Road Traffic Monitoring summary

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Artificial Intelligence & Information Analysis Lab

Road Traffic Monitoring

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Introduction

- Road Traffic Monitoring can be defined as the study of interactions between means of transport and infrastructure, in order to develop an optimal transport network.
- Why is it essential?
  - Time
  - Safety
  - Environmental impact

Traffic Attributes

The most important Traffic Attributes being monitored are:

- ***Traffic Flow***
- ***Traffic Speed***
- ***Traffic Density***
- ***Road Occupancy***

Event detection is not considered as Traffic Attribute, but it is a very important task handled by Traffic Monitoring Systems.

Traffic Flow

- ***Traffic Flow*** q is defined as the number of passing vehicles m from a reference point over time T.

$$q = \frac{m}{T}$$

- ***Inverse Traffic Flow*** h is defined as time that elapses between the two passing vehicles.

$$h = \frac{1}{q}$$

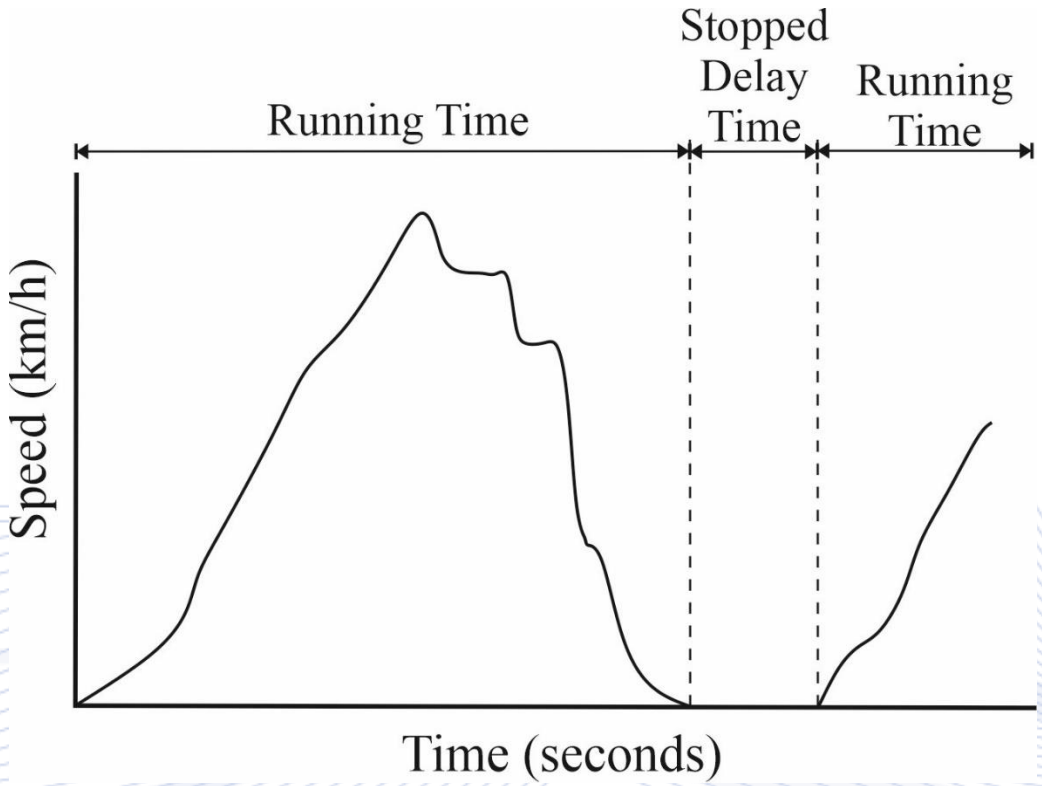
Average Traffic Speed

Travel time is the time needed to go from point A to point B.

- ***Running time*** **,** the mean of transport is in motion.
- ***Stopped time*****,** the mean of transport is stopped (or moving slow).

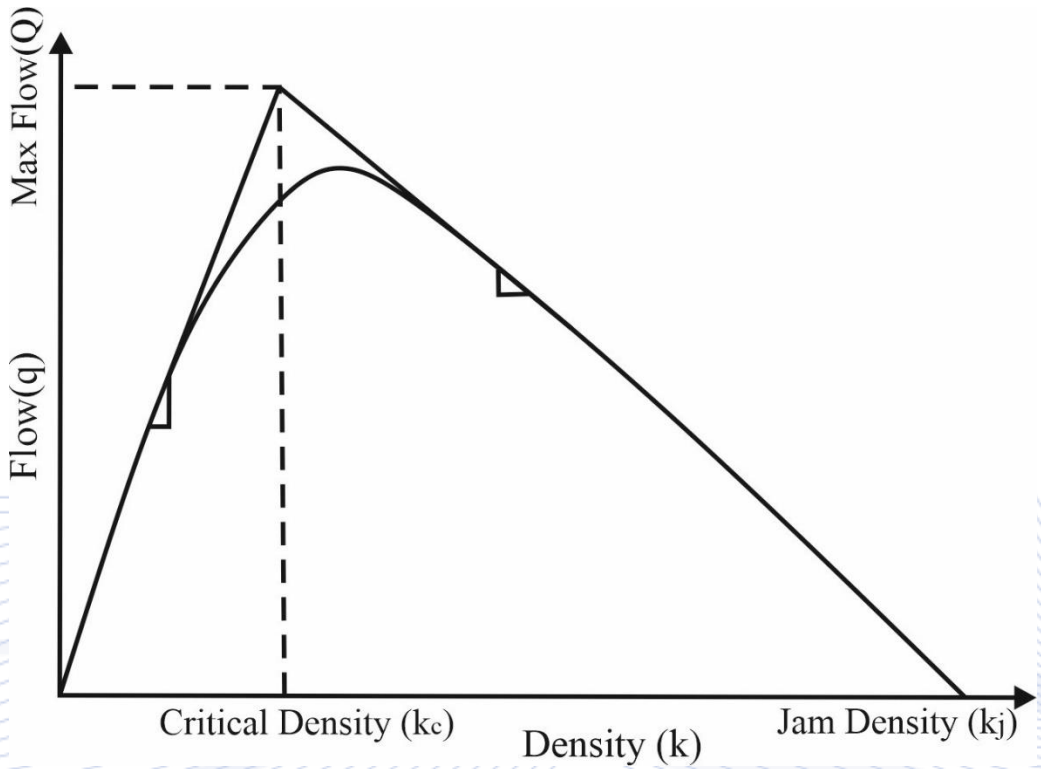
The ***Average Traffic Speed*** is calculated by measuring the travel time of vehicles over a short roadway segment, whose length d is known.

Average Traffic Speed



Running and Stopped Time.

Flow Density relationship



Flow Density relationship.

Traffic Data Variation

- Time of the Day variation.
- Day of the Week variation.
- Season of the Year variation.
- Directional Variation.
- Geographic Variation.

Traffic motoring systems search for patterns that can describe such variations.

Traffic Counter

Traffic Counter is considered any device that is used for collecting the Traffic Data and calculating ***Traffic Attributes***.

- ***Portable*** : can be moved very easily, usually there is no need for infrastructure invasion.
- **Permanent**: installed in the infrastructure (pavement invasion etc.)

Sensing technologies

- ***Inductive loops***
- ***Pneumatic road tubes***
- Magnetometer applications
- Radars (microwave, infared, ultrasonic, acoustic)
- ***Video Imaging***

There are also Traffic monitoring systems, that use multiple sensing technologies, and perform ***Data Fusion***.

Pneumatic road tubes

Pneumatic Road Tubes (from [HAQ1998]).

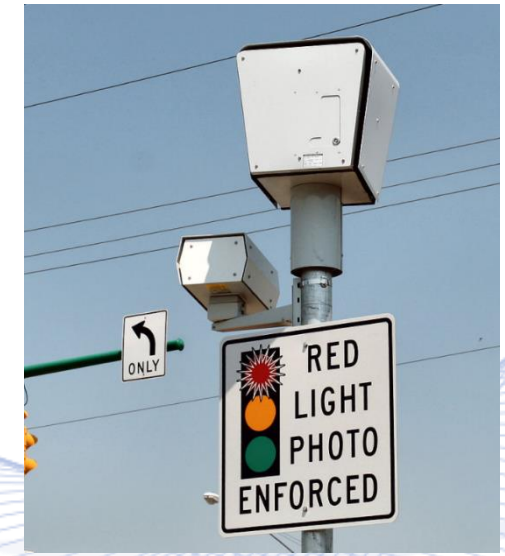
Inductive loop detectors

Inductive loop detector on traffic light (from [WIKI]).

Video Imaging

- Imagery of a traffic scene is analyzed to determine changes between successive frames.
- ***Object Detection and Tracking algorithms*** are used in order to detect the objects of interest.
- Once the 2D localization and 3D localization of the objects is performed, the Traffic Attributes and their Data Products can be calculated.

Traffic Sensors/Cameras



Stationary camera on traffic signal.

Traffic Attributes calculation

- Video imaging Traffic counters needed to:
  - Count the number of objects of interest.
  - Calculate their speed.
  - Identify their trajectory.
- Most common approaches used by Traffic Counters are:
  - Traffic attributes ***by detection***.
  - Traffic attributes ***by clustering***.
  - Traffic attributes ***by regression***.

Traffic attributes by detection

- Supervised methods which use previously trained detectors to detect objects of interest.
  - ***Monolithic detection.***
  - ***Part-based detection.***
  - ***Shape-matching detection.***

Monolithic detection

- Detect ***the regions*** $\mathcal{R}_{1n_t}, \dots, \mathcal{R}_{nn_t}$ that contain the n objects of interest that exist in the current frame $\mathcal{F}_{n_t}$ of the video.

$$\bigcup_{i=1}^{n} \mathcal{R}_{n_t} \subset \mathcal{F}_{n_t}$$

- Calculate the coordinates of the ***centroids*** $\mathbf{x}_{1n_t}, \dots, \mathbf{x}_{nn_t}$ of each region $\mathcal{R}_{in_t}$ the current frame $\mathcal{F}_{n_t}$.

$$\mathbf{x}_{in_t} = [n_1, n_2, n_t]^T, \text{ for } i = 1, \dots, N$$

Object Detection and Tracking

- The most common methodologies that are used for Detecting the regions of the objects of interest are the ***Convolutional Neural Networks***.
  - R-CNN,Fast R-CNN, Faster R-CNN

- ***Tracking*** is the process of locating a moving object over time, and the most common methods used by Traffic Counters are:
  - Feature Point based Tracking
  - Region Similarity based Tracking
  - KCF Tracker

Object Tracking

- Again, the only difference with Monolithic detection algorithms is that they are trained to detect the ***perimeters*** $\mathcal{S}_{in_t}$ of the objects of interest based on their shapes.

$$\mathcal{S}_{in_t} \subset \mathcal{R}_{in_t}$$

- e.g., for pedestrian Traffic Flow calculation, the shape of the human body is very unique. Thus, such methods, can be applied quite successfully.

Counting Objects

- Define m ***Tracking Regions*** $\mathcal{T}_1, \dots, \mathcal{T}_m$,

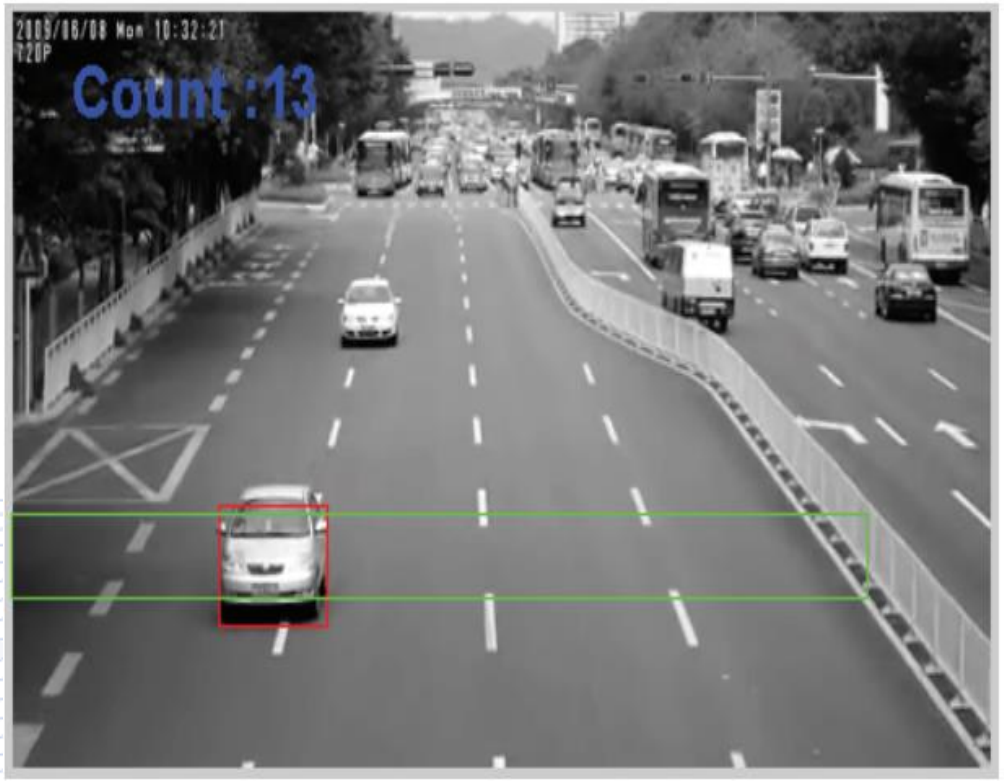
$$\bigcup_{i=1}^{m} \mathcal{T}_i \subset \mathcal{F}$$

- Define w ***Count Regions*** $\mathcal{C}_1, \dots, \mathcal{C}_w$,

$$\bigcup_{i=1}^{w} \mathcal{C}_i \subset \bigcup_{j=1}^{m} \mathcal{T}_j$$

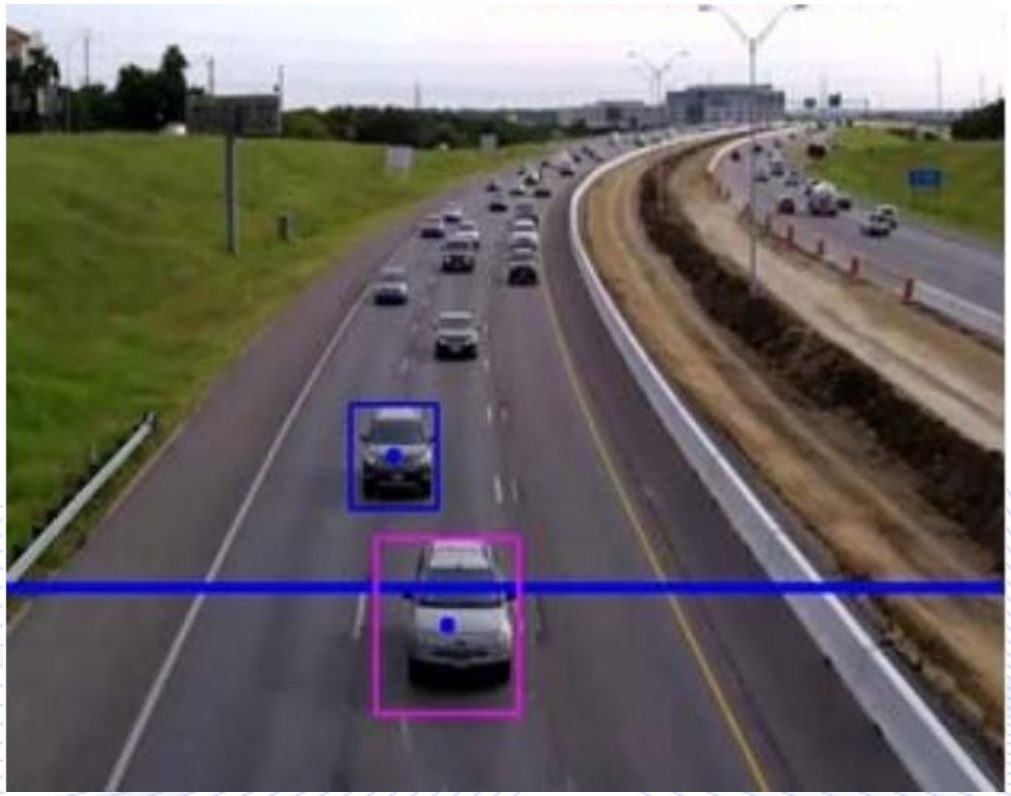
- The position of $\mathcal{T}_i$, $\mathcal{C}_i$ remain constant over the discrete time n_t.
- m, w are selected according to the needs of the Traffic Counter.

Directional Traffic Flow



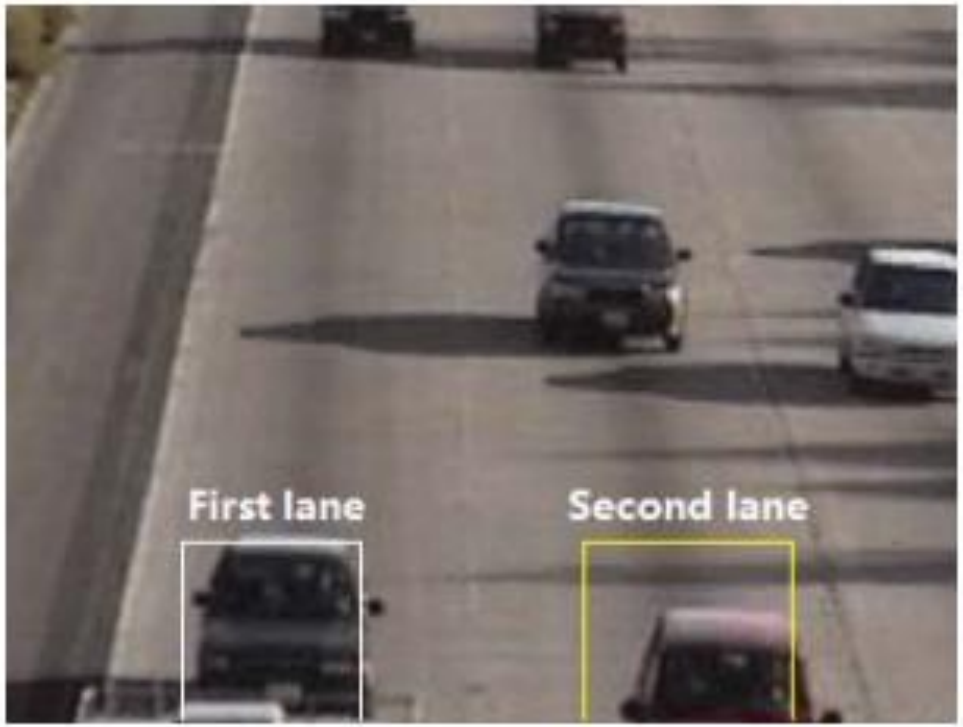
Vehicle Tracking and counting (from [BHA2014]).

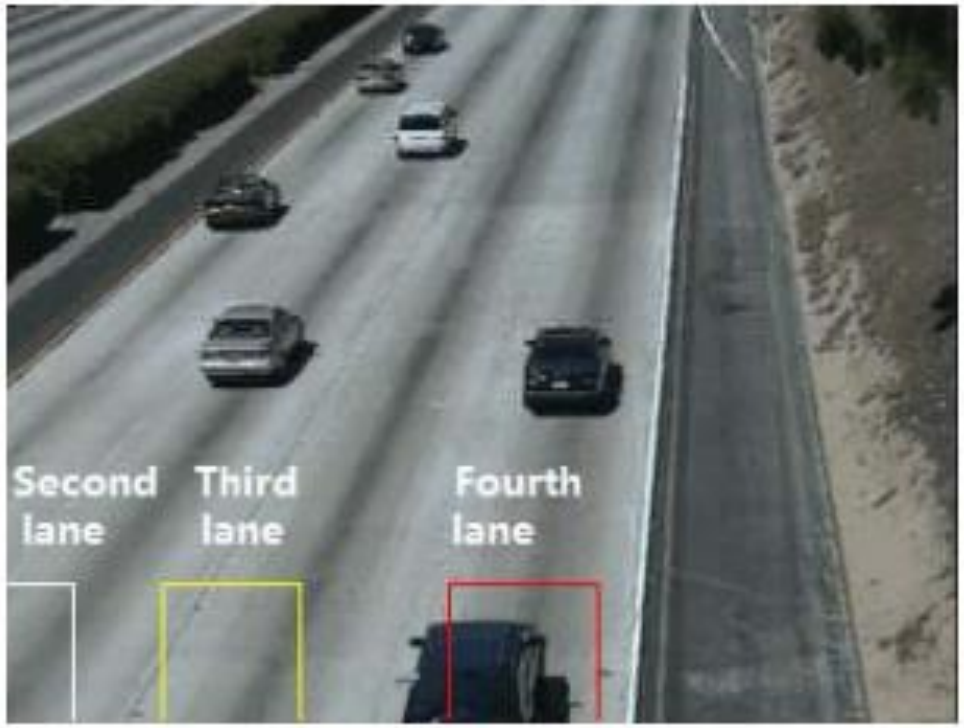
Directional Traffic Flow



Vehicle Tracking and counting (from [BOU2018]).

Lane Traffic Flow



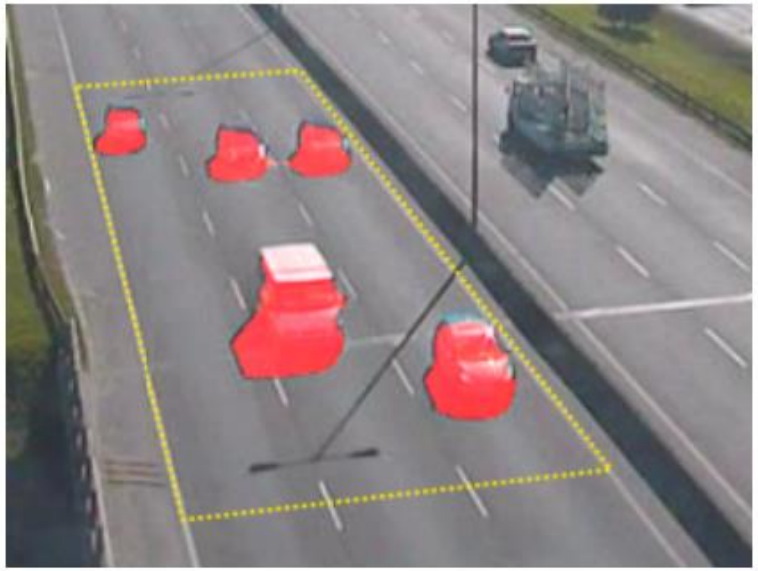


Multi-lane counting (from [ZHU2013]).

Traffic Density

a) Lane detection; b) Counting results (from [TORO2015]).

Road Occupancy



$\mathcal{T}_i$ (dotted yellow line), detected $\mathcal{R}_{jn_t}$ (red) (from [YAB2016]).

Counting based on trajectories

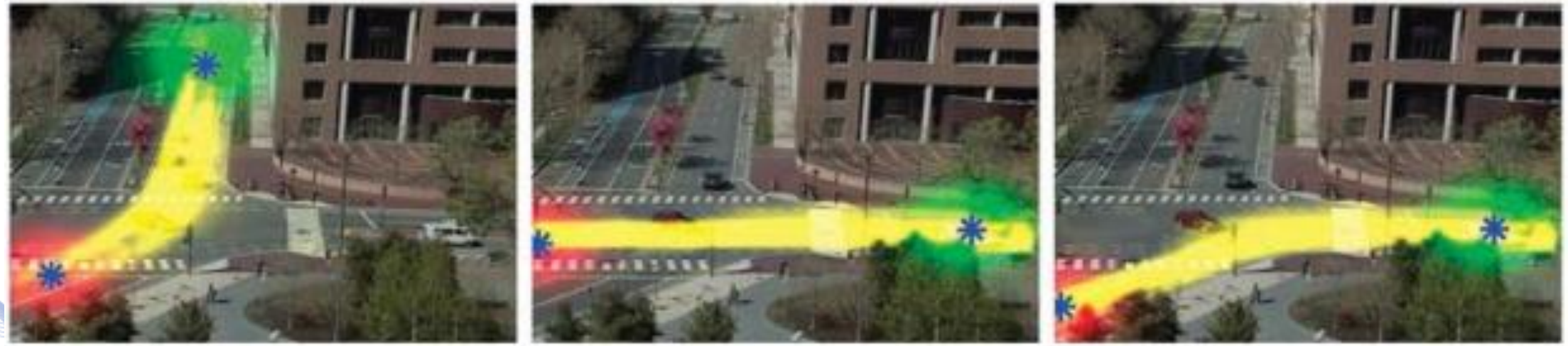
Instead of counting objects in Count Regions, Traffic Counters can count the number of objects by detecting their ***Trajectories*** $\mathcal{J}_i$.

$$\mathcal{J}_i = \{\mathbf{x}_{in_t}\}_{n_t = n_{t_{in}}}^{n_{t_{out}}}$$

$$\mathbf{x}_{it} \in \mathcal{R}_{it}$$

- $\mathbf{x}_{in_t}$ the centroid of region $\mathcal{R}_{in_t}$
- $i = 1, \ldots, n$, the number of tracked objects.
- $n_{t_{in}}, n_{t_{out}}$, the first and the last frame of tracked object.

Sources, Sinks of trajectories



Source (red) ,Sink (green) areas and points(blue)

$\mathcal{S}_j, \mathcal{E}_k$, $(\mathbf{x}_{i(n_{t_{in}})}, \mathbf{x}_{i(n_{t_{out}})})$ (from [ZHA2013]).

Directional Traffic Flow from trajectories

- The Directional Traffic Flow can be calculated via:

$$q_{jk} = f \frac{c_{jk}}{N_{n_t}}$$

  - $j = 1, \ldots, m$ the number of source areas.
  - $k = 1, \ldots, k$ the number of Sink areas.
  - N_{n_t} the number of monitoring frames
  - f the framerate $[\frac{1}{sec}]$.

Traffic Attributes by clustering

- Instead of detecting and tracking objects, Feature Points $\mathbf{p}_{1n_t}, \ldots, \mathbf{p}_{kn_t}$ are being tracked at each frame $\mathcal{F}_t$.
- For each feature point $\mathbf{p}_{in_t}$ define:

$$\mathbf{X}_{in_t} = [\mathbf{p}_{in_t}, \mathbf{v}_{in_t}, n_t]$$

  - $\mathbf{v}_{in_t} = [v_{ixn_t}, v_{iyn_t}]$, the velocity at frame n_t.
  - $\mathbf{p}_{in_t} = [x_{in_t}, y_{in_t}]$, the discrete coordinates of the point.

Traffic Attributes by clustering

Clustering feature points into vehicles (from [ZHA2013]).

Counting by classification

Typical $\mathcal{L}_{1,2,3}$ (red arrows) and detected $\mathcal{J}_{1,2,3,4}$ (colored based on classification results) (from [LIU2020]).

Average Traffic Speed

- Once the trajectories $\mathcal{J}_i$ has been identified the average ***Space Mean Speed*** and average ***Time Mean Speed*** can be calculated after performing the following transformations:

$$f_1 : \mathcal{J}_i = \{\mathbf{x}_{in_{t_{in}}}, \dots, \mathbf{x}_{in_{t_{out}}}\} \rightarrow \{\boldsymbol{X}_{it_{in}}, \dots, \boldsymbol{X}_{it_{out}}\}$$

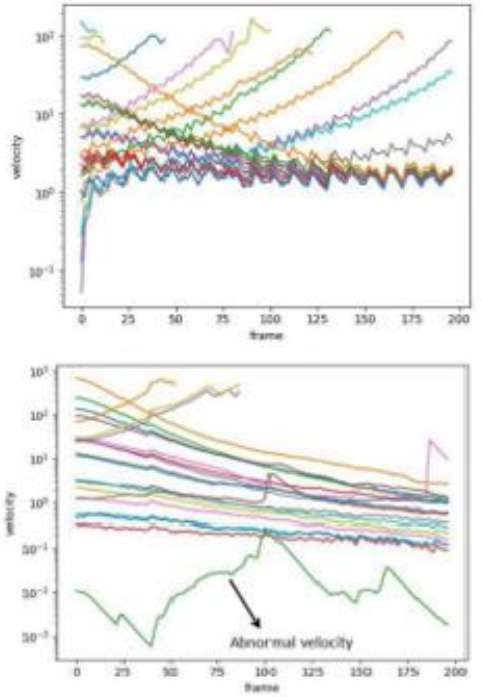
$$f_2 : \{\boldsymbol{X}_{it_{in}}, \dots, \boldsymbol{X}_{it_{out}}\} \rightarrow \{\boldsymbol{V}_{it_{in}}, \dots, \boldsymbol{V}_{it_{out}}\}$$

- $\boldsymbol{X}_{it} = [X_i, Y_i, Z_i, t]^T$, world coordinates of $\mathbf{x}_{in_t}$ at real time t.
- $\boldsymbol{V}_{it} = [U_{ixt}, U_{iyt}, U_{izt}, t]$, velocity of $\boldsymbol{X}_{it}$ at real time t.

Event Detection

- The function of the speed of vehicles over time can also be used for identifying events in highways
- The concept is that the trajectories $\mathcal{J}_i$ of moving vehicles and their velocities is being calculated.
- Finally, search for abnormal behaviors in the diagram $V_i(t)$, comparing it to the other vehicles that are being tracked.
- The abnormal behaviors are detected using heuristic methods in the diagrams of the velocities of the present vehicles.

Event Detection



Identify stalling car (from [XU2018]).

Counting by regression

- Instead of detecting and then counting the objects, Supervised algorithms can be used to directly learn the number of objects by mapping global image characteristics.
- Such methods, require large number of labeled training images and they are not common.
- The only Traffic Attribute that can calculate is the Traffic Flow.

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Q & A

Thank you very much for your attention!

More material in
http://icarus.csd.auth.gr/cvml-web-lecture-series/

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