Doctoral Meeting

Line-based Structure-from-Motion

- Roi Santos

Artificial Vision Group

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Centro Singular de Investigación en Tecnoloxías da Información

UNIVERSIDADE DE SANTIAGO DE COMPOSTELA

Main topics

- From 2D line detection, to 3D line reconstruction

- Context
- 2D
  - Detection of straight segments
  - Line matching on pairs of views
    - Results
  - Matching outlier detection
- 3D
  - Simple triangulation
  - 3D reconstruction based on lines
    - Simple 2-views triangulation
    - Line based SfM
      - Bundle adjustment
      - Results
- Applications
- Future work

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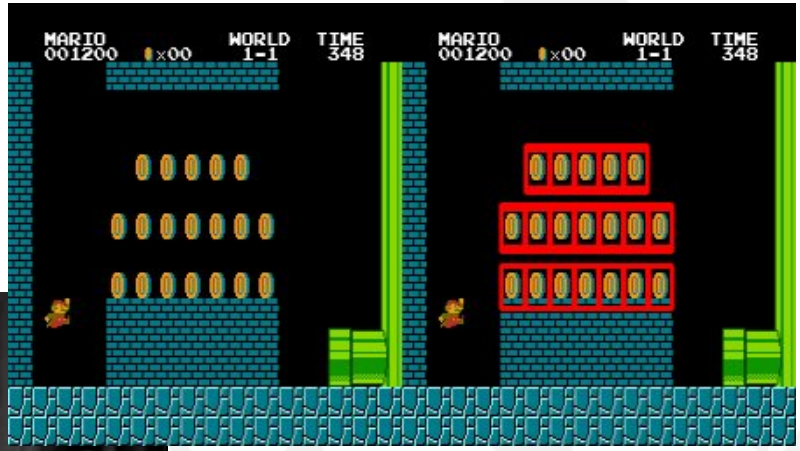
• Context

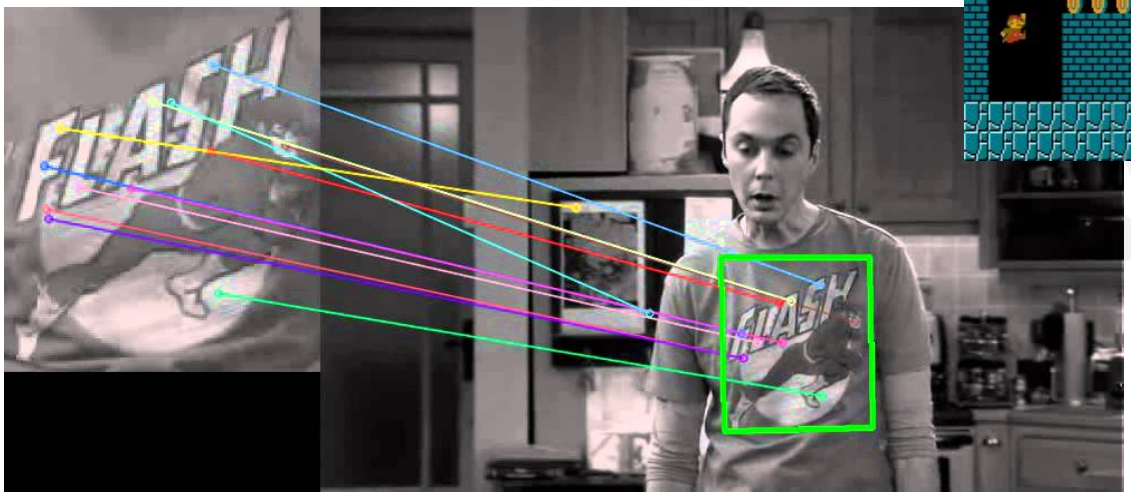
Feature matching is a fundamental task in Computer Vision.

We can match primitives or more complex geometrical forms.

Applications:
- Structure-from-Motion
- SLAM
- Image understanding



Template matching



Feature points matching

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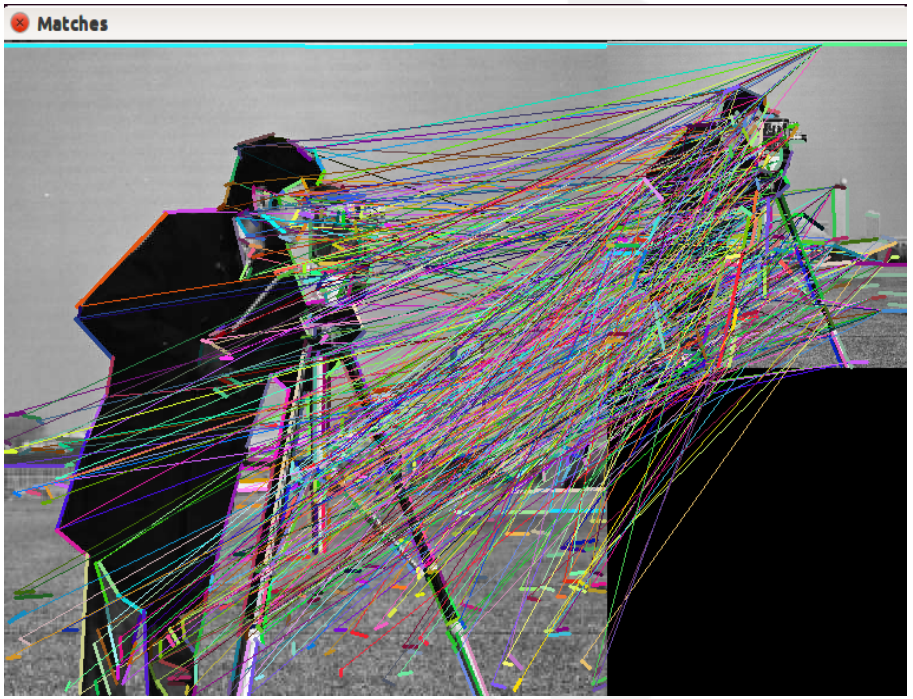
• Context – Line segments

Work with line segments

- Line detection
- Line matching
- Line based 3D reconstruction

Line detection (OpenCV)



Line matching (OpenCV)

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2D

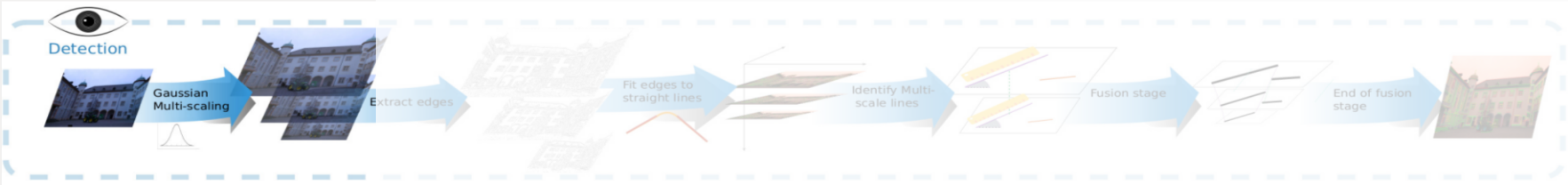
- Hypothesis

A combination of
- line segment detector based on phase congruency and
- line matcher based on individual appearance and structure

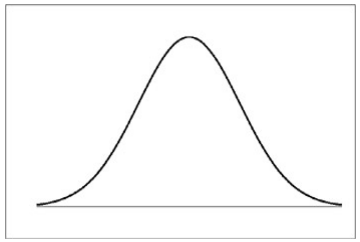
can improve the state-of-the-art matching.

• 2D - Detection

- Downsample images
- Extract edges



Convolution with Gaussian



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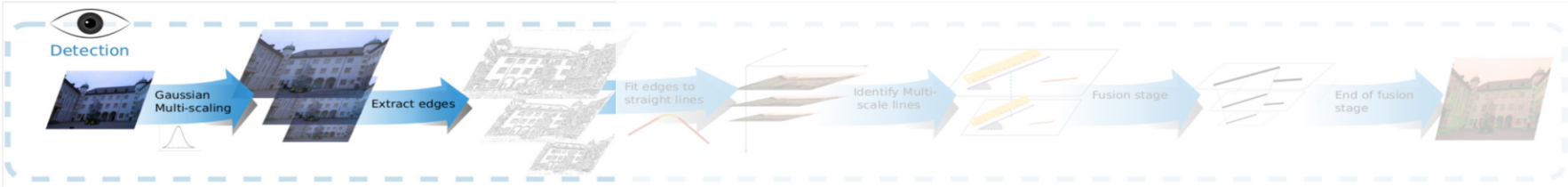
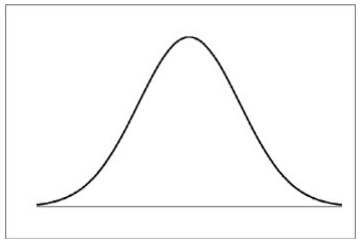
• 2D - Detection

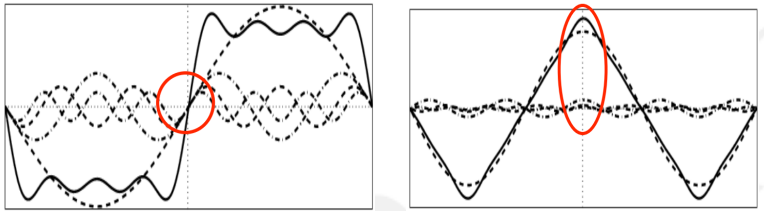
- Downsample images
- Extract edges

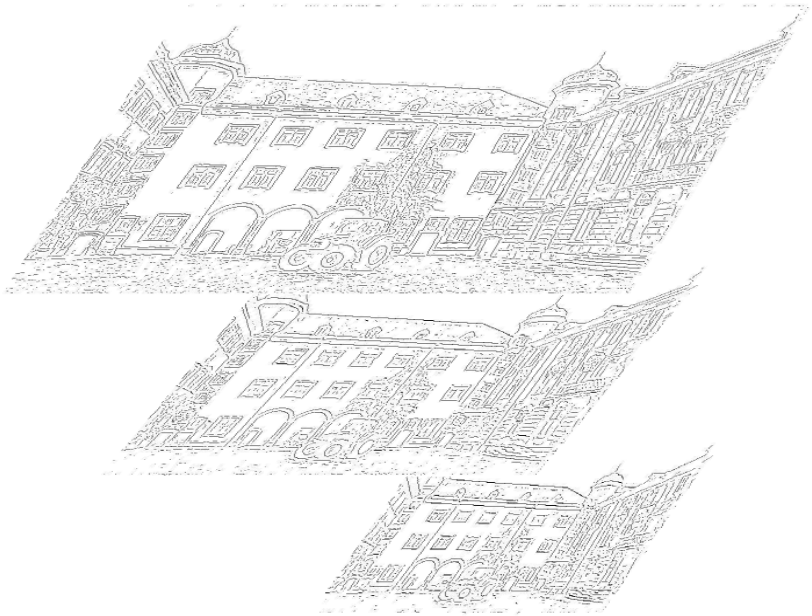


Convolution with Gaussian



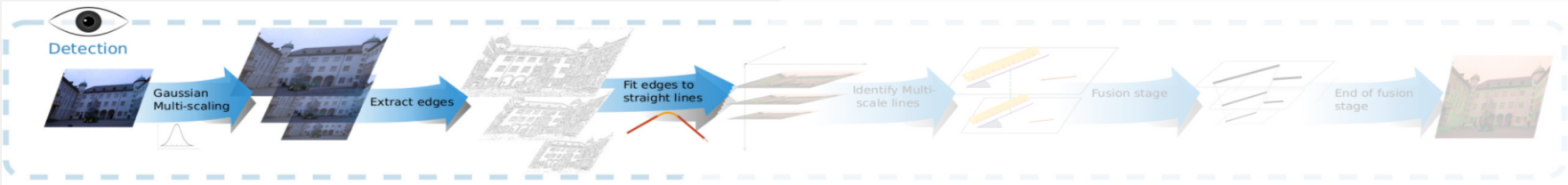
Max. phase congruency



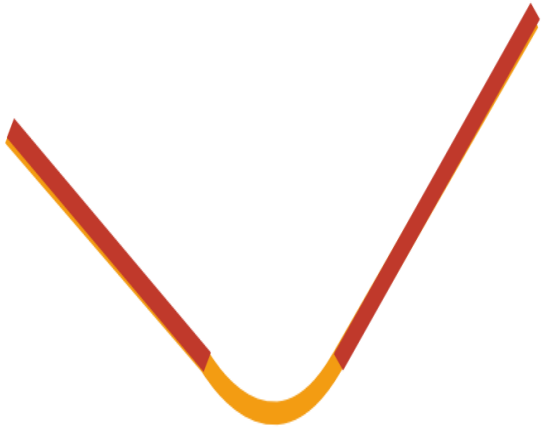


• 2D - Detection

- Fit to straight lines
- Identify multi-scale

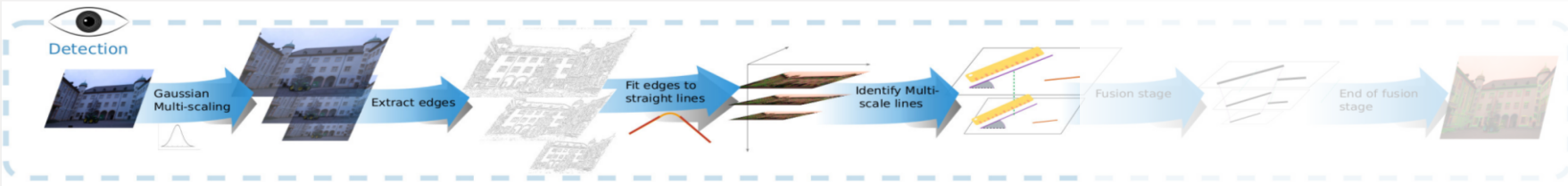


Linear regression + 15º threshold



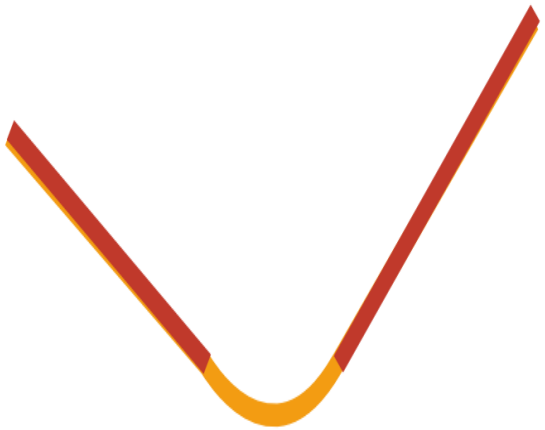
• 2D - Detection

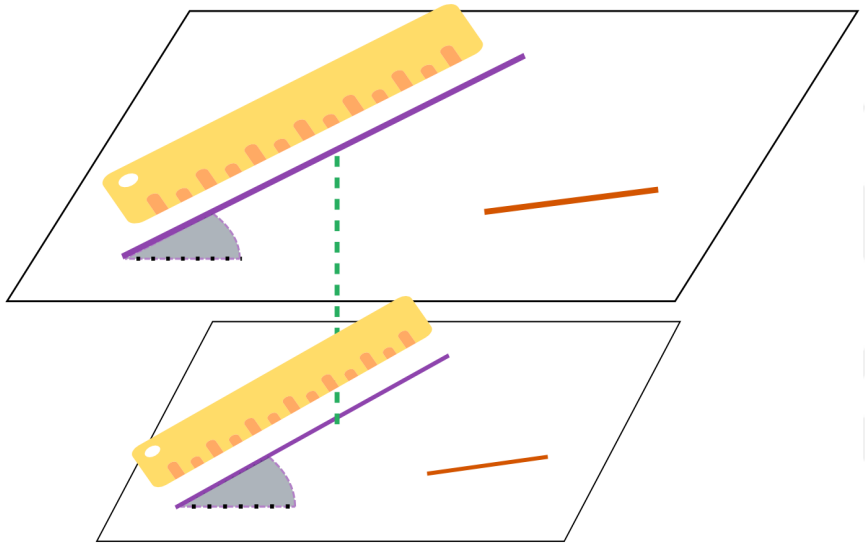
- Fit to straight lines
- Identify multi-scale



Linear regression + 15º threshold

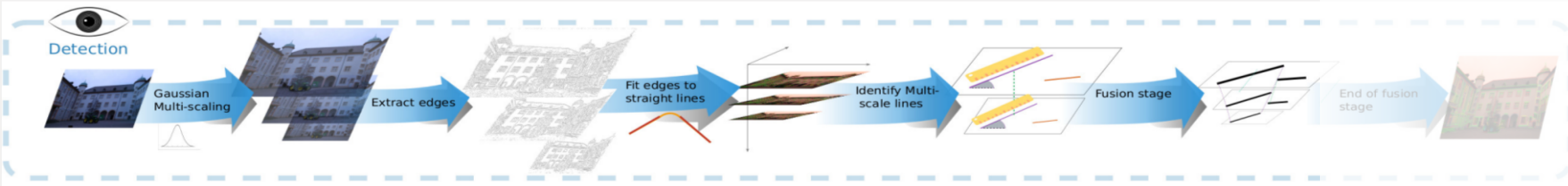
Merge segments into one scale



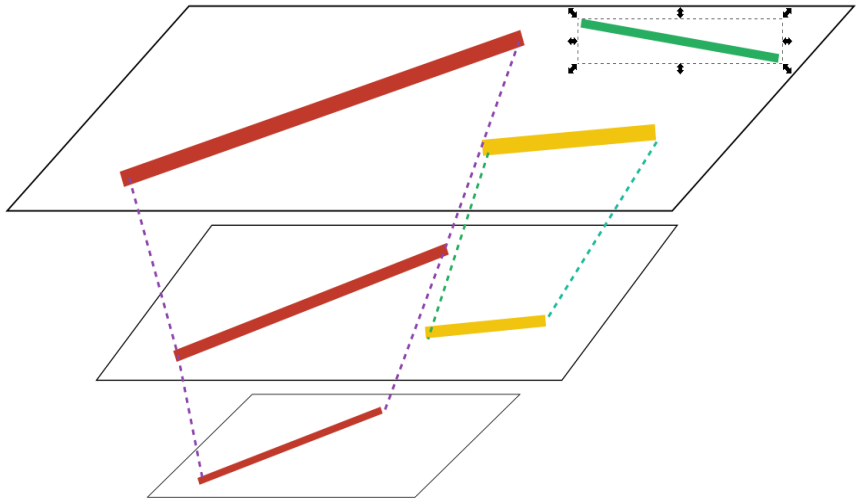


2D - Detection

- End of multi-scale fusion

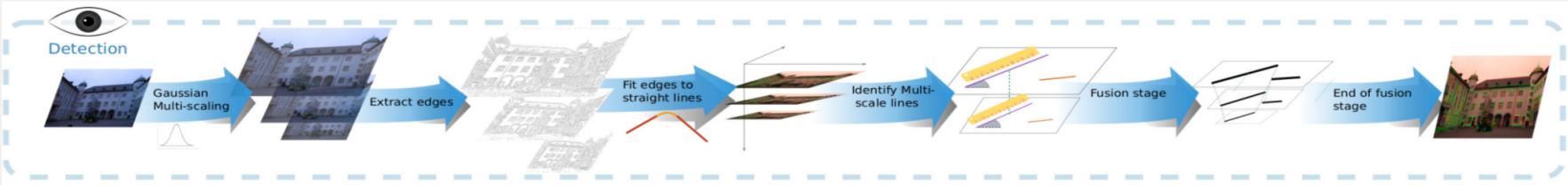


Line segments are classified.



• 2D - Detection

- End of multi-scale fusion



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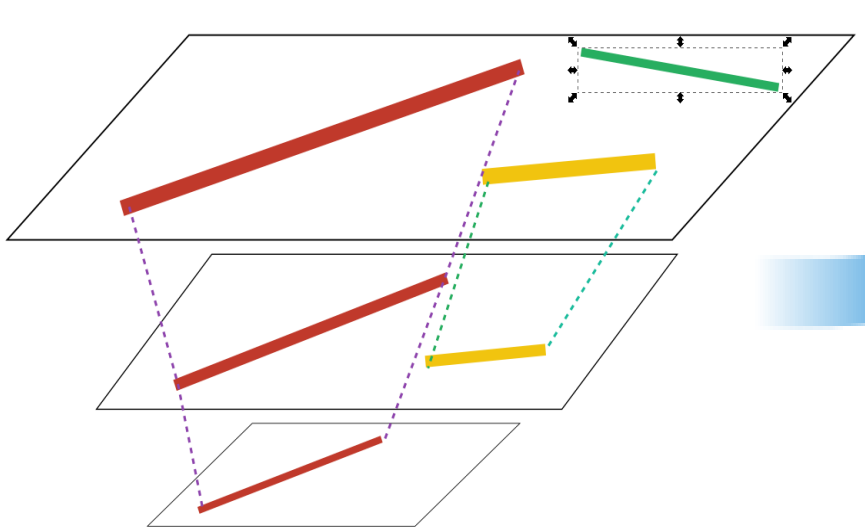

• 2D - Detection

TASK

Detect segments on the scale-space

ADVANTAGES AGAINST THE COMPETITION

- Resilience to changes in illumination conditions
- Less segment fragmentation
- Scale-space information for matching

APLICATIONS

Multi-view matching of different shapes

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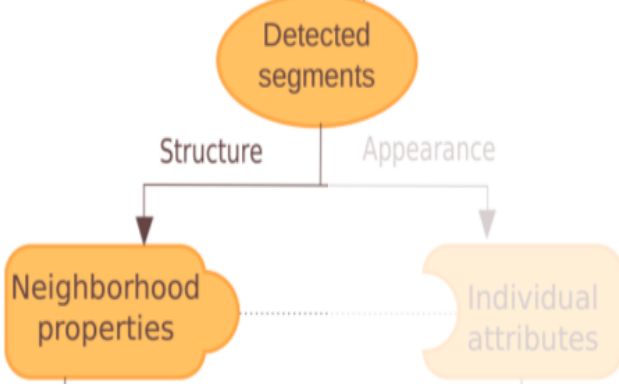
2D - Matching

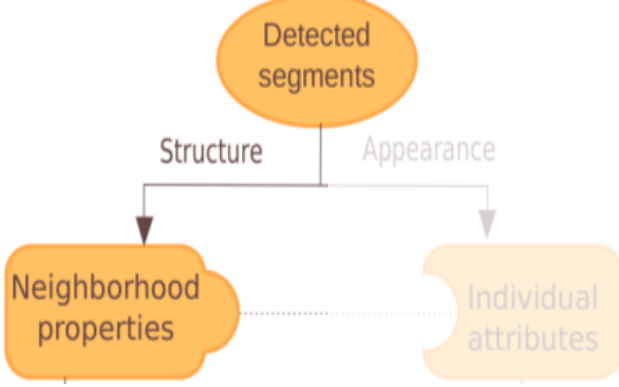
- Look for **groups of segments**



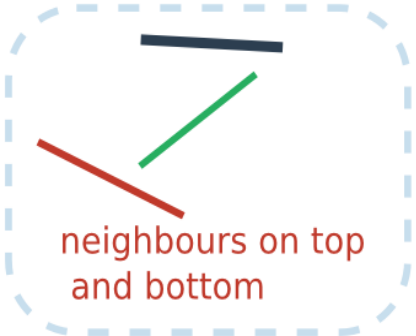
Divide and conquer
Build relations between groups of lines

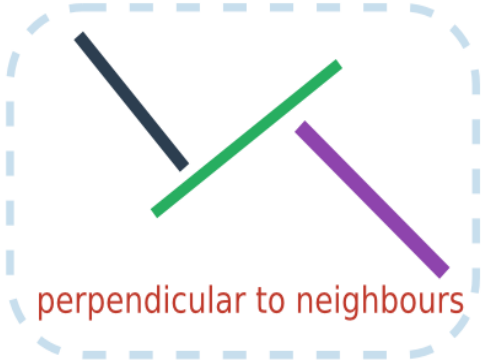
• 2D - Matching

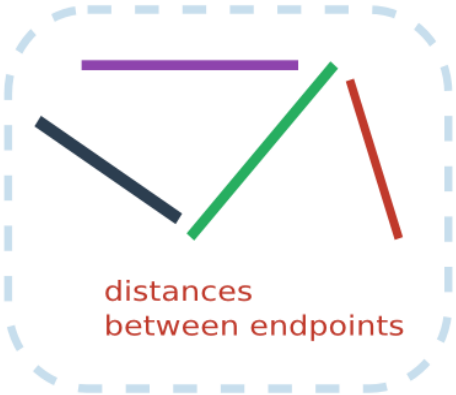
- Look for **groups of segments**

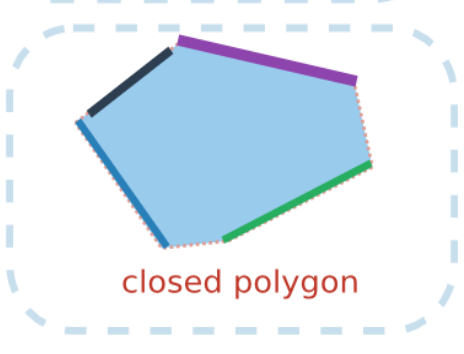


Divide and conquer
Build relations between groups of lines









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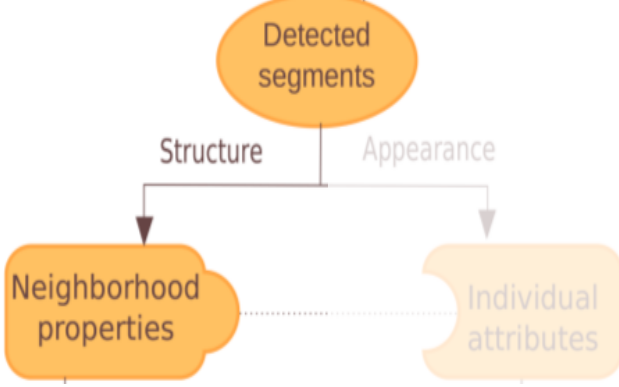
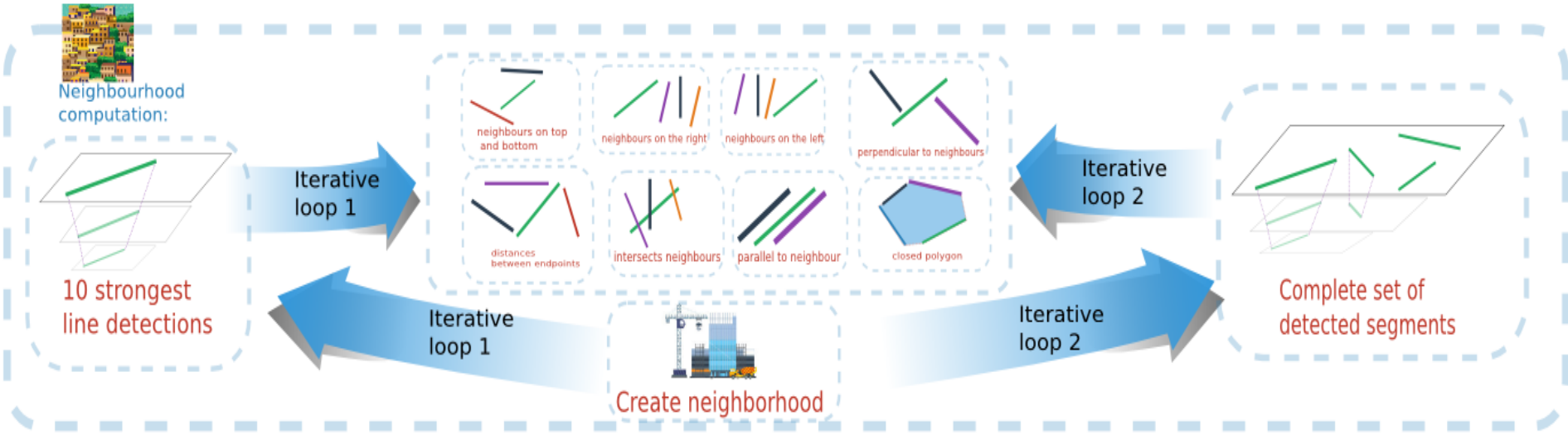
• 2D - Matching

- Construct **groups of segments**

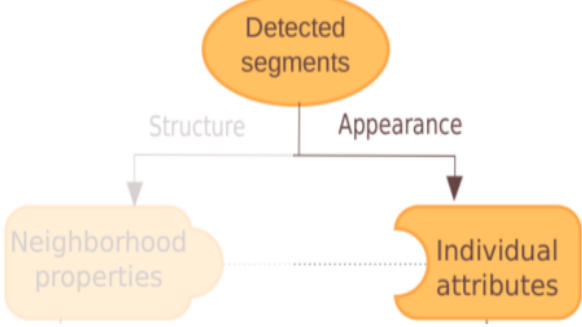




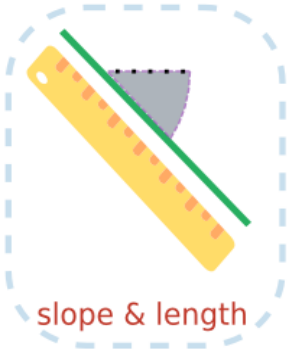
- Two Iterative processes
- Build relations between groups of lines

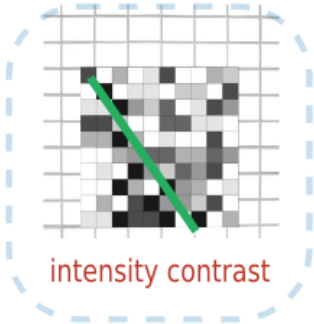
• 2D - Matching

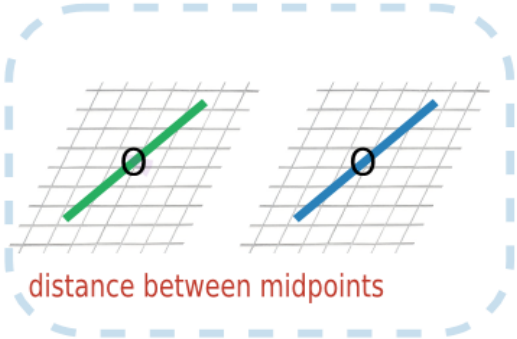
- Characterize **individual lines**



Store segment attributes







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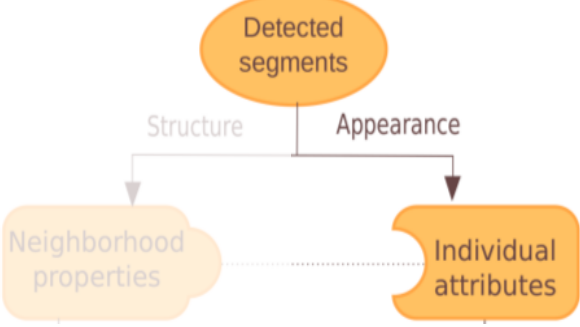
• 2D - Matching

- Characterize **individual lines**

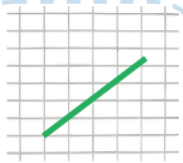


Find global transformation:

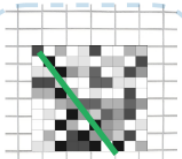
Individual segment similarity:

slope & length

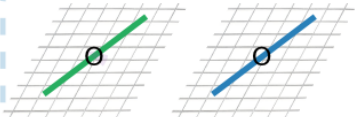
intensity correlation



phase congruency



intensity contrast



distance between midpoints

PCA

Similarity vector

Image global transformation

weight down the components featuring larger variance

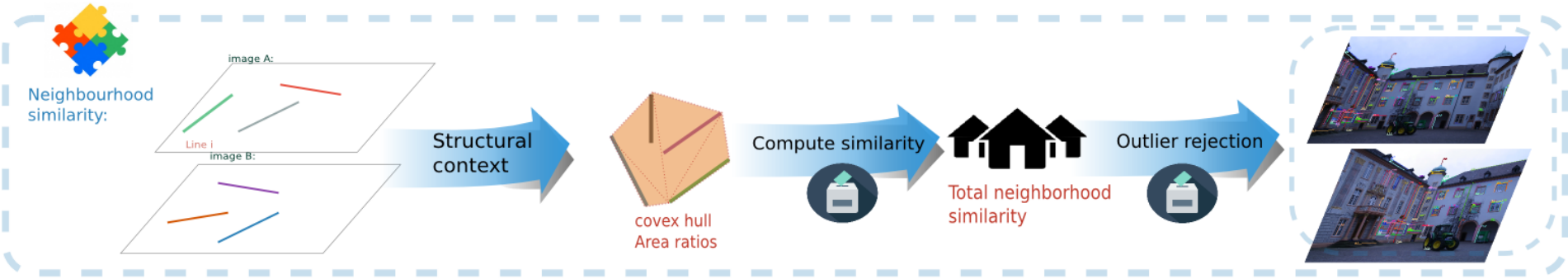
translation

Rotation

CiTUS

2D - Matching

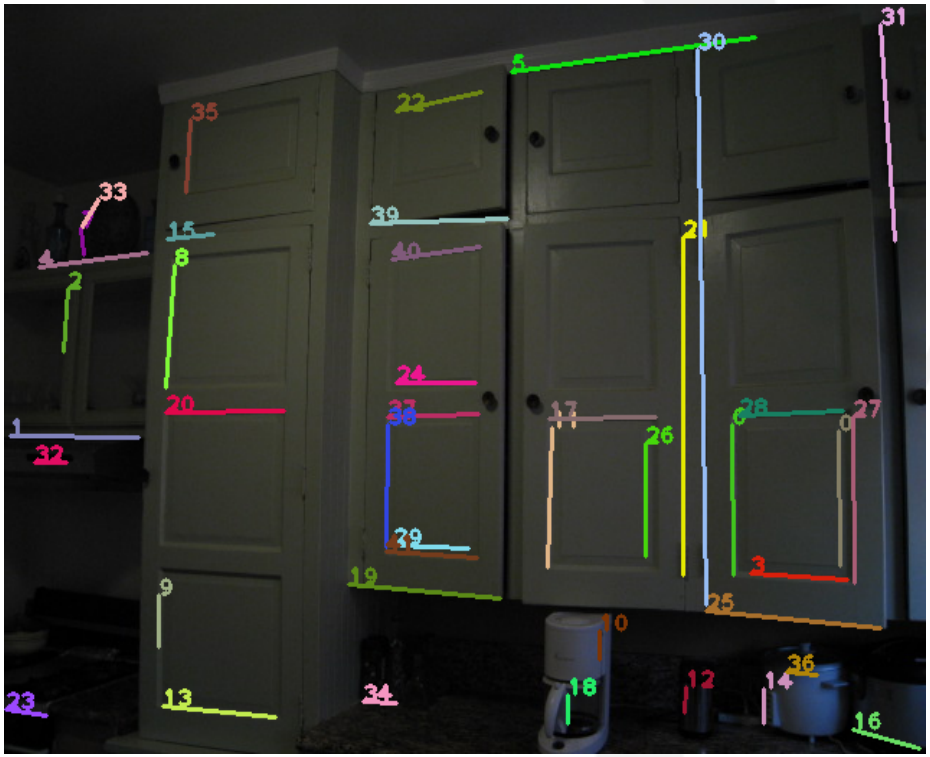
- Iterative algorithm for **creating hypothesis**



- Similarity between groups of segments
  - Each line votes their neighbors
  - A line can be part of several different neighborhoods

• 2D – Matching: Results

Method	Line Correspondences	Correct counterparts	Redundant lines	Avg. length dissimilarity	Avg. segment length (pix.)	Total length (pix.)	Time (s)
CLPI	1	0	-	-	-	-	7
LJL	52	41	2	0.38	62.2	3300	38
LBD	24	8	0	0.38	67.7	1692.8	1
LS	49	45	ND	ND	ND	ND	6
Proposed	42	33	0	0.16	73.9	3104.9	20

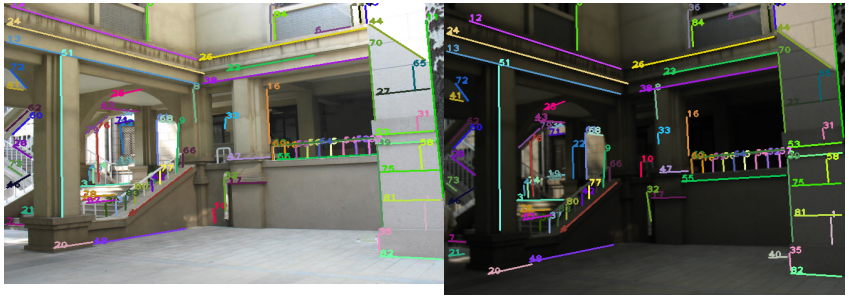


• 2D – Matching: Results

Method	Line Correspondences	Correct counterparts	Redundant lines	Avg. length dissimilarity	Avg. segment length (pix.)	Total length (pix.)	Time (s)
CLPI	0	0	-	-	-	-	20
LJL	27	27	3	0.38	100	2699.9	4
LBD	40	17	2	0.51	93.0	3722.8	1
LS	44	40	ND	ND	ND	ND	7
Proposed	22	22	0	0.12	187.5	4124.9	38

• 2D – Matching: Results

Method	Inlier ratio	Avg. length	Avg. dissimilarity	Processing time (s)
CLPI (Jia et al. (2016))	27.25%	67.3 pix.	0.23	39
LJL (Li et al. (2016b))	85.91%	59.3 pix.	0.33	154
LBD (Zhang and Koch (2013))	24.27%	66.6 pix.	0.40	2
LS (Wang et al. (2009a))	91.94%	-	-	6
Proposed	92.22%	105.1 pix.	0.14	39



• 2D - Matching

TASK

Find counterparts of the detections on other images

ADVANTAGES AGAINST THE COMPETITION

- Better use of **Structure** of groups of lines & **Appearance** individual segments
- PCA to discriminate hypothesis
- Finds global transformation

APLICATIONS

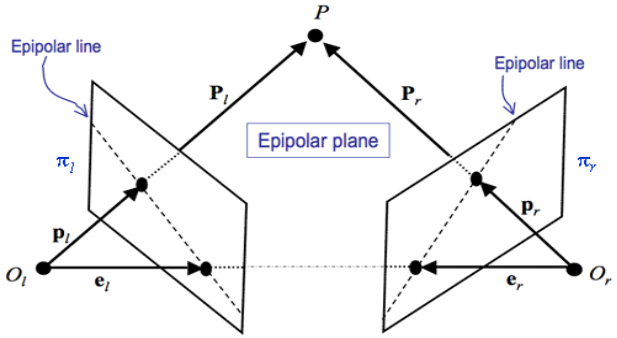
Understanding scene, autonomous robots
3D scene reconstruction

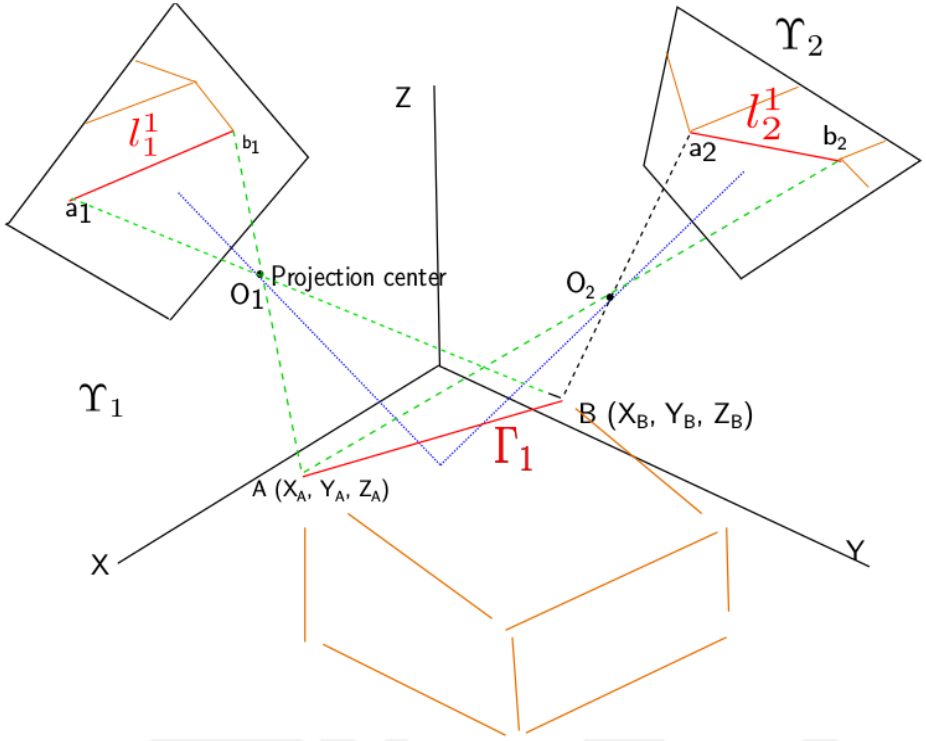
CiTiUS

- A 3D line based sketch aimed for low texture and low resolution images can add valuable information for the understanding of an scene.

3D - Stereo

- Triangulation from two views

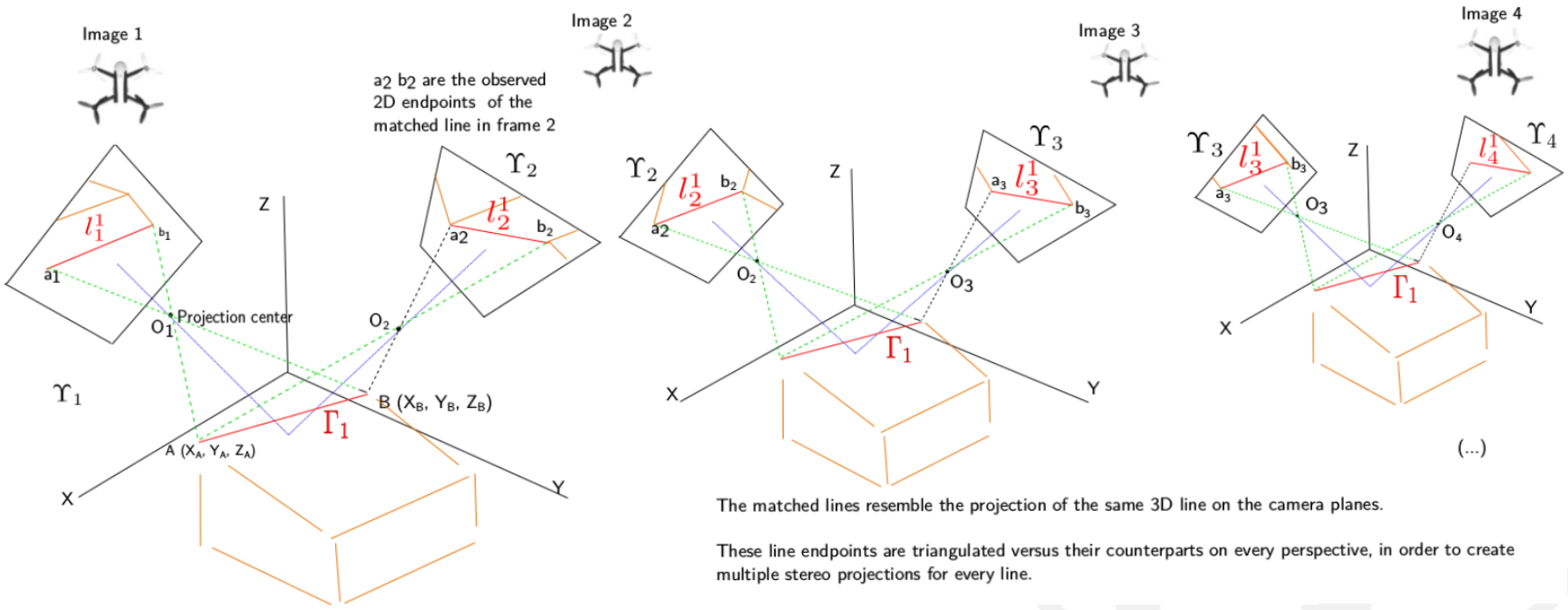




- Create stereo sub-systems
  - Constraints between correspondences
  - Five-point Relative Pose Problem (Nistér 2004)

3D - Stereo

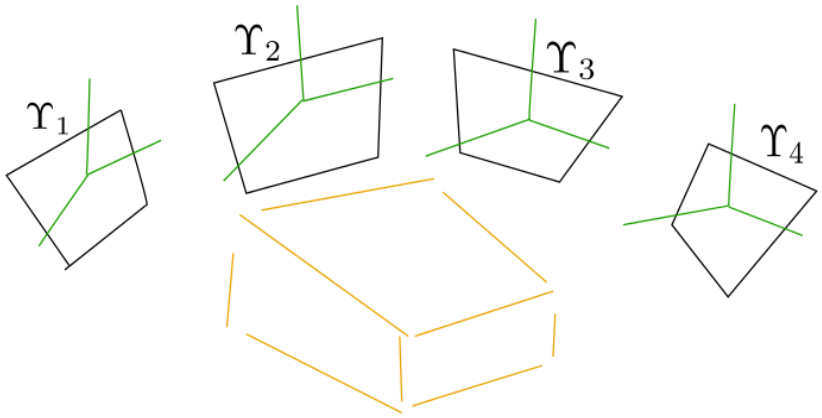
- Triangulation from two views



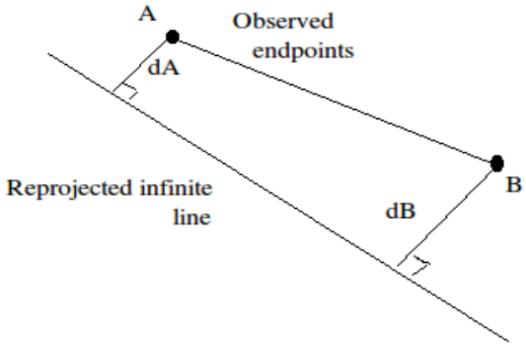
- All the possible pairs of images are merged
- Multi-view entity
  - Refers to a real segment with counterparts on several views

3D – Bundle adjustment

- Structure-From-Motion from 3 or more views



- Unifies multiple stereo projections to an **unique sketch.**
- Least squares optimization.
  - Based on Levenberg-Marquardt
- Obtains most probable 3D points and camera poses.
  - Minimizes the total **reprojection error** on the camera planes



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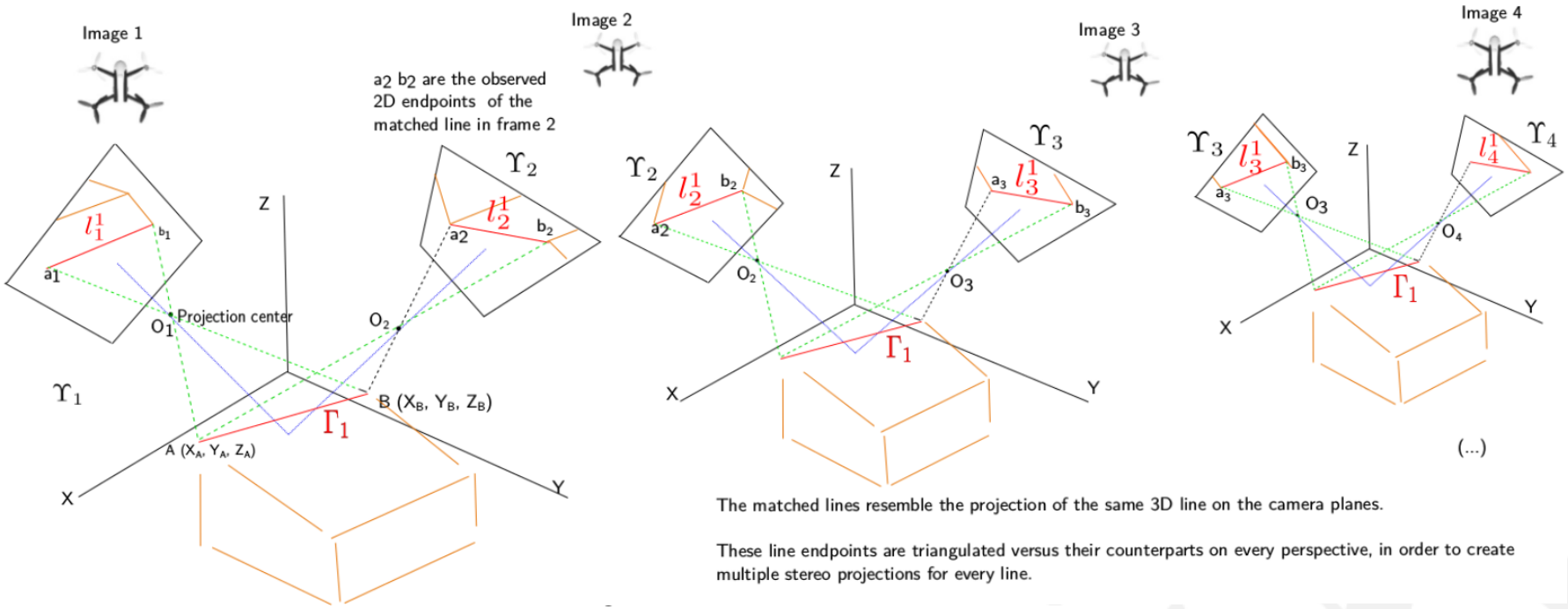
• 3D – Bundle adjustment

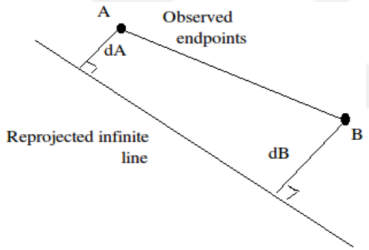
- Structure-From-Motion from 3 or more views



The matched lines resemble the projection of the same 3D line on the camera planes.

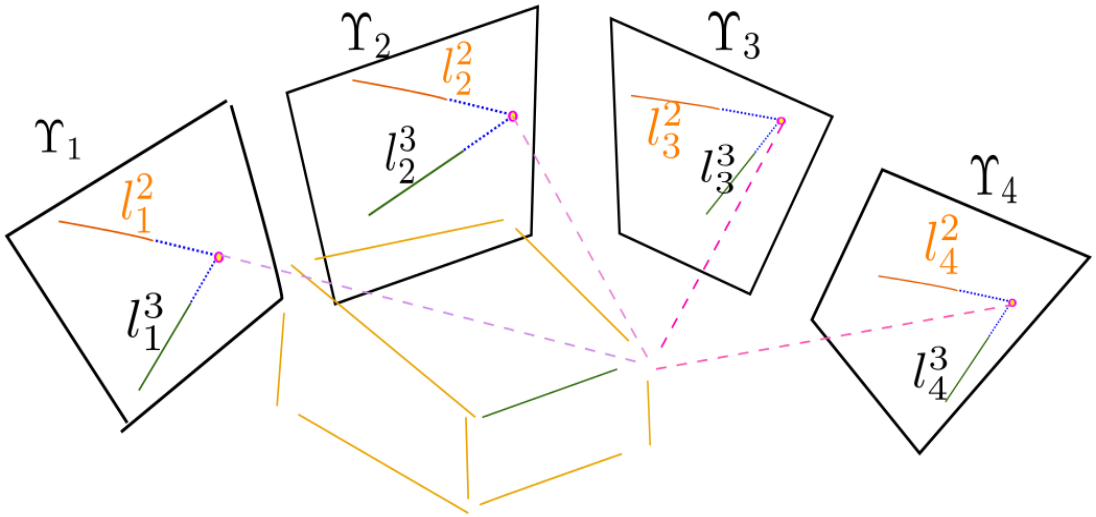
These line endpoints are triangulated versus their counterparts on every perspective, in order to create multiple stereo projections for every line.

for $\boldsymbol{\Upsilon}^j \in \Upsilon$ **do**
  for $\boldsymbol{\Gamma}_i \in \Gamma$ **do**
    Add cost function with:
    $\{\epsilon_i^j\}^2 = d(proj_{\boldsymbol{\Upsilon}^j}\boldsymbol{\Gamma}_i, A_i^j)^2 + d(proj_{\boldsymbol{\Upsilon}^j}\boldsymbol{\Gamma}_i, B_i^j)^2$,
    with $\{A_i^j, B_i^j\} \in \boldsymbol{L}_i$ observed endpoints of $\boldsymbol{L}_i$ on $\boldsymbol{\Upsilon}^j$
  end
  if $j >= 2$ **then**
    Solve SBA for Υ , Γ
  end
end



• 3D – Structures in the spatial sketch

- Exploitation of coplanar intersections



- 1) Fit Spatial lines to different planes
  - Group coplanar lines
- 2) Intersect coplanar lines on the images
  - Add coplanar line intersections into the reconstructions

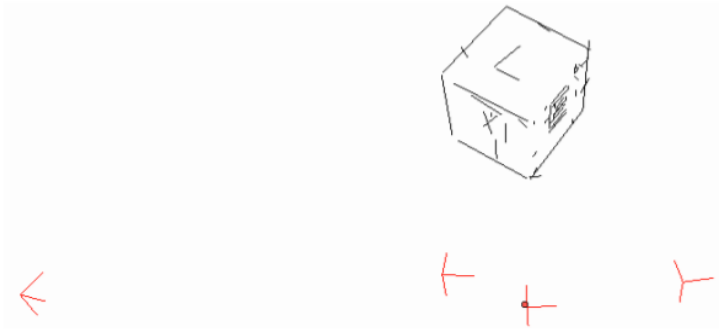
Useful when a low number of lines is available

• 3D – Results

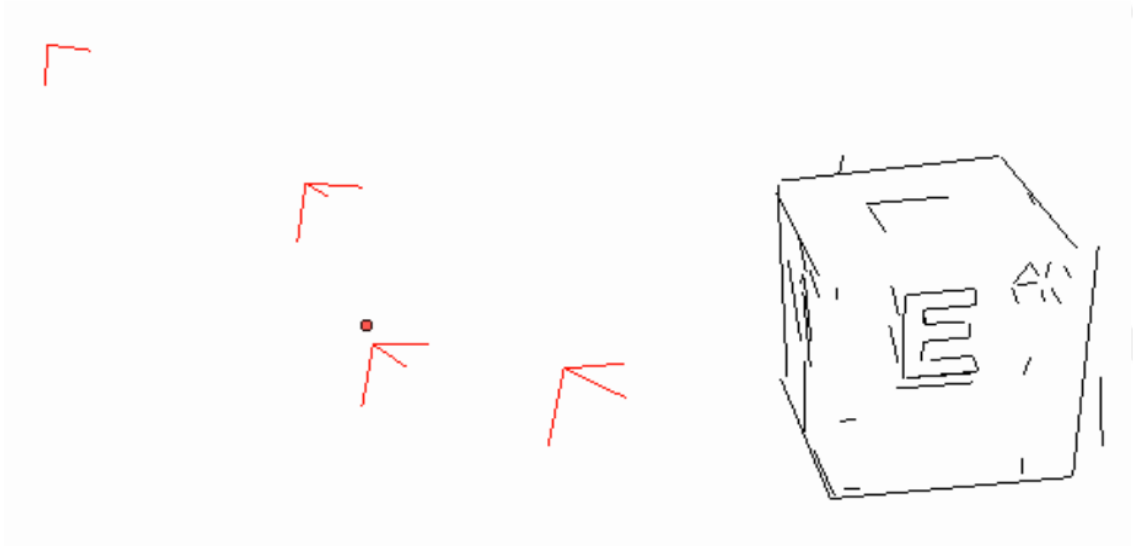
- Camera poses and 3D lines retrieved exclusively from matched segments

With four images showing:

(a)



(b)



(c)

• 3D – Results

- Matched segments teaming with Point Cloud

Method	Line detection and matching	Depends on point cloud	First 3D estimation	Final result
Proposed	Appearance and structure [21]	NO	Linear triangulation	Bundle adjustment
Line3D++ [16] (M. Hofer 2016)	LSD and SfM pipeline	YES	Depends on point cloud	Bundle adjustment

• 3D – Quantitative evaluation

- Distances to Ground Truth mesh, Timber Frame House (Jain et al. 2010)

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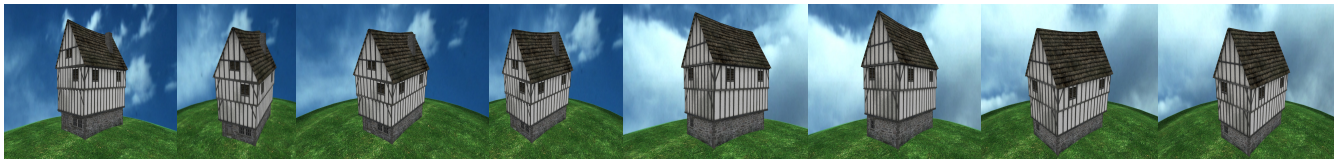

8 and 10 images

Proposed

Line3D++ (2016)

• 3D – Quantitative evaluation

- Distances to Ground Truth mesh, Timber Frame House (Jain et al. 2010)

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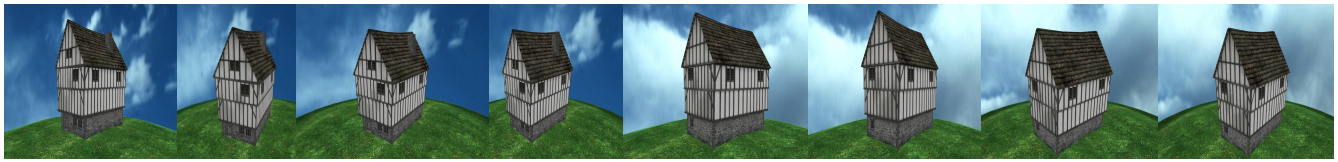
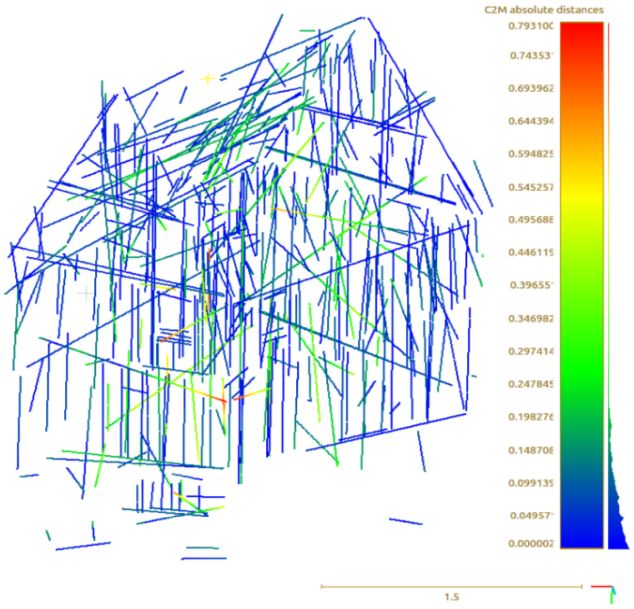
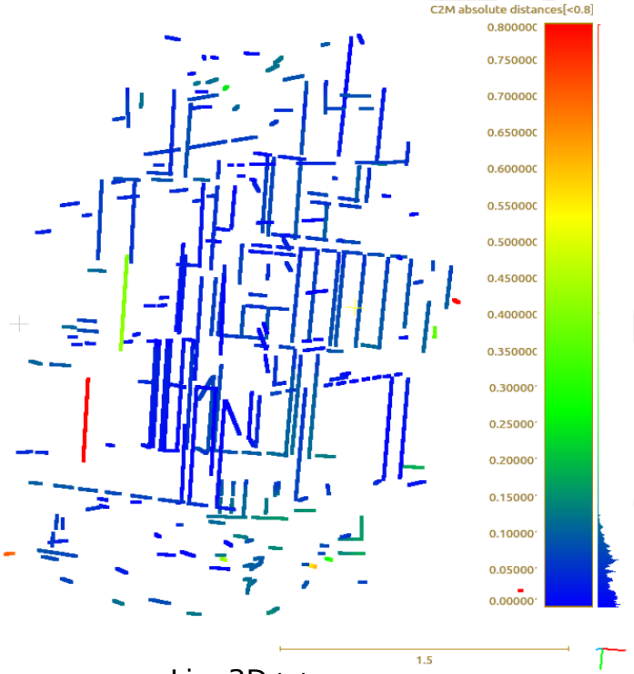


With 10 images:



Proposed



Line3D++ (2016)

• 3D – Quantitative evaluation

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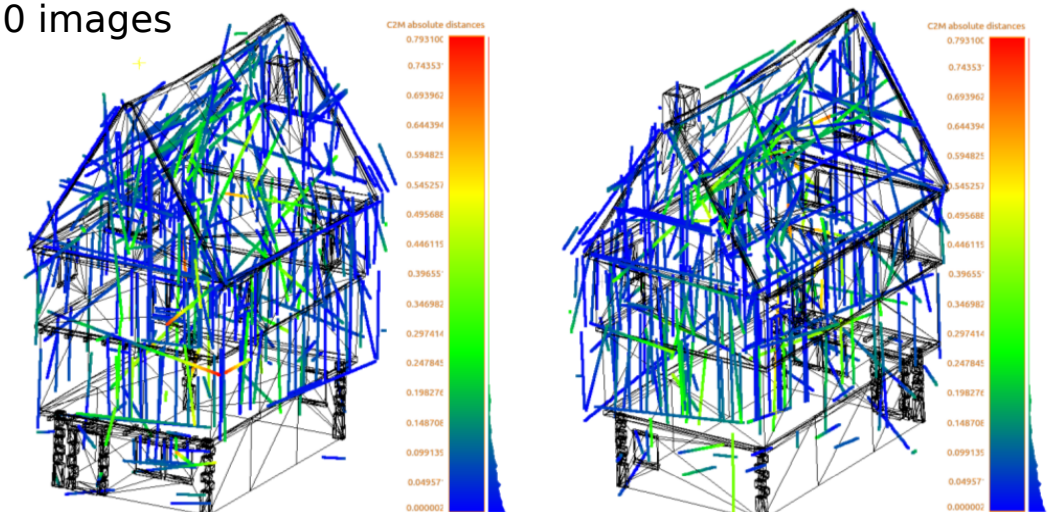
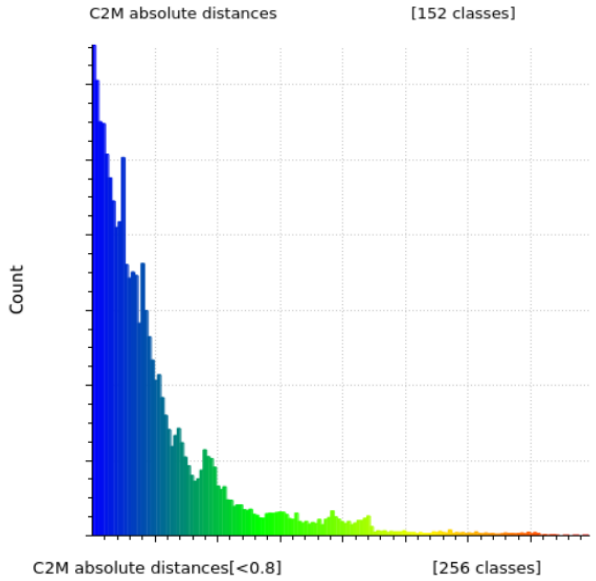
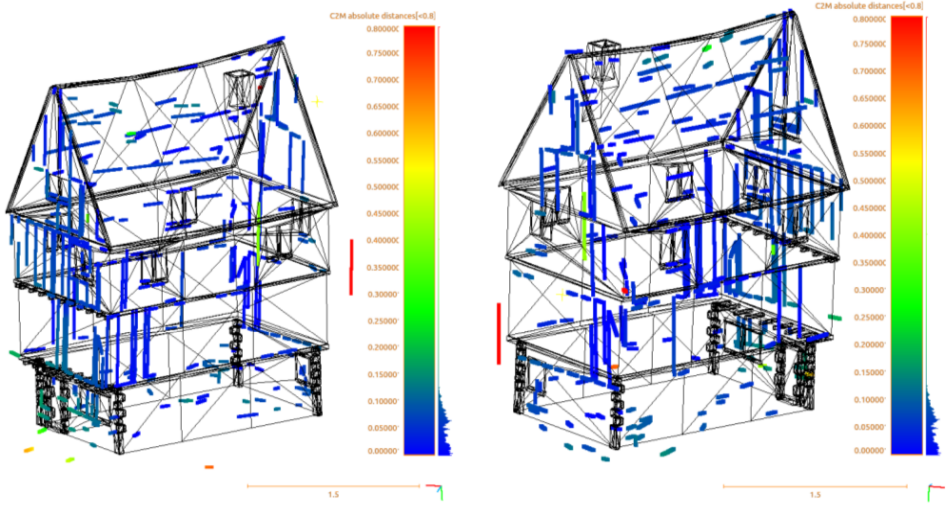
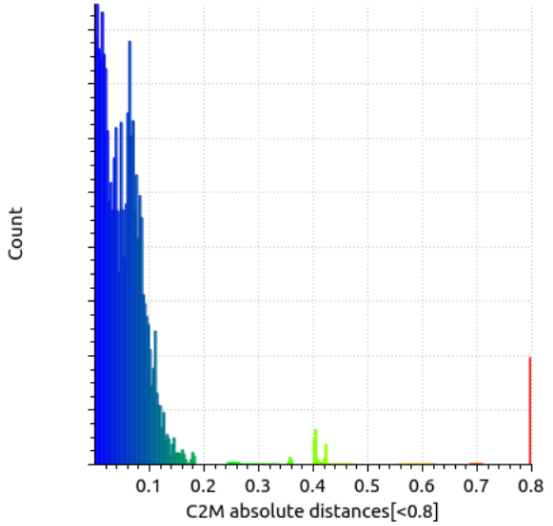
Proposed





Line3D++
(M. Hofer 2016)





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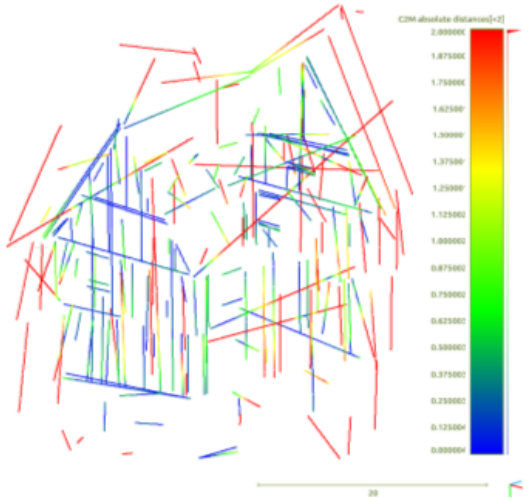
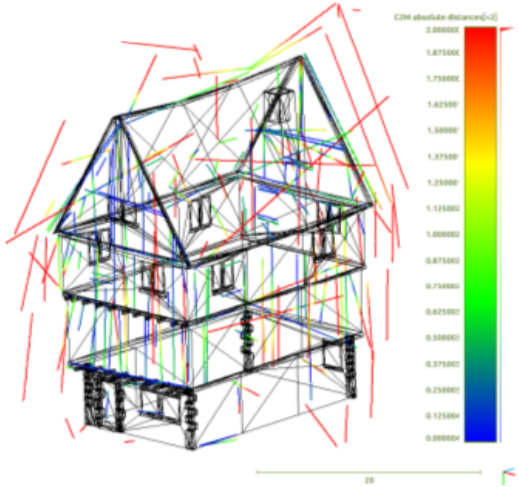
• 3D – Quantitative evaluation

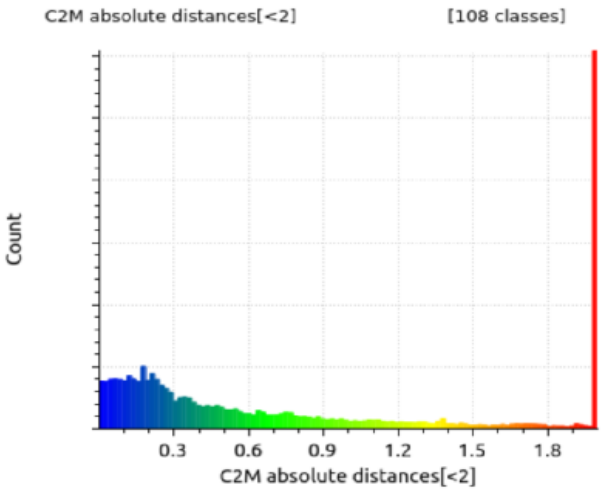
- Distances to Ground Truth mesh, Timber Frame House (Jain et al. 2010)

With 8 images

Proposed







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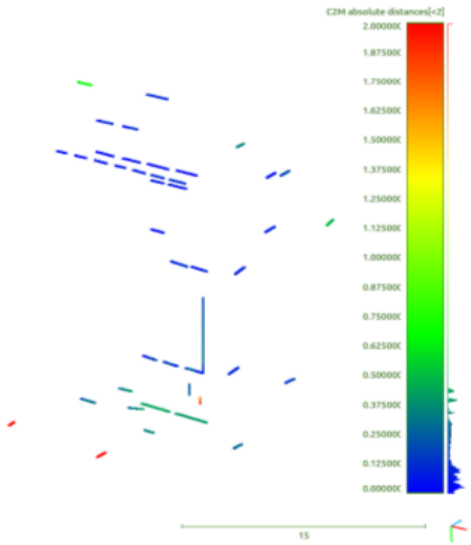
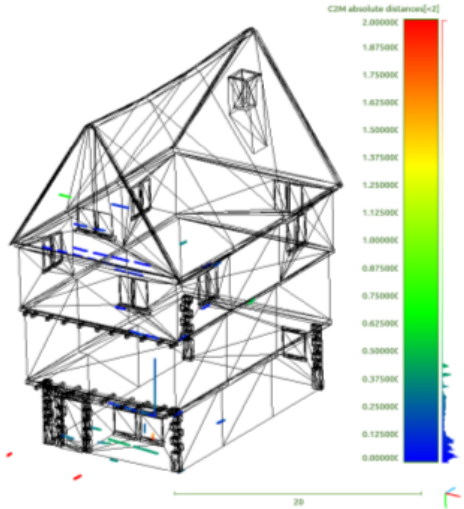
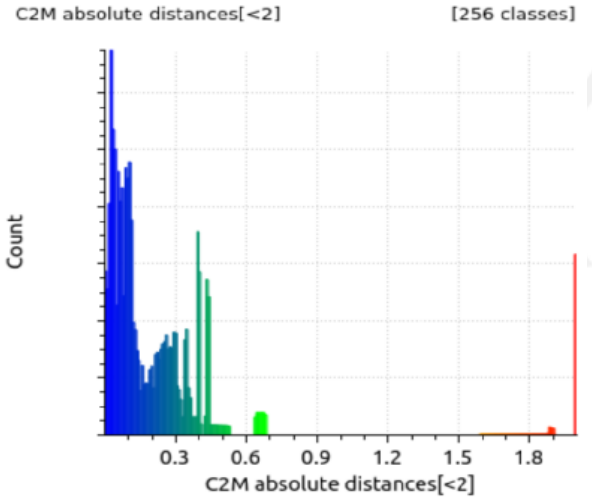


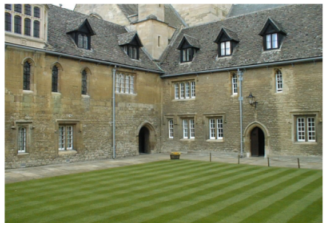




• 3D – Qualitative comparison

- Oxford dataset. Merton College (1024×768)

Proposed



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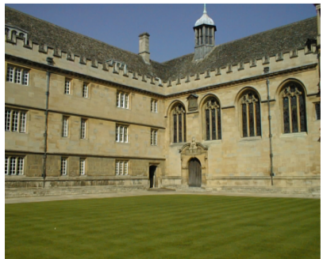
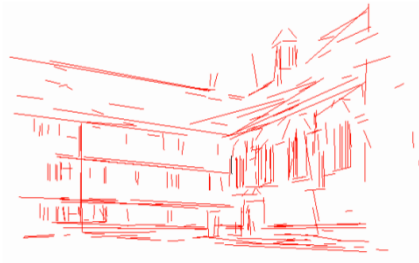
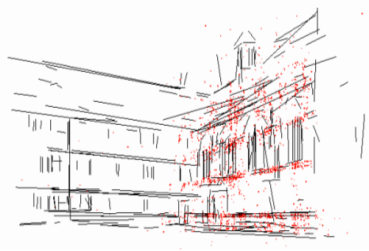
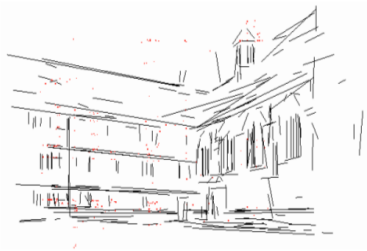




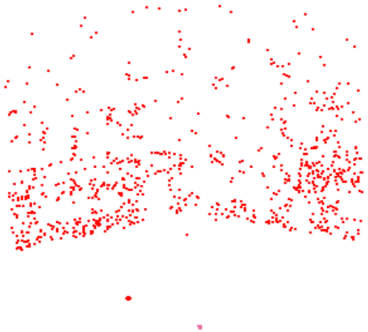




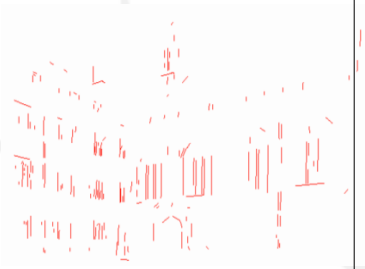
Line3D++

No result

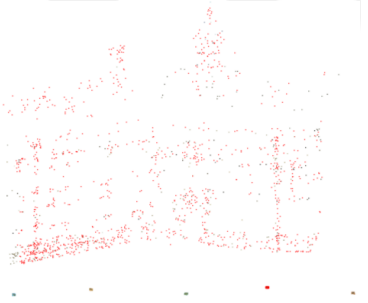
SIFT



Line3D++



SIFT



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• 3D sketch

TASK

Obtain a **3D straight segment** based abstraction of a scene/object.

ADVANTAGES AGAINST THE COMPETITION

- Higher resilience to an absence of a dense point cloud
- More 3D lines when a low number of images is available
- More 3D lines when the resolution is low (hence low number of lines)
- Identifies and exploits 3D structures

APLICATIONS

Build 3D sketch of man-made environments (buildings, interiors of offices)
Reconstruct simple 3D objects

CiTiUS

• 3D Applications – Matching Outlier detector

Matching results with the proposed method

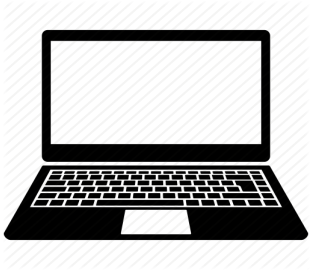
kNN over coplanar intersections

In red, the suspicious line intersections

Check counterparts of coplanar intersections

Suspicious matching outliers

- 3D Applications – UAV real-time 3D sketch



ROS

UAV LAB

Implementation

- Due to software registration

LANGUAGE

C++, ROS

FEATURES

- Real time from images and camera intrinsic parameters
- Performs detection, matching and 3D reconstruction
- Bundle adjustment
- Output: PLY file with lines, points and camera poses.

REAL TIME APLICATION WITH UAV

Parrot Bebop 2

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Near future

MAIN

Defend Thesis

TBD

- Matching would benefit from Machine Learning?
- Improve how matched lines are projected.

OUR PAPERS

Published:

- Journal **Pattern Recognition** (2014) about Line Detection and Matching
- Congress **IbPRIA** (2015)
- Congress **IEEE AIPR** (2017)

Awaiting response:

- Journal **Pattern Recognition** (2017) about 3D Reconstruction ONGOING REVISION .
- Congress **ICCV** (2018) about Line Matching.
- Journal **CVIU** (2018) about Line Matching.

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Near future

THANK YOU

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