The Intelligent-Agent Model – a Fully Two-Dimensional Microscopic Traffic Flow Model

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- 1. Starting point: the Intelligent-Driver Model
- 2. 2d generalisation: the Intelligent-Agent Model
- 3. Lane-based mixed traffic: cars, trucks, and motorcycles
- 4. Lane-free mixed traffic flow: Bicycles
- 5. Summary

1. Starting point: the Intelligent-Driver Model

$$\frac{\mathrm{d}v}{\mathrm{d}t} = a\left[1 - \left(\frac{v}{v_0}\right)^4 - \left(\frac{s^*(v,v_l)}{s}\right)^2\right]$$ IDM acceleration

$$s^*(v,v_l) = s_0 + \max\left(0, vT + \frac{v(v-v_l)}{2\sqrt{ab}}\right)$$ desired gap

free acceleration: $a[1-(v/v_0)^4]$, repulsive force: $-a(s^*/s)^2$

Parameter	Cars Highway	Cars City	Trucks Hwy	Bicycles
Desired speed v_0	$120\,\mathrm{km/h}$	$50\,\mathrm{km/h}$	$80\,\mathrm{km/h}$	$20\,\mathrm{km/h}$
Time gap T	$1.0\,\mathrm{s}$	$1.0\,\mathrm{s}$	$1.8\,\mathrm{s}$	$0.6\,\mathrm{s}$
Minimum gap s_0	$2\,\mathrm{m}$	$2\,\mathrm{m}$	$3\,\mathrm{m}$	$0.4\,\mathrm{m}$
Acceleration a	$1.5\,\mathrm{m/s^2}$	$2.0\,\mathrm{m/s^2}$	$0.5\,\mathrm{m/s^2}$	$1.0\,\mathrm{m/s^2}$
Comf. deceleration b	$1.5\,\mathrm{m/s^2}$	$2.0\,\mathrm{m/s^2}$	$1.0\,\mathrm{m/s^2}$	$1.5\,\mathrm{m/s^2}$

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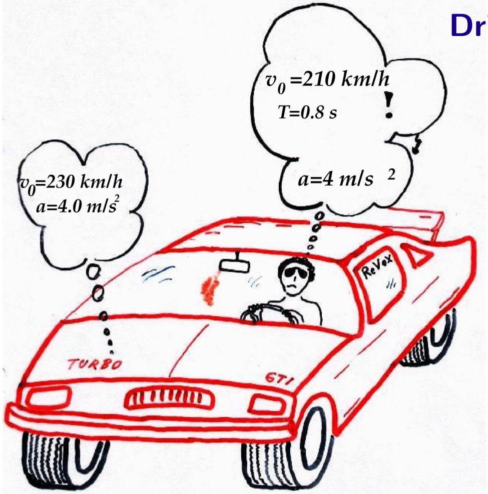
Driving styles



Aggressive driver:
v_0, a and b high, T and s_0 low

Relaxed driver:
v_0, a low, b normal, T and s_0 high

Experienced responsive driver:
a high, b low, rest normal

Experienced defensive driver:
v_0, a normal, b low, T and s_0 high

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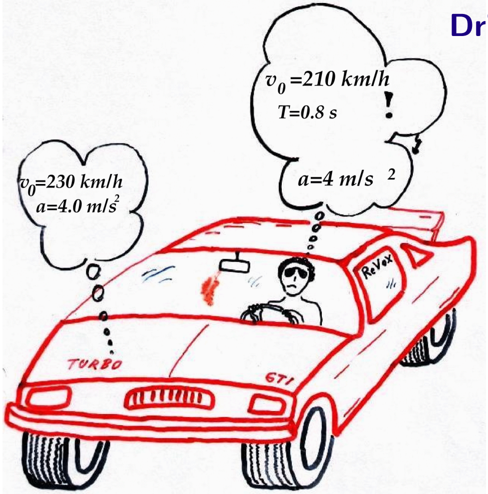

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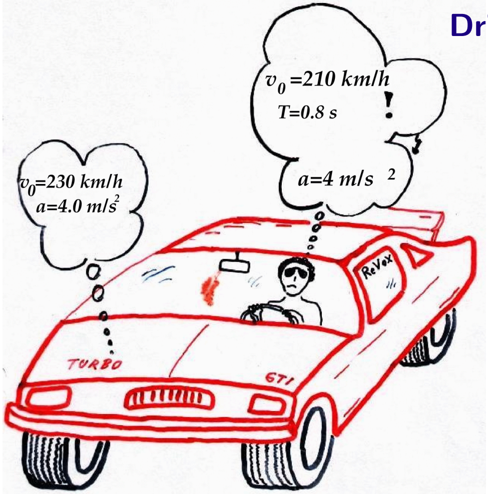

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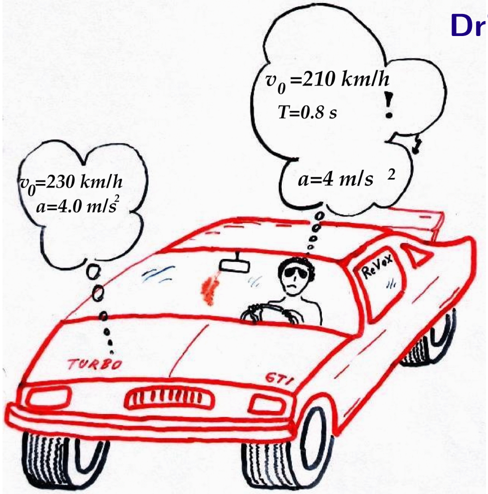

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2. 2d generalisation: the Intelligent-Agent Model

General model

$$\frac{\mathrm{d}\boldsymbol{v}_i}{\mathrm{d}t} = \boldsymbol{f}_i^{\text{self}}(\boldsymbol{v}_i) + \sum_j \boldsymbol{f}_{ij}^{\text{int}}(\boldsymbol{r}_i, \boldsymbol{v}_i, \boldsymbol{r}_j, \boldsymbol{v}_j) + \sum_b \boldsymbol{f}_{ib}$$

- $\boldsymbol{f}_i^{\text{self}}(\boldsymbol{v}_i)$: Self-driving force (acceleration) of the intelligent agents
- $\boldsymbol{f}_i^{\text{int}}(\boldsymbol{r}_i, \boldsymbol{v}_i, \boldsymbol{r}_j, \boldsymbol{v}_j)$: interaction force with the neighboring vehicles, obstacles, and traffic lights j (also rear agents considered)
- $\boldsymbol{f}_{ib}$ boundary forces to keep the agent in the driveable area

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General idea for the formulation (longitudinal)

- **Separate** the CF model in a free-flow and interacting contribution ($\boldsymbol{v} = (v, w)'$, $\boldsymbol{f} = (f, g)'$)

$$\left(\frac{\mathrm{d}v}{\mathrm{d}t}\right)_{\text{CF}}(s, v, v_l) = f^{\text{self}}(v) + f^{\text{CF,int}}(s, v, v_l)$$

- If a follower is on a collision course to a leader, the longitudinal interaction leader $\to$ follower is **equal to the CF interaction**. The interaction follower $\to$ leader can be a **small fraction** of that

- If a follower is not on collision course, the longitudinal interaction **decreases exponentially** with the lateral gap. Likewise, the longitudinal interaction with the **boundary** decreases exponentially with the lateral gap

- The interaction forces of all objects in a neighborhood are **added**.

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- The lateral self force is nonzero for agents **entering** or **leaving** the driveable area
- The lateral interaction force follows from the **incentive criterion** of the lane-changing model MOBIL ($\boldsymbol{x} = (x, y)'$):

$$g_{ij}^{\text{int}} \propto \frac{\mathrm{d} f_{ij}^{\text{int}}}{\mathrm{d} y}$$

  Particularly, this leads to **repulsive** lateral forces **exponentially decreasing** with the lateral gaps to vehicles and boundaries
- If the 1d car-following model is formulated such that a collision (negative longitudinal gap) leads to the maximum repulsive force, we **automatically** have repulsive forces if two vehicles drive in parallel at a very close gap
- Existence of lanes: **floor potential** with maxima parallel to the lane markers leading to lateral forces away from the lane markers. Disobeying drivers (moto-cyclists) can ignore it

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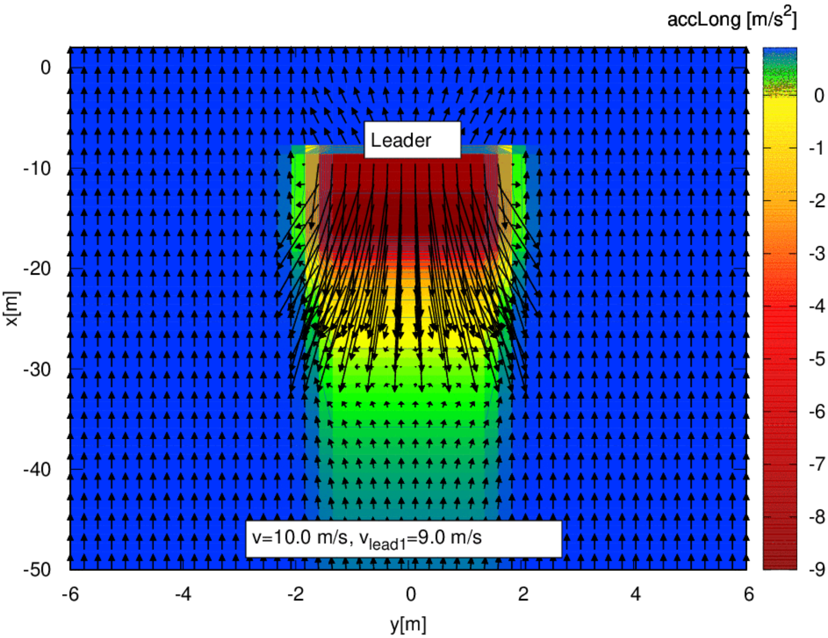
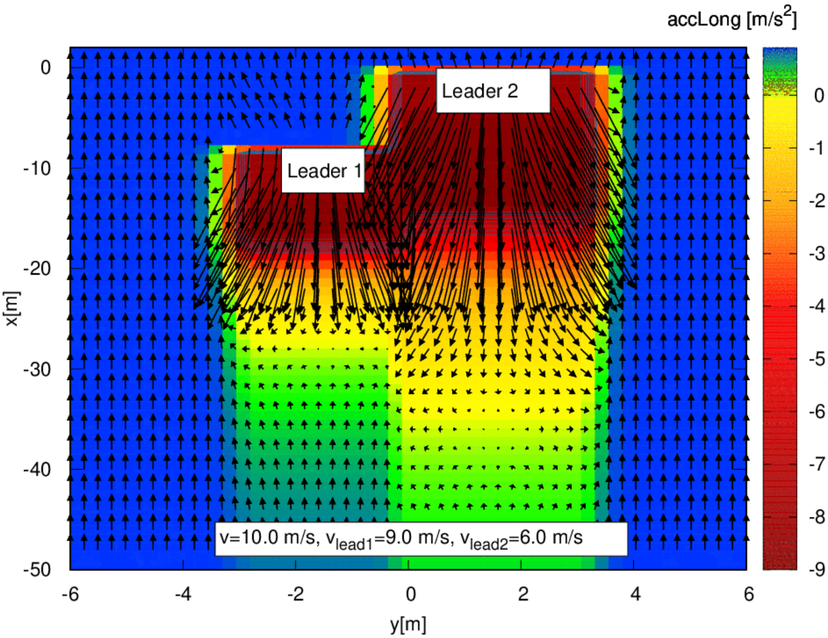
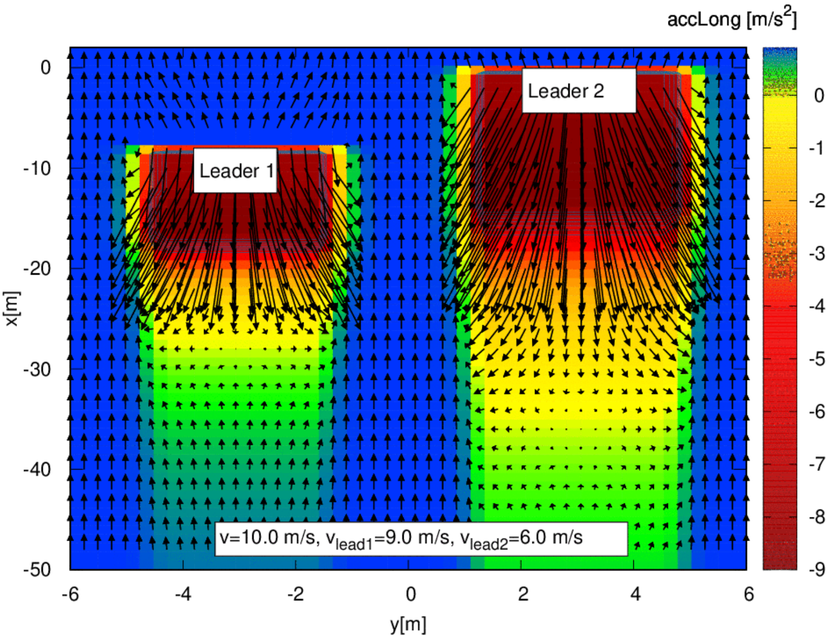
Force field of the IDM-based IPM (single leader)



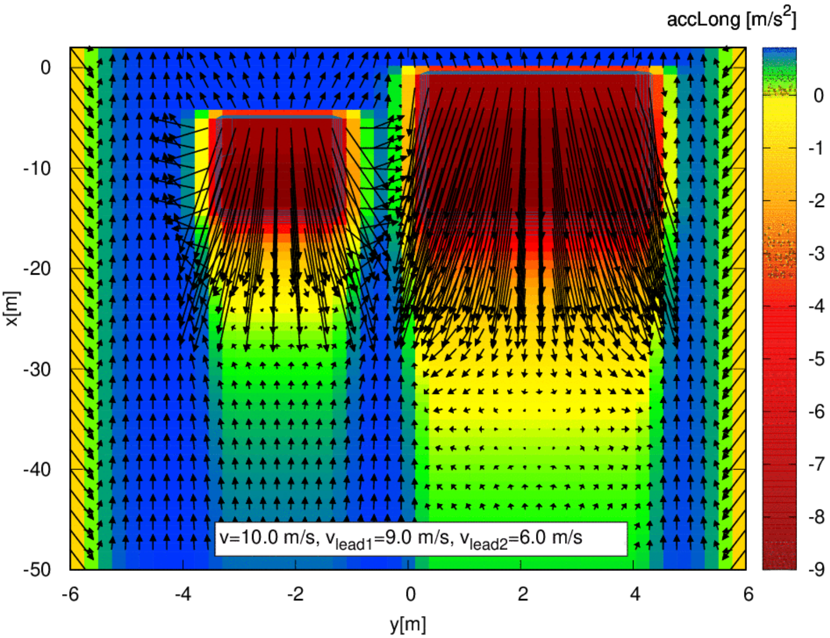
Force field for two leaders close together



Force field for two leaders further apart



Adding the boundary forces

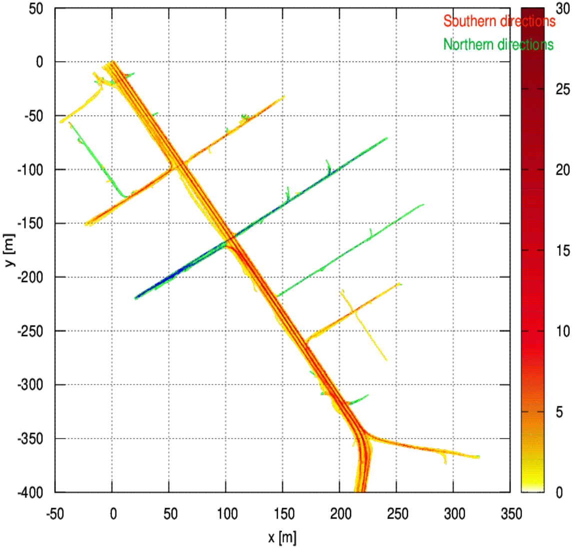


3. Simulating lane-based mixed traffic: cars, trucks, and motorcycles

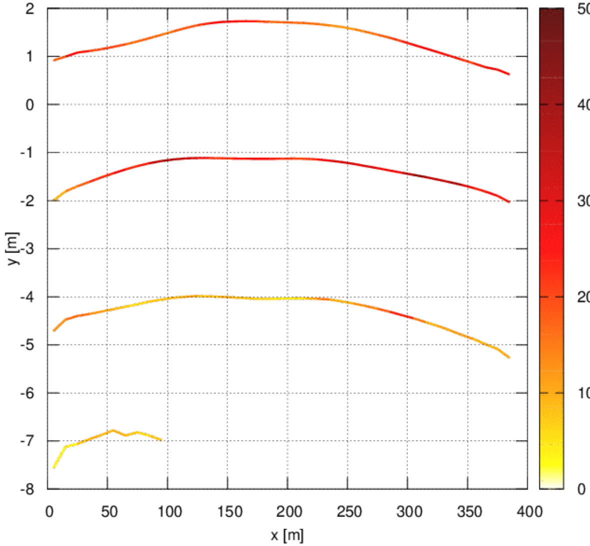
Simulate!

Data: city traffic of Athens from the PNEUMA project

Section covered by the drone d1

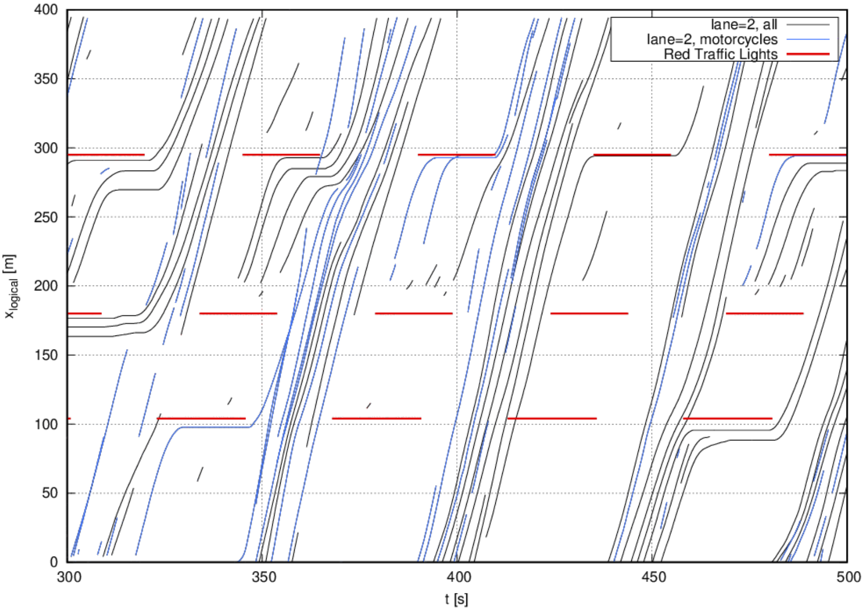


Heatmap of the transformed data

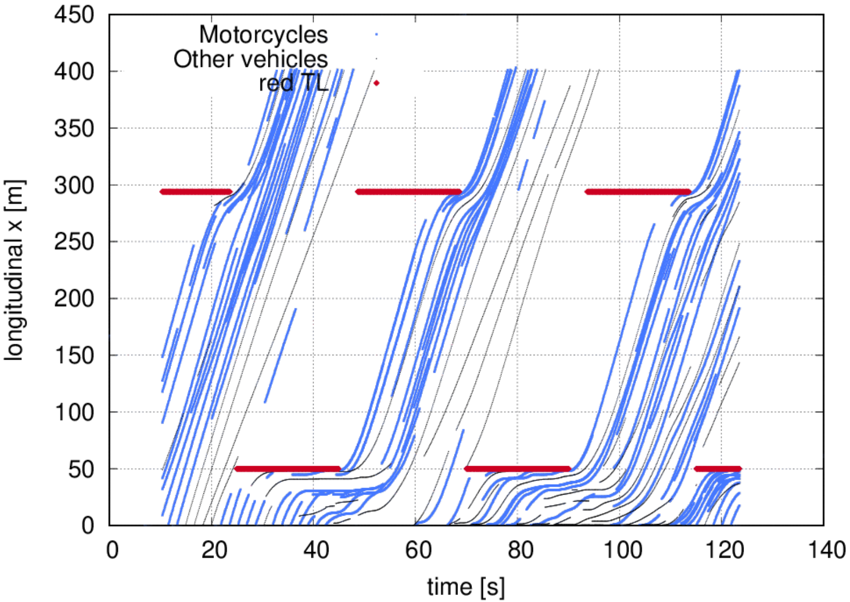


Data-driven lane reconstruction (“Akadimias”, South)

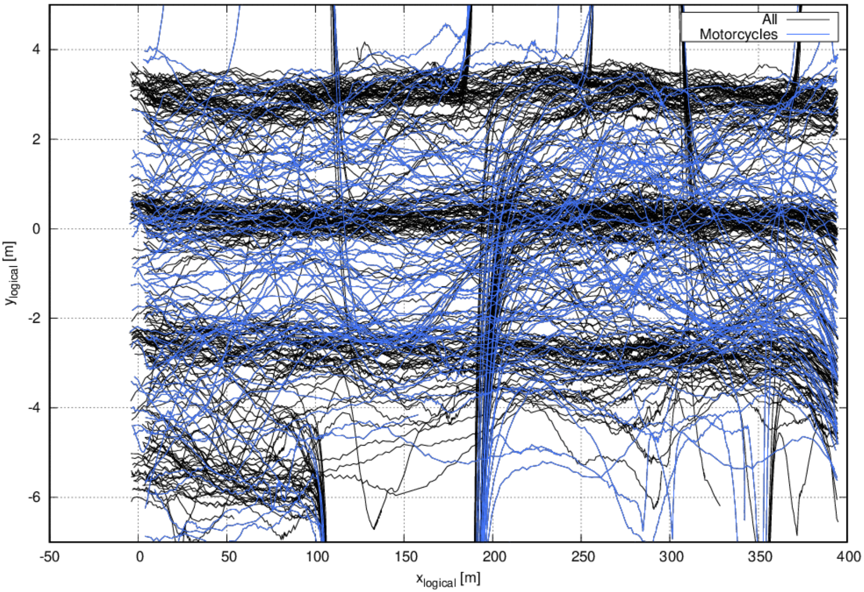
The street "Akadimias" (one-way, SE), x-t plot, middle lane



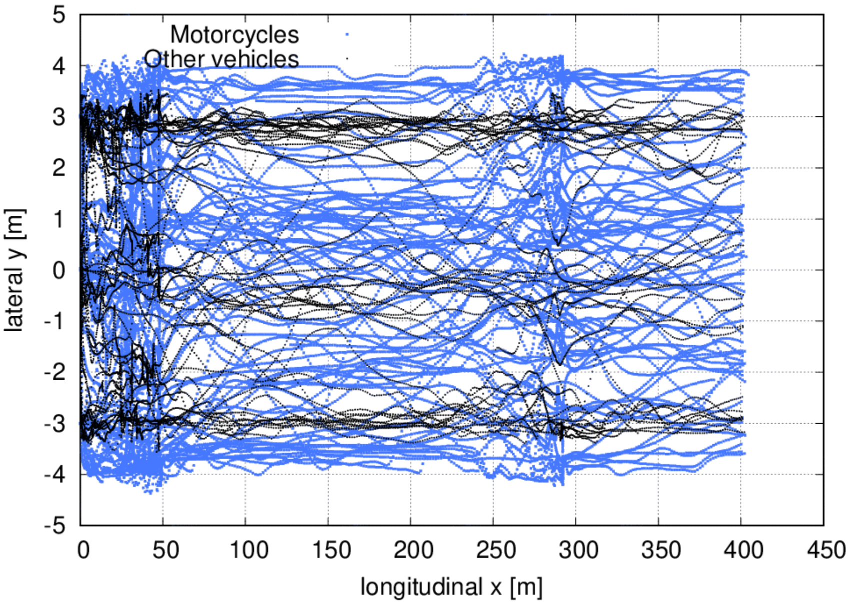
Simulation result 1: x-t plot



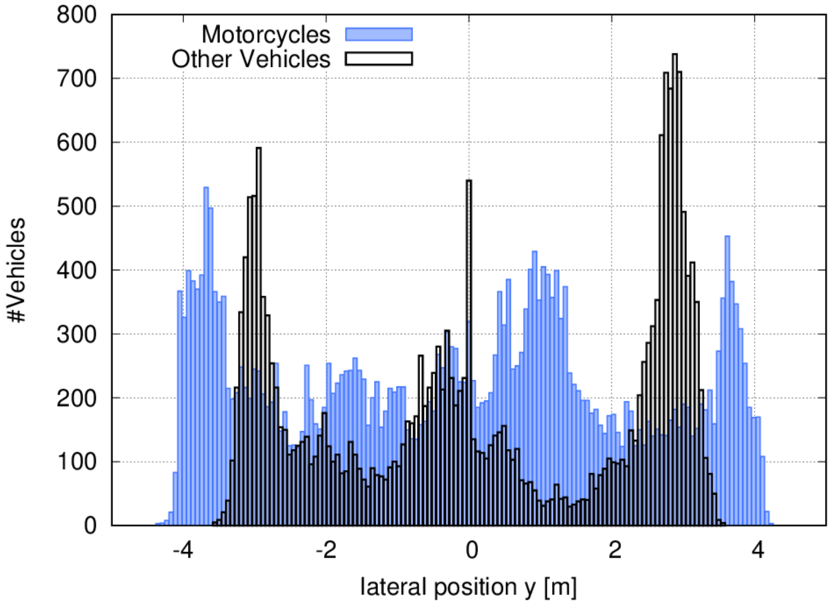
The street "Akadimias" x-y plot



Simulation result 2: x-y plot

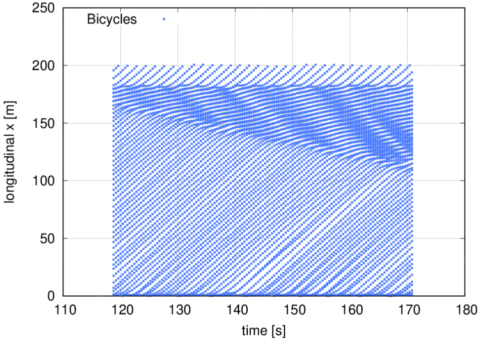


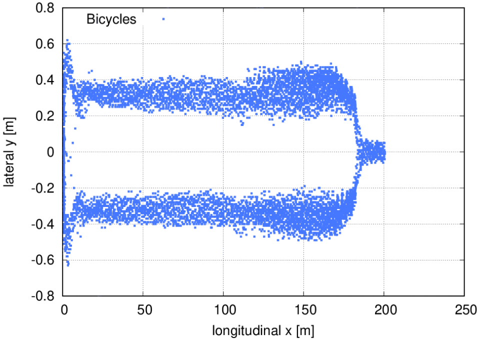
Simulation result 3: cross-section histogram

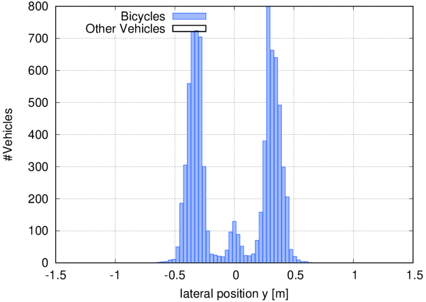


4. Lane-free mixed traffic flow: Bicycles

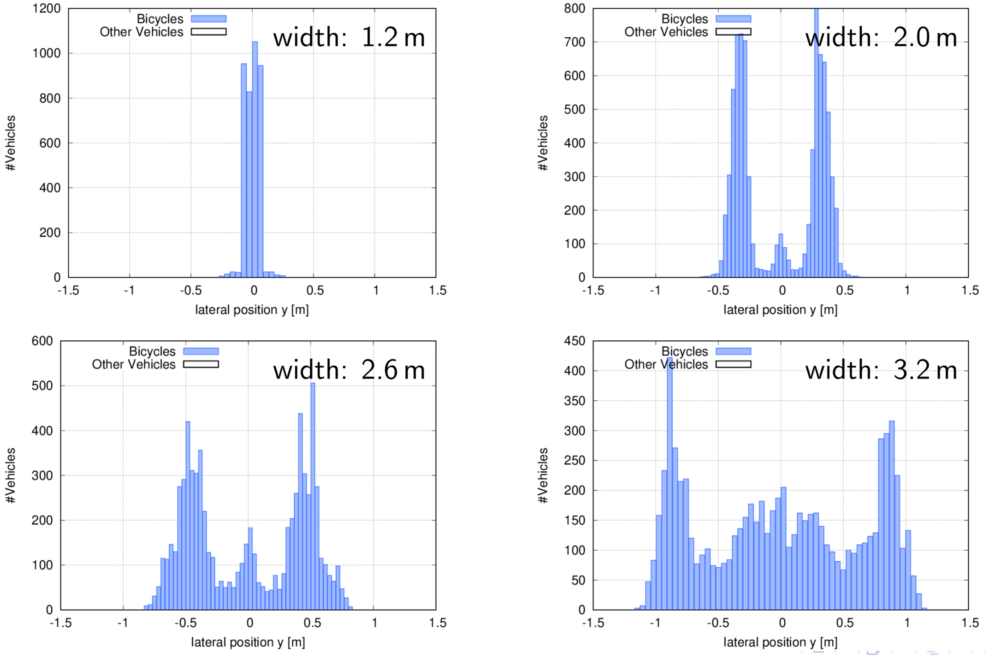
Bikepath of width 2.0 m







Self-organized lateral distribution



5. Summary

- We have proposed a new **fully 2d** model based on classical 1d car-following models
- It has the structure of the Social-Force Model for pedestrians but incorporates the behaviour of drivers of high-speed vehicles
- For essentially unidirectional traffic, for slow (bicycles) and fast (cars) agents
- With a floor field representing lanes, lane changes with realistic 2d trajectories emerge from the balance of forces. Likewise zipper merges and the use of free space between the lanes by motorcyclists
- For lane-free traffic, the balance of forces leads to the spontaneous formation of lanes and staggered following, in agreement with observations.

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