

HOW TO ACHIEVE REAL-TIME 3D MAPPING?

SSRR 2013 - Rescue Robotics Camp

François Pomerleau - October 21, 2013 - Linköping, Sweden

AFTERNOON PLANNING

45 min - **Lecture**

15 min - **Break**

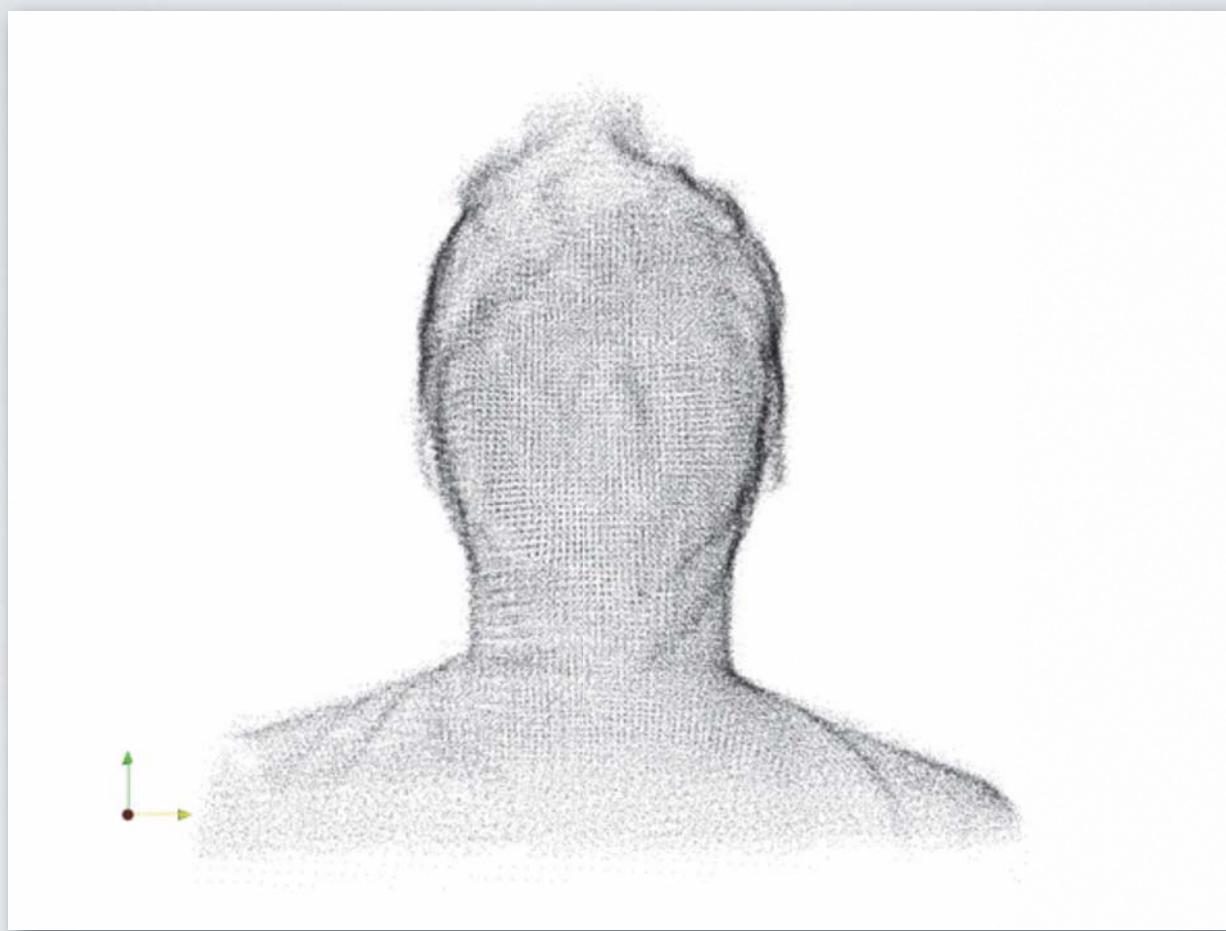
15 min - **Introduction to some 3D tools**

45 min - **Exercises**

15 min - **Break**

X min - **Exercises or Integration on the robots**

WHO AM I?



build with a Kinect and libpointmatcher

WHO ARE YOU?

- I'm doing research on 3D mapping
- I need 3D mapping for my research
- Generally dealing with Search & Rescue applications
- No idea why I'm here

WHO ARE YOU?

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REAL-TIME



OUTLINE

- Registration algorithms in the context of SLAM
- Iterative Closest Point and its variants
- Solution influences and selection

SLAM FRAMEWORK

Main steps:

- Prediction
- Measurement
- Update

Further reading:

- [1] H. Durrant-Whyte and T. Bailey, "Simultaneous localization and mapping: part I," *IEEE Robot. Automat. Mag.*, vol. 13, no. 2, pp. 99–110, 2006.
- [2] T. Bailey and H. Durrant-Whyte, "Simultaneous localization and mapping (SLAM): part II," *IEEE Robot. Automat. Mag.*, vol. 13, no. 3, pp. 108–117, 2006.

SLAM FRAMEWORK

Key challenges:

- State estimation / state fusion
- Map representations
- Loop detection / alignment error recovery
- Data management

SLAM FRAMEWORK

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Registration

REGISTRATION

Two main types of registration used in robotics:

- photometric:
energy reflection (regular images), energy emission (thermal images)
- geometric:
position, surface, volume, etc.

REGISTRATION

Pros

Photometric

- Low cost/weight/energy sensors;
- Rich textures;
- Larger volume of publications on state estimations;

Geometric

- Direct depth measurements;
- Robust to environment changes;
- Larger volume of publications on map representations;

REGISTRATION

	Photometric	Geometric
Pros	<ul style="list-style-type: none">• Low cost/weight/energy sensors;• Rich textures;• Larger volume of publications on state estimations;	<ul style="list-style-type: none">• Direct depth measurements;• Robust to environment changes;• Larger volume of publications on map representations;
Cons	<ul style="list-style-type: none">• No depth;• Dependent on external light source;	<ul style="list-style-type: none">• Heavy/expensive sensors;• Systematic noise;

REGISTRATION

Photometric

Pros

- Low cost/weight/energy sensors;
- Rich textures;
- Larger volume of publications on state estimations;

Geometric

Cons

- No depth;
- Dependent on external light source;

- Direct depth measurements;
- Robust to environment changes;
- Larger volume of publications on map representations;

- Heavy/expensive sensors;
- Systematic noise;

Which one is the best?

REGISTRATION

Photometric

Pros

- Low cost/weight/energy sensors;
- Rich **textures**;
- Larger volume of publications on state estimations;

Geometric

Cons

- No depth, scale ambiguity;
- Dependent on external light source;

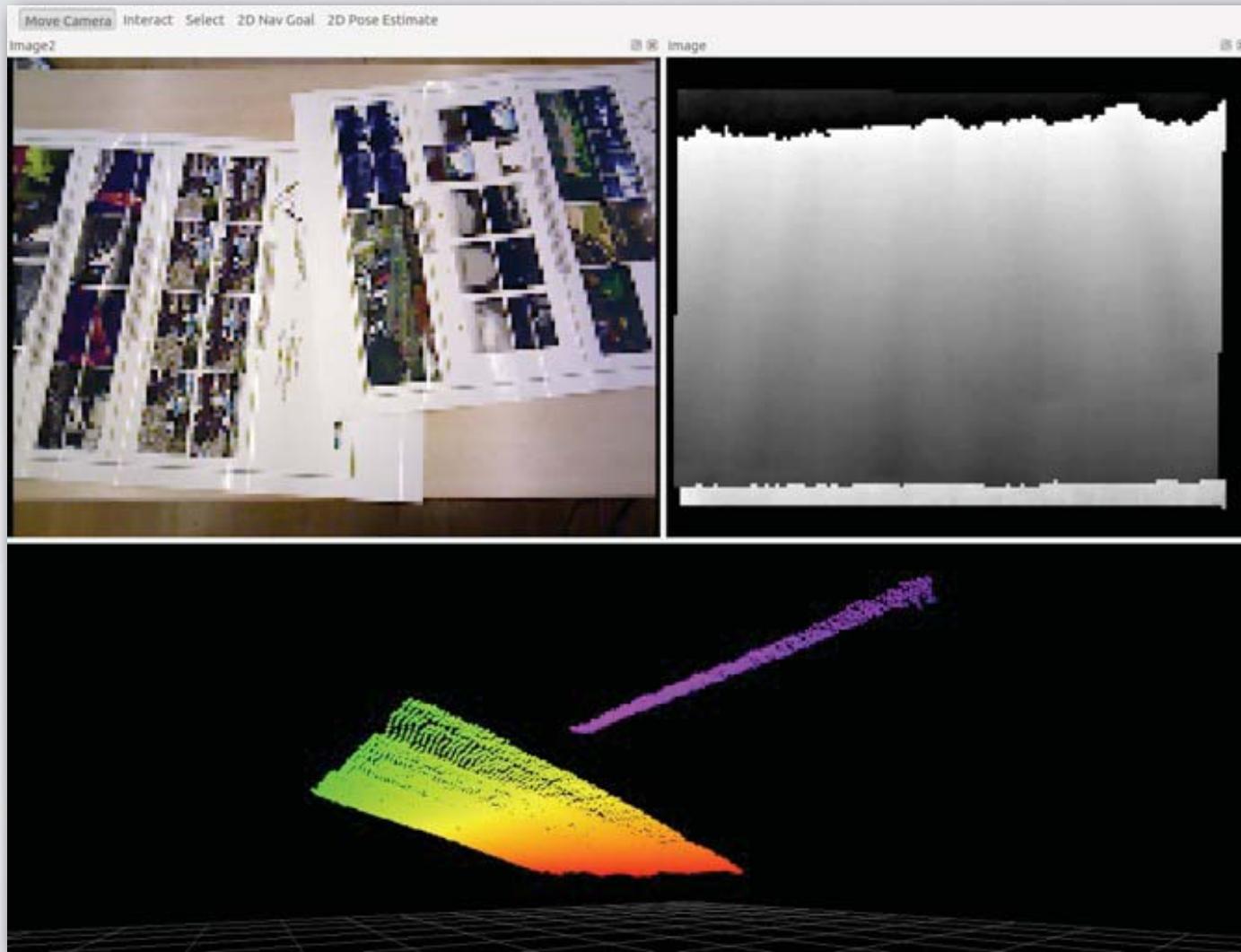
- Direct depth measurements;
- Robust to environment changes;
- Larger volume of publications on map representations;

- Heavy/expensive sensors;
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Which one is the best?

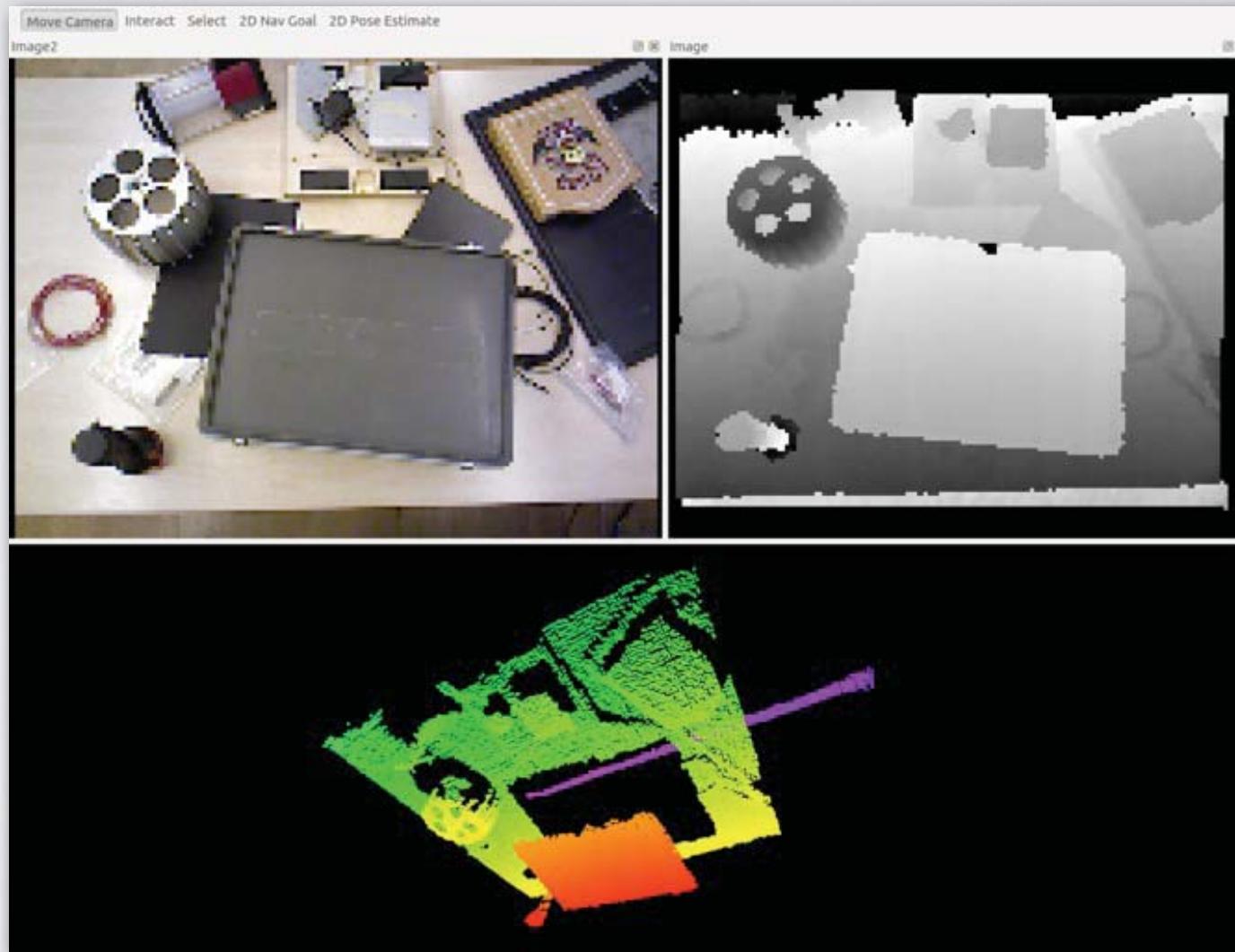
REGISTRATION

Textures:



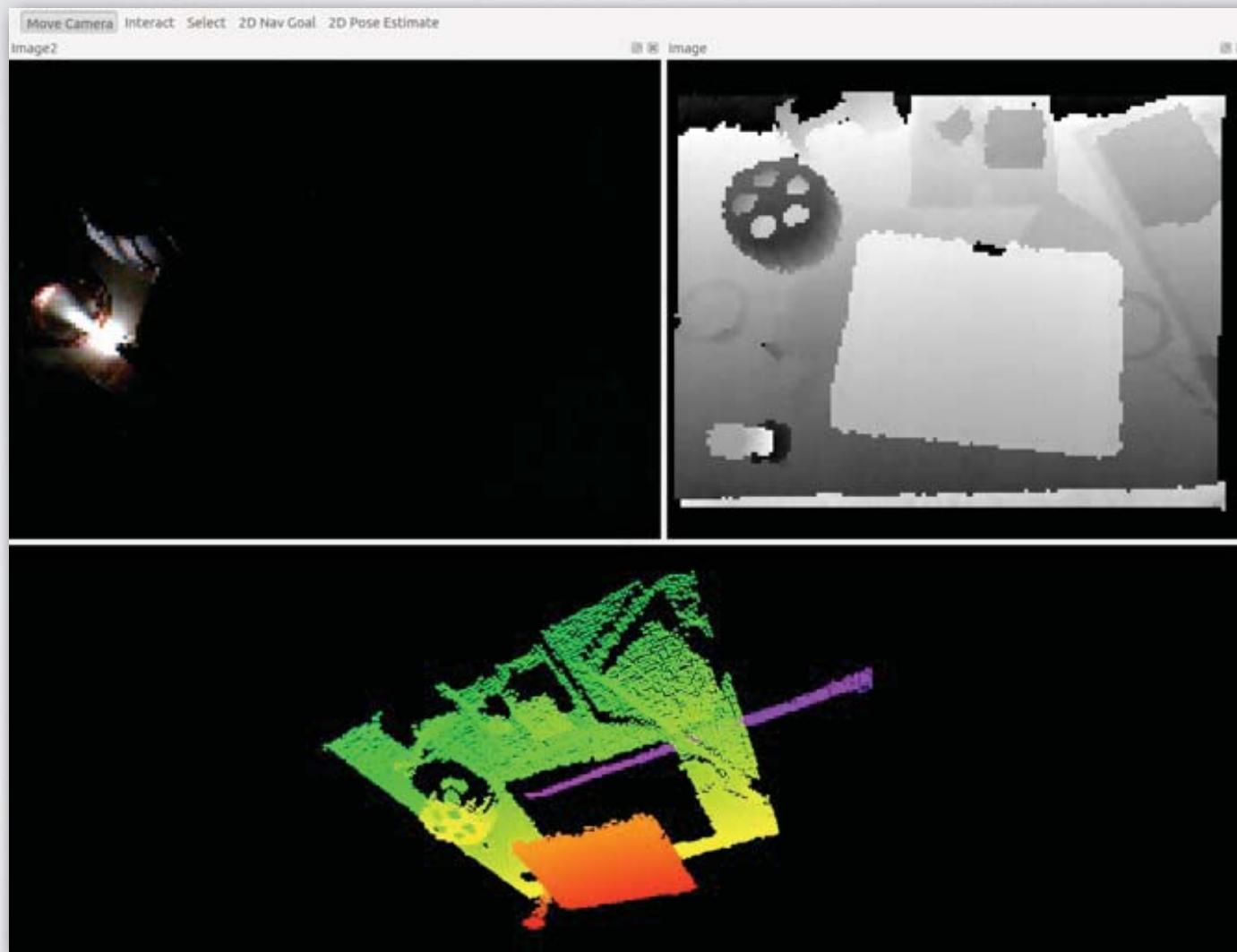
REGISTRATION

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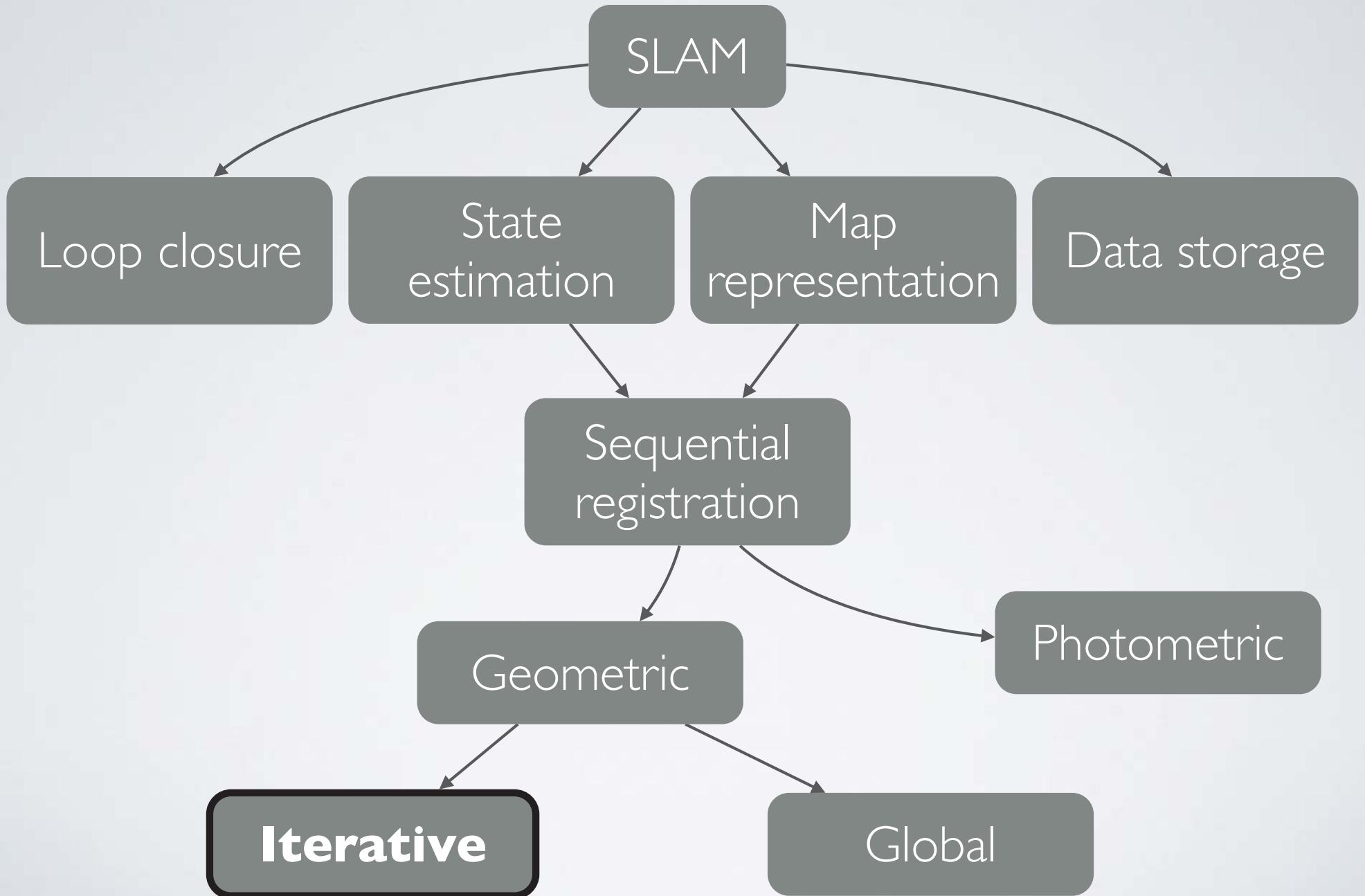


REGISTRATION

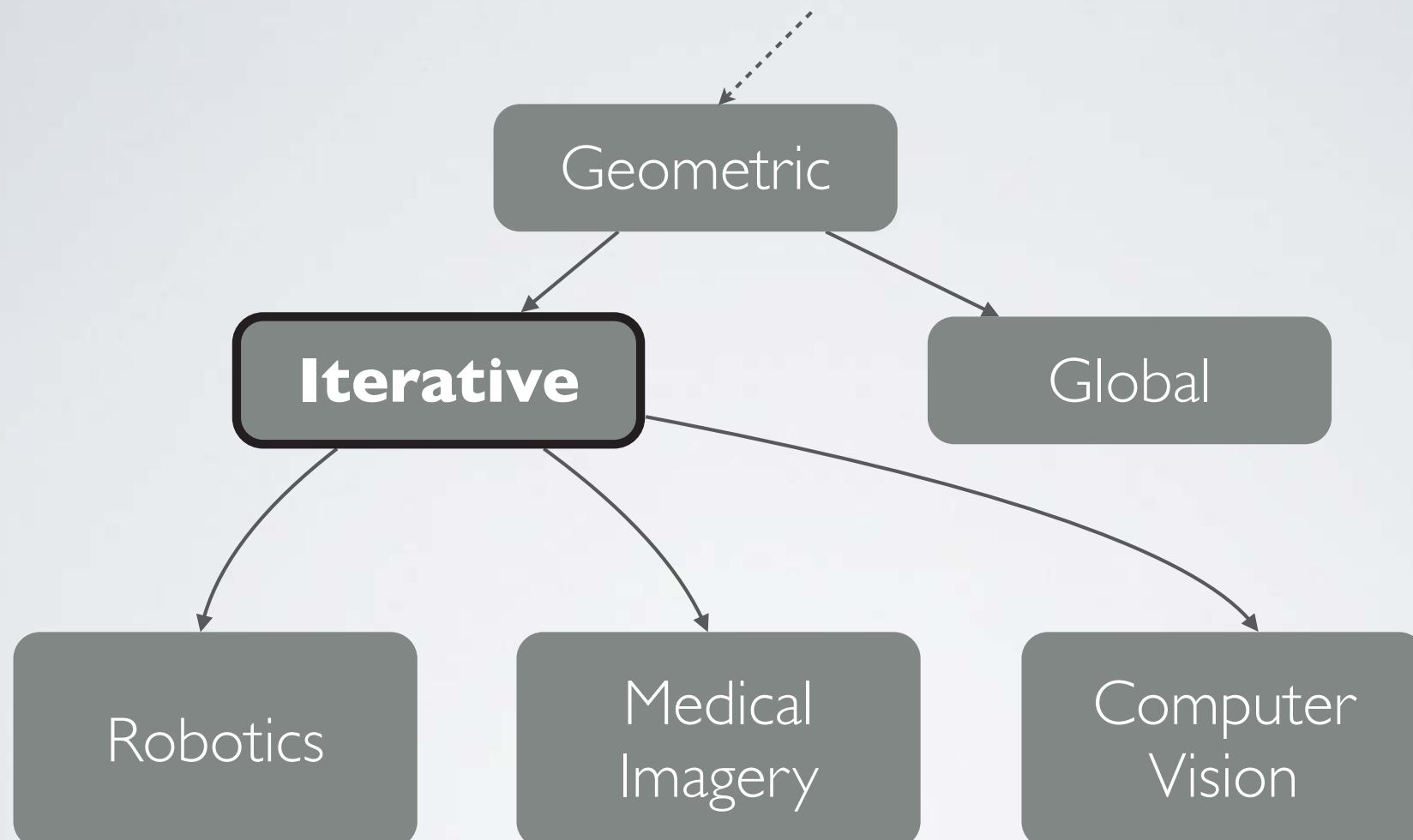
Textures:



REGISTRATION



REGISTRATION (ICP)



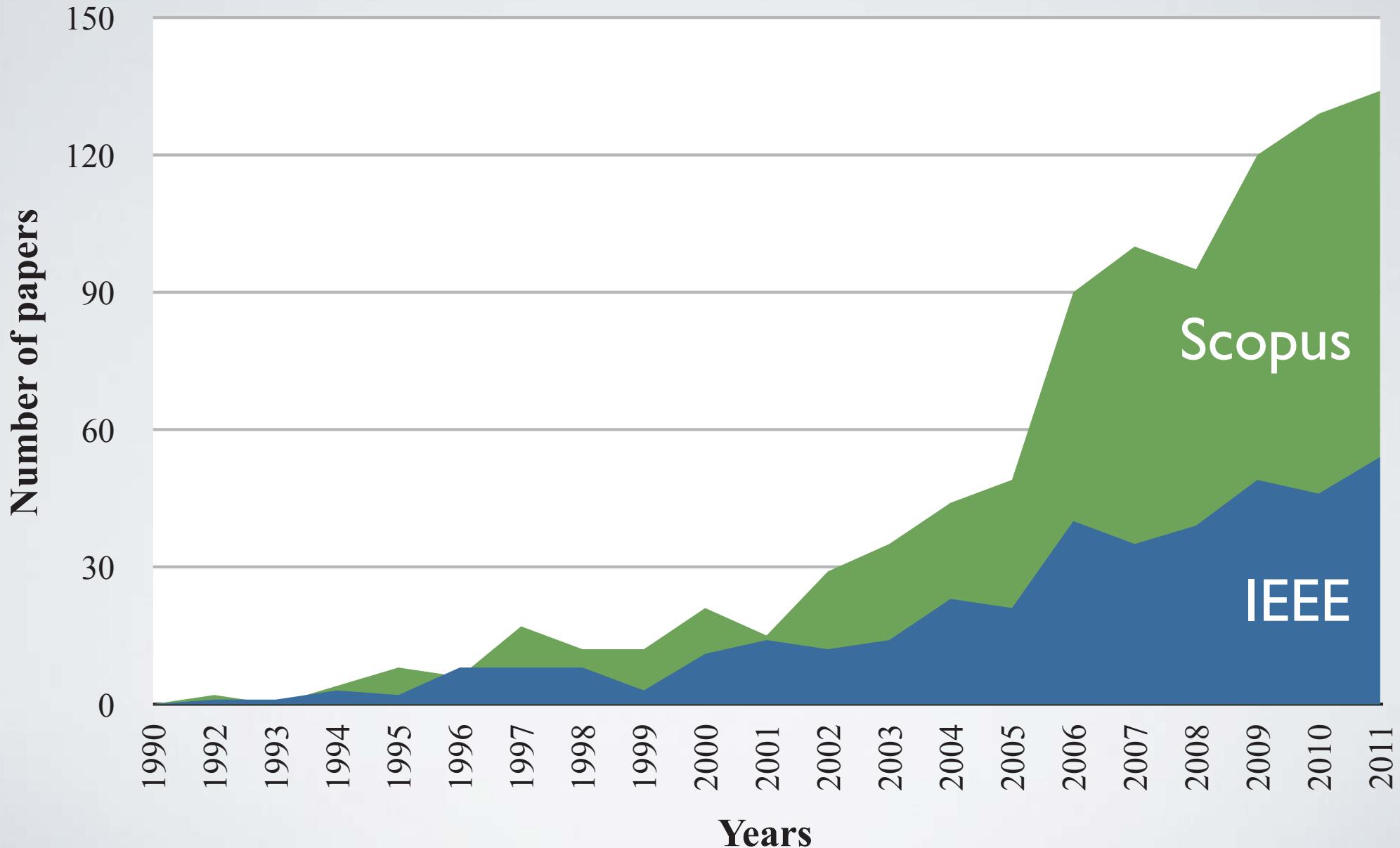
Zhang [1994]

Champeboux et al. [1992]

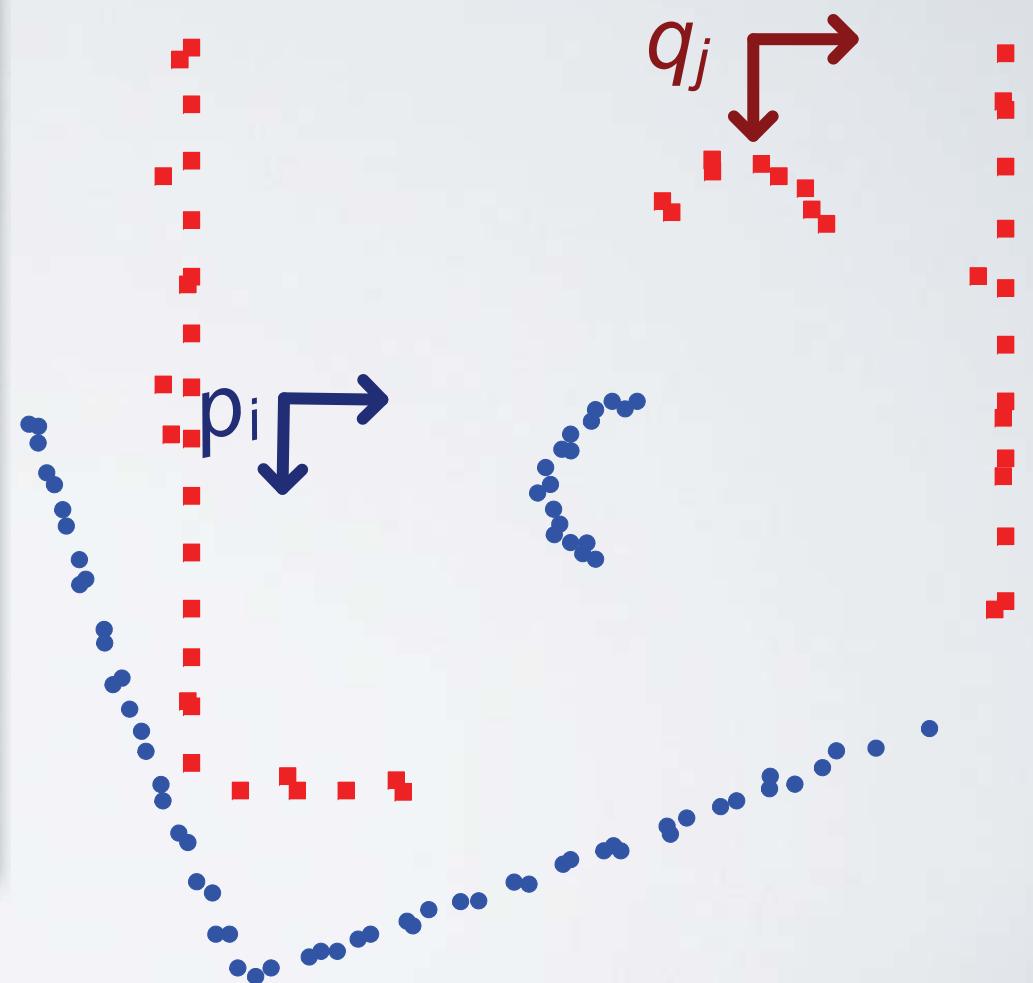
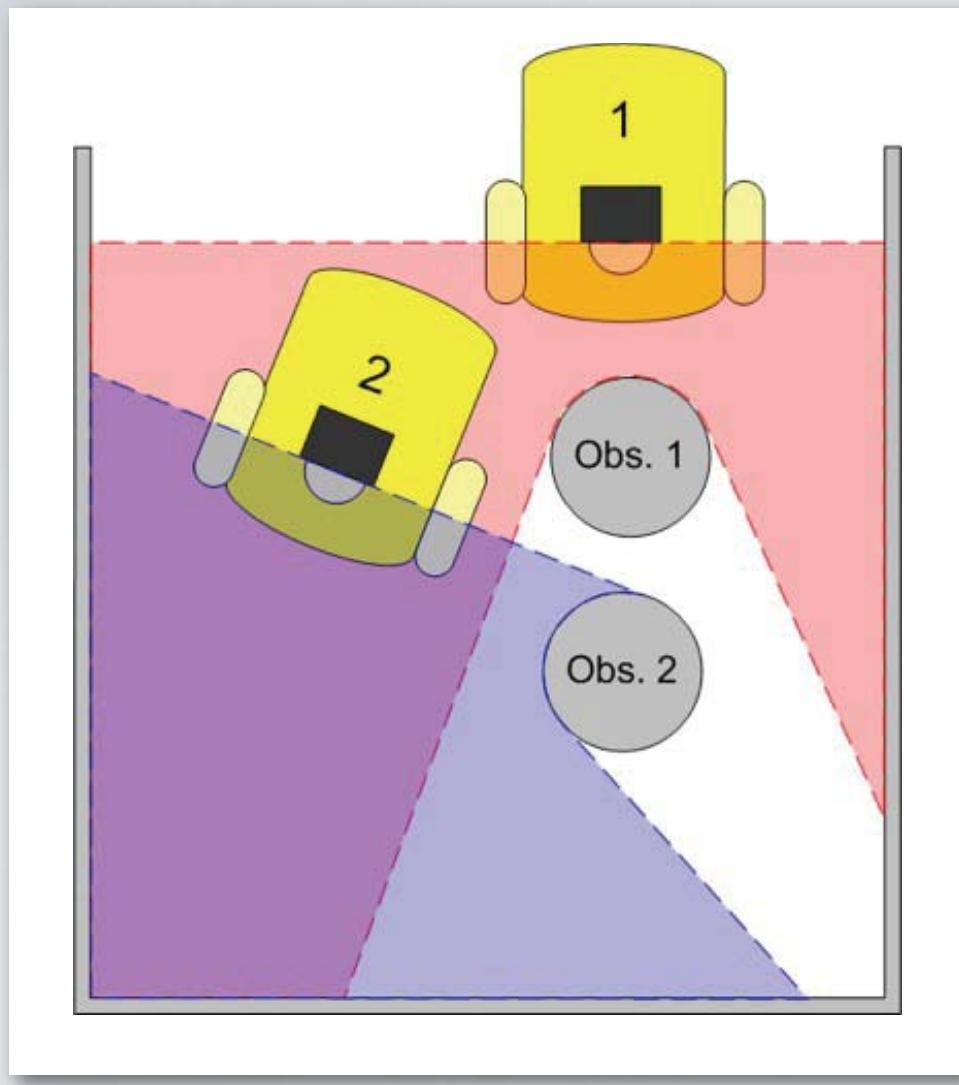
Besl and McKay [1992]

Chen and Medioni [1992]

REGISTRATION (ICP)

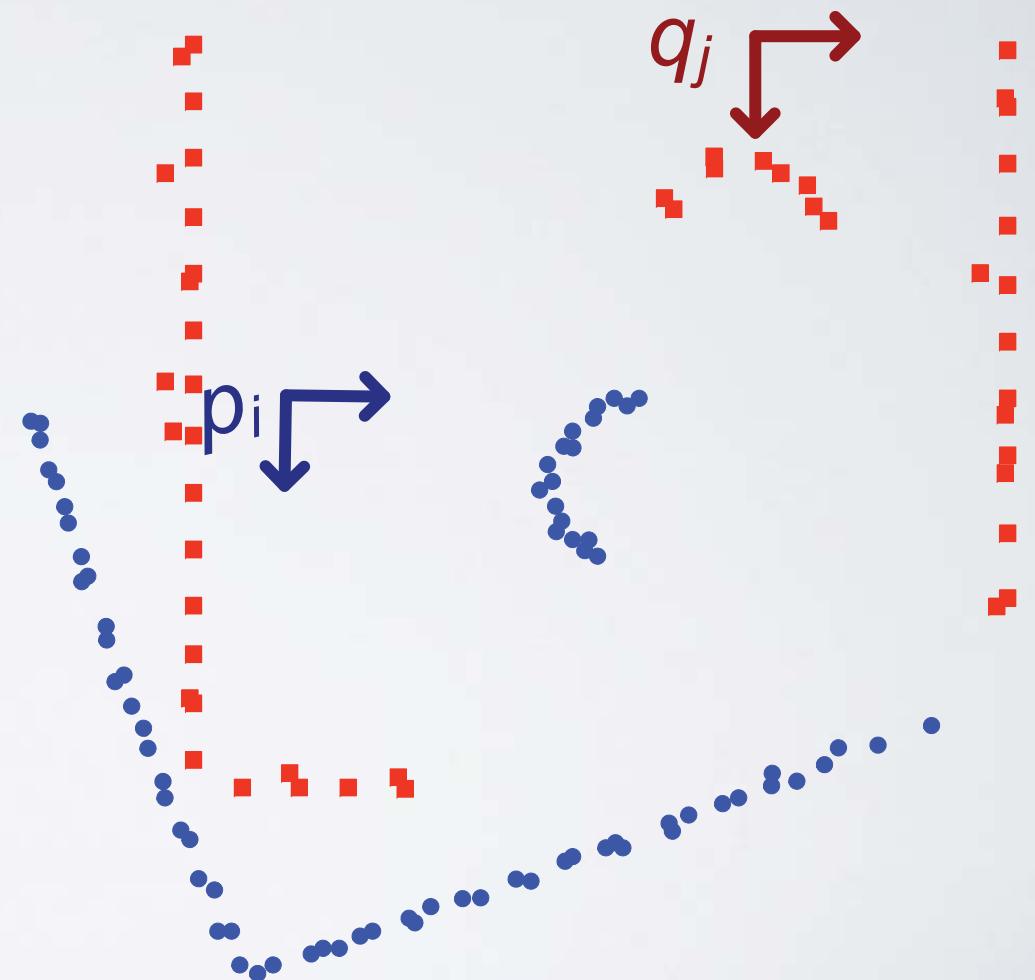


ICP - TOY EXAMPLE IN 2D



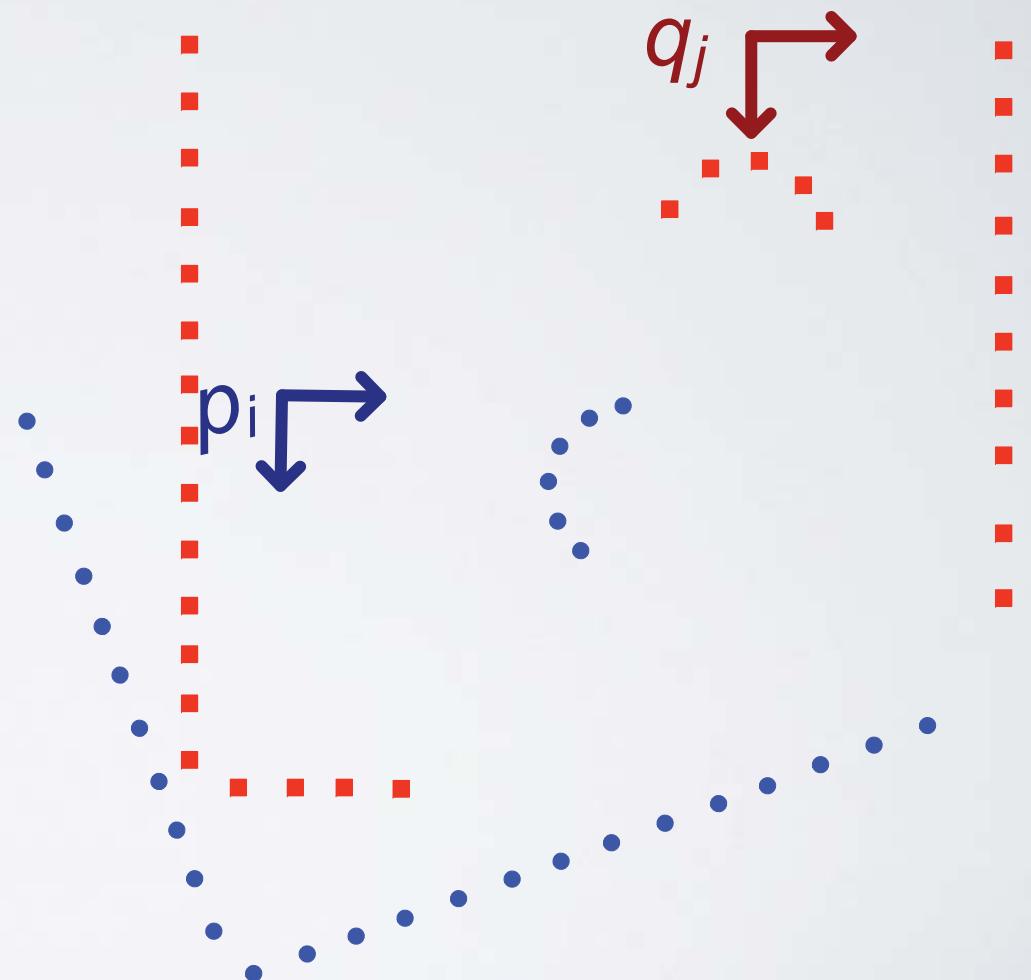
ICP - TOY EXAMPLE IN 2D

1. Preprocessing
2. Matching
3. Rejection
4. Error
5. Minimization



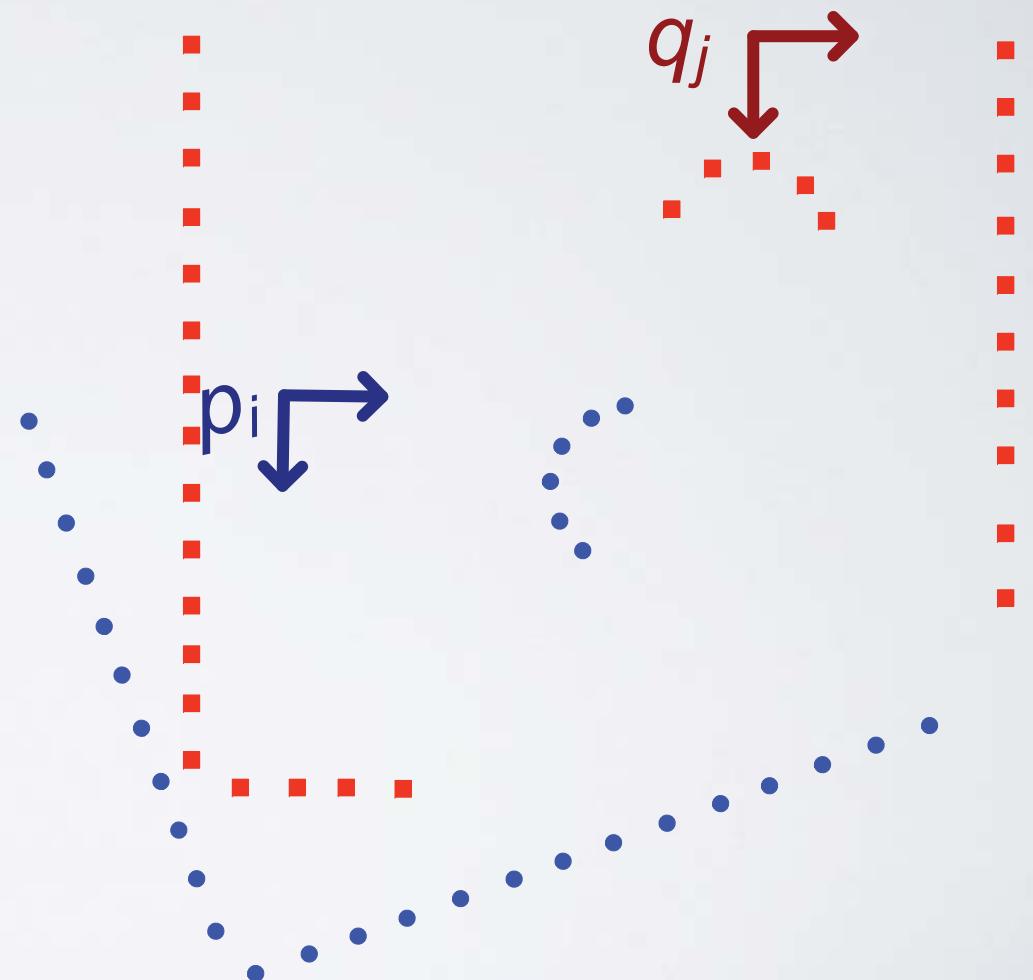
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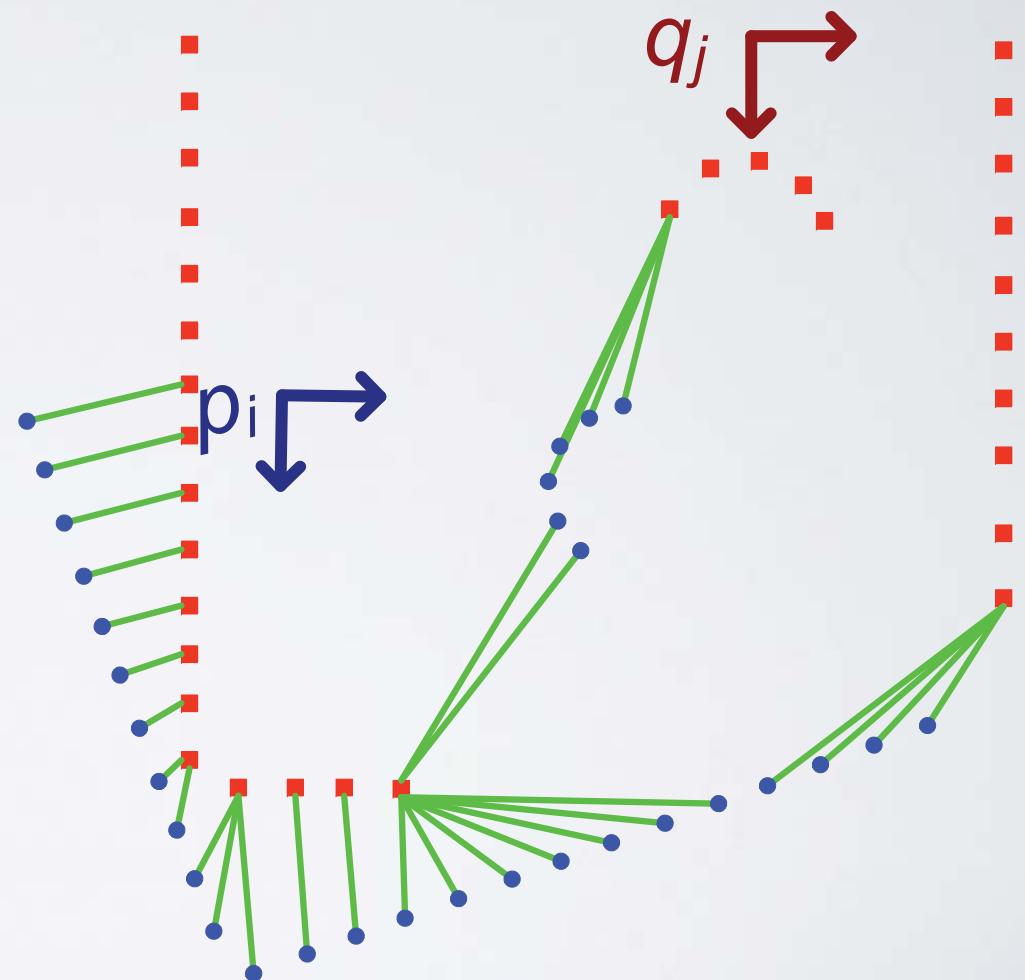
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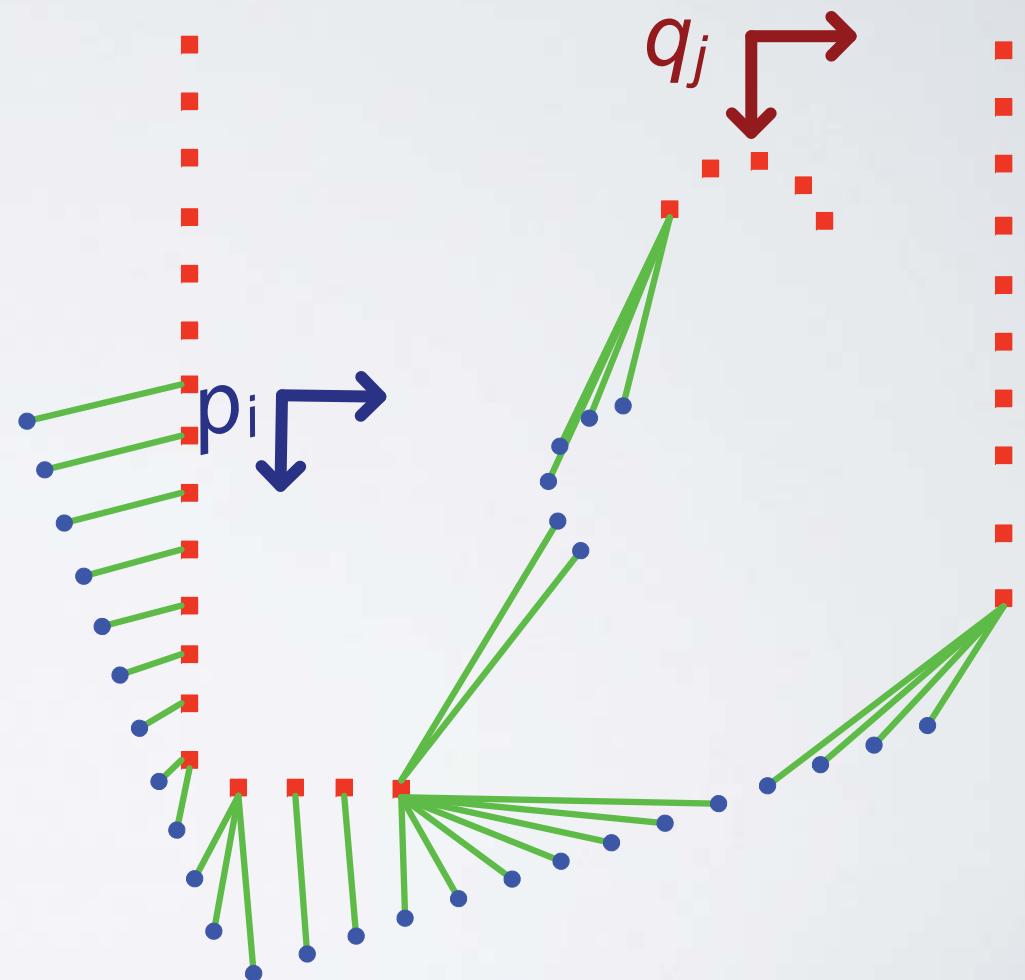
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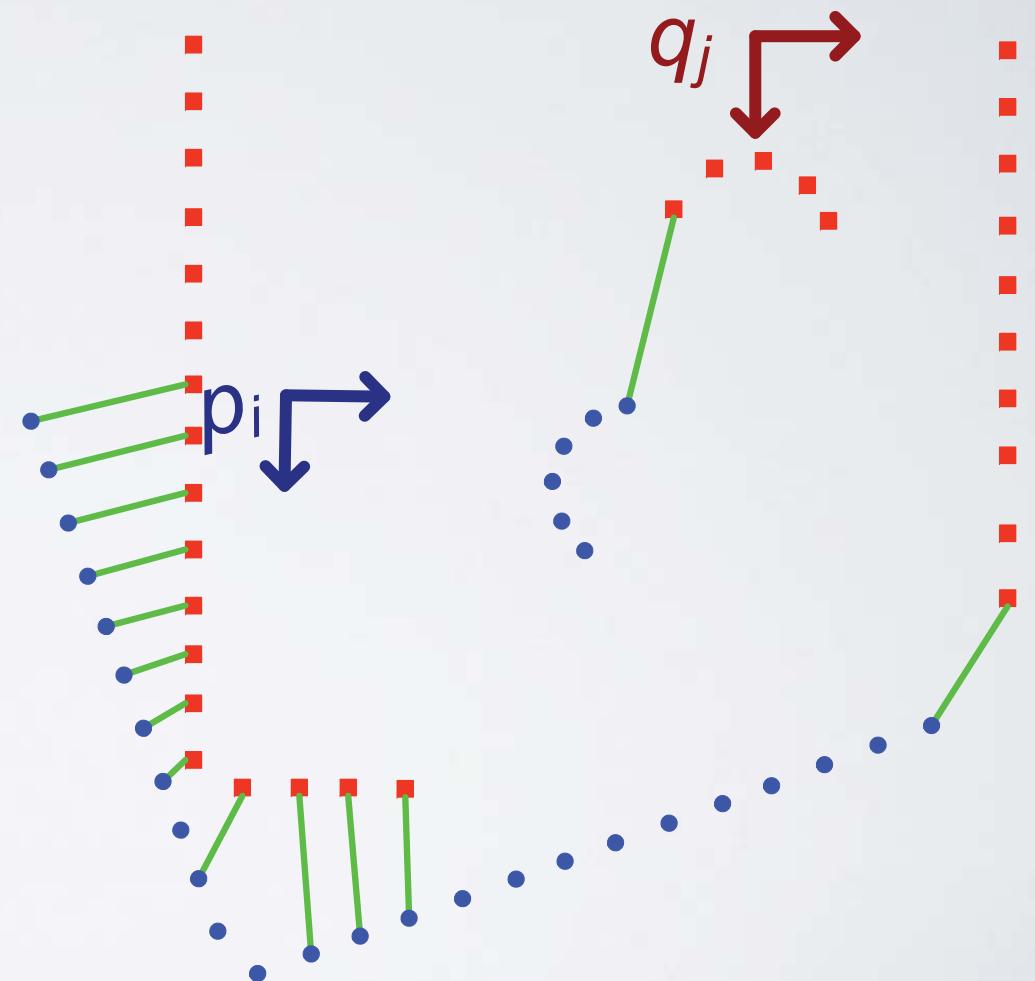
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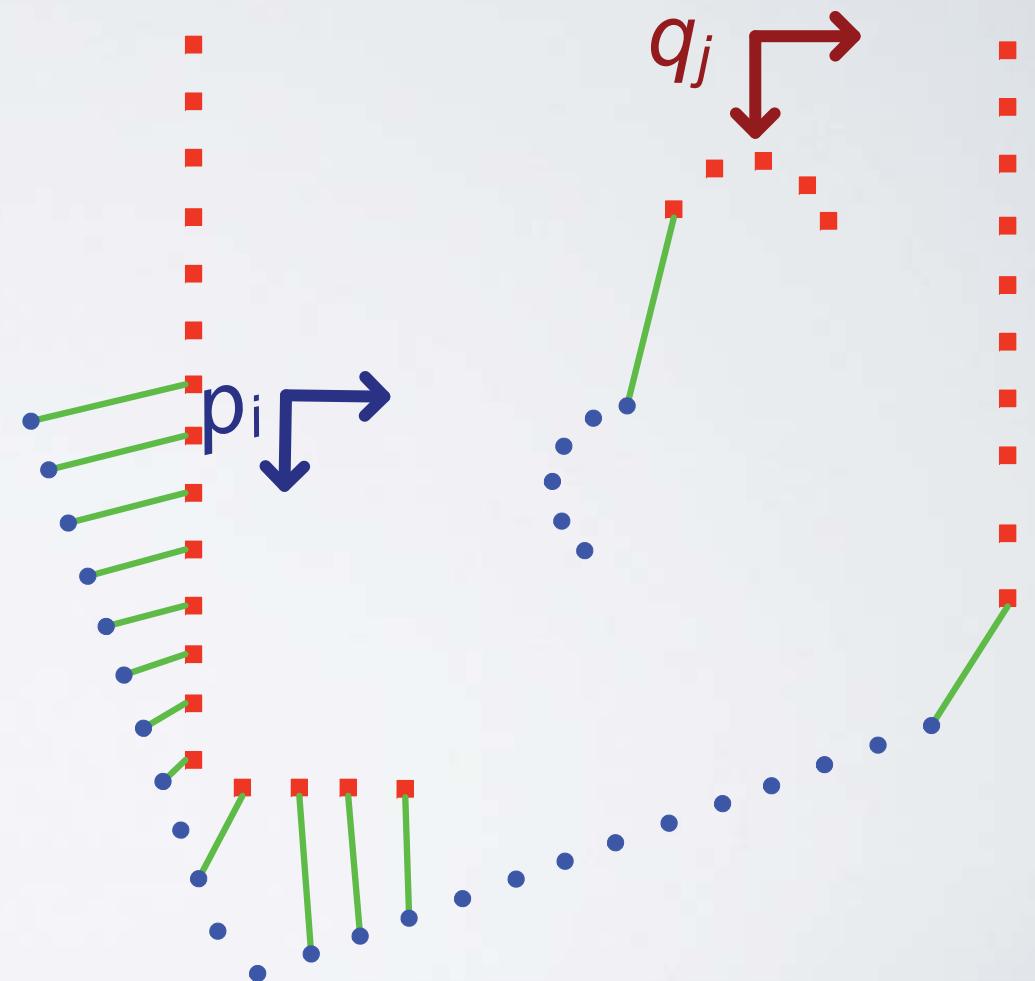
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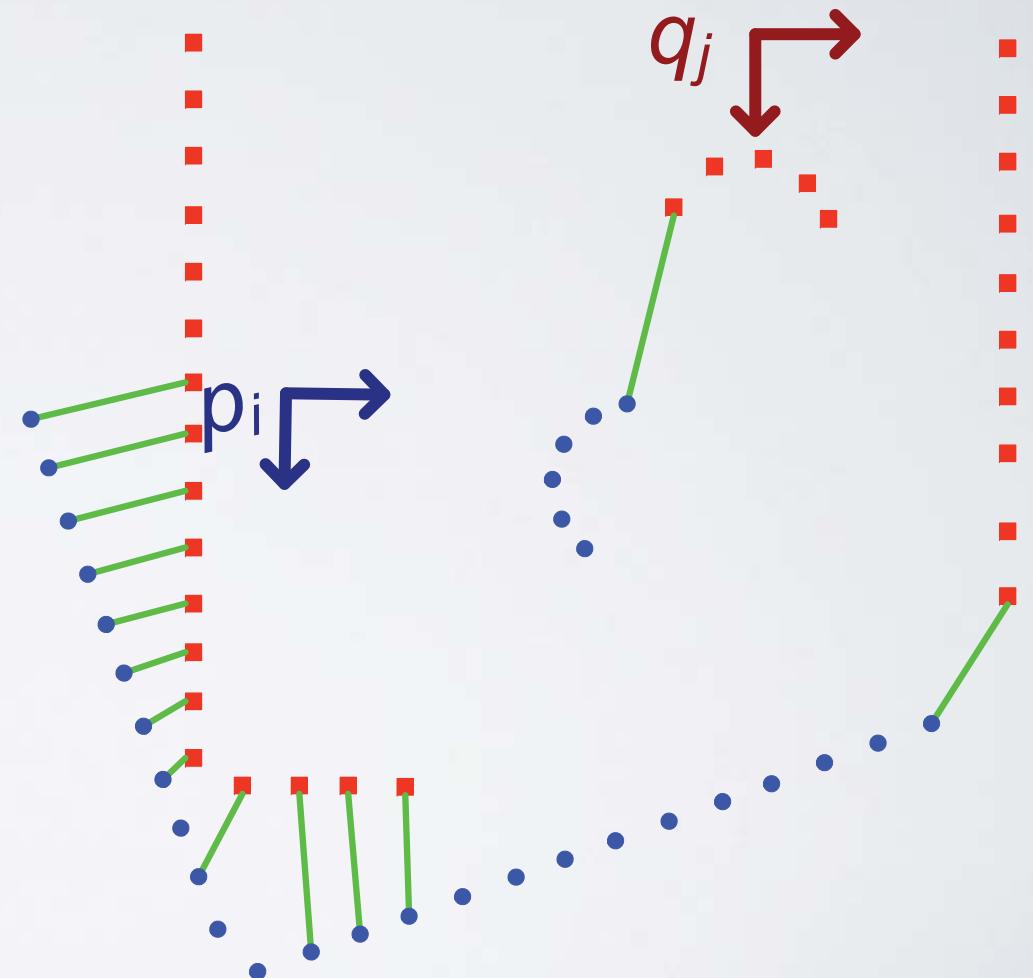
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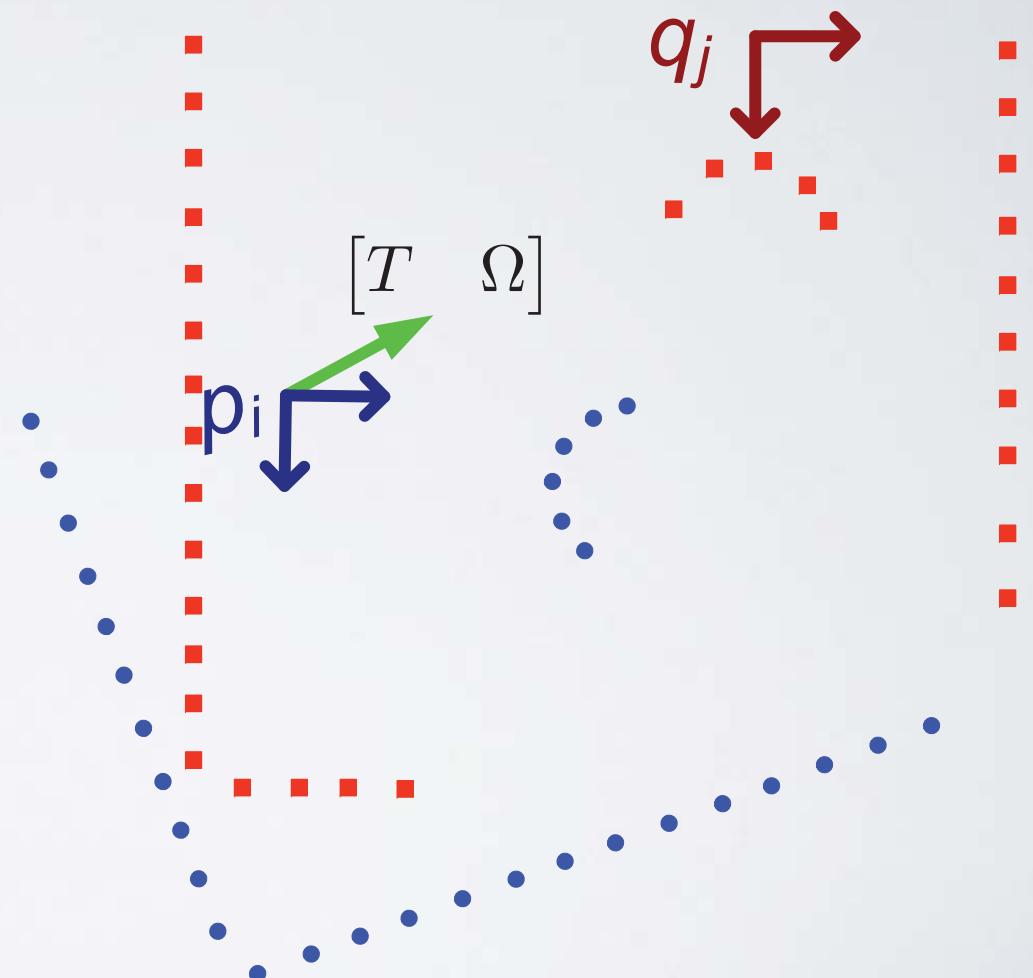
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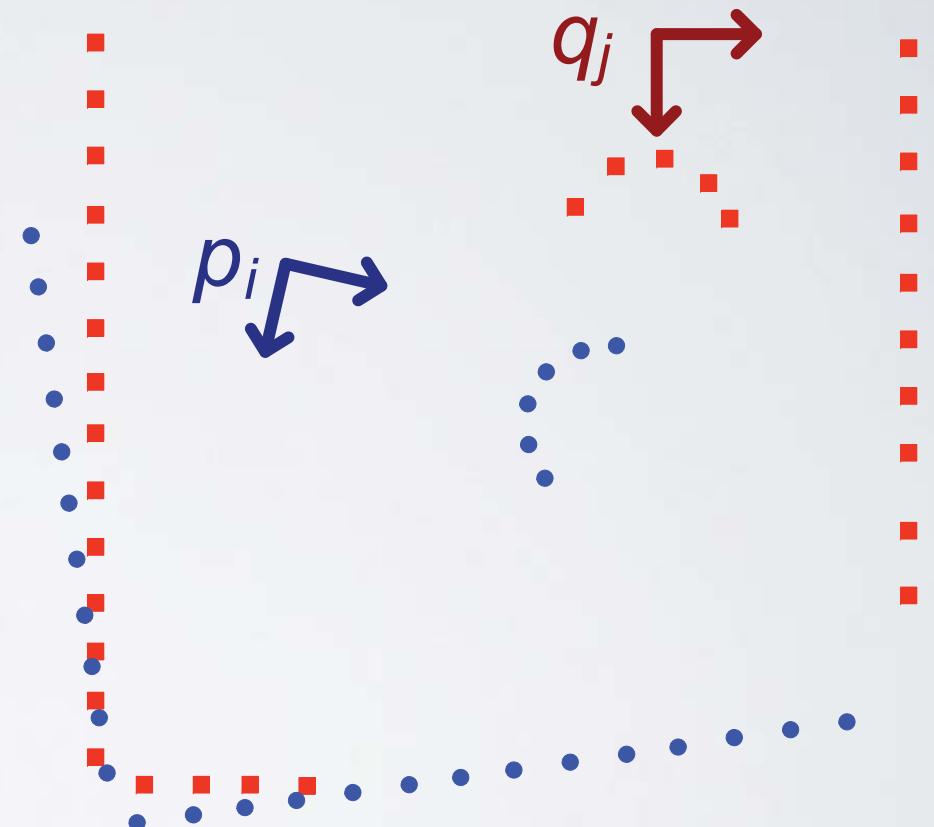
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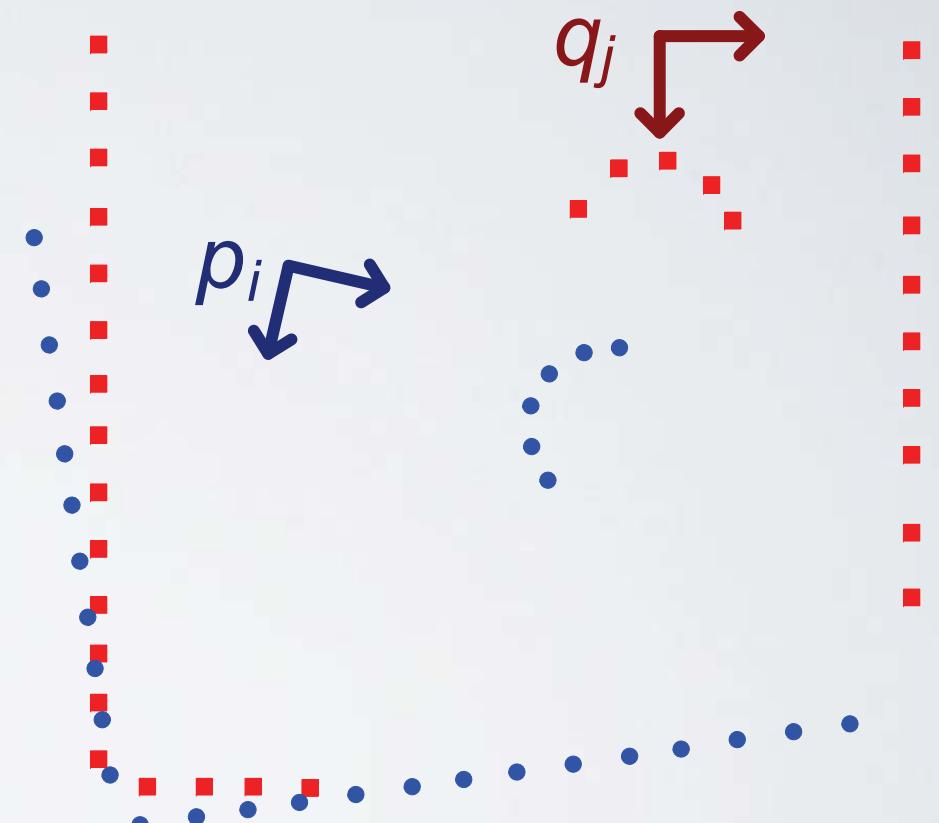
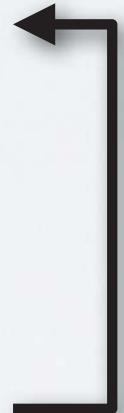
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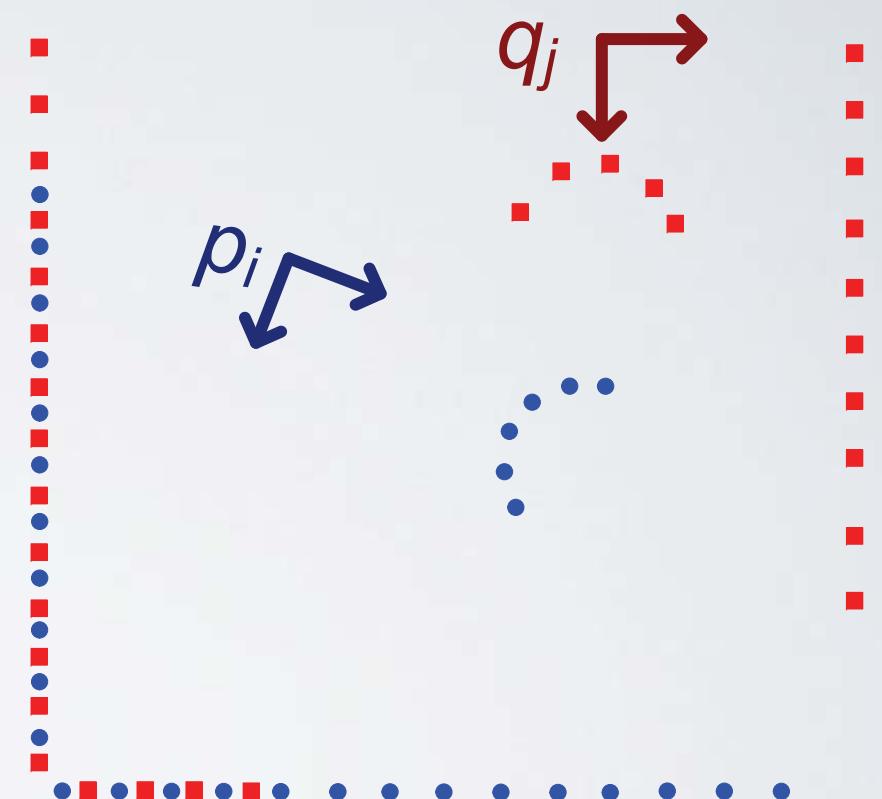


ICP - TOY EXAMPLE IN 2D

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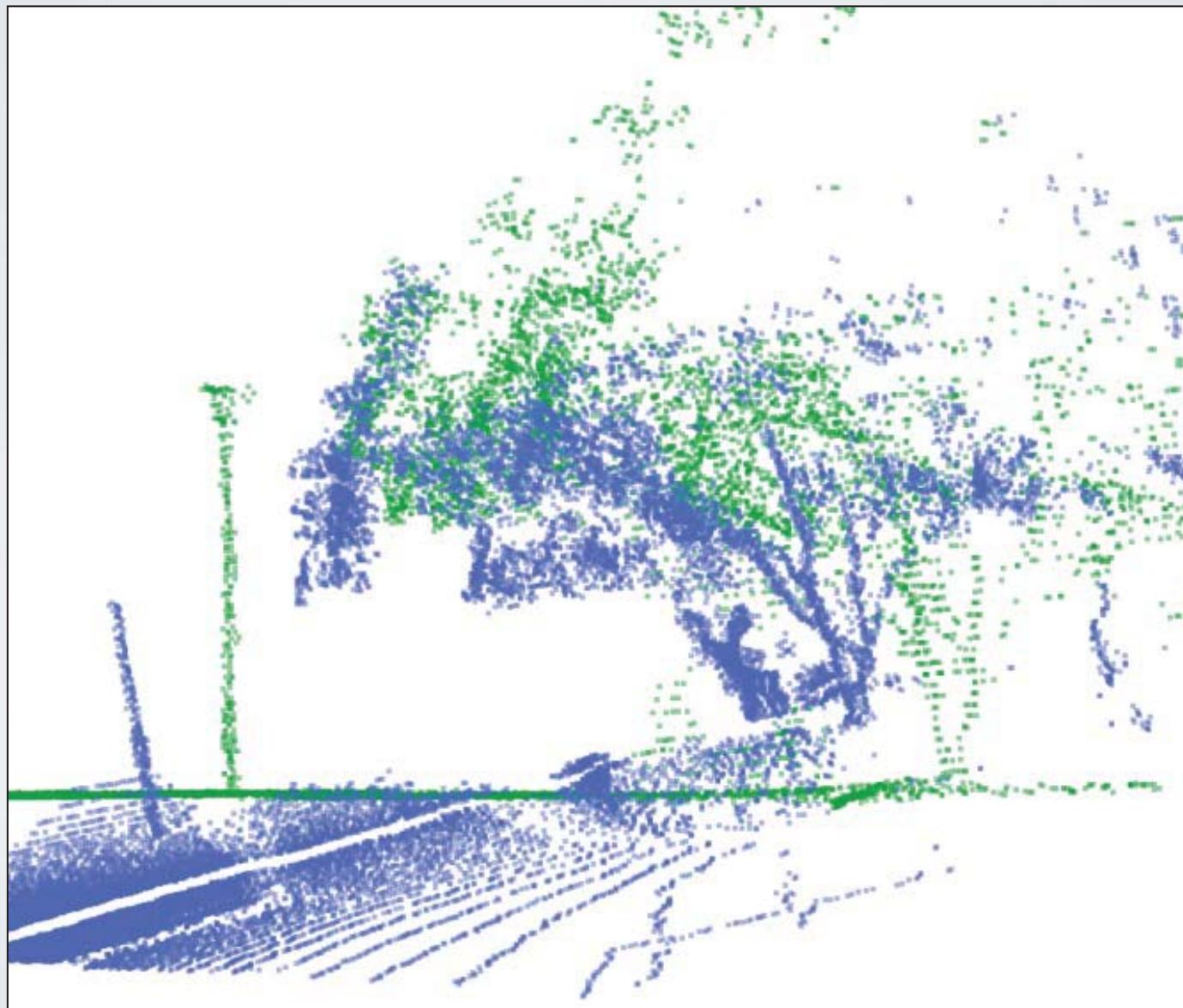
End conditions



ICP - EXAMPLE IN 3D

Reading

Reference

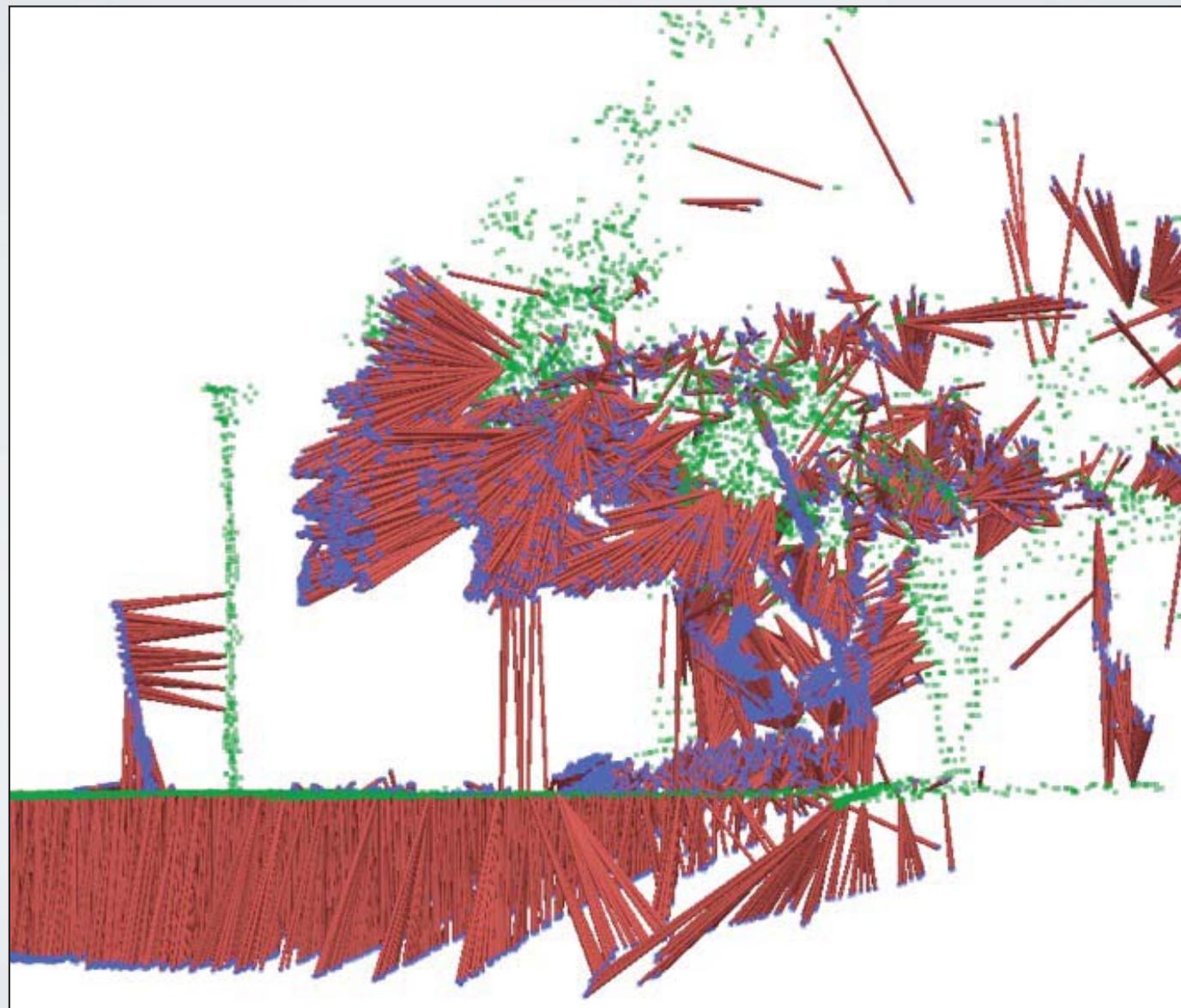


ICP - EXAMPLE IN 3D

Reading

Error

Reference



ICP - EXAMPLE IN 3D

Reading

Error

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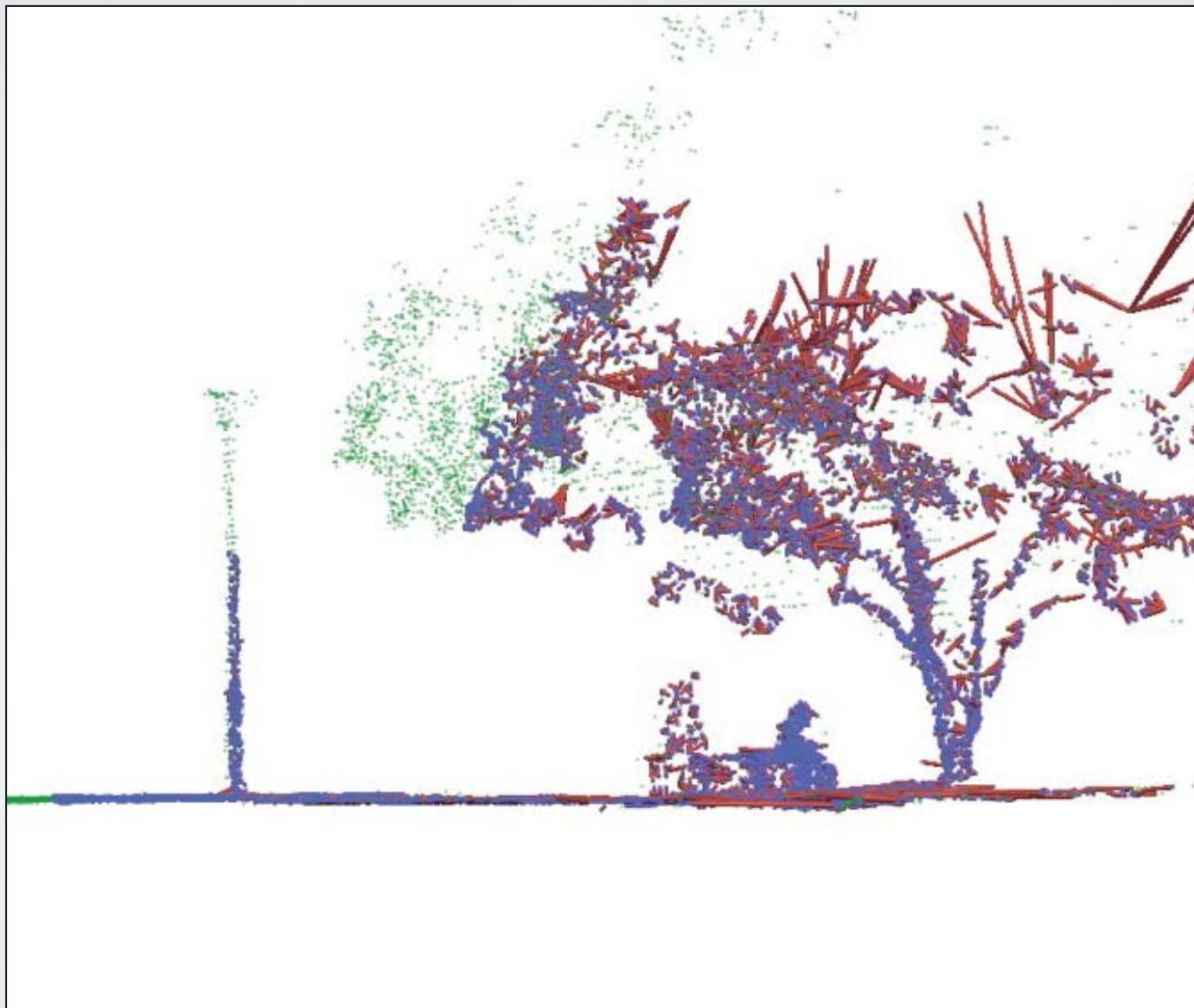


ICP - EXAMPLE IN 3D

Reading

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ICP - EXAMPLE IN 3D

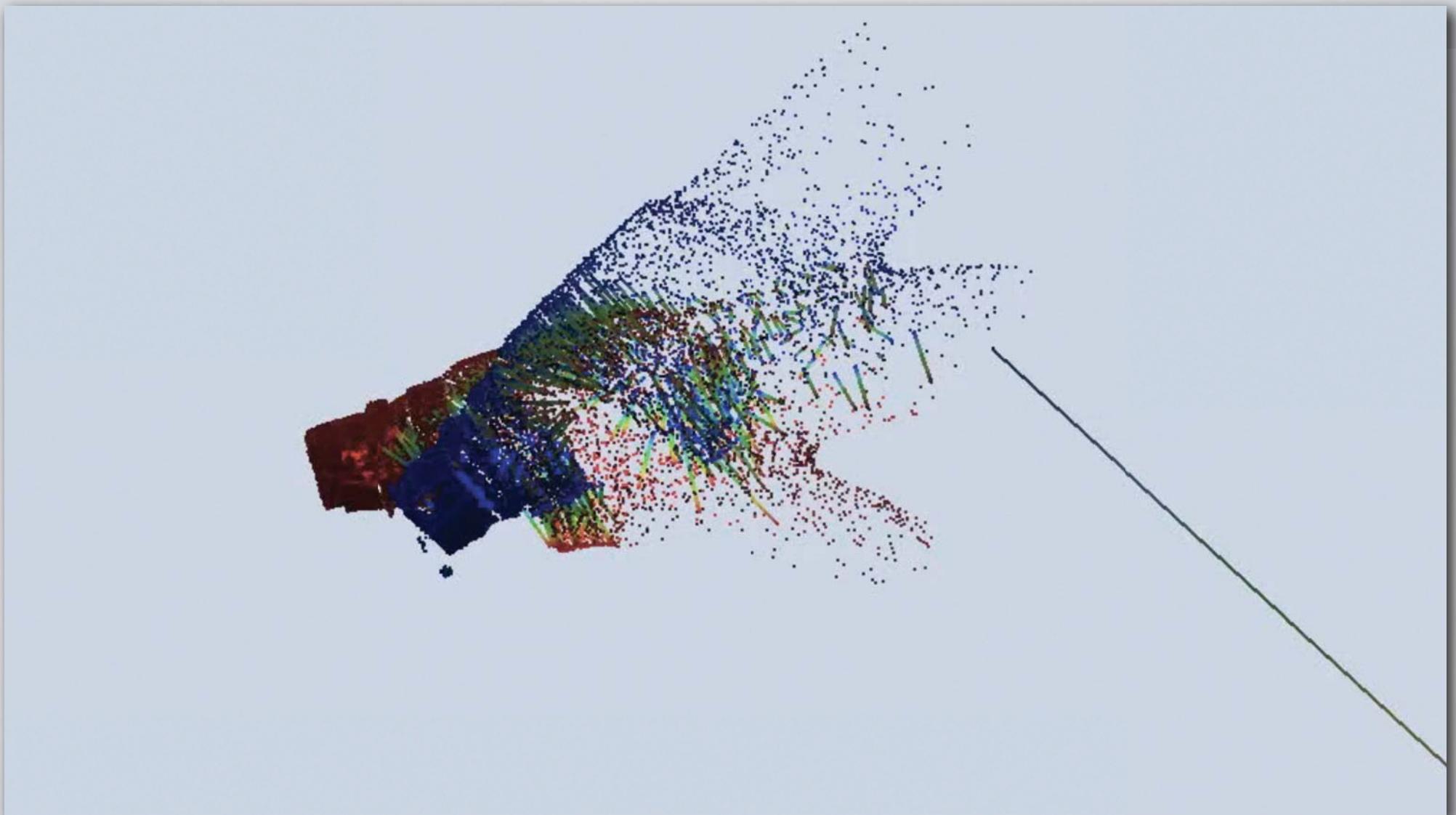
Reading

Error

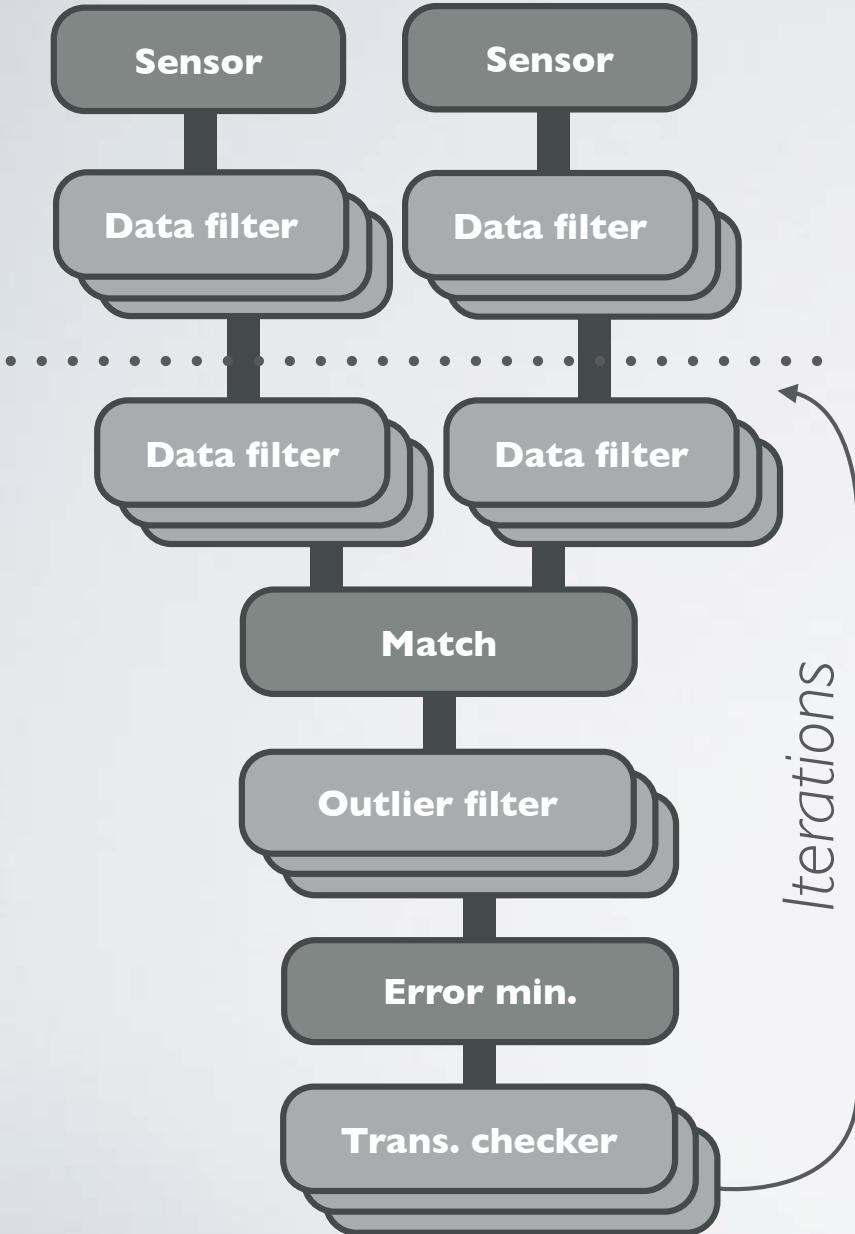
Reference



ICP - EXAMPLE IN 3D (PIPE)

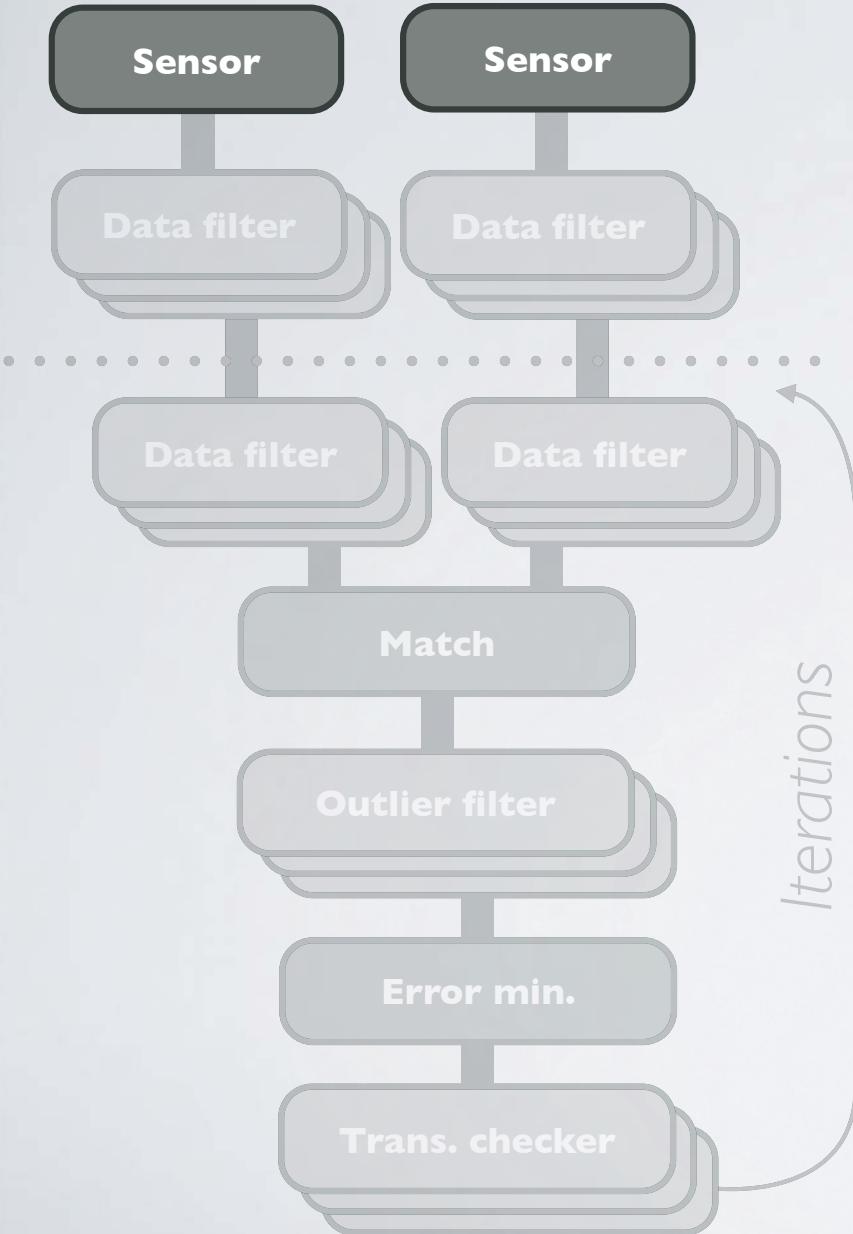


OVERVIEW



- Sensors
- Data filters
- Matching function
- Robust regression
- Minimization
- Convergence detection

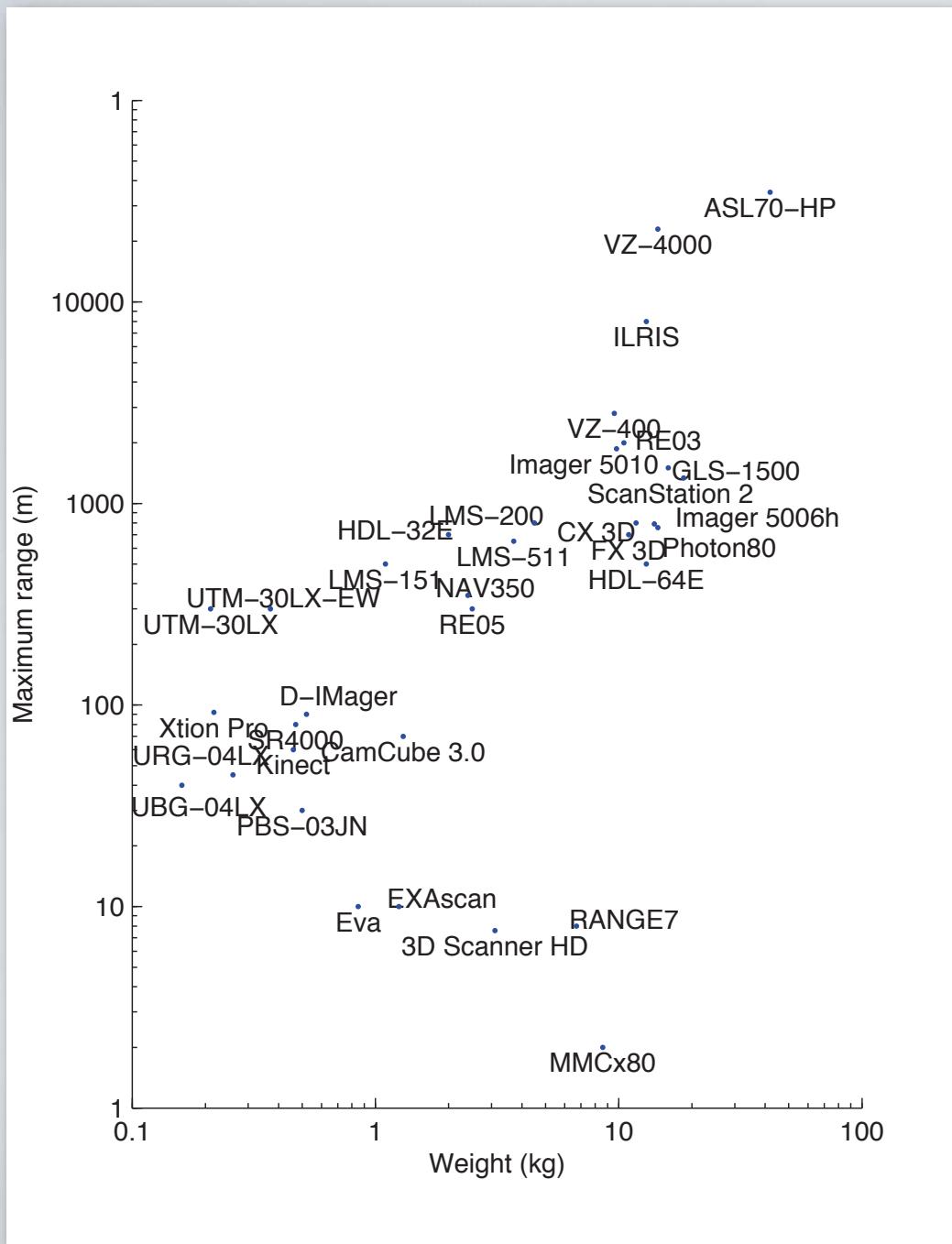
SENSORS



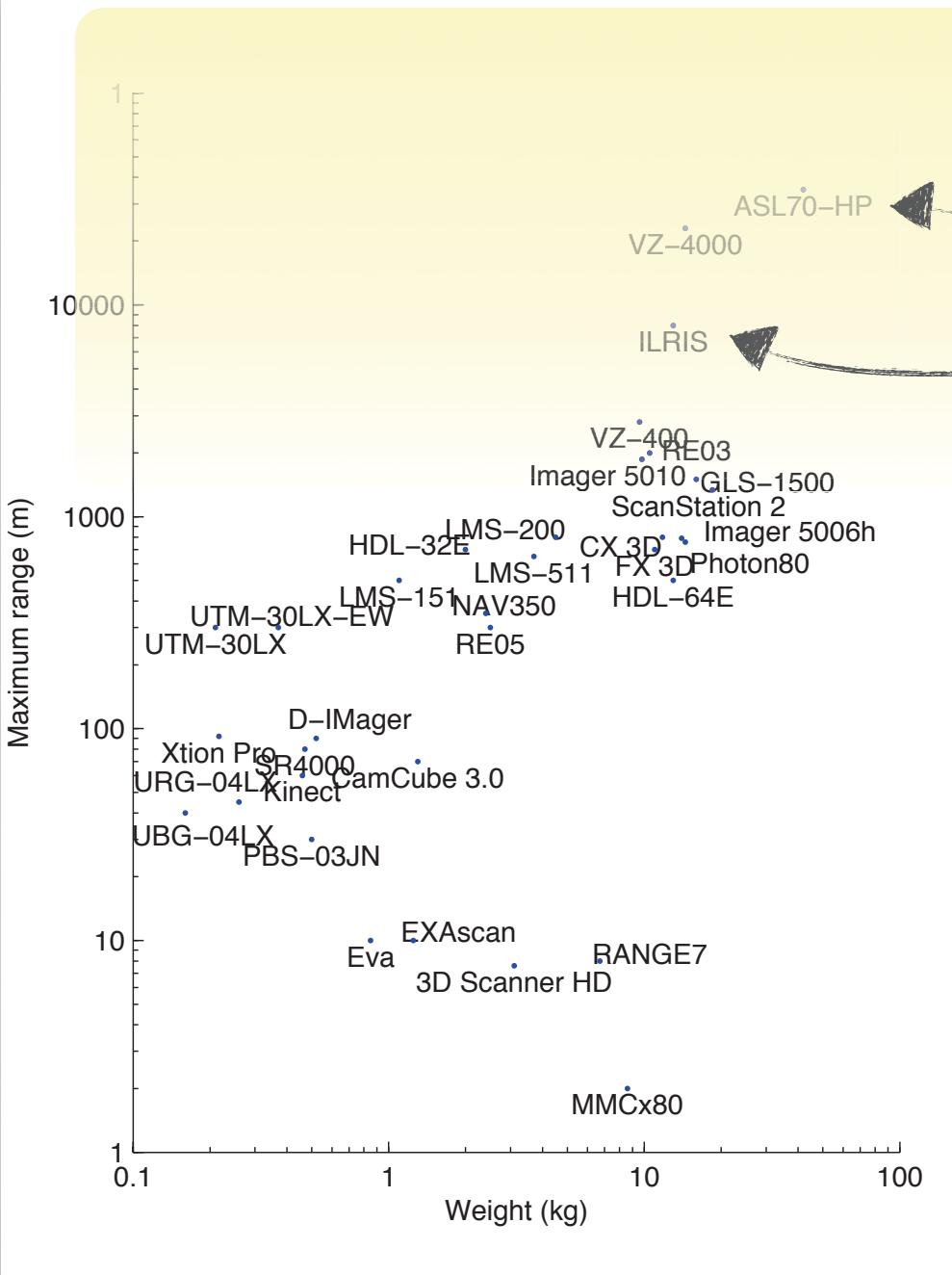
Characteristics:

- Power consumption
- Field of view
- Accuracy/repeatability
- Min/max distance
- Frequency
- Weight
- Volume
- Type of detection
- Wave lenght
- Etc.

AVAILABLE SENSORS



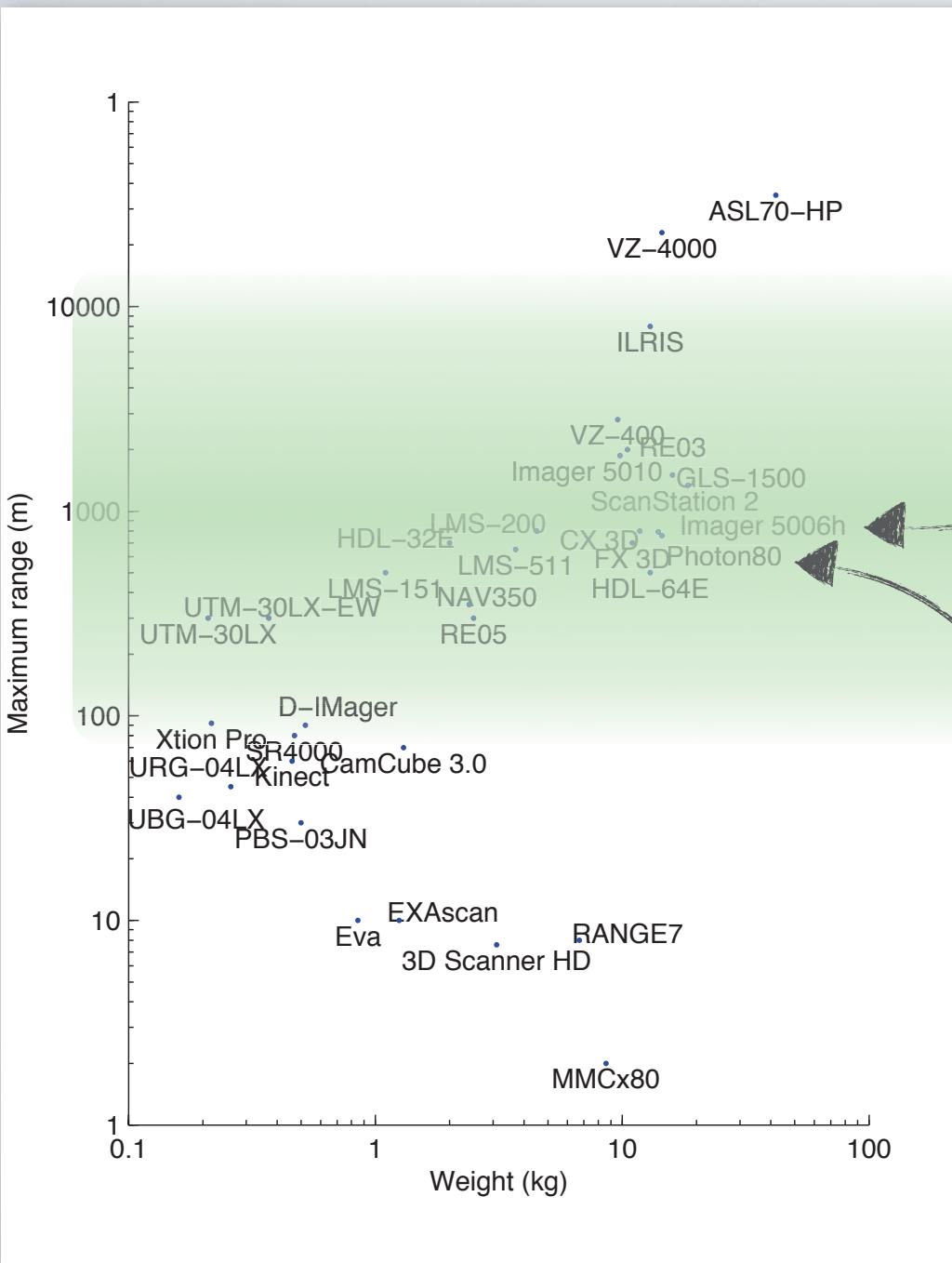
AVAILABLE SENSORS



Airborne Survey



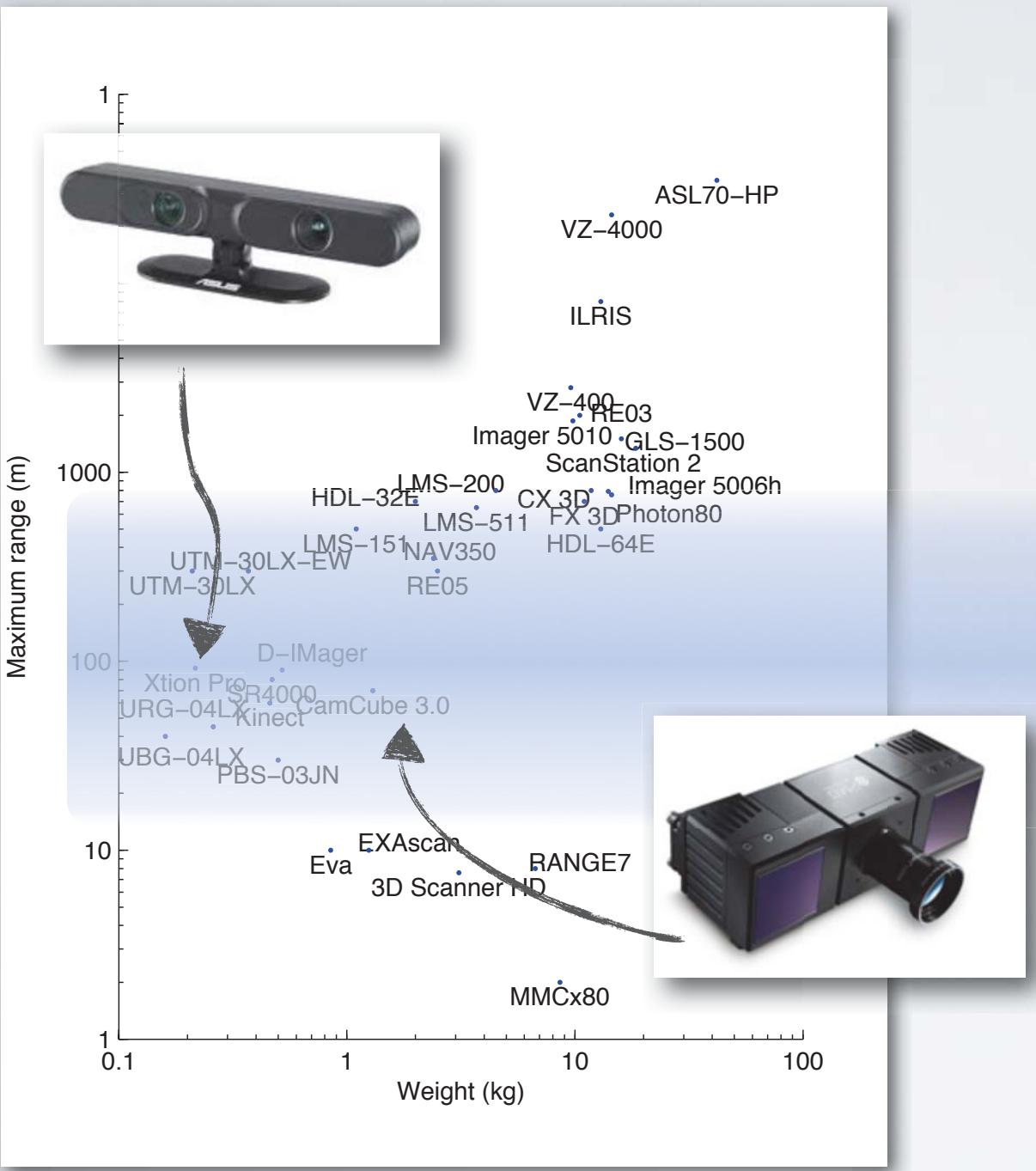
AVAILABLE SENSORS



Terrestrial Survey

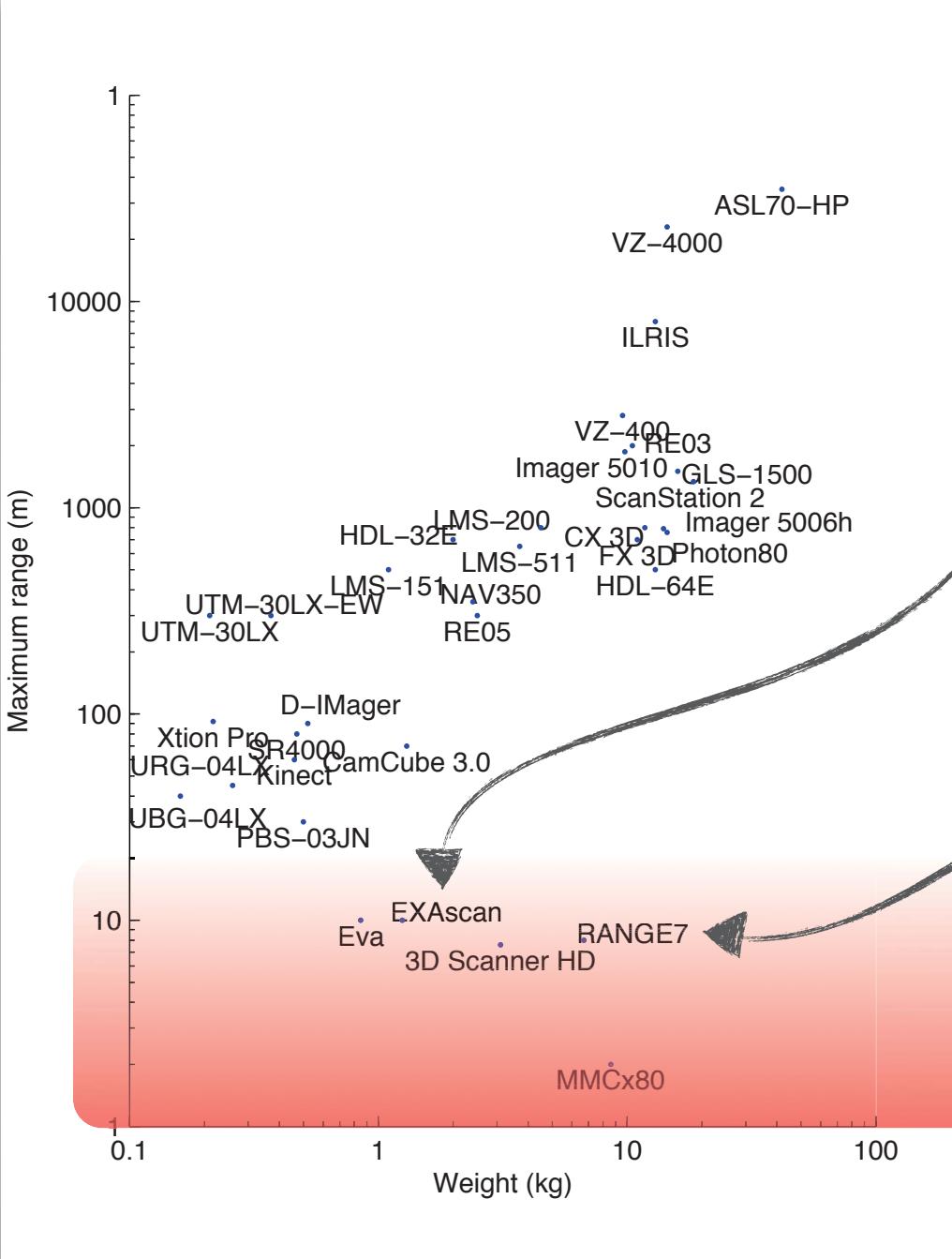


AVAILABLE SENSORS



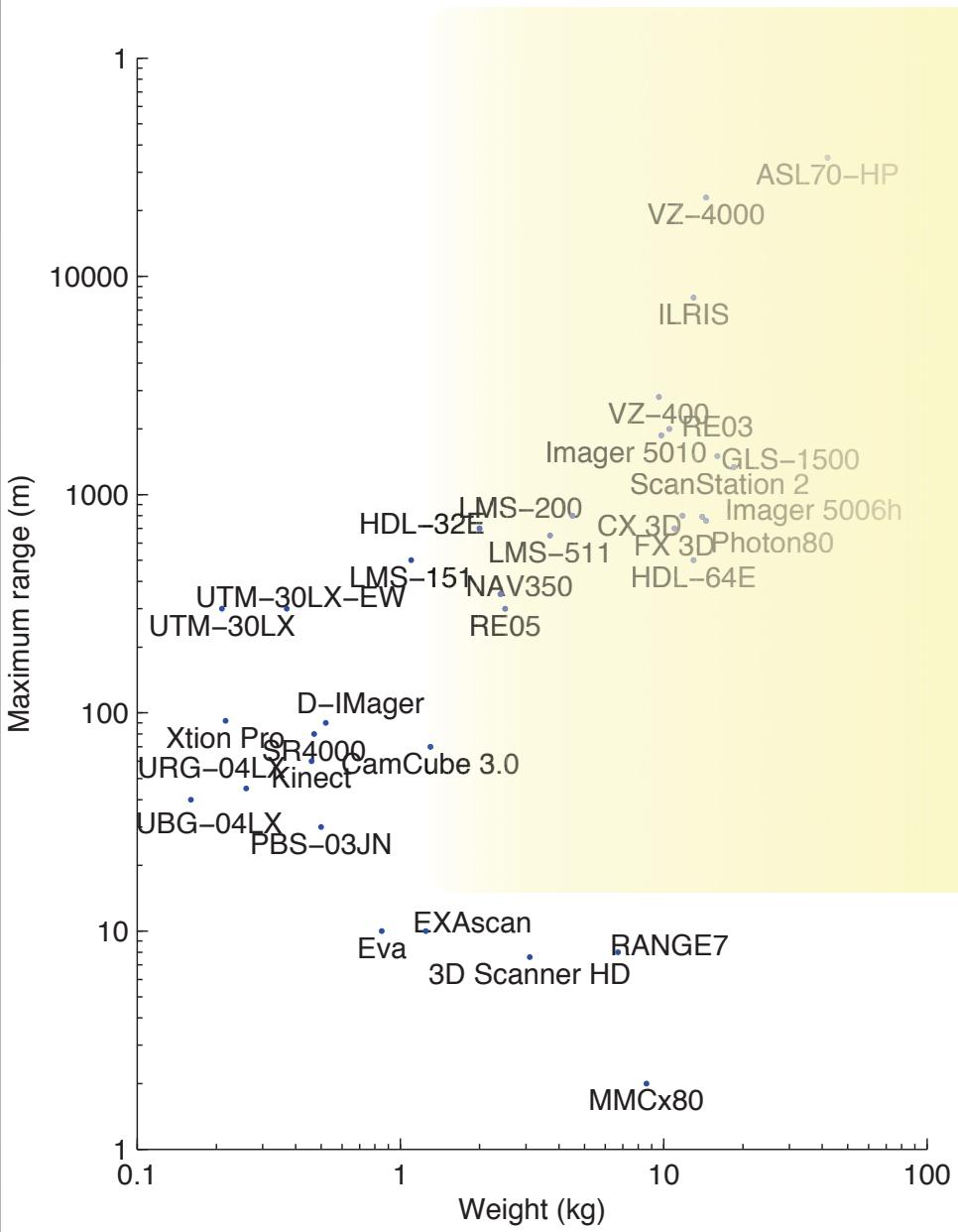
Safety
Robotics
Entertainment

AVAILABLE SENSORS

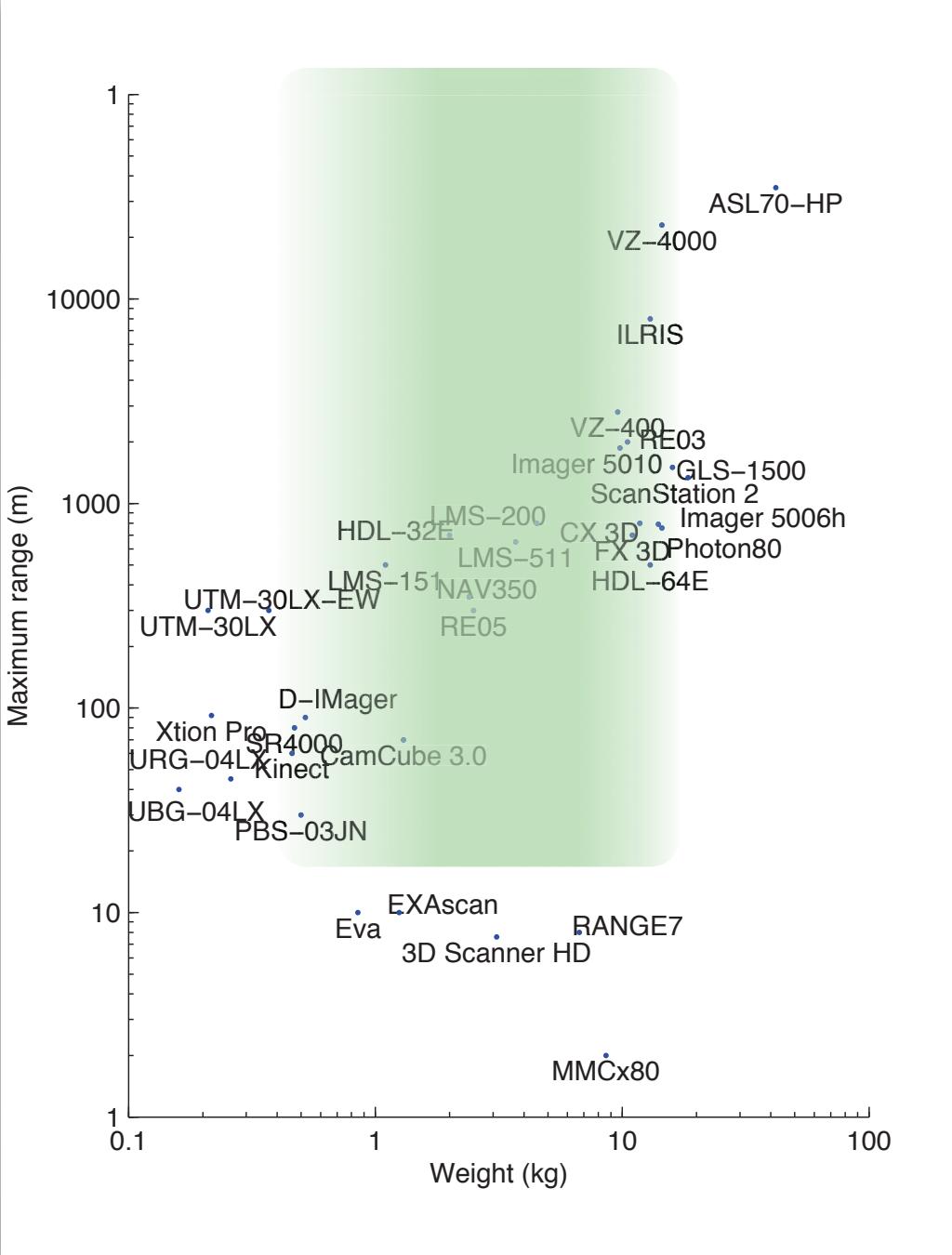


Industrial Inspection

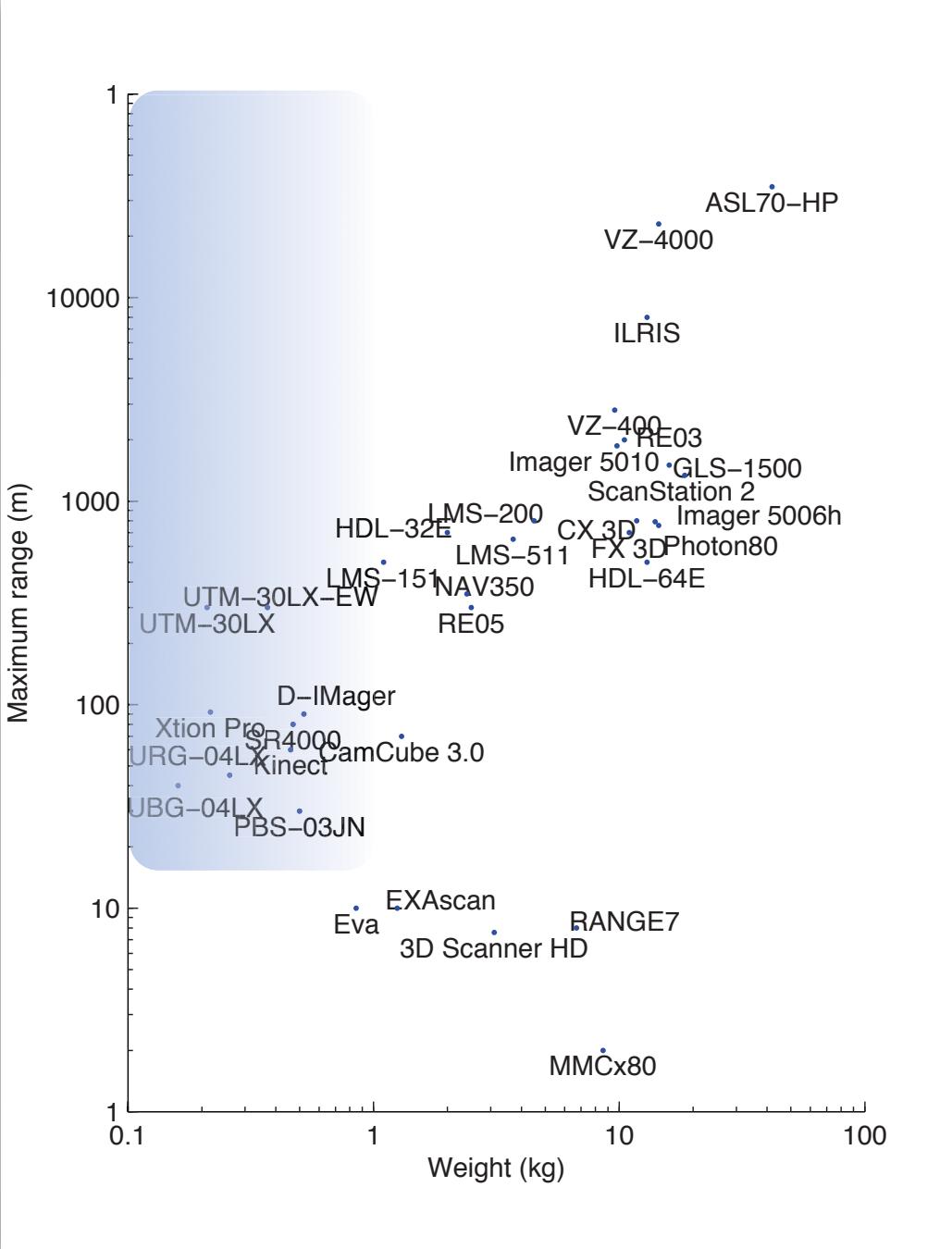
AVAILABLE SENSORS



AVAILABLE SENSORS



AVAILABLE SENSORS



SENSORS

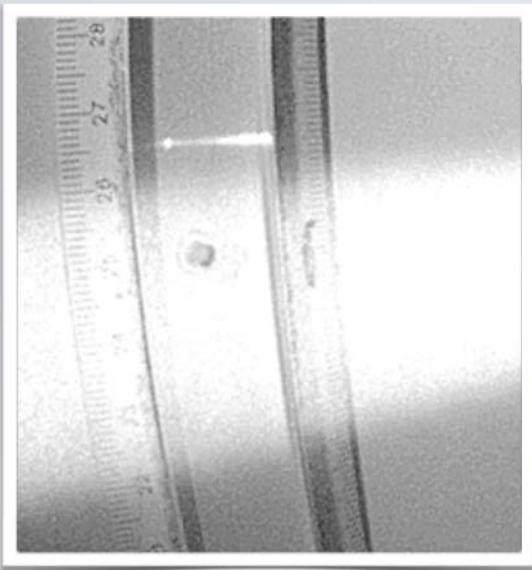
Uncertainty:

- Laser beam width
- Depth measurement
- Types of surface

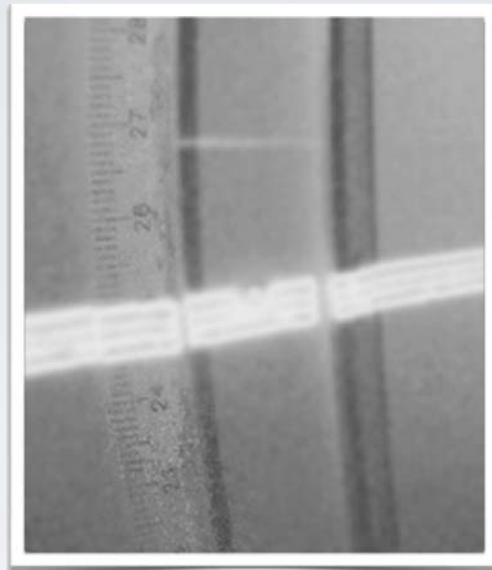
Impact on registration:

- Mixed pixels
- Point cloud density
- Sensor position

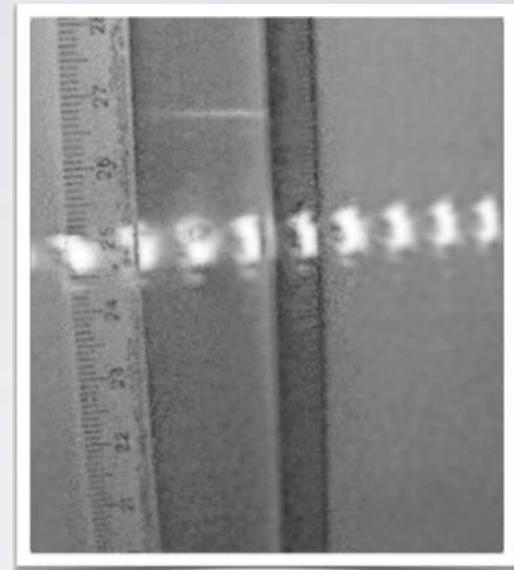
SENSOR UNCERTAINTY



LMS-151: **0.83 deg**



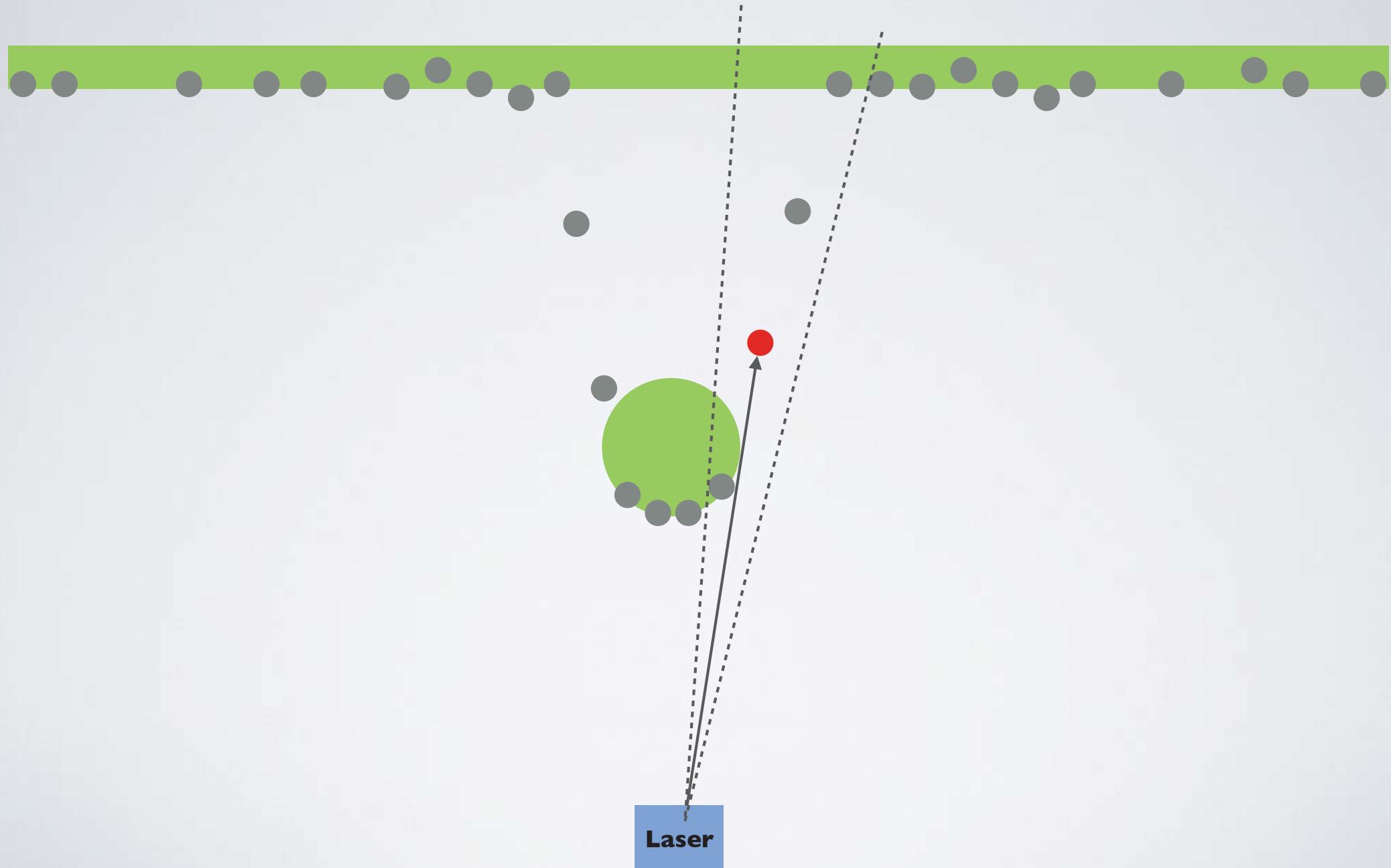
UTM-30LX: **0.13 deg**



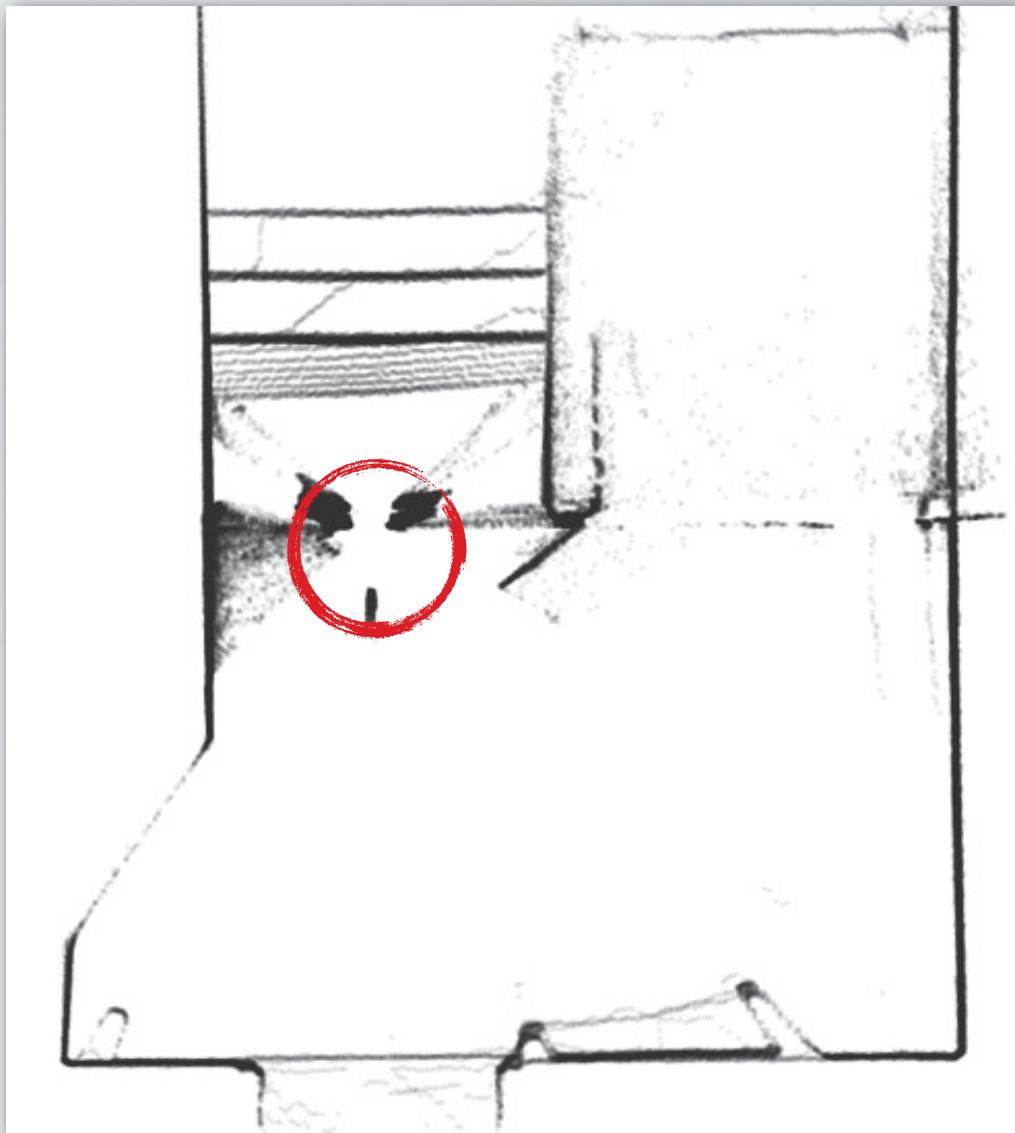
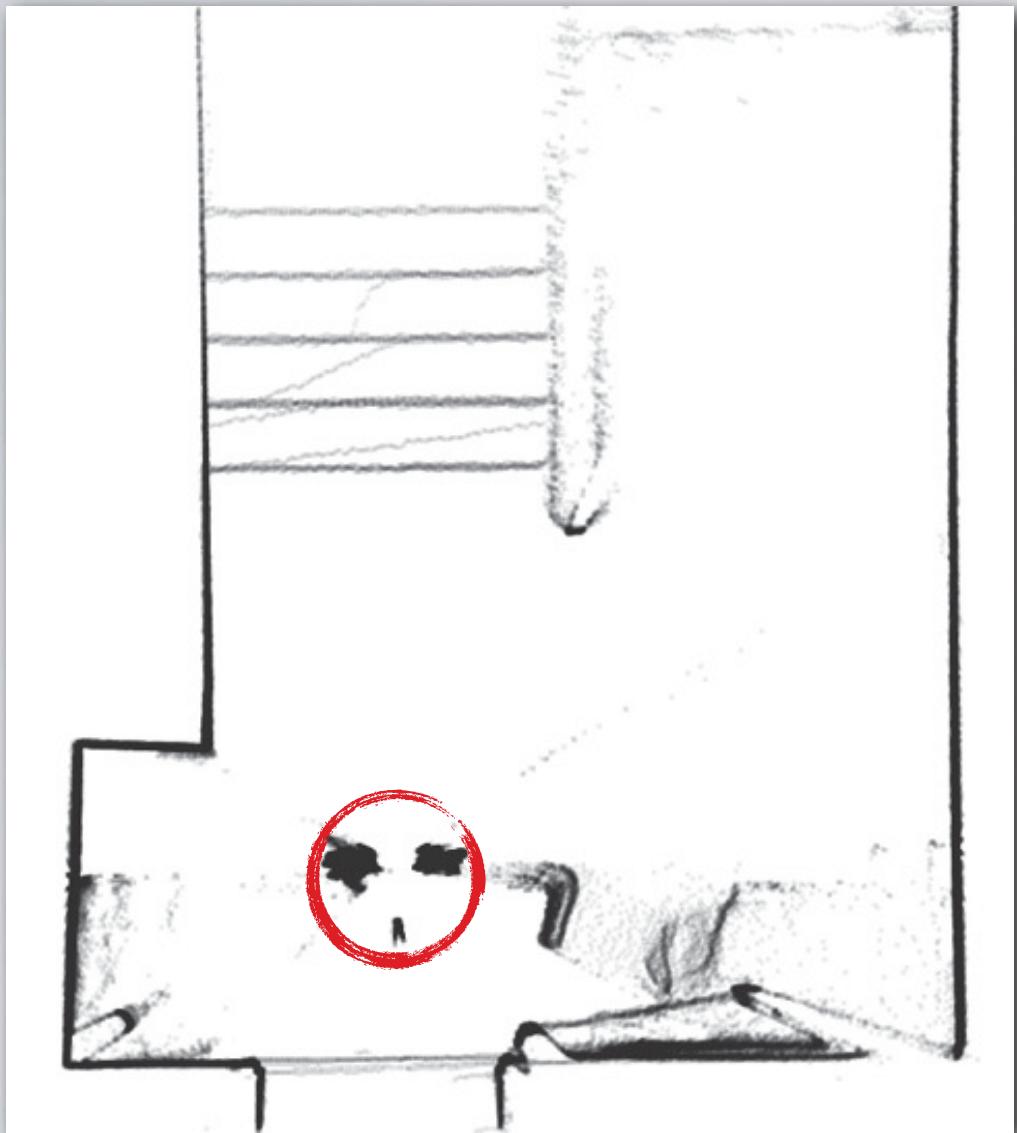
URG-04LX: **0.14 deg**



SHADOW POINT (MIXED PIXEL)



SHADOW POINT (MIXED PIXEL)



Top view of a staircase

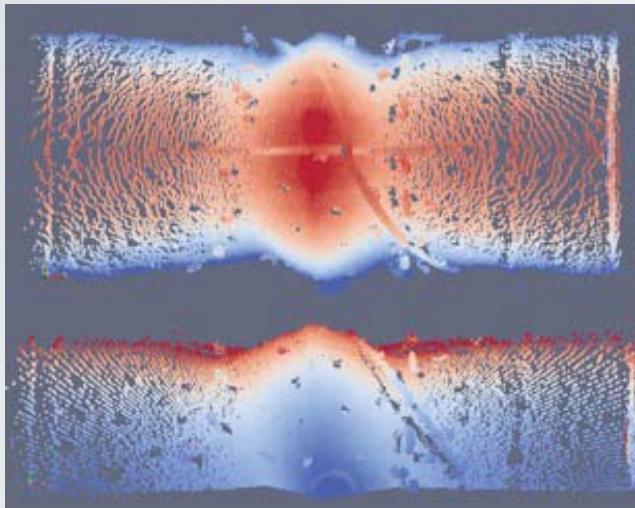
SENSOR BEAM

Impact of large beam radius:

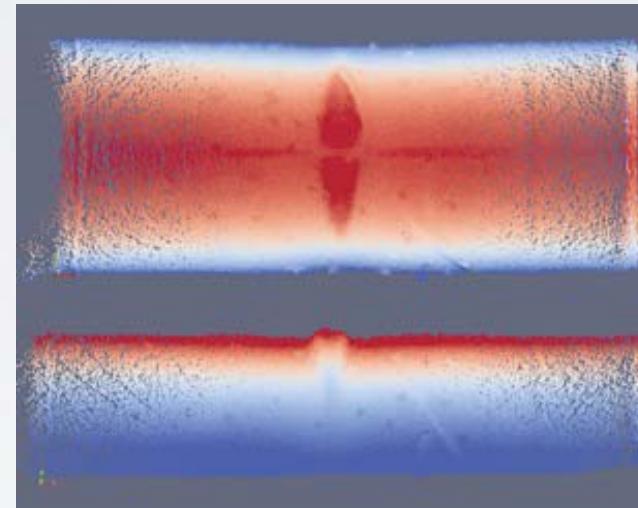
- More mixed pixels (shadow points)
- More safety (with overlap between beams)

TYPES OF SURFACE

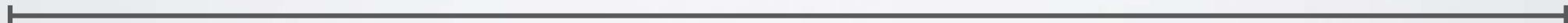
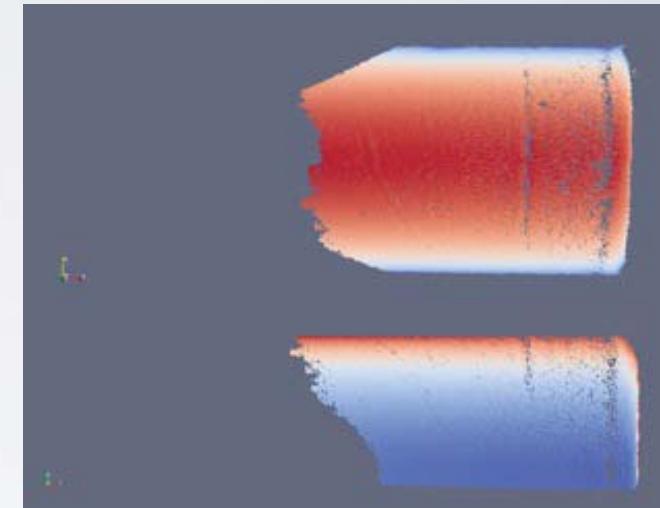
URG-04LX



UTM-30LX

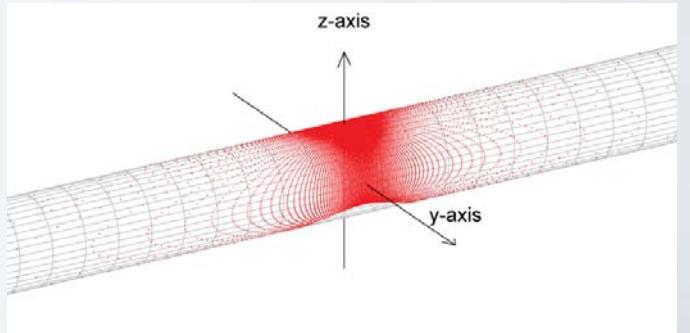
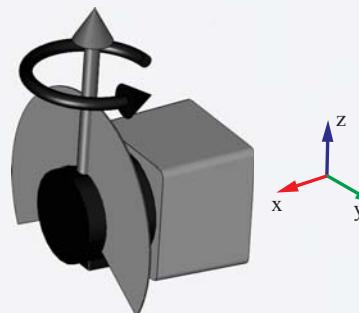
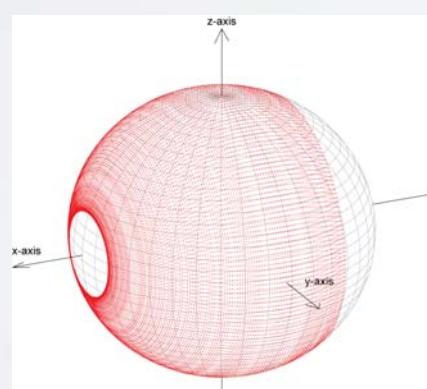
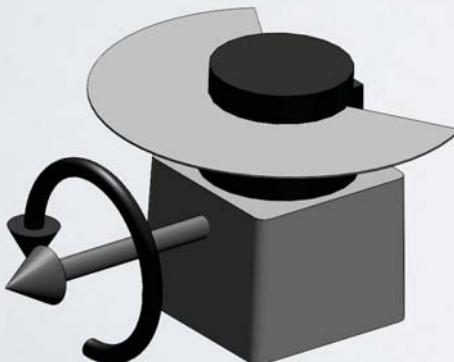
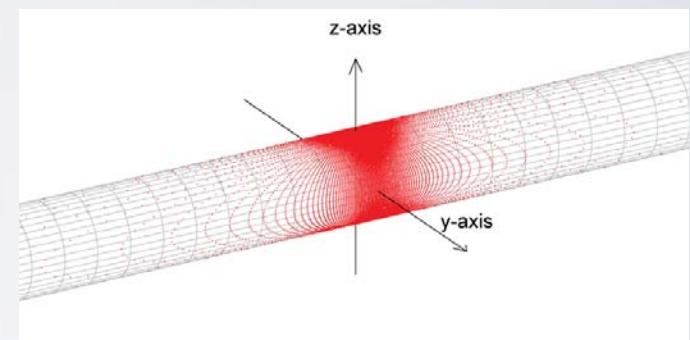
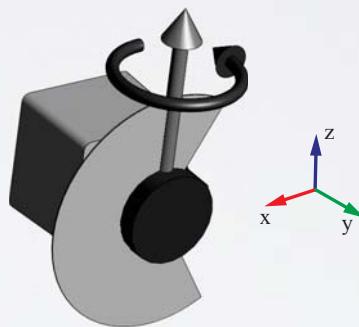
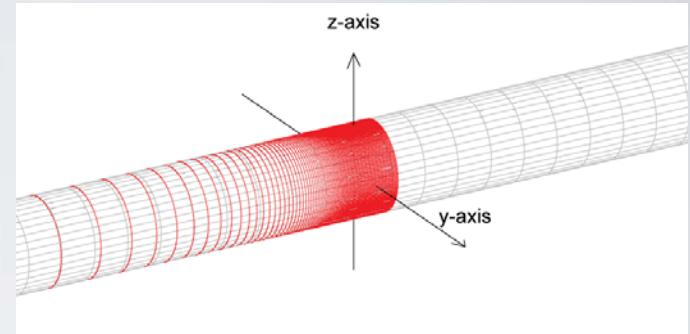
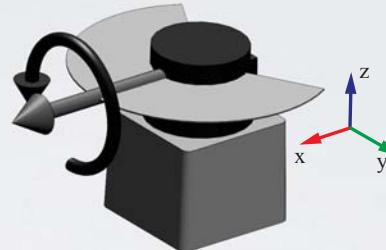
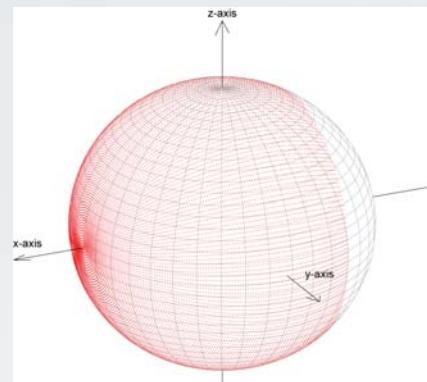
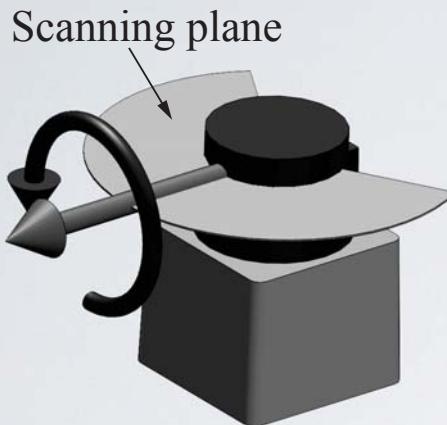


Kinect

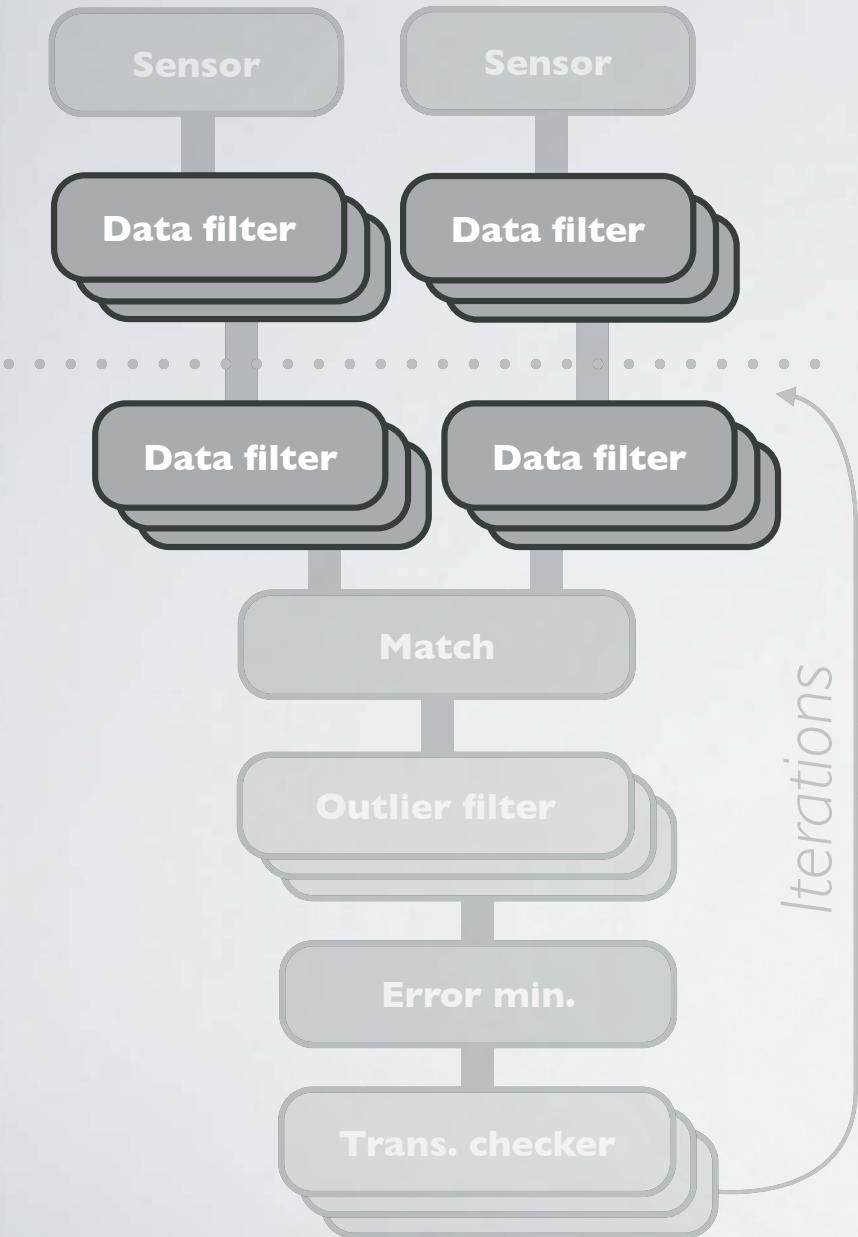


Aluminum tube

POINT CLOUD DENSITY



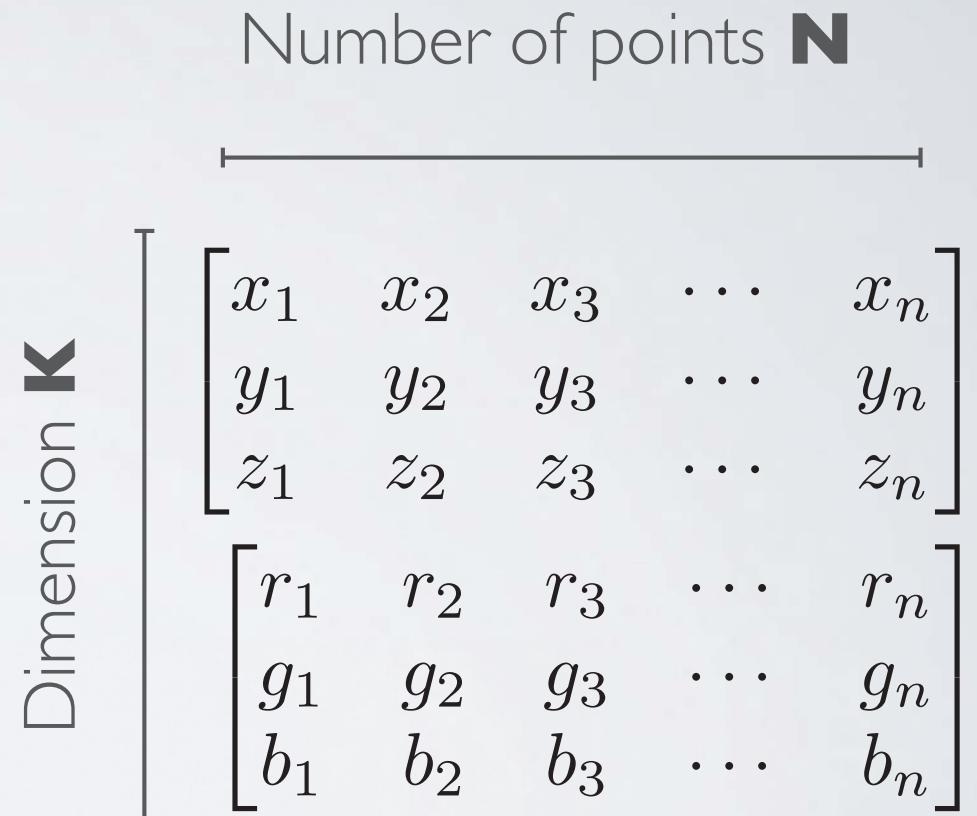
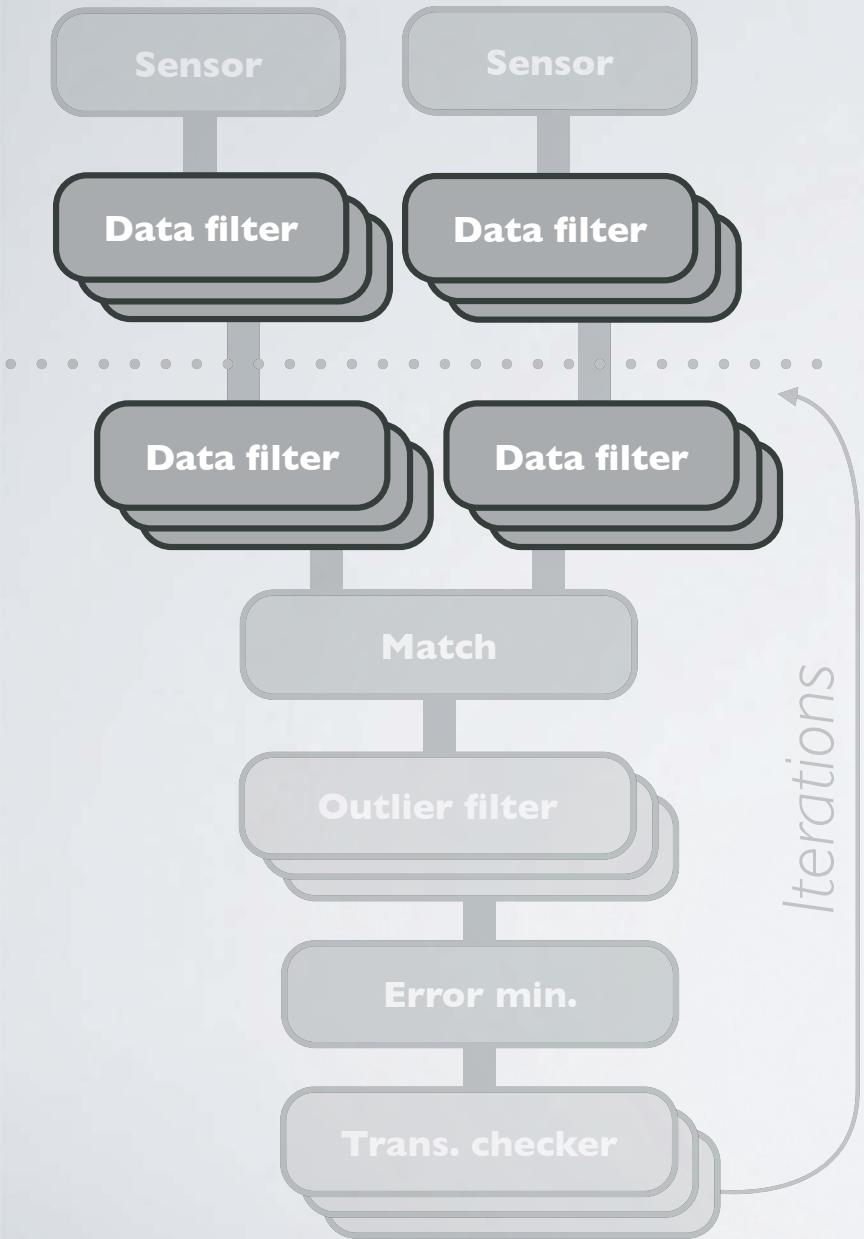
DATA FILTERS



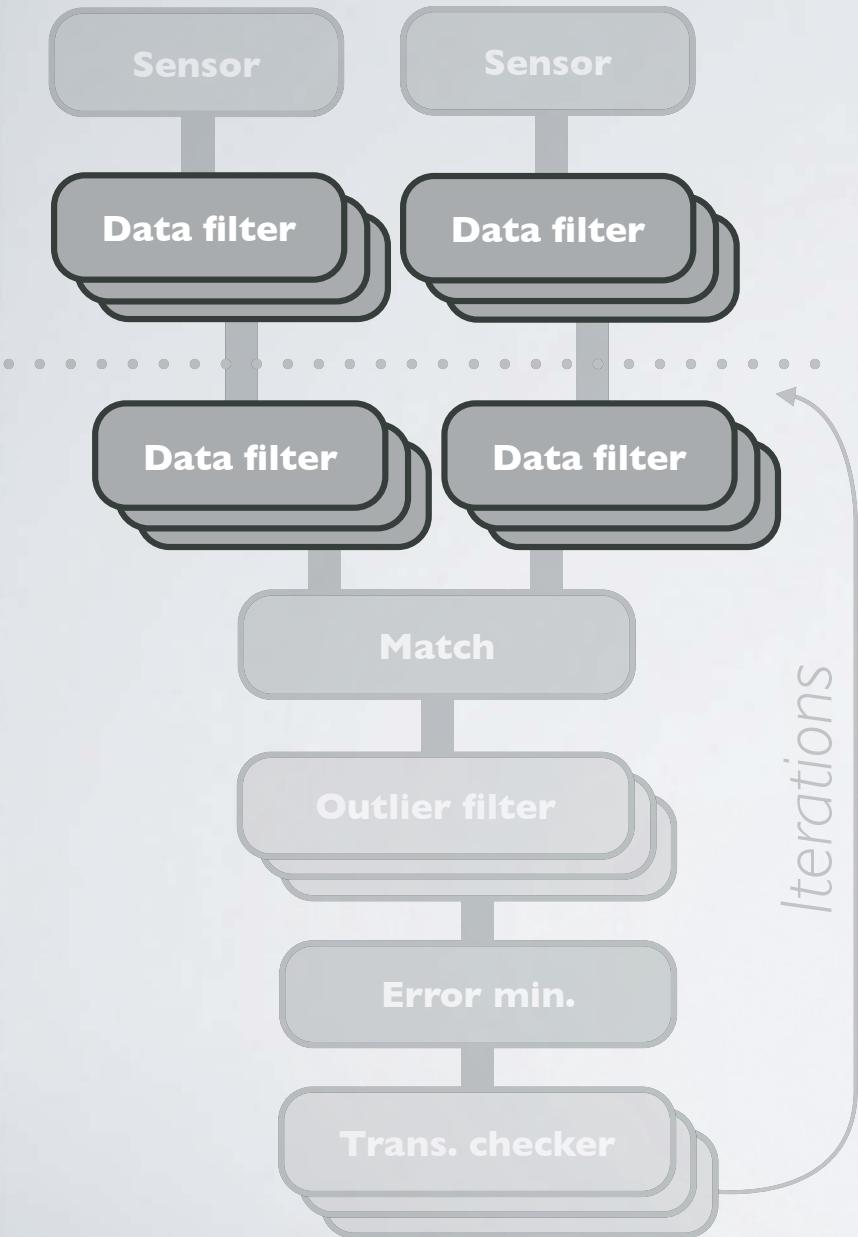
Main goals:

- Filter noise
- Reduce redundant information
- Augment discrepancy of points

DATA FILTERS



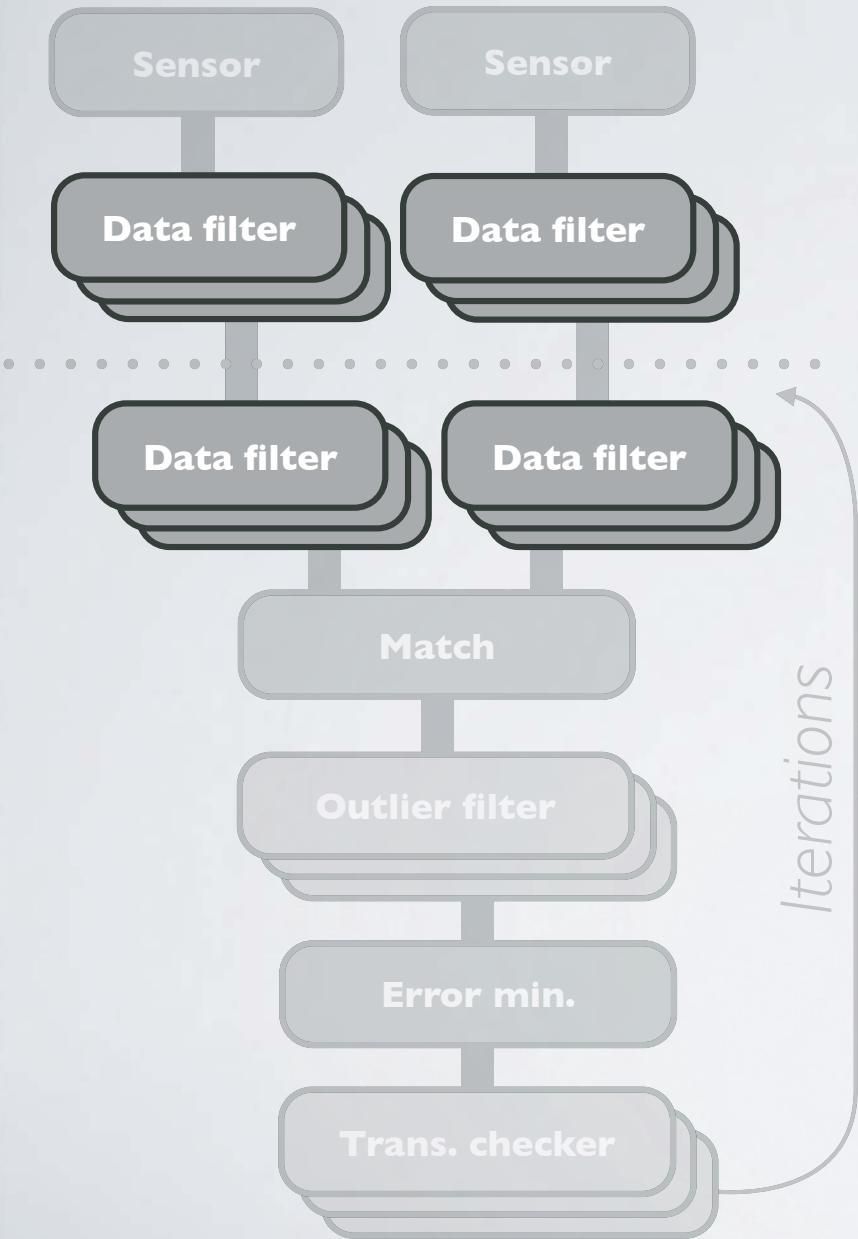
DATA FILTERS



Main goals:

- Filter noise (reduce **N**)
- Reduce redundant information (reduce **N**)
- Augment discrepancy of points (augment **K**)

DATA FILTERS



Examples:

- Point reduction
- Sensor noise weight
- Surface extraction

POINT REDUCTION

Fixed-step subsampling

- Very fast
- May generate artifact

Random subsampling

- Fast
- More control on reduction factor

Density

- Slow (needs a kD-tree)
- Reduce minimization local minima

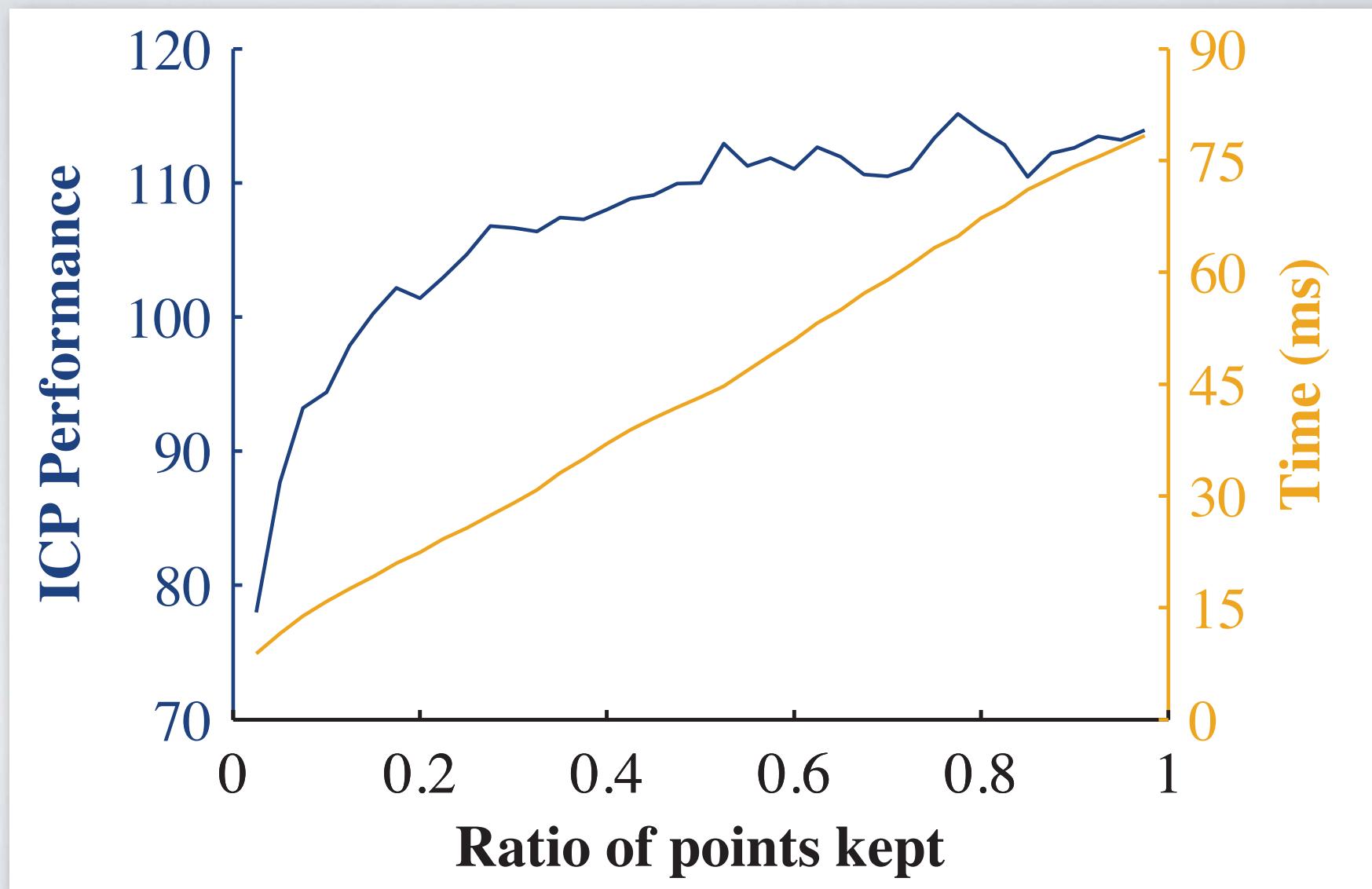
Geometric sampling [Gelfand et al. 2003]

- Very slow
- Reduce more minimization local minima

POINT REDUCTION

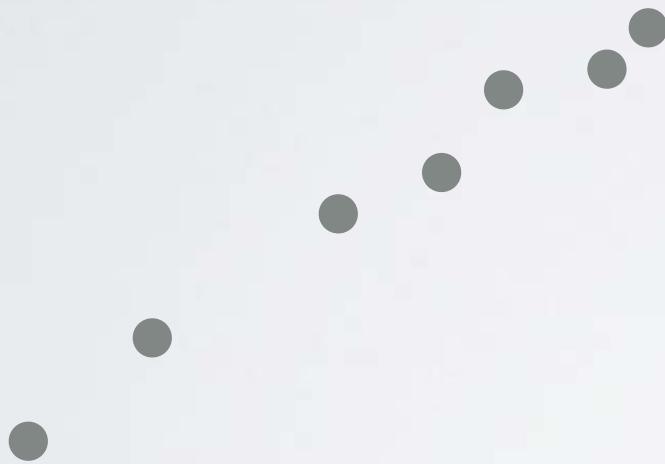
Random subsampling

$N = 40,230$



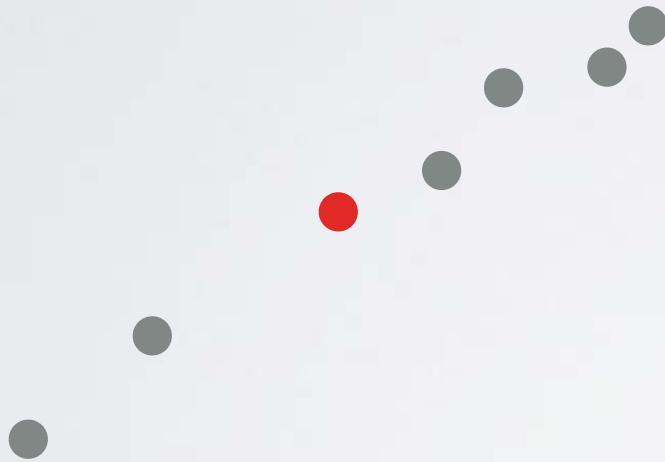
SURFACE EXTRACTION

For each point:



SURFACE EXTRACTION

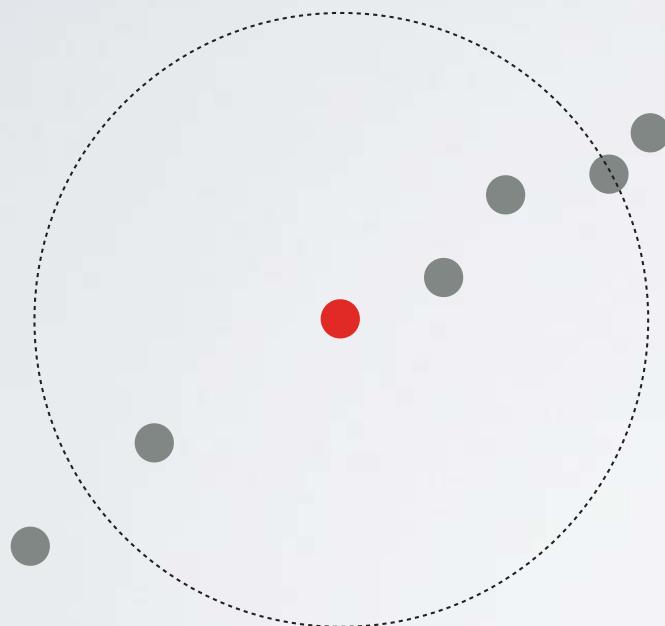
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SURFACE EXTRACTION

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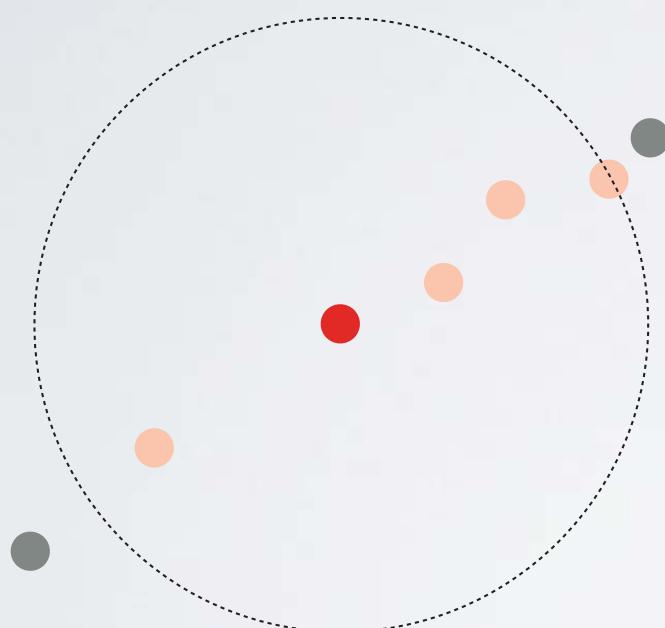
- I. Define neighborhood



SURFACE EXTRACTION

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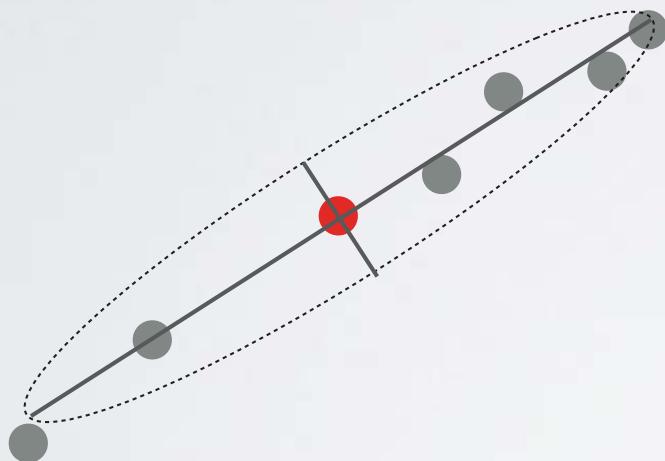
1. Define neighborhood
2. Subtract “center”



SURFACE EXTRACTION

For each point:

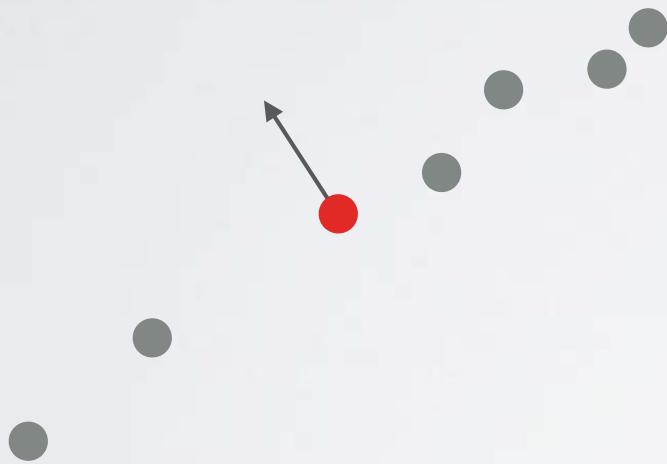
1. Define neighborhood
2. Subtract “center”
3. Eigen value decomposition



SURFACE EXTRACTION

For each point:

1. Define neighborhood
2. Subtract “center”
3. Eigen value decomposition
4. Select the Eigenvector
associated with the smallest
Eigenvalue



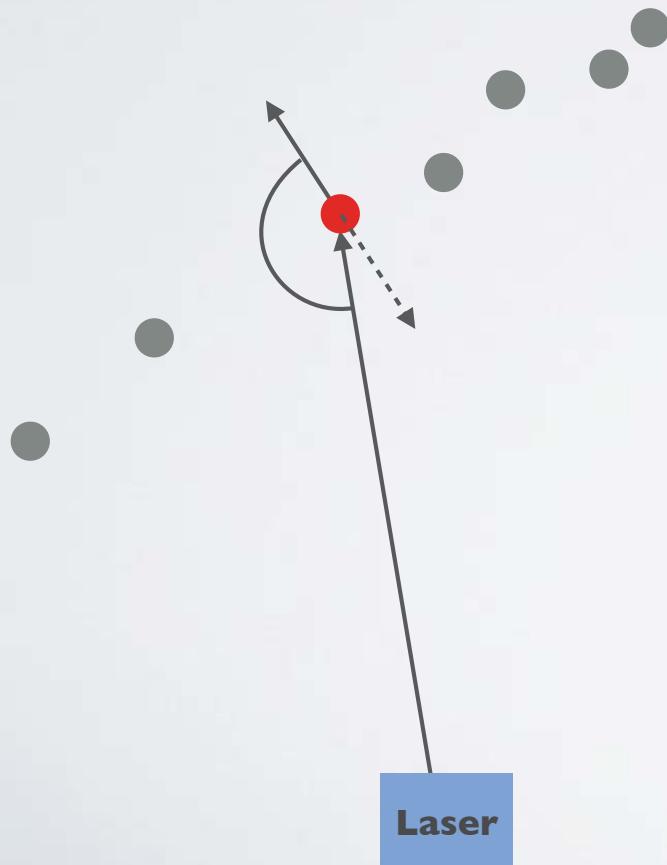
SURFACE EXTRACTION

For each point:

1. Define neighborhood
2. Subtract “center”
3. Eigen value decomposition
4. Select the Eigenvector associated with the smallest Eigenvalue

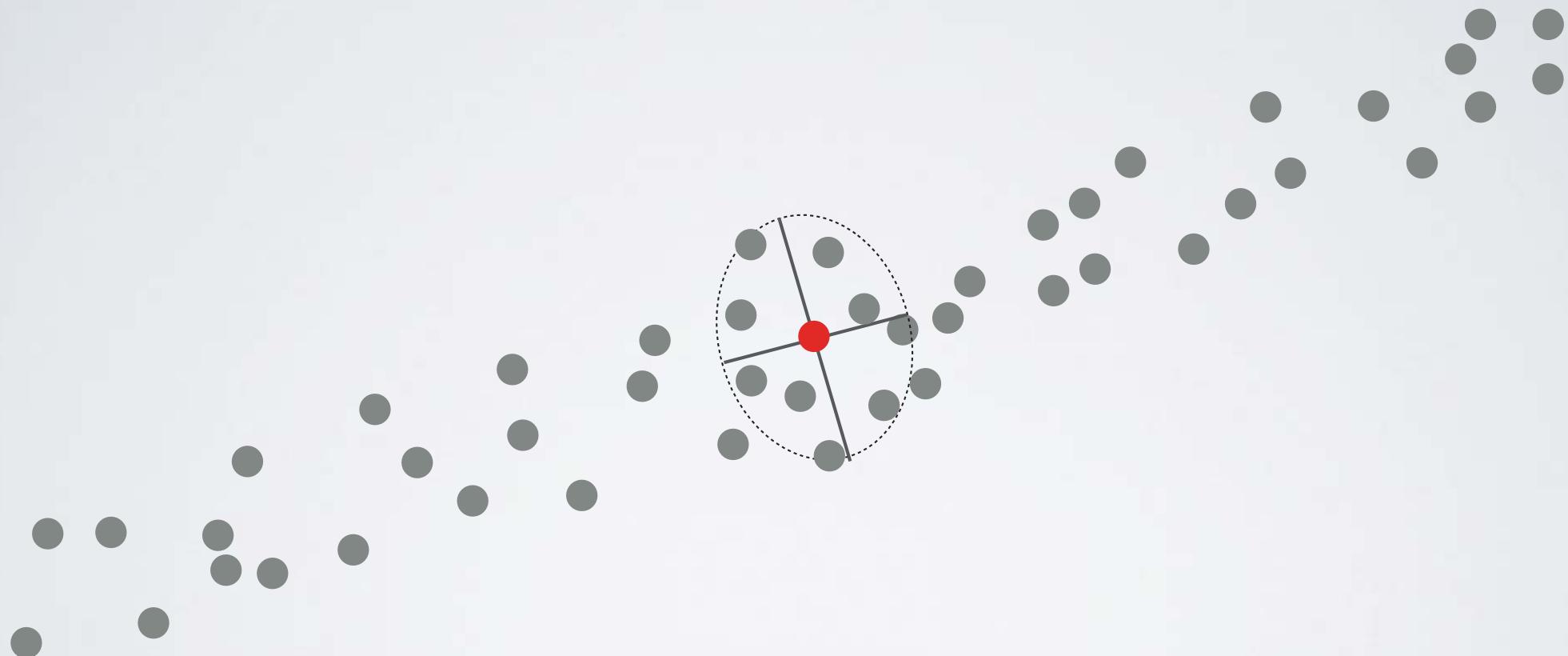
Bonus

- Reorient the vector

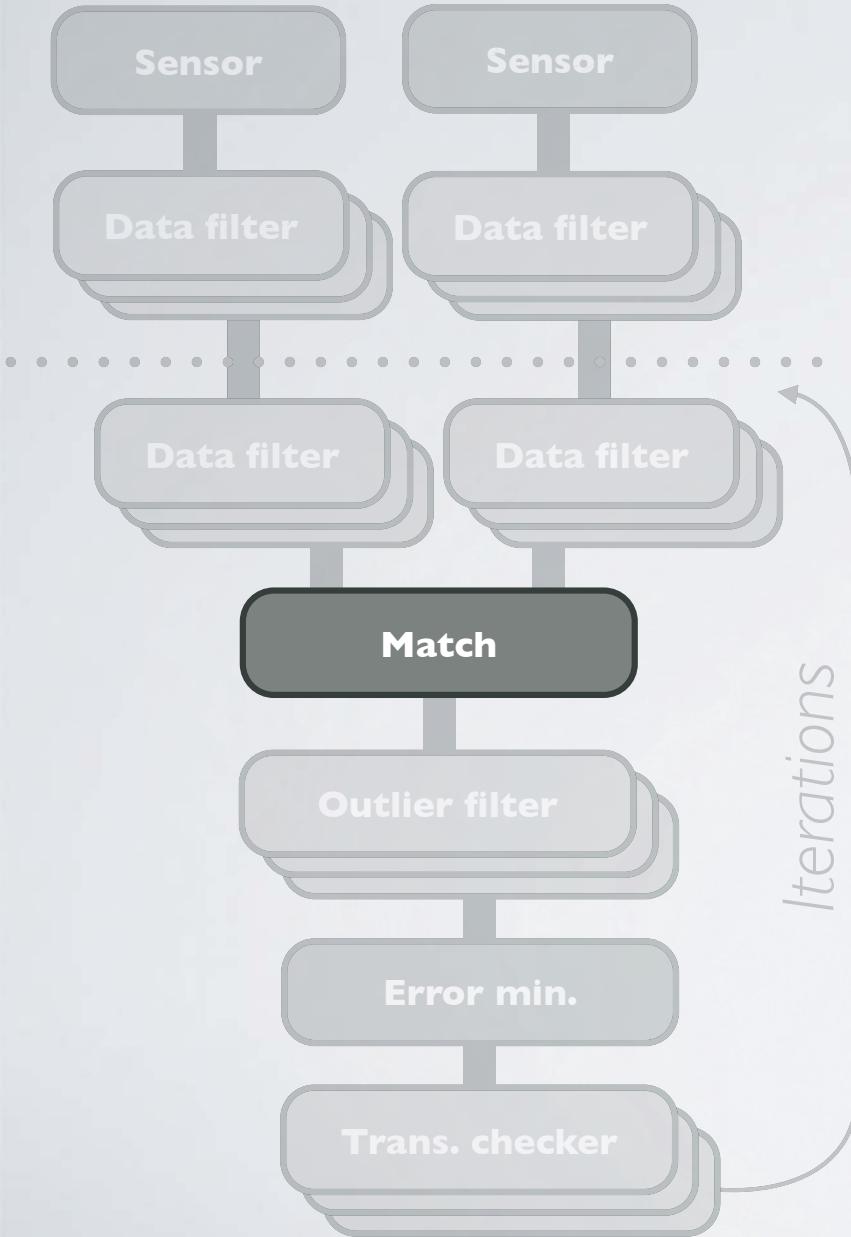


SURFACE EXTRACTION

Impact of the environment...



MATCHING



Main goal:

- Augment robustness to misalignment

MATCHING

Match direction:

- From reading to reference
- From reference to reading
- Both direction

MATCHING

Match direction:

- From reading to reference
- From reference to reading
- Both direction

Number of matches

- one to one (typical)
- one to many (slower but more robust)

MATCHING

Match direction:

- From reading to reference
- From reference to reading
- Both direction

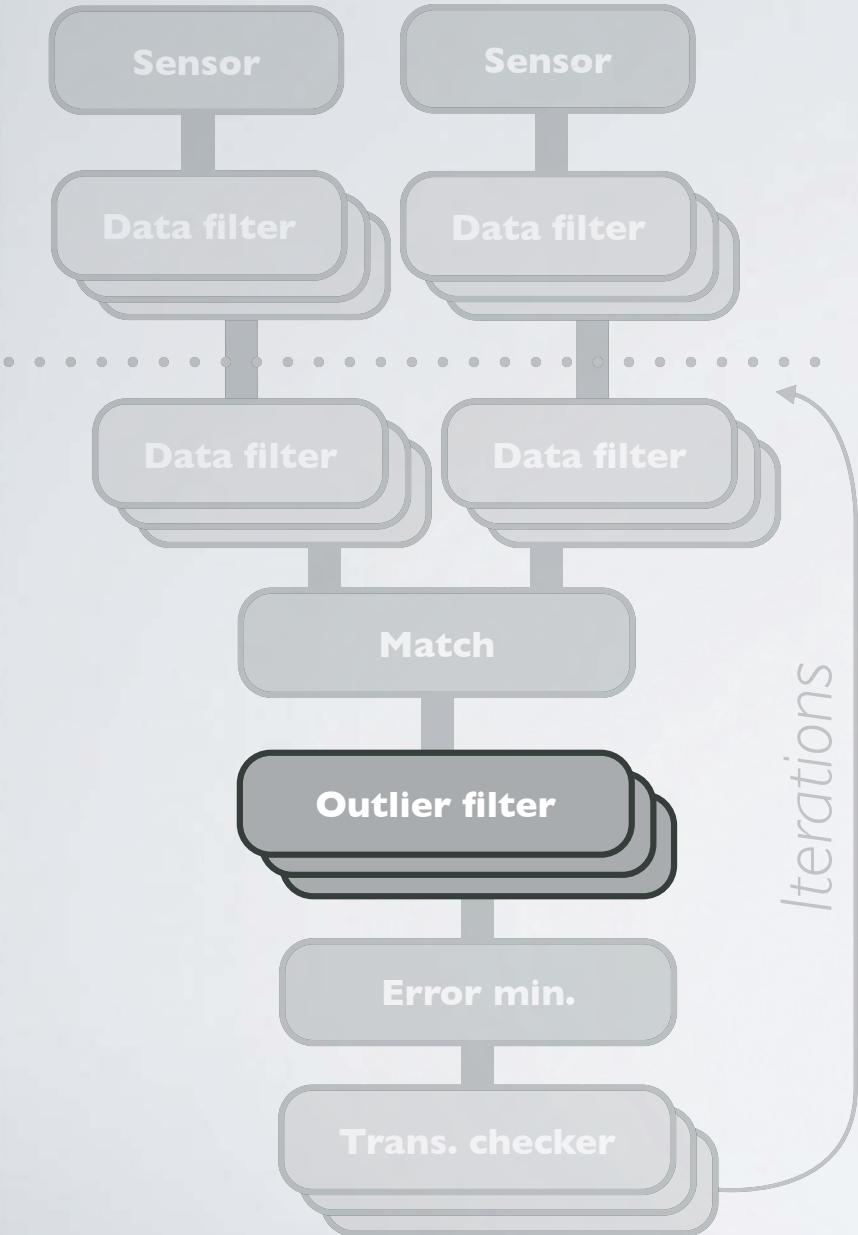
Number of matches

- one to one (typical)
- one to many (slower but more robust)

Metric

- kD-tree
- Euclidian distance on points
 - Euclidian distance on points and descriptors
 - Euclidian distance on descriptors
 - Mahalanobis distance
 - Probabilistic distance (entropy)
 - Others

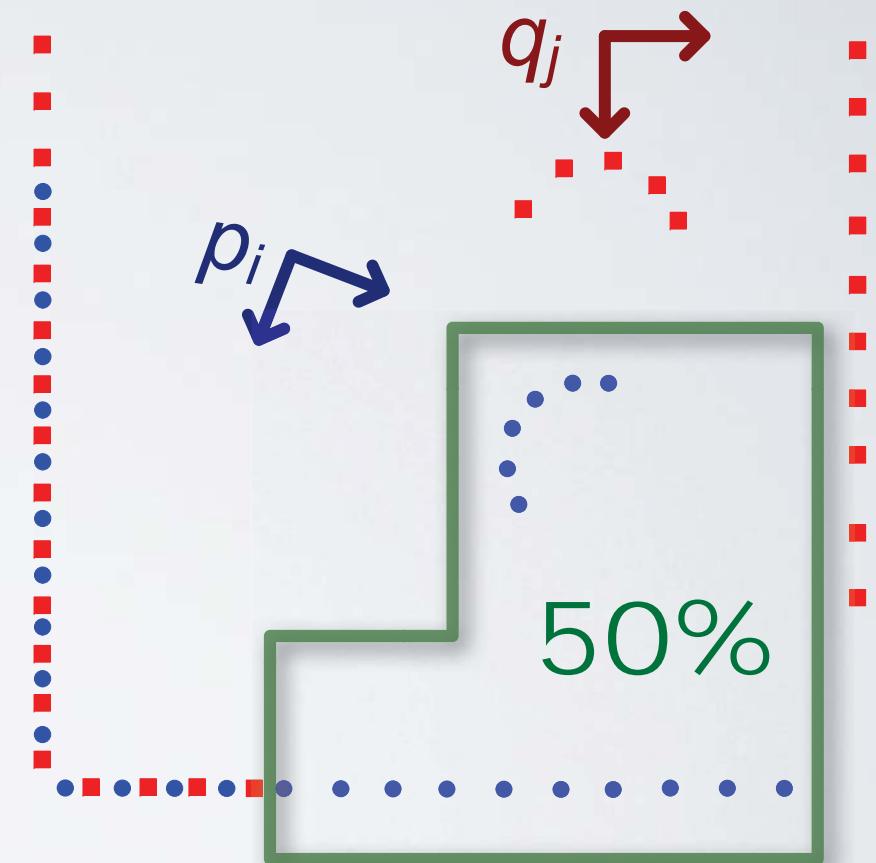
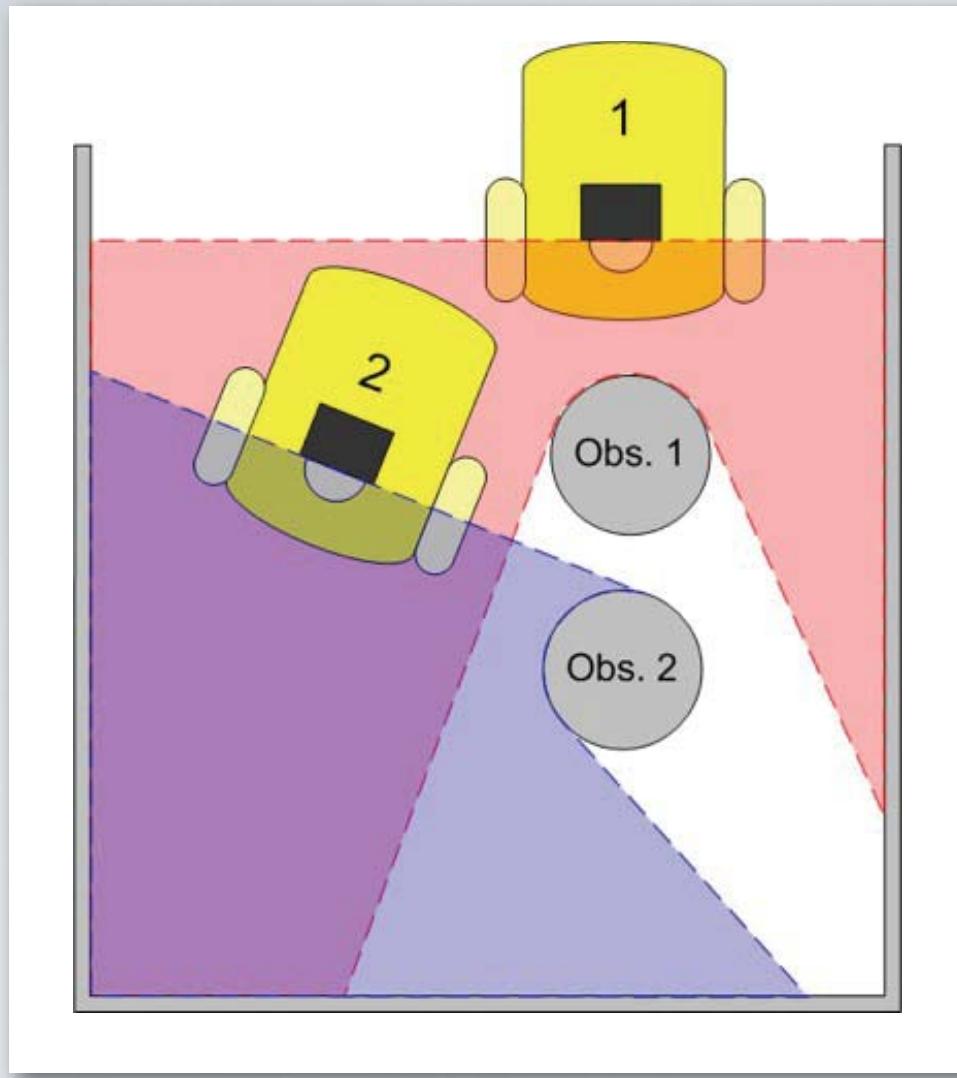
ROBUST REGRESSION



Main goal:

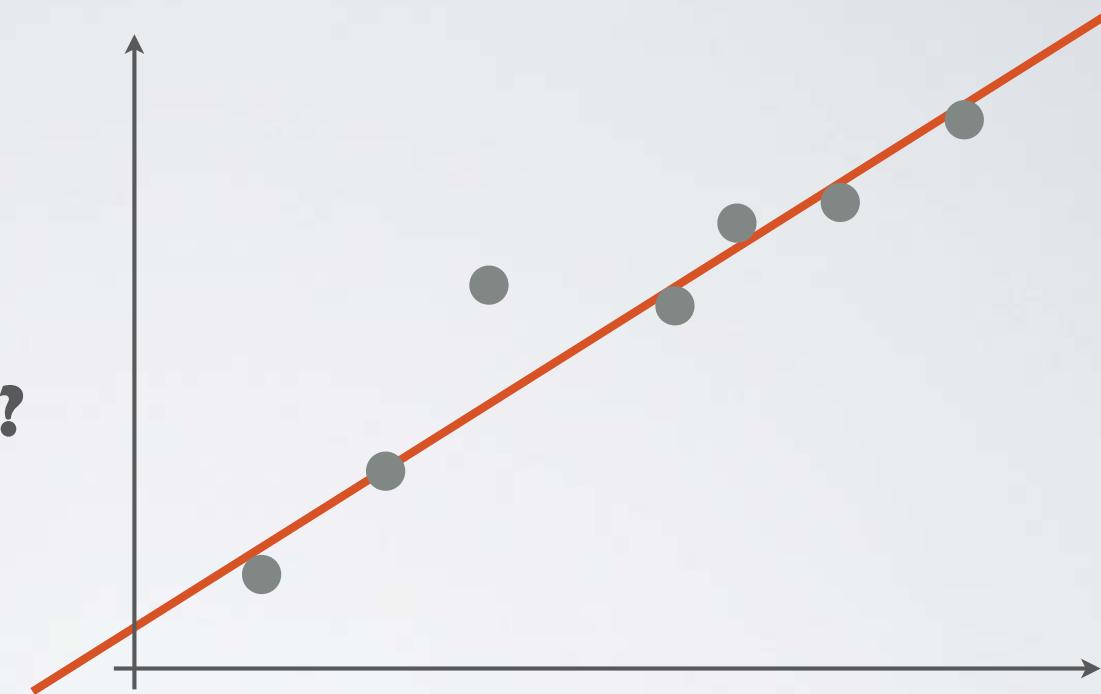
- Augment robustness to overlap
- Augment robustness to noise
- Augment robustness to dynamic elements

ROBUST REGRESSION



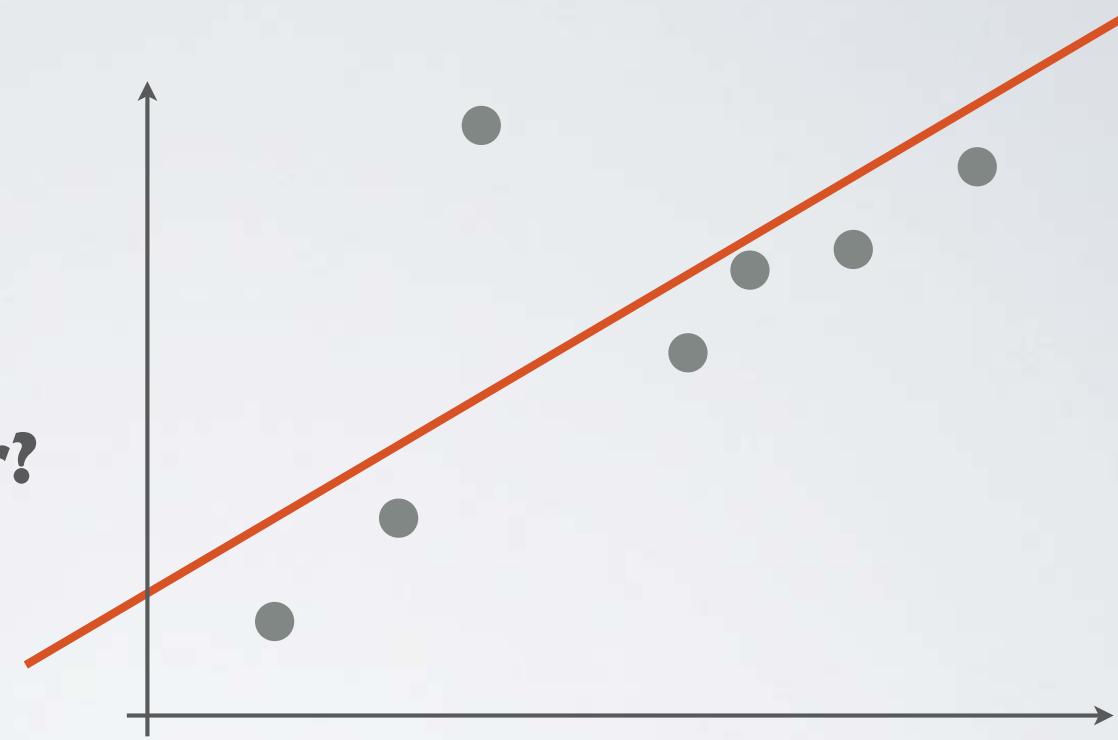
ROBUST REGRESSION

**Why mean
least-squared is
sensible to outlier?**



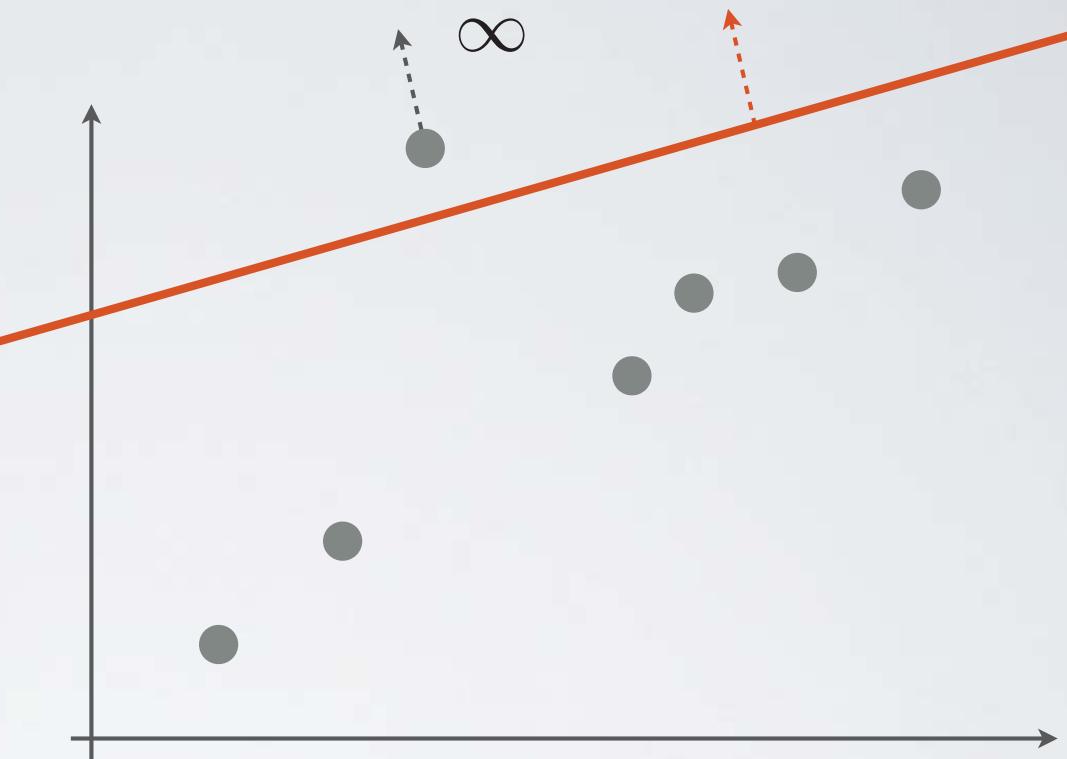
ROBUST REGRESSION

**Why mean
least-squared is
sensible to outlier?**



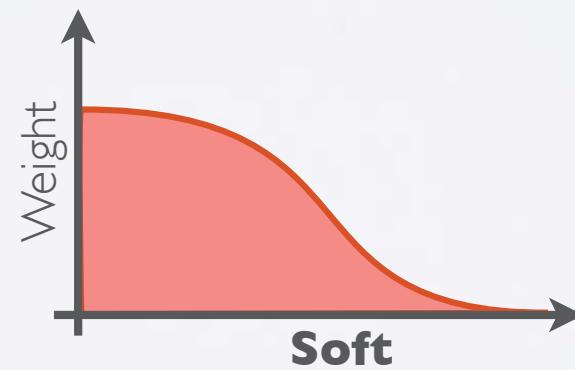
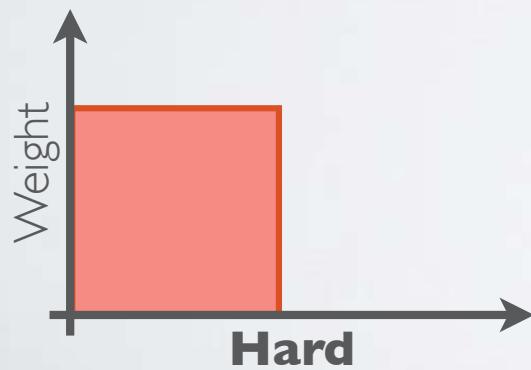
ROBUST REGRESSION

**Why mean
least-squared is
sensible to outlier?**



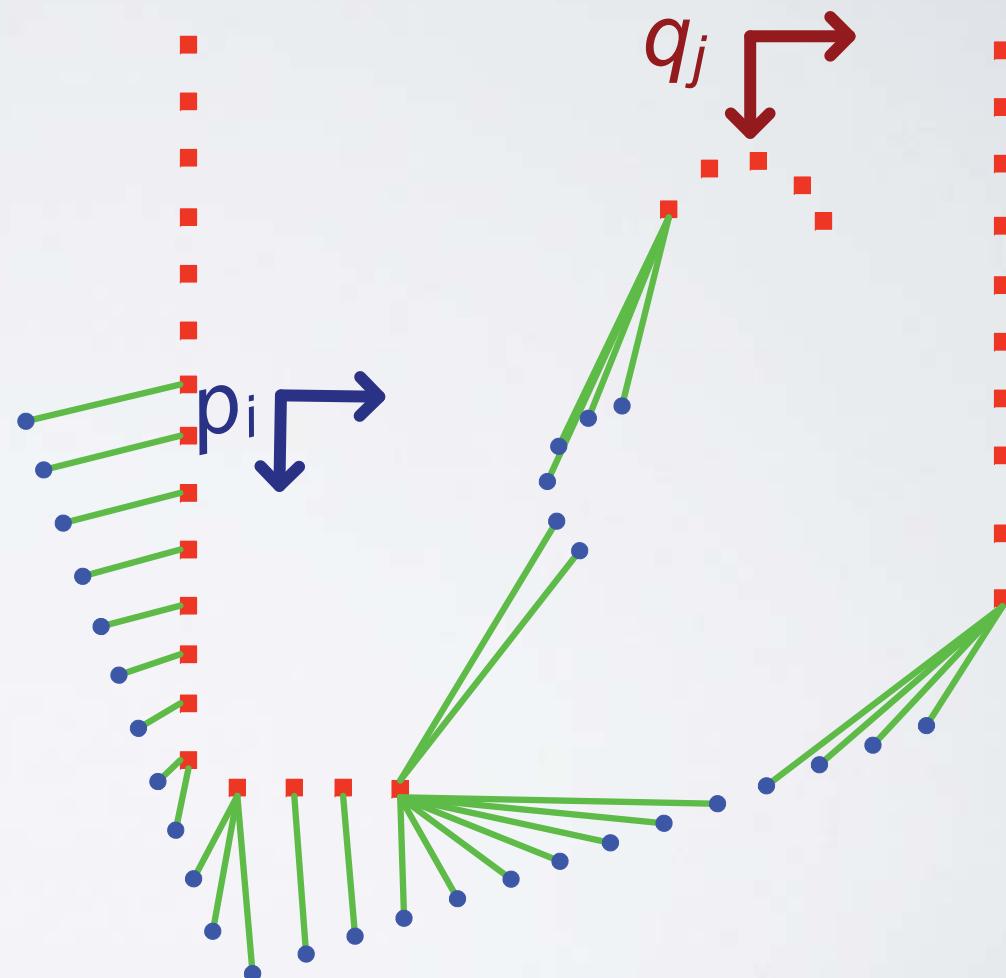
ROBUST REGRESSION

Why mean least-squared is sensible to outlier?



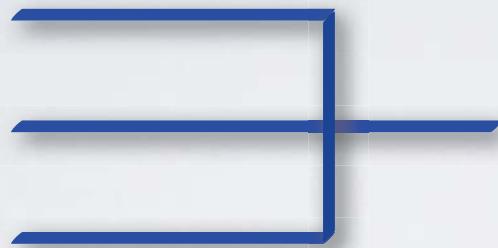
REJECTION

- Fix
- Zhang (*Zhang 94*)
- Mean (*Druon 06*)
- Median (*Diebel 04*)
- Trimmed (*Chetverikov 02*)

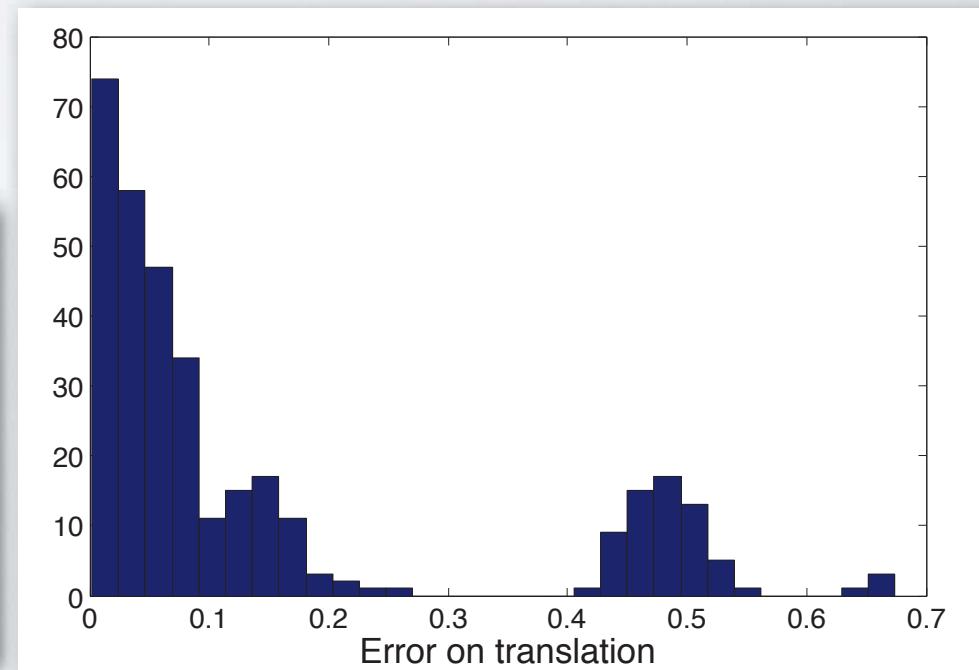
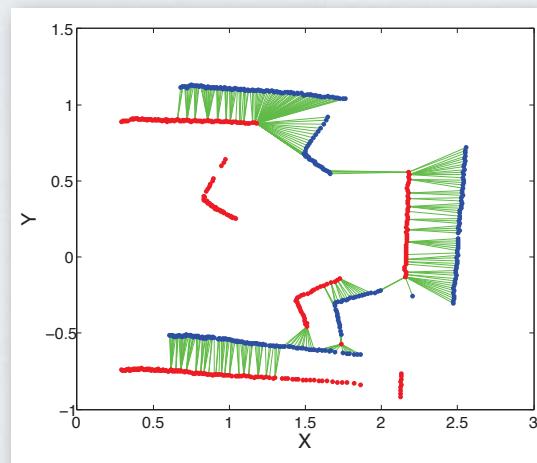


REJECTION

- Fix
- Zhang
- Mean
- Median
- Trimmed

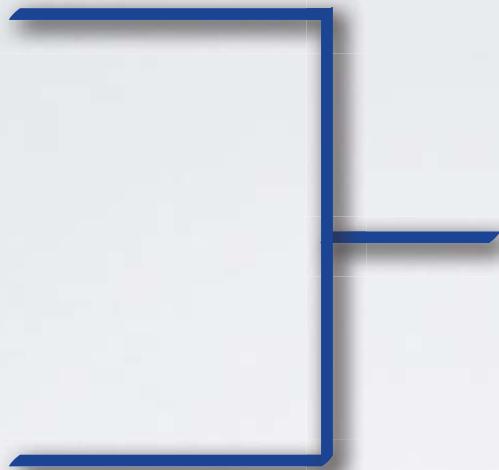


Assume unimodal distribution

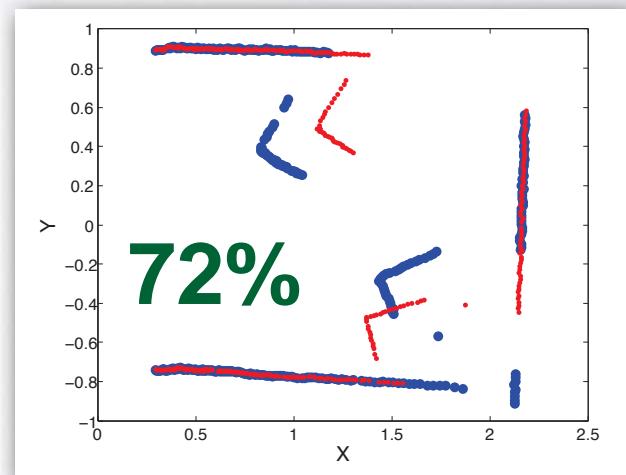
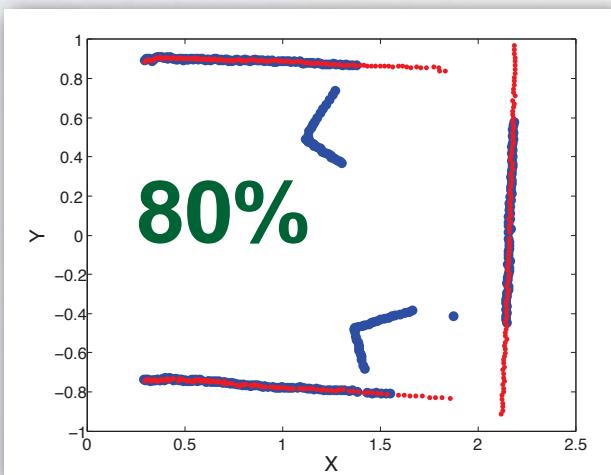


REJECTION

- Fix
- Zhang
- Mean
- Median
- Trimmed



Assume few variation in overlapping ratio



REJECTION

- Fix
- Zhang
- Mean
- Median
- Trimmed

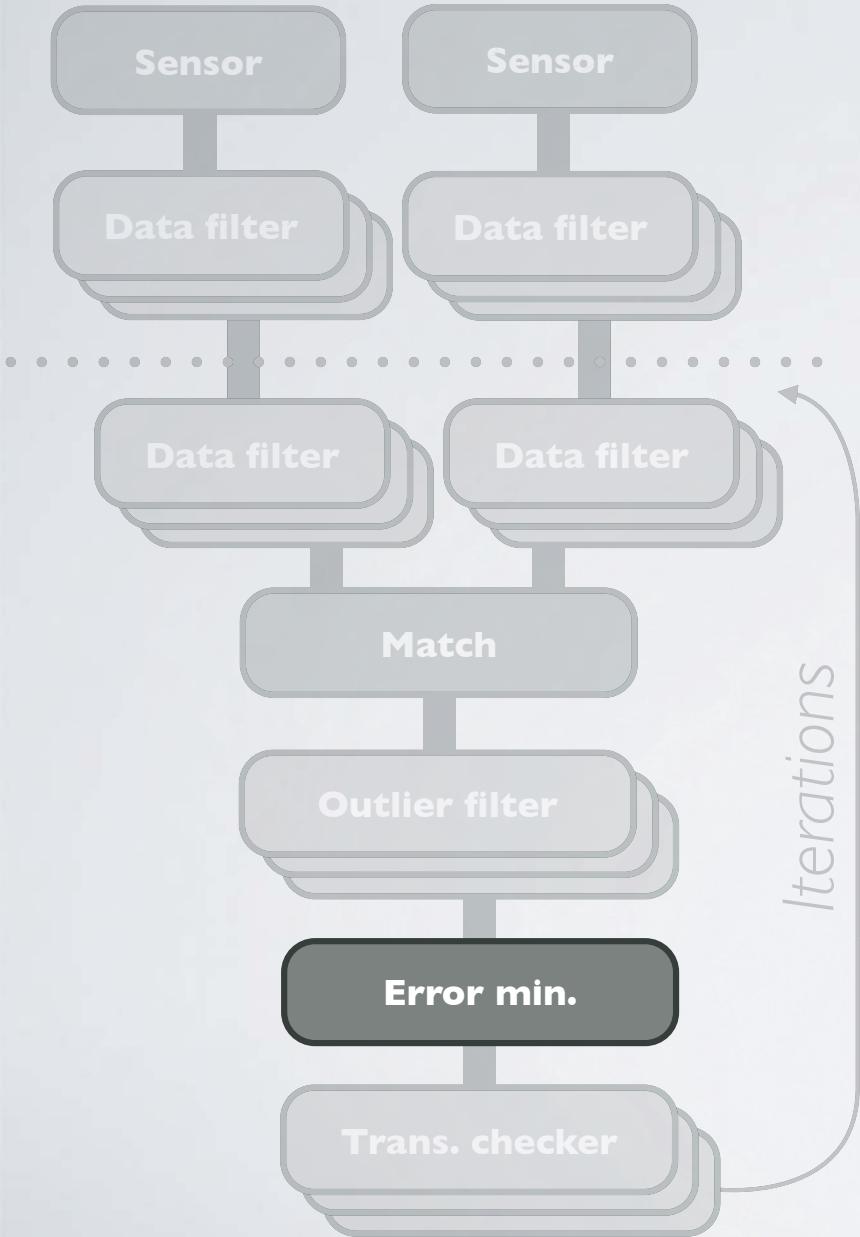


Require sorting

REJECTION

- Fix
 - Zhang
 - Mean
 - Median
 - Trimmed
-
- Probabilistic (*Feldmar 96*) (*Phillips 07*)
 - RANSAC (*Arun 87*)

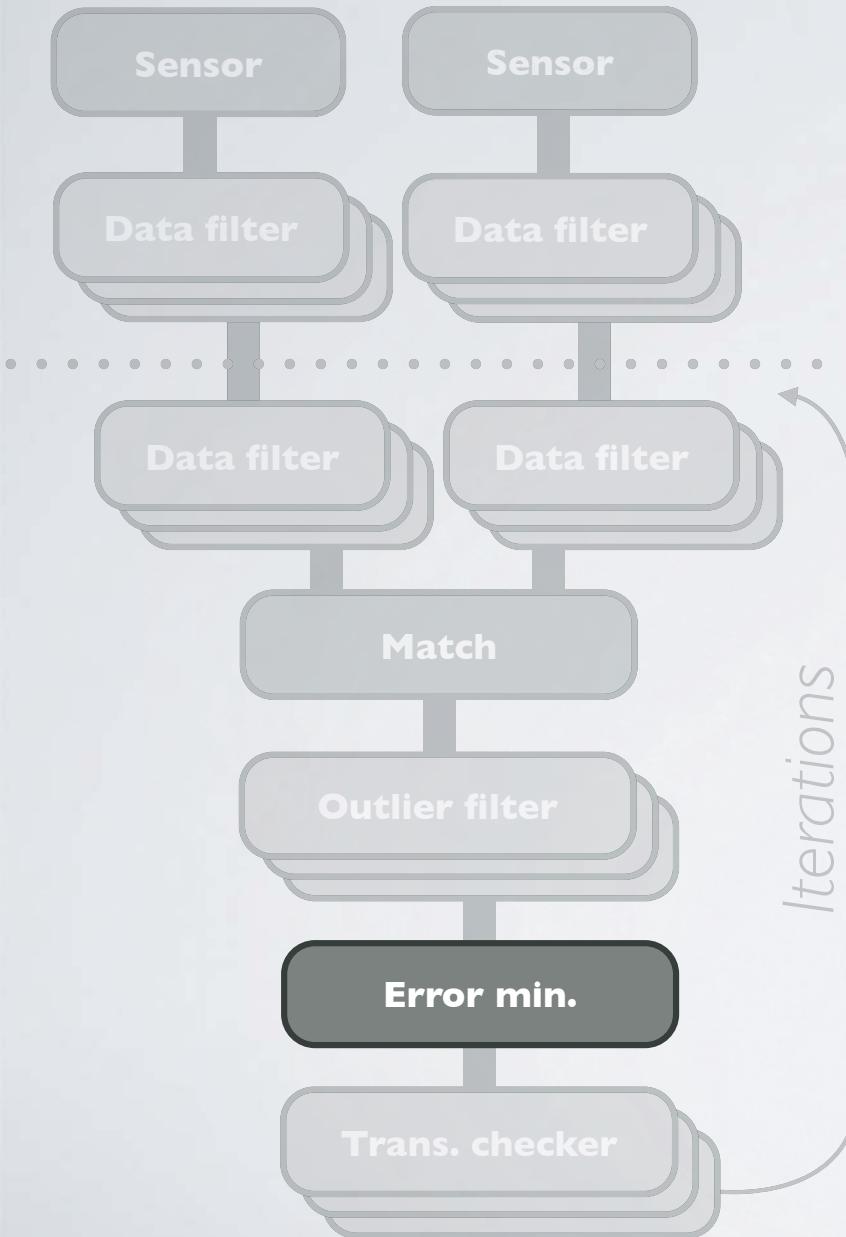
MINIMIZATION



Main goal:

- Rapid convergence
- Well constrained

MINIMIZATION

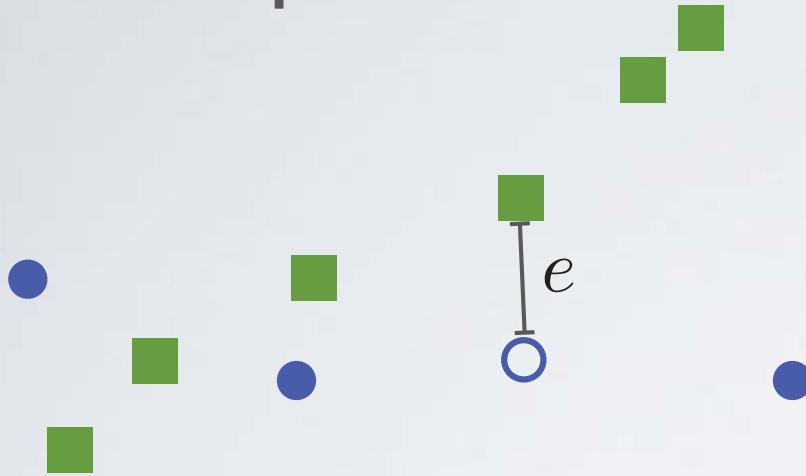


Error metrics:

- Point-to-point
 - Point-to-plane
 - and many more...

MINIMIZATION

Point-to-point



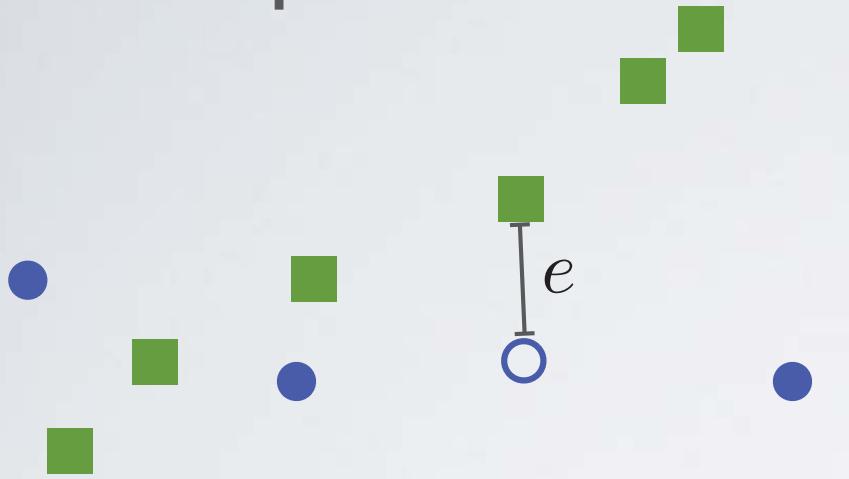
$$\sum_{i=0}^N \|\hat{T} * p_i - q_i\|^2$$

Besl and McKay [1992]

Walker et al. [1991] Horn [1987] Arun et al. [1987]

MINIMIZATION

Point-to-point

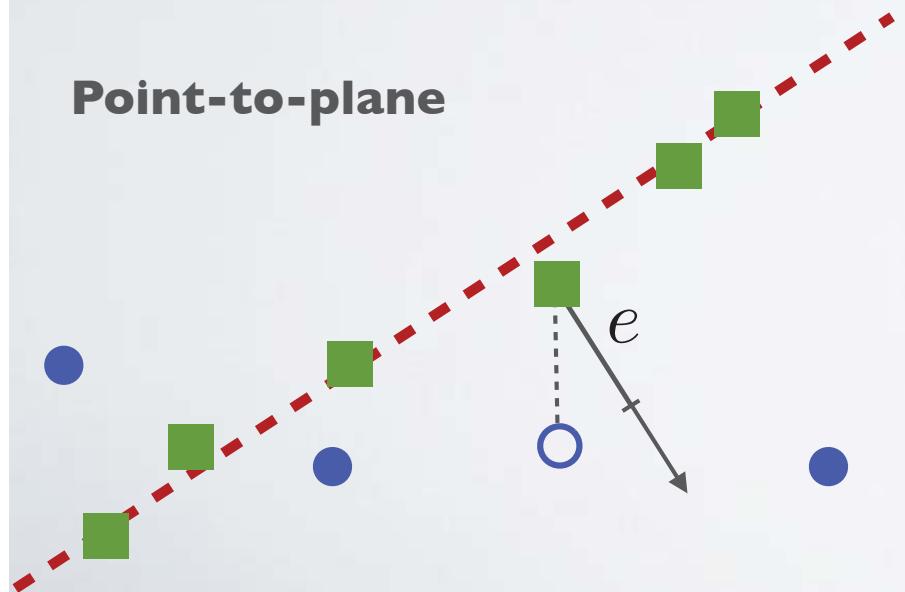


$$\sum_{i=0}^N \|\hat{T} * p_i - q_i\|^2$$

Besl and McKay [1992]

Walker et al. [1991] Horn [1987] Arun et al. [1987]

Point-to-plane

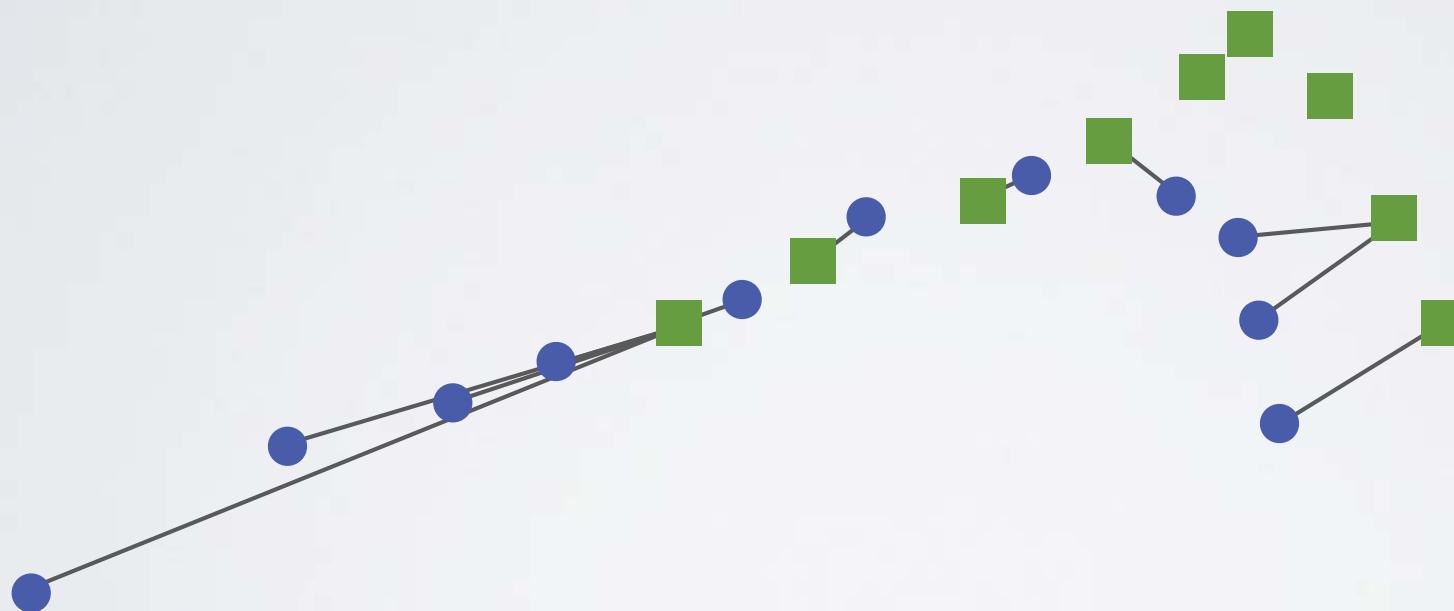


$$\sum_{i=0}^N \|\hat{T} * (p_i - q_i) \cdot n_i\|^2$$

Chen and Medioni [1992]

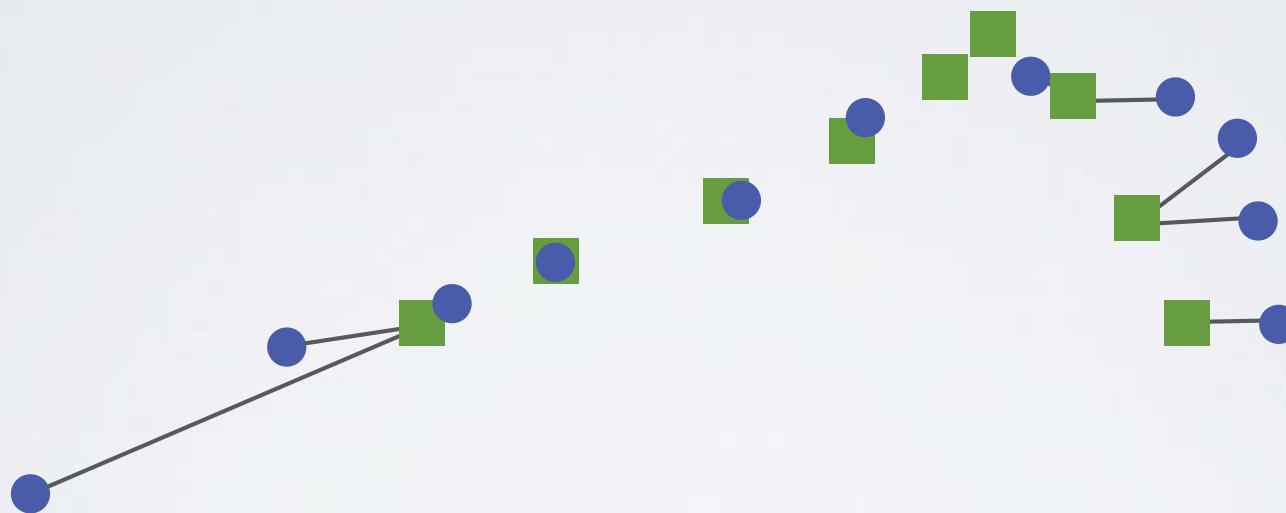
MINIMIZATION

Sliding situation



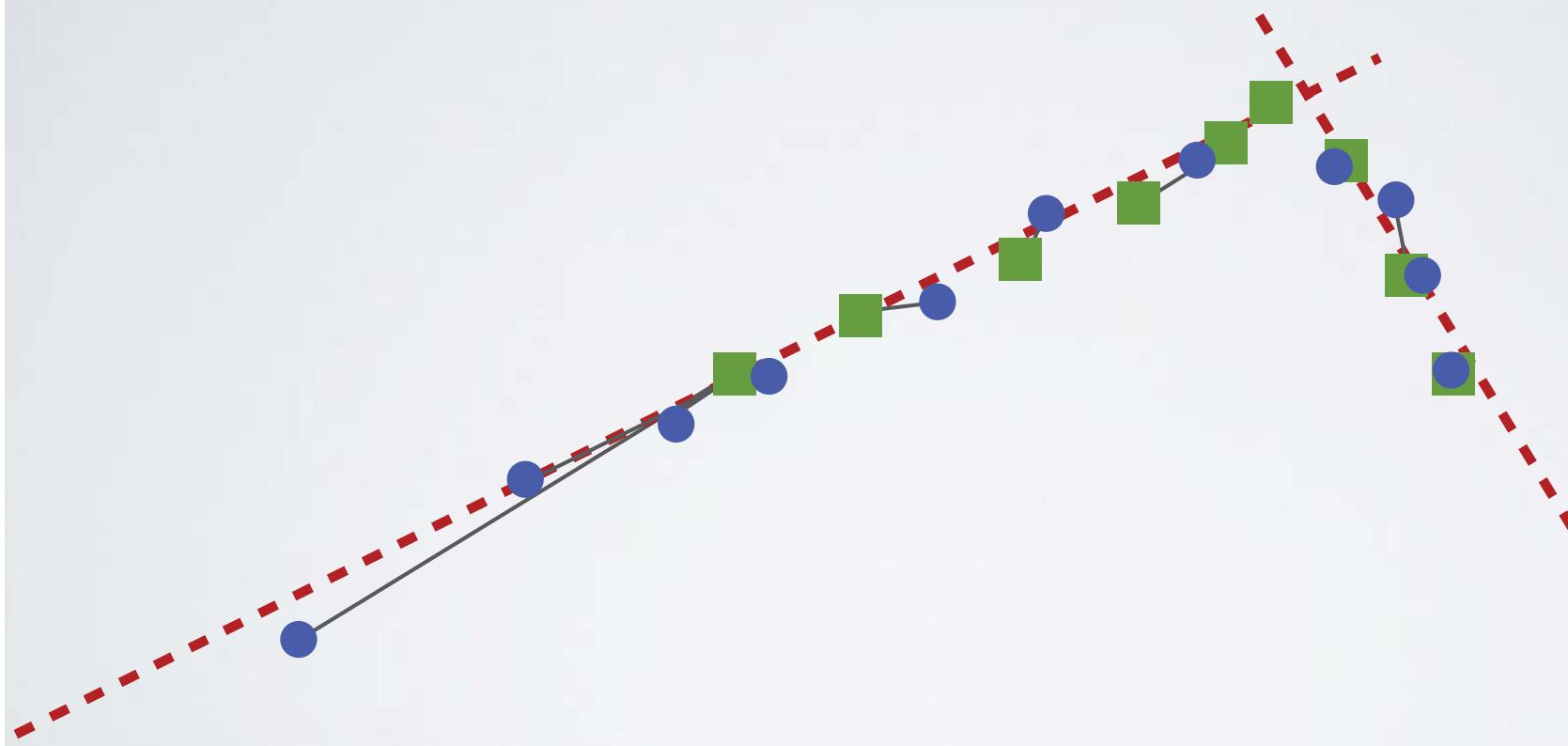
MINIMIZATION

Point-to-point

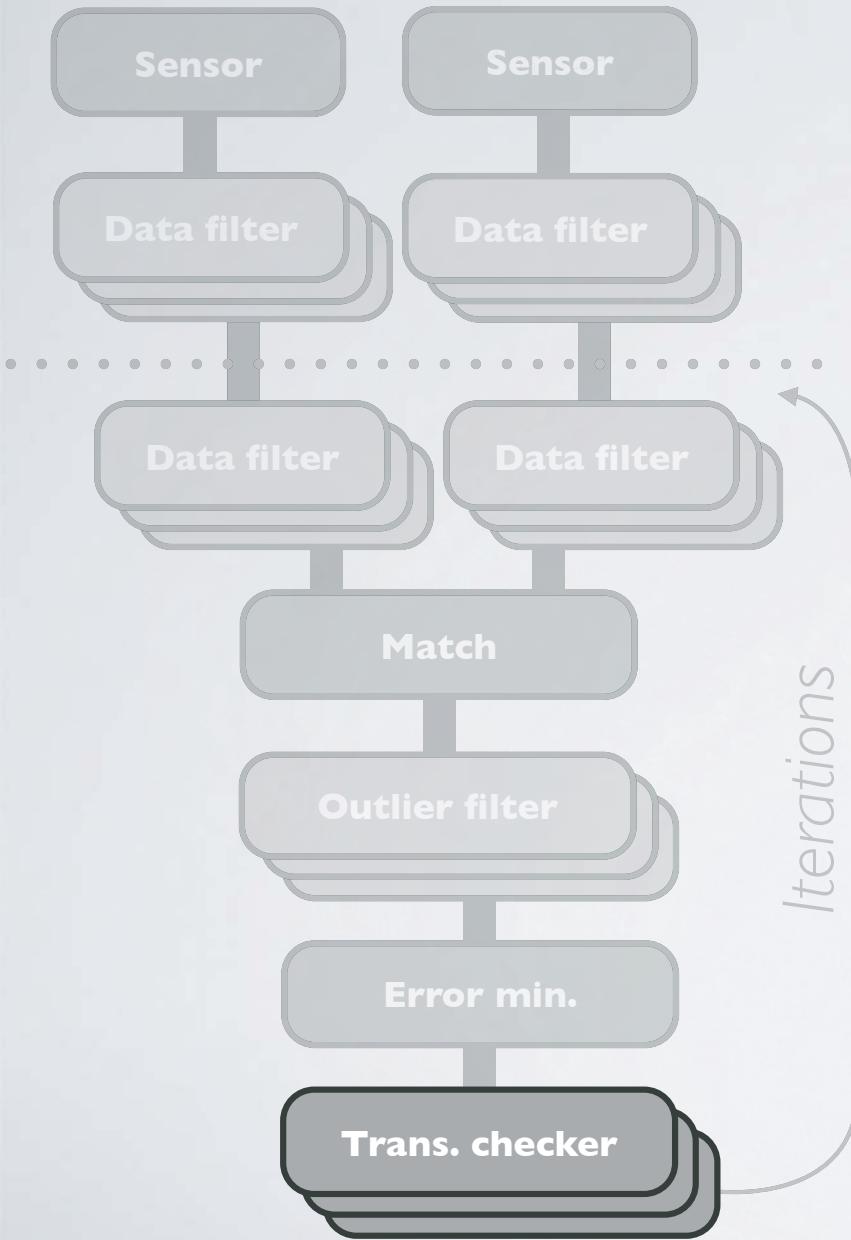


MINIMIZATION

Point-to-plane



CONVERGENCE DETECTION



Main goal:

- Iteration early out

CONVERGENCE DETECTION

Maximum number of iterations

- Blind

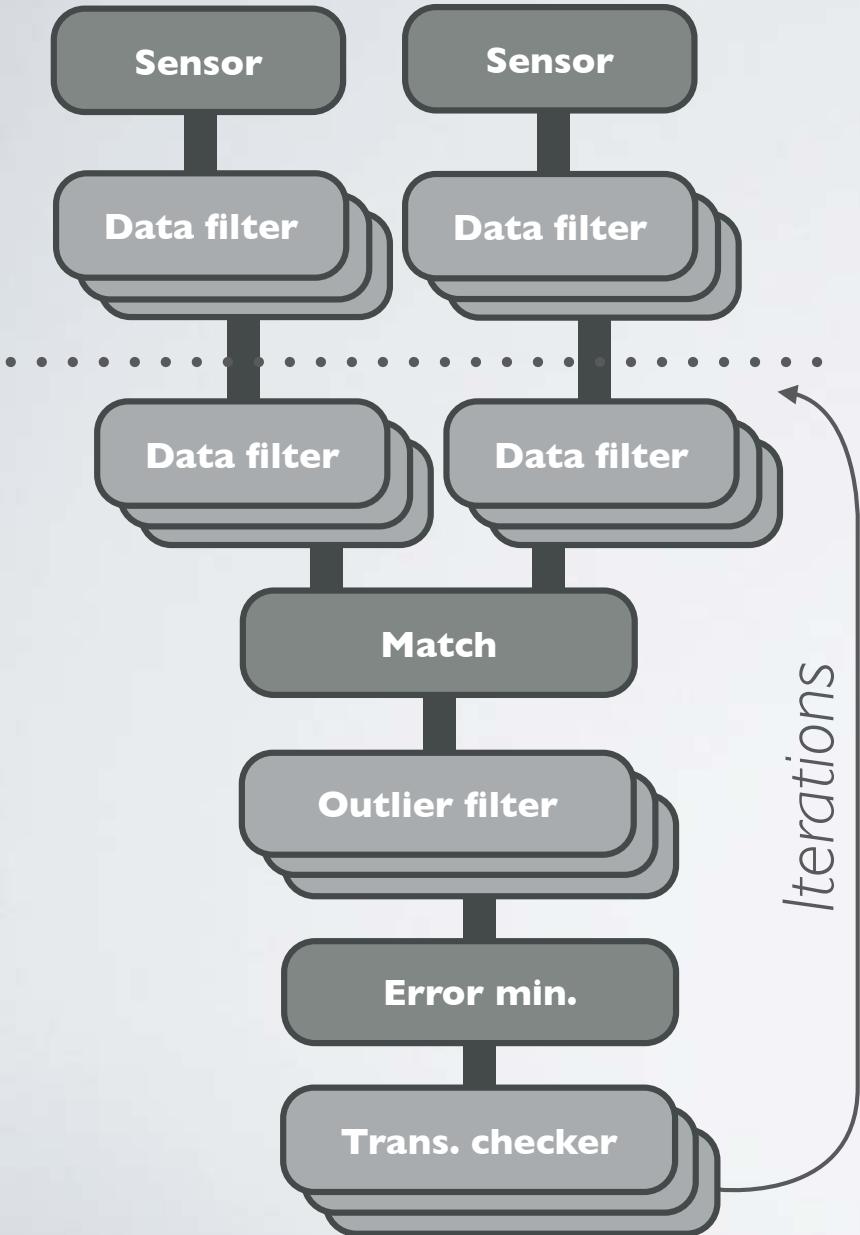
Absolute motion

- Limit based on expected sensor noise
- Detect divergence
- Deals with rotation and translation separately

Motion difference between iterations

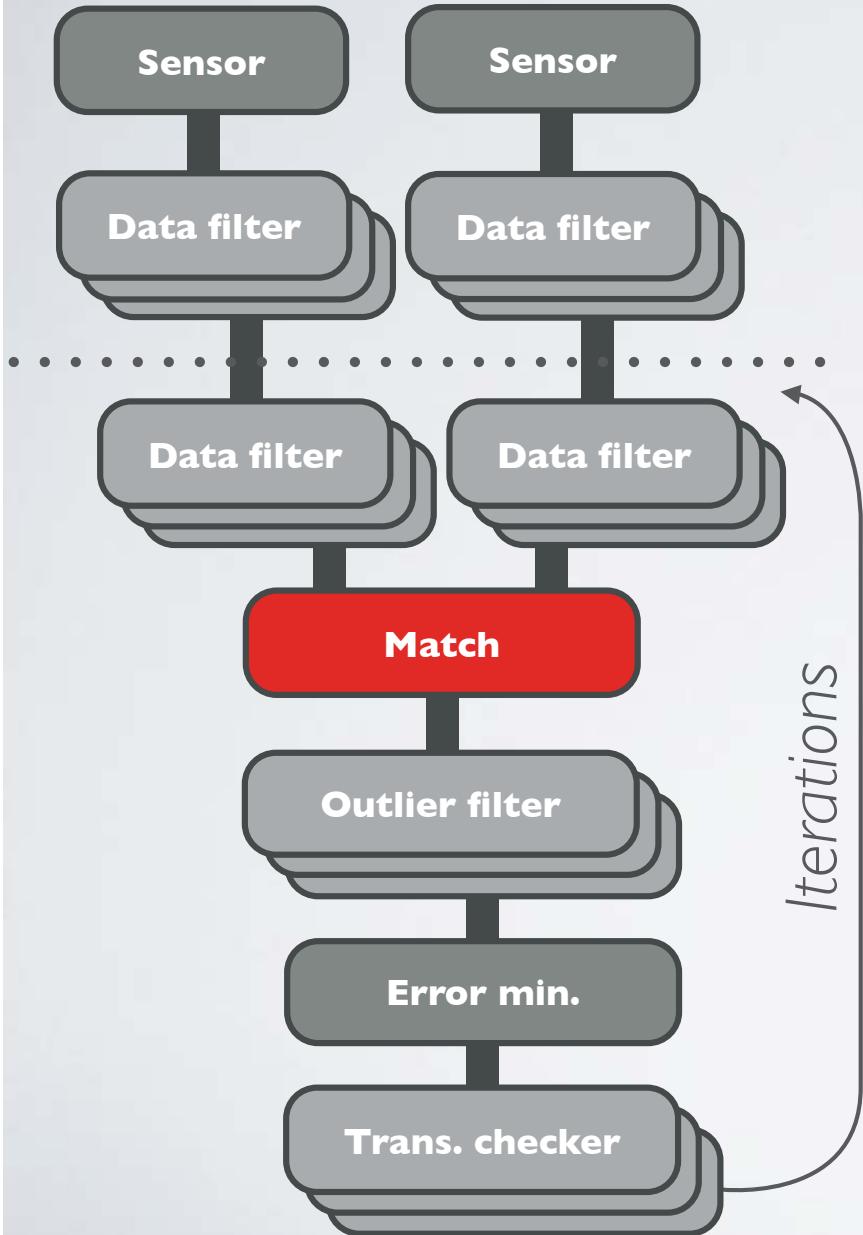
- Detect convergence up to wanted noise
- Deals with rotation and translation separately

SUMMARY



Accuracy
VS
Speed

SUMMARY



Augment speed

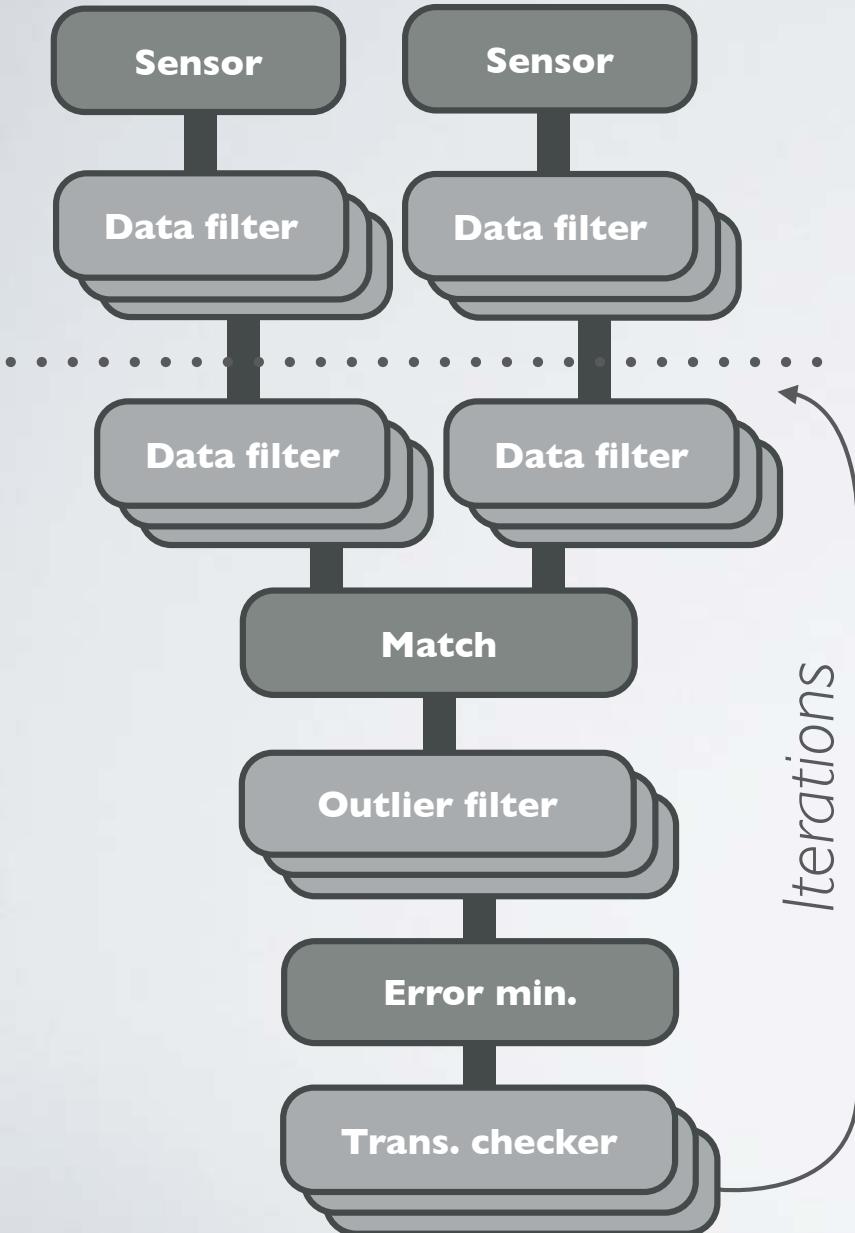
Reduce nb. points as soon as possible
Compute only the minimum

Approximative search (kd-tree)

-
Point-to-plane take less iterations

Relax targeted values

SUMMARY



Augment accuracy

Keep more points

Augment the number of matches

Adjust your expected overlap

Verify that normal vectors are well extracted

Add more iterations

SUMMARY

- ▶ Environment
 - ▶ type of structures
 - ▶ selected path
- ▶ Mobile agent
 - ▶ velocity of the robot
 - ▶ uncertainty in between reg.
 - ▶ self occlusion
- ▶ Sensing modality
 - ▶ refresh rate of the sensor
 - ▶ sensor noise
 - ▶ points distributions
 - ▶ sensor field of view