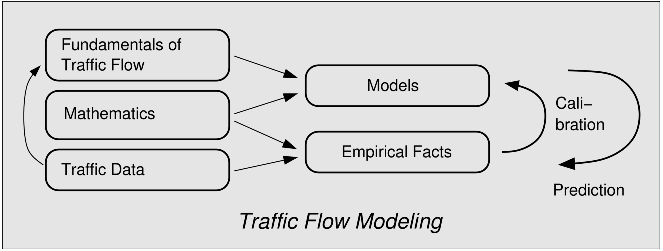
Part I: Traffic Flow Data

Lecture 01: Trajectory Data

- 0. Definition of Traffic Flow Dynamics
- 1. Trajectory and Floating-Car (FC) Data
- 1.1. Trajectory Data
- 1.2. Floating-Car Data
- 1.3. Extended Floating-Car Data

Definition of Traffic Flow Dynamics

Traffic Flow Dynamics describes the interplay of many **driver-vehicle units** with themselves and with the infrastructure.



- Tools: **mathematical models**, i.e. sets of equations
- Methods: **simulations** to solve and visualize the equations
- Use cases:
  - Data analysis ⇒ jam warning systems and dynamic navigation
  - Generating surrounding traffic for driving simulators
  - Assessing the traffic flow impact of new infrastructure controls, or technologies (ACC, V2X communication, assistance systems)
  - Autonomous driving

Delimitation from other fields

Time Scale	Field	Models	Aspect of Traffic (examples)
< 0.1 s	vehicle dynamics	sub-microscopic	control of engine and brakes
1 s 10 s 1 min 10 min	traffic flow dynamics	car-following models macroscopic models	reaction time, time gap acceleration and deceleration cycle period of traffic lights stop-and-go waves
1 h 1 day 1 year 5 years 50 years	transportation planning	route assignment traffic demand statistics age pyramid	peak hour daily demand pattern building/changing infrastructure socioeconomic structure demographic change

- Delimitation from above: **transportation planning**
- Delimitation from below: **vehicular dynamics** (transmission, clutch, engine controller, electronic stability program,...)

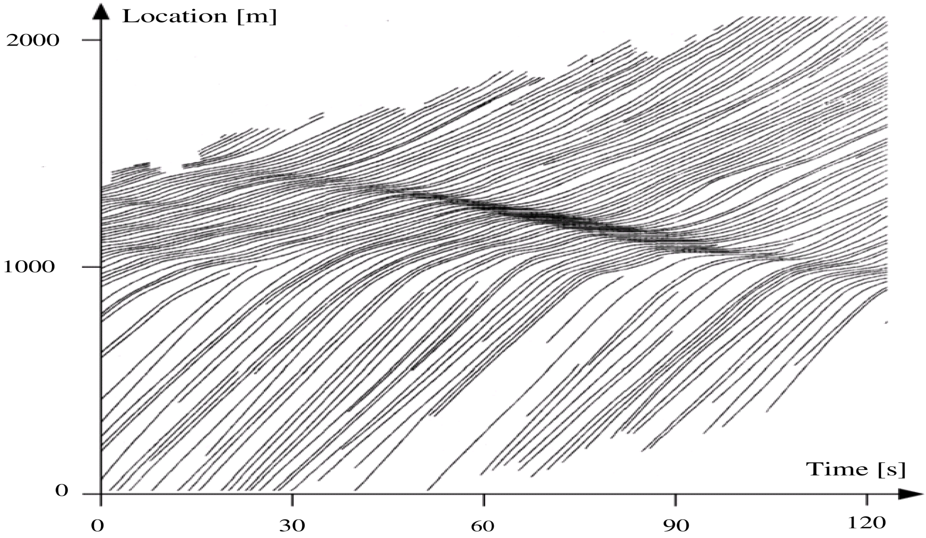
Traffic Flow Data

Without data, we operate in empty space without feedback to reality!

Data categories:

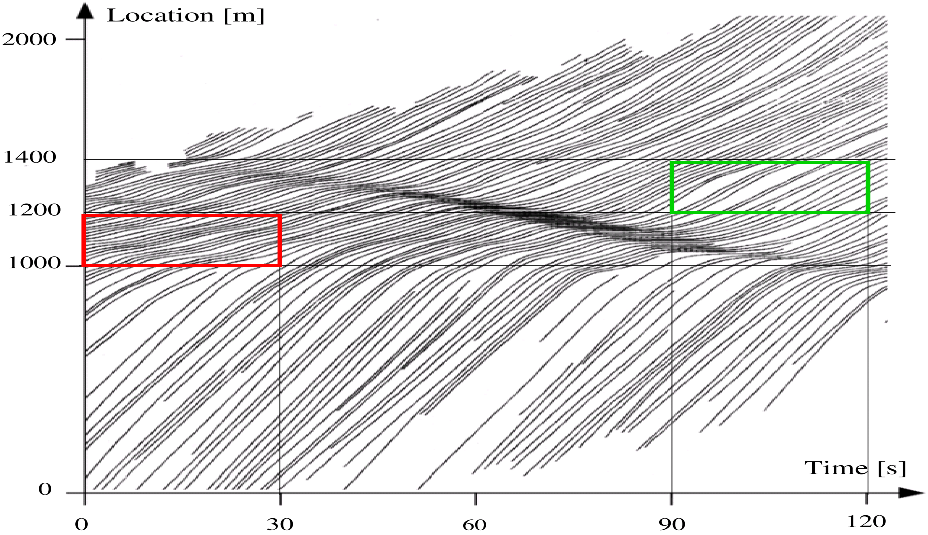
- **Trajectory data**: full (x_i, y_i, t) coverage of all vehicles i in a certain spatiotemporal region, typically taken from external camera images
- **Floating-car (FC) data**: GPS records from inside a vehicle
  - **Extended FC (xFC) data**: Other inside-vehicle sensors recorded as well
- **Cross-sectional data**: Typically recorded from stationary detector stations
- **Event-oriented data**: Accident and traffic jam information
- **Infrastructure data**: Besides the road network the traffic-light phases etc

1.1. Trajectory Data



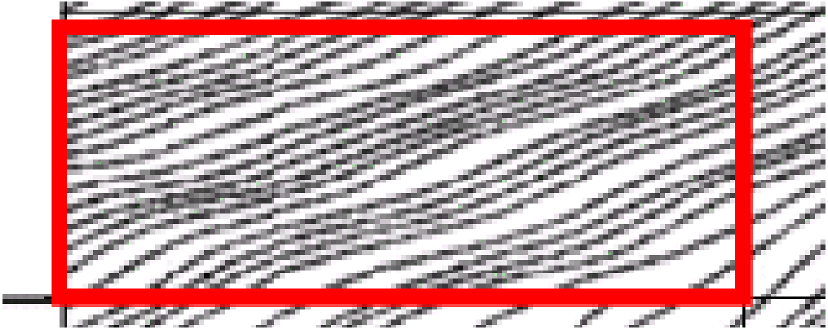
The original: trajectories showing a stop-and-go wave on a British motorway segment. [Adapted from: J. Treiterer et al. (1970)]

Determining the state from trajectory data



? Estimate the wave velocity and the lane-changing intensity (#changes/h/km)

Determining the local state of the boxed regions I



Region 1: $[0\,\mathrm{s}, 30\,\mathrm{s}] \times [1\,000\,\mathrm{m}, 1\,200\,\mathrm{m}]$

? Estimate the local density $\rho(\bar{x}, \bar{t})$ by trajectory counting

! (15+13)/2 per 200 m=70 veh/km

? estimate the local flow $Q(\bar{x}, \bar{t})$ by counting

! (11+14)/2 per 30 s=25 veh/min=1 500 veh/h

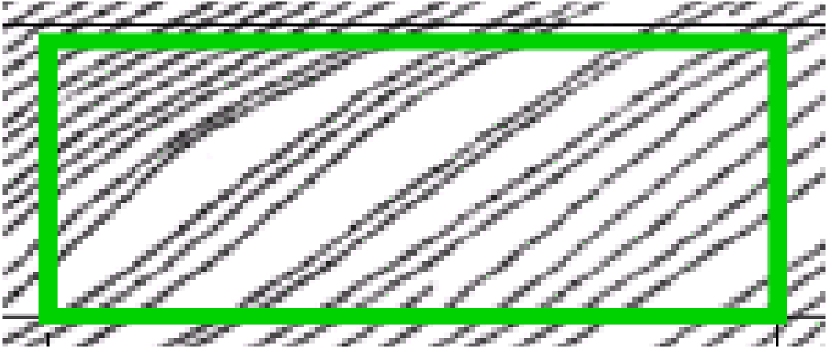
? estimate the local speed $V(\bar{x}, \bar{t})$ by the gradient method and compare with the hydrodynamic relation $V = Q/\rho$

! Diagonal: $180\,\mathrm{m}/28\,\mathrm{s} \approx 6.5\,\mathrm{m/s} = 23\,\mathrm{km/h}$;

Hydrodynamic relation:

$V = Q/\rho = 1\,500\,\mathrm{veh/h}/70\,\mathrm{veh/km} = 21\,\mathrm{km/h}$

Determining the local state of the boxed regions II

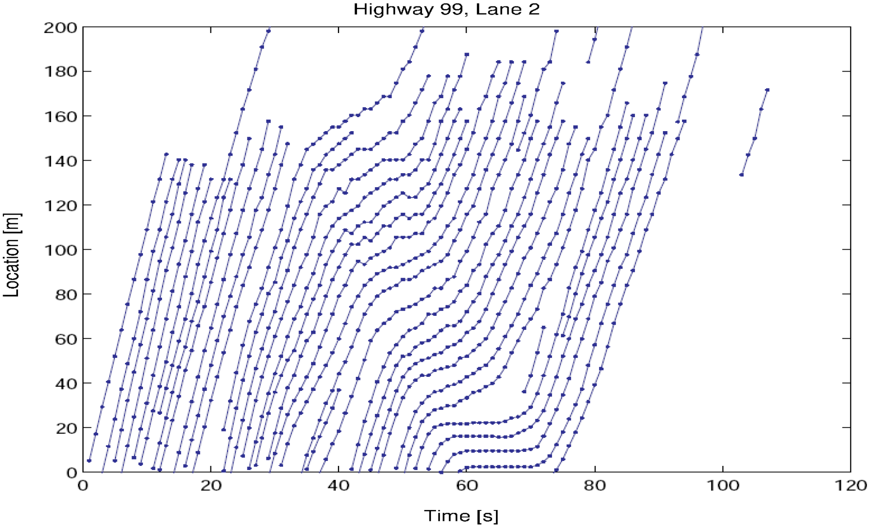


Region 2: $[90\,\mathrm{s}, 120\,\mathrm{s}] \times [1\,200\,\mathrm{m}, 1\,400\,\mathrm{m}]$

- ? Estimate the local density $\rho(\bar{x}, \bar{t})$ by trajectory counting
  - ! (10+8)/200 m=45 veh/km
- ? estimate the local flow $Q(\bar{x}, \bar{t})$ by counting
  - ! (14+16)/2 veh/30 s=1 800 veh/h
- ? estimate the local speed $V(\bar{x}, \bar{t})$ by the gradient method and by the hydrodynamic relation
  - ! 200 m/18 s=11 m/s=40 km/h; Hydrodynamic relation:

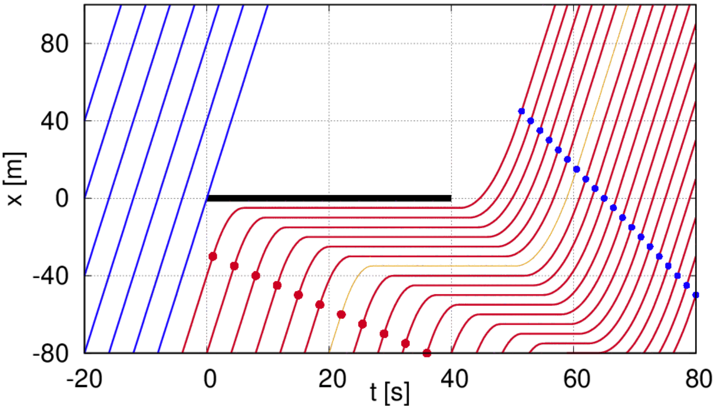
$$V = Q/\rho = 1\,800\,\mathrm{veh/h}/45\,\mathrm{veh/km} = 40\,\mathrm{km/h}$$

Problem I



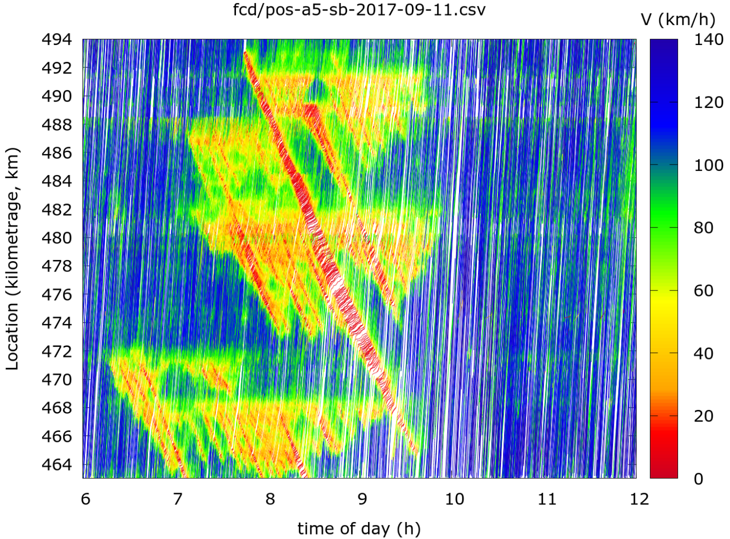
- ? Which situation is displayed here?
- ? Estimate the propagation velocity of the stop-and-go wave
- ? Which microscopic situation could be shown at $t \approx 70\,\mathrm{s}$ and $x \approx 40\,\mathrm{m}$?

Problem II



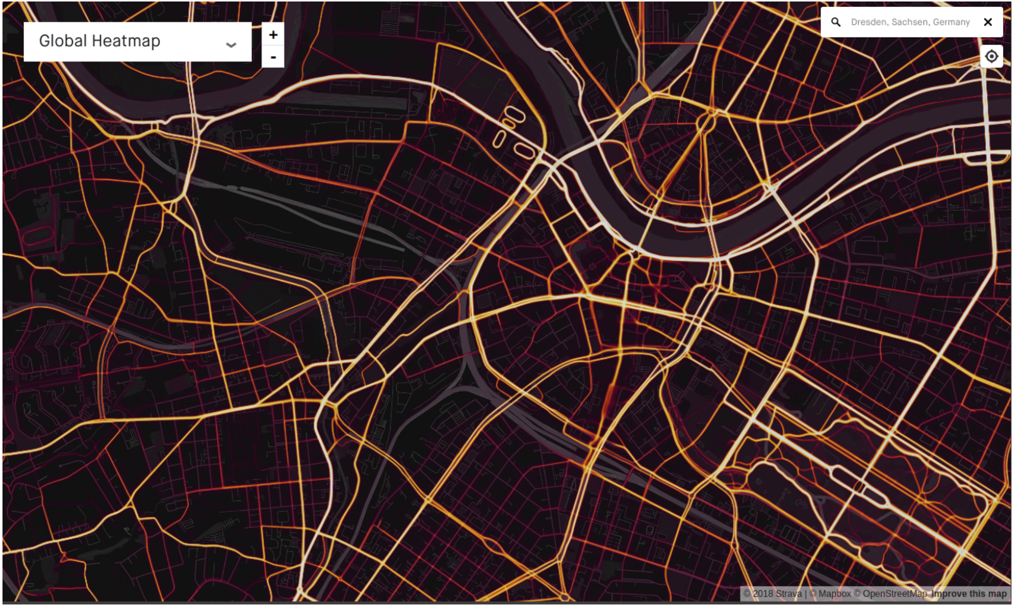
- ? Which situation could be displayed here? traffic light
- ? Calculate the braking and acceleration distances (the braking starts and the acceleration ends at the red and blue bullets, respectively). 25 m and 50 m, respectively
- ? Calculate the minimum braking deceleration and acceleration needed during these maneuvers Speed $v_0 = 10\,\mathrm{m/s}$, deceleration $b = v_0^2/(2s_{\text{decel}}) = 2\,\mathrm{m/s^2}$, acceleration $a = 1\,\mathrm{m/s^2}$
- ? Estimate the velocity of the upstream and downstream boundaries of the queue $c_{\text{up}} = -40\,\mathrm{m}/30\,\mathrm{s} = -4.8\,\mathrm{km/h}$, $c_{\text{down}} = 0$ or $w = -11.5\,\mathrm{km/h}$

1.2. Floating-Car (FC) Data



- Principle: transmit geo-referenced coordinates obtained by satellite navigation to a data center
- Data sources: Everybody using a smartphone-based or built-in navigation system (Google Maps, TomTom, ...); additionally probe vehicles from logistics companies

“Floating-pedestrian data”: Strava Heatmap



(Dresden)

Differences between trajectory and FC data

- Position of the data source: stationary *vs.* mobile; out-of-system *vs.* in the system
- Sampled spatiotemporal regions: very small *vs.* huge
- Scalability: Non-existent (at present) *vs.* huge (essentially all roads with significant traffic, worldwide)
- Completeness of sampling: 100 % *vs.* unknown and small (the **penetration rate** is a few percent, at most)
- Computation requirement: huge (extract trajectories from images) vs. small (just map-match the transmitted coordinates)
- Precision: a few centimeters (depending on pixel size) *vs.* about 10 m (depending on how many satellite systems are being used)
- Sampling frequency: high (every 100 ms) *vs.* low (several seconds)

? Discuss if and how the actual *data* (what is measured?) differ between these two sampling methods

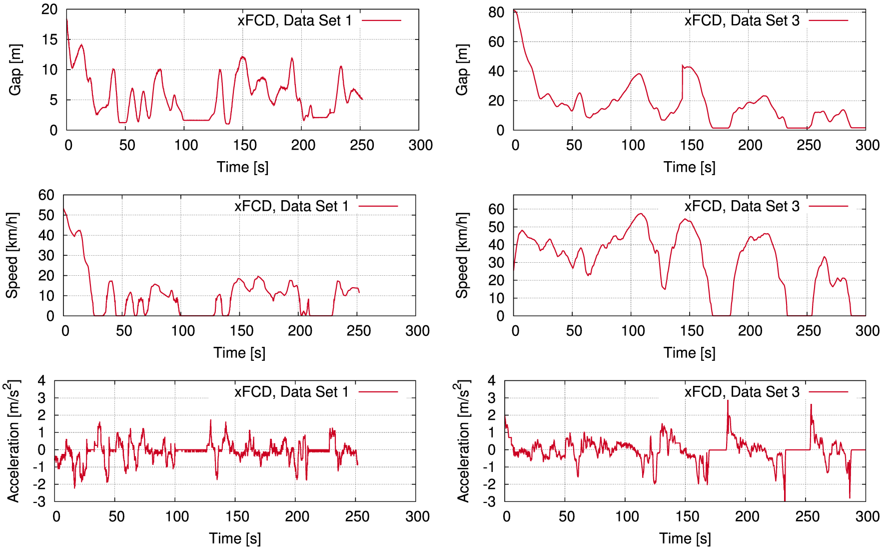
Problems

? Discuss suitable applications for trajectory and FC data. Consider navigation, assistance systems, model development, model calibration and validation, autonomous driving

! This follows from the properties described above:

- Navigation: We need a wide coverage while a precision of some 10 meters is enough ⇒ FC data. Notice that we have a nice example of an *anti-Murphy's Law*
- Assistance systems: For some (congestion/jam warning), FC data are enough (again, *anti-Murphy's Law* applies) for others (ACC, traffic-light-assistant) none is enough ⇒ xFC data below
- Model development, calibration and validation: We need complete coverage, 100 millisecond sampling and centieter-100 millisecond precision: Trajectory data
- Autonomous driving: None is enough: xFC data, future high-precision navigation, high-precision digital maps, C2X communication and more are needed

1.3 Extended Floating-Car (xFC) Data



XFC data are normal FC data augmented by additional information provided by vehicle sensors via the internal ehicle data bus (CAN bus)

Description of xFC data

The sampling interval is typically between 10 ms and 100 ms. At present, only used in **probe vehicles** for special, mainly scientific, applications

- Directly measured speed and speedometer reading
- Sometimes precise DGPS measurements
- throttle and/or braking pedal pressure
- steering angle
- lights on/off, left winker on/off etc
- distance gap to leader or to other surrounding objects
- relative speed to leader
- desired ACC deceleration, ...

Problems

? Discuss the differences between directly measured speed, speedometer reading and GPS speed

! (i) Directly measured: Physical measurement typically using the tyre rotation rate (error prone; it is remarkably difficult to measure speed with low errors)

(ii) Speedometer reading: In order to stay on the safe (legislative) side, the speedometer reading is a few percent higher than the directly measured one

(iii) GPS speed: Time derivative of the GPS positions projected to the driving direction (only useful if DGPS is used)

? How to determine the leader's speed v_l?

! By the gap $s(t)$ to the leader: Approaching rate (relative speed) $\Delta v = v - v_l = -\frac{\mathrm{d}s}{\mathrm{d}t}$. Or get Δv directly by the Doppler effect if the distance sensor (Radar) implements this.

? Discuss differences between FC and xFC data regarding sampling rate, precision, availability

! A few ms *vs.* a few s; a few cm *vs.* a few meters (no lane detection possible!); widespread *vs.* rare;

? Discuss possible use cases

! "normal" FC data: Navigation, traffic-state detection, jam warning systems; xFC data: ACC, autonomous driving, traffic flow model development, understanding of driving behaviour.