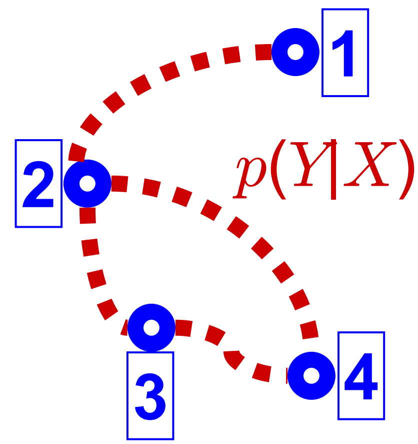
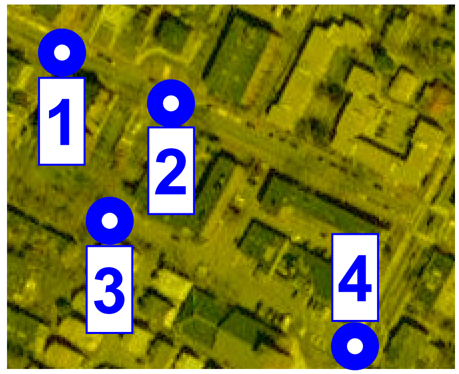
Network Topology and Geometry

- Complementary:
  - *Topology* of the camera graph: connectivity and transitions between cameras
    - Fuel truck #538 was seen in camera 3 at 5:39pm, in camera 4 at 5:41pm,…
  - *Geometry*: where cameras are looking
    - Fuel truck #538 was heading toward the power plant between 5:39pm and 5:41pm





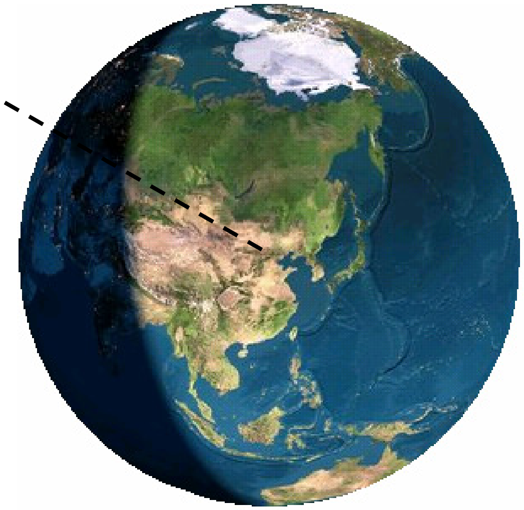
Note: all images adjusted for presentation purposes

Motivating Scenario

- Large network of cameras
  - *I.e.* hundreds or thousands
  - Location unknown, *e.g.*
    - Existing installations
    - Very rapid physical installation requirements
- Regular traffic instrumented with GPS receivers (patrols, service vehicles, *etc.*)

- …need to know camera locations

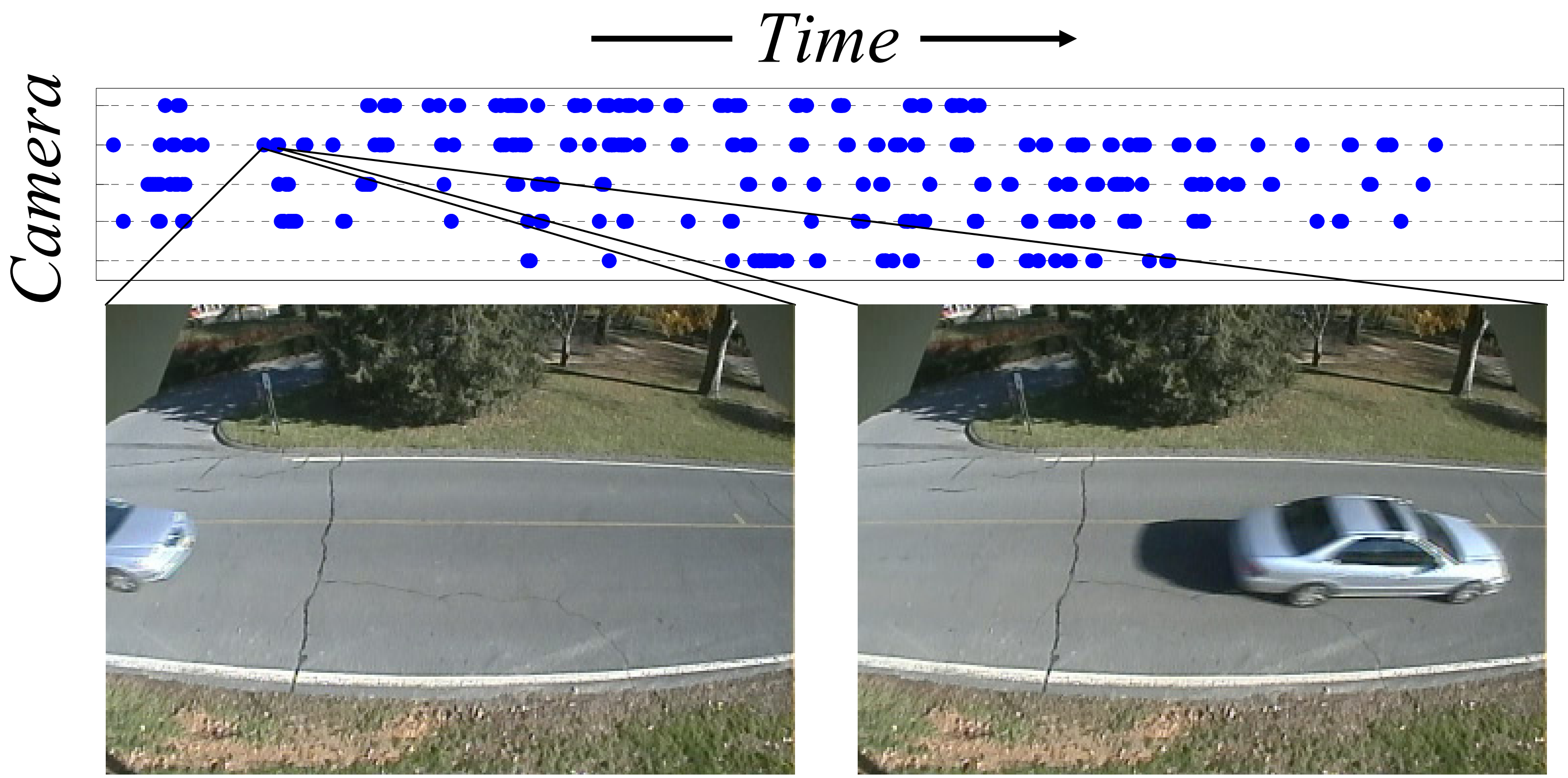
Cameras as Tripwires



- This paper:
  - Narrow field-of-view (relative to GPS resolution)
  - Camera as a tripwire

Input Data (1)

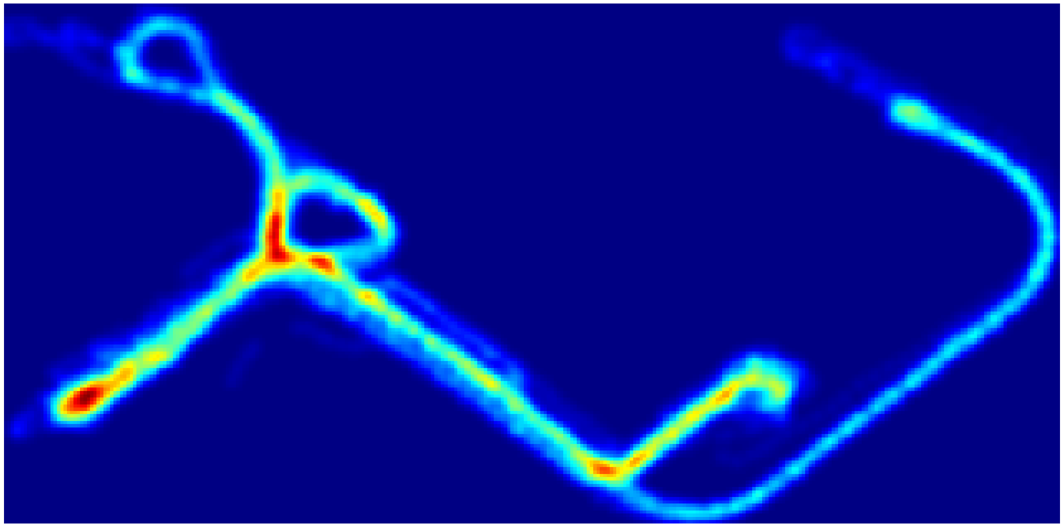
- Time instants when each camera observed a vehicle entering or exiting: $\{(t_{cj})\}$
  - Vehicle identity not known



Input data (2)

- GPS Tracks (5 vehicles): $\{(lat_{vi}, lon_{vi}, t_{vi})\}$
  - Not known: when a particular vehicle is seen in a particular camera

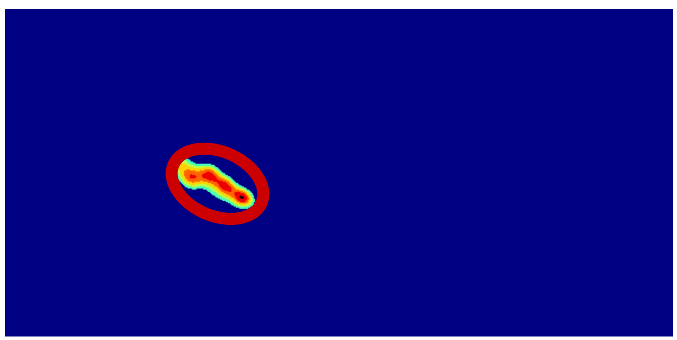
$p(vehicle\ @\ lat, lon)$ abbreviated as $p(lat, lon)$



Estimation: What We Want

$$\hat{p}(lat, lon | lat, lon \in camera)$$

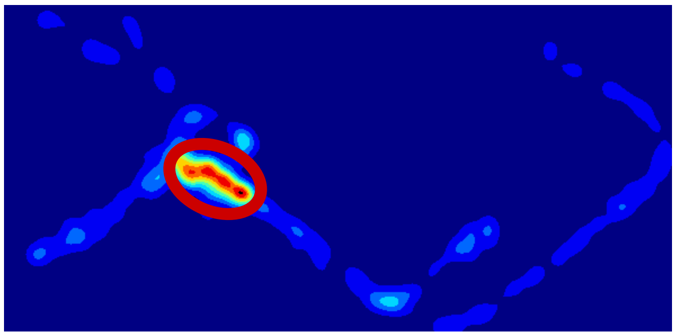
…but, we don't know when a specific instrumented vehicle is visible



Camera location: probability (lat,lon) being in the field of view = p(vehicle being at (lat,lon) when the camera is tripped)

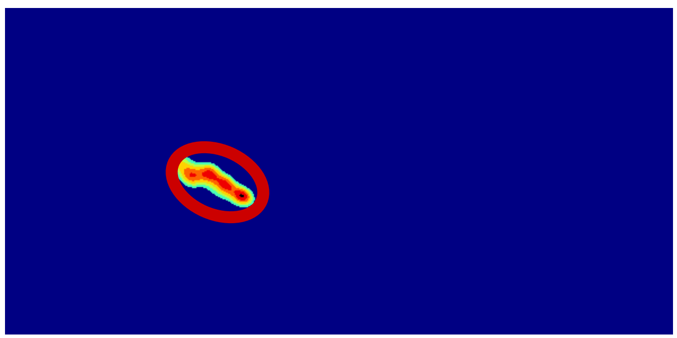
Estimation: What We Get

$$\tilde{p}(lat, lon | lat, lon \in camera) =$$
$$(1-\alpha)\hat{p}(lat, lon | lat, lon \in camera) + \alpha p(lat, lon)$$

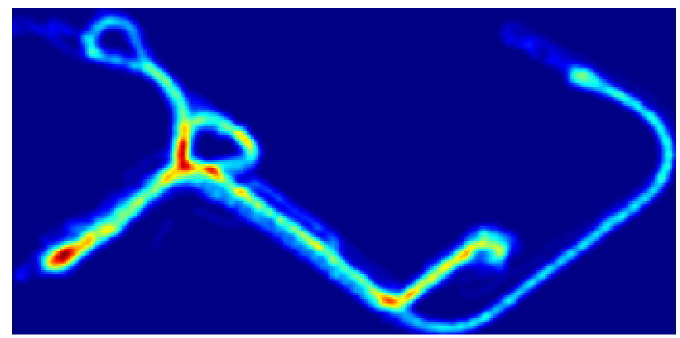


=

$(1-\alpha)$

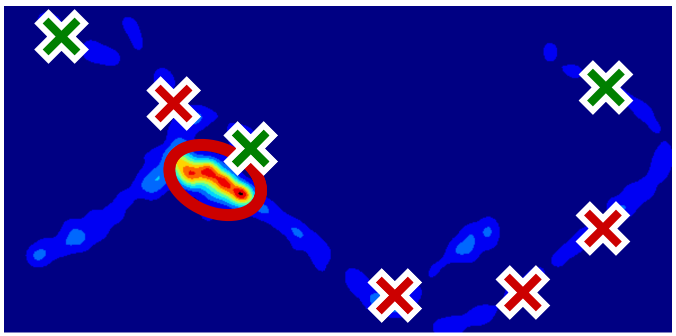


$+\,\alpha$



Camera Sees Nothing

$$\tilde{p}(lat, lon | lat, lon \in camera) =$$
$$(1-\alpha)\hat{p}(lat, lon | lat, lon \in camera) + \alpha p(lat, lon)$$



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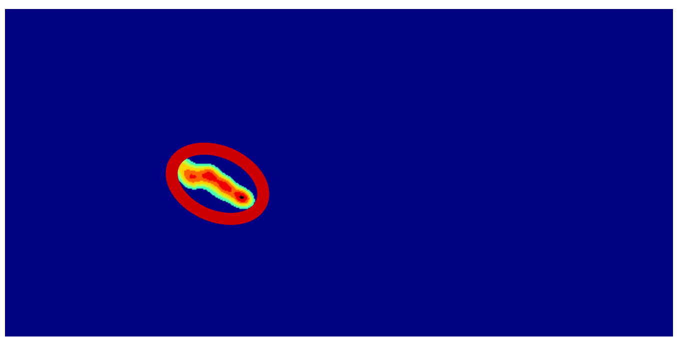
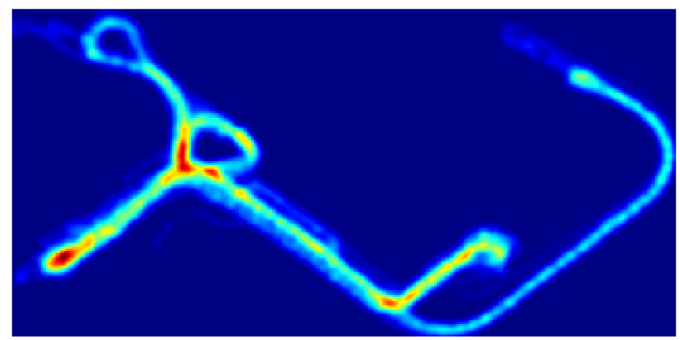
$(1-\alpha)$



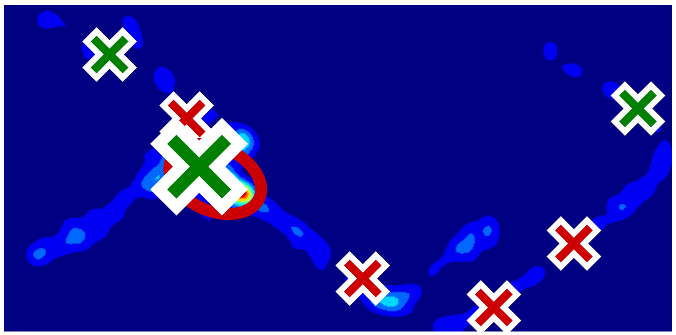
$+\,\alpha$



- ✕ GPS-instrumented vehicle
- ✕ Non-instrumented vehicle

Camera Sees a GPS Vehicle

$$\tilde{p}(lat, lon | lat, lon \in camera) =$$
$$(1-\alpha)\hat{p}(lat, lon | lat, lon \in camera) + \alpha p(lat, lon)$$



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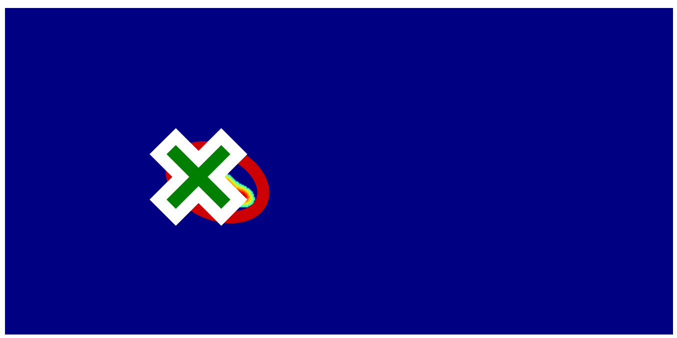
$(1-\alpha)$



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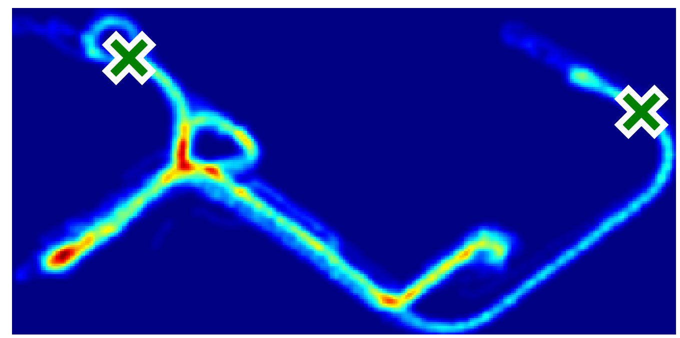
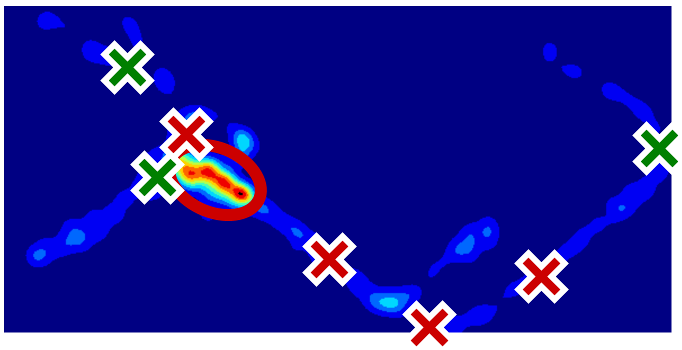


- GPS-instrumented vehicle
- Non-instrumented vehicle

Camera Sees Nothing

$$\tilde{p}(lat, lon | lat, lon \in camera) =$$
$$(1-\alpha)\hat{p}(lat, lon | lat, lon \in camera) + \alpha p(lat, lon)$$



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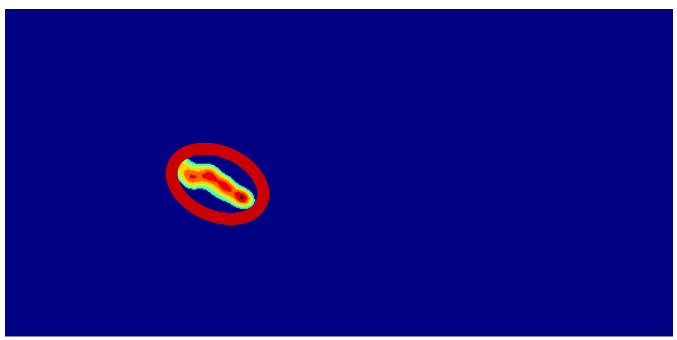
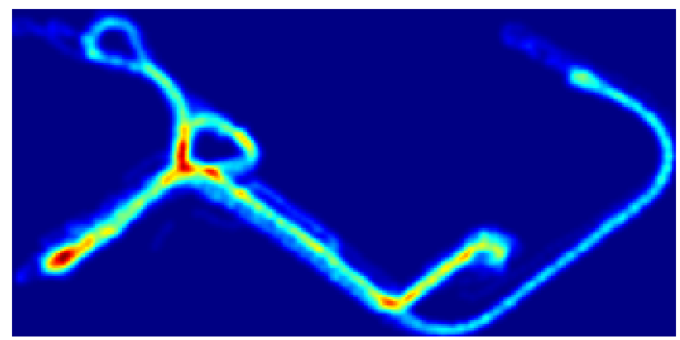
$(1-\alpha)$



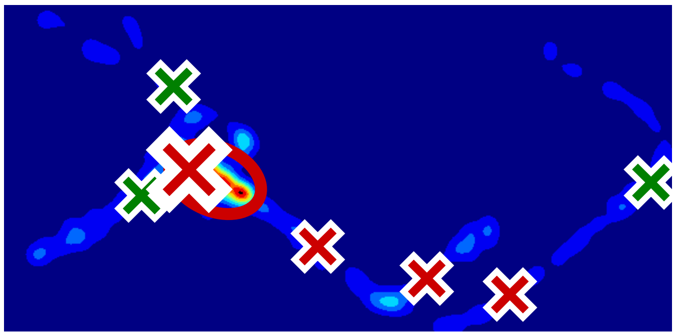
$+\alpha$

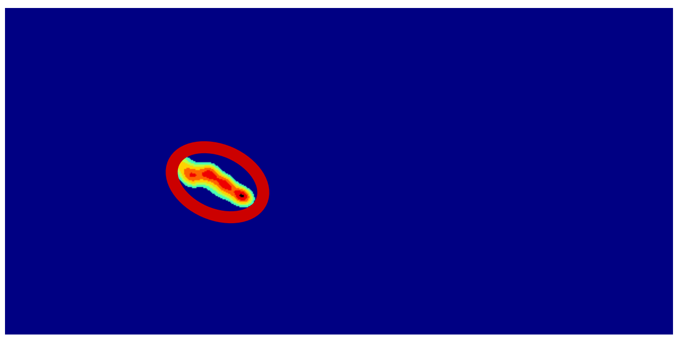
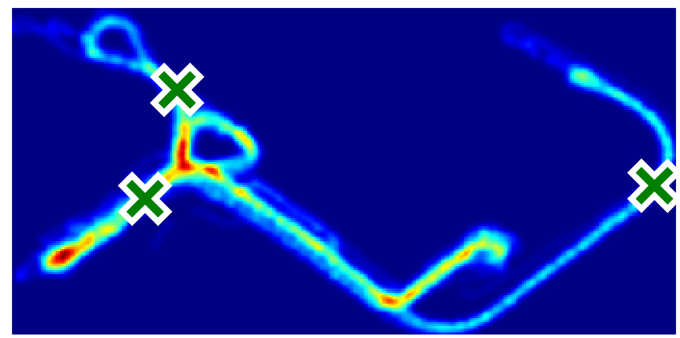


- GPS-instrumented vehicle
- Non-instrumented vehicle

Camera Sees a Distracter

$$\tilde{p}(lat, lon | lat, lon \in camera) =$$
$$(1-\alpha)\hat{p}(lat, lon | lat, lon \in camera) + \alpha p(lat, lon)$$

 =

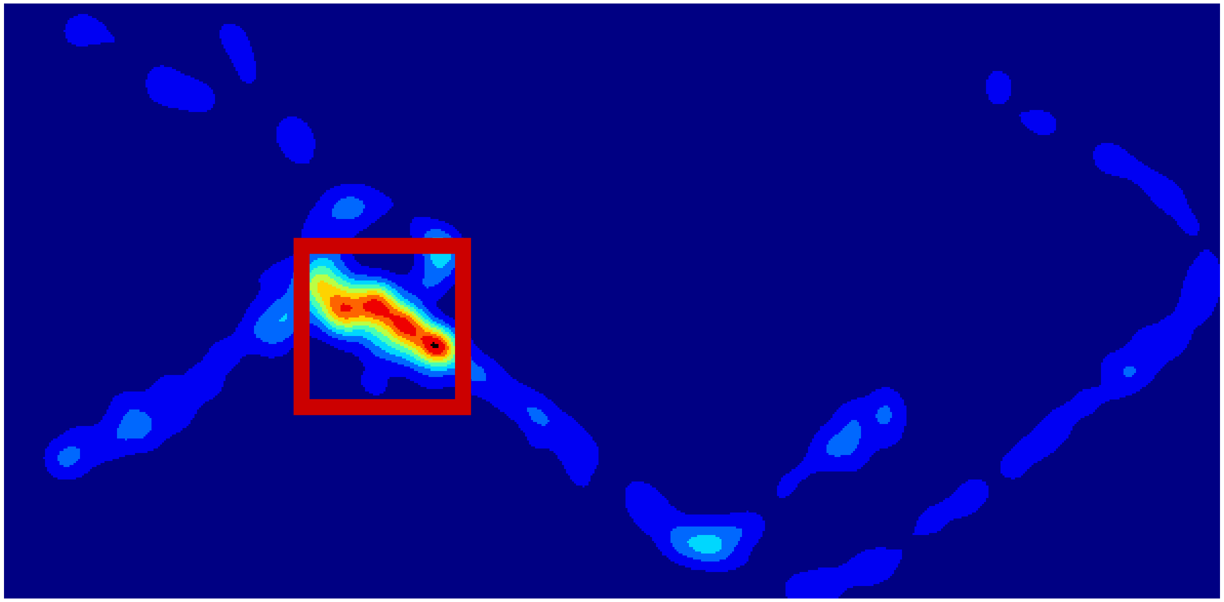
$(1-\alpha)$  $+\,\alpha$ 

- GPS-instrumented vehicle
- Non-instrumented vehicle

Best Cluster of Peaks

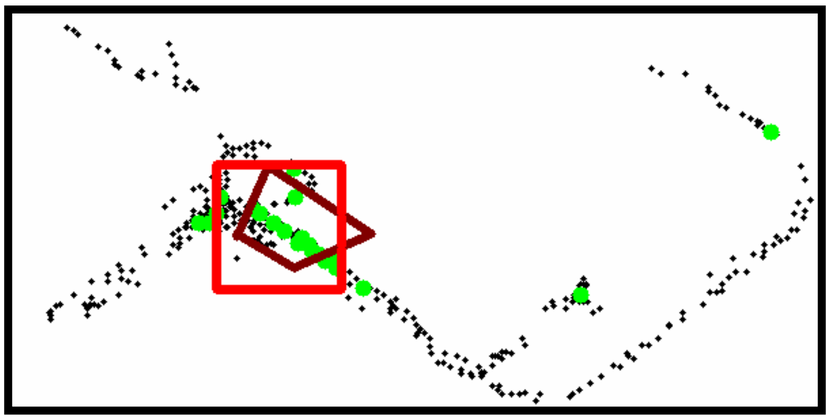
$$\tilde{p}(lat, lon | lat, lon \in camera) =$$
$$(1 - \alpha)\hat{p}(lat, lon | lat, lon \in camera) + \alpha p(lat, lon)$$

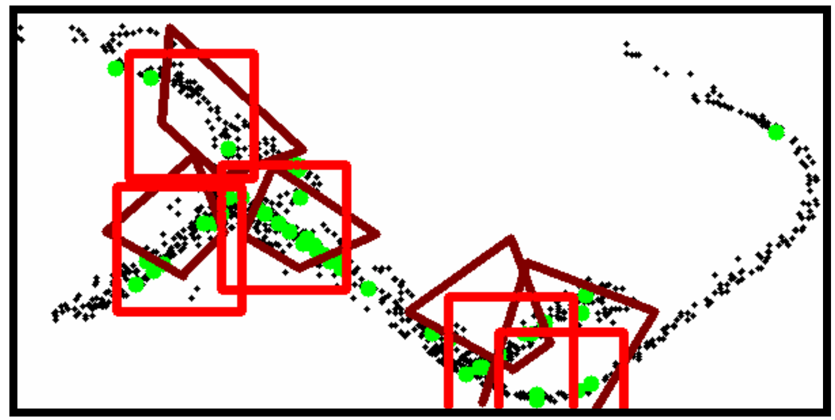
$$\tilde{p}(lat, lon | lat, lon \in camera)$$



$$h(\hat{p}) \ll h(p) \rightarrow \text{look for peaks}$$

Results





- Bright red squares: estimated camera fields of view
- Dark red trapezoids: ground truth (rough)
- Light green dots: peaks in $\tilde{p}(x, y|c)$
- Dark green dots: non-peak votes in $\tilde{p}(x, y|c)$

Conclusions

- No given correspondence
- Topology
  - Tripwire data → network topology and transitions
  - Can model appearance changes
- Geometry
  - Tripwire data + GPS side information → camera locations

Questions…

Thank you

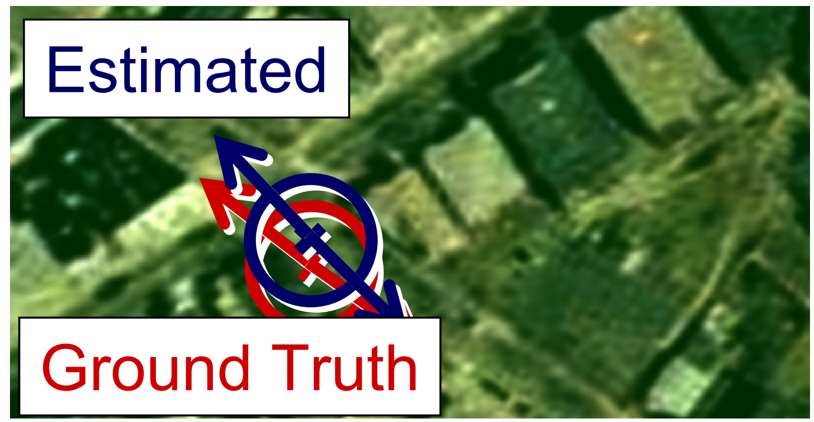
Extra Slides…

Location + Pose

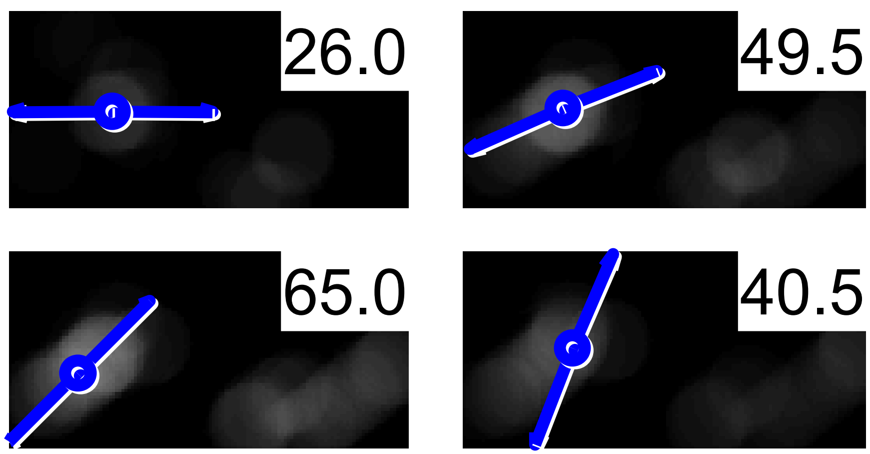
Voting Spaces

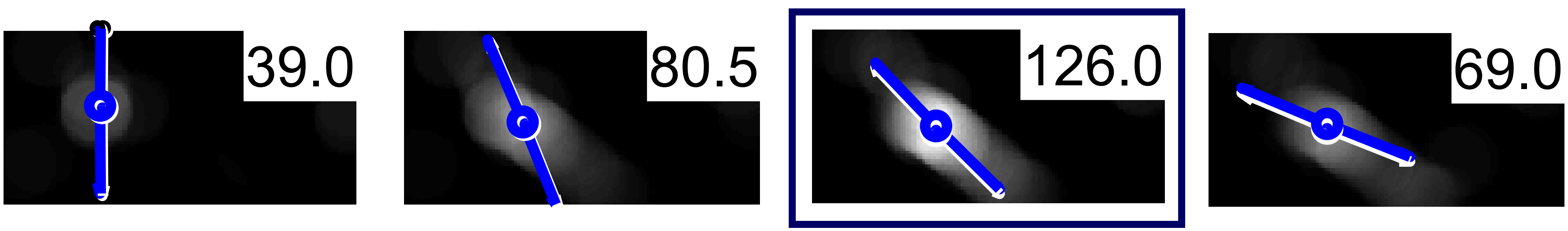
- Conditioned on Traffic Direction

*Best Estimate Overlaid on a Satellite Map**



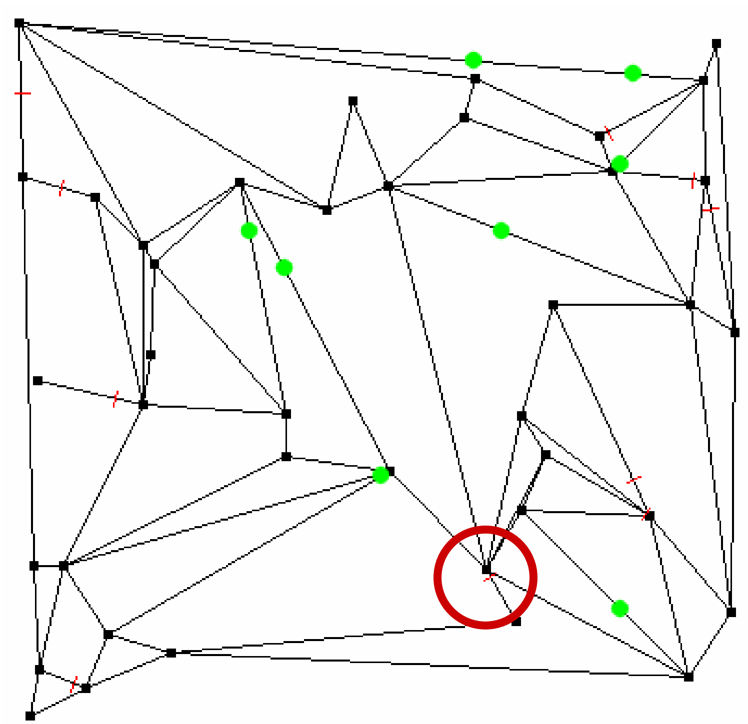
* *true satellite image substituted*



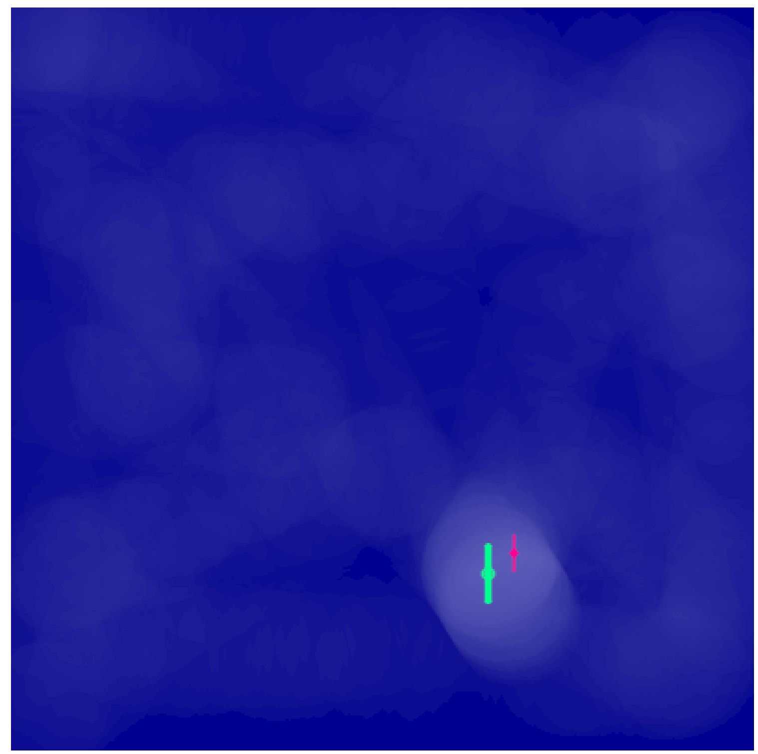


Sample Simulated Network

- 40 Intersections
- 80 Roads
- 8 Vehicles
- 10 Cameras
- Total road length: 4.2km
- Mean speed: 60kph

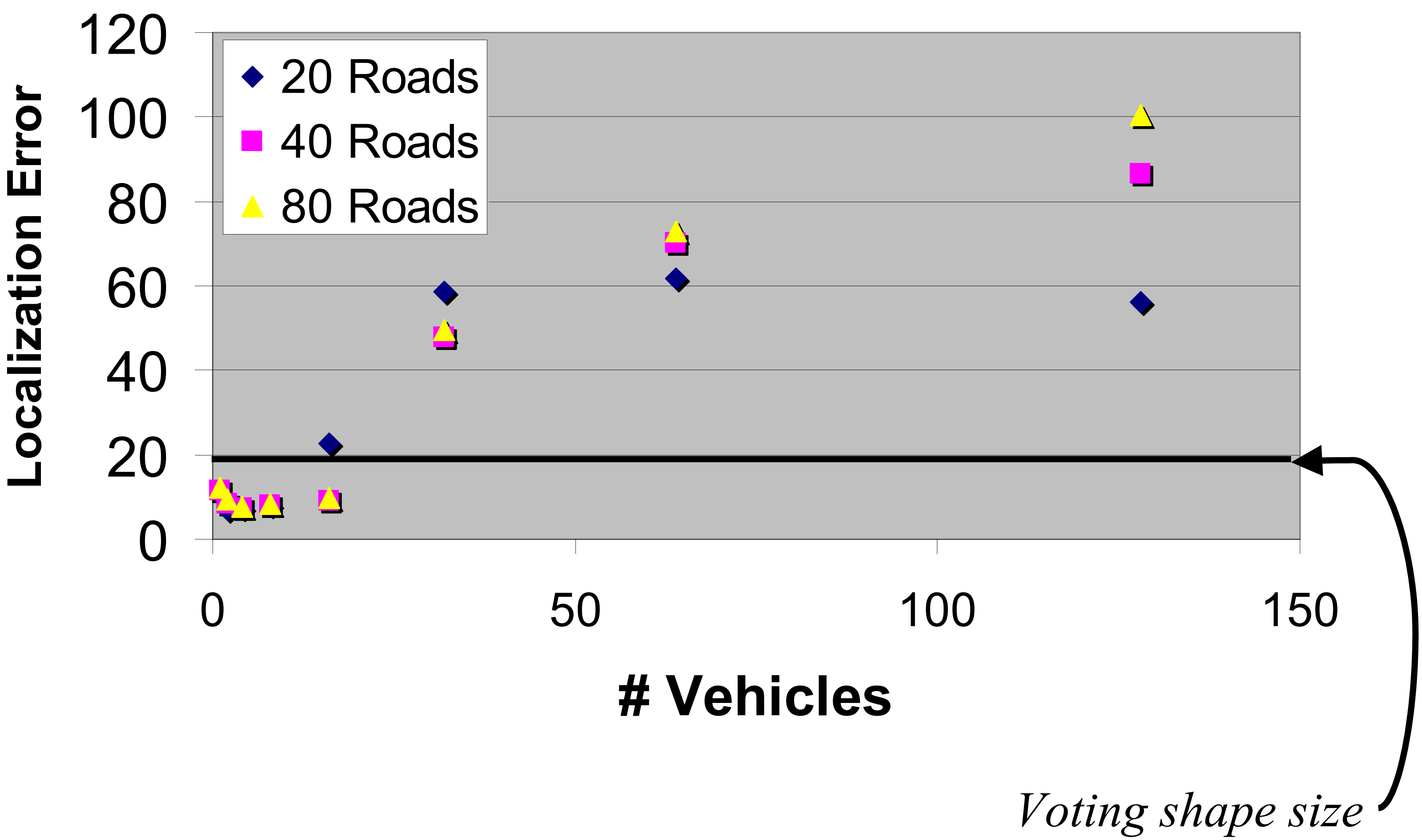


Rendering of Network
(with one camera circled)

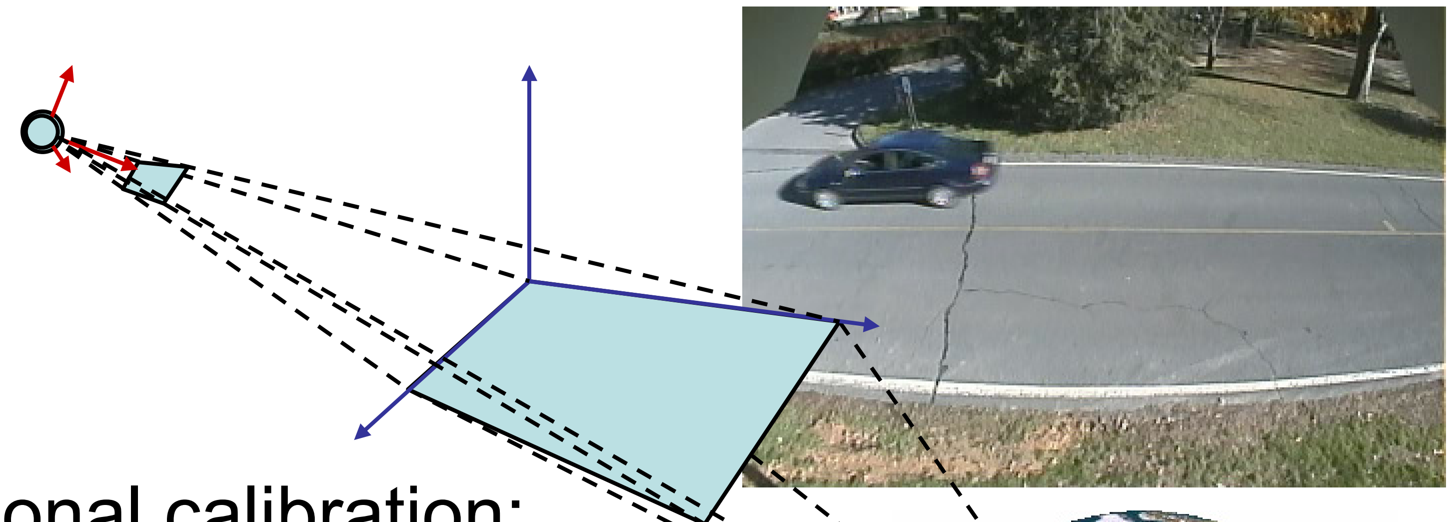


Estimated (red) / Actual (green)
Camera Location

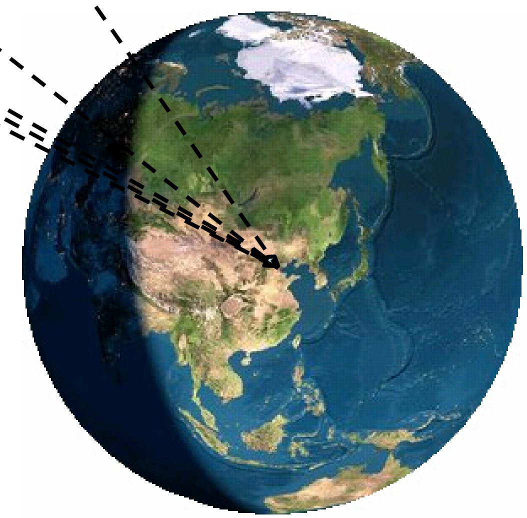
Simulation Results



Calibration



- Traditional calibration:
  - pixels ↔ object coordinates
- Geodetic calibration:
  - pixels ↔ (latitude, longitude)
- **This paper:**
  - **Narrow field-of-view (relative to GPS resolution)**
  - **Camera as a tripwire**



Why Not Just…

…take a GPS reading on the camera?

- **It’s hard:** GPS signals often blocked
- **It’s wrong:** Need GPS readings of the imaged area, not of the camera

…manually correspond ima
readings?

- Hazardous environments
- Advertises boundaries of
- Does not scale well to hu
  sensors that may be distr