \mathcal{S}_2$ then $X = Y$
- Statistical tests
  - Mann-Whitney
  - Kolmogorov-Smirnov

Results

Primitive fusion

Results

Primitive fusion

Results

- Very small difference in the distributions
  ⇨ rejection

Primitive fusion

Results

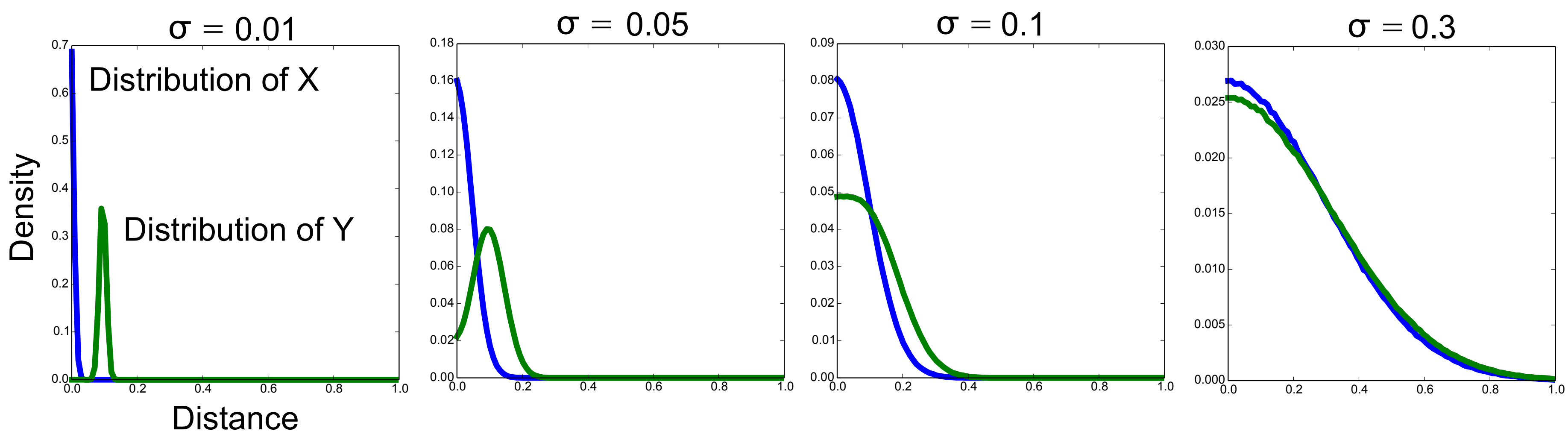
- Very small difference in the distributions
  ⇨ rejection
- No user control on acceptance

Primitive fusion

Primitive fusion

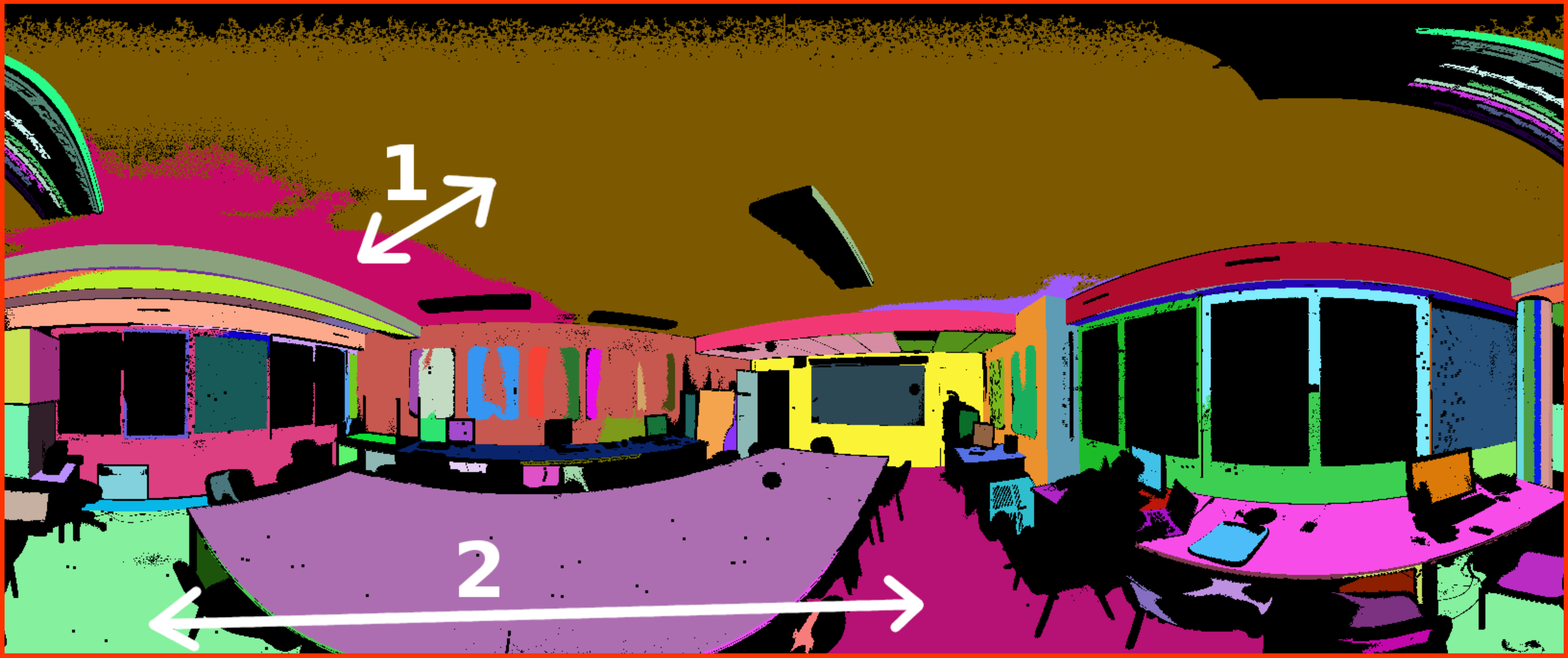
Smooth distributions to ensure a controlled fusion

Example: two parallel lines at distance 0.1



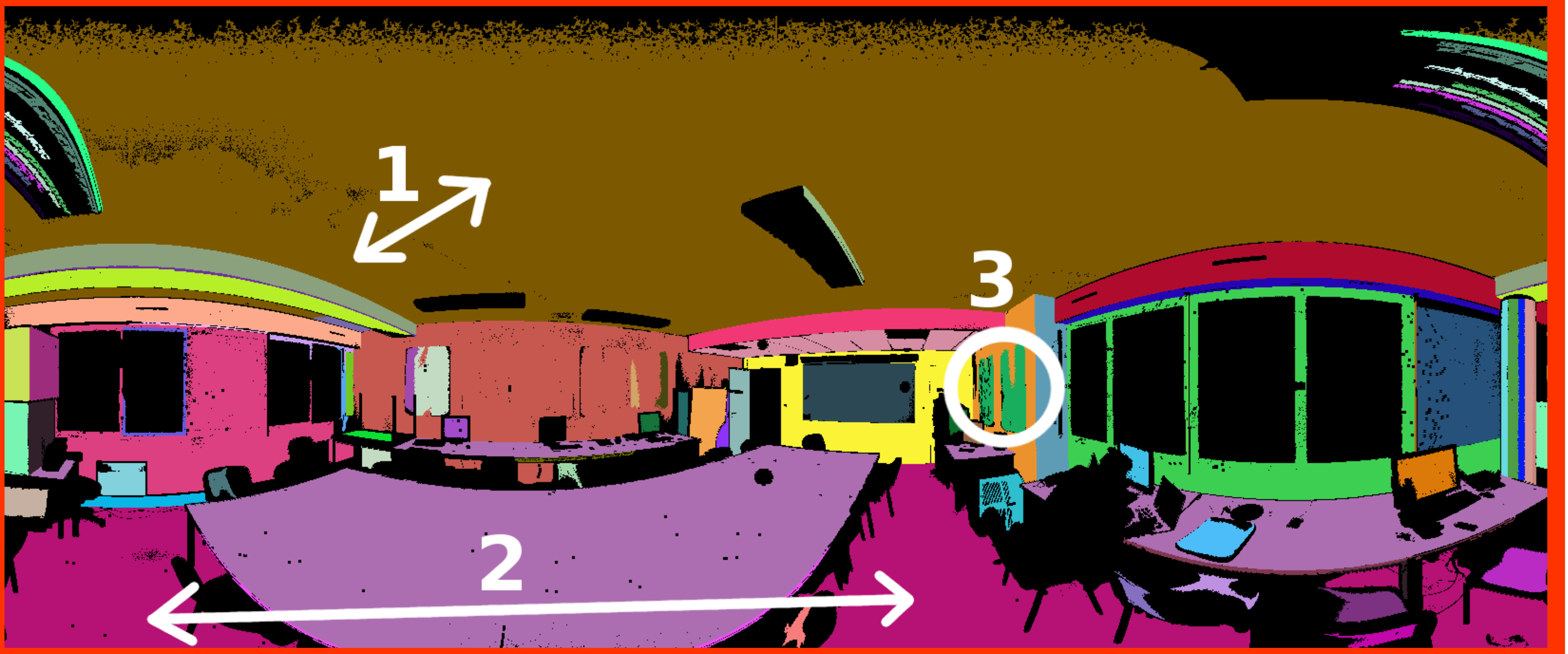
Results

Increasing the level of smoothing



Results

Increasing the level of smoothing

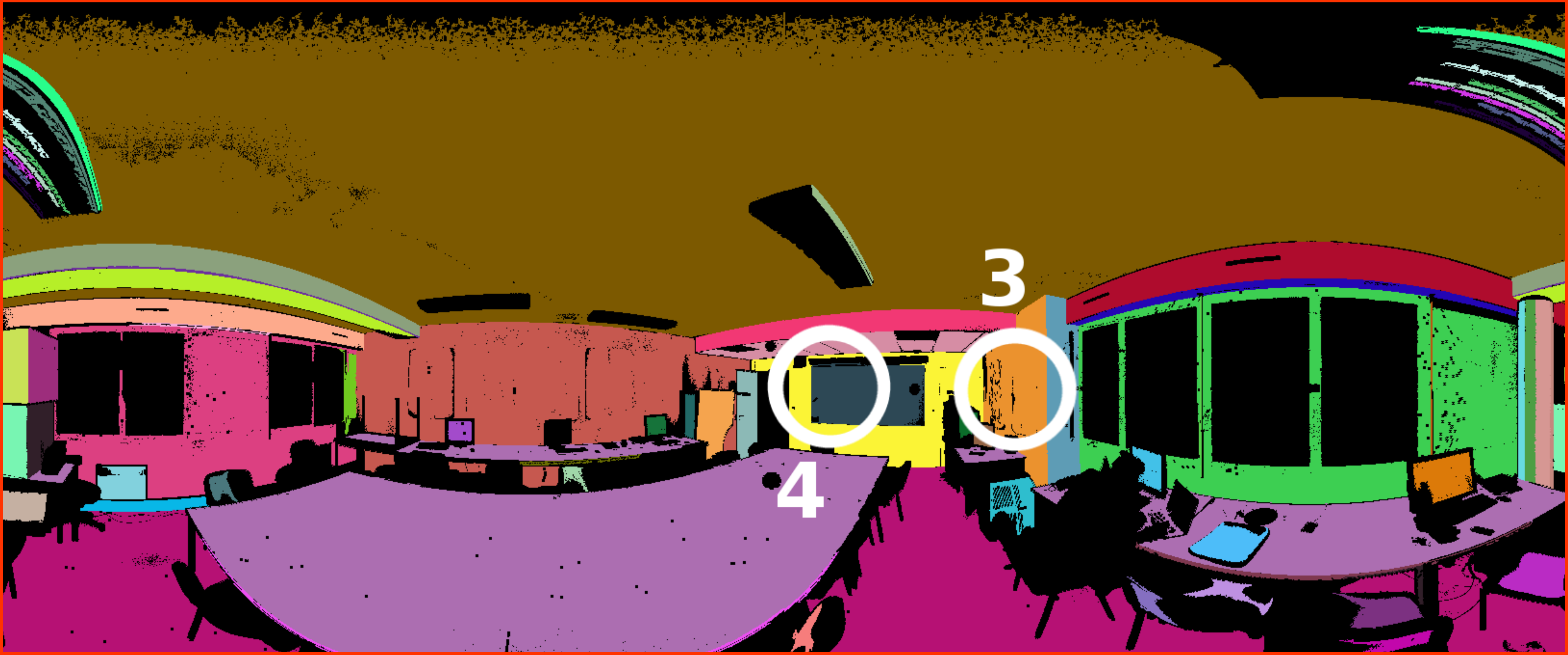


Smoothing level: 0.01

Primitive fusion

Results

Increasing the level of smoothing



Smoothing level: 0.02

Primitive fusion

Results

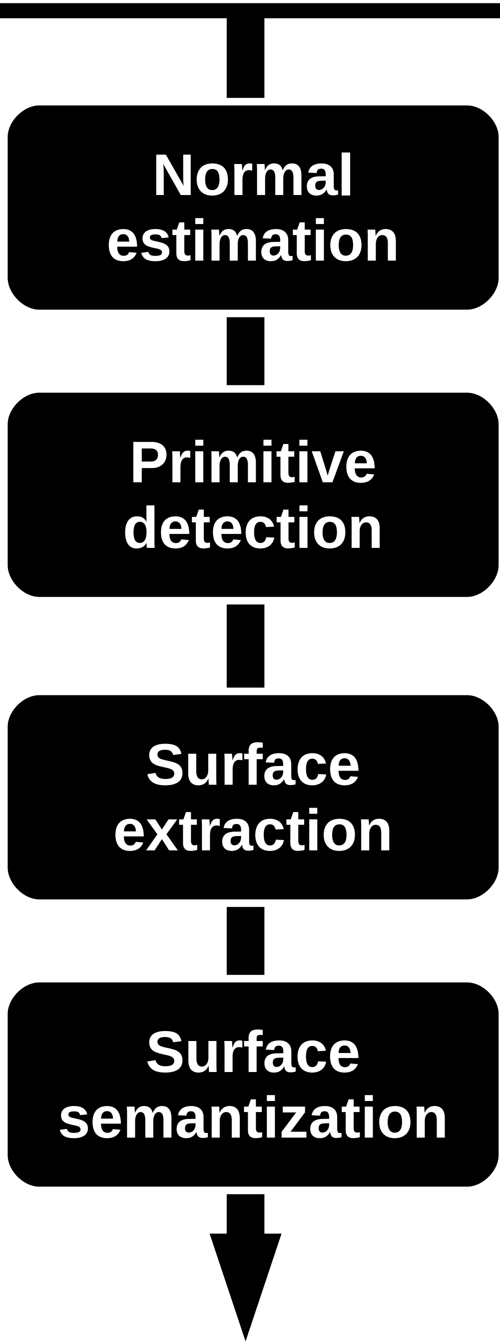
Increasing the level of smoothing

Smoothing level: 0.03

Conclusion

- Criterion for primitives fusion
  - robustness to noise
  - support for any primitive type (plane, cylinder...)
  - intuitive user control on merging
- Limits
  - empirical relation between noise and fusion distance

Pipeline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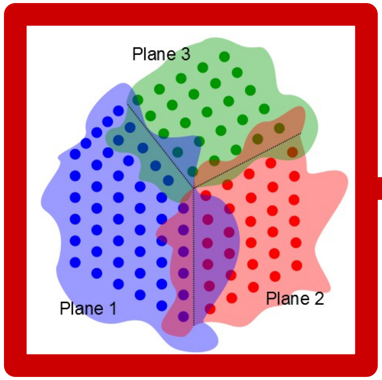
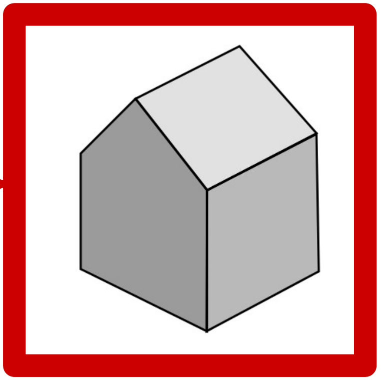
Surface semantization

Global geometric information



Primitives

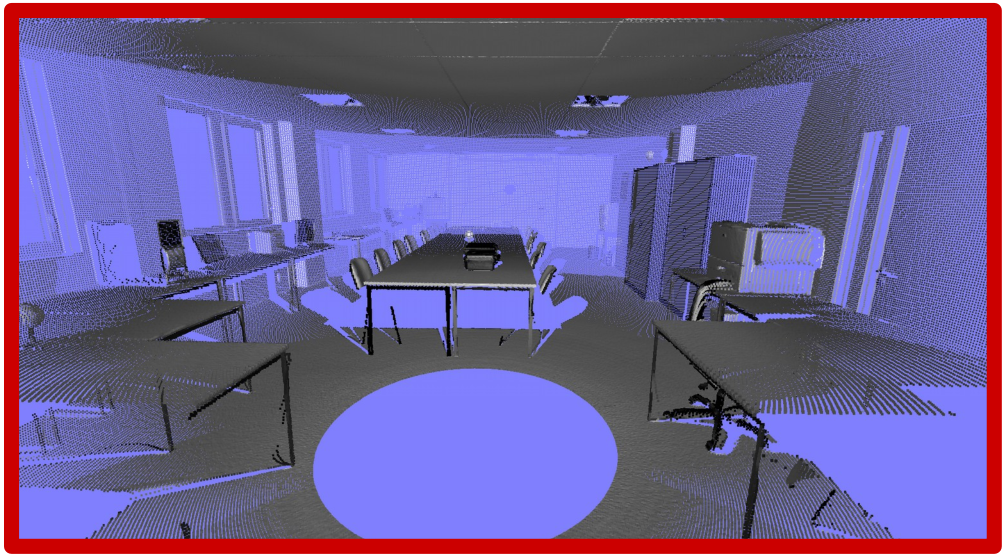


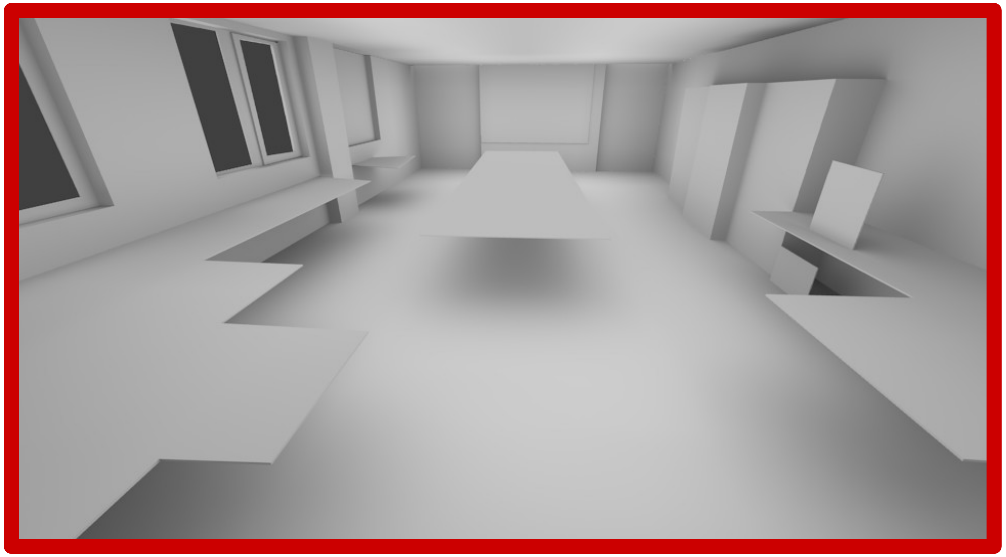
Surface

Objective

Automatic surface reconstruction from laser scan

- watertight without self intersection
- piecewise planar
- extended plausibly in hidden region



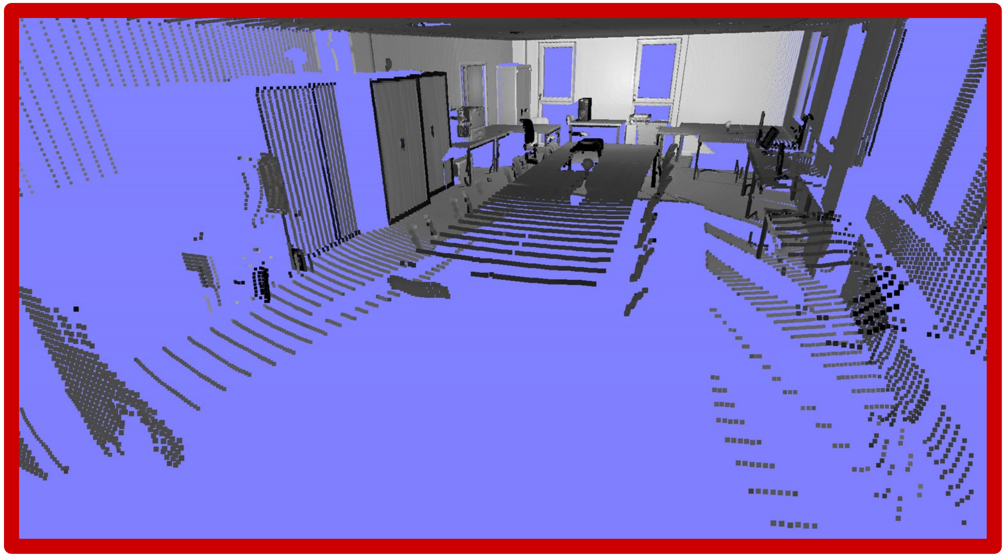


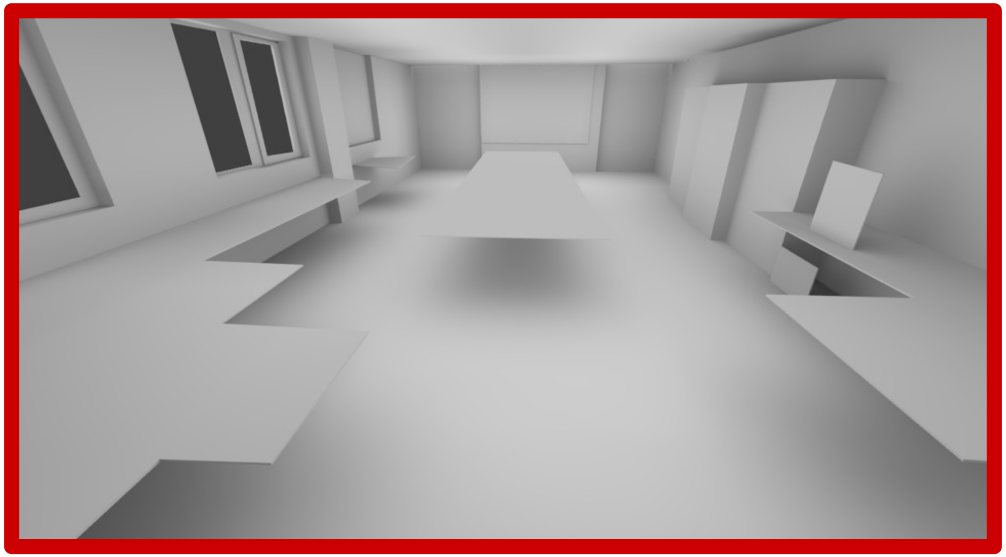
Surface extraction

Objective

Automatic surface reconstruction from laser scan

- watertight without self intersection
- piecewise planar
- extended plausibly in hidden region
  with support for data anisotropy





Previous work

- Smooth priors
  - e.g. Poisson reconstruction
- Voxelisation
  - biased, expensive
- Delaunay tetrahedralization
  - visible regions only
- Plane adjacency
  - visible near adjacency
- Manhattan world assumption
  - too restrictive: 3 directions only

Surface extraction

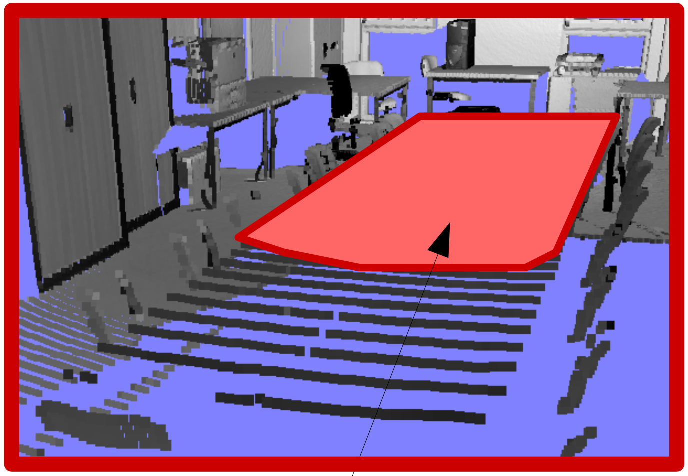
Chauve et al.

A.-L. Chauve, P. Labatut, J.P. Pons
Robust piecewise-planar 3D reconstruction and completion from large-scale unstructured point data. CVPR 2010

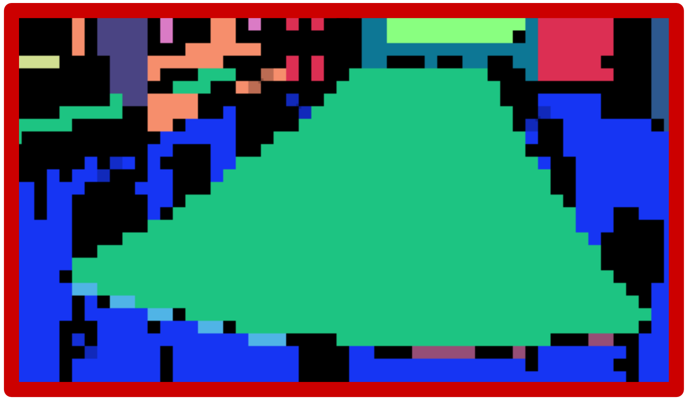
- Plane arrangement
  - Visible planes
  - Hidden plane hypotheses (called ghosts)
- Binary labelization of resulting 3D cell complex (empty or full)
  - Surface minimization, graph-cut optimization
- Advantages
  - watertight and non self-intersecting surfaces
  - preservation of sharp edges
  - extension of primitives far in hidden regions
  - more plausible surfaces thanks to hidden plane hypotheses

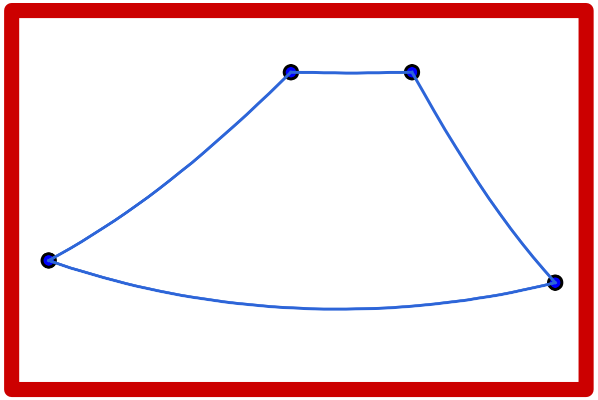
Chauve et al. (2)

- Limitations
  - wrong primitive borders with anisotropic point clouds
- Our method
  - determination of borders in laser depth image



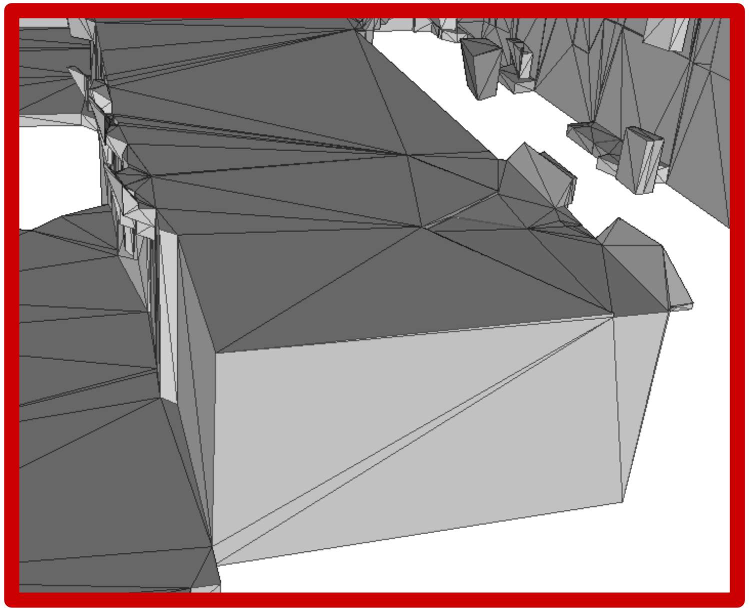
α-shape



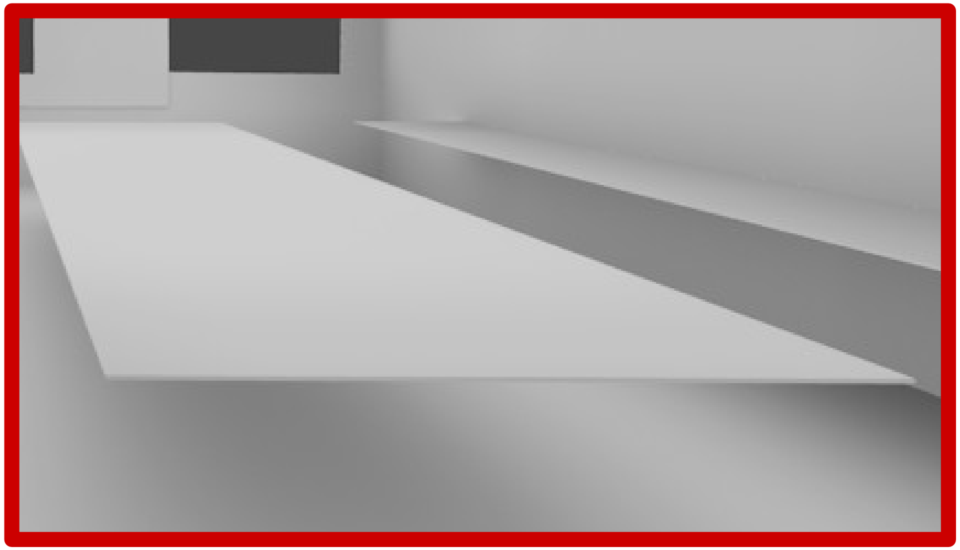


Chauve et al. (3)

- Limitations
  - missing plane hypotheses

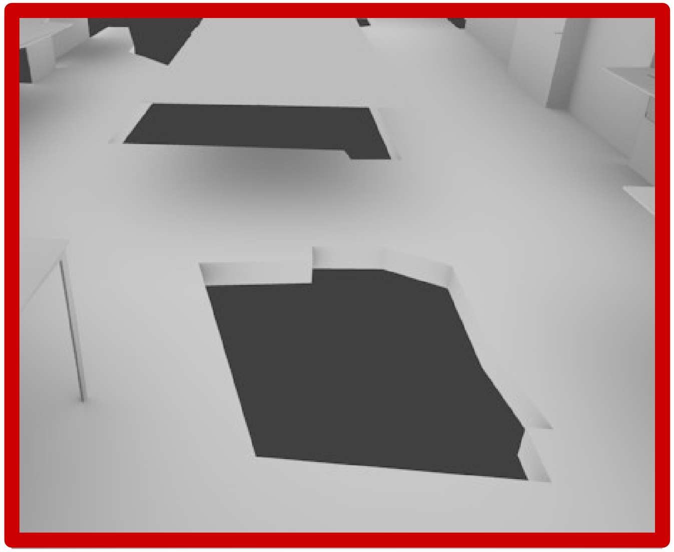


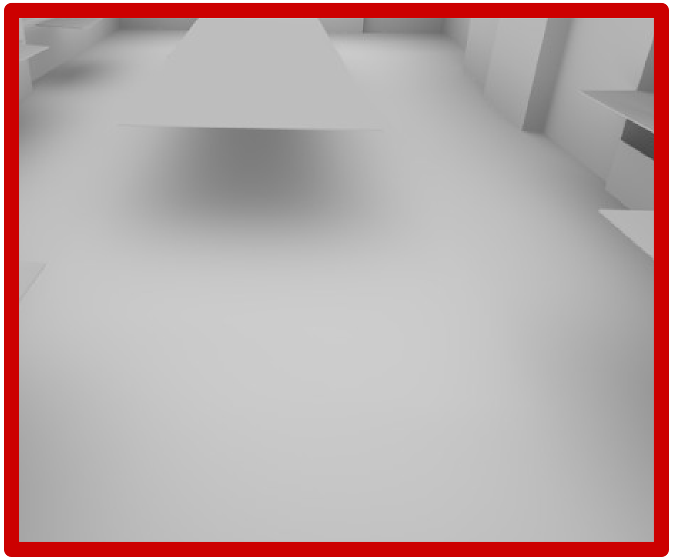
- Our method
  - generation of parallel ghosts (for thin objects without detected thickness)



Chauve et al. (4)

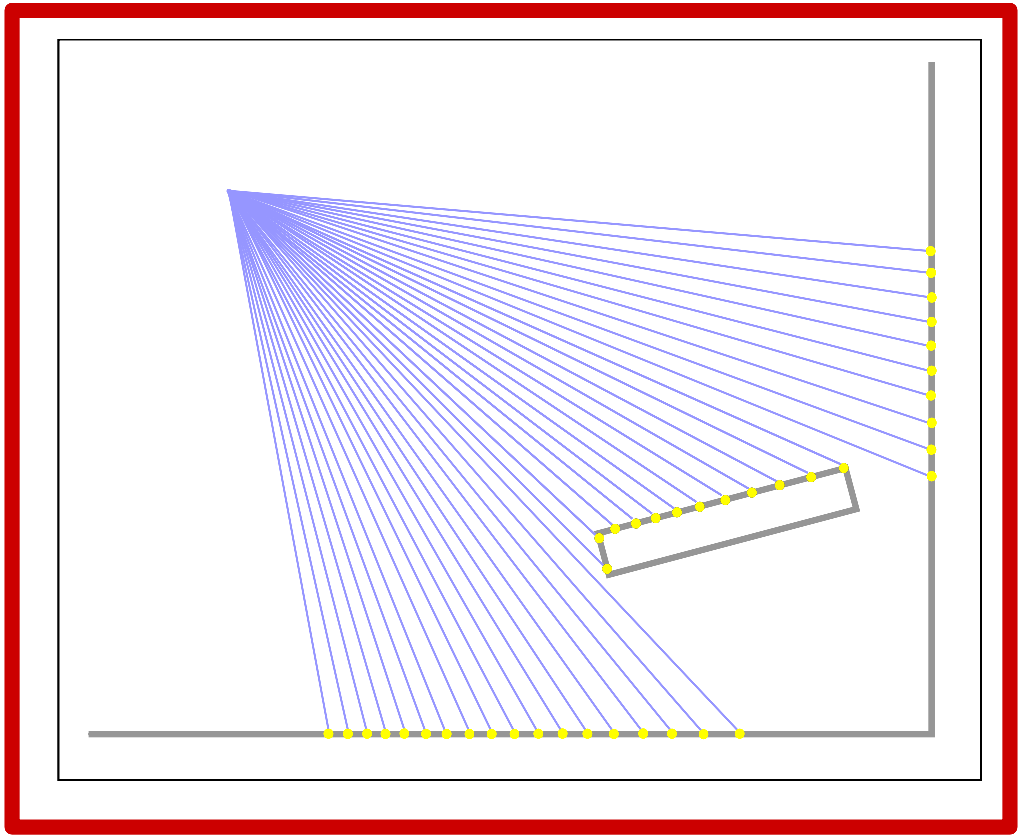
- Limitations
  - Holes and truncated corners due to area minimization
- Our method
  - Edge length and corner number minimization





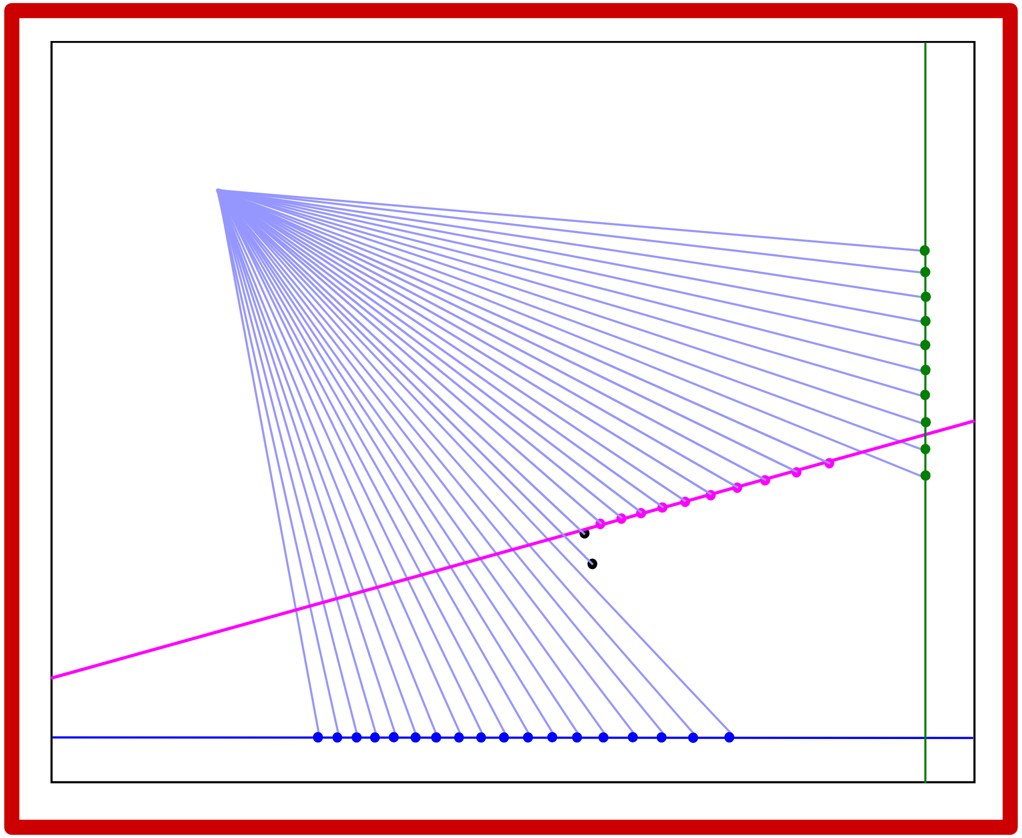
Overview of the method

- Laser point cloud



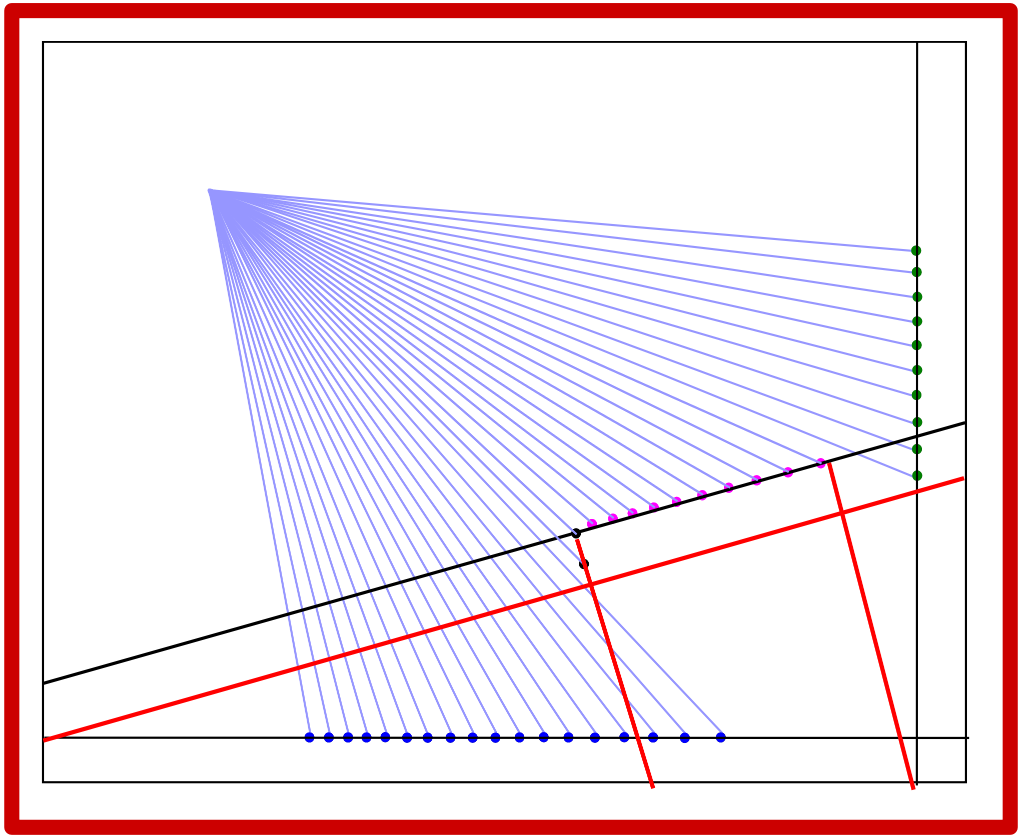
Overview of the method

- Laser point cloud
- Primitive extraction



Overview of the method

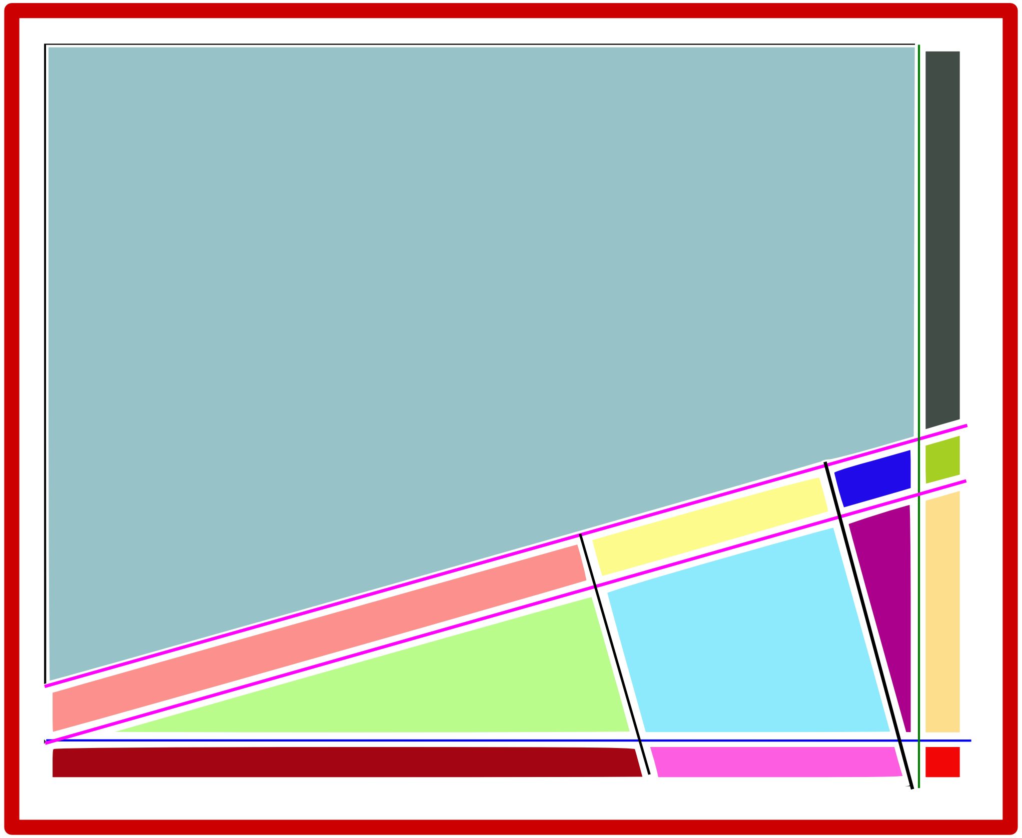
- Laser point cloud
- Primitive extraction
- Ghost generation



Surface extraction

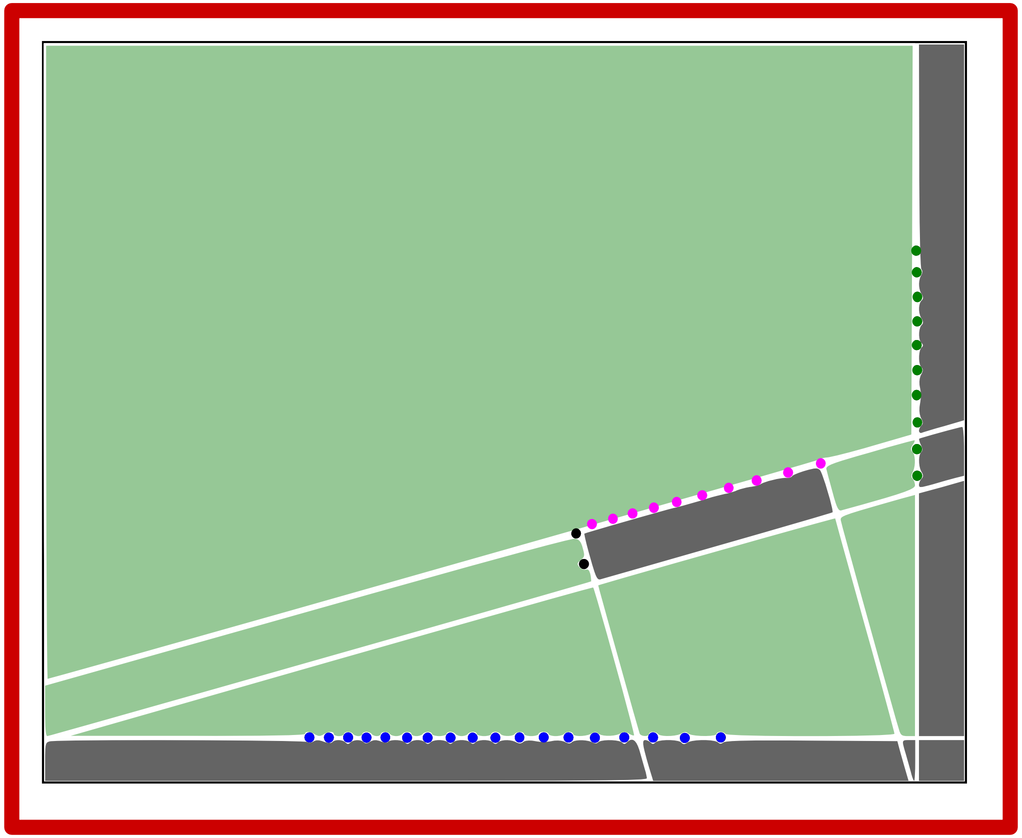
Overview of the method

- Laser point cloud
- Primitive extraction
- Ghost generation
- Volume partition using a plane arrangement



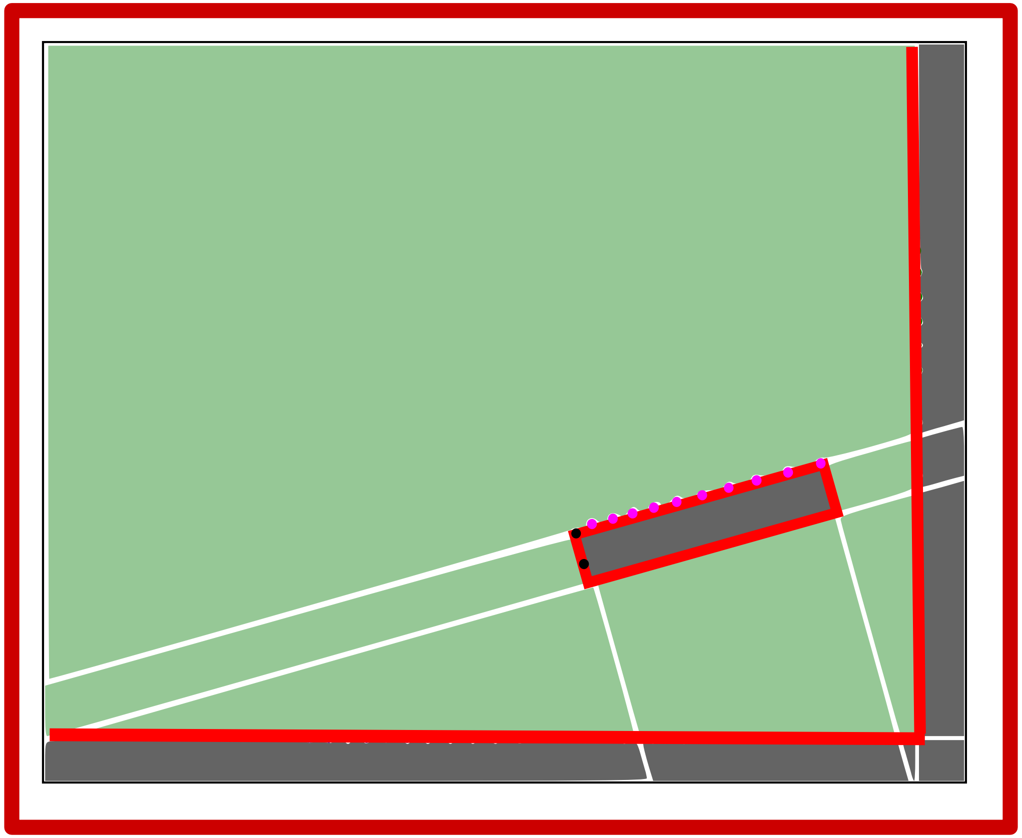
Overview of the method

- Laser point cloud
- Primitive extraction
- Ghost generation
- Volume partition using a plane arrangement
- Binary partition using linear programming



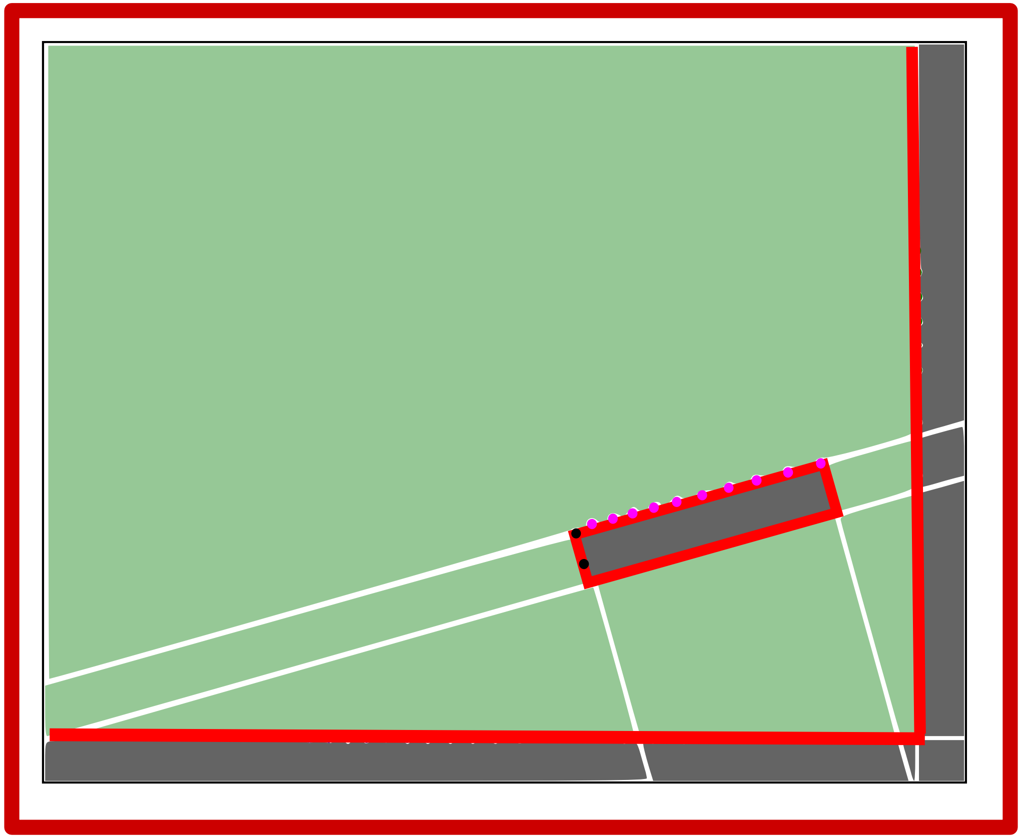
Overview of the method

- Laser point cloud
- Primitive extraction
- Ghost generation
- Volume partition using a plane arrangement
- Binary partition using linear programming
- Surface extraction



Overview of the method

- Laser point cloud
- Primitive extraction
- Ghost generation
- Volume partition using a plane arrangement
- Binary partition using linear programming
- Surface extraction

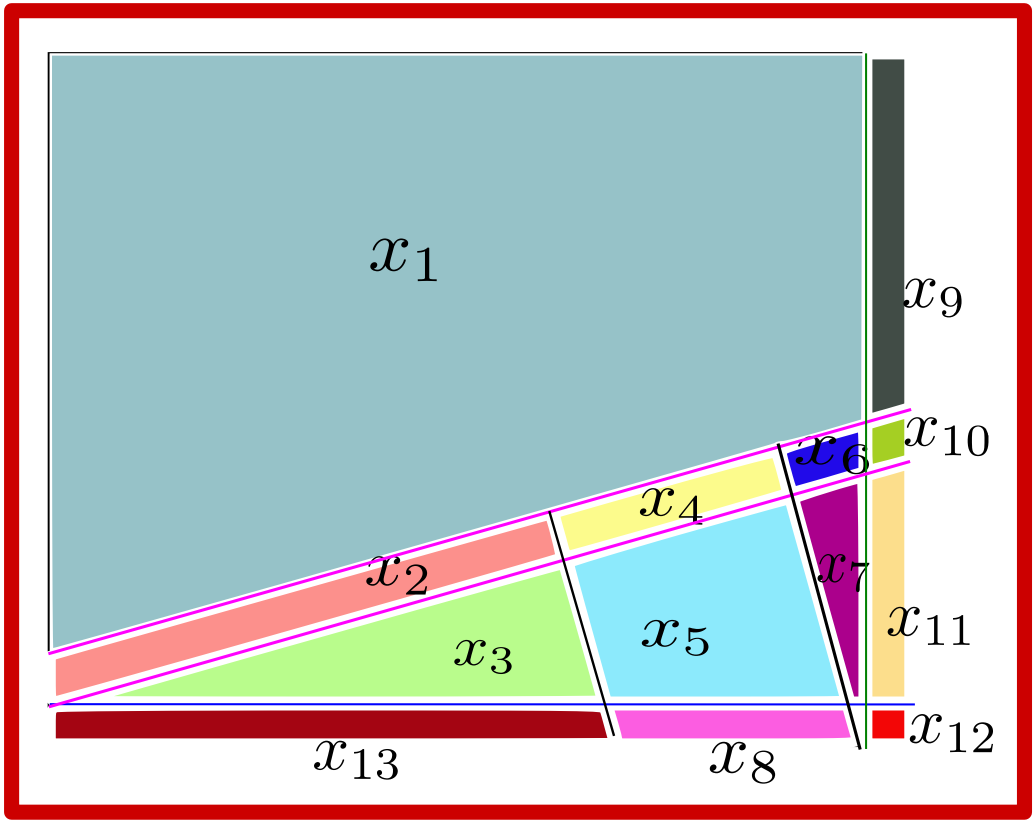


Surface extraction

Partition

- Partition the volume with a plane arrangement
- Labelization of each cell as empty or occupied

$$\mathbf{x} = (x_1, x_2, \ldots, x_N) \in \{0,1\}^N$$



Energy formulation

- Energy

$$E = E_{data} + E_{regul}$$

Data term

Penalizes a surface disagreeing with observations

Regularization term

Penalizes a complex surface in the hidden areas

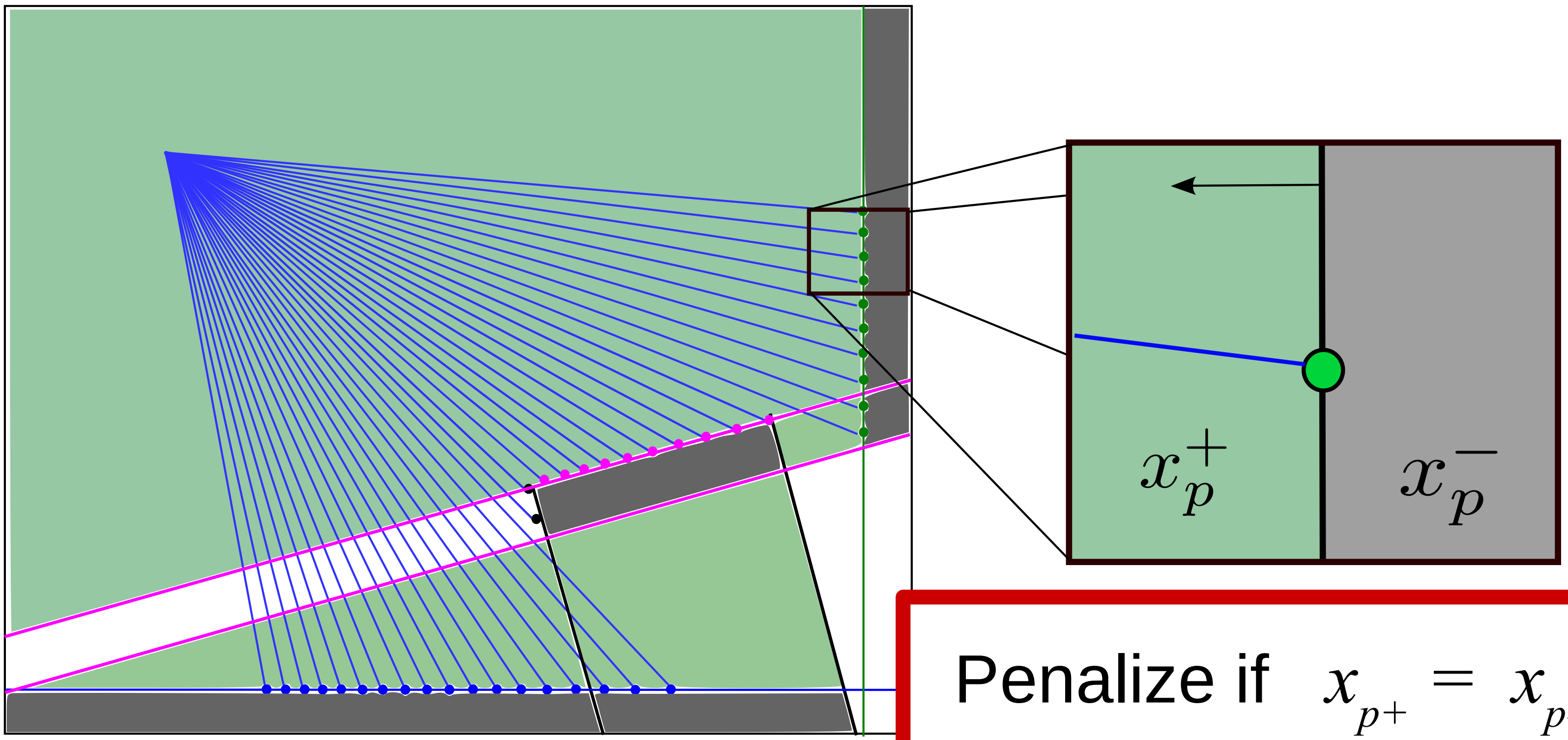
Data term

$$E_{data} = E_{prim} + E_{vis}$$

Surface extraction

Data term

$$E_{data} = \boxed{E_{prim}} + E_{vis}$$

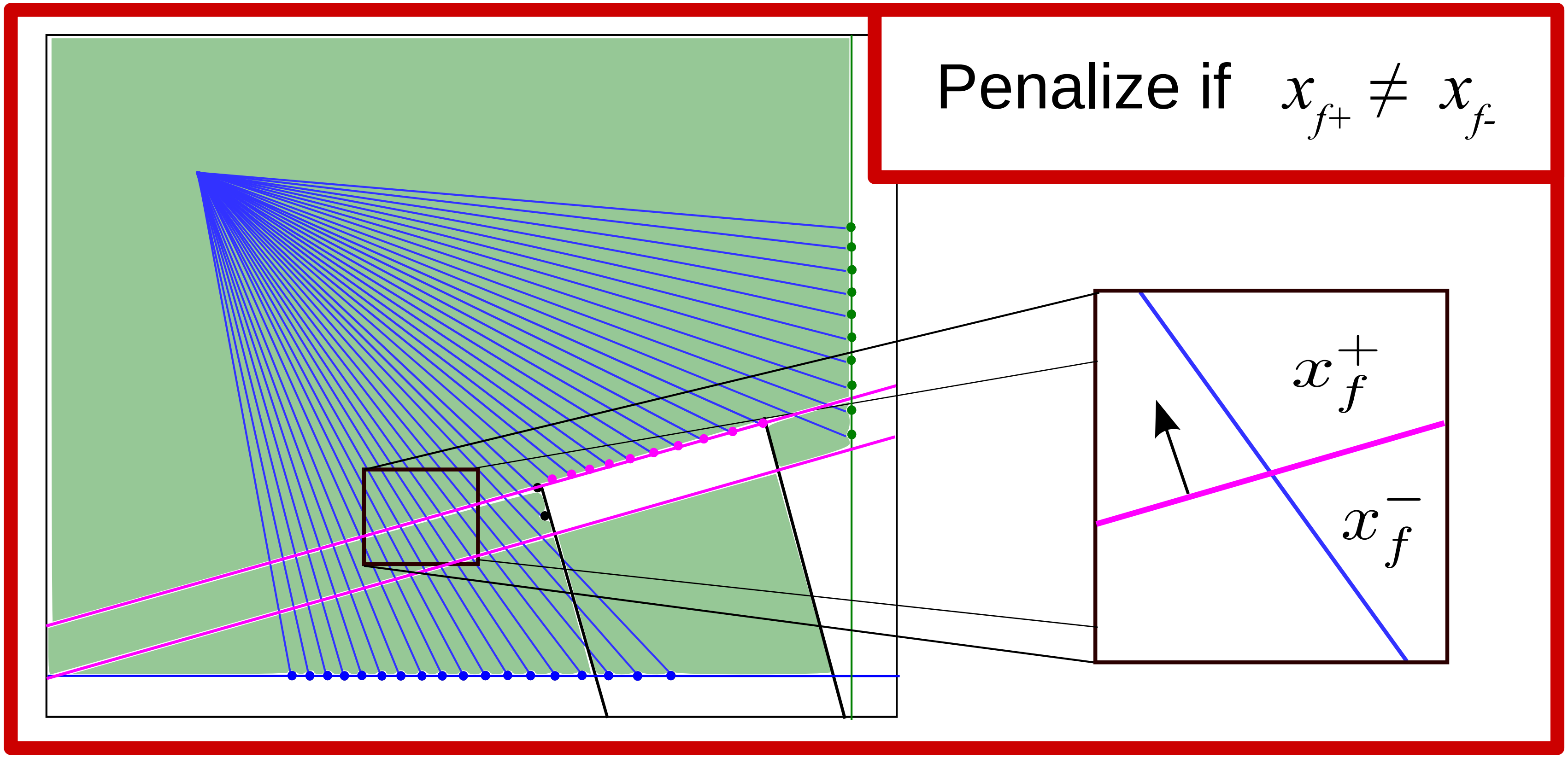


Penalize if $x_{p+} = x_{p-}$

Surface extraction

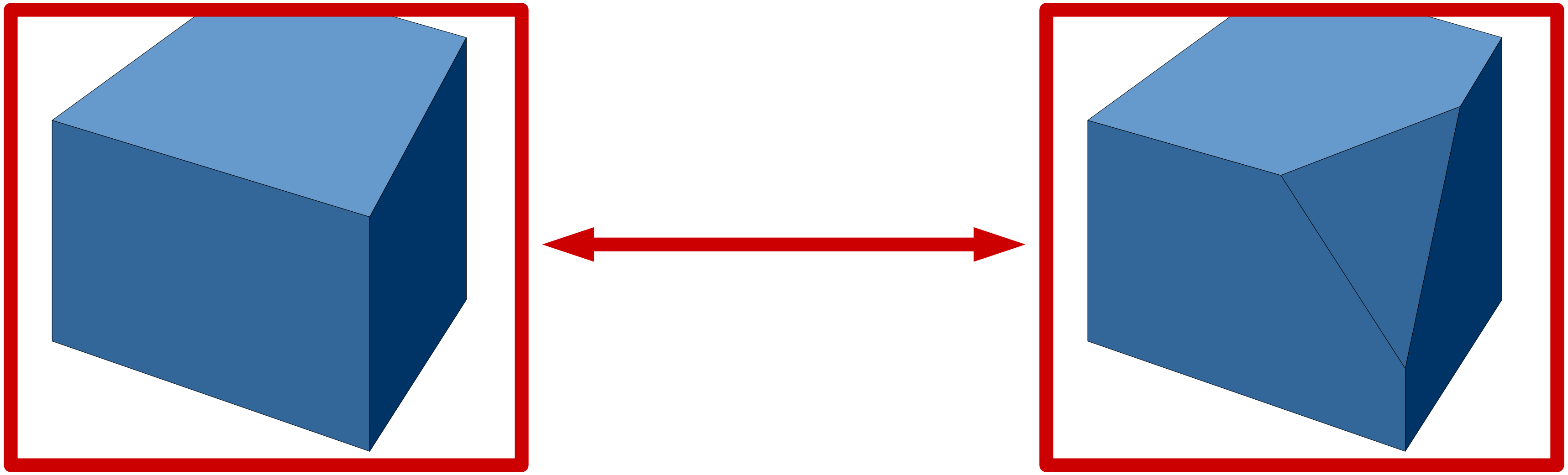
Data term

$$E_{data} = E_{prim} + \boxed{E_{vis}}$$



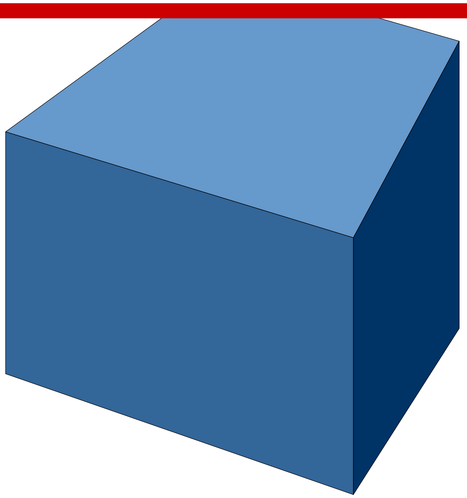
Surface extraction

Edge and Corner Regularization

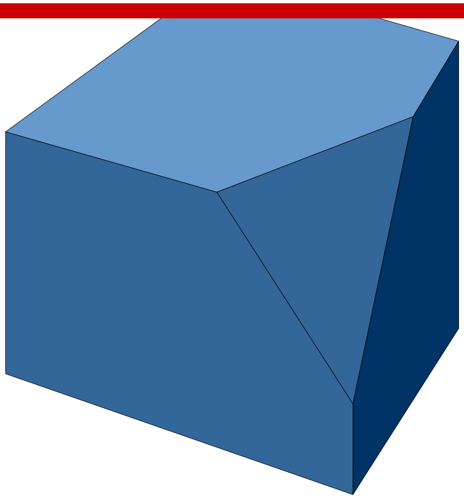


Surface extraction

Edge and Corner Regularization



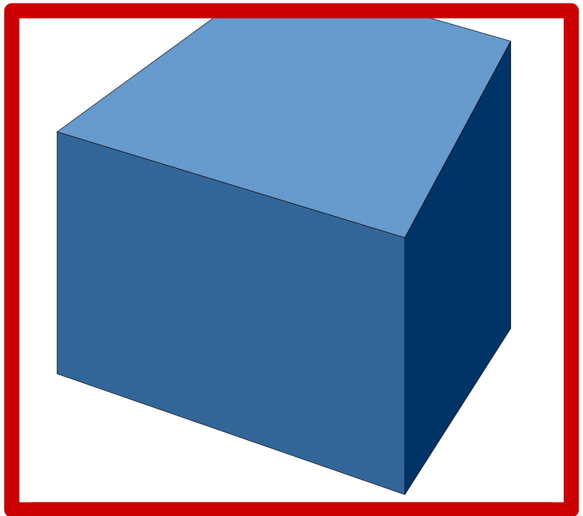
Shorter edges
Smaller corner number



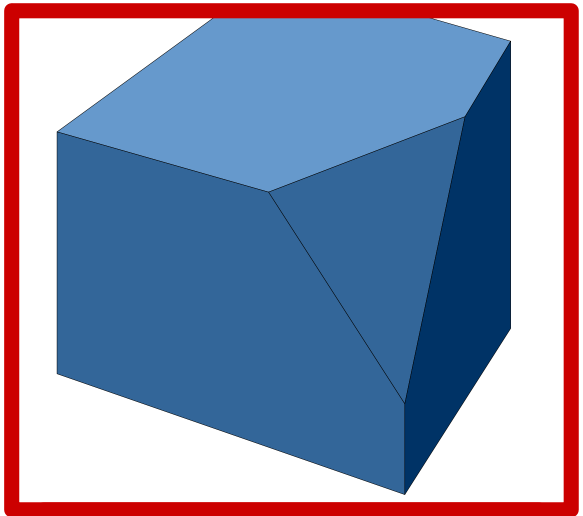
Smaller area

Surface extraction

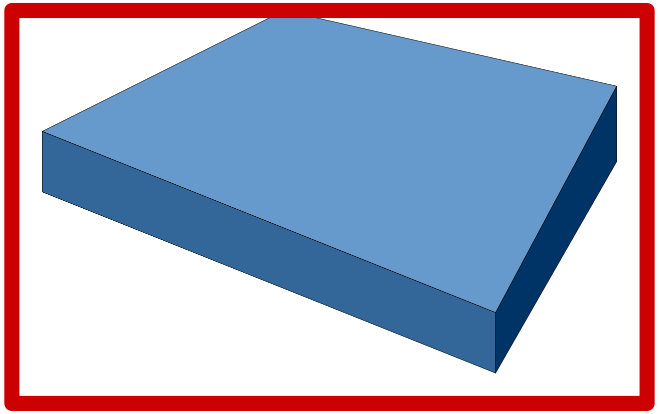
Edge and Corner Regularization

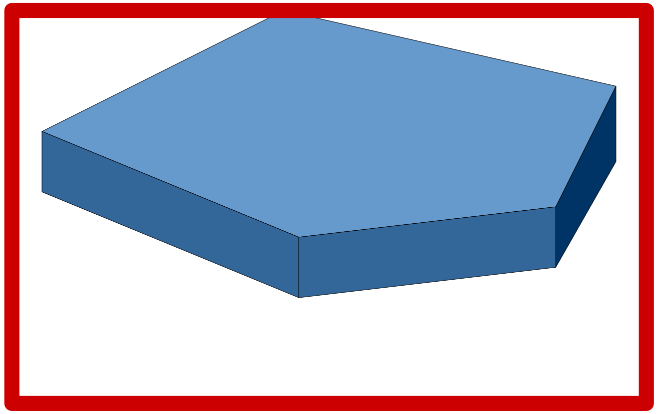


Shorter edges
Smaller corner number



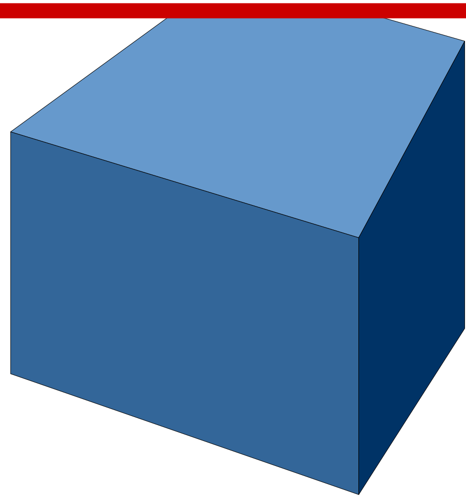
Smaller area



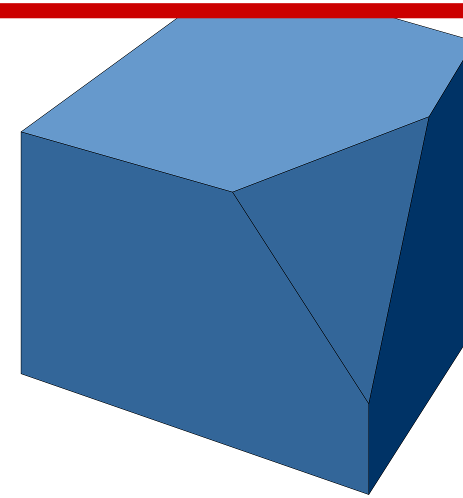


Surface extraction

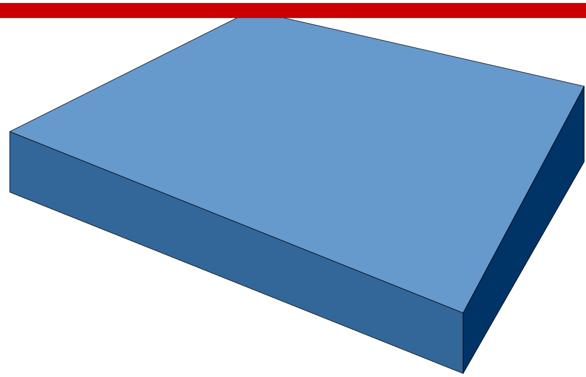
Edge and Corner Regularization



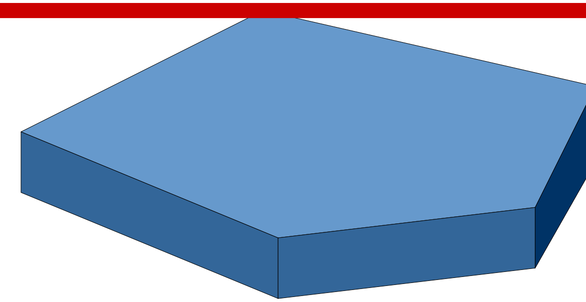
Shorter edges
Smaller corner number



Smaller area



Smaller corner number



Smaller area
Shorter edges

Regularization term

$$E_{regul} = E_{area} + E_{edge} + E_{corner}$$

Area penalization

Edge length penalization

Corner number penalization

Surface extraction

Regularization term

$$E_{regul} = E_{area} + E_{edge} + E_{corner}$$

Area penalization

Edge length penalization

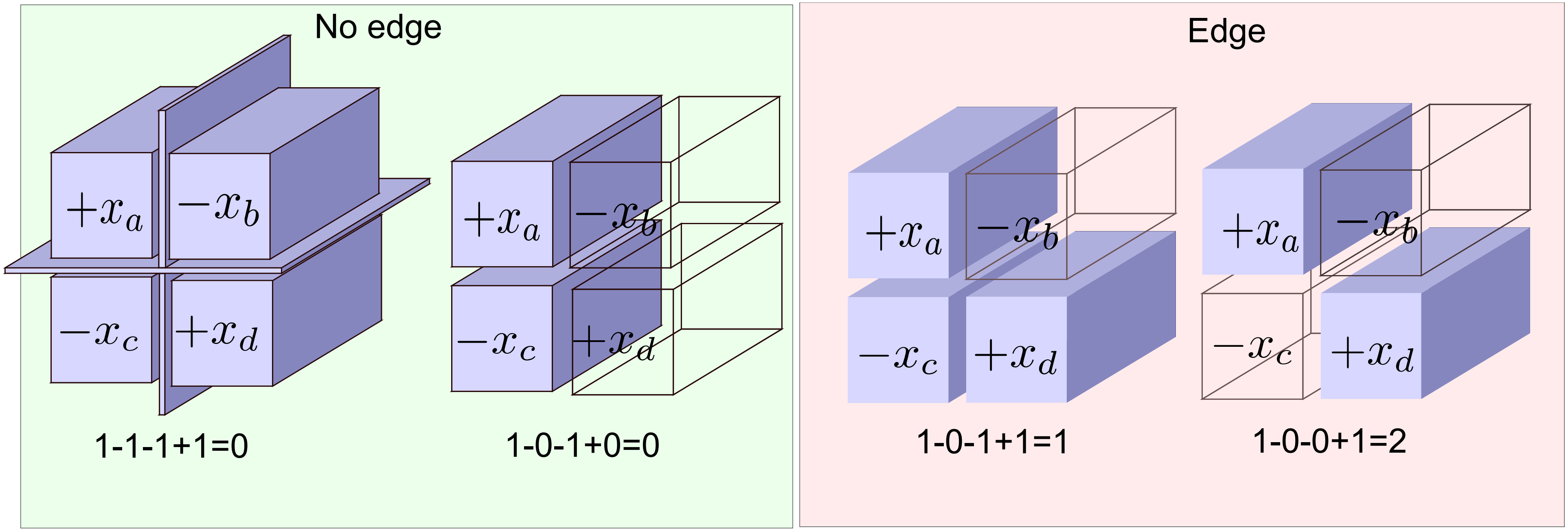
Corner number penalization

Surface extraction

Edge term

$$E_{edge}(\mathbf{x}) = \sum_{e\in\mathcal{E}} |h_e(\mathbf{x})|$$

$$h_e(x) = x_a - x_b - x_c + x_d$$

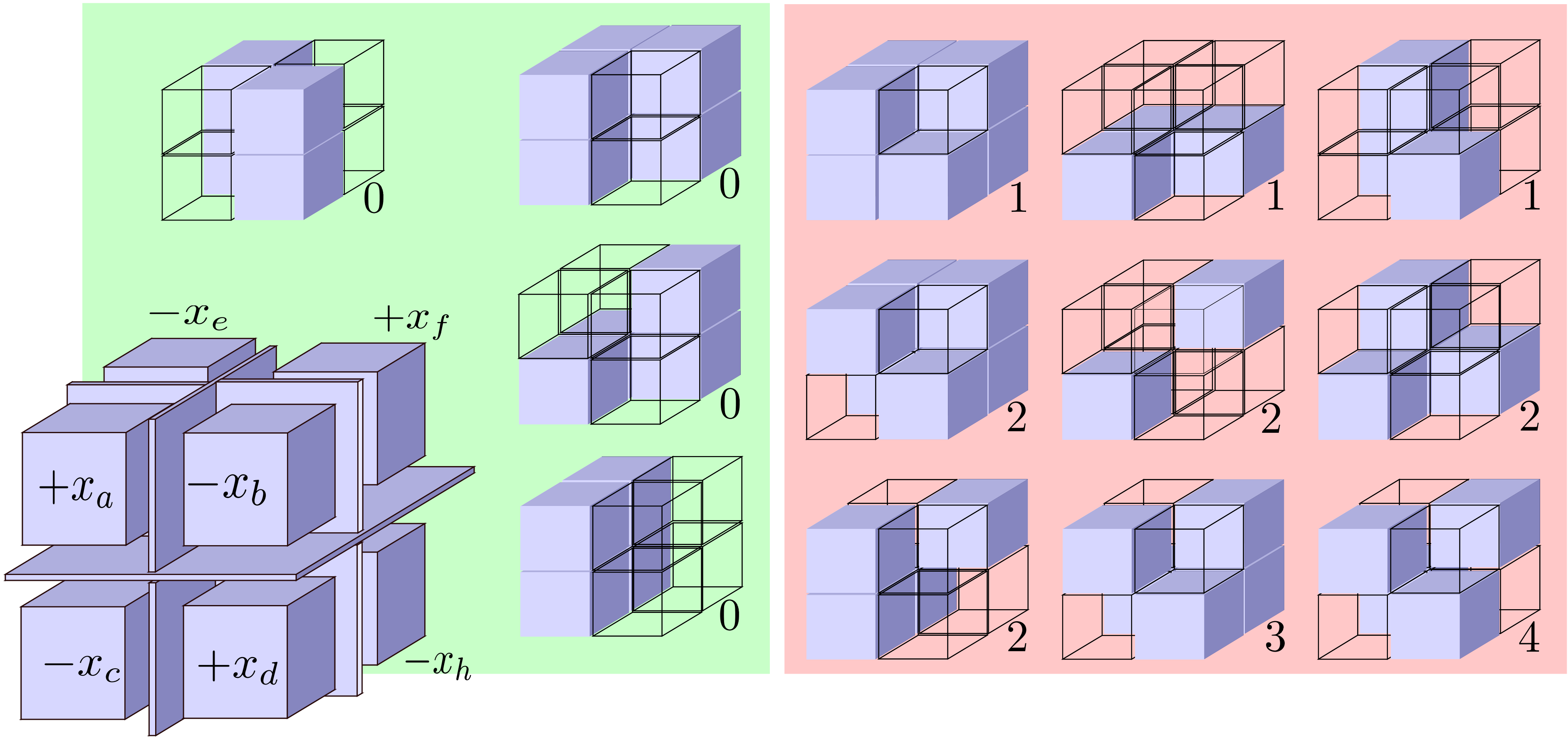


Surface extraction

Corner term

$$E_{corner}(\mathbf{x}) = \sum_{v \in \mathcal{V}} |h_v(\mathbf{x})|$$

$$h_v(x) = x_a - x_b - x_c + x_d - x_e + x_f + x_g - x_h$$



Energy minimization

- Objective

$$argmin_{\mathbf{x}}\ E(\mathbf{x})$$

- Very challenging for Markov Random Field
  - Edges: 4th order potential
  - Corners: 8th order potential

  - Tree-reweighted Belief Propagation: extremely slow
  - Lazy Flipper: local minimum, extremely suboptimal

Linear relaxation

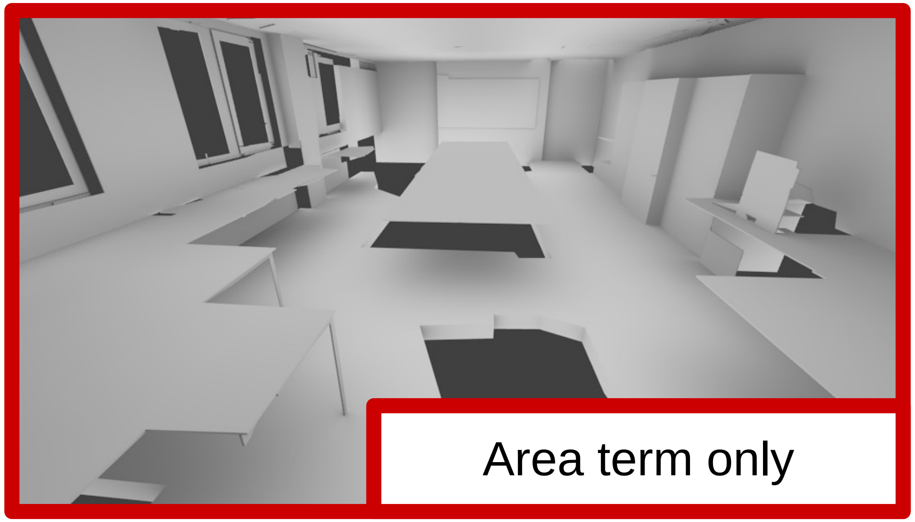
- Reformulation and relaxation

$$min_{x,y} \sum_i w_i y_i \quad s.t. \;\; x \in [0,1]^N, \forall i : -y_i \leq H_i \,.\, x \leq y_i$$

- This is a standard Linear Program

Surface extraction

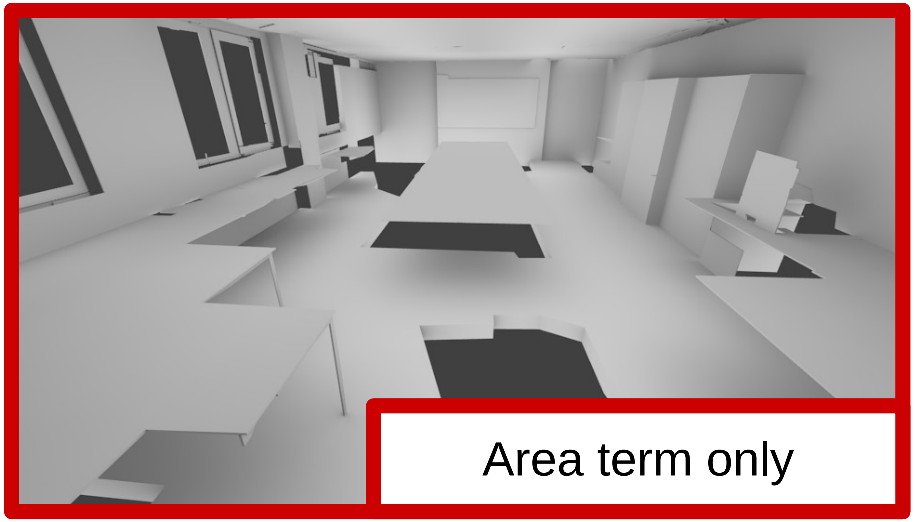
Results: meeting room



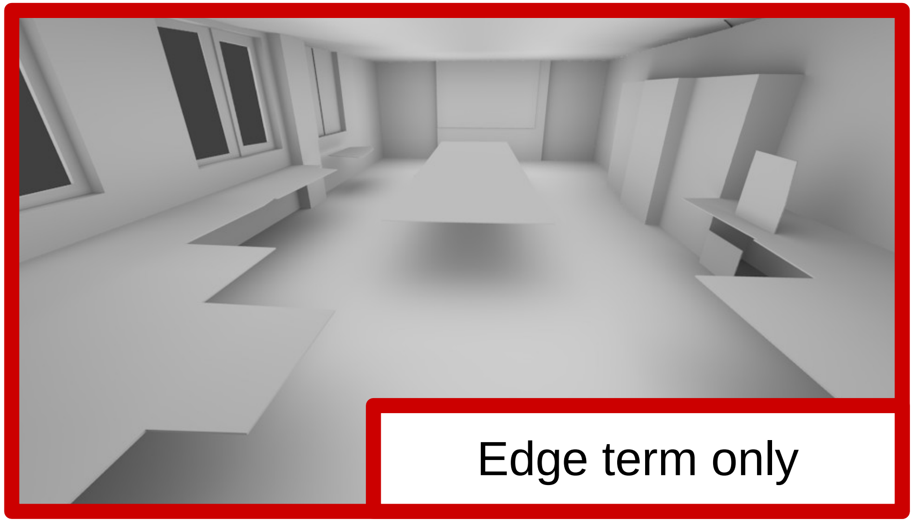
Surface extraction

Results: meeting room

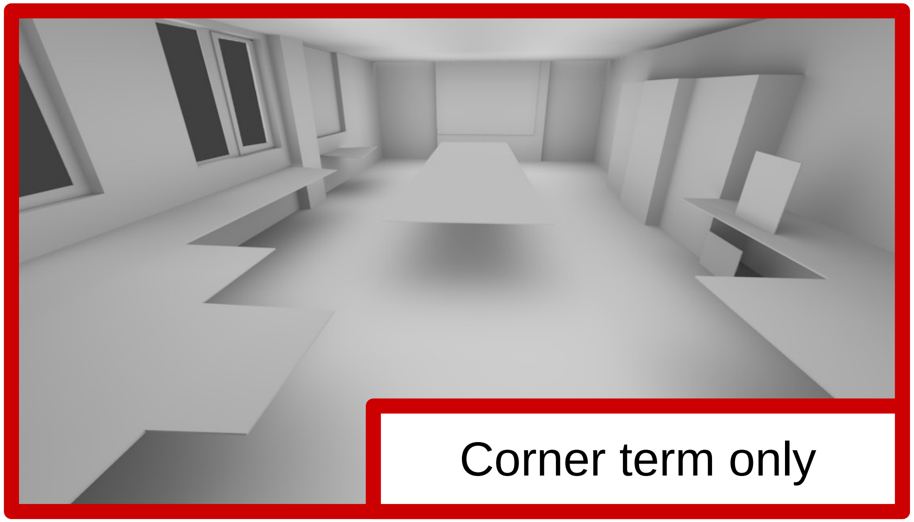
Chauve et al.



Area term only



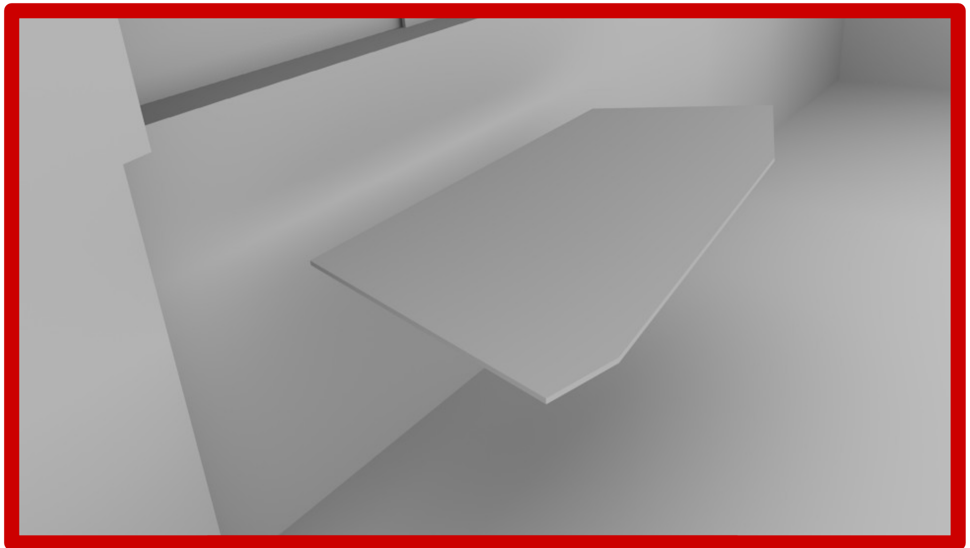
Edge term only



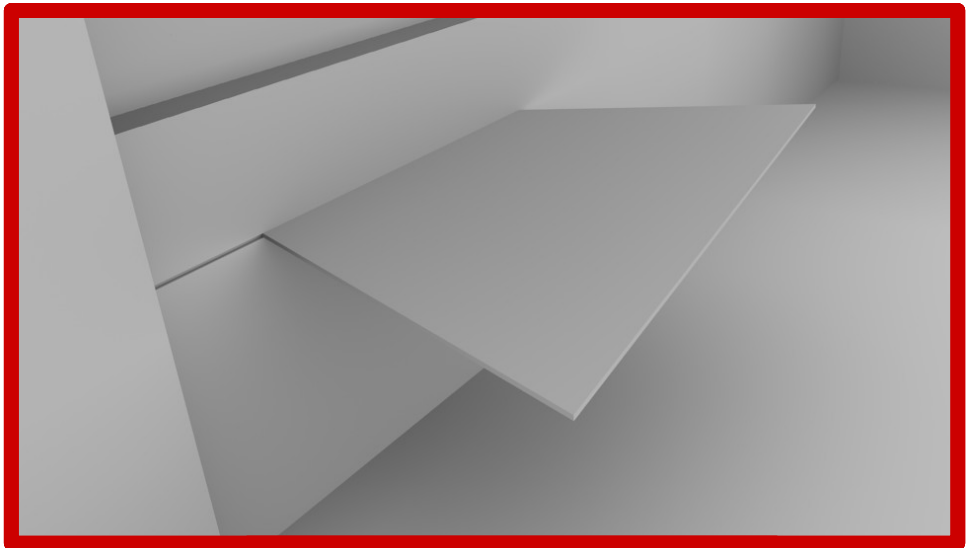
Corner term only

Surface extraction

Results: meeting room



Edge term only

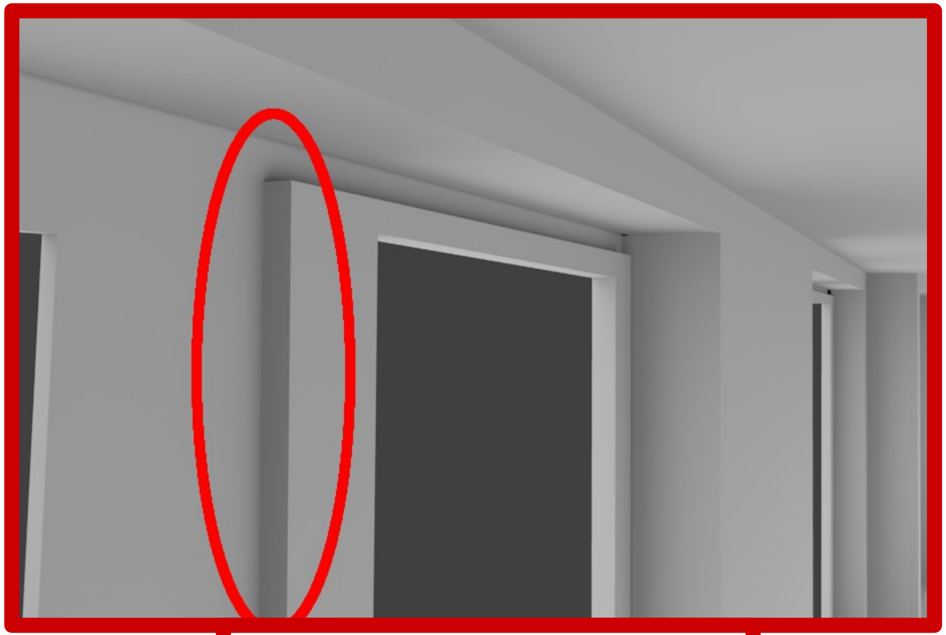


Corner term only

Surface extraction

Results: meeting room

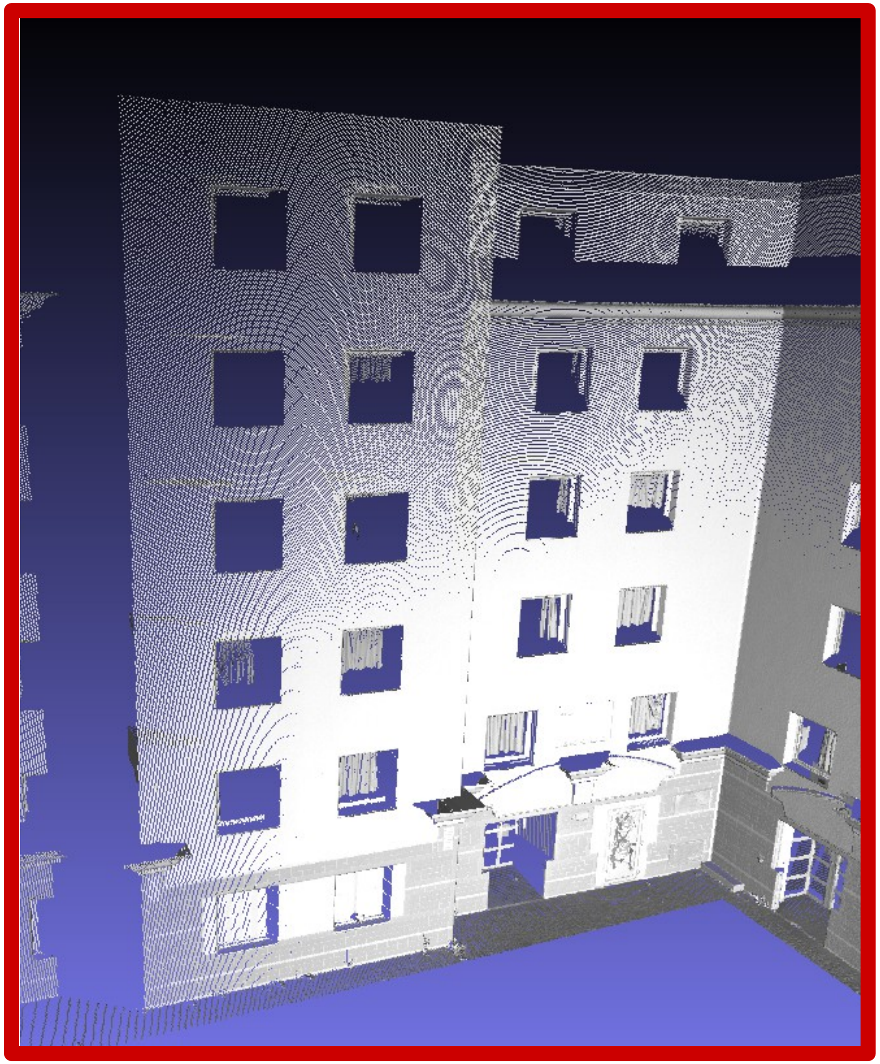
Corner only



Edge + corner

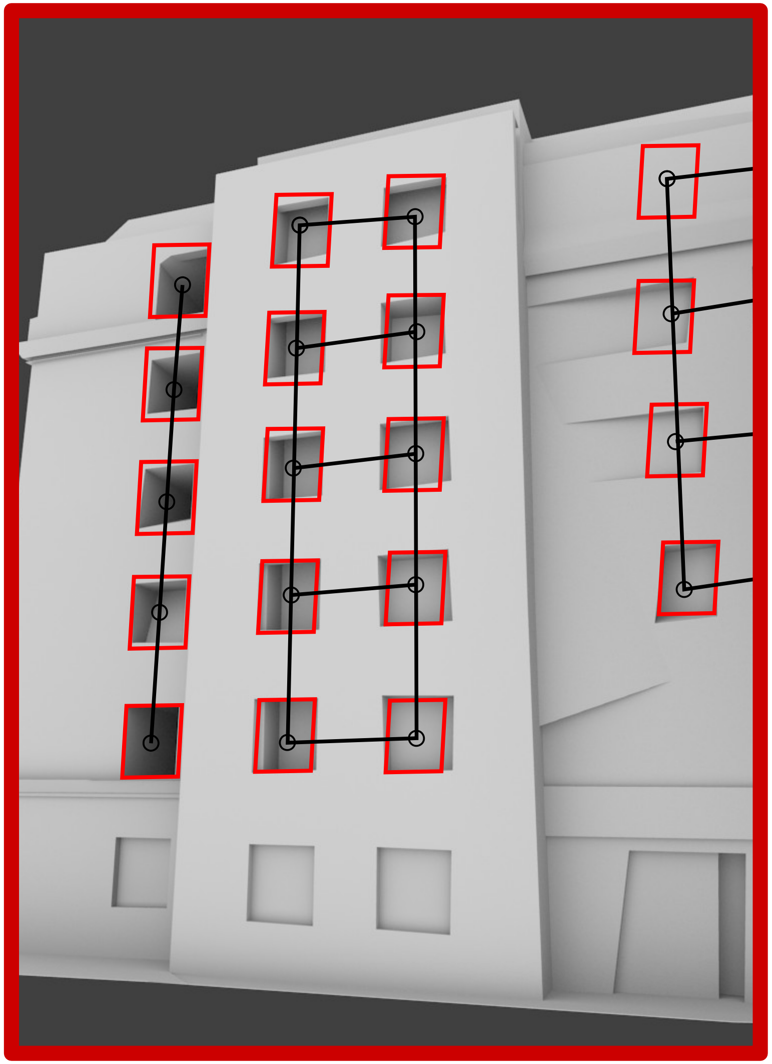
Surface extraction

Results: facade

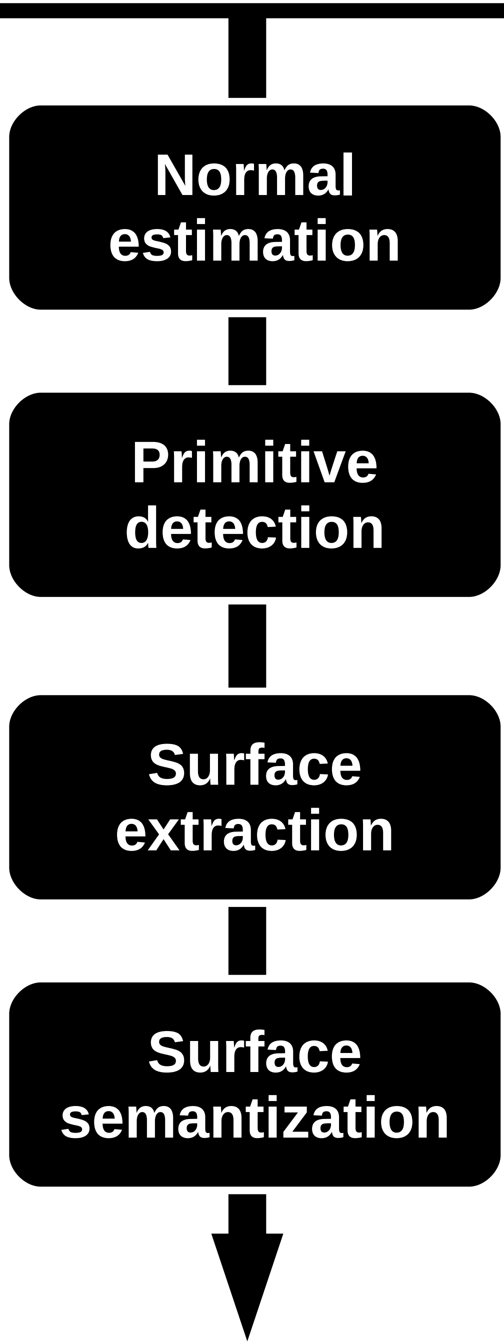


Conclusion

- A method for piecewise planar surface reconstruction
- Compared to Chauve et al.
  - handling of anisotropy
  - better surface hypotheses in hidden areas
  - better regularization on edge length and corner number
- Limits and perspectives
  - scaling to entire buildings
  - need for regularity discovery



Pipeline


Normal estimation
Primitive detection
Surface extraction
Surface semantization

Pipeline

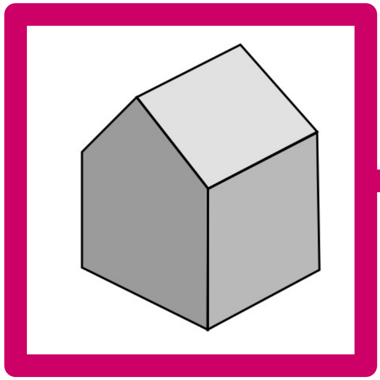
Normal estimation

Primitive detection

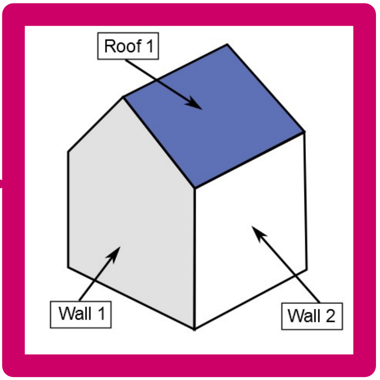
Surface extraction

Surface semantization

Global semantic information



Surface

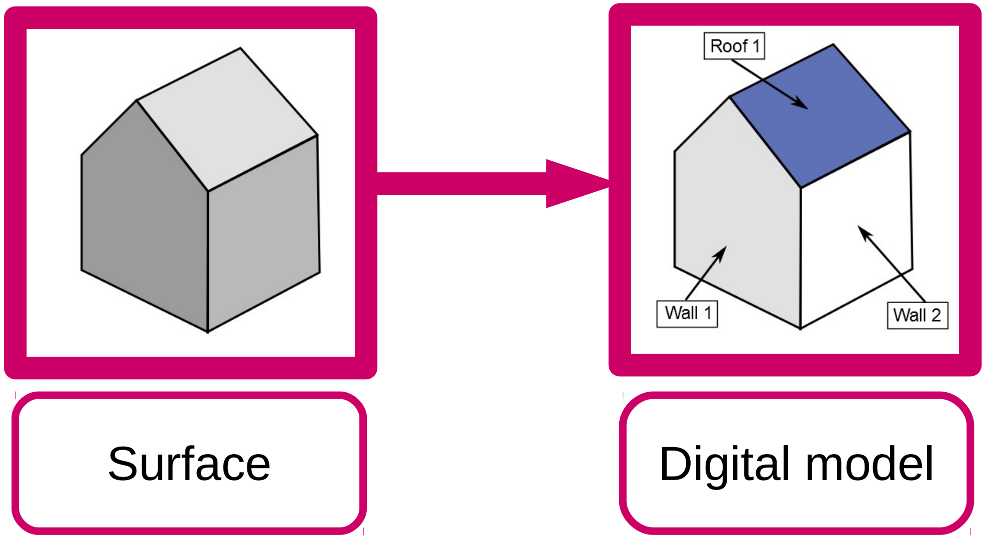


Digital model

Semantic enrichment

Building semantization

- Input: surface + semantic priors
- Output: semantized surface

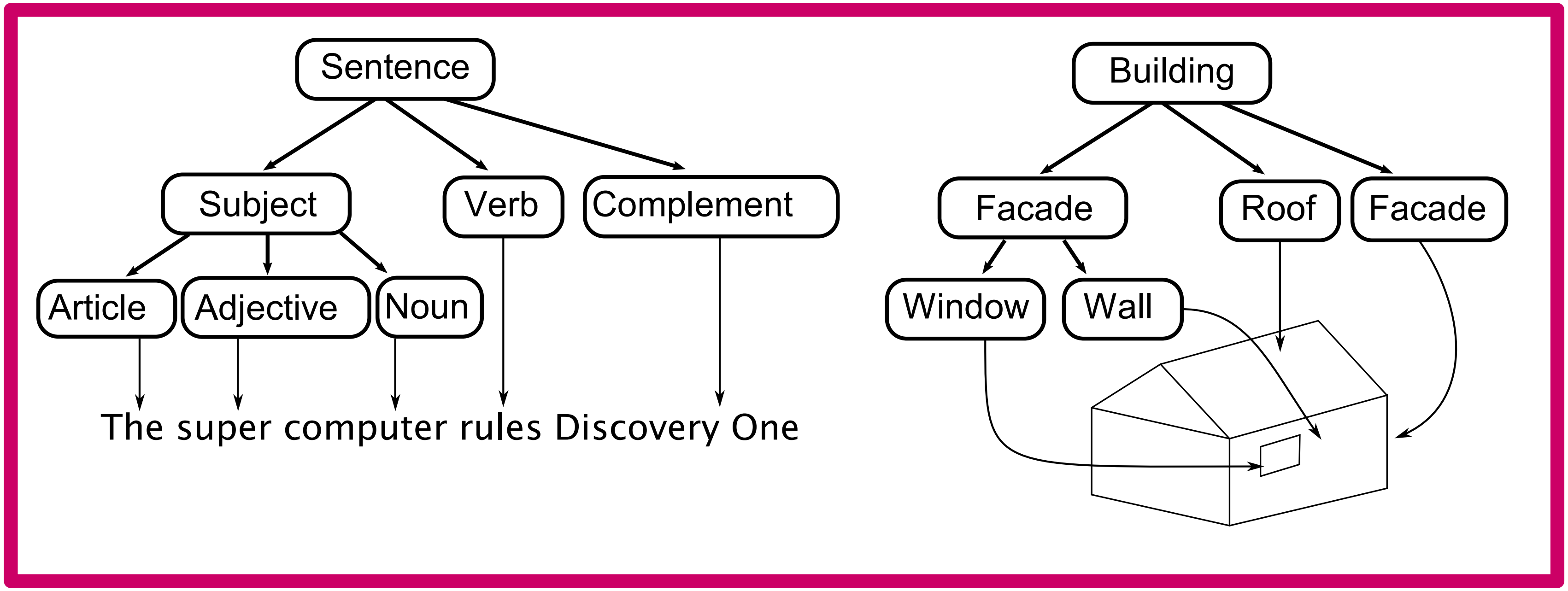


Method:

- Bottom-up
- Based on grammars

Grammars

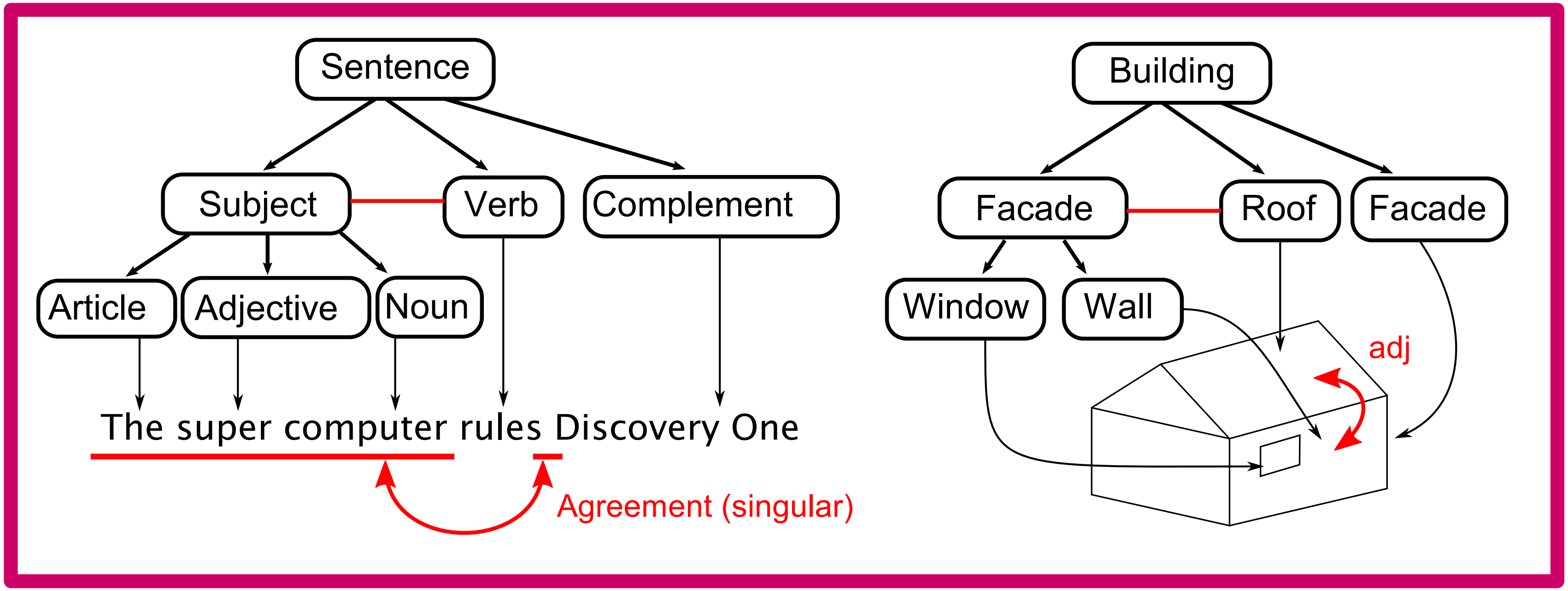
Expression of hierarchical decompositions



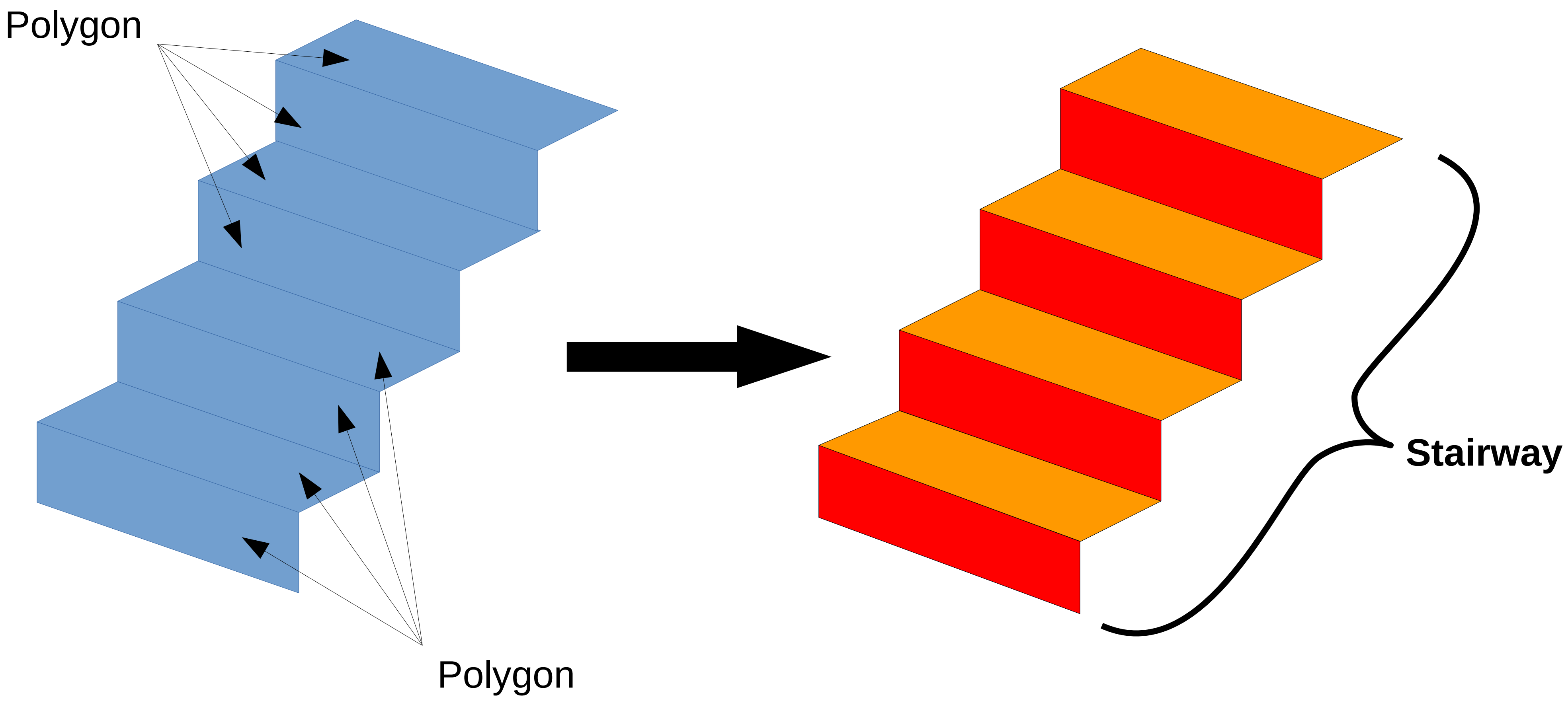
Semantic enrichment

Constrained attribute grammars

Expression of complex relations between elements

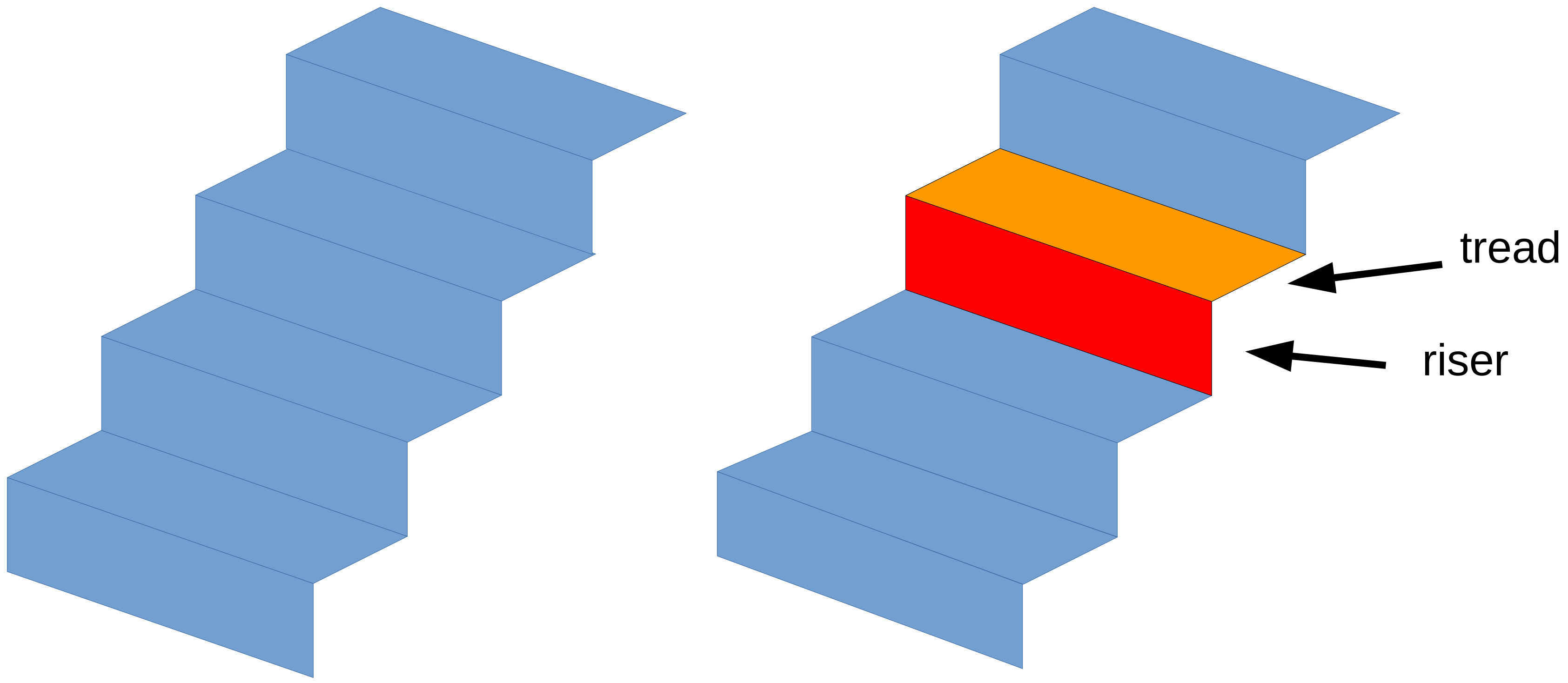


Stairway grammar



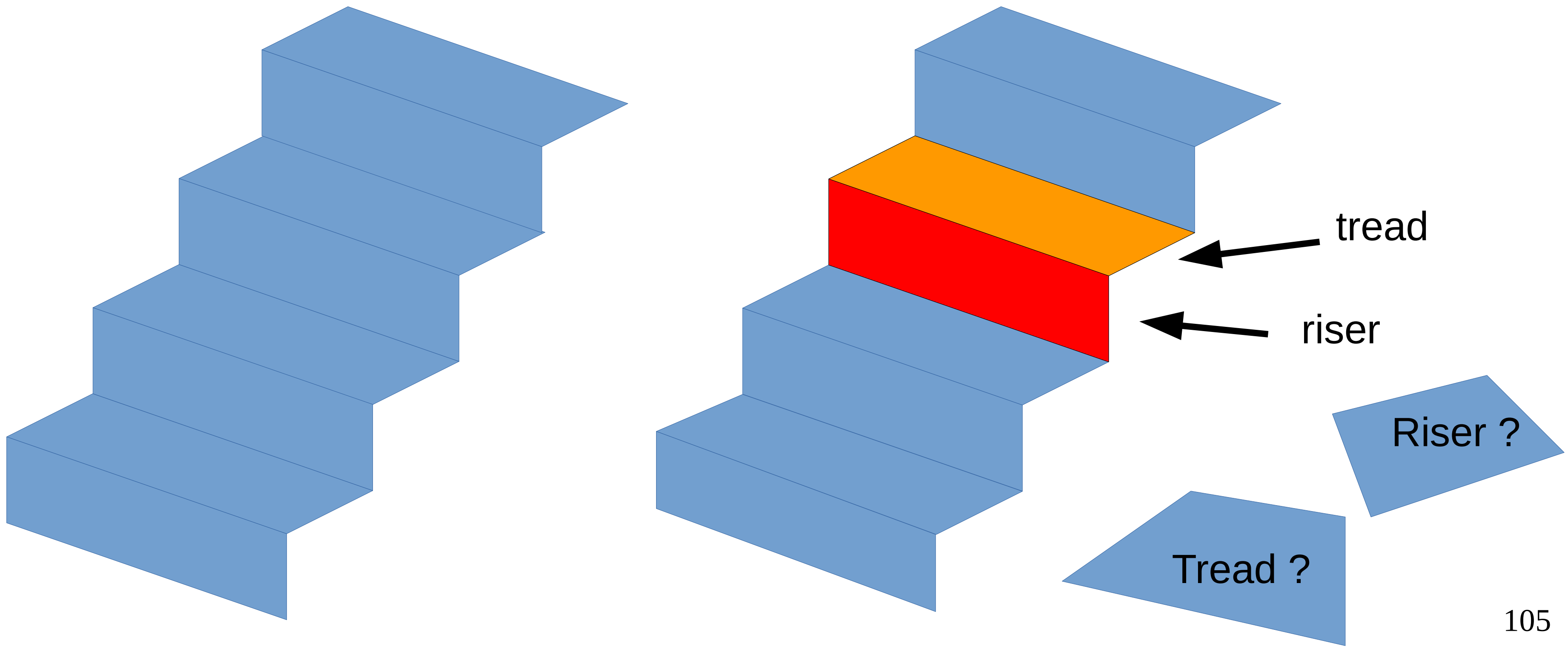
Basic rule

Tread t	$\rightarrow$	Polygon p
Riser r	$\rightarrow$	Polygon p
Step s	$\rightarrow$	Tread t, Riser r



Basic rule

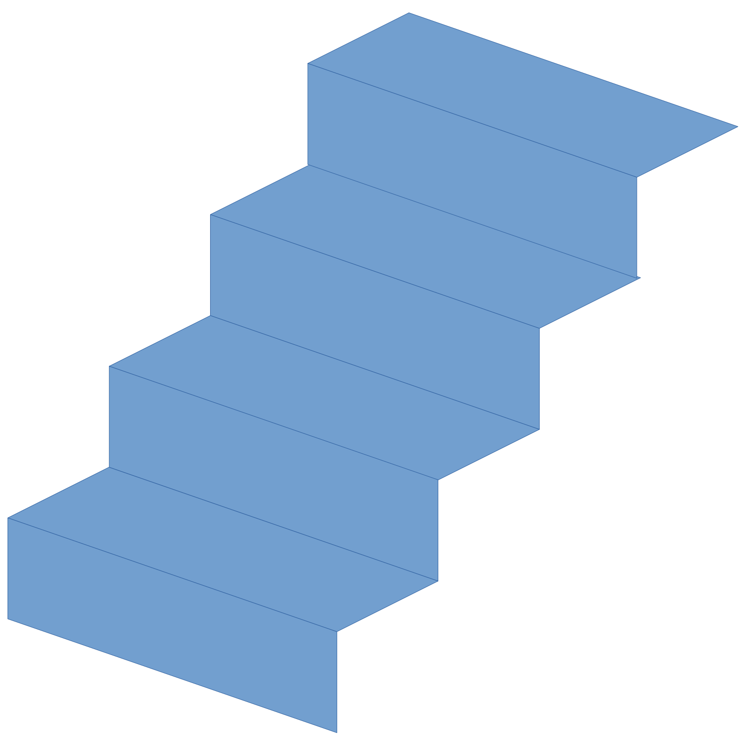
Tread t	$\rightarrow$	Polygon p
Riser r	$\rightarrow$	Polygon p
Step s	$\rightarrow$	Tread t, Riser r

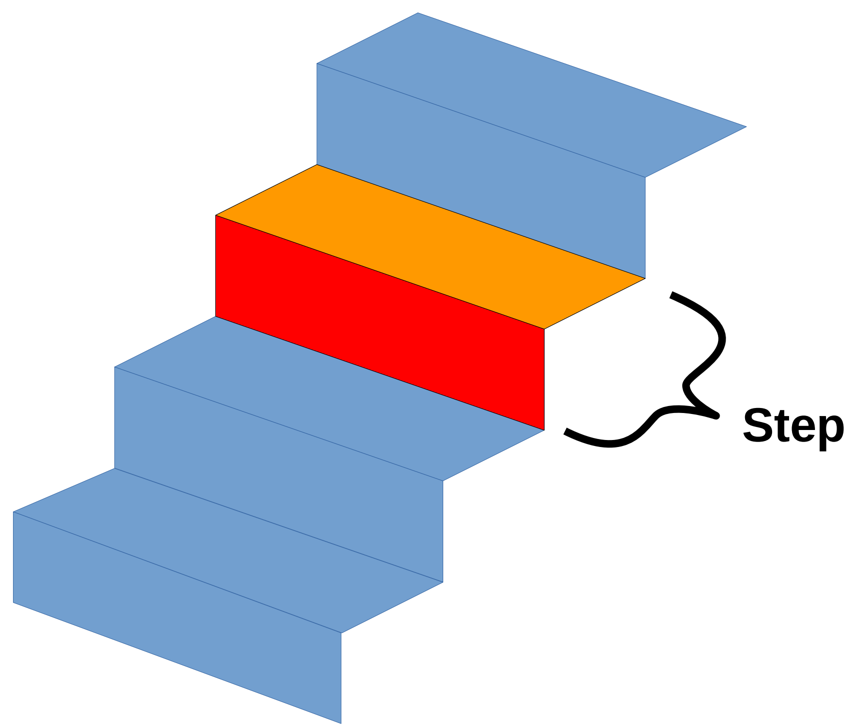


Semantic enrichment

Conditional rule

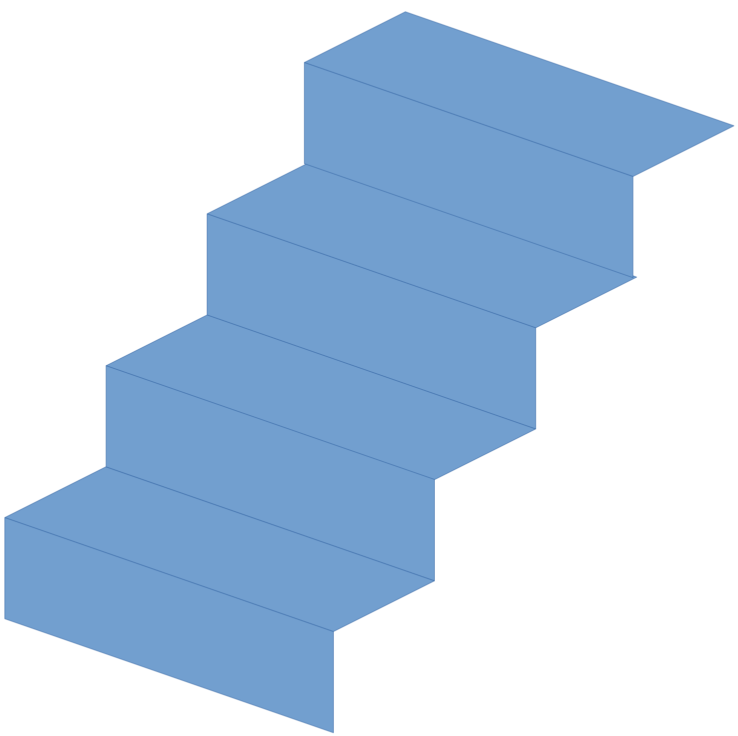
Tread t	$\rightarrow$	Polygon p	(horizontal(p), p.length < 2)
Riser r	$\rightarrow$	Polygon p	(vertical(p), $0.05 < p$.width < 0.25)
Step s	$\rightarrow$	Tread t, Riser r	(edgeAdj(t,r), above(t,r))

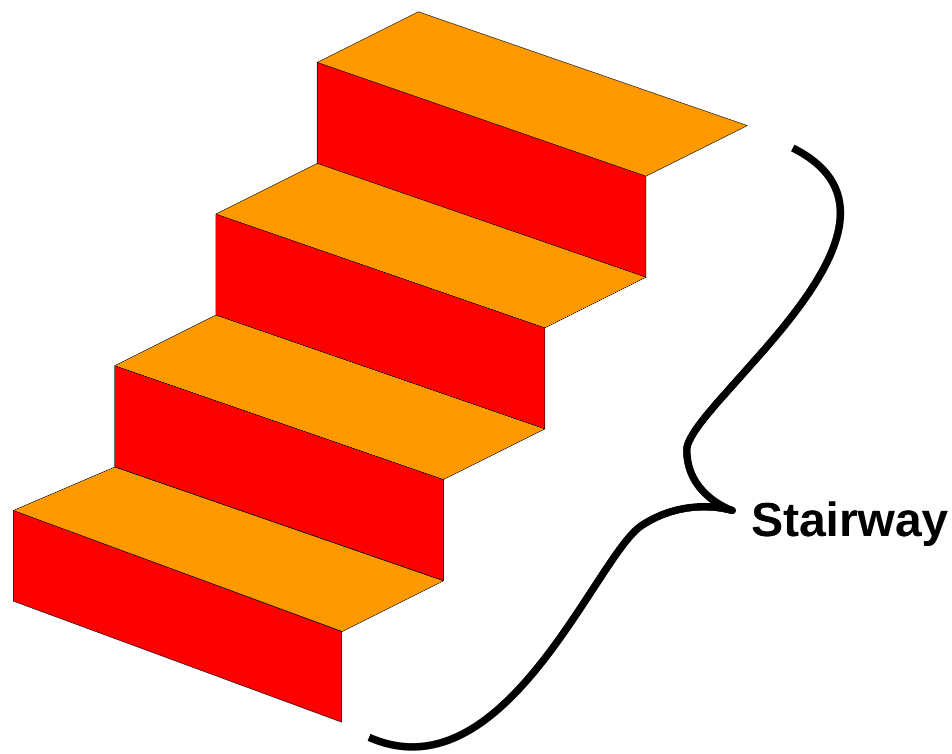




Collections

Tread t	$\rightarrow$	Polygon p	(horizontal(p), p.length < 2)
Riser r	$\rightarrow$	Polygon p	(vertical(p), $0.05 < p$.width < 0.25)
Step s	$\rightarrow$	Tread t, Riser r	(edgeAdj(t,r), above(t,r))
Stairway w	$\rightarrow$	**sequence**(Step s, edgeAdj) ms	

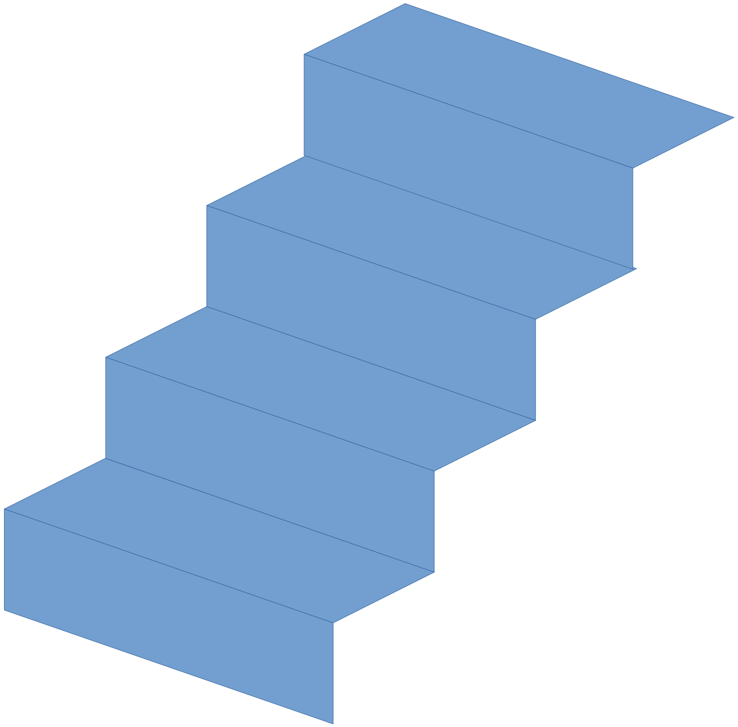


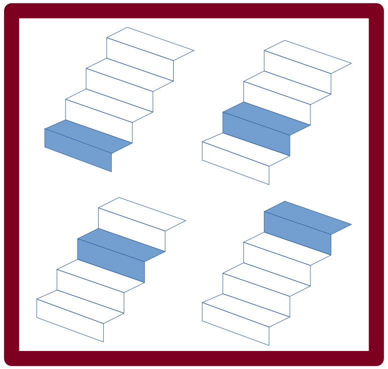


Semantic enrichment

Combinatorial Explosion

- Enumerating collections may lead to combinatorial explosion

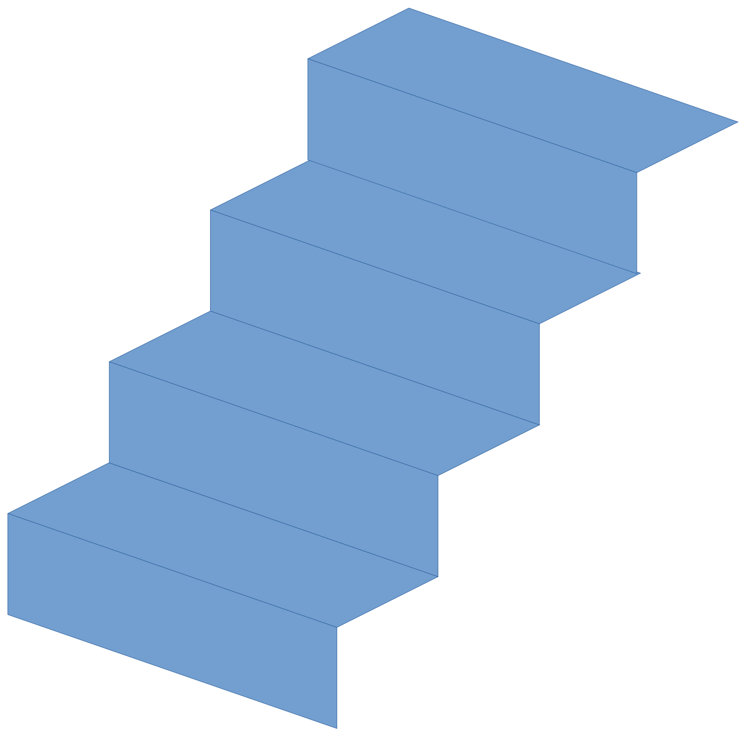


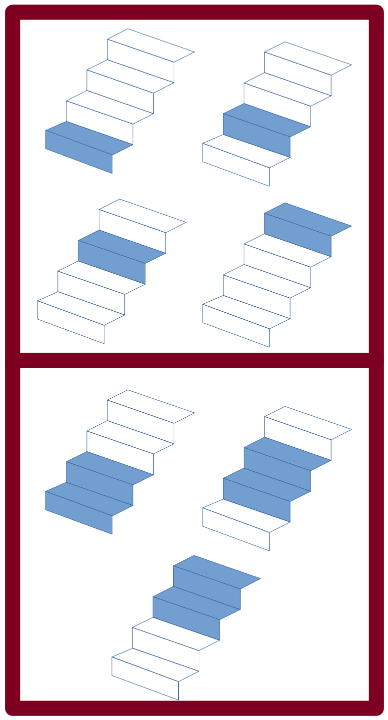


Semantic enrichment

Combinatorial Explosion

- Enumerating collections may lead to combinatorial explosion





Semantic enrichment

Combinatorial Explosion

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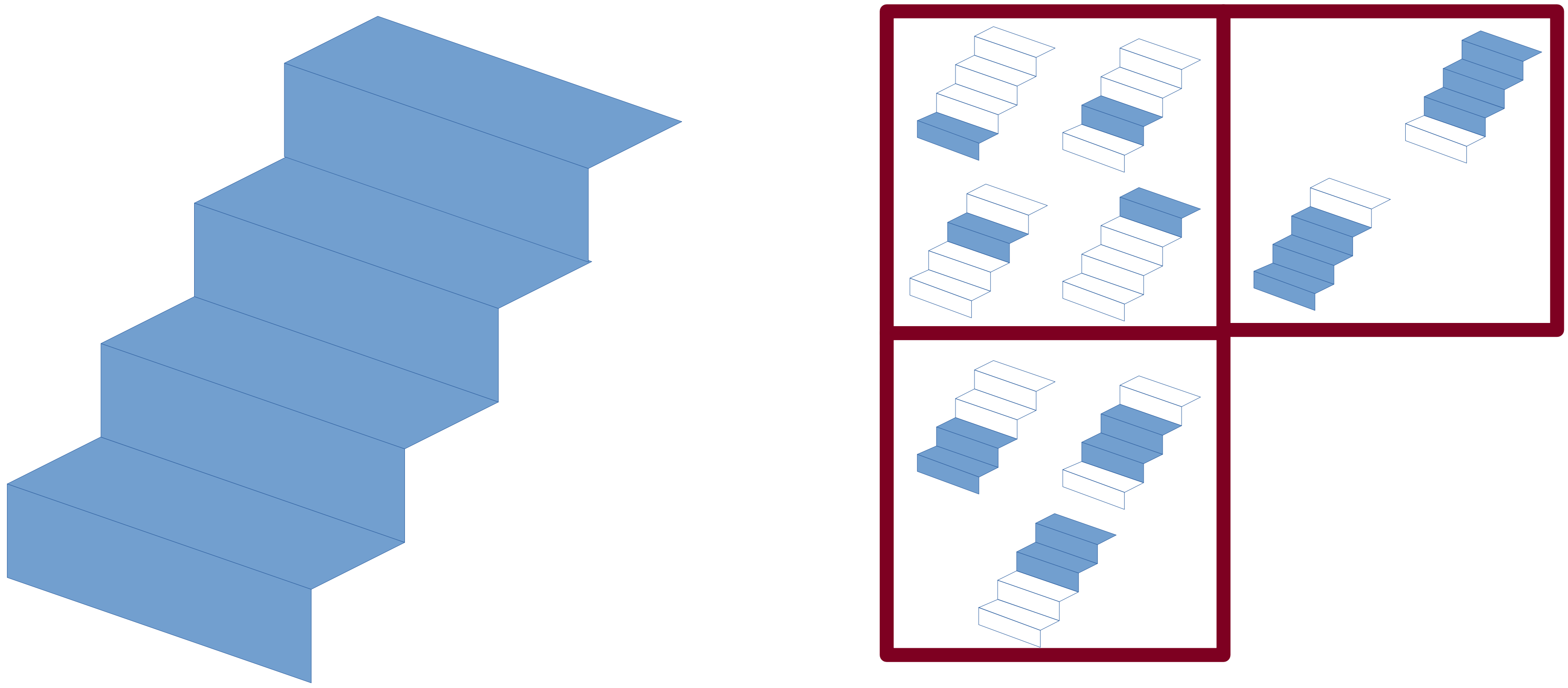

Semantic enrichment

Combinatorial Explosion

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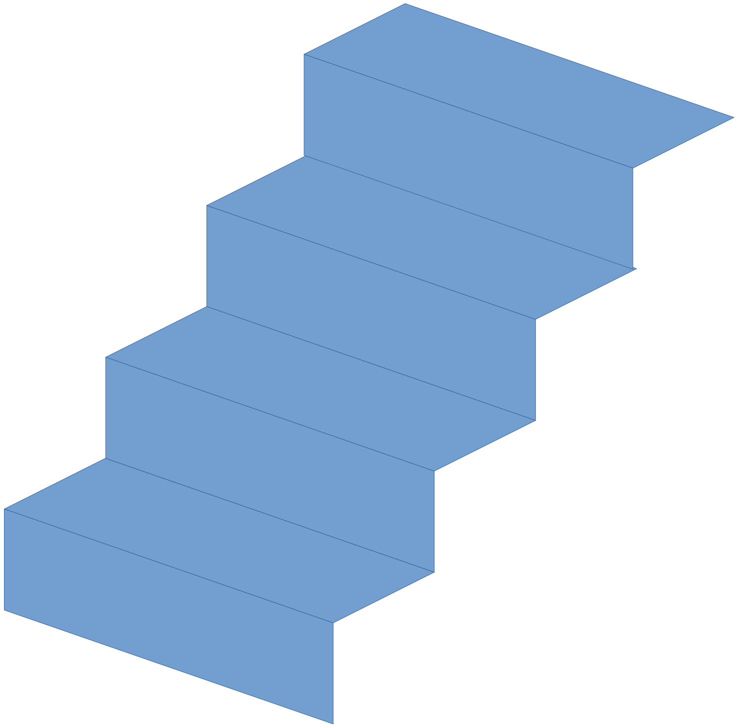
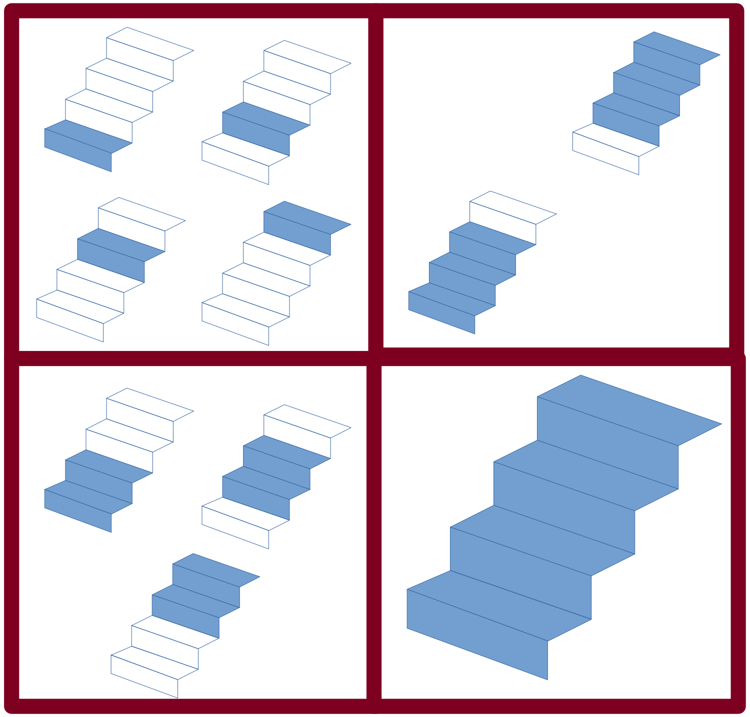




Total: 4 + 3 + 2 + 1 = 10 possible sequences

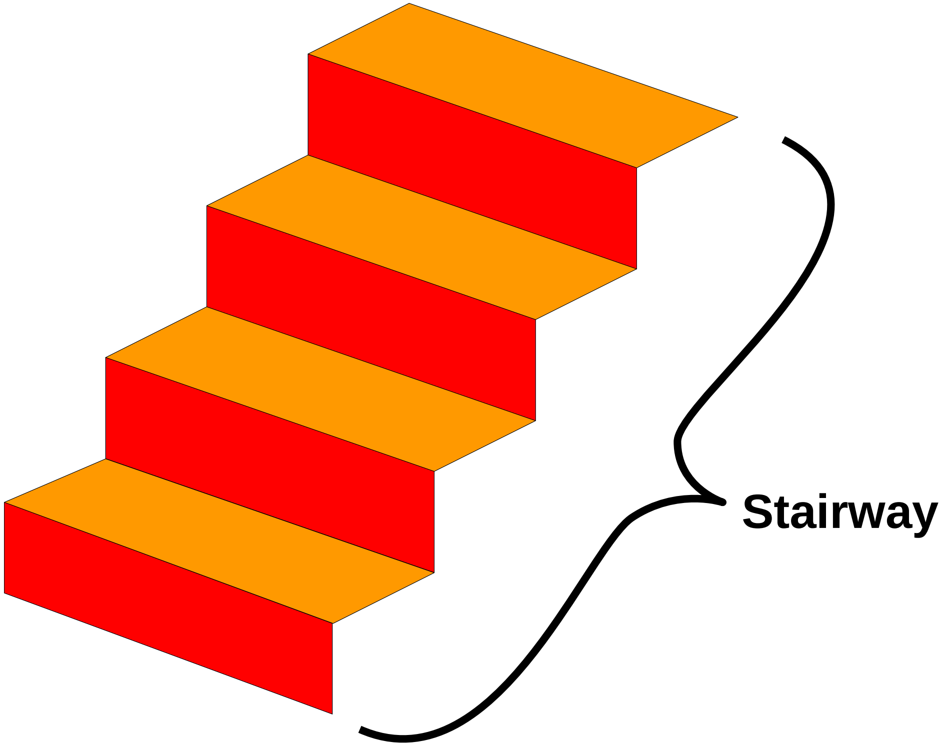
Maximal collections

Tread t	$\rightarrow$	Polygon p	(horizontal(p), p.length < 2)
Riser r	$\rightarrow$	Polygon p	(vertical(p), $0.05 < p$.width < 0.25)
Step s	$\rightarrow$	Tread t, Riser r	(edgeAdj(t,r), above(t,r))
Stairway w	$\rightarrow$	**maxseq**(Step s, edgeAdj) ms	

In practice, useful = largest collection:

Maximal operators (**maxseq**, **maxcycle**,…)

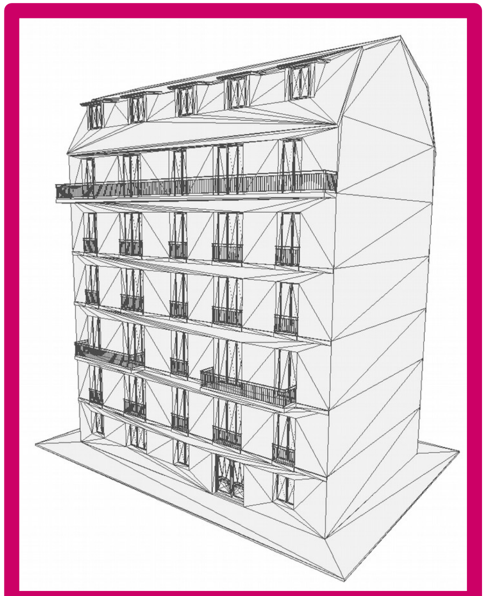
- fast computation
- low number of instances



Results

- Two grammars
  - Facade
  - Stairway
- Experiments
  - synthetic data: CAD models, simulated laser scans
  - real data: laser scans, photogrammetric data

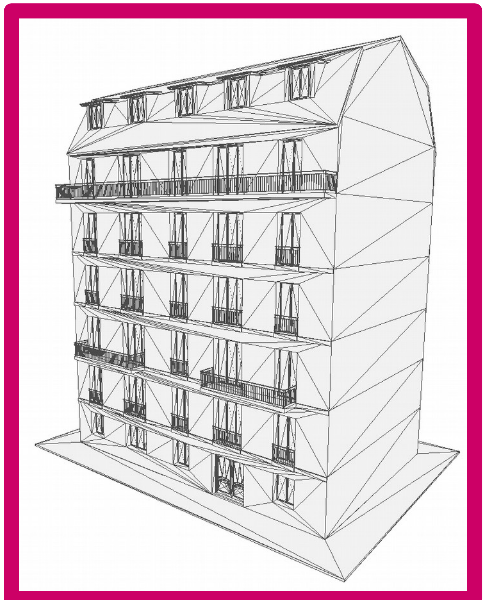
CAD Models



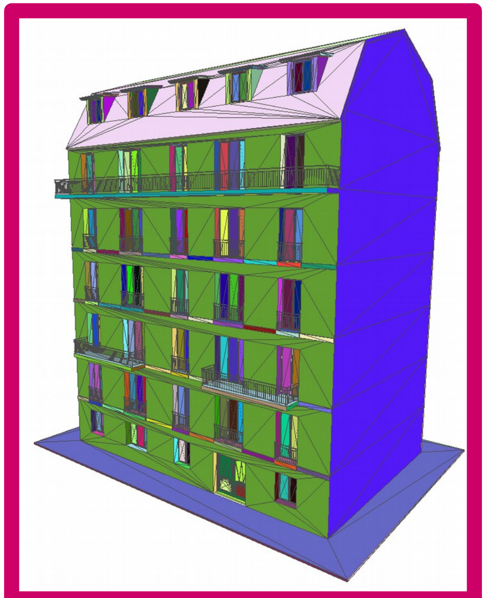
Triangle soup

Semantic enrichment

CAD Models



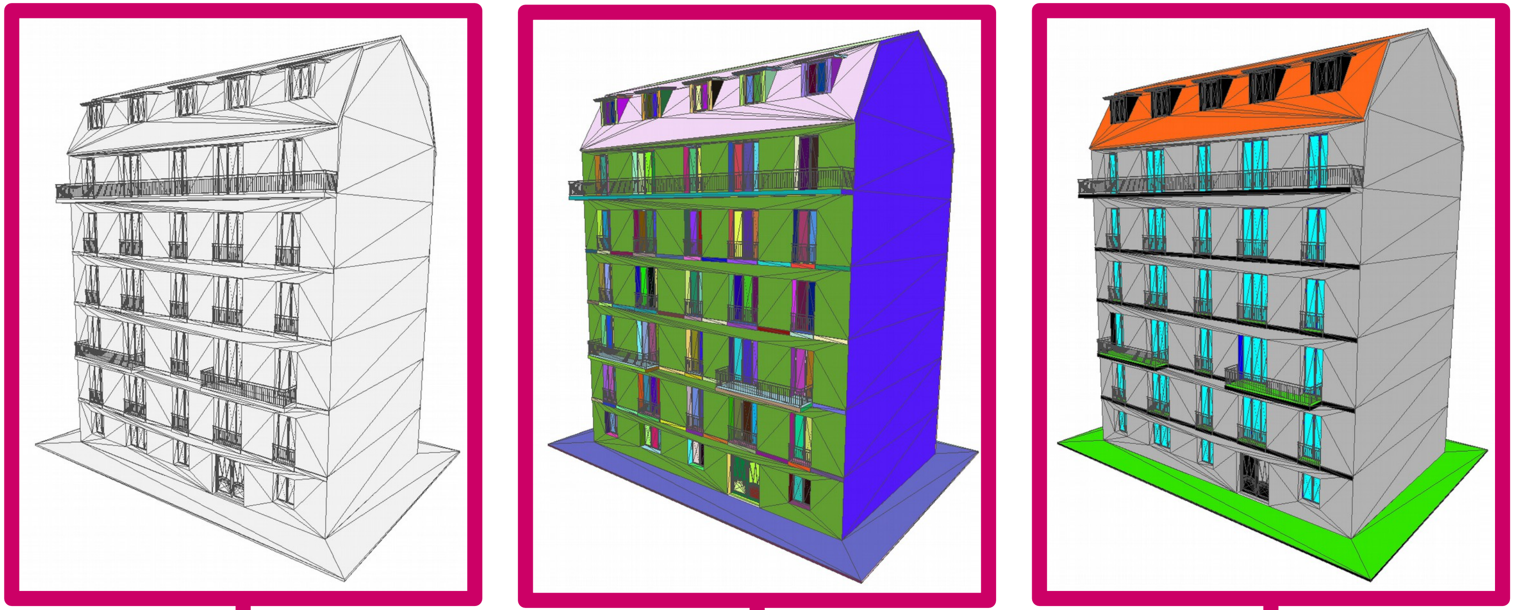
Triangle soup



Polygons

Semantic enrichment

CAD Models



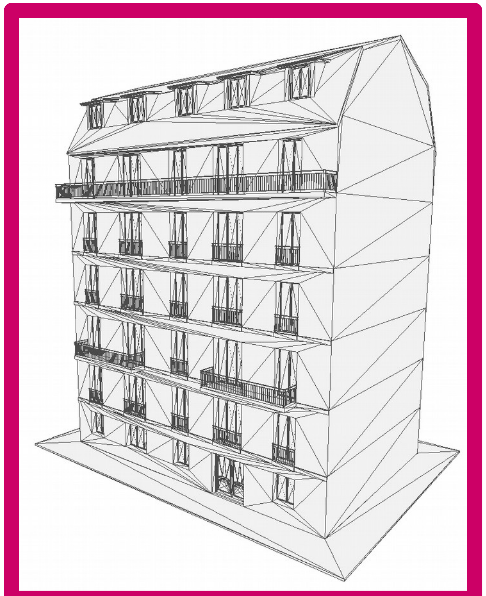
Triangle soup

Polygons

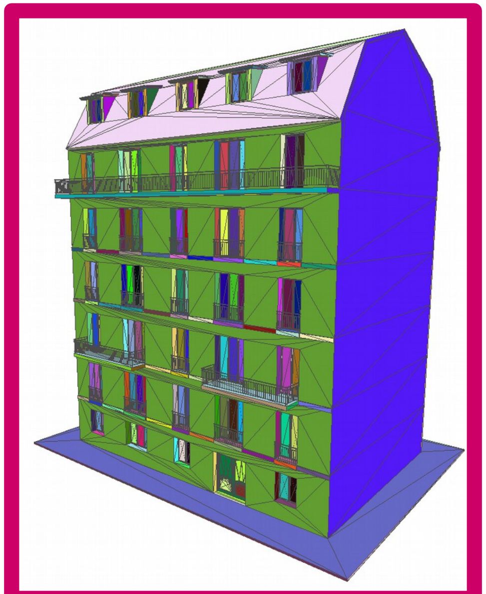
Semantized model

Semantic enrichment

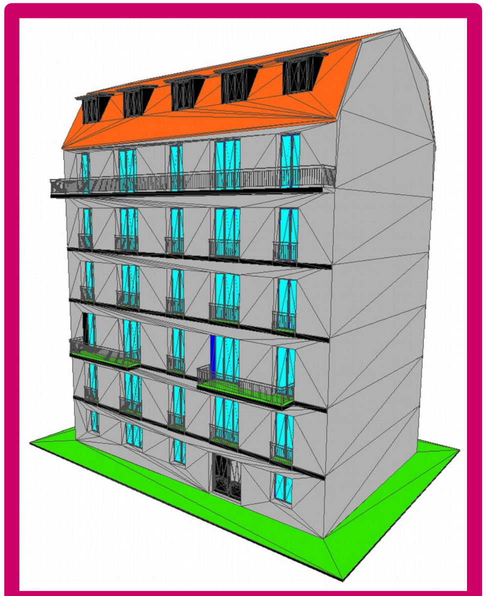
CAD Models



Triangle soup



Polygons

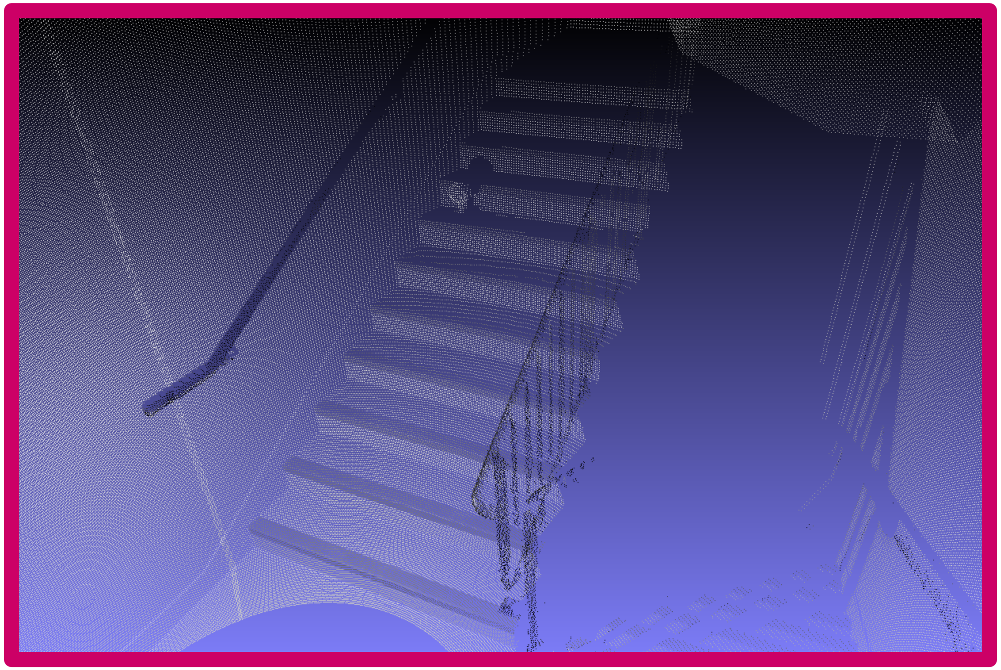


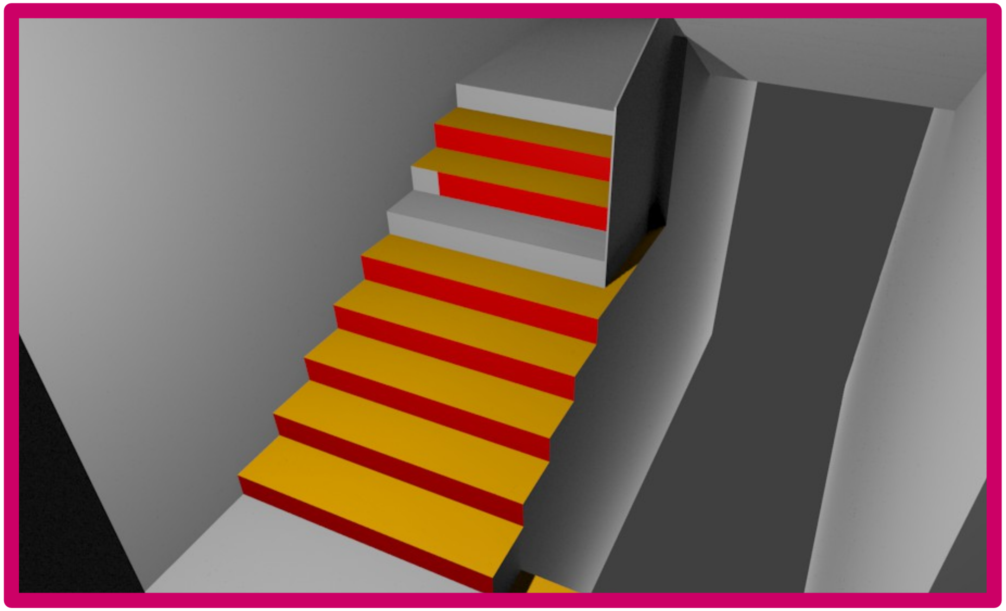
Semantized model

Semantized model + texture

Semantic enrichment

Real laser scan: stairs





Conclusion

Grammar-based building semantization method

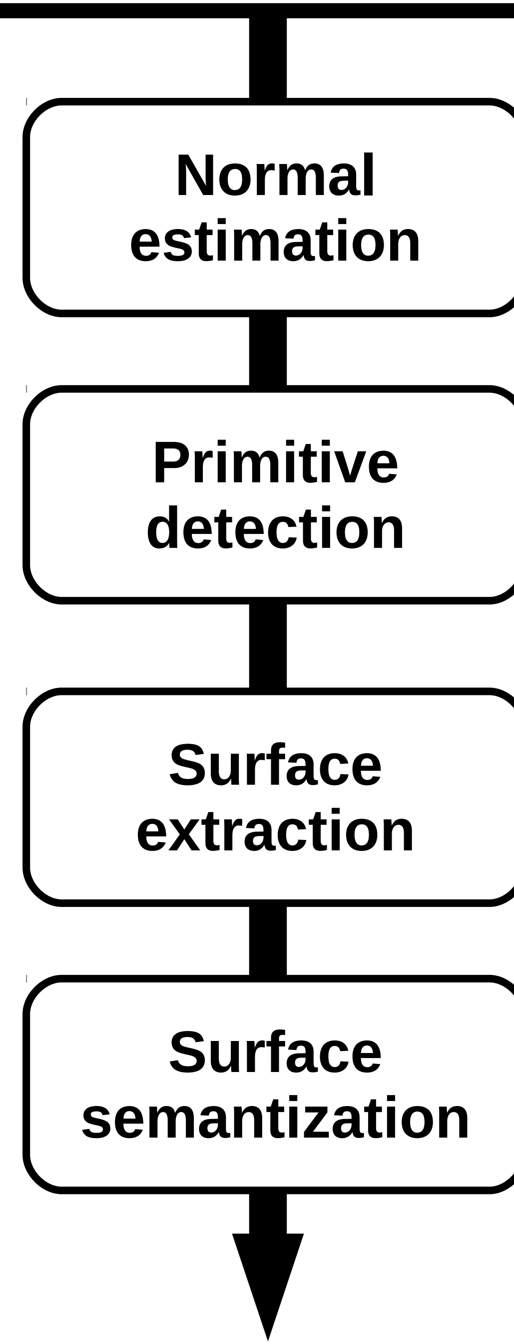
- pure bottom-up parsing
- combinatorial explosion containment
- grammars easy to design
- grammars maintainable by non computer scientist

Limits and perspectives

- need of flexibility (missing elements, merged geometries)
- learning of rule parameters

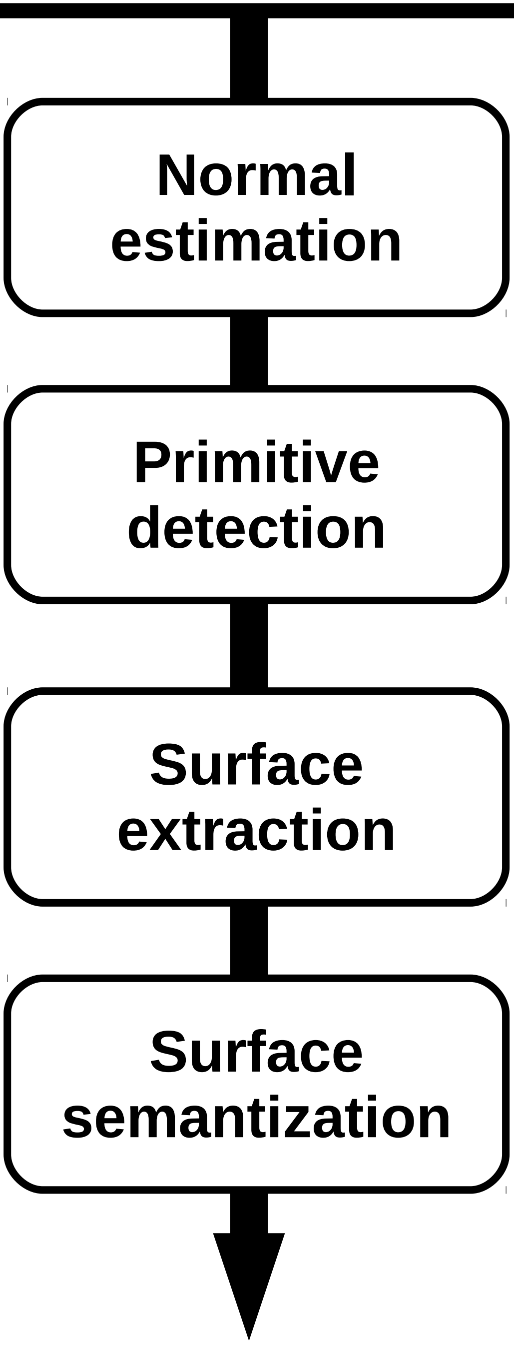
Conclusion

- Pipeline for surface reconstruction and semantization from point cloud
- A step towards automatic BIM reconstruction



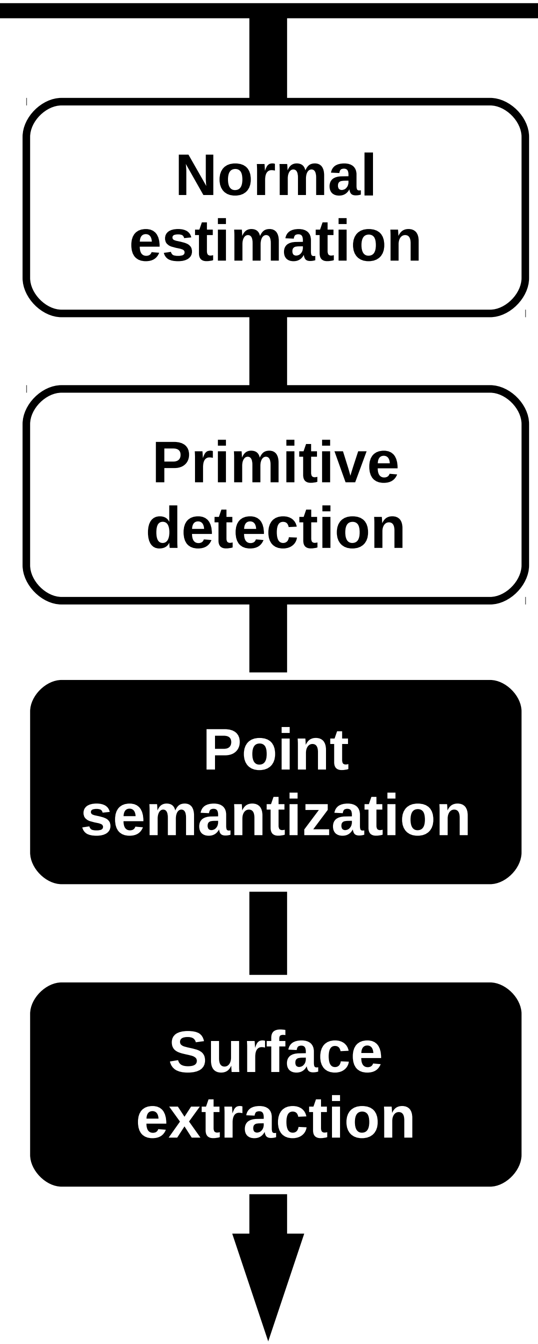
General perspectives

- Arbitrary order
  - surface useful for semantization



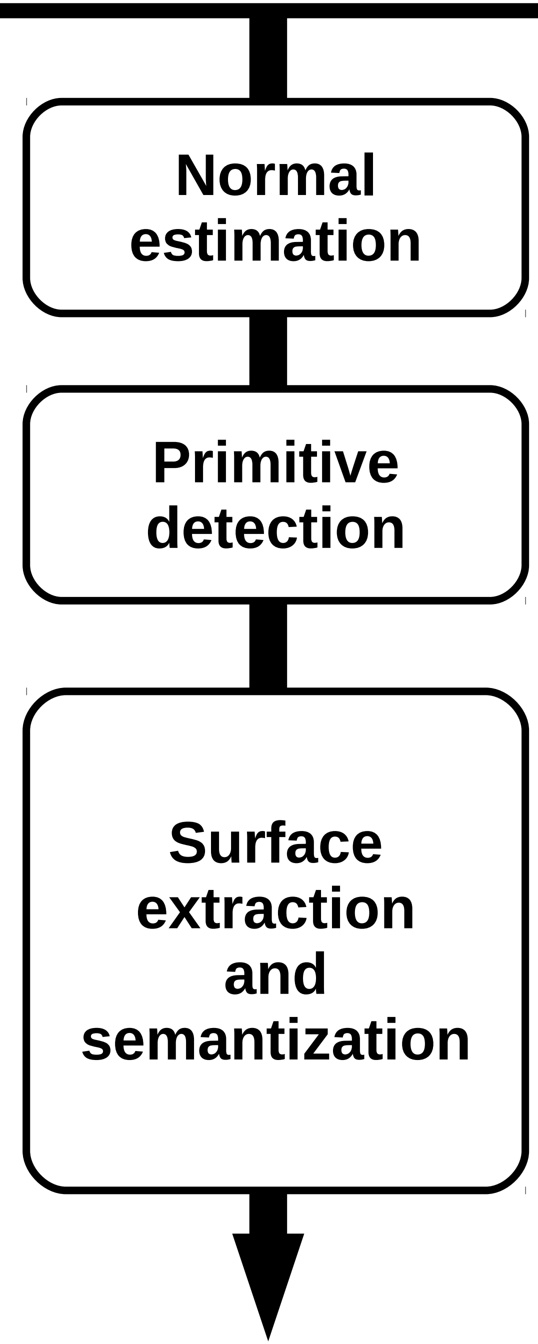
General perspectives

- Arbitrary order
  - surface useful for semantization
  - semantics useful for surface reconstruction



General perspectives

- Arbitrary order
  - surface useful for semantization
  - semantics useful for surface reconstruction
- Simultaneous or iterated semantics and surface extraction



General perspectives

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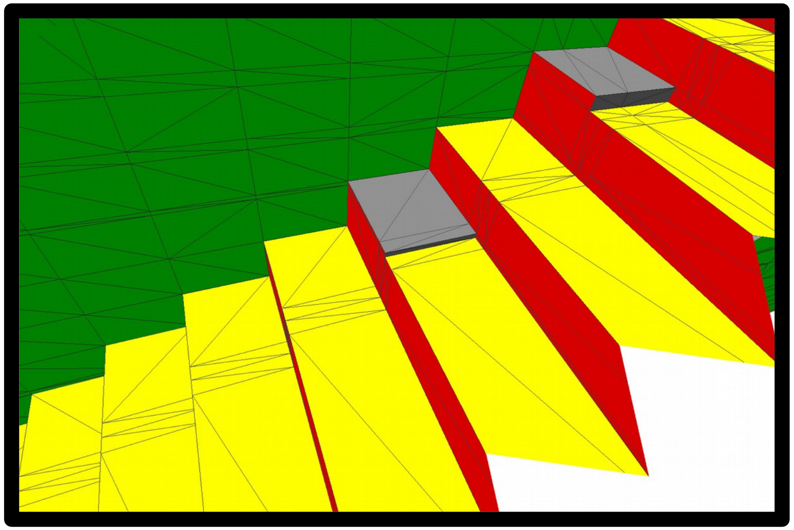
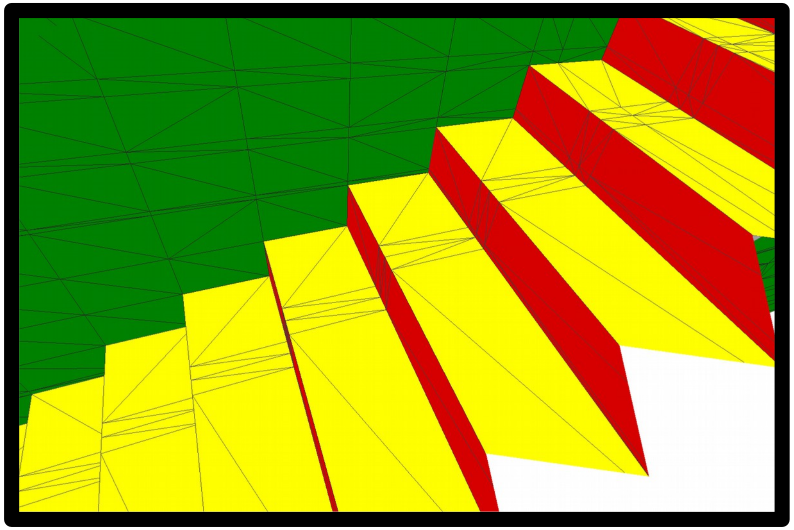
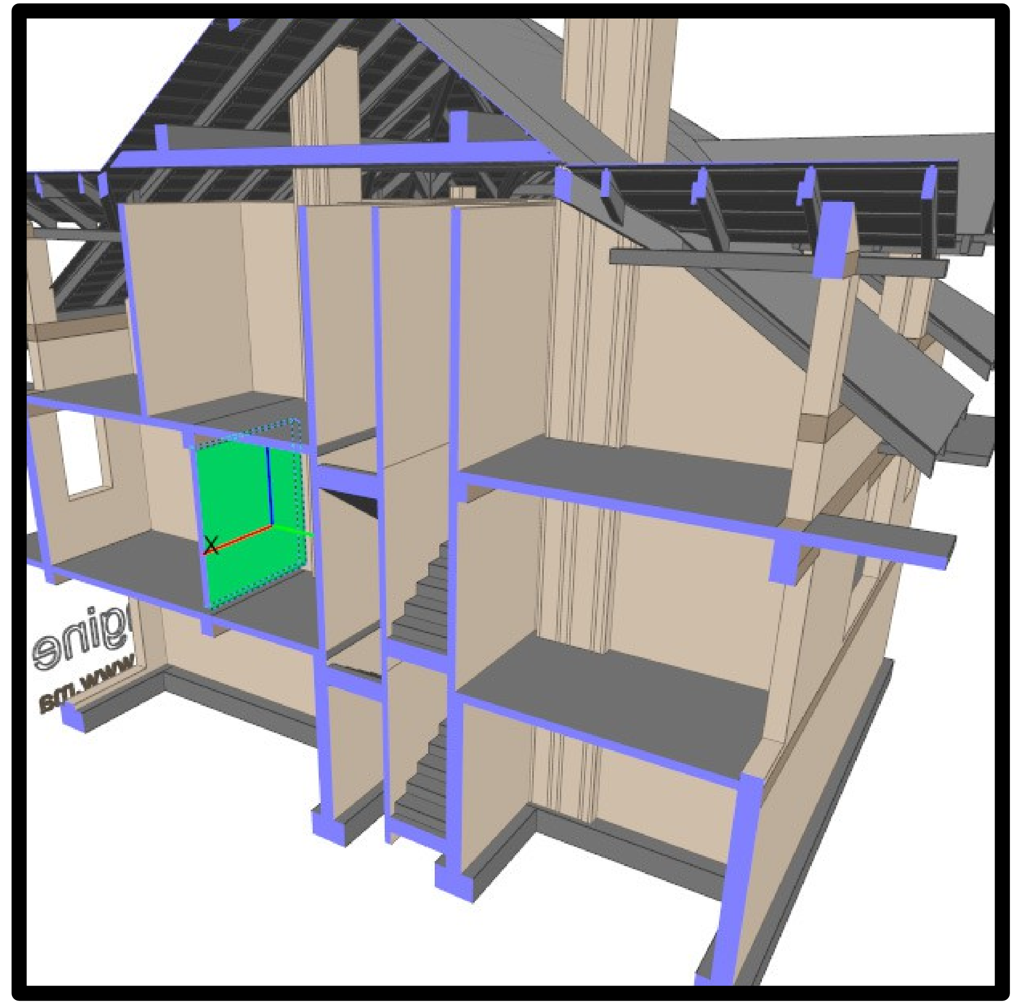




General perspectives

- Arbitrary order
  - surface useful for semantization
  - semantics useful for surface reconstruction
- Simultaneous or iterated semantics and surface extraction
- Dealing with volumes



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Thank you for your attention

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