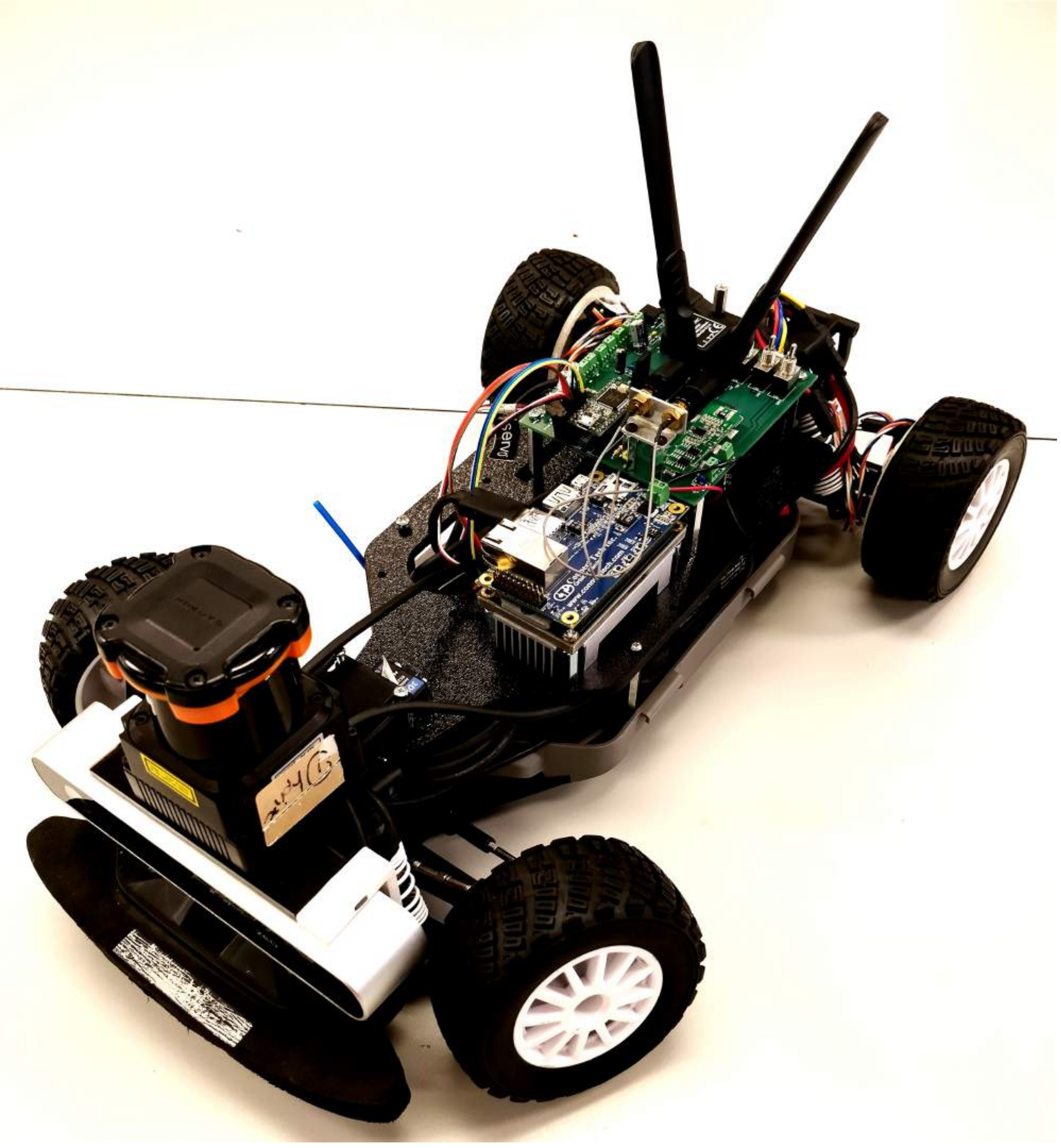


F1/10 Autonomous Racing

Scan Matching

Madhur Behl

CS 4501/SYS 4582
Spring 2018
Rice Hall 120

Localization and Mapping

Where am I ?

Scene Understanding

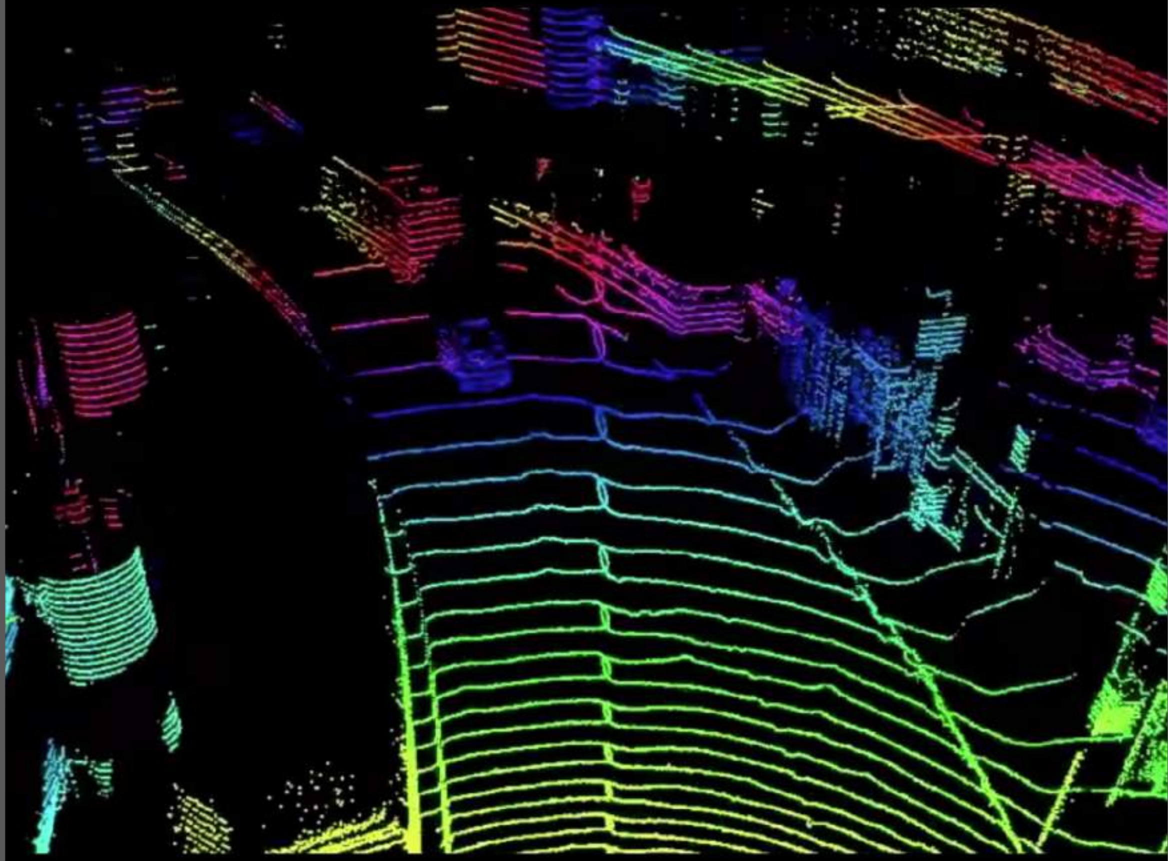
Where/who/what/why of
everyone/everything else ?

Trajectory Planning and Control

Where should I go next ?
How do I steer and accelerate ?

Human Interaction

How do I convey my intent to the
passenger and everyone else ?



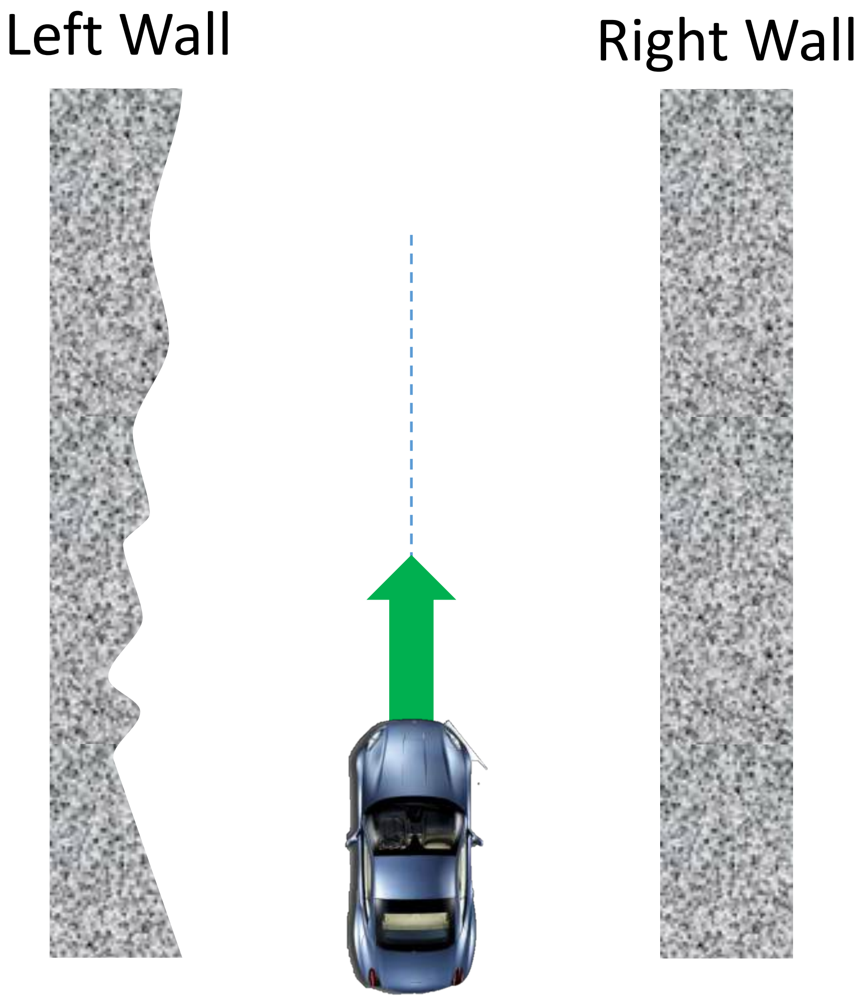
Scan Matching

Odometry with LIDAR

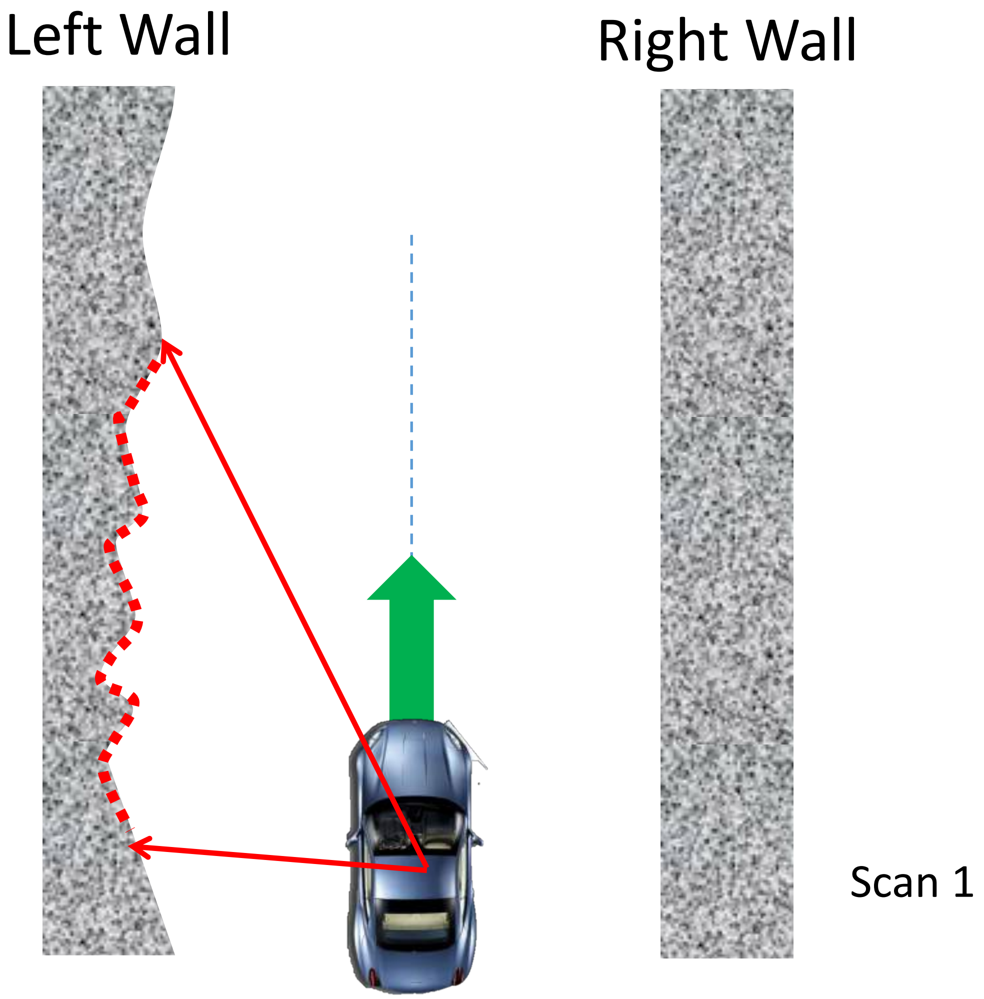
- Odometry = Estimation of position (x, y, z) and attitude (θ, φ, ψ)

- In what follows, will use “position” as short for “position and attitude”

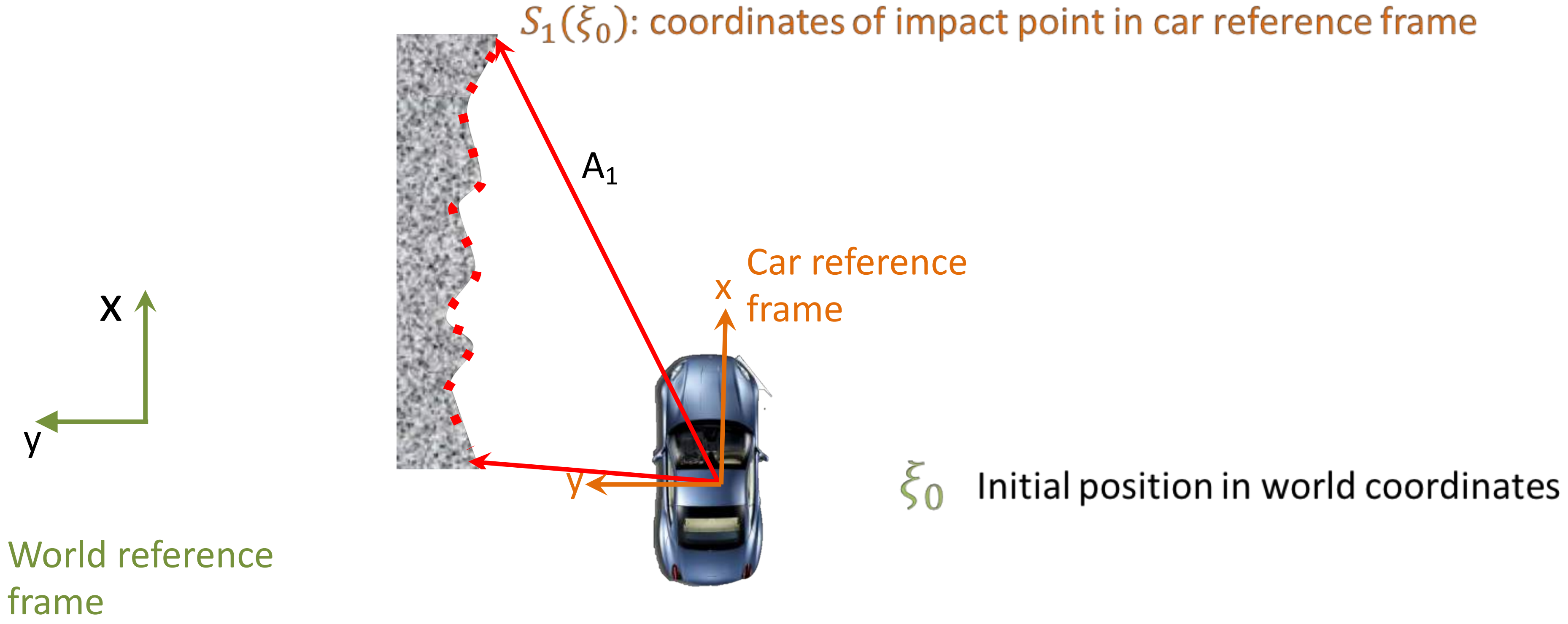
LIDAR for odometry: Scan matching



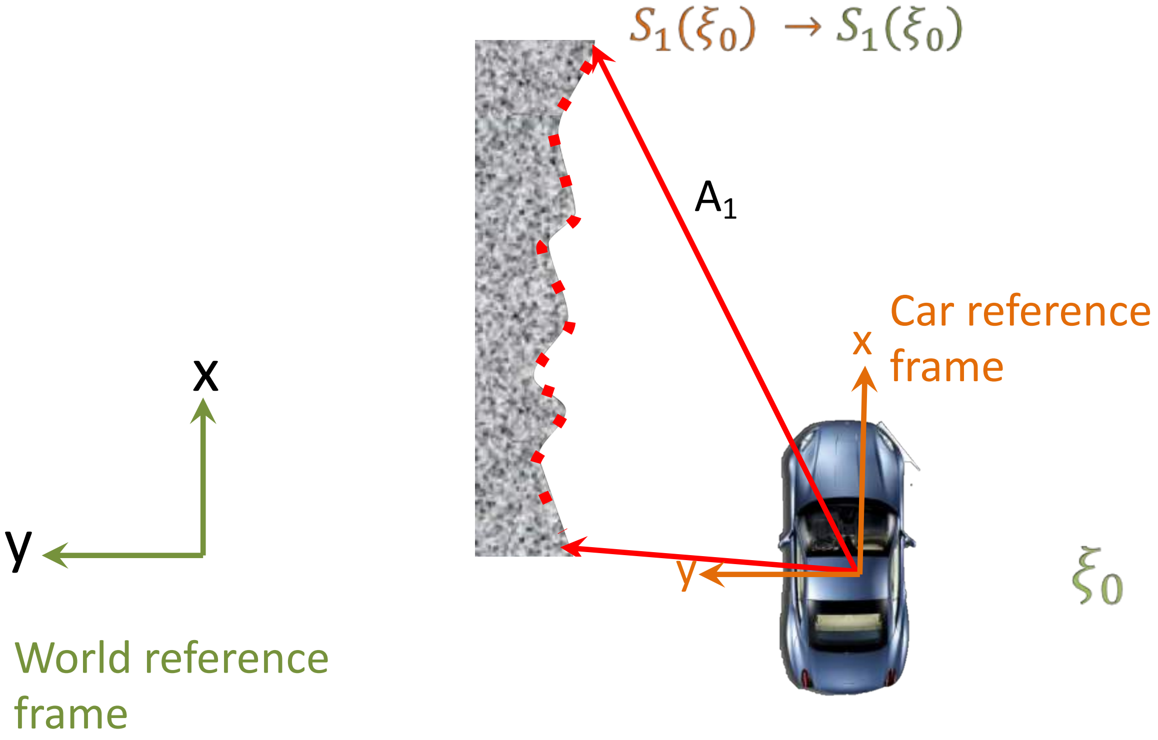
LIDAR for odometry: Scan matching



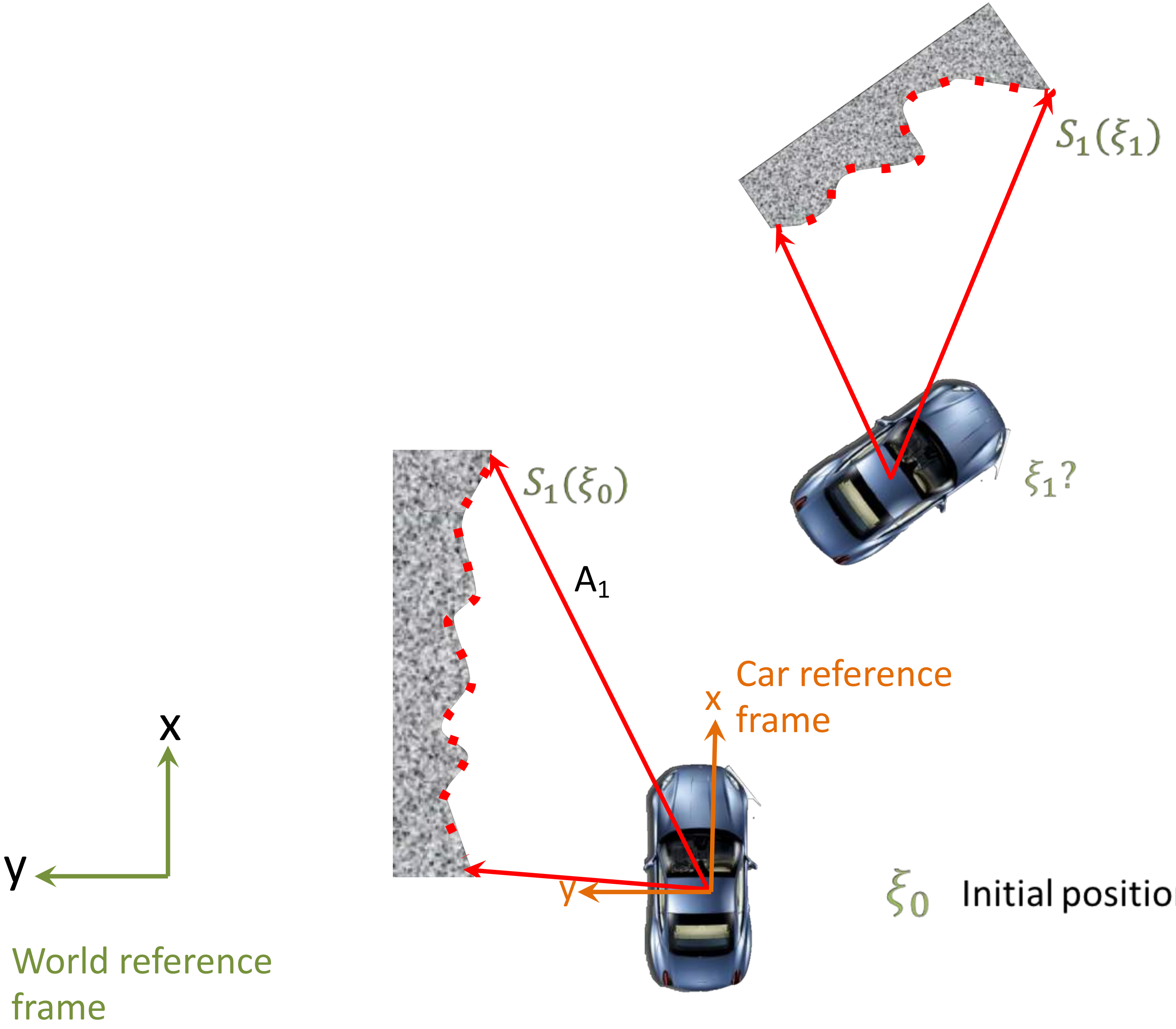
LIDAR for odometry: Scan 1



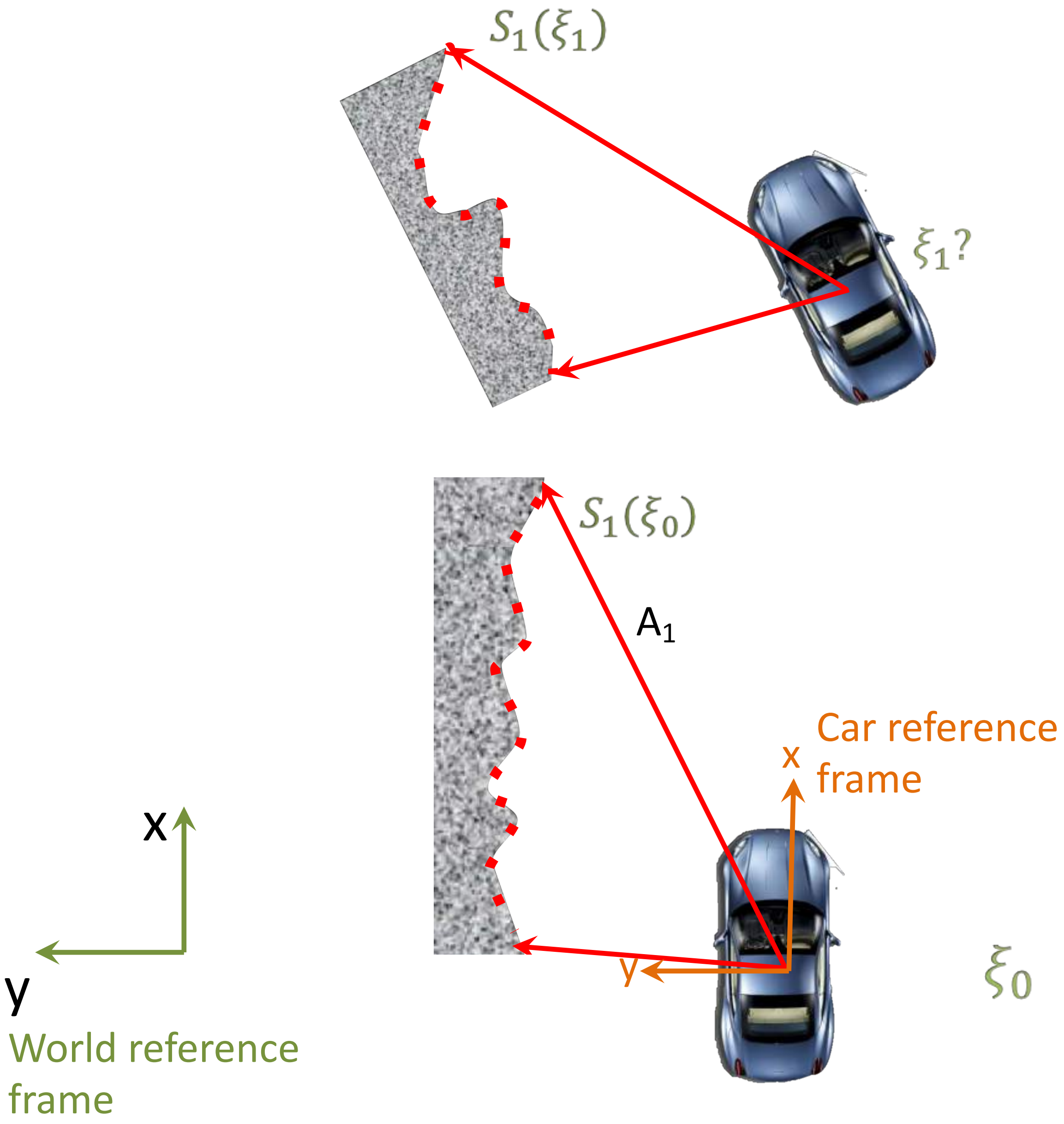
LIDAR for odometry: Scan 1



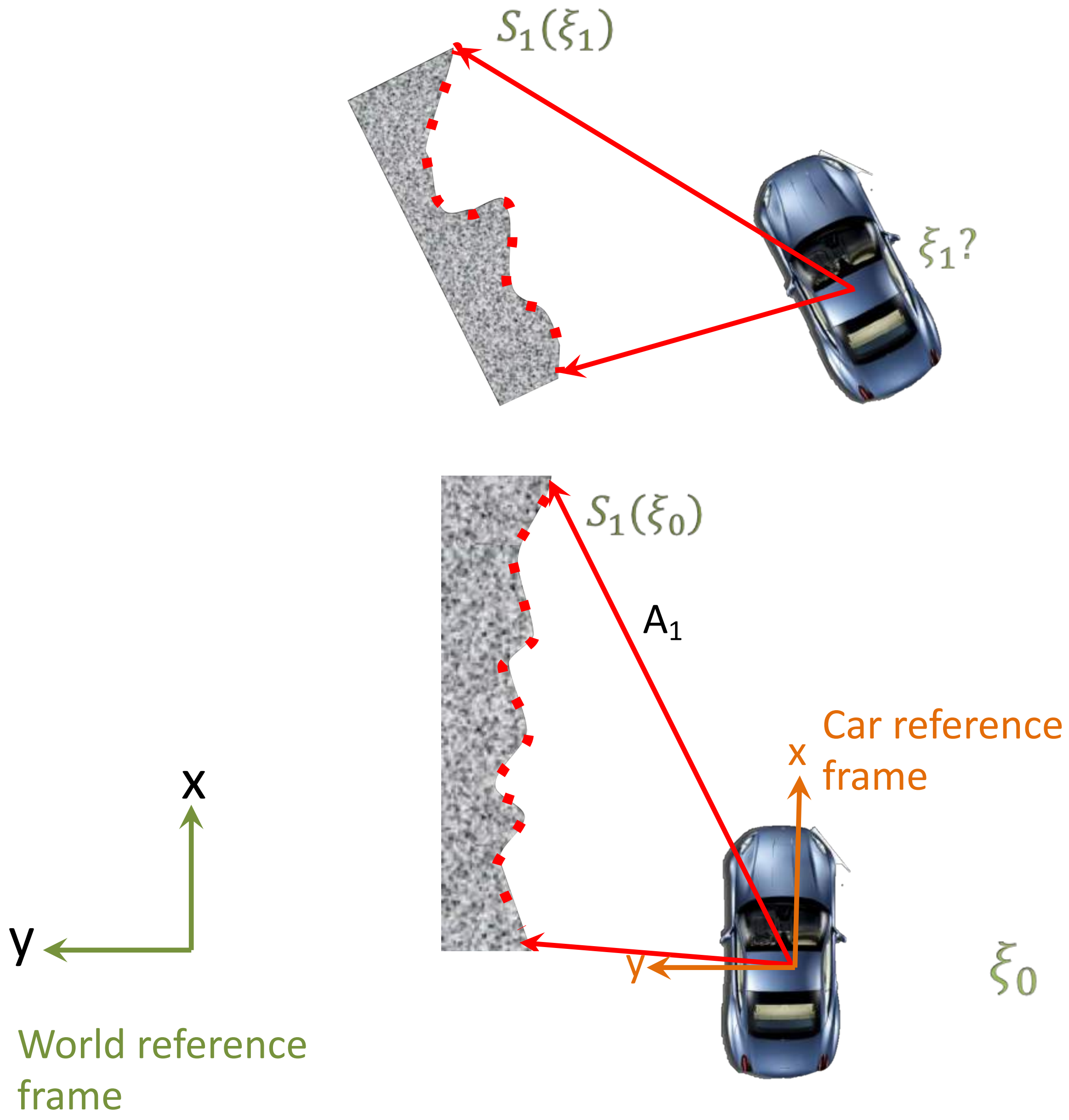
ξ_0 Initial position in world coordinates



ξ_0 Initial position in world coordinates

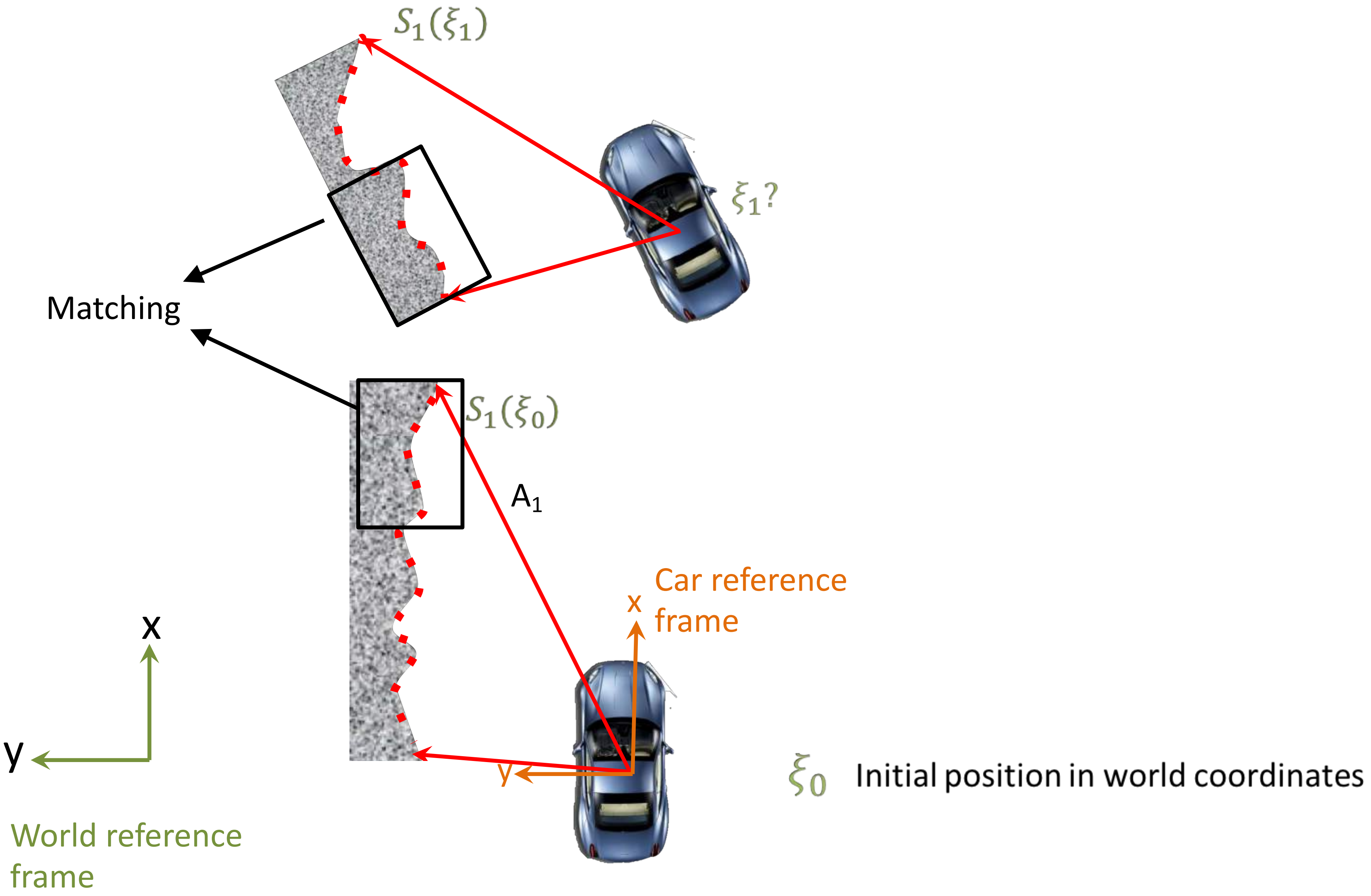


ξ_0 Initial position in world coordinates

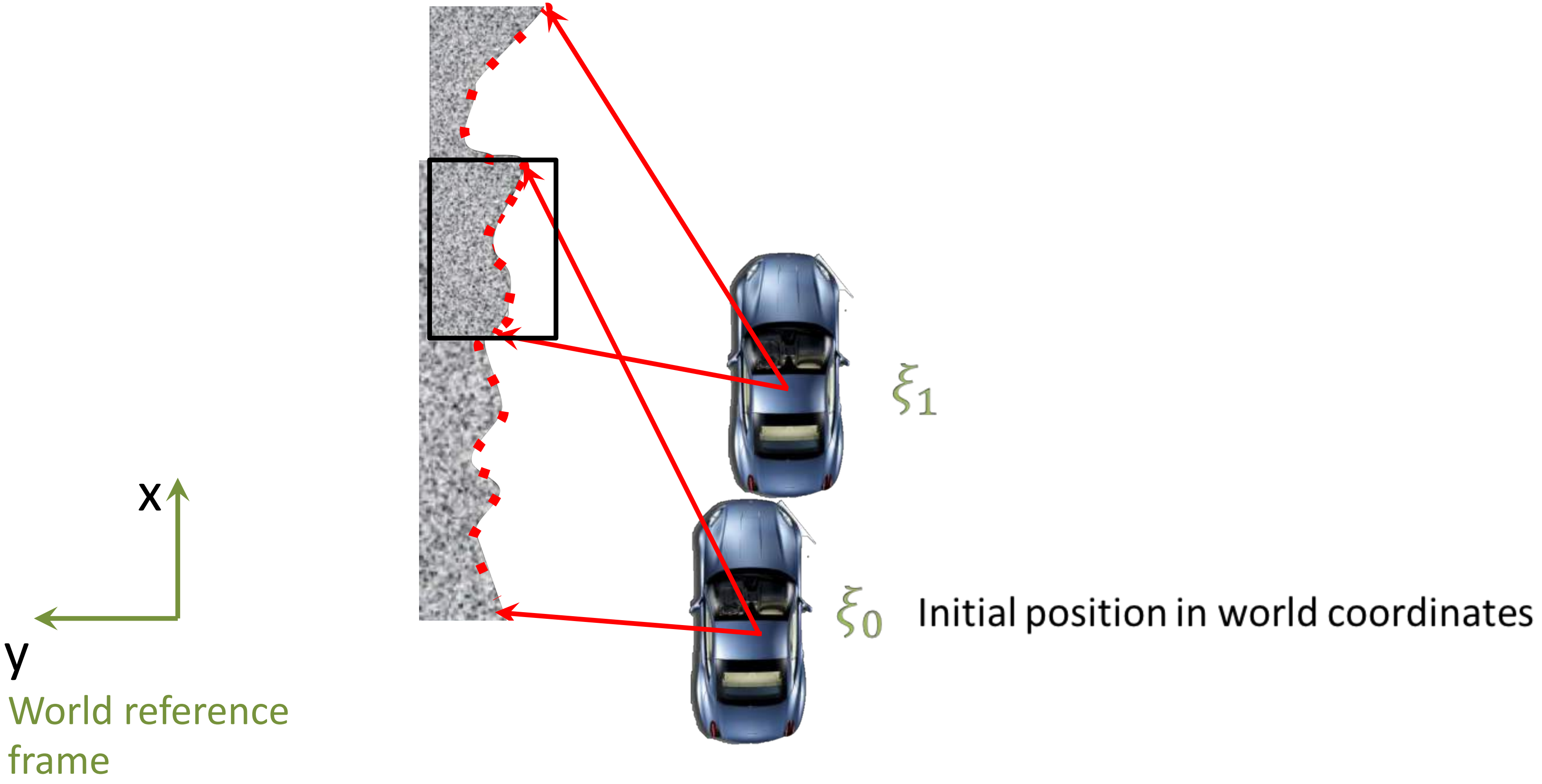


Premise:
most likely car position at Scan 2 is the position that gives best overlap between the two scenes

ξ_0 Initial position in world coordinates

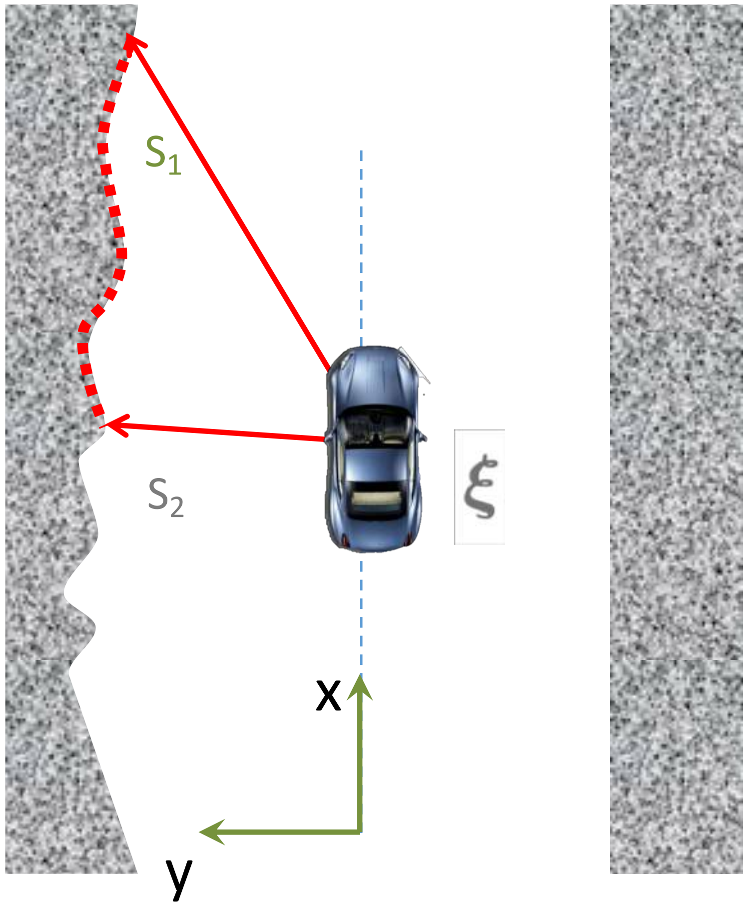


$S_1(\xi_1)$
$\xi_1?$
Matching
$S_1(\xi_0)$
A_1
Car reference frame
x
y
x
y
World reference frame
ξ_0 Initial position in world coordinates



x
y
World reference frame
ξ_1
ξ_0
Initial position in world coordinates

Scan matching: optimization

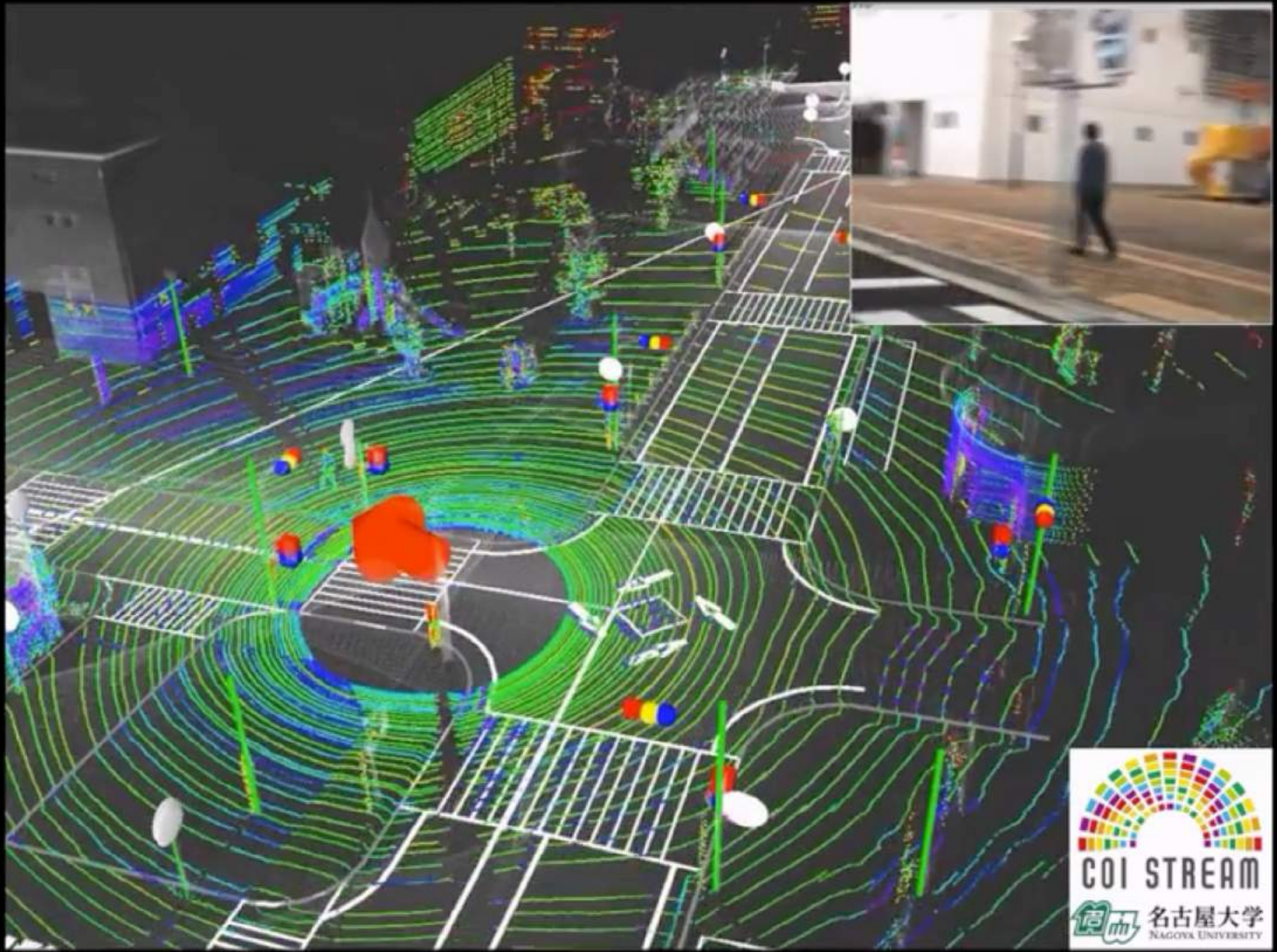


Impact coordinates of i^{th} step in world frame

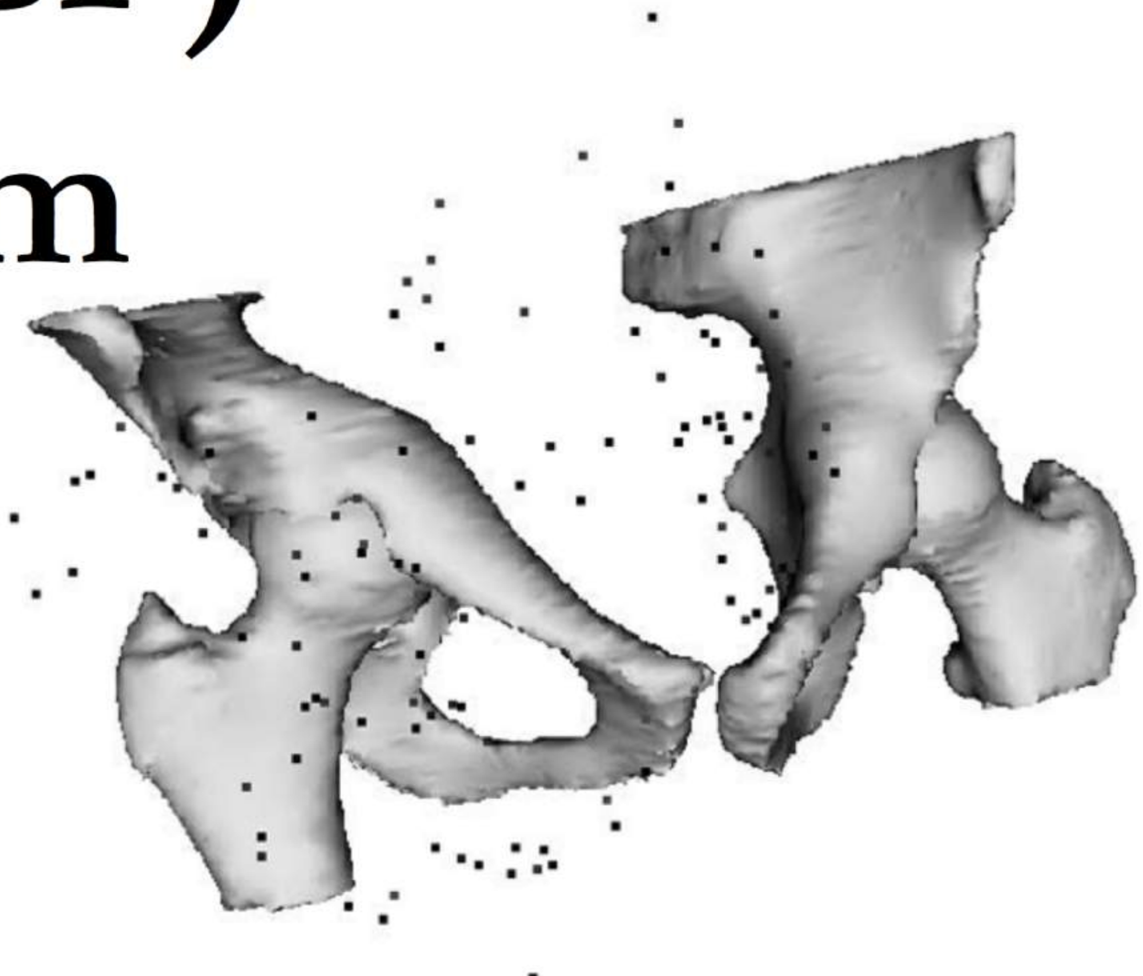
Total of n steps (n = 1084)

$$\boldsymbol{\xi}^* = \underset{\boldsymbol{\xi}}{\operatorname{argmin}} \sum_{i=1}^{n} \left[1 - M(\mathbf{S}_i(\boldsymbol{\xi}))\right]^2$$

Measure of match


COI STREAM
名古屋大学
NAGOYA UNIVERSITY

Iterative Closest Point (ICP) Algorithm



- Given: two corresponding point sets:

$$X = \{x_1, ..., x_n\}$$

$$P = \{p_1, ..., p_n\}$$

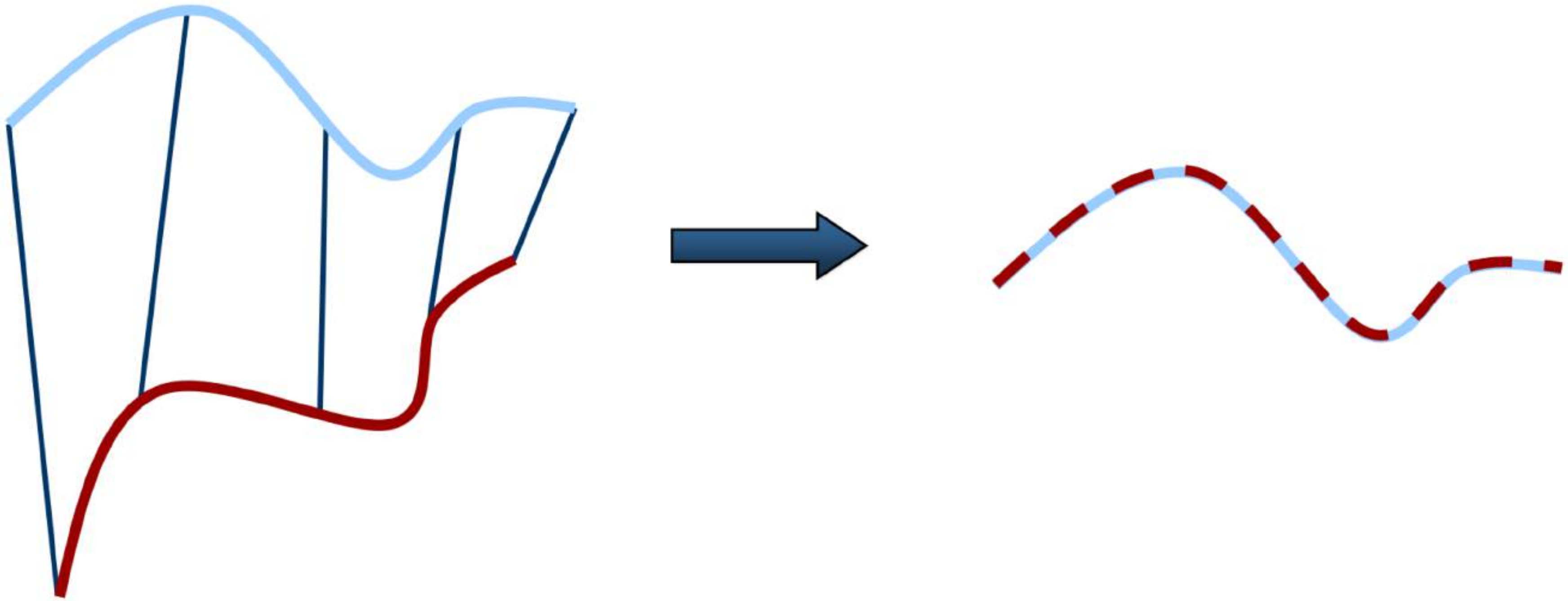
- Wanted: translation t and rotation R that minimizes the sum of the squared error:

$$E(R, t) = \frac{1}{N_p} \sum_{i=1}^{N_p} ||x_i - Rp_i - t||^2$$

Where x_i and p_i are corresponding points.

Key Idea

- If the correct correspondences are known, the correct relative rotation/translation can be calculated in closed form.



Center of Mass

$$\mu_x = \frac{1}{N_x}\sum_{i=1}^{N_x} x_i \quad \text{and} \quad \mu_p = \frac{1}{N_p}\sum_{i=1}^{N_p} p_i$$

are the centers of mass of the two point sets.

Idea:

- Subtract the corresponding center of mass from every point in the two point sets before calculating the transformation.
- The resulting point sets are:

$$X' = \{x_i - \mu_x\} = \{x_i'\}$$

and

$$P' = \{p_i - \mu_p\} = \{p_i'\}$$

SVD

Let $W = \sum_{i=1}^{N_p} x'_i p'^T_i$

denote the singular value decomposition (SVD) of W by:

$$W = U \begin{bmatrix} \sigma_1 & 0 & 0 \\ 0 & \sigma_2 & 0 \\ 0 & 0 & \sigma_3 \end{bmatrix} V^T$$

where $U, V \in \mathbb{R}^{3\times3}$ are unitary, and

$\sigma_1 \geq \sigma_2 \geq \sigma_3$ are the singular values of W.

SVD

Theorem (without proof):

If rank(W) = 3, the optimal solution of E(R,t) is unique and is given by:

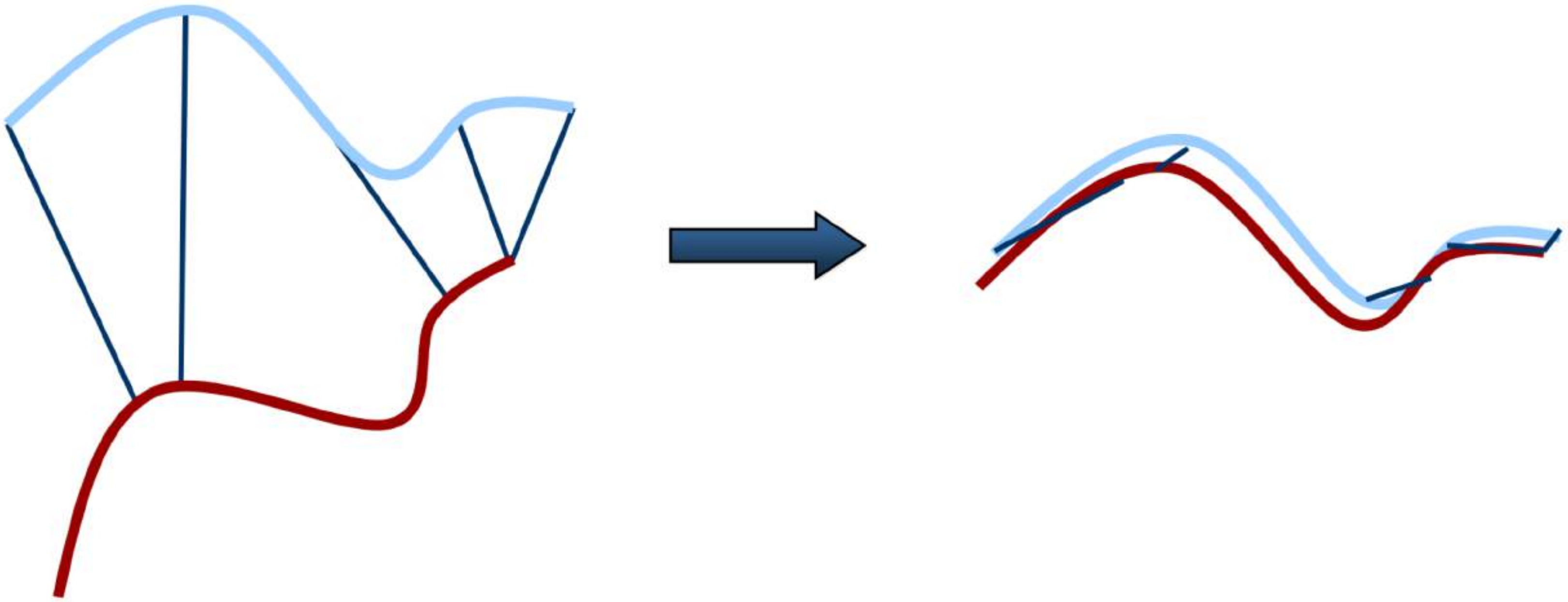
$$R = UV^T$$
$$t = \mu_x - R\mu_p$$

The minimal value of error function at (R,t) is:

$$E(R,t) = \sum_{i=1}^{N_p} (||x_i'||^2 + ||y_i'||^2) - 2(\sigma_1 + \sigma_2 + \sigma_3)$$

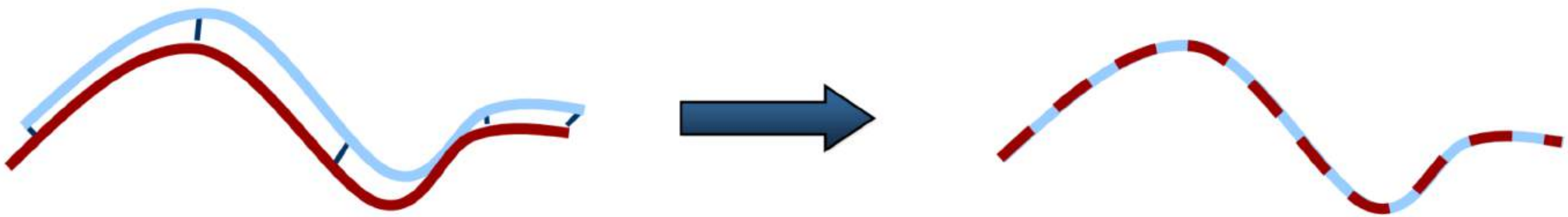
ICP with Unknown Data Association

- If correct correspondences are not known, it is generally impossible to determine the optimal relative rotation/translation in one step



ICP-Algorithm

- Idea: iterate to find alignment
- Iterated Closest Points (ICP) [Besl & McKay 92]
- Converges if starting positions are "close enough"



ICP-Variants

- Variants on the following stages of ICP have been proposed:

  1. Point subsets (from one or both point sets)
  2. Weighting the correspondences
  3. Data association
  4. Rejecting certain (outlier) point pairs

Performance of Variants

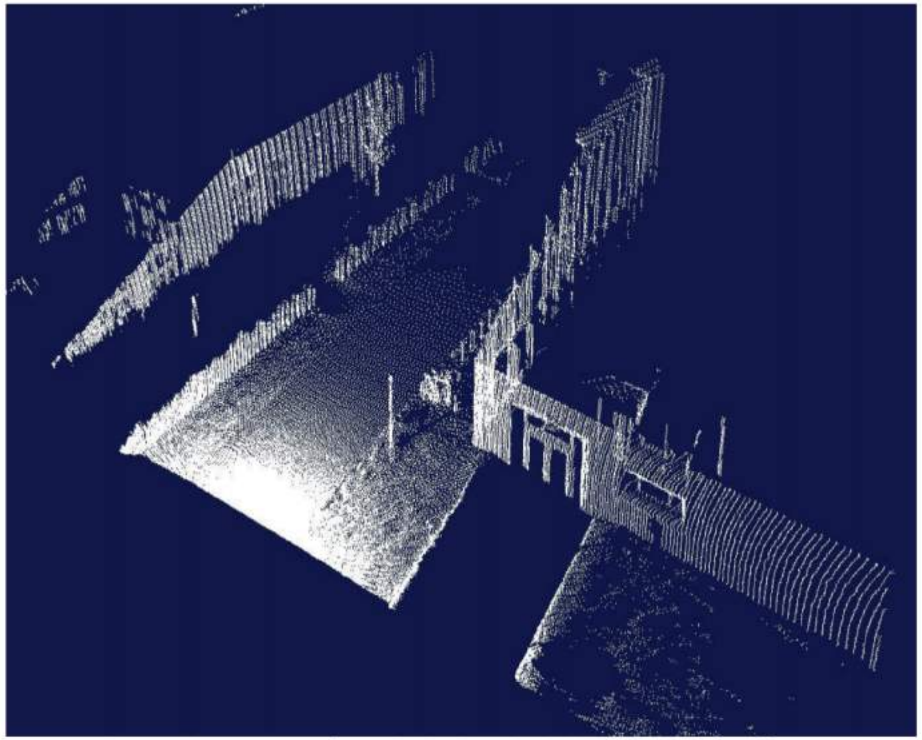
- Various aspects of performance:
  - Speed
  - Stability (local minima)
  - Tolerance wrt. noise and/or outliers
  - Basin of convergence
    (maximum initial misalignment)
- Here: properties of these variants

Selecting Source Points

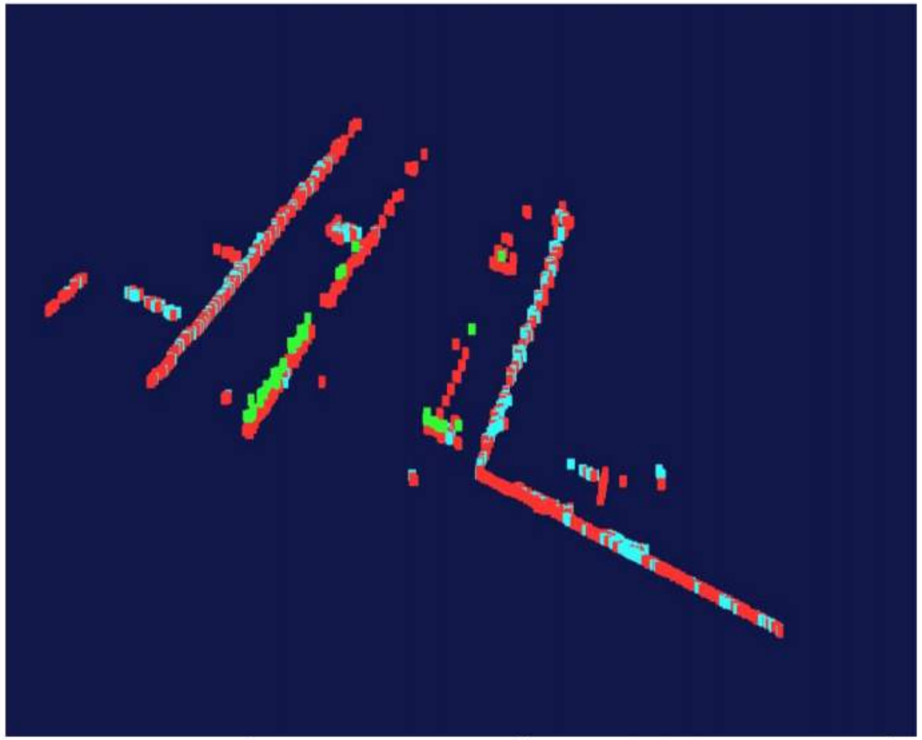
- Use all points
- Uniform sub-sampling
- Random sampling
- Feature based Sampling
- Normal-space sampling
  - Ensure that samples have normals distributed as uniformly as possible

Feature-Based Sampling

- try to find “important” points
- decrease the number of correspondences
- higher efficiency and higher accuracy
- requires preprocessing



3D Scan (~200.000 Points)



Extracted Features (~5.000 Points)

ICP Variants

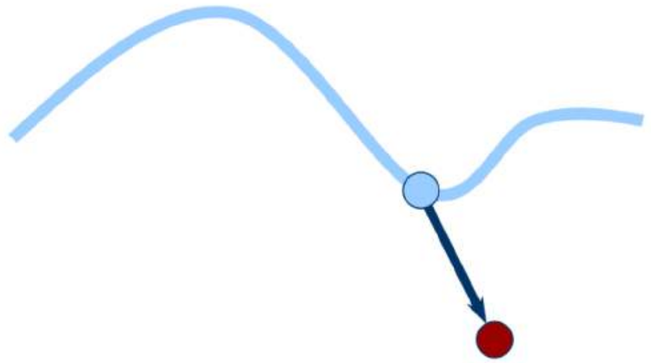
1. Point subsets (from one or both point sets)
2. Weighting the correspondences
3. Data association
4. Rejecting certain (outlier) point pairs

Data Association

- has greatest effect on convergence and speed
- Closest point
- Normal shooting
- Closest compatible point
- Projection
- Using kd-trees or oc-trees

Closest-Point Matching

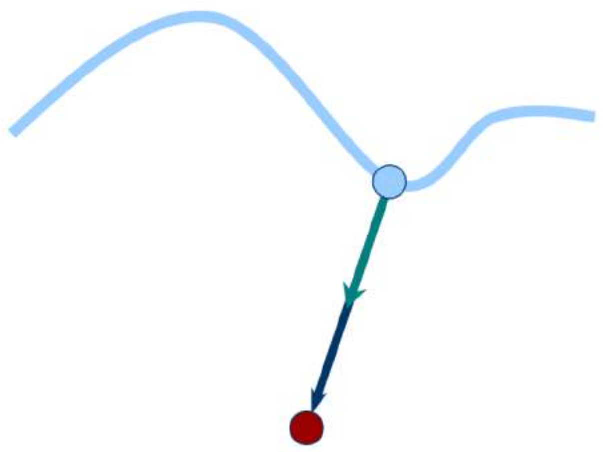
- Find closest point in other the point set



Closest-point matching generally stable, but slow and requires preprocessing

Normal Shooting

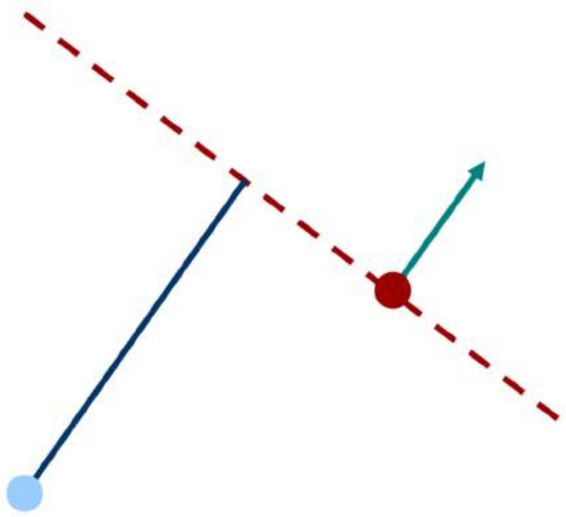
- Project along normal, intersect other point set

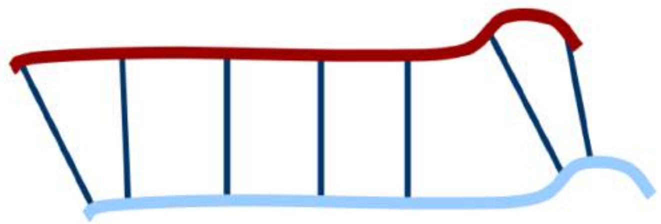


Slightly better than closest point for smooth structures, worse for noisy or complex structures

Point-to-Plane Error Metric

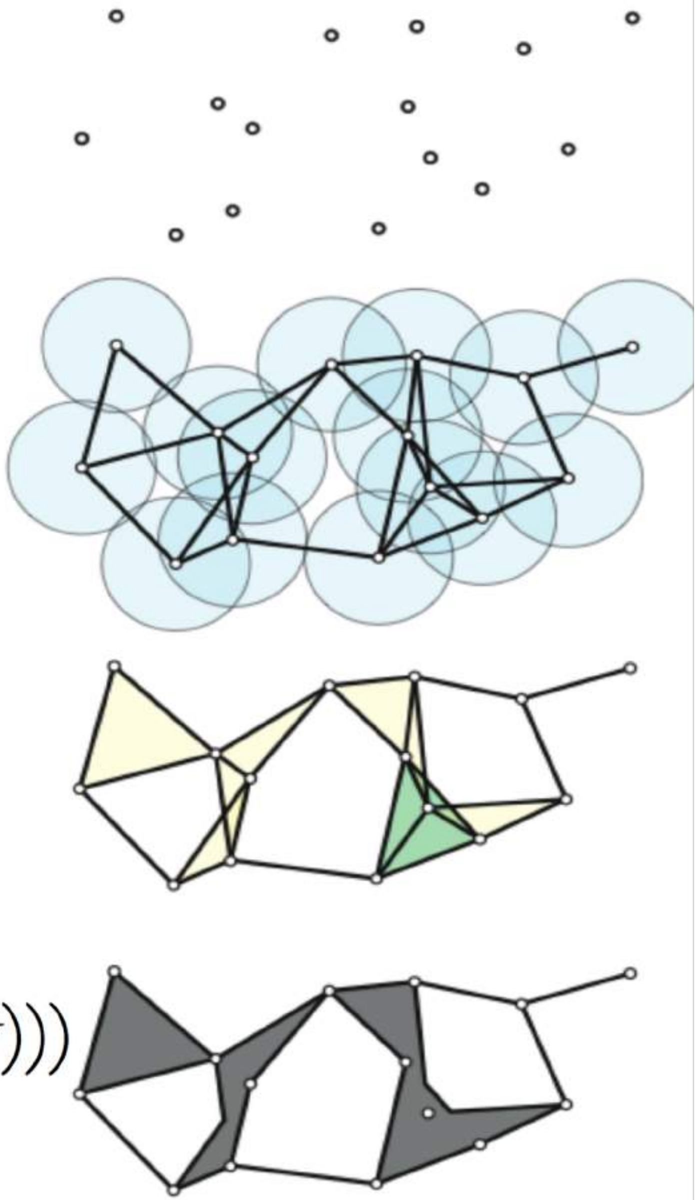
- Using point-to-plane distance instead of point-to-point lets flat regions slide along each other [Chen & Medioni 91]



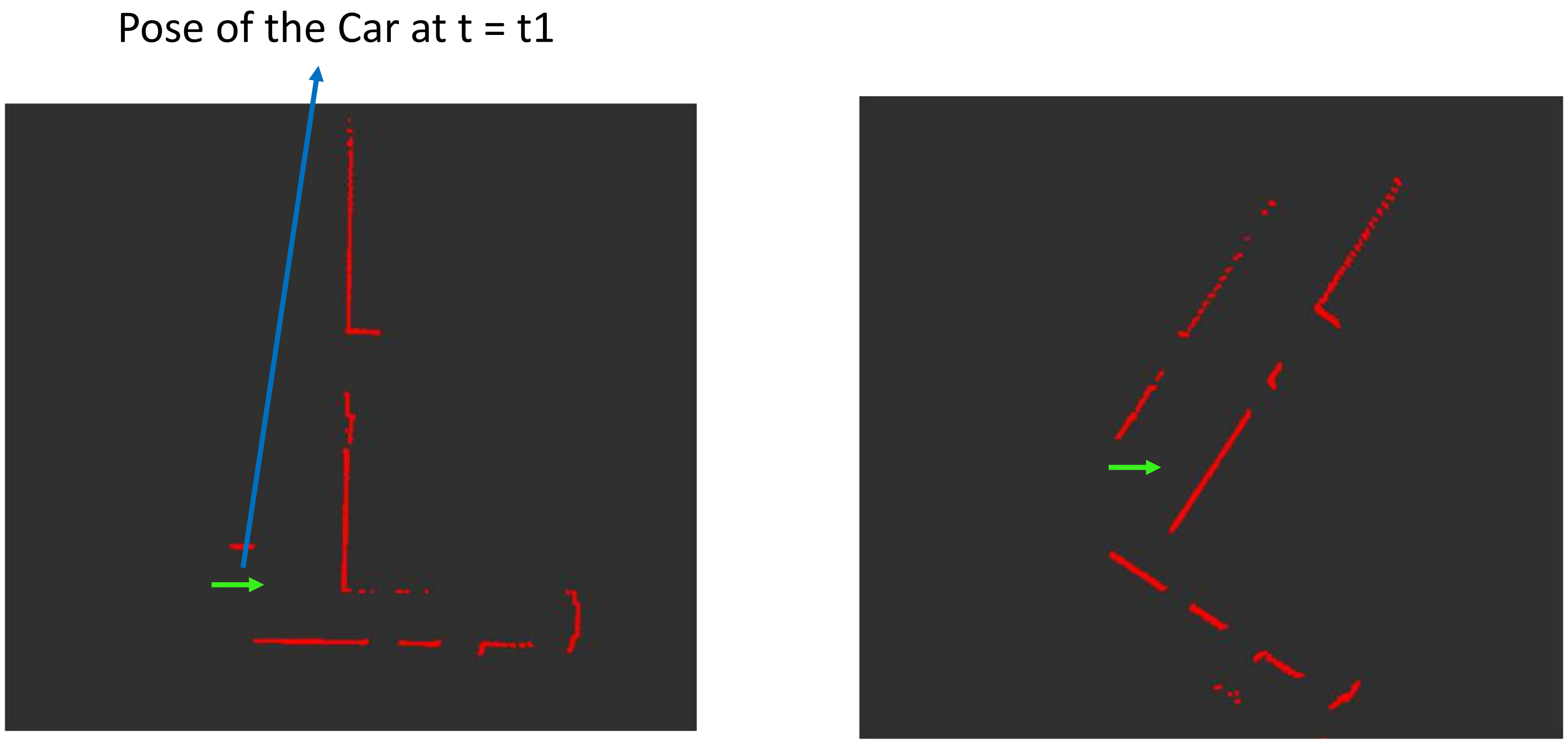


Data Types

- Point sets
- Line segment sets (polylines)
- Implicit curves : $f(x,y,z) = 0$
- Parametric curves : $(x(u),y(u),z(u))$
- Triangle sets (meshes)
- Implicit surfaces : $s(x,y,z) = 0$
- Parametric surfaces $(x(u,v),y(u,v),z(u,v)))$



Scan Matching



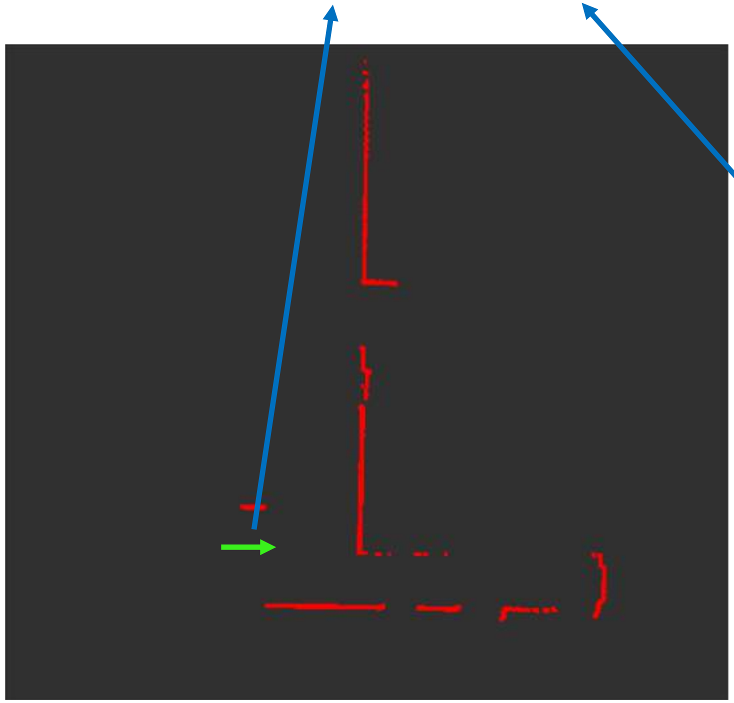
Laser Scans w.r.t car at Time t = t_1

Laser Scans w.r.t car at Time t = t_2

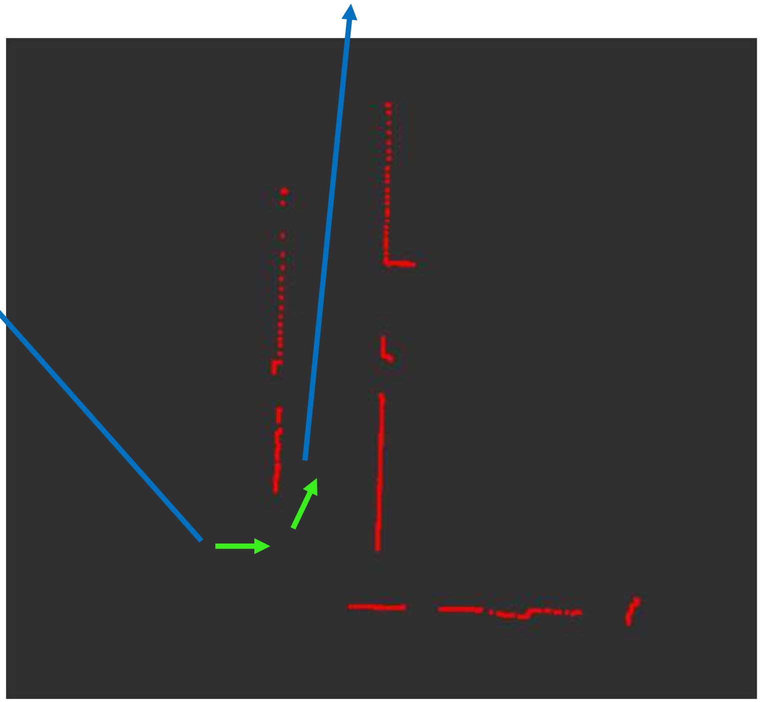
Scan Matching

Pose of the Car at t = t1

Pose of the Car at t=t2

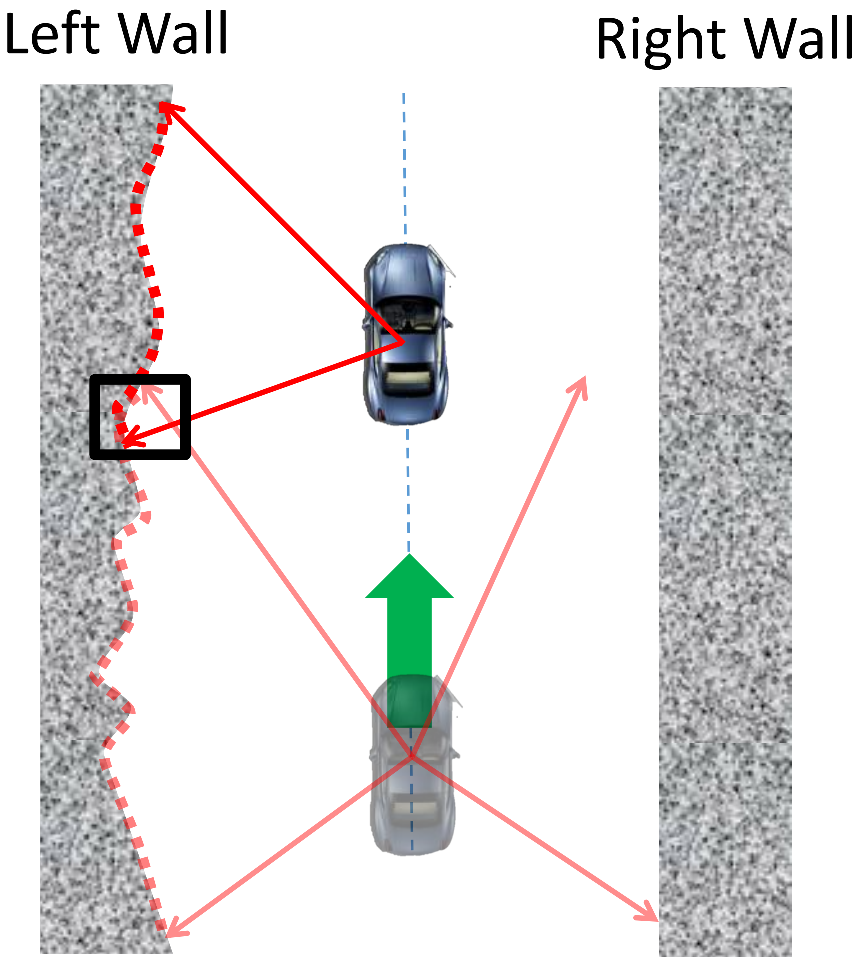


Laser Scans w.r.t car at Time t = t_1



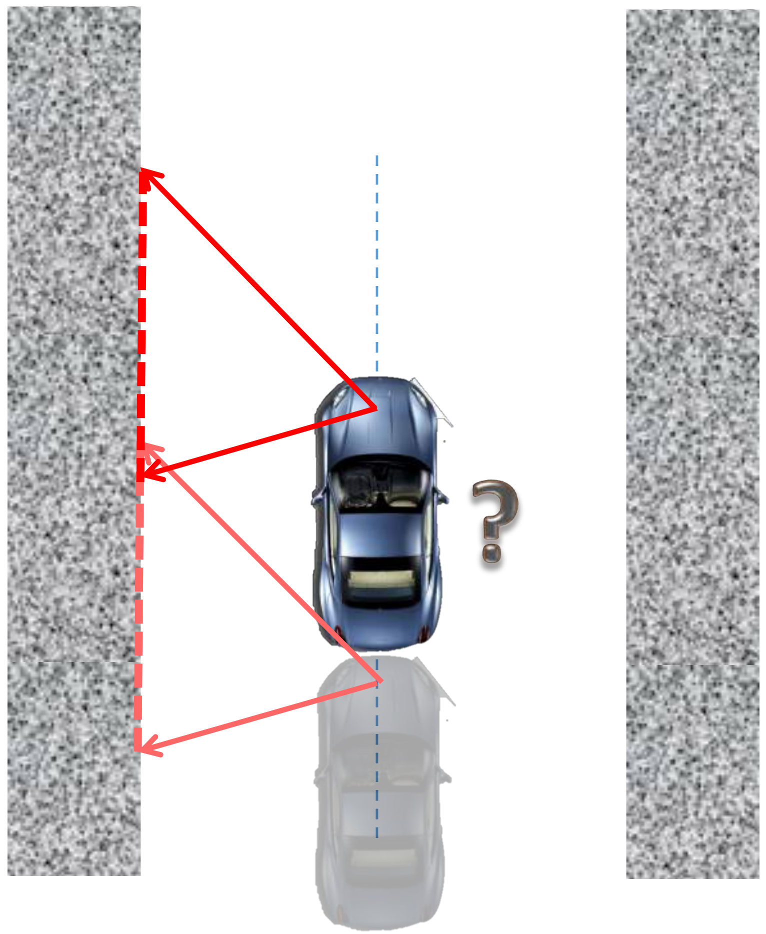
Laser Scans w.r.t car at Time t = t_2

Scan matching: requirements



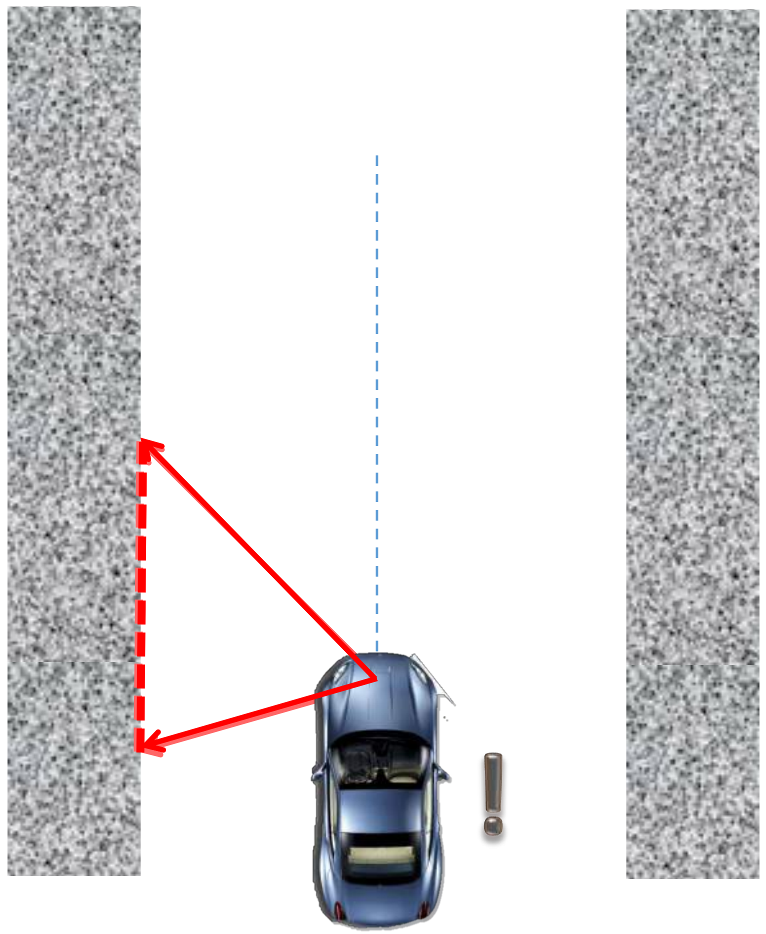
- Sufficiently fast scan rate
- A slow scan rate can lead to few matches between scans.
- Not really a risk for today's LIDARs

Scan matching : requirements



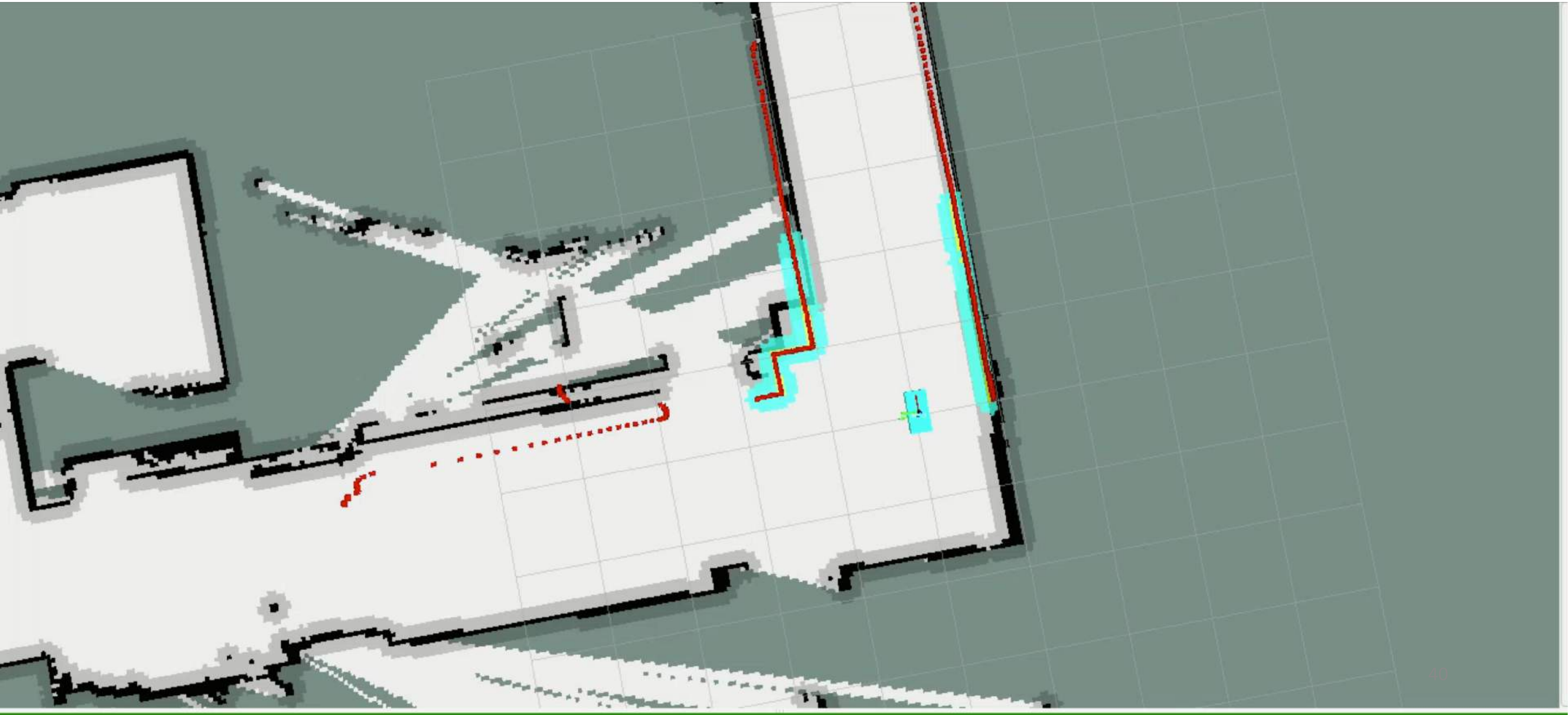
- Non-smooth, or heterogeneous, surfaces.
- Smooth surfaces all look the same to the matching algorithm.

Scan matching : requirements



- Non-smooth, or heterogeneous, surfaces.
- Best match between scans is if car did not move.

Failed scan matching



hokuyo_node

electric | fuerte | groovy | hydro | indigo | jade | Documentation Status

Package Summary

✔ Released ✖ No API documentation

A ROS node to provide access to SCIP 2.0-compliant Hokuyo laser range finders (including 04LX).

- Maintainer status: maintained
- Maintainer: Chad Rockey <chadrockey AT gmail DOT com>
- Author: Brian P. Gerkey, Jeremy Leibs, Blaise Gassend
- License: LGPL

Package Links

Tutorials
Troubleshooting
FAQ
Change List
Reviews

Dependencies (9)
Jenkins jobs (4)

Wiki

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urg_node

groovy | hydro | indigo | jade | kinetic

Documentation Status

Package Summary

✔ Released ✔ Continuous integration ✔ Documented

urg_node

- Maintainer status: maintained
- Maintainer: Tony Baltovski <tony.baltovski AT gmail DOT com>
- Author: Chad Rockey <chadrockey AT gmail DOT com>, Mike O'Driscoll <modriscoll AT clearpath DOT ai>
- License: BSD
- Bug / feature tracker: https://github.com/ros-drivers/urg_node/issues

Package Links

- **Code API**
- **Msg API**
- FAQ
- Changelog
- Change List
- Reviews

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Used by (3)

Jenkins jobs (10)

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laser_scan_matcher

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scan_tools: *laser_ortho_projector* | *laser_scan_matcher* | *laser_scan_sparsifier* | *laser_scan_splitter* | *ncd_parser* | *polar_scan_matcher* | *scan_to_cloud_converter*

Package Summary

✔ Released ✔ Continuous integration ✔ Documented

An incremental laser scan matcher, using Andrea Censi's Canonical Scan Matcher (CSM) implementation. See the web site for more about CSM. NOTE the CSM library is licensed under the GNU Lesser General Public License v3, whereas the rest of the code is released under the BSD license.

- Maintainer status: maintained
- Maintainer: Ivan Dryanovski <ccnyroboticslab AT gmail DOT com>, Carlos <cjaramillo AT gc.cuny DOT edu>, Isaac

Package Links

Code API
FAQ
Changelog
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Dependencies (10)
Used by (1)
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scan_tools

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scan_tools: *laser_ortho_projector* | *laser_scan_matcher* | *laser_scan_sparsifier* | *laser_scan_splitter* | *ncd_parser* | *polar_scan_matcher* | *scan_to_cloud_converter*

Package Links

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- scan_tools

Page

- Immutable Page
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- Attachments
- More Actions:

Package Summary

✔ Released ✔ Continuous integration ✔ Documented

Laser scan processing tools.

- Maintainer status: maintained
- Maintainer: Ivan Dryanovski <ccnyroboticslab AT gmail DOT com>, Carlos <ciaramillo AT gc cuny DOT edu>, Isaac I.Y. Saito <iiysaito AT opensource-robotics tokyo DOT jp>

2

NDT result is used as likelihood function in particle filtering algorithm.

Road marker matching is also used to improve localization accuracy.

Live Demo: /laserscan & Scan Matching