Relative motion from <u>unknown</u> correspondences

Iterative Closest Point SLAM

Absolute orientation problem in **SE(2)**

$$\mathbf{z}^v = \arg\min_{\mathbf{t},\theta} \sum_i \left\| \mathbf{R}_\theta \mathbf{p} + \mathbf{t} - \mathbf{q} \right\|^2 = \arg\min_{\mathbf{t},\theta} \sum_i \|\mathbf{R}_\theta \mathbf{p}'_i - \mathbf{q}'_i\|^2 + \|\mathbf{R}_\theta \tilde{\mathbf{p}} + \mathbf{t} - \tilde{\mathbf{q}}\|^2$$

Substitution: $\mathbf{p}'_i = \mathbf{p}_i - \underbrace{\frac{1}{N}\sum_i \mathbf{p}_i}_{\tilde{\mathbf{p}}}, \quad \mathbf{q}'_i = \mathbf{q}_i - \underbrace{\frac{1}{N}\sum_i \mathbf{q}_i}_{\tilde{\mathbf{q}}}$

Can be always zero
by appropriate choice of $\mathbf{t}$

Depends only on θ

Solution: $\mathbf{H} = \sum_i \mathbf{p}'_i \mathbf{q}'^{\top}_i$ … covariance matrix

$$\theta^\star = \arg\min_\theta \sum_i \|\mathbf{R}_\theta \mathbf{p}'_i - \mathbf{q}'_i\|^2 = \arctan\left(\frac{H_{xy} - H_{yx}}{H_{xx} + H_{yy}}\right)$$

$$\mathbf{t}^\star = \arg\min_{\mathbf{t}} \|\mathbf{R}_{\theta^\star} \tilde{\mathbf{p}} + \mathbf{t} - \tilde{\mathbf{q}}\|^2 = \tilde{\mathbf{q}} - \mathbf{R}_{\theta^\star} \tilde{\mathbf{p}}$$

Absolute orientation problem in **SE(3)**

$$\mathbf{z}^{v} = \arg\min_{\mathbf{t},\mathbf{R}} \sum_i \left\| \mathbf{R}\mathbf{p} + \mathbf{t} - \mathbf{q} \right\|^2 = \arg\min_{\mathbf{t},\mathbf{R}} \sum_i \|\mathbf{R}\mathbf{p}'_i - \mathbf{q}'_i\|^2 + \|\mathbf{R}\tilde{\mathbf{p}} + \mathbf{t} - \tilde{\mathbf{q}}\|^2$$

Substitution: $\mathbf{p}'_i = \mathbf{p}_i - \underbrace{\frac{1}{N}\sum_i \mathbf{p}_i}_{\tilde{\mathbf{p}}}, \quad \mathbf{q}'_i = \mathbf{q}_i - \underbrace{\frac{1}{N}\sum_i \mathbf{q}_i}_{\tilde{\mathbf{q}}}$

Can be always zero by appropriate choice of $\mathbf{t}$

Depends only on $\mathbf{R}$

Solution: $\mathbf{H} = \sum_i \mathbf{p}'_i \mathbf{q}'^{\top}_i$ … covariance matrix with SVD decomposition $\mathbf{H} = \mathbf{U}\mathbf{S}\mathbf{V}^{\top}$

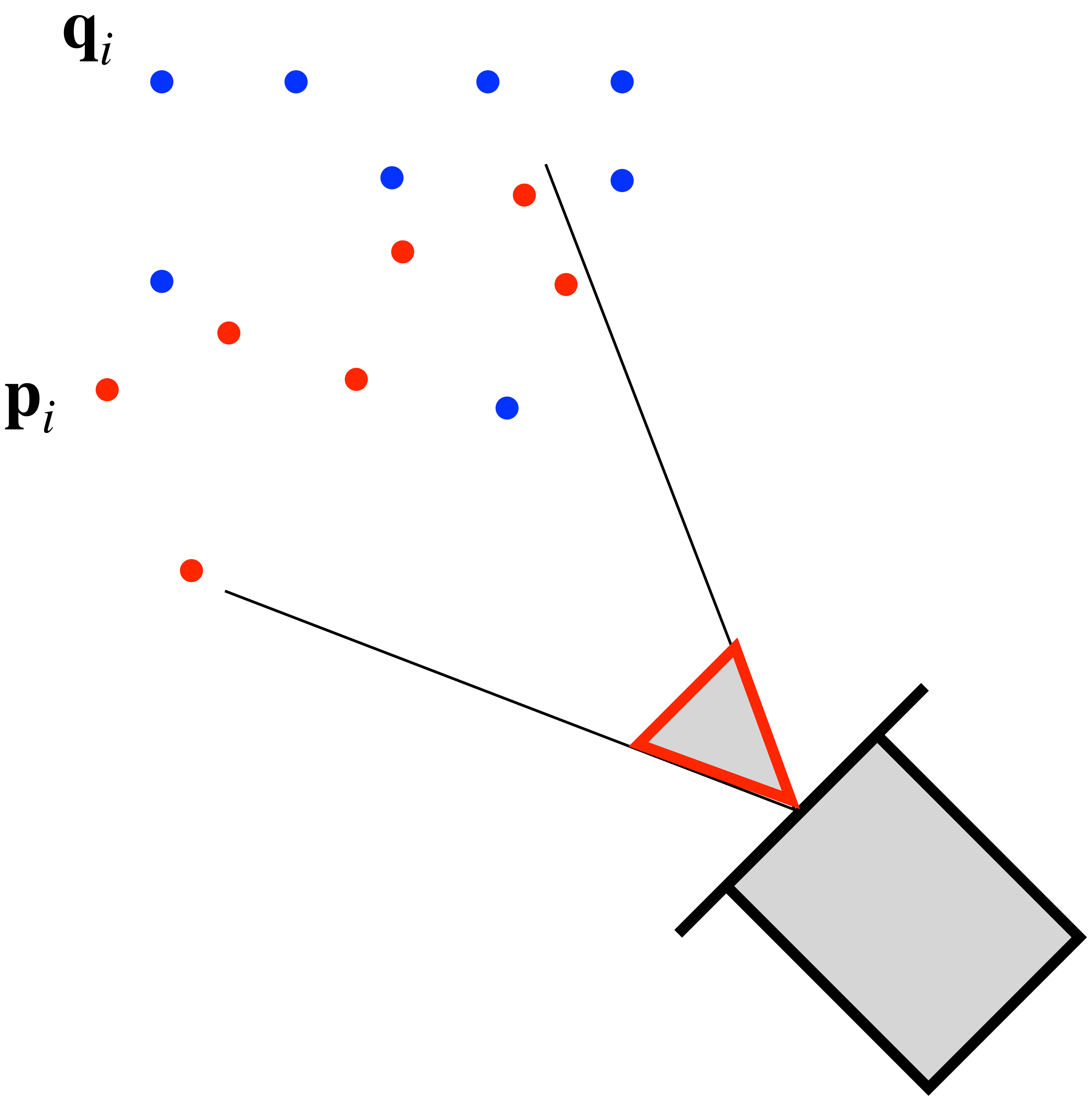
$$\mathbf{R}^{\star} = \arg\min_{\mathbf{R}} \sum_i \|\mathbf{R}\mathbf{p}'_i - \mathbf{q}'_i\|^2 = \mathbf{V}\mathbf{U}^{\top}$$

$$\mathbf{t}^{\star} = \arg\min_{\mathbf{t}} \|\mathbf{R}^{\star}\tilde{\mathbf{p}} + \mathbf{t} - \tilde{\mathbf{q}}\|^2 = \tilde{\mathbf{q}} - \mathbf{R}^{\star}\tilde{\mathbf{p}}$$

Python:

```python
H = P @ Q.T
U, S, V = np.linalg.svd(H, full_matrices=True)
```

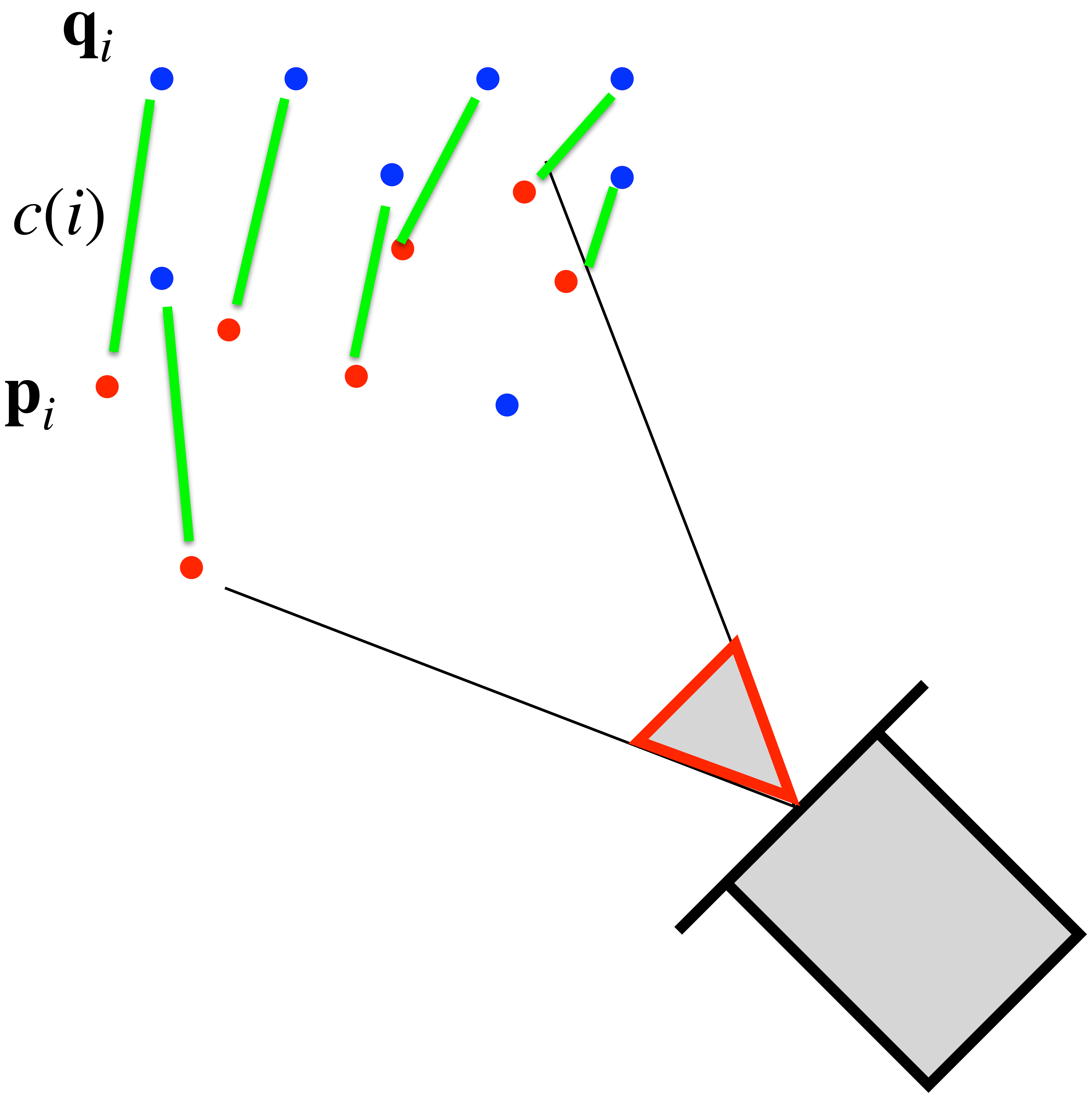
Pose from **known** correspondences



Input: pointcloud $\mathbf{q}_i$

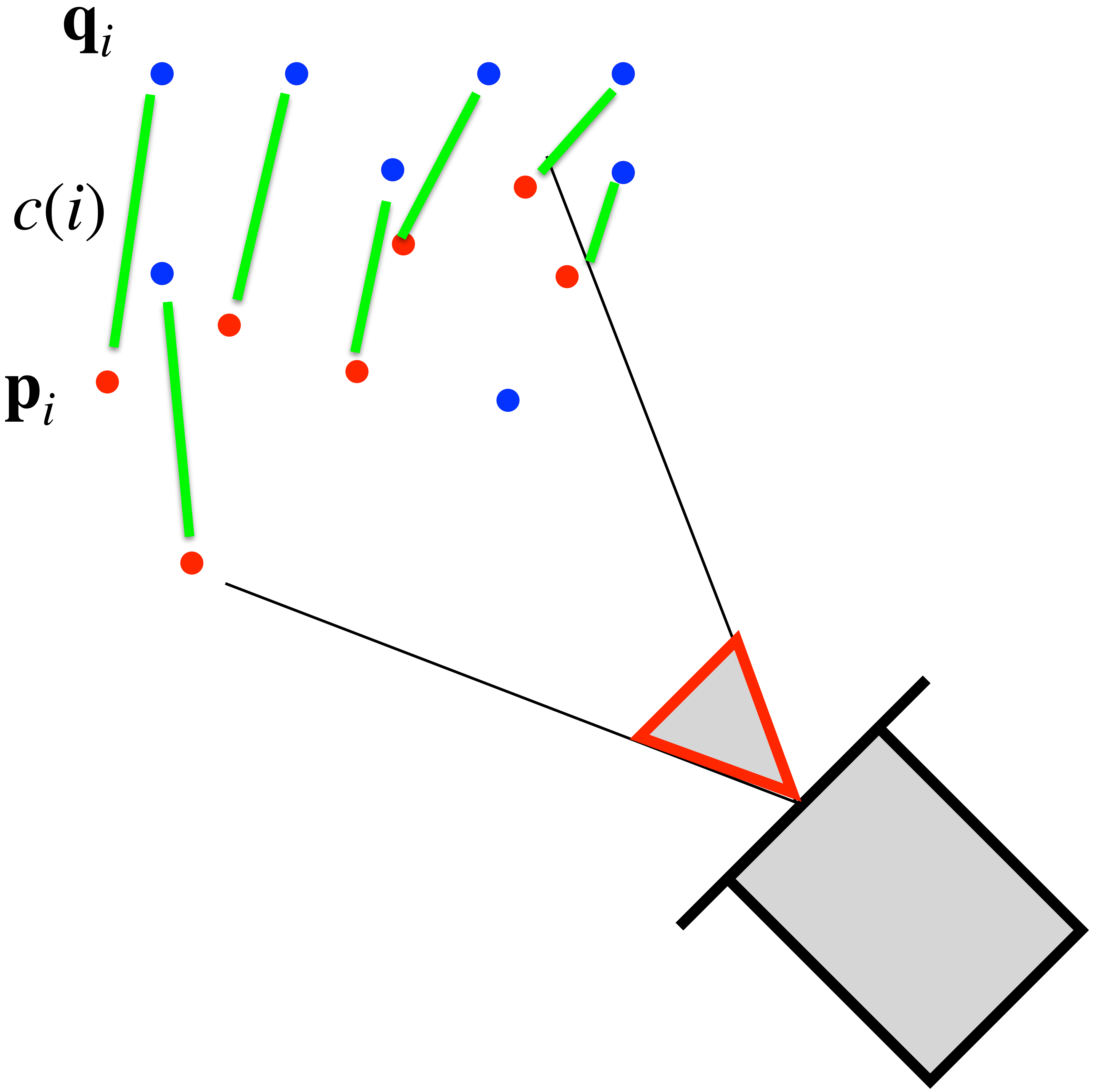
pointcloud $\mathbf{p}_i$

Pose from **known** correspondences



Input: pointcloud $\mathbf{q}_i$
pointcloud $\mathbf{p}_i$
correspondences $c(i)$

Pose from **known** correspondences

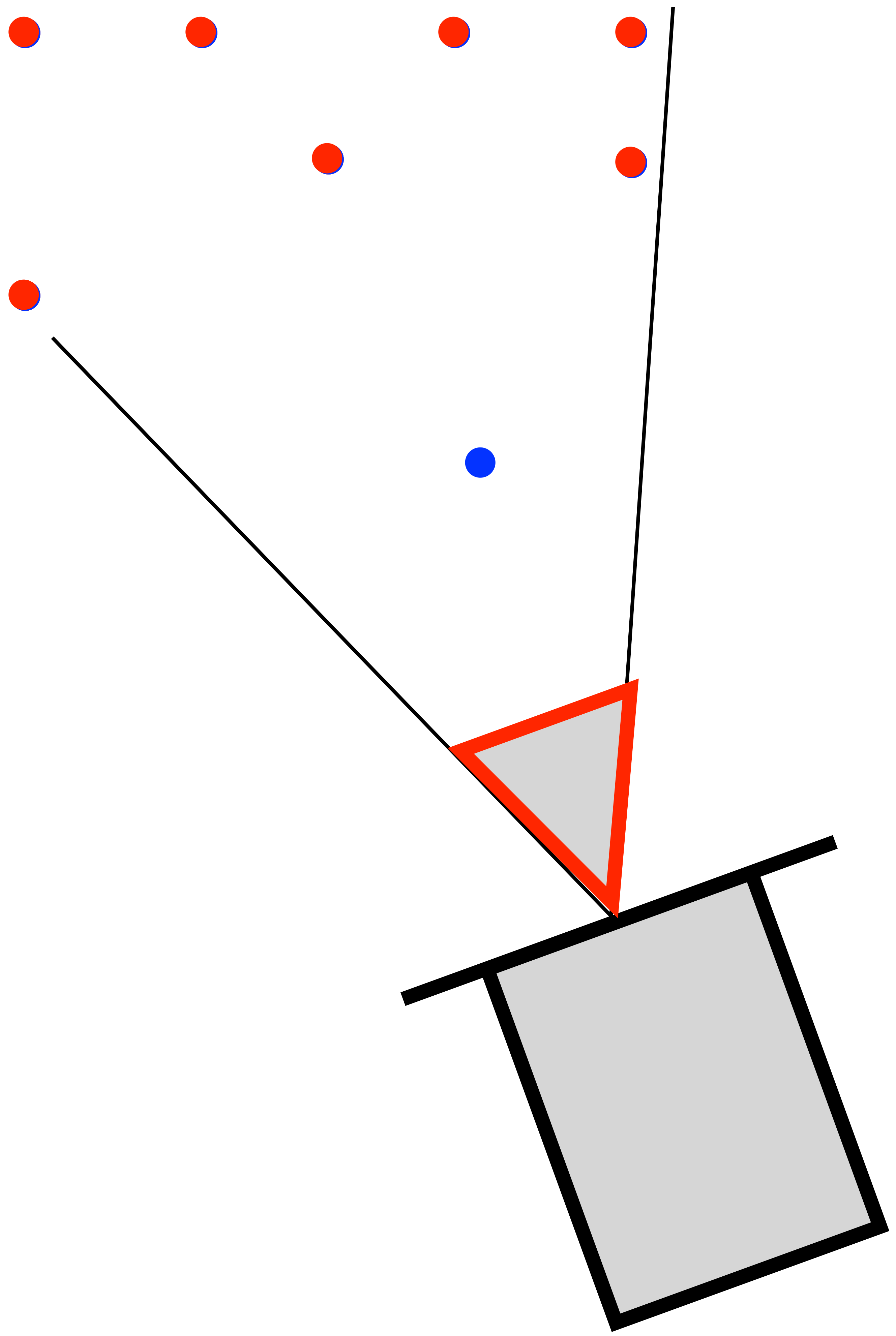


Input: pointcloud $\mathbf{q}_i$
pointcloud $\mathbf{p}_i$
correspondences $c(i)$

1. Solve absolute orientation:

$$\mathbf{R}^\star, \mathbf{t}^\star, = \underset{\mathbf{R}\in SO(3),\mathbf{t}}{\arg\min} \sum_i \| \mathbf{R}\mathbf{p}_i + \mathbf{t} - \mathbf{q}_{c(i)} \|^2$$

Pose from **known** correspondences



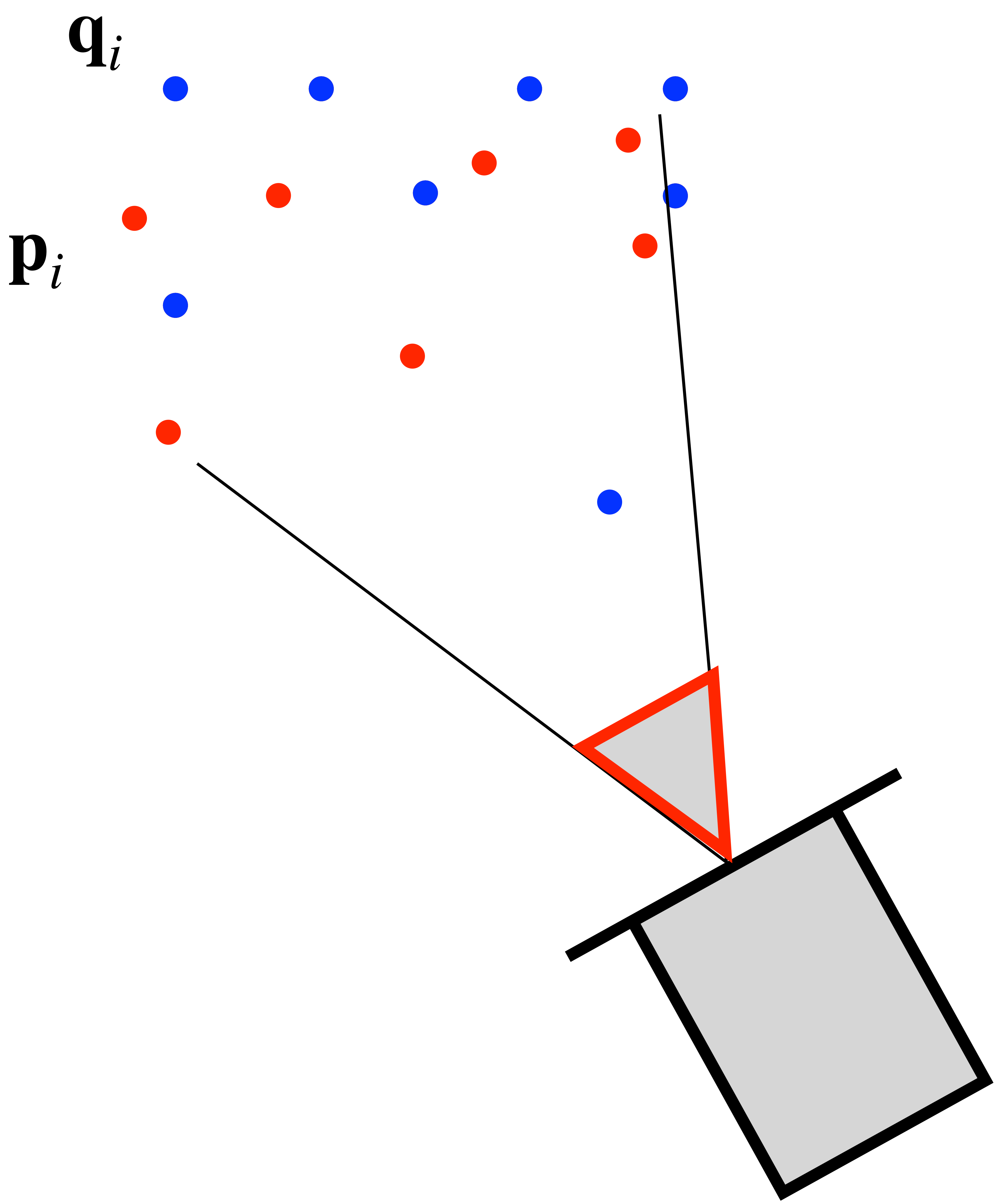
Input: pointcloud $\mathbf{q}_i$
pointcloud $\mathbf{p}_i$
correspondences $c(i)$

1. Solve absolute orientation:

$$\mathbf{R}^\star, \mathbf{t}^\star, = \underset{\mathbf{R}\in SO(3),\mathbf{t}}{\arg\min} \sum_i \left\| \mathbf{R}\mathbf{p}_i + \mathbf{t} - \mathbf{q}_{c(i)} \right\|^2$$

Output: $\mathbf{R}^\star, \mathbf{t}^\star \Rightarrow \mathbf{z}_t^v$

Pose from **unknown** correspondences

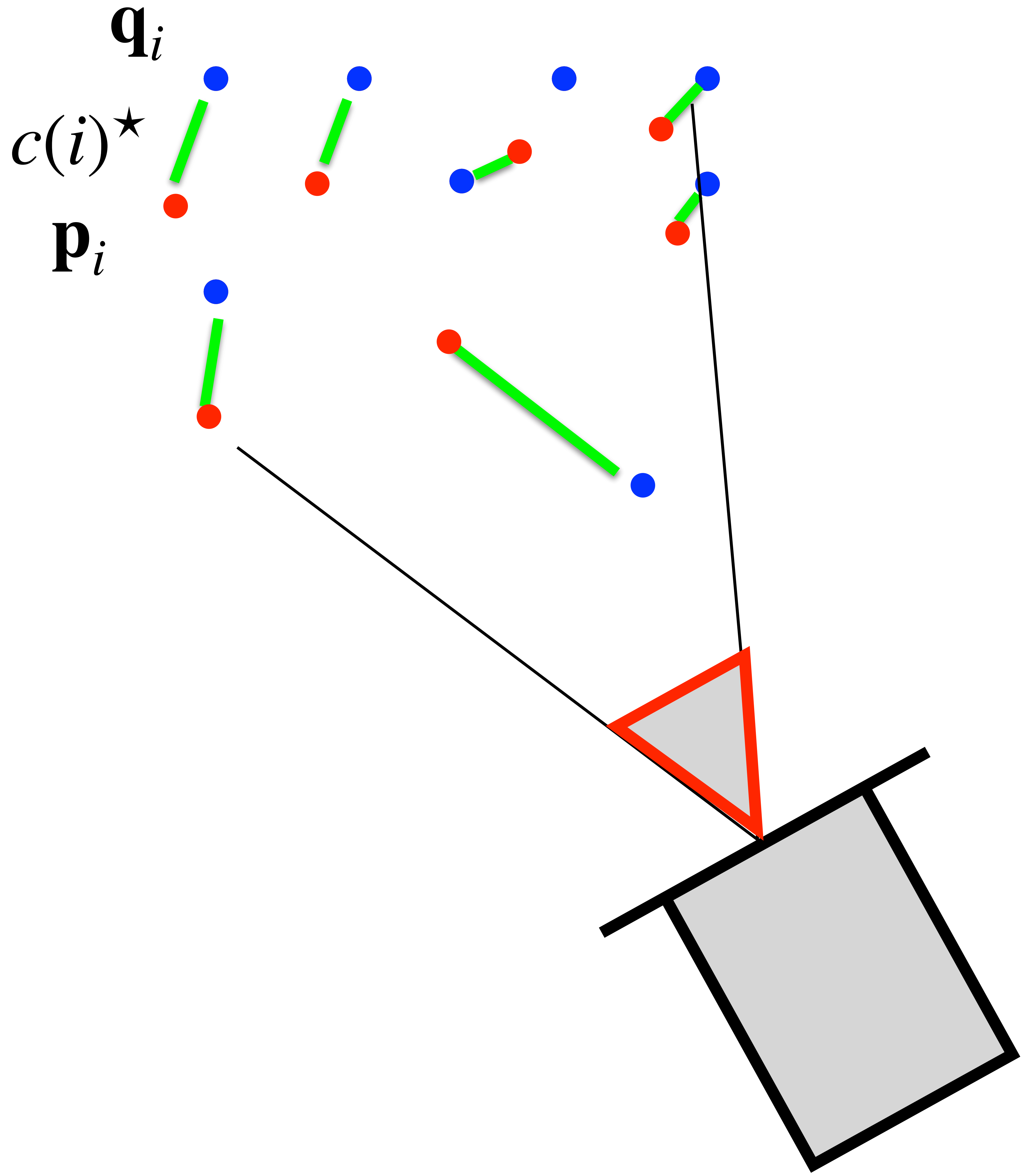


Input: pointcloud $\mathbf{q}_i$
pointcloud $\mathbf{p}_i$
~~correspondences $c(i)$~~

1. Initialize $\mathbf{R}^\star = \mathbf{R}_0, \mathbf{t}^\star = \mathbf{t}_0$
2. Solve nearest neighbour:

$$c(i)^\star = \arg\min_{c(i)} \sum_i \left\| \mathbf{R}^\star \mathbf{p}_i + \mathbf{t}^\star - \mathbf{q}_{c(i)} \right\|^2$$

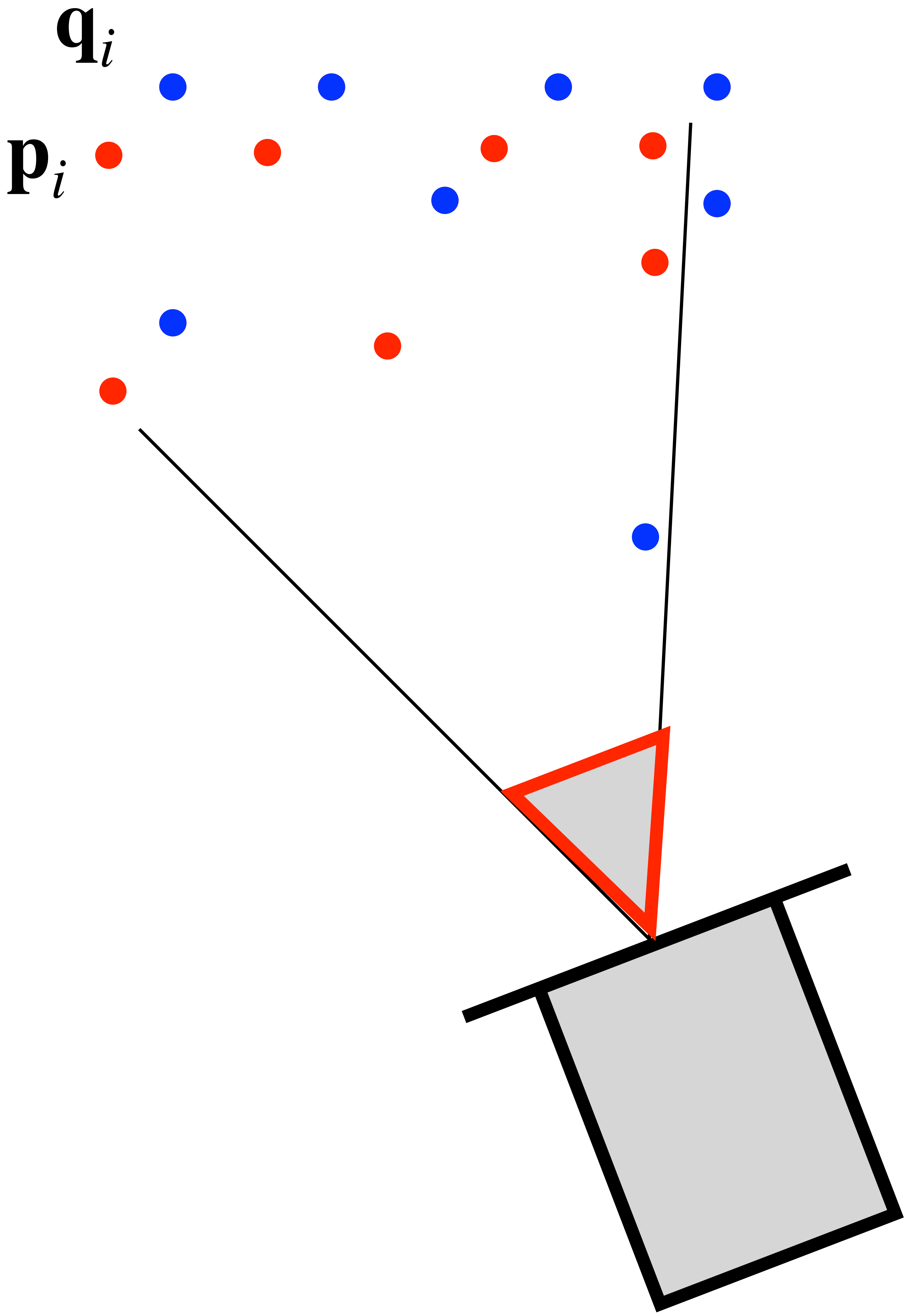
Pose from **unknown** correspondences



Input: pointcloud $\mathbf{q}_i$
pointcloud $\mathbf{p}_i$
~~correspondences $c(i)$~~

1. Initialize $\mathbf{R}^\star = \mathbf{R}_0, \mathbf{t}^\star = \mathbf{t}_0$
2. Solve nearest neighbour:
$$c(i)^\star = \underset{c(i)}{\arg\min} \sum_i \left\| \mathbf{R}^\star \mathbf{p}_i + \mathbf{t}^\star - \mathbf{q}_{c(i)} \right\|^2$$
3. Solve absolute orientation:
$$\mathbf{R}^\star, \mathbf{t}^\star, = \underset{\mathbf{R}\in SO(3),\mathbf{t}}{\arg\min} \sum_i \left\| \mathbf{R}\mathbf{p}_i + \mathbf{t} - \mathbf{q}_{c(i)^\star} \right\|^2$$

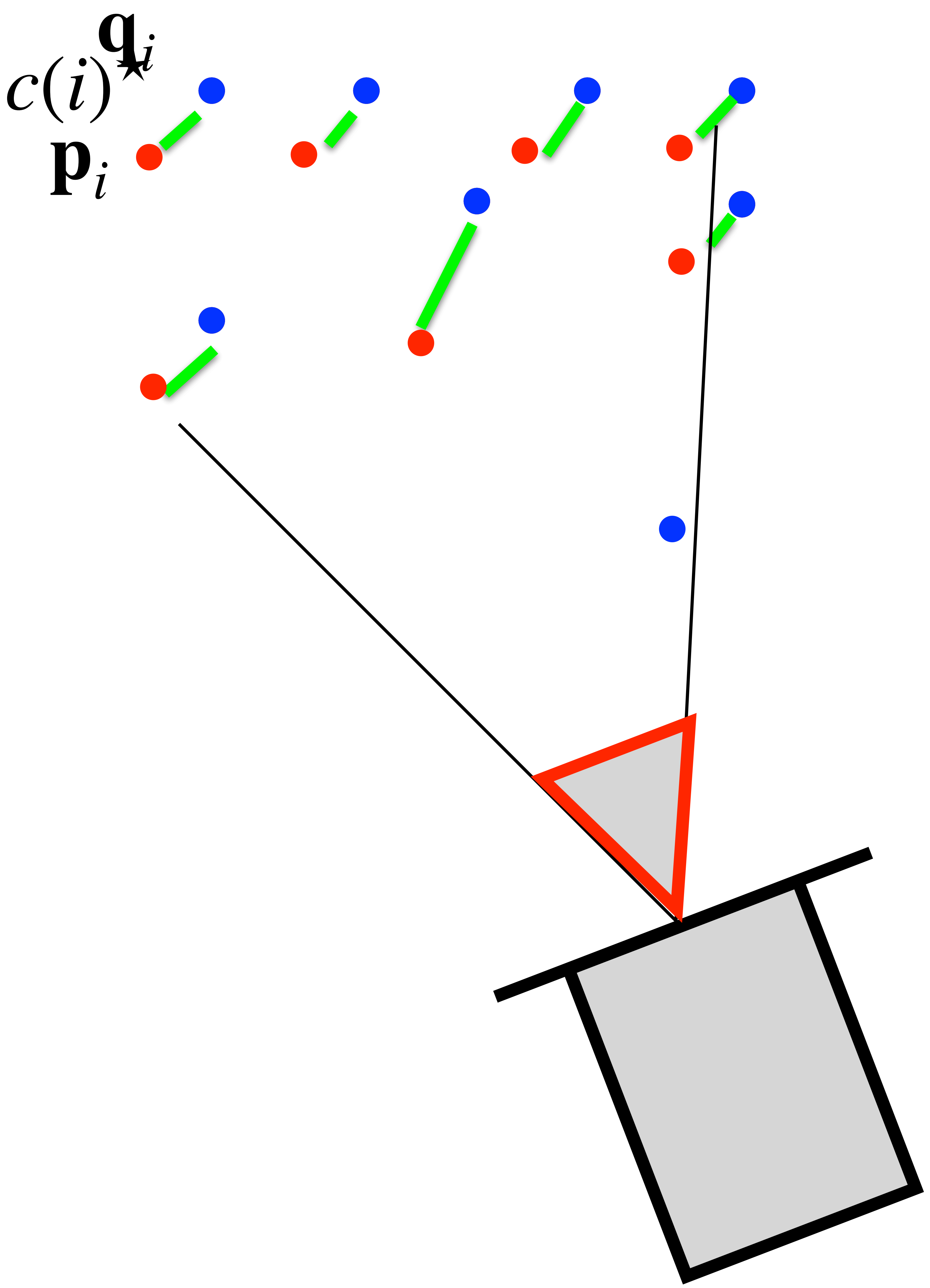
Pose from **unknown** correspondences



Input: pointcloud $\mathbf{q}_i$
pointcloud $\mathbf{p}_i$
~~correspondences $c(i)$~~

1. Initialize $\mathbf{R}^\star = \mathbf{R}_0, \mathbf{t}^\star = \mathbf{t}_0$
2. Solve nearest neighbour:
$$c(i)^\star = \arg\min_{c(i)} \sum_i \left\| \mathbf{R}^\star \mathbf{p}_i + \mathbf{t}^\star - \mathbf{q}_{c(i)} \right\|^2$$
3. Solve absolute orientation:
$$\mathbf{R}^\star, \mathbf{t}^\star, = \arg\min_{\mathbf{R}\in SO(3),\mathbf{t}} \sum_i \left\| \mathbf{R}\mathbf{p}_i + \mathbf{t} - \mathbf{q}_{c(i)^\star} \right\|^2$$

Pose from **unknown** correspondences



Input: pointcloud $\mathbf{q}_i$

pointcloud $\mathbf{p}_i$

~~correspondences $c(i)$~~

1. Initialize $\mathbf{R}^\star = \mathbf{R}_0,\ \mathbf{t}^\star = \mathbf{t}_0$

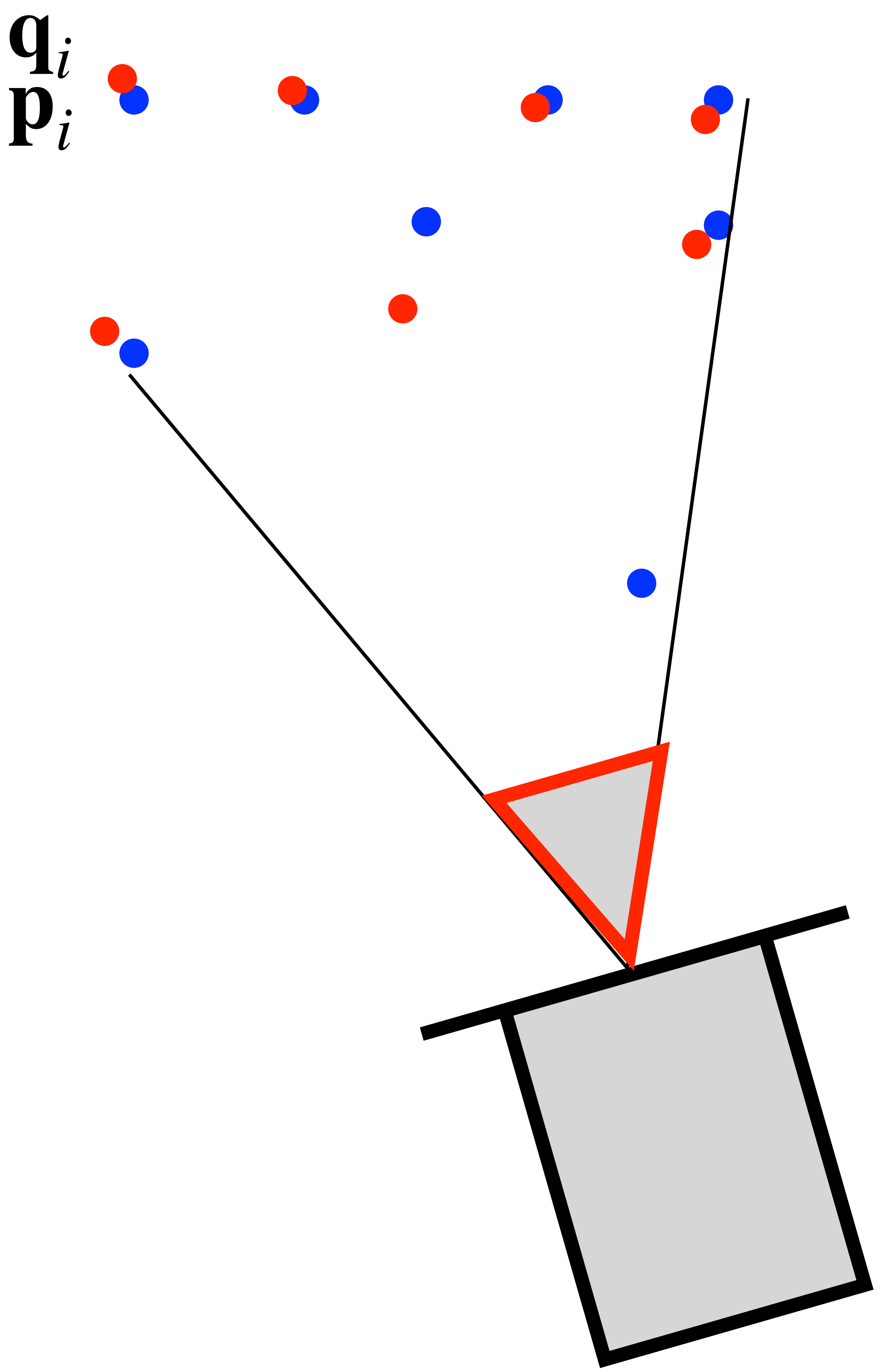
2. Solve nearest neighbour:

$$c(i)^\star = \underset{c(i)}{\arg\min} \sum_i \left\| \mathbf{R}^\star \mathbf{p}_i + \mathbf{t}^\star - \mathbf{q}_{c(i)} \right\|^2$$

3. Solve absolute orientation:

$$\mathbf{R}^\star, \mathbf{t}^\star, = \underset{\mathbf{R}\in SO(3),\mathbf{t}}{\arg\min} \sum_i \left\| \mathbf{R}\mathbf{p}_i + \mathbf{t} - \mathbf{q}_{c(i)^\star} \right\|^2$$

Pose from **unknown** correspondences



Input: pointcloud $\mathbf{q}_i$

pointcloud $\mathbf{p}_i$

~~correspondences $c(i)$~~

1. Initialize $\mathbf{R}^\star = \mathbf{R}_0, \mathbf{t}^\star = \mathbf{t}_0$

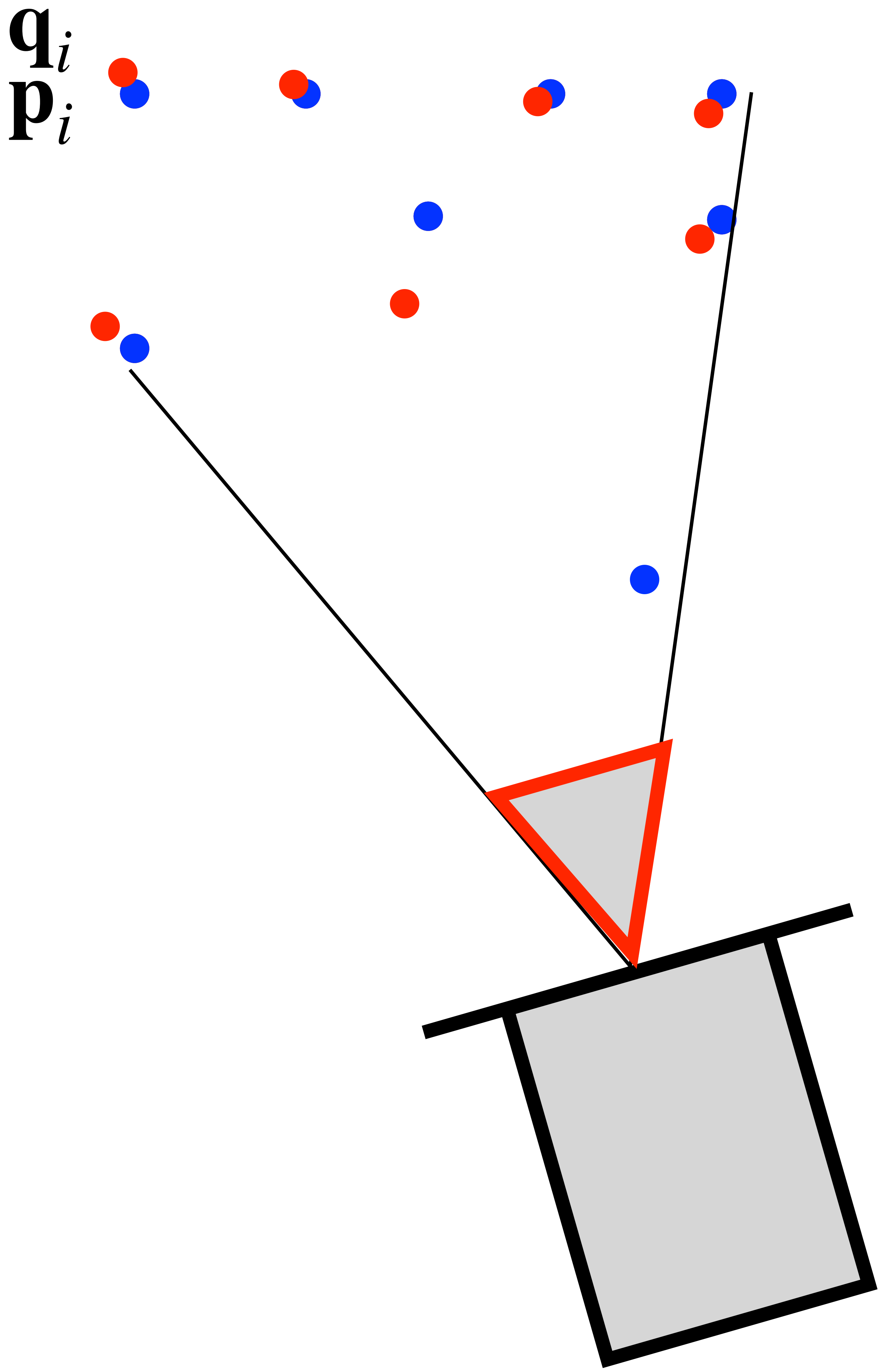
2. Solve nearest neighbour:

$$c(i)^\star = \arg\min_{c(i)} \sum_i \left\| \mathbf{R}^\star \mathbf{p}_i + \mathbf{t}^\star - \mathbf{q}_{c(i)} \right\|^2$$

3. Solve absolute orientation:

$$\mathbf{R}^\star, \mathbf{t}^\star, = \arg\min_{\mathbf{R} \in SO(3), \mathbf{t}} \sum_i \left\| \mathbf{R}\mathbf{p}_i + \mathbf{t} - \mathbf{q}_{c(i)^\star} \right\|^2$$

Pose from **unknown** correspondences



Input: pointcloud $\mathbf{q}_i$
pointcloud $\mathbf{p}_i$
~~correspondences $c(i)$~~

1. Initialize $\mathbf{R}^\star = \mathbf{R}_0, \mathbf{t}^\star = \mathbf{t}_0$
2. Solve nearest neighbour:

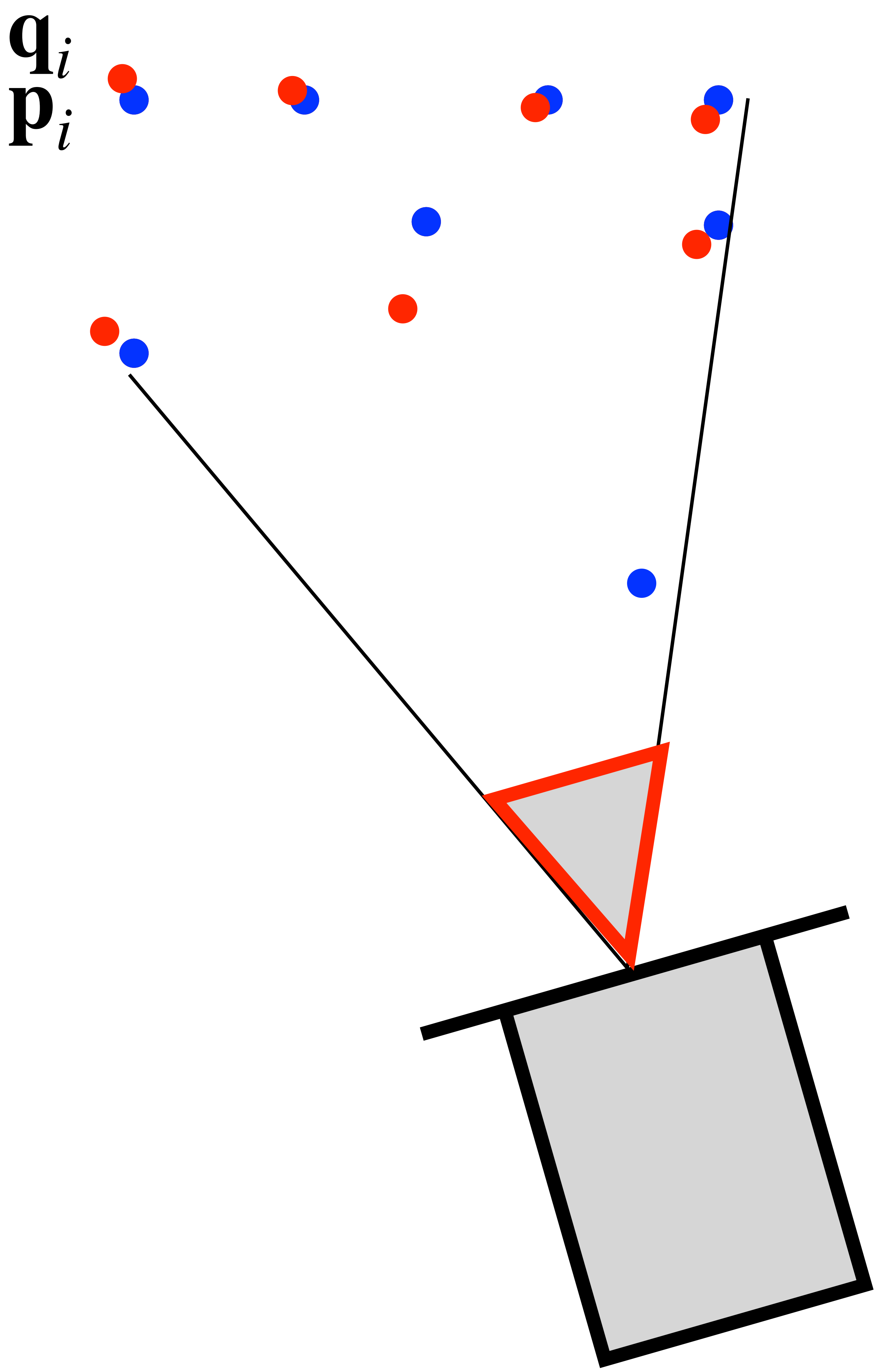
$$c(i)^\star = \arg\min_{c(i)} \sum_i \left\| \mathbf{R}^\star \mathbf{p}_i + \mathbf{t}^\star - \mathbf{q}_{c(i)} \right\|^2$$

3. Solve absolute orientation:

$$\mathbf{R}^\star, \mathbf{t}^\star, = \arg\min_{\mathbf{R}\in SO(3),\mathbf{t}} \sum_i \left\| \mathbf{R}\mathbf{p}_i + \mathbf{t} - \mathbf{q}_{c(i)^\star} \right\|^2$$

Output: $\mathbf{R}^\star, \mathbf{t}^\star \Rightarrow \mathbf{z}_t^v$

Pose from **unknown** correspondences with **outlier** rejection



Input: pointcloud $\mathbf{q}_i$
pointcloud $\mathbf{p}_i$
~~correspondences $c(i)$~~

1. Initialize $\mathbf{R}^\star = \mathbf{R}_0, \mathbf{t}^\star = \mathbf{t}_0$

2. Solve nearest neighbour:

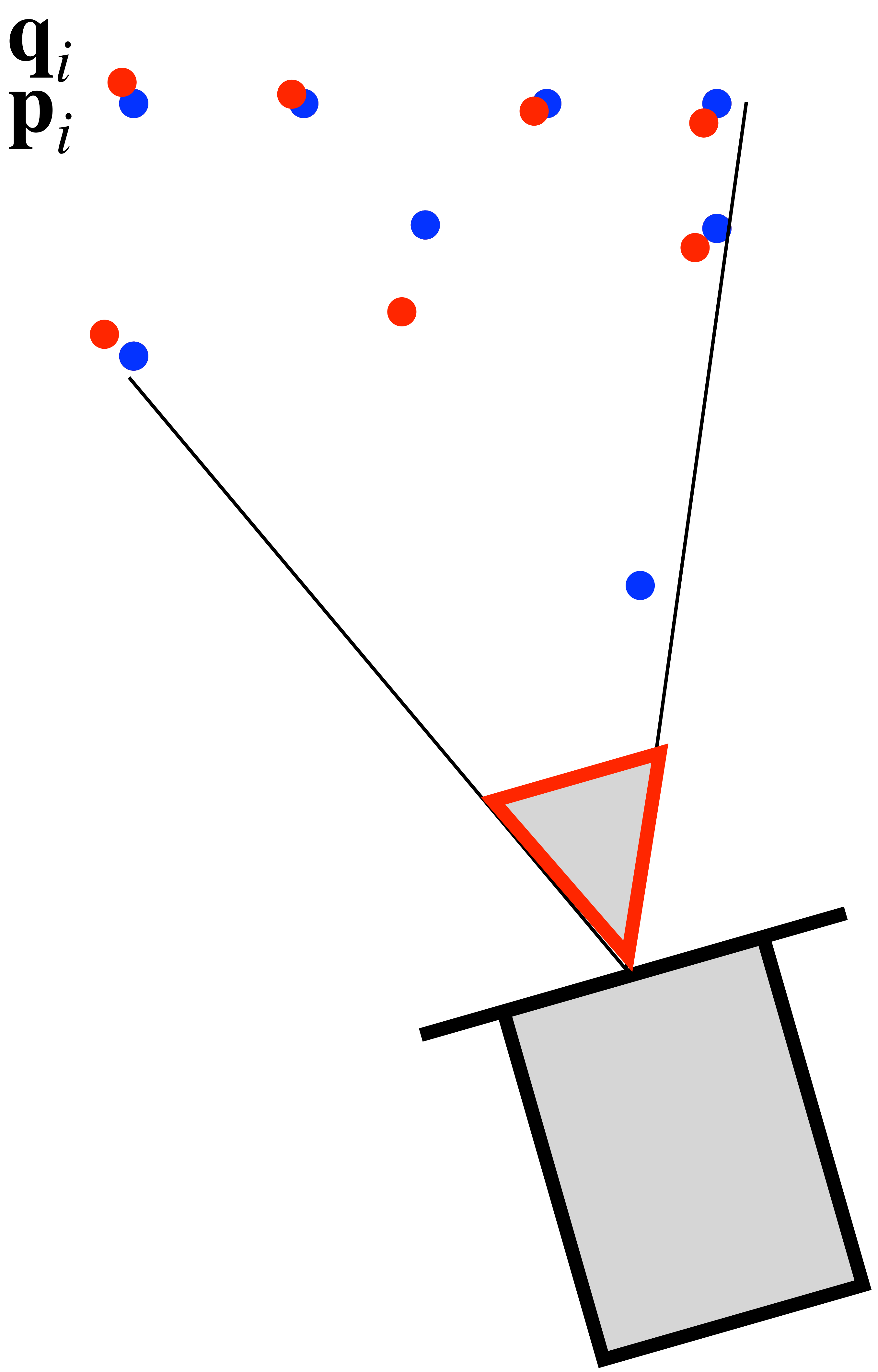
$$c(i)^\star = \arg\min_{c(i)} \sum_i \left\| \mathbf{R}^\star \mathbf{p}_i + \mathbf{t}^\star - \mathbf{q}_{c(i)} \right\|^2$$

3. Solve absolute orientation:

$$\mathbf{R}^\star, \mathbf{t}^\star, = \arg\min_{\mathbf{R} \in SO(3), \mathbf{t}} \sum_i \left\| \mathbf{R}\mathbf{p}_i + \mathbf{t} - \mathbf{q}_{c(i)^\star} \right\|^2$$

Output: $\mathbf{R}^\star, \mathbf{t}^\star \Rightarrow \mathbf{z}_t^v$

Pose from **unknown** correspondences with **outlier** rejection



Input: pointcloud $\mathbf{q}_i$
pointcloud $\mathbf{p}_i$
~~correspondences $c(i)$~~

1. Initialize $\mathbf{R}^\star = \mathbf{R}_0, \mathbf{t}^\star = \mathbf{t}_0$
2. Solve nearest neighbour:

$$c(i)^\star = \arg\min_{c(i)} \sum_i \left\| \mathbf{R}^\star \mathbf{p}_i + \mathbf{t}^\star - \mathbf{q}_{c(i)} \right\|^2$$

3. Outlier rejection by median thresholding:

`if` $\|\mathbf{R}^\star \mathbf{p}_i + \mathbf{t}^\star - \mathbf{q}_{c(i)^\star}\|^2 \geq \theta$ `then` $c(i)^\star =$ 🗑

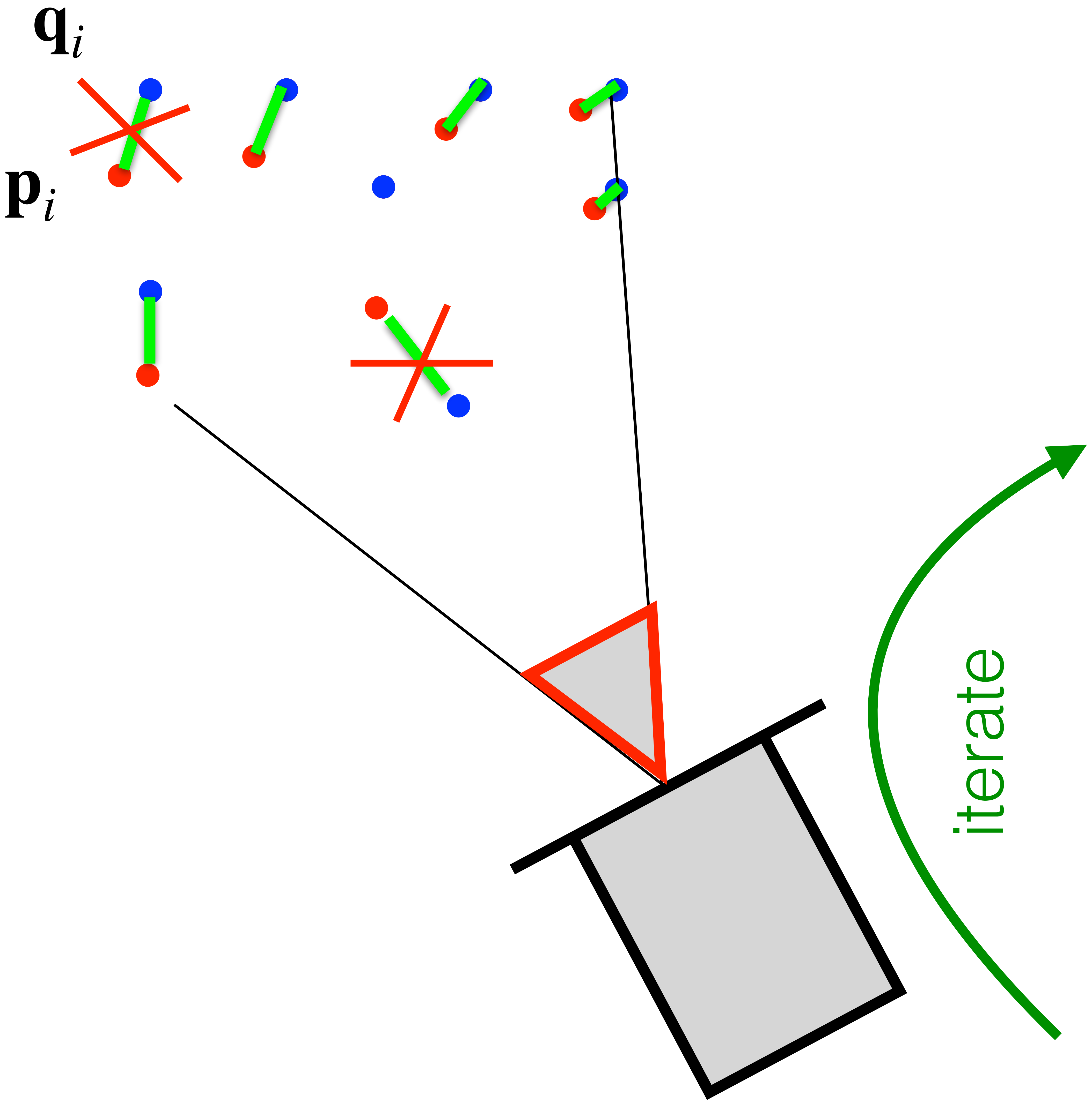
4. Solve absolute orientation:

$$\mathbf{R}^\star, \mathbf{t}^\star, = \arg\min_{\mathbf{R} \in SO(3), \mathbf{t}} \sum_i \left\| \mathbf{R} \mathbf{p}_i + \mathbf{t} - \mathbf{q}_{c(i)^\star} \right\|^2$$

iterate

Output: $\mathbf{R}^\star, \mathbf{t}^\star \;\Rightarrow\; \mathbf{z}_t^v$

Pose from **unknown** correspondences with **outlier** rejection

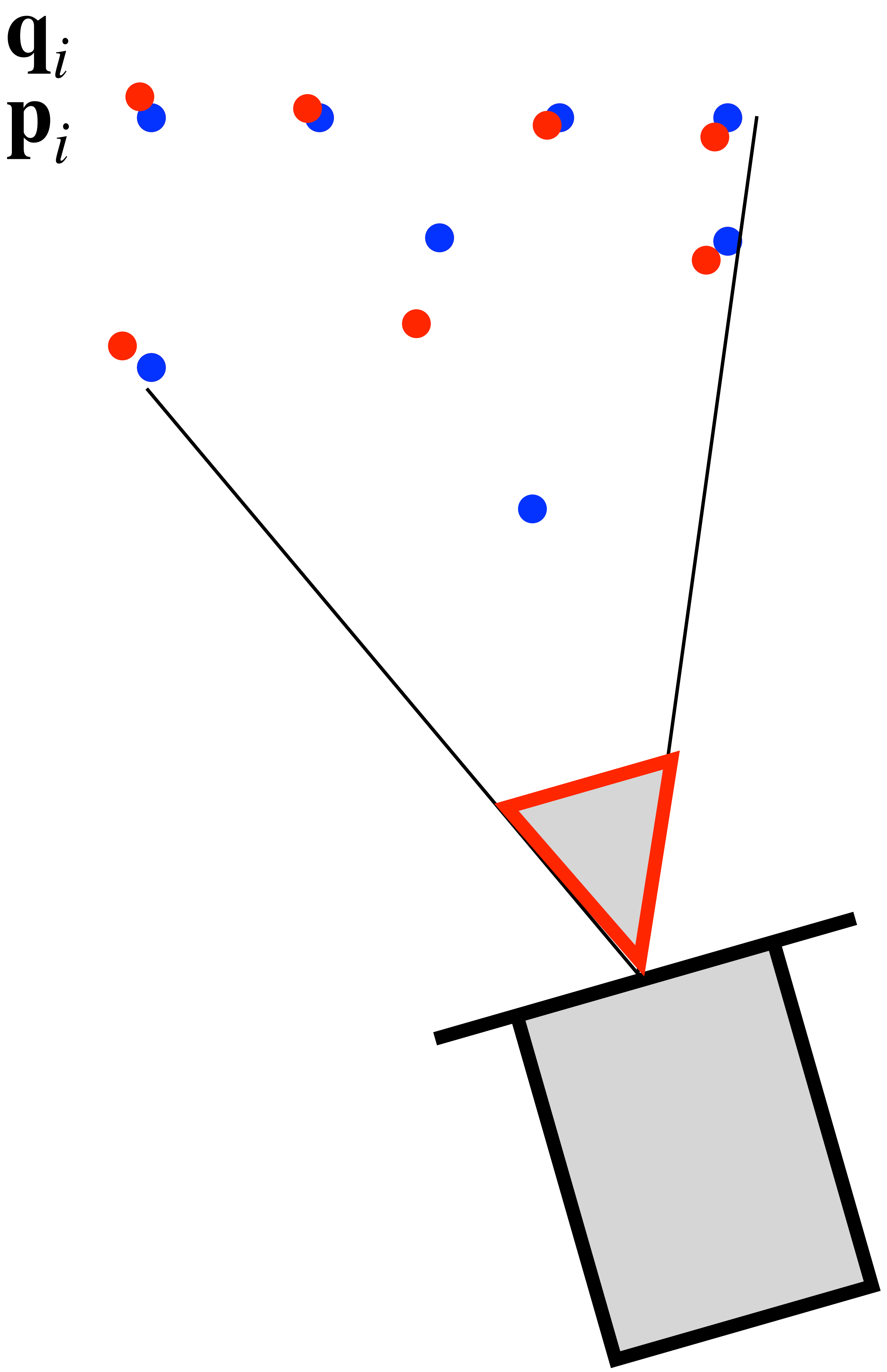


Input: pointcloud $\mathbf{q}_i$
pointcloud $\mathbf{p}_i$
~~correspondences $c(i)$~~

1. Initialize $\mathbf{R}^\star = \mathbf{R}_0, \mathbf{t}^\star = \mathbf{t}_0$
2. Solve nearest neighbour:
$$c(i)^\star = \arg\min_{c(i)} \sum_i \left\| \mathbf{R}^\star \mathbf{p}_i + \mathbf{t}^\star - \mathbf{q}_{c(i)} \right\|^2$$
3. Outlier rejection by median thresholding:
`if` $\|\mathbf{R}^\star \mathbf{p}_i + \mathbf{t}^\star - \mathbf{q}_{c(i)^\star}\|^2 \geq \theta$ `then` $c(i)^\star =$ 🗑
4. Solve absolute orientation:
$$\mathbf{R}^\star, \mathbf{t}^\star, = \arg\min_{\mathbf{R}\in SO(3),\mathbf{t}} \sum_i \left\| \mathbf{R}\mathbf{p}_i + \mathbf{t} - \mathbf{q}_{c(i)^\star} \right\|^2$$

Output: $\mathbf{R}^\star, \mathbf{t}^\star \Rightarrow \mathbf{z}_t^v$

Pose from **unknown** correspondences with **outlier** rejection



ICP [1991]

Input: pointcloud $\mathbf{q}_i$

pointcloud $\mathbf{p}_i$

~~correspondences $c(i)$~~

1. Initialize $\mathbf{R}^\star = \mathbf{R}_0, \mathbf{t}^\star = \mathbf{t}_0$
2. Solve nearest neighbour:

$$c(i)^\star = \arg\min_{c(i)} \sum_i \left\| \mathbf{R}^\star \mathbf{p}_i + \mathbf{t}^\star - \mathbf{q}_{c(i)} \right\|^2$$

3. Outlier rejection by median thresholding:

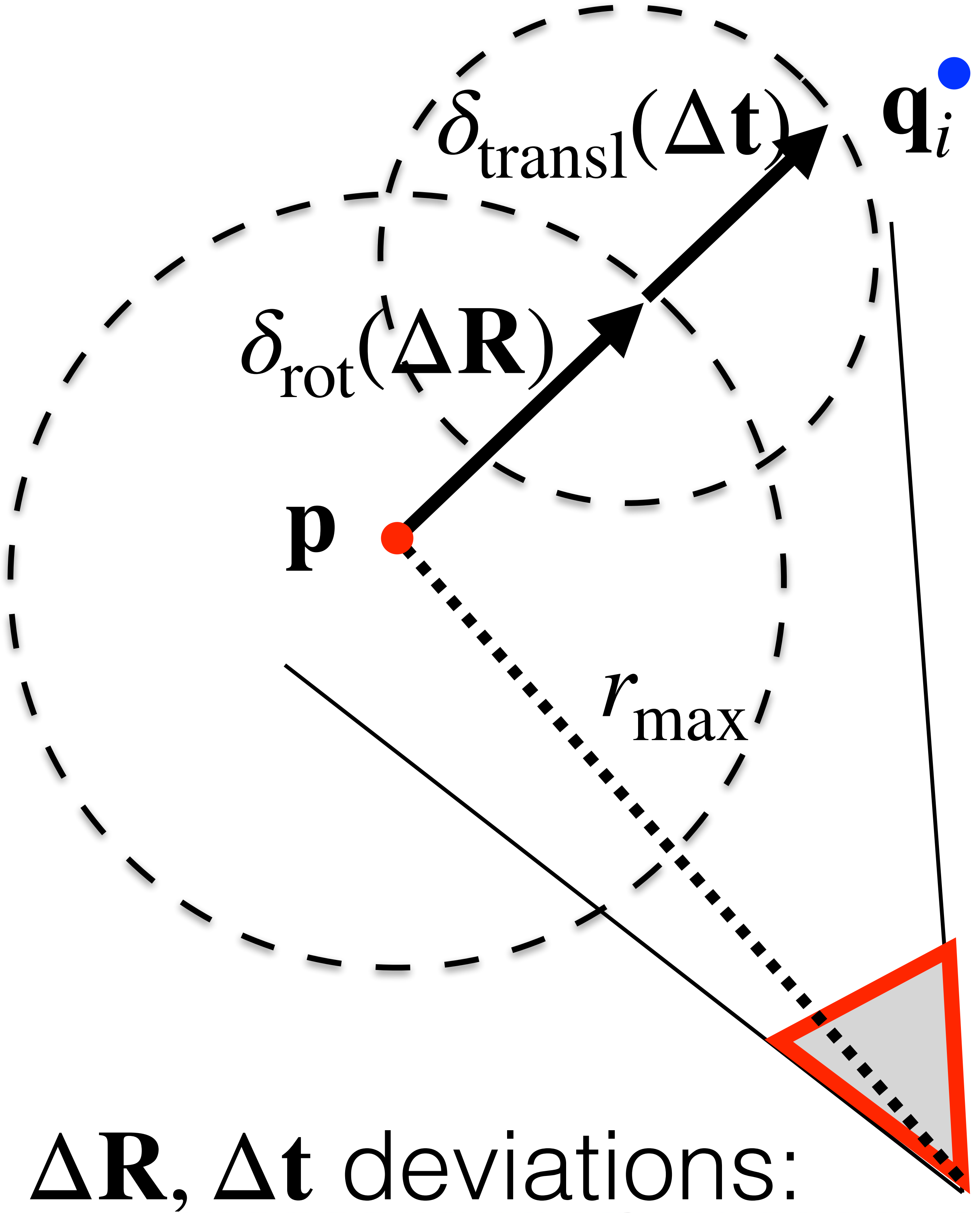
`if` $\|\mathbf{R}^\star \mathbf{p}_i + \mathbf{t}^\star - \mathbf{q}_{c(i)^\star}\|^2 \geq \theta$ `then` $c(i)^\star =$ 🗑

4. Solve absolute orientation:

$$\mathbf{R}^\star, \mathbf{t}^\star, = \arg\min_{\mathbf{R} \in SO(3), \mathbf{t}} \sum_i \left\| \mathbf{R}\mathbf{p}_i + \mathbf{t} - \mathbf{q}_{c(i)^\star} \right\|^2$$

Output: $\mathbf{R}^\star, \mathbf{t}^\star \;\Rightarrow\; \mathbf{z}_t^v$

Pose from **unknown** correspondences with **outlier** rejection



Max $\Delta\mathbf{R}, \Delta\mathbf{t}$ deviations:

$$\delta_{\text{rot}}(\Delta\mathbf{R}) = 2\, r_{\max} \sin\left(\frac{1}{2}\arccos\left(\frac{\operatorname{tr}(\Delta R)-1}{2}\right)\right)$$

$$\delta_{\text{transl}}(\Delta\mathbf{t}) = \|\Delta\mathbf{t}\|$$

UB on outlier rejection threshold:

$$\theta = \delta_{\text{rot}}(\Delta\mathbf{R}) + \delta_{\text{transl}}(\Delta\mathbf{t})$$

KISS ICP [2023]

Input: pointcloud $\mathbf{q}_i$
pointcloud $\mathbf{p}_i$
~~correspondences $c(i)$~~

1. Initialize $\mathbf{R}^\star = \mathbf{R}_0, \mathbf{t}^\star = \mathbf{t}_0$
2. Solve nearest neighbour:

$$c(i)^\star = \arg\min_{c(i)} \sum_i \left\| \mathbf{R}^\star \mathbf{p}_i + \mathbf{t}^\star - \mathbf{q}_{c(i)} \right\|^2$$

3. Outlier rejection by median thresholding:

`if` $\|\mathbf{R}^\star\mathbf{p}_i + \mathbf{t}^\star - \mathbf{q}_{c(i)^\star}\|^2 \geq \theta$ `then` $c(i)^\star =$ 🗑

Solve absolute orientation:

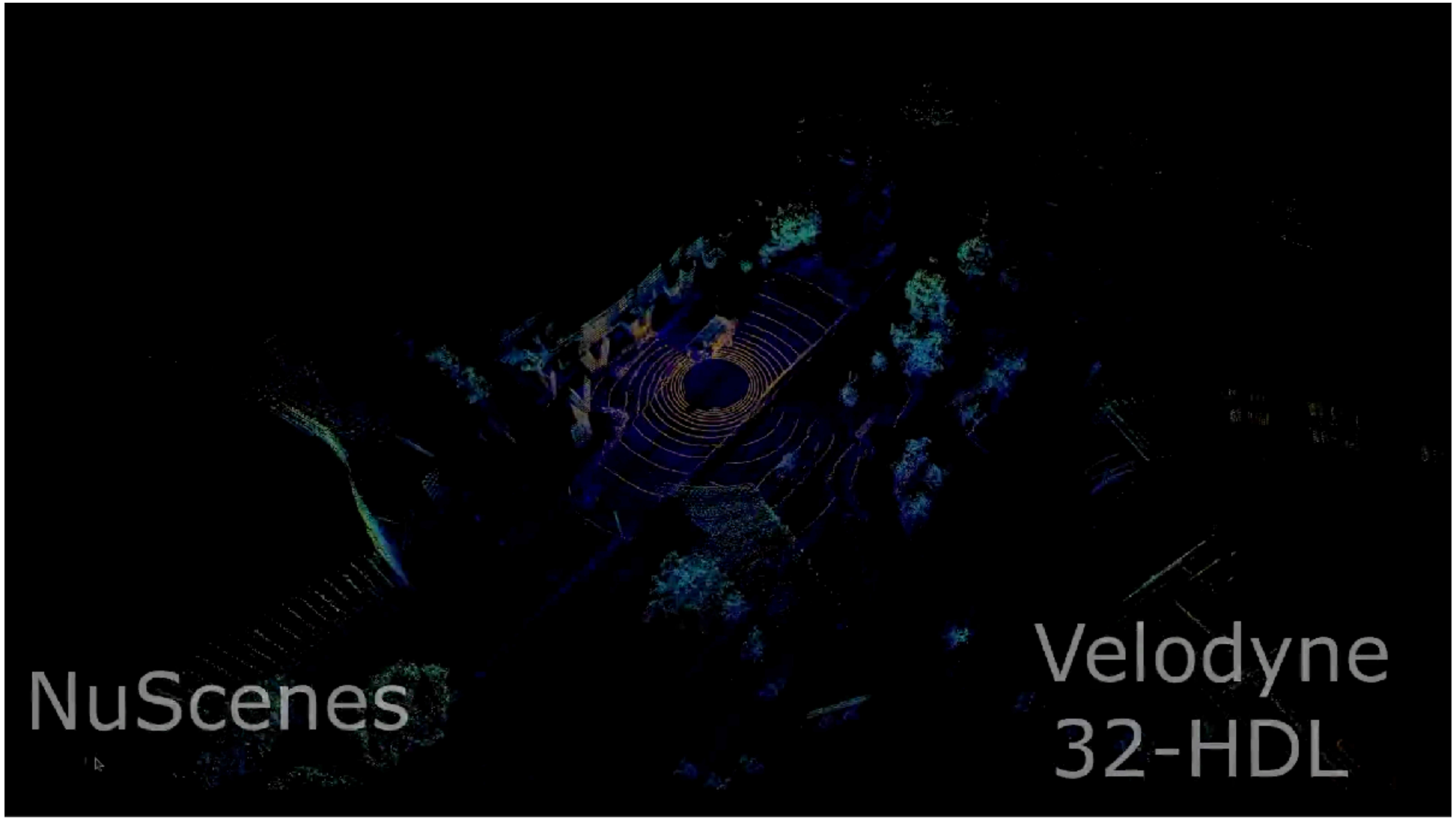
$$\mathbf{R}^\star, \mathbf{t}^\star, = \arg\min_{\mathbf{R}\in SO(3),\mathbf{t}} \sum_i \rho\left(\left\| \mathbf{R}\mathbf{p}_i + \mathbf{t} - \mathbf{q}_{c(i)^\star} \right\|^2 \right)$$

Output: $\mathbf{R}^\star, \mathbf{t}^\star \Rightarrow \mathbf{z}_t^v$

https://arxiv.org/pdf/2209.15397.pdf

Pose from **unknown** correspondences with **outlier** rejection
KISS ICP [2023]

- Good generalization (same params for various car/drone/segway/handheld lidars)
- ROS compatible code: https://github.com/PRBonn/kiss-icp
- Second best opensource approach on autonomous driving dataset challenge (Kitti



Why do they show results on autonomous car dataset?

ICP SLAM - known issues

- Converges to a local minima with unknown region of convergence
  => good initialization needed

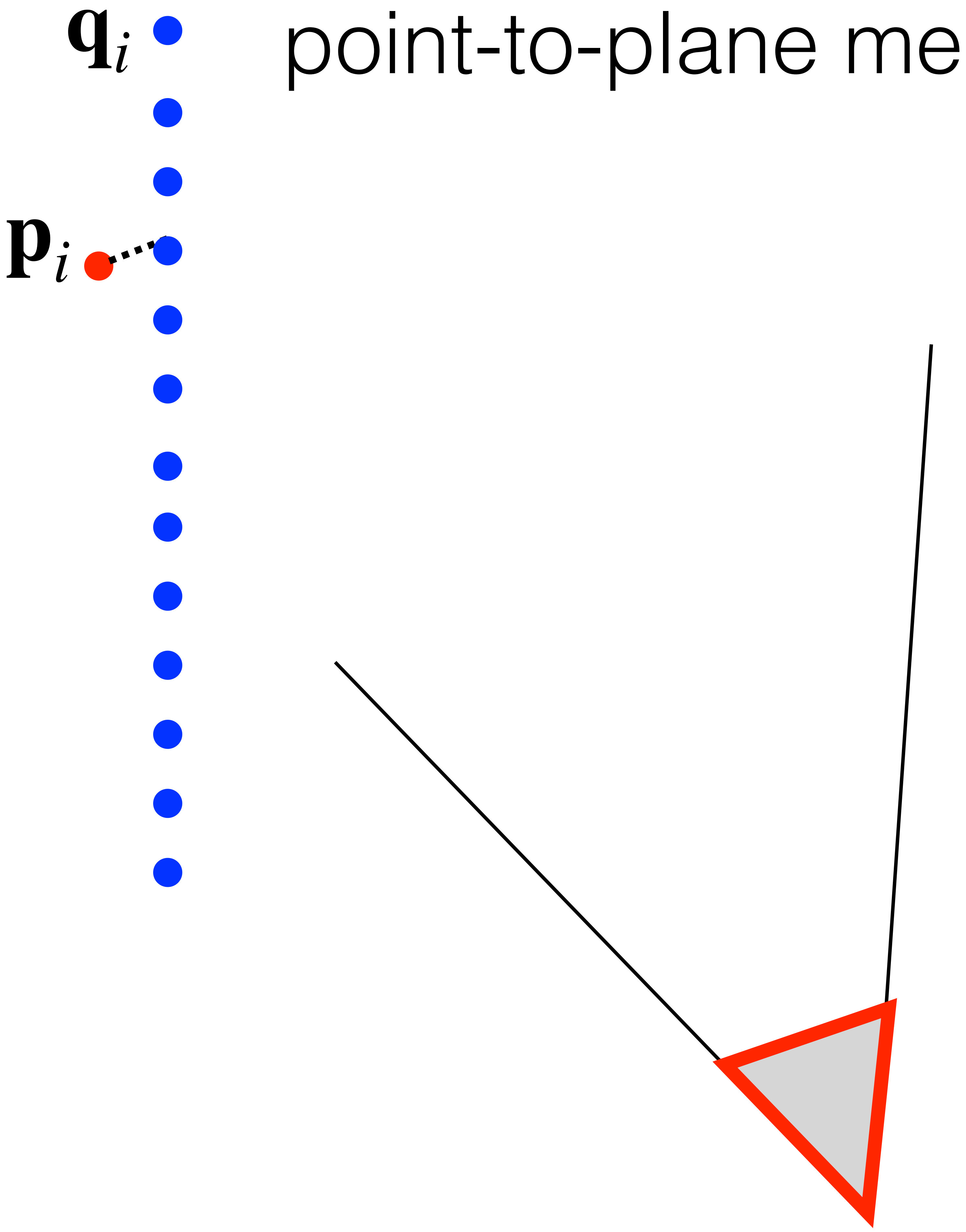
ICP SLAM - known issues

- Converges to a local minima with unknown region of convergence
  => good initialization needed
- Fails in degenerate environments
  (e.g. forward motion in long hallways, or rotation in circular room)
  => other models (point2plane) and sensors (camera) often introduced.

ICP SLAM - known issues

- Converges to a local minima with unknown region of convergence
  => good initialization needed
- Fails in degenerate environments
  (e.g. forward motion in long hallways, or rotation in circular room)
  => other models (point2plane) and sensors (camera) often introduced.

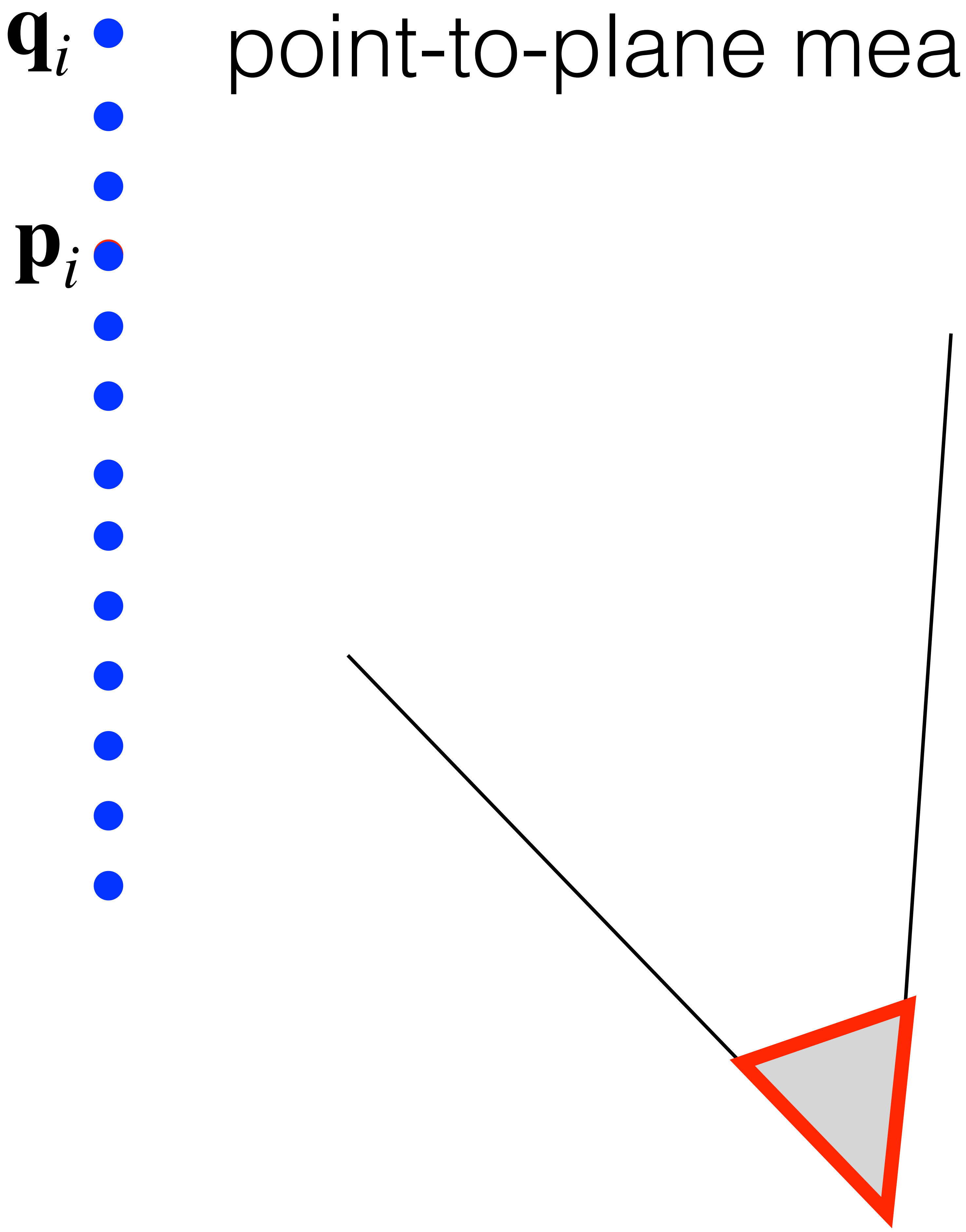
point-to-plane measurement probability model



Absolute orientation:

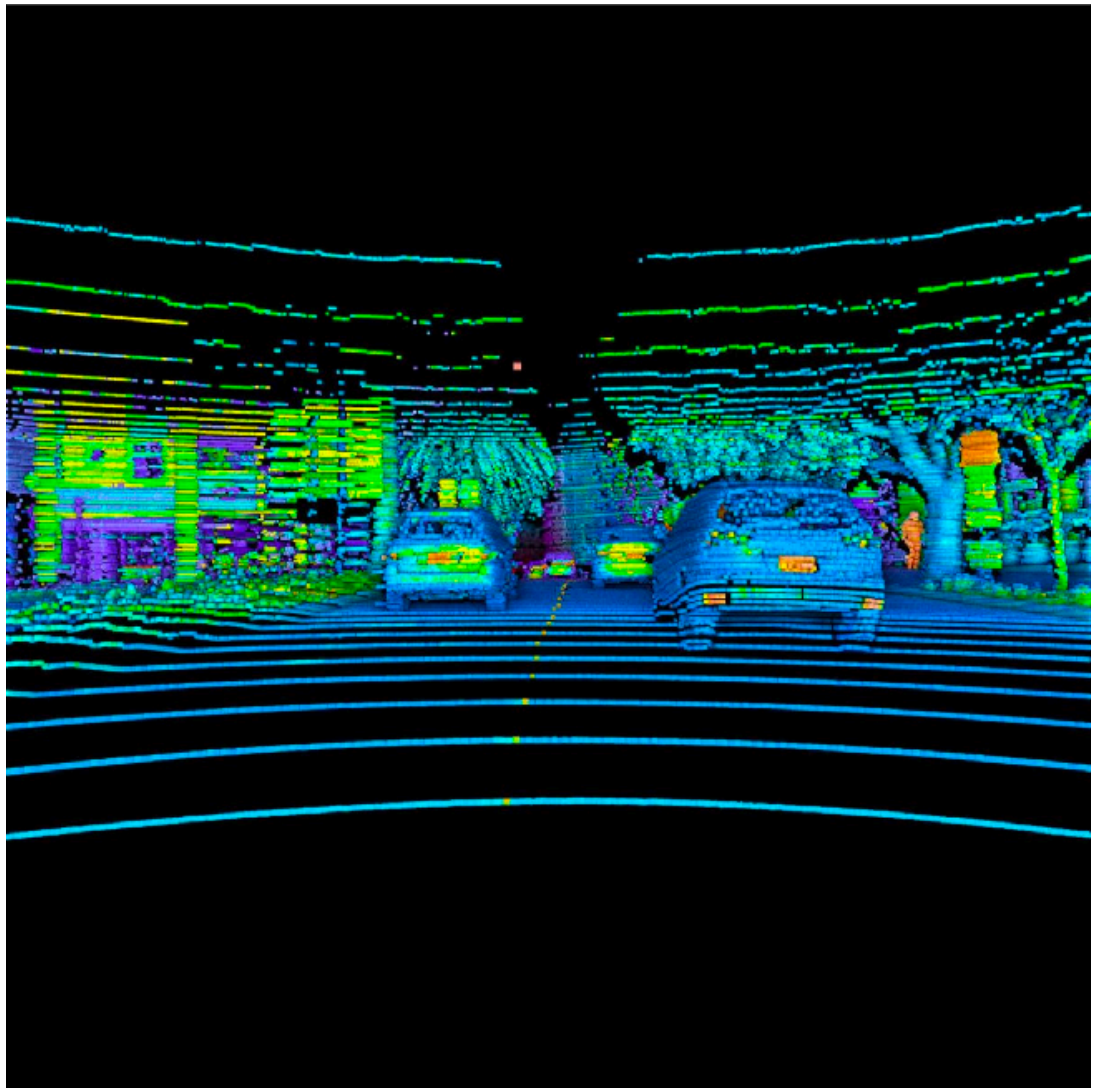
$$\mathbf{R}^{\star}, \mathbf{t}^{\star}, = \underset{\mathbf{R}\in SO(3),\mathbf{t}}{\arg\min} \sum_{i} \left\| \mathbf{R}\mathbf{p}_i + \mathbf{t} - \mathbf{q}_i \right\|^2$$

point-to-plane measurement probability model

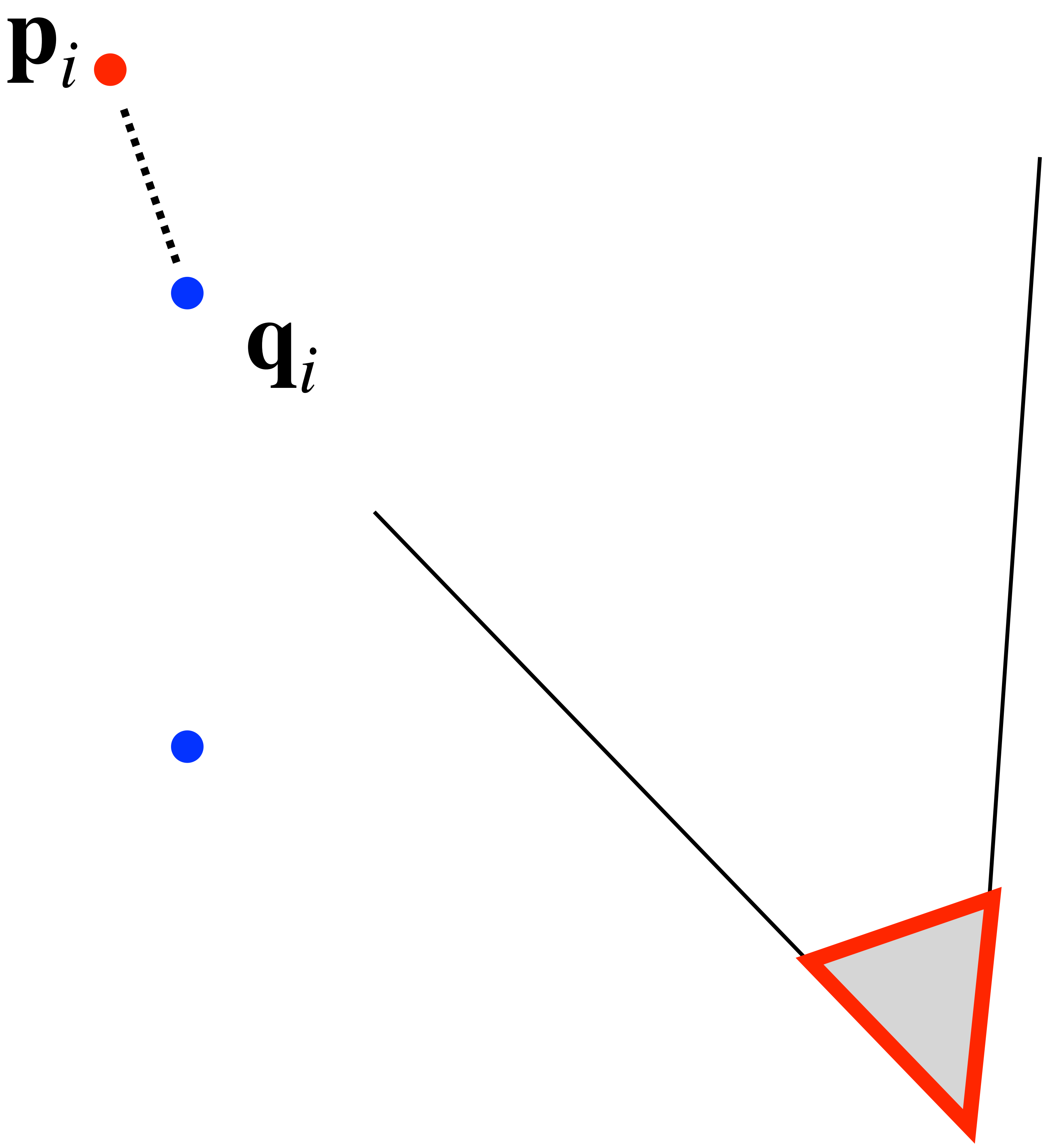


Absolute orientation:

$$\mathbf{R}^\star, \mathbf{t}^\star, = \operatorname*{arg\,min}_{\mathbf{R}\in SO(3),\mathbf{t}} \sum_i \left\| \mathbf{R}\mathbf{p}_i + \mathbf{t} - \mathbf{q}_i \right\|^2$$

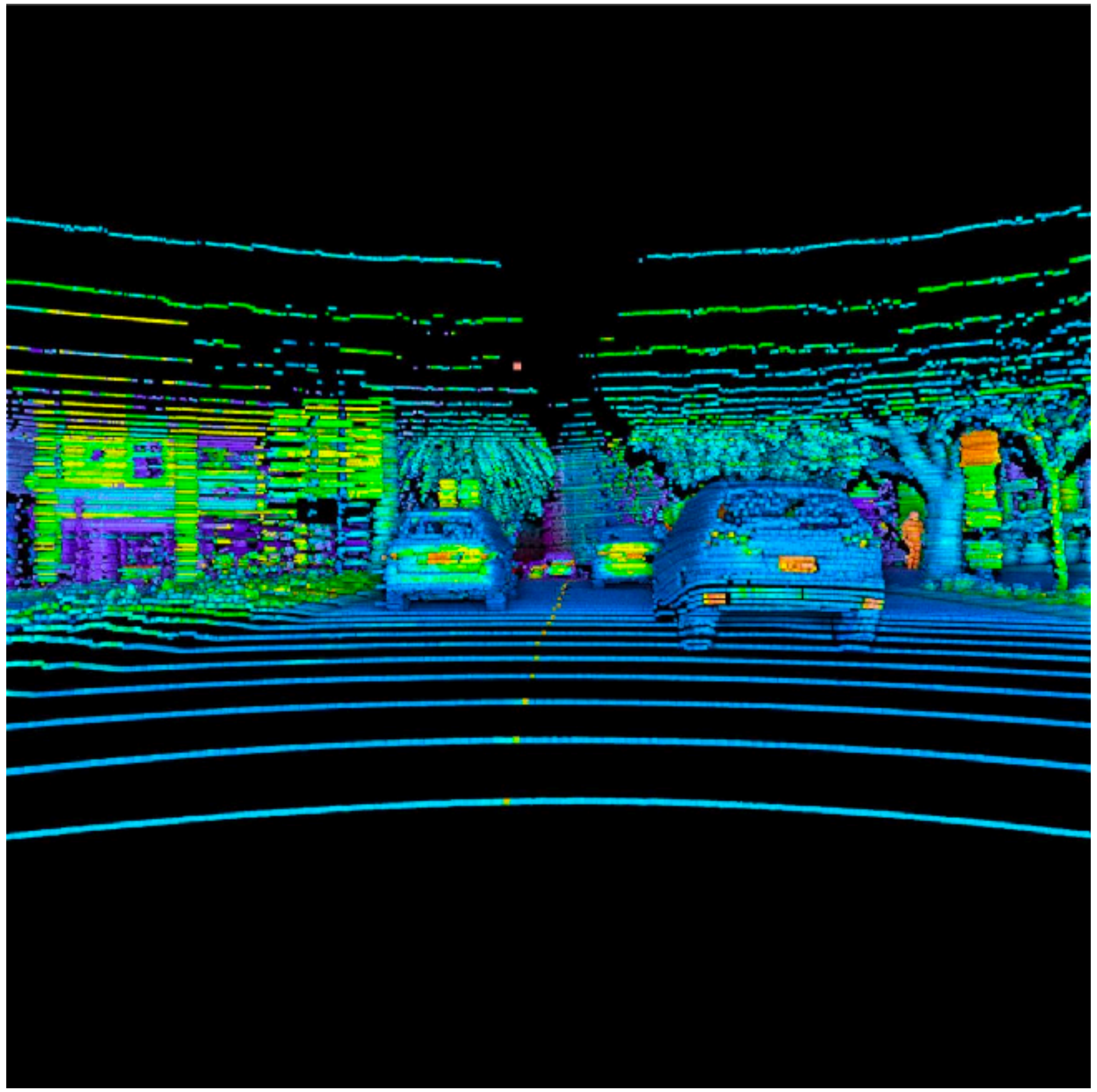


- point-to-plane measurement probability model

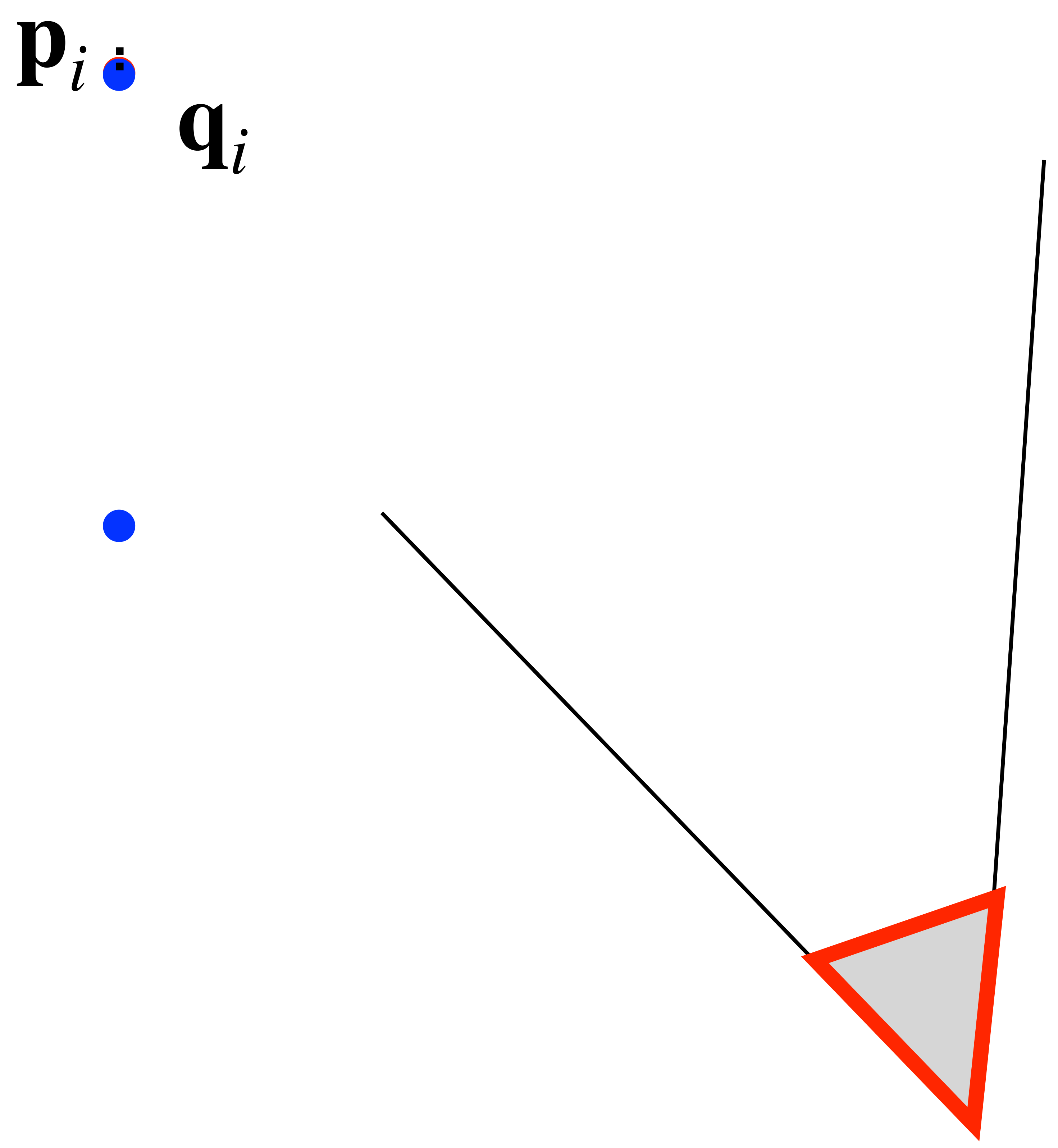


Absolute orientation:

$$\mathbf{R}^\star, \mathbf{t}^\star, = \underset{\mathbf{R}\in SO(3),\mathbf{t}}{\arg\min} \sum_i \left\| \mathbf{R}\mathbf{p}_i + \mathbf{t} - \mathbf{q}_i \right\|^2$$

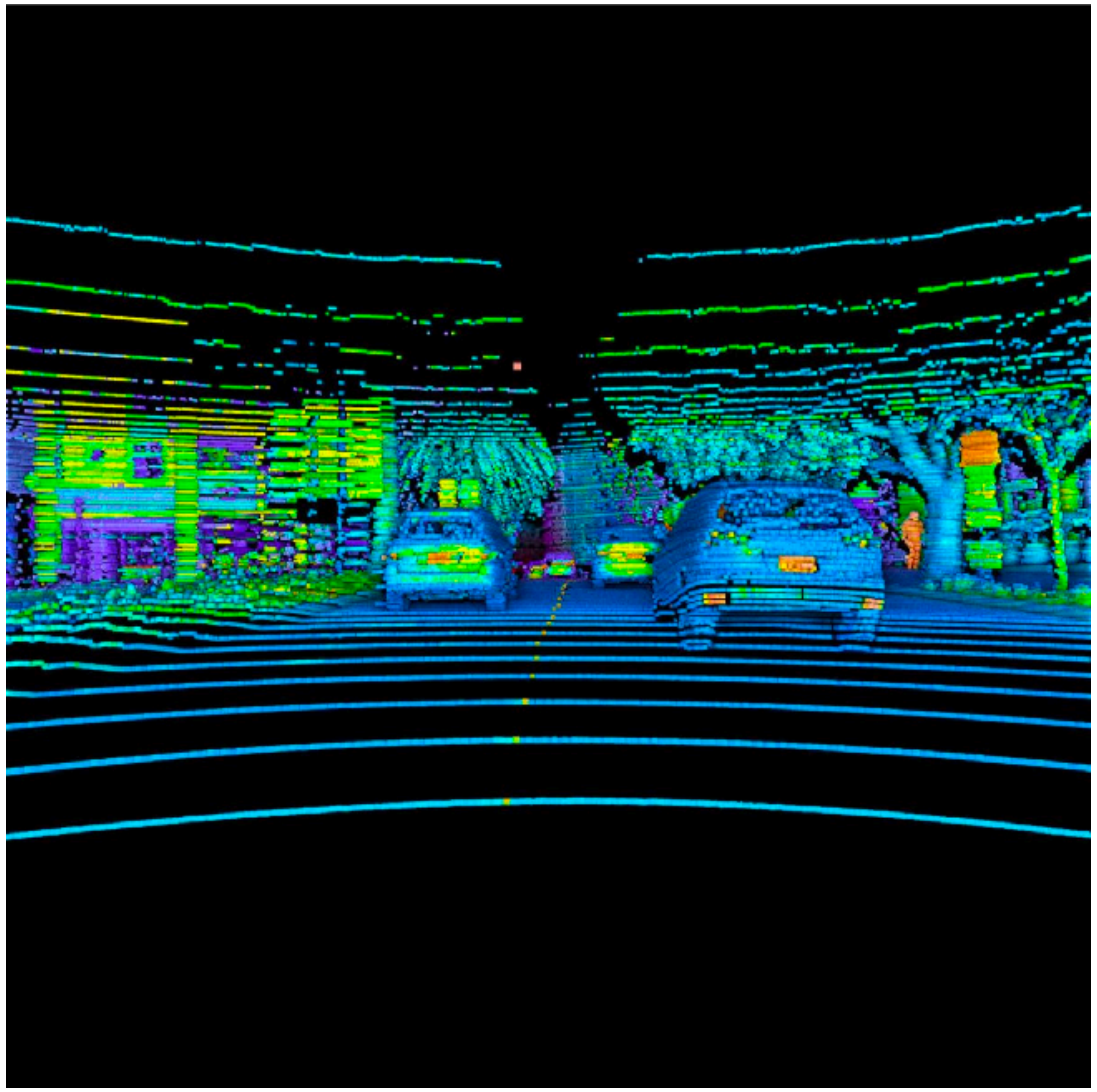


- point-to-plane measurement probability model

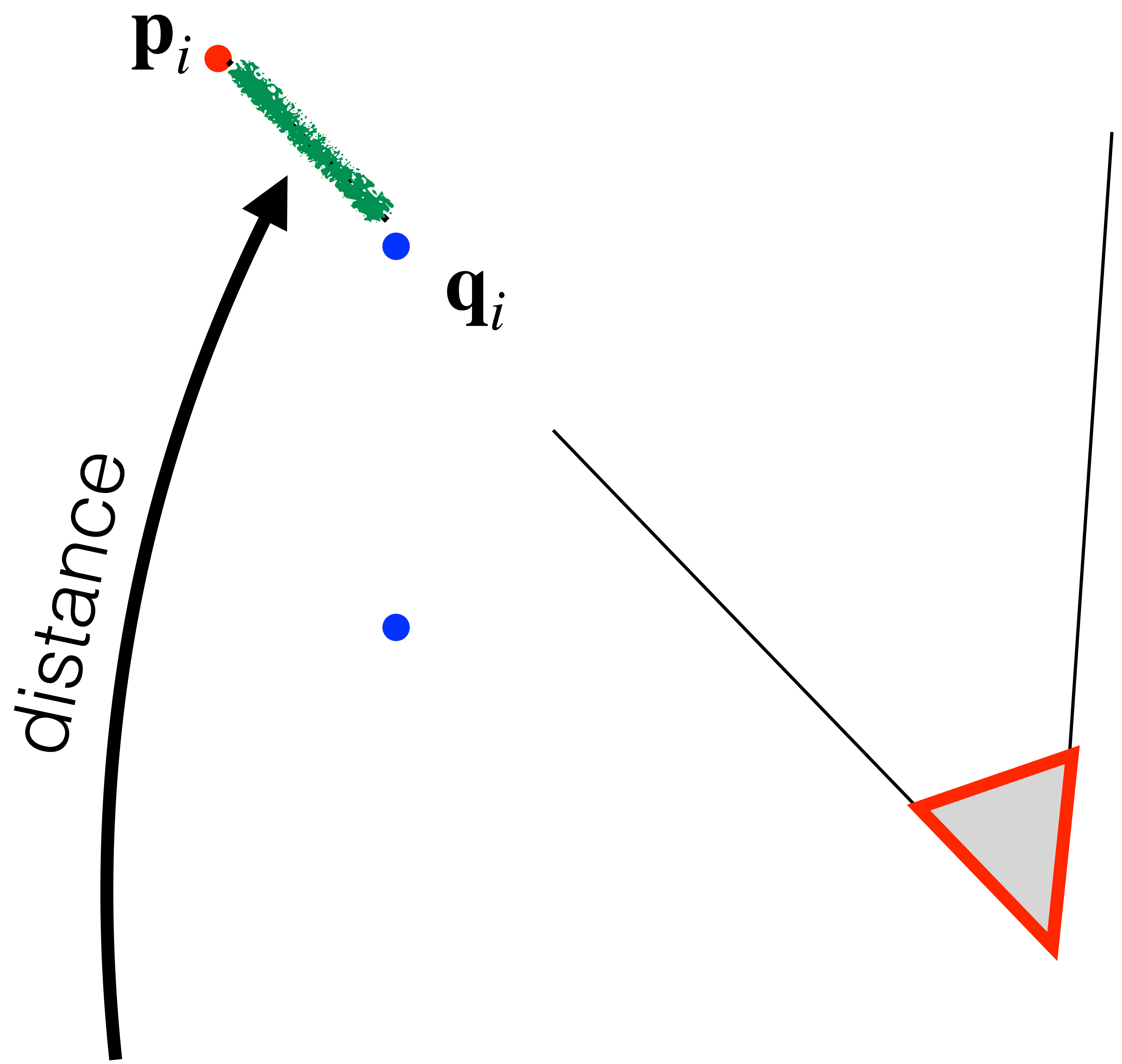


Absolute orientation:

$$\mathbf{R}^\star, \mathbf{t}^\star, = \underset{\mathbf{R}\in SO(3),\mathbf{t}}{\arg\min} \sum_i \left\| \mathbf{R}\mathbf{p}_i + \mathbf{t} - \mathbf{q}_i \right\|^2$$



- point-to-plane measurement probability model

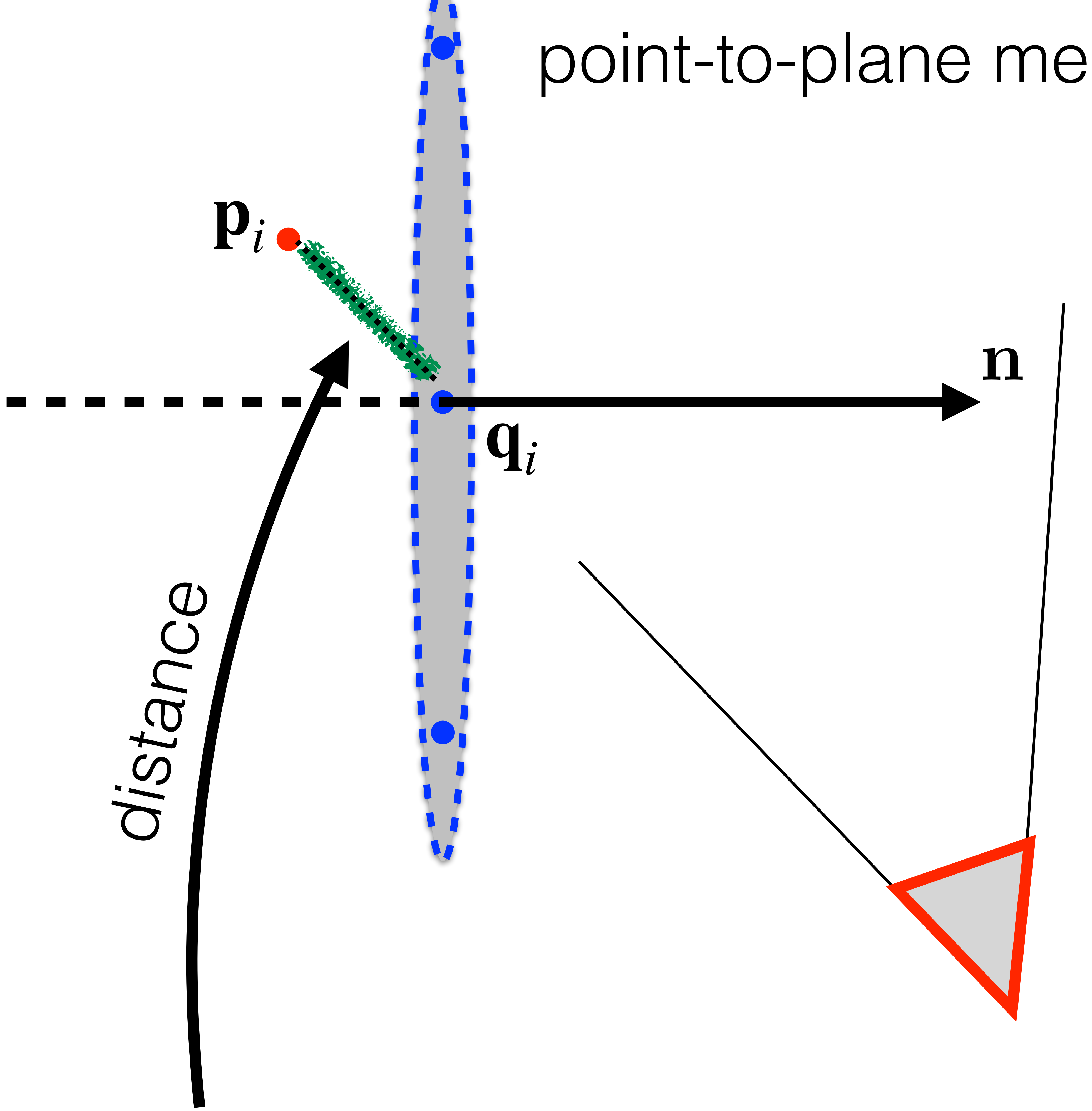


$$\| \mathbf{R}\mathbf{p}_i + \mathbf{t} - \mathbf{q}_i \|^2$$

Absolute orientation:

$$\mathbf{R}^\star, \mathbf{t}^\star, = \underset{\mathbf{R}\in SO(3), \mathbf{t}}{\arg\min} \sum_i \| \mathbf{R}\mathbf{p}_i + \mathbf{t} - \mathbf{q}_i \|^2$$

point-to-plane measurement probability model

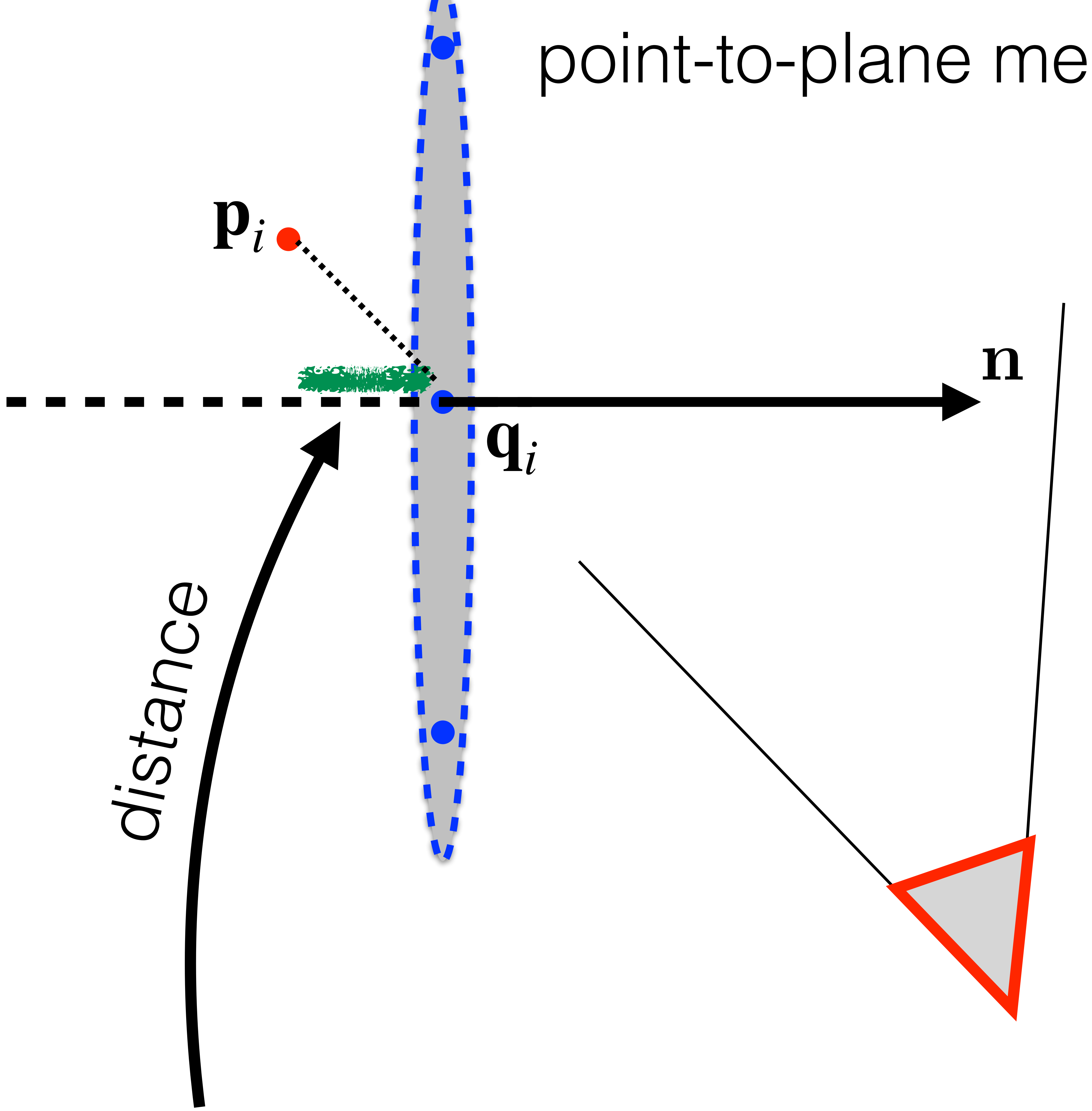


$$\| \mathbf{R}\mathbf{p}_i + \mathbf{t} - \mathbf{q}_i \|^2$$

Absolute orientation:

$$\mathbf{R}^\star, \mathbf{t}^\star, = \arg\min_{\mathbf{R}\in SO(3),\mathbf{t}} \sum_i \| \mathbf{R}\mathbf{p}_i + \mathbf{t} - \mathbf{q}_i \|^2$$

point-to-plane measurement probability model



$$\left\| \mathbf{n}^\top(\mathbf{R}\mathbf{p}_i + \mathbf{t} - \mathbf{q}_i) \right\|^2$$

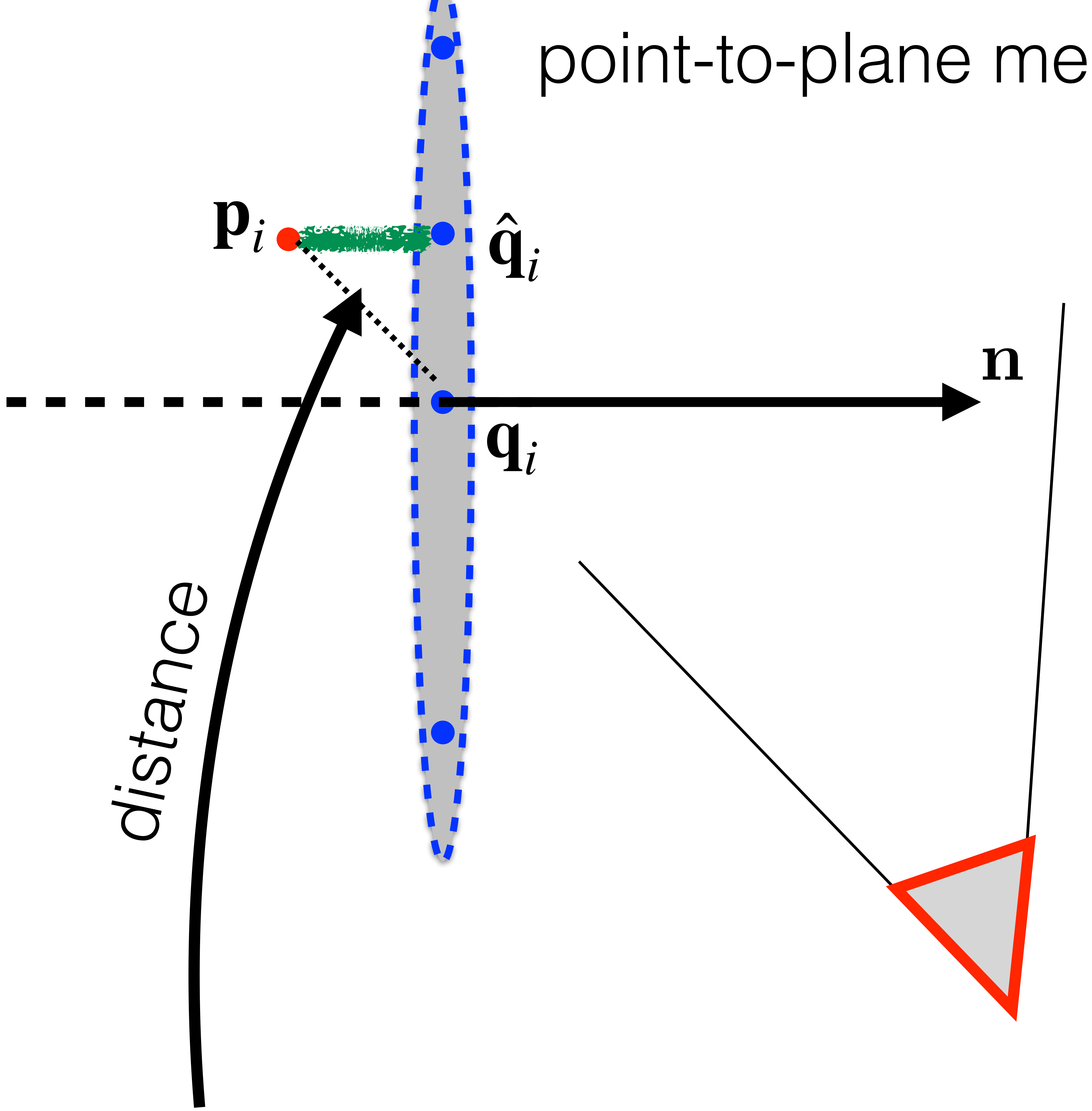
Absolute orientation:

~~$\mathbf{R}^\star, \mathbf{t}^\star, = \arg\min_{\mathbf{R}\in SO(3),\mathbf{t}} \sum_i \left\| \mathbf{R}\mathbf{p}_i + \mathbf{t} - \mathbf{q}_i \right\|^2$~~

$$\mathbf{R}^\star, \mathbf{t}^\star, = \arg\min_{\mathbf{R}\in SO(3),\mathbf{t}} \sum_i \left\| \mathbf{n}^\top(\mathbf{R}\mathbf{p}_i + \mathbf{t} - \mathbf{q}_i) \right\|^2$$

Does not have closed-form solution

point-to-plane measurement probability model



$$\left\| \mathbf{R}\mathbf{p}_i + \mathbf{t} - \hat{\mathbf{q}}_i \right\|^2$$

Absolute orientation:

$$\cancel{\mathbf{R}^\star, \mathbf{t}^\star, = \arg\min_{\mathbf{R}\in SO(3),\mathbf{t}} \sum_i \left\| \mathbf{R}\mathbf{p}_i + \mathbf{t} - \mathbf{q}_i \right\|^2}$$

$$\cancel{\mathbf{R}^\star, \mathbf{t}^\star, = \arg\min_{\mathbf{R}\in SO(3),\mathbf{t}} \sum_i \left\| \mathbf{n}^\top(\mathbf{R}\mathbf{p}_i + \mathbf{t} - \mathbf{q}_i) \right\|^2}$$

$$\mathbf{R}^\star, \mathbf{t}^\star, = \arg\min_{\mathbf{R}\in SO(3),\mathbf{t}} \sum_i \left\| \mathbf{R}\mathbf{p}_i + \mathbf{t} - \hat{\mathbf{q}}_i \right\|^2$$

Avoid gradient optimization => create virtual map point $\hat{\mathbf{q}}_i$

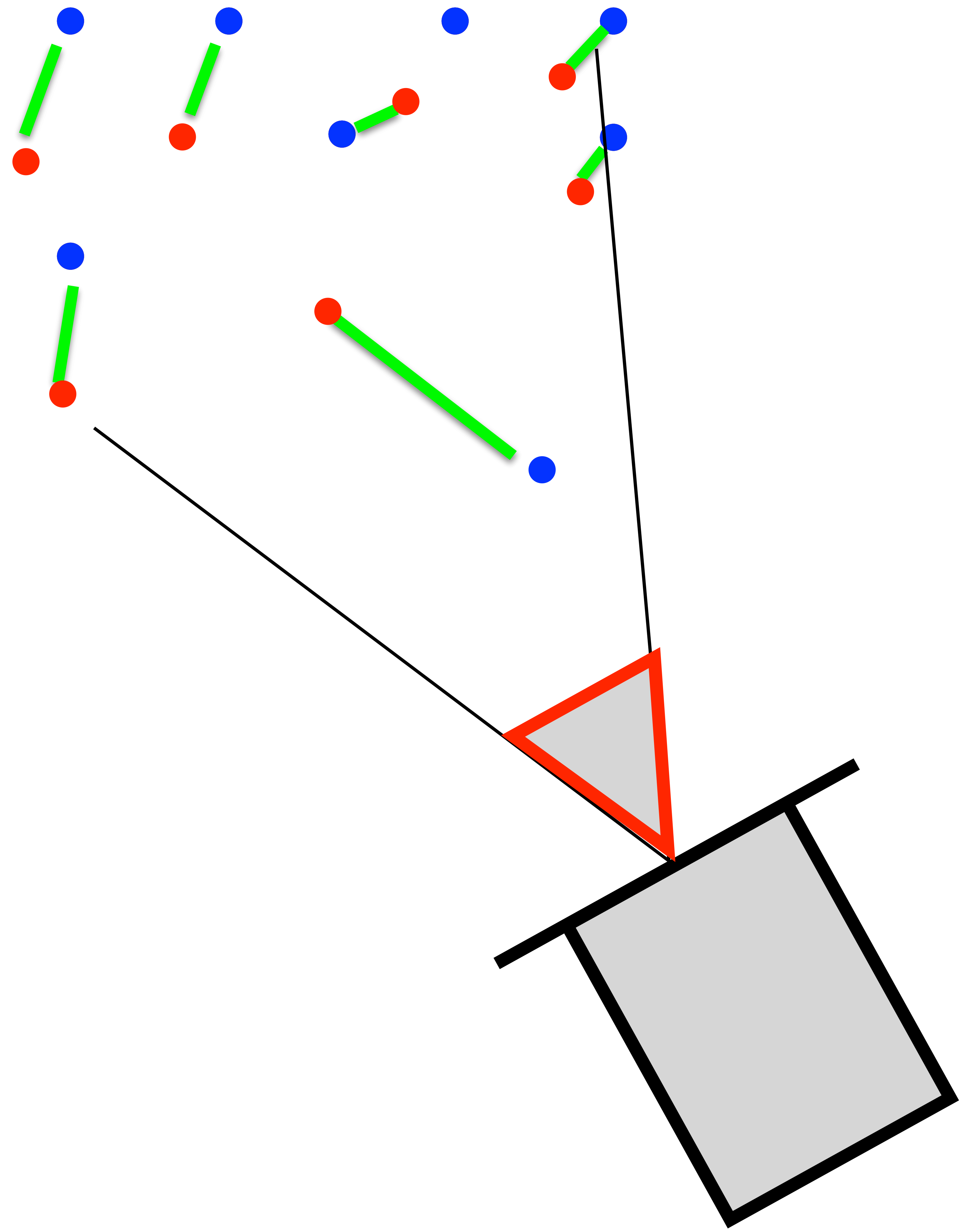
ICP SLAM - known issues

- Converges to a local minima with unknown region of convergence
  => good initialization needed
- Fails in degenerate environments
  (e.g. forward motion in long hallways, or rotation in circular room)
  => other models (point2plane) and sensors (camera) often introduced.

ICP SLAM - known issues

- Converges to a local minima with unknown region of convergence
  => good initialization needed
- Fails in degenerate environments
  (e.g. forward motion in long hallways, or rotation in circular room)
  => other models (point2plane) and sensors (camera) often introduced.

Alignment quality is determined by the quality of correspondences



Compatibility measure:

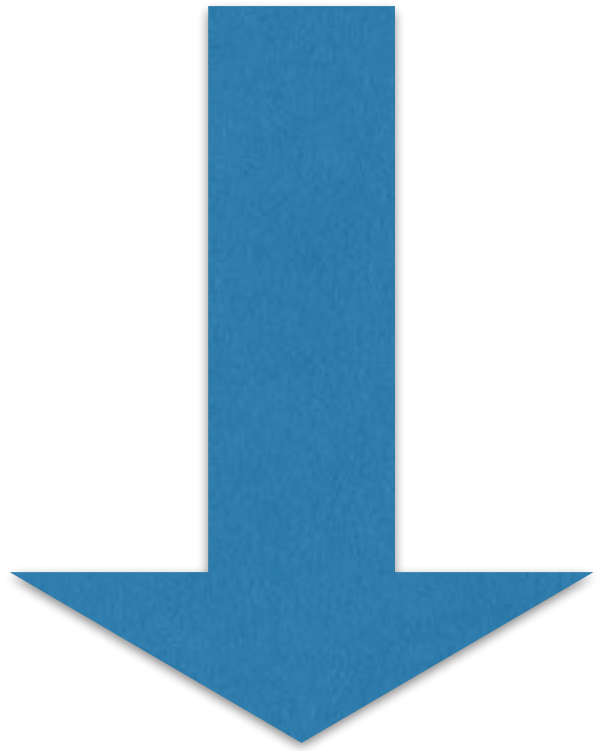
- Lidar
  - normals
  - curvature
  - any measure of shape similarity
- Camera
  - colors
  - semantic consistency (car-car)
  - any measure of visual similarity
  - dynamic object suppression

ICP SLAM - known issues

- Converges to a local minima with unknown region of convergence
  => good initialization needed
- Fails in degenerate environments
  (e.g. forward motion in long hallways, or rotation in circular room)
  => other models (point2plane) and sensors (camera) often introduced.
- Pointcloud map is not suitable for planning
  => better representation (e.g. occupancy grid)

Maps

- 2D/3D pointcloud map
- 2D/3D Occupancy grid
- 2.5D map (hightmap)
- Surfel/feature map
- Semantic map
- Cost map
- Traversability map
- Topological map
- Functional map



Concrete
(common understanding, ROS message)

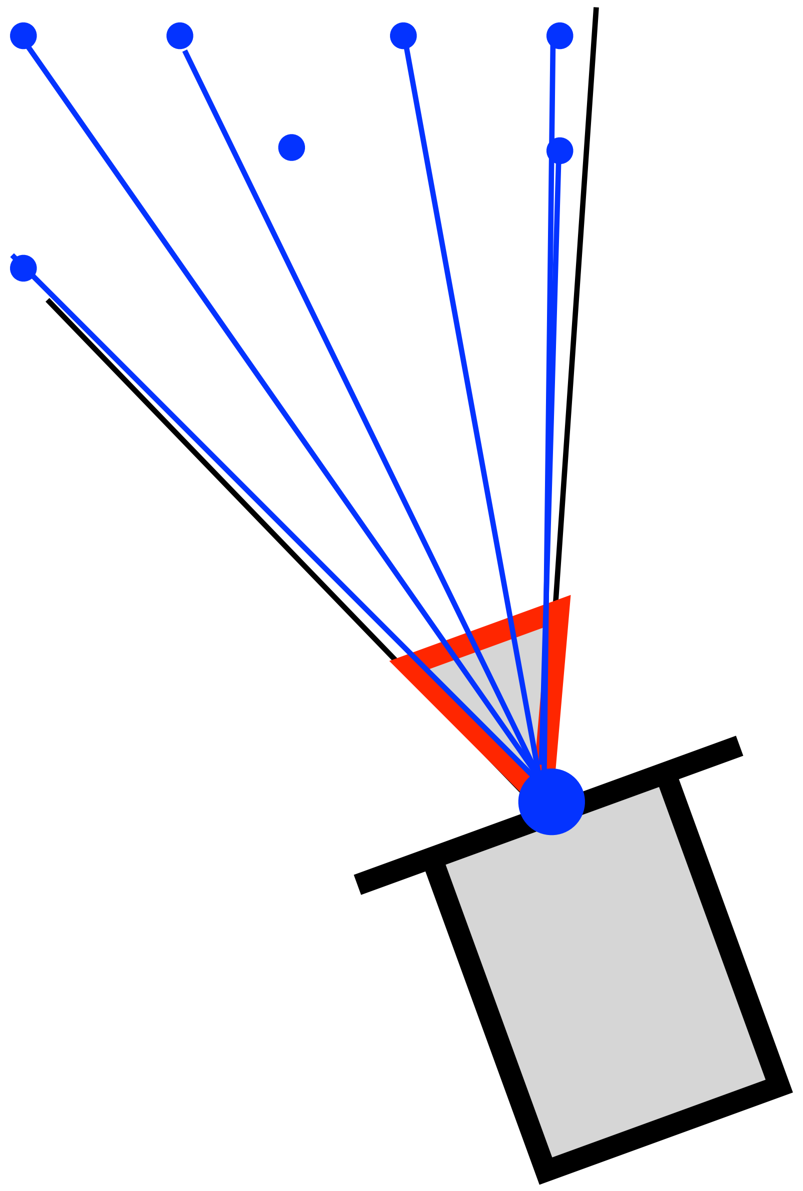
Abstract
(Everyone has its own understanding)

Naive: If pointcloud map is available you can use ICP to align wrt existing map => abs. loc

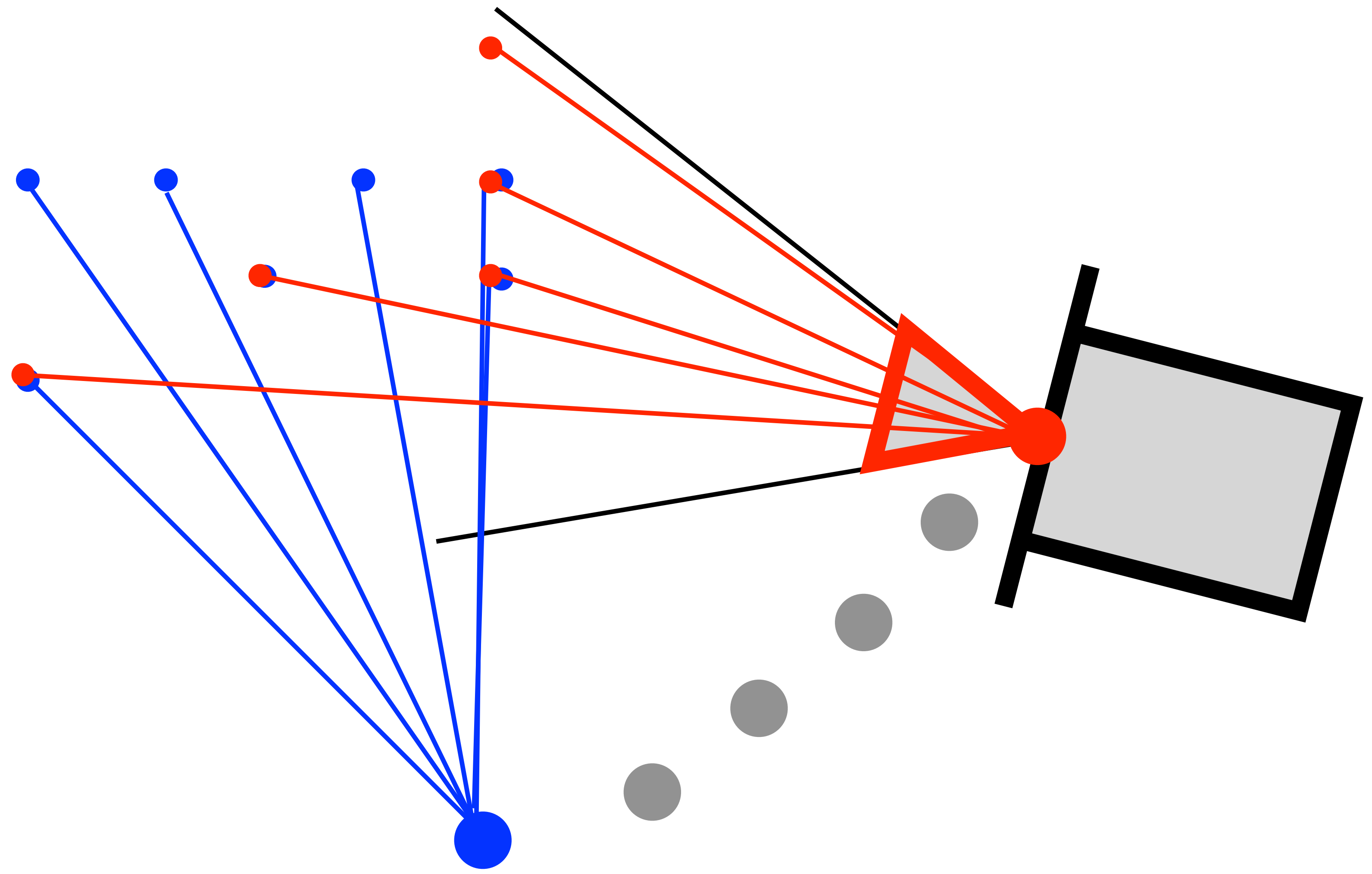
Drawback and advantages?

Less naive: combine the map with the factorgraph

Bundle adjustment with ICP



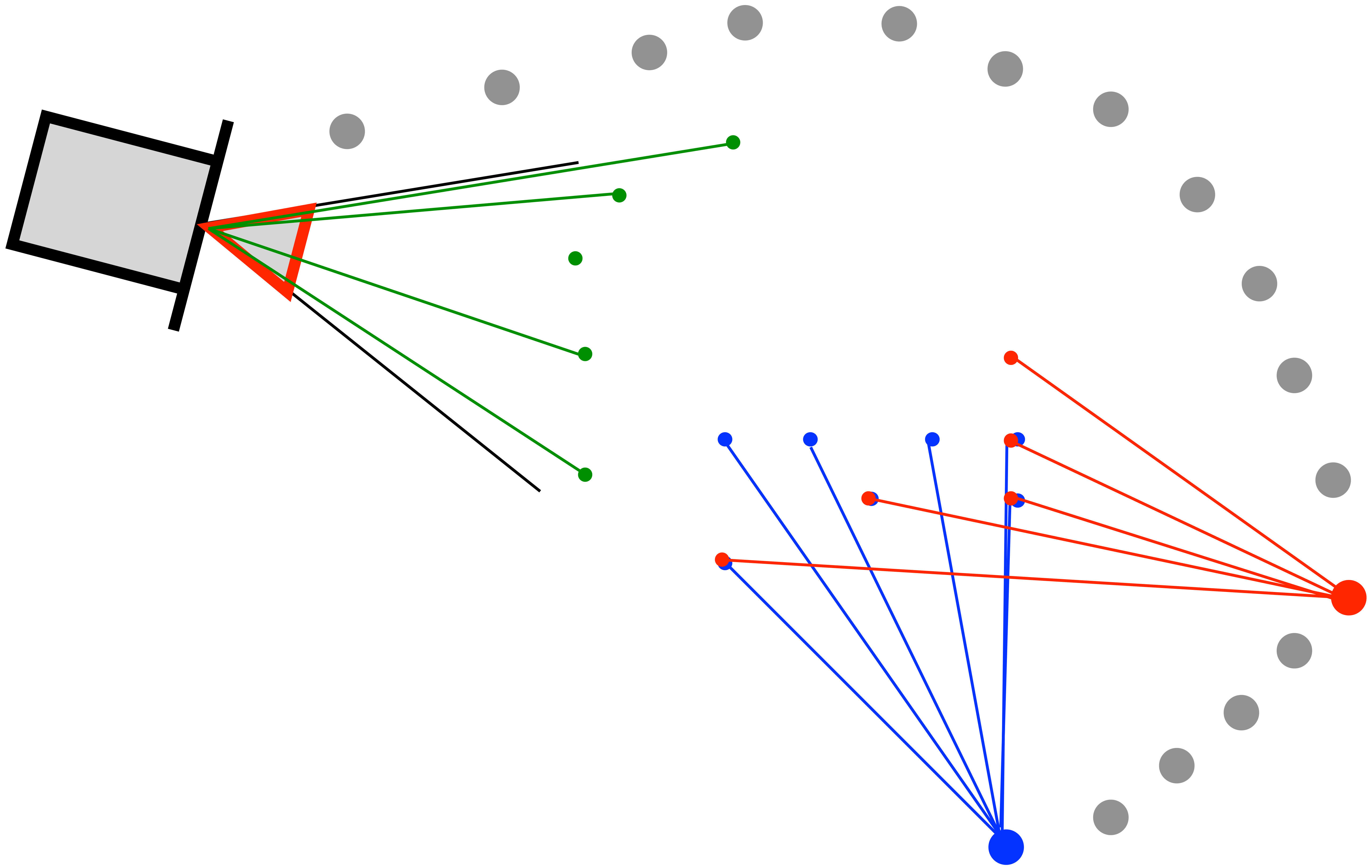
Bundle adjustment with ICP



Some poses connected with its own pointcloud (keyframes)

When factorgraph optimized the current map is union of keyframes

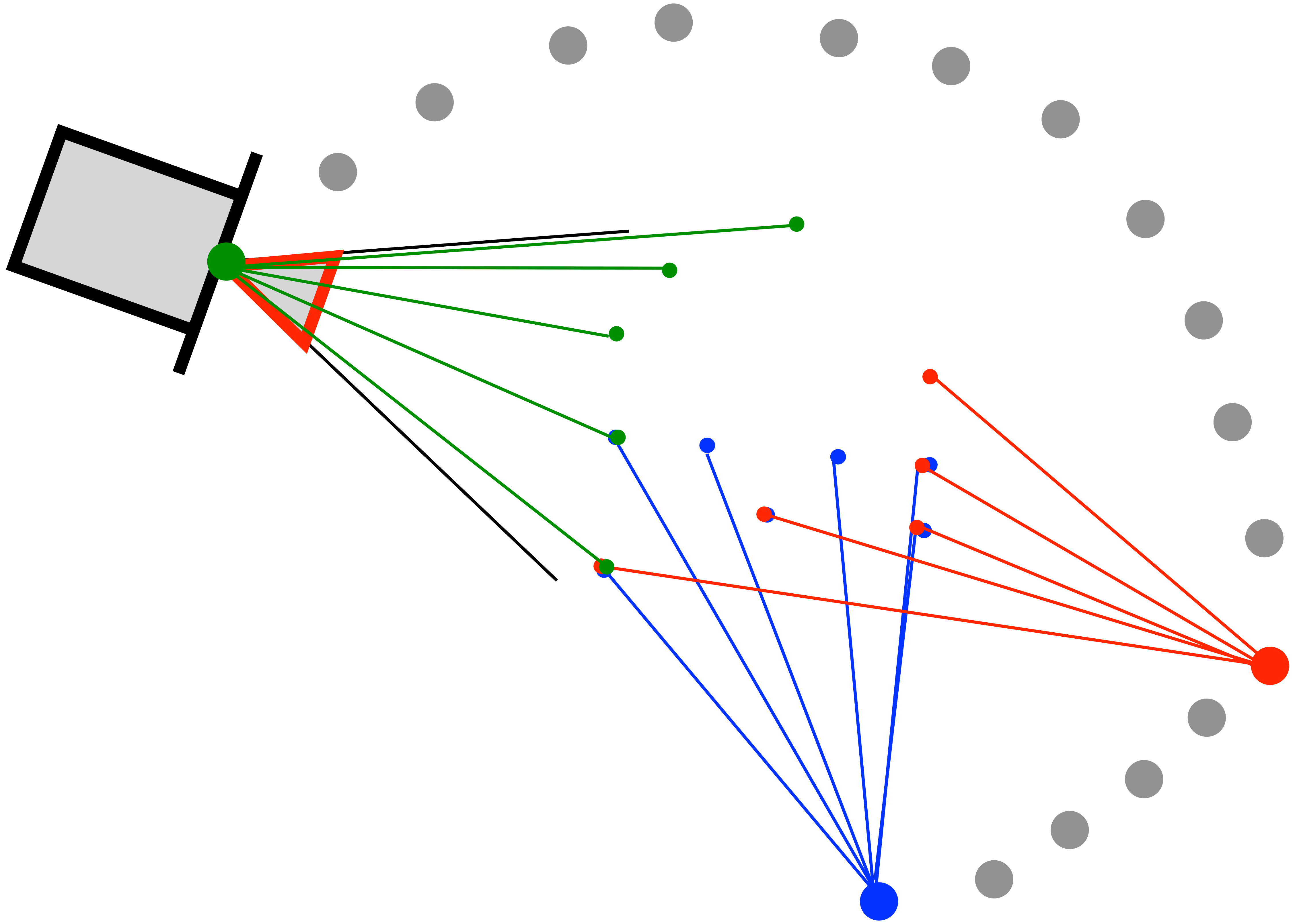
Bundle adjustment with ICP



Some poses connected with its own pointcloud (keyframes)

When factorgraph optimized the current map is union of keyframes

Bundle adjustment with ICP



Some poses connected with its own pointcloud (keyframes)

When factorgraph optimized the current map is union of keyframes

Occupancy grid

- Exploration requires to distinguish
    - “occupied”/“unoccupied” assess traversability
    - “unknown” space to motivate the exploration.
- Evently spaced bins with random variables representing its occupancy

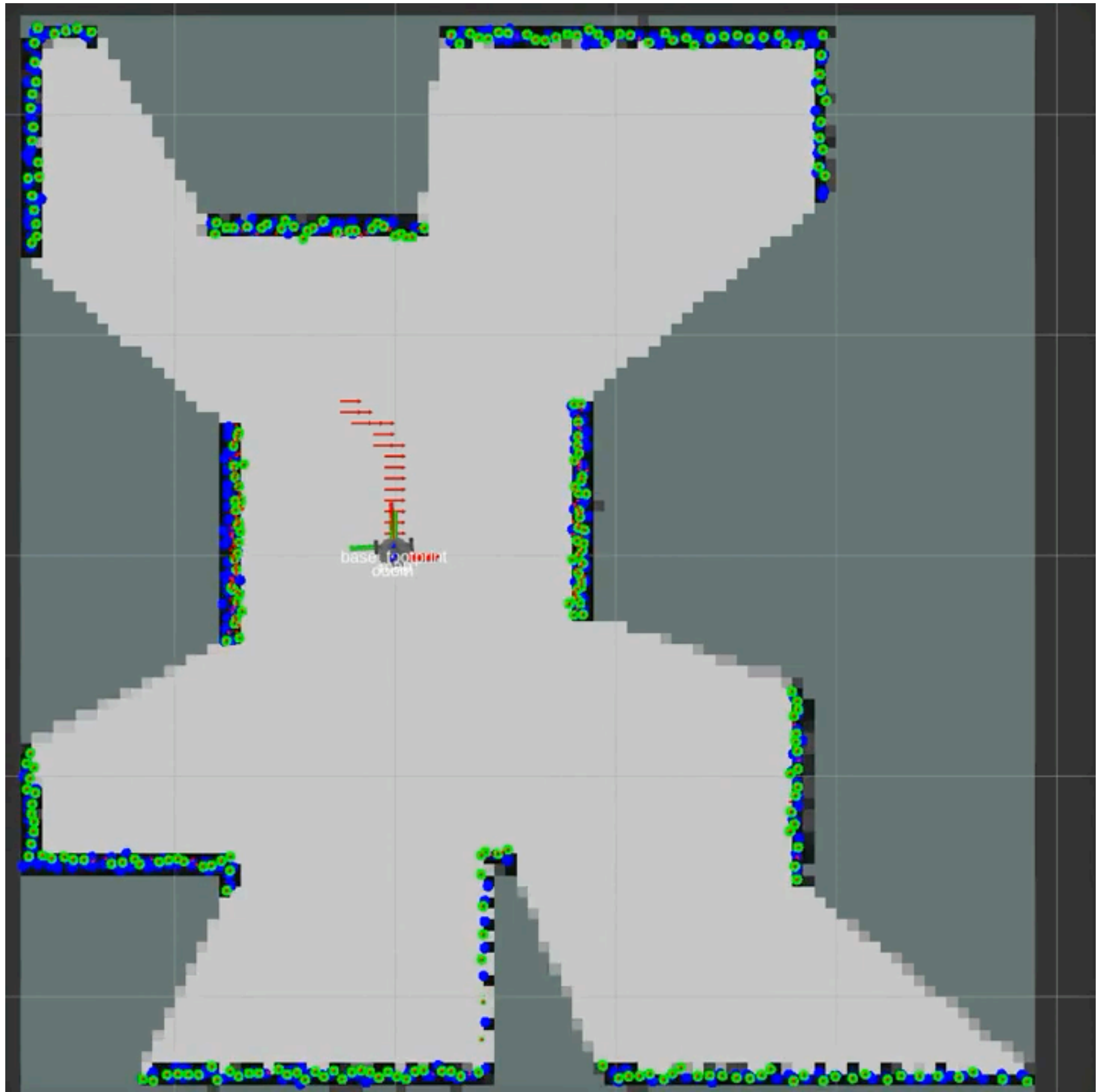
Occupancy grid

- Exploration requires to distinguish
  - “occupied”/“unoccupied” assess traversability
  - “unknown” space to motivate the exploration.
- Evently spaced bins with random variables representing its occupancy

■ …. occupied (+1)

▨ …. unknown (0)

□ …. unoccupied (-1)



Memory requirements:

10x10cm bins =>10^8 bins/km^2
1byte/bin =>0.1GB/km^2

Octomap representation

ICP SLAM - known issues

- Converges to a local minima with unknown region of convergence
  => good initialization needed
- Measurement probability model fails in degenerate environments
  (e.g. forward motion in long hallways, or rotation in circular room)
  => other models (point2plane) and sensors (camera) often introduced.
- Pointcloud map is not suitable for planning
  => better representation (e.g. occupancy grid)
- **Next:** Normal distribution sensitive to outliers due to L2 norm minimization
  => RANSAC