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Application of the lattice Boltzmann method to estimate road capacity decrease depending on lane number and flow density

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- 1 Introduction
- 2 LBM method
- 3 Results
- 4 Conclusion

Why ? How ? What ?

- Predict traffic flows to help public services and road planning.
- Exploring new numerical simulations.
- Try to study the influence of truck concentration, vehicle incoming density on congestions.

Application

A numerical method to estimate the road capacity at critical points, without modeling each vehicle.

Meso-scale

- Macro-scale is only looking at density and average speed flow etc.
- Micro-scale is able to track each vehicle.
- The Prigogine theory [4] is focusing on a in-between meso-scale, where vehicles are indiscernible but have statistical effect.
- It has the advantage of being efficient and detailed [1].

Application to multi-classes

Multi-class traffic flow are addressed through interactions between statistical groups [6]

The LBM is a very efficient and flexible mesoscopic solver.

LBM building and usage in other field [5]:

- Multi-phase fluid mechanics,
- Biological process,
- Thermal engineering.

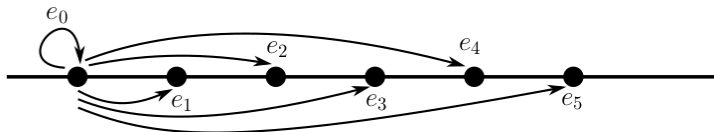
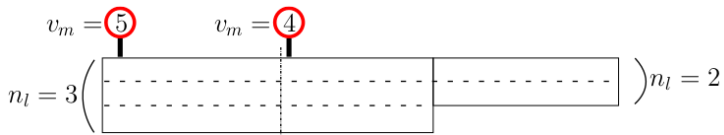


Figure: Soap bubble

LBM for road traffic

- The Prigogine theory is a special case of the Boltzmann equation.
- LBM can capture non-linear effects: stop and go effects [2].
- LBM can be extended to multi-class traffic flows [3].

- 1 Introduction
- 2 LBM method
- 3 Results
- 4 Conclusion



Rewritten **streaming** step to include number of lane changes:

$$f_{c,i}(x + e_i \delta_t, t + \delta_t) = f_{c,i}(x, t + \delta_t) \frac{n_l(x)}{n_l(x + e_i \delta_t)}, \quad (1)$$

Statistical **interactions**:

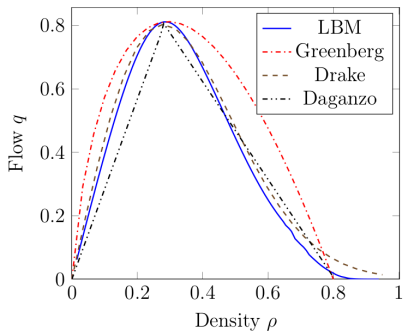
$$f_{c,i}(x, t + \delta_t) = f_{c,i}(x, t) + \frac{1}{\tau} \left(f_{c,i}^{(0)} - f_{c,i} \right) . \quad (2)$$

Equilibrium distribution $f_{c,i}^{(0)}$ is computed from macroscopic quantities.

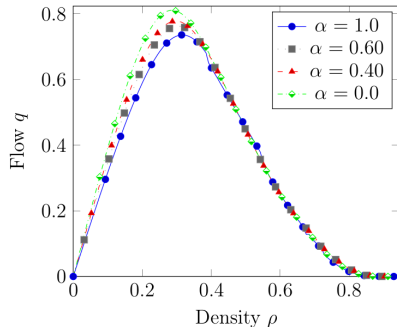
Macroscopic quantities recovered from statistical moments:

$$\text{density } \rho_c = \sum_{i=0}^{m-1} f_{c,i}(x, t), \quad \text{flow } q_c = \sum_{i=0}^{m-1} e_i f_{c,i}(x, t), \quad (3)$$

Fundamental diagram facing other methods [3]:



Truck concentration parameter sensitivity:



- 1 Introduction
- 2 LBM method
- 3 Results**
- 4 Conclusion

Parameters	Values	Lines	Scenario	Situation
(ρ_{in}, α)	(0.10, 0)	red dashed on fig. 5	S1-a	Free-flow
(ρ_{in}, α)	(0.105, 0)	blue solid on fig. 5	S1-b	Congested
(ρ_{in}, α)	(0.105, 0.115)	green dot-dashed on fig. 5	S1-c	Free-flow
(ρ_{in}, α)	(0.10, 0)	red dashed on fig. 6	S2-a	Free-flow
(ρ_{in}, α)	(0.105, 0)	blue solid on fig. 6	S2-b	Congested
(ρ_{in}, α)	(0.105, 0.115)	green dot-dashed on fig. 6	S2-c	Free-flow

Table 1.a Input parameters studied according to different scenarios, see table 2.

Scenario name	Road parameters	Values	Space	Description
S1	n_l	4	$\forall x \in [0, 2500]$	lane reduction with 2 sections
	$v_{m,1}$	5	$\forall x \in [0, 2500]$	
	$v_{m,2}$	4	$\forall x \in [0, 2500]$	
	n_l	2	$\forall x \in [2500, 5000]$	
	$v_{m,1}$	5	$\forall x \in [2500, 5000]$	
	$v_{m,2}$	4	$\forall x \in [2500, 5000]$	
S2	n_l	4	$\forall x \in [0, 2000]$	lane reduction with 3 sections
	$v_{m,1}$	5	$\forall x \in [0, 2000]$	
	$v_{m,2}$	4	$\forall x \in [0, 2000]$	
	n_l	3	$\forall x \in [2000, 3750]$	
	$v_{m,1}$	5	$\forall x \in [2000, 3750]$	
	$v_{m,2}$	4	$\forall x \in [2000, 3750]$	
	n_l	2	$\forall x \in [3750, 5000]$	
	$v_{m,1}$	5	$\forall x \in [3750, 5000]$	
	$v_{m,2}$	4	$\forall x \in [3750, 5000]$	

Table 2: (a) Characteristics of road sections in scenarios S1 and S2.

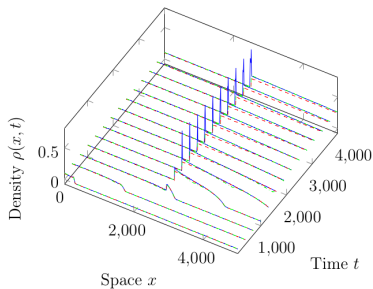


Figure 5. Road change from 4 to 2 lanes: red dashed line corresponds to S1-a, blue solid line corresponds to S1-b, dashed green corresponds to S1-c, see table 1.

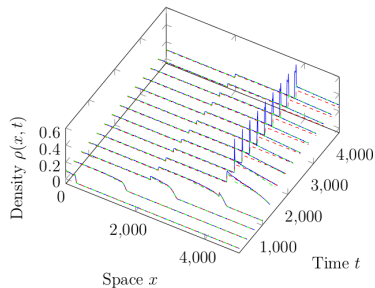


Figure 6. Road change from 4 to 3 and 3 to 2 lanes: red dashed line corresponds to S2-a, blue solid line corresponds to S2-b, dashed green corresponds to S2-c, see table 1.

Parameters	Values	Lines	Scenario	Situation
(ρ_{in}, α)	(0.169, 0)	red dashed on fig. 7	S3-a	Free-flow
(ρ_{in}, α)	(0.17, 0)	blue solid on fig. 7	S3-b	Congested
(ρ_{in}, α)	(0.17, 0.03)	green dot-dashed on fig. 7	S3-c	Free-flow
(ρ_{in}, α)	(0.169, 0)	red dashed on fig. 8	S4-a	Free-flow
(ρ_{in}, α)	(0.17, 0)	blue solid on fig. 8	S4-b	Congested
(ρ_{in}, α)	(0.17, 0.03)	green dot-dashed on fig. 8	S4-c	Free-flow

Table 1, b Input parameters studied according to different scenarios, see table 2.

Scenario name	Road parameters	Values	Space	Description
S3	n_l	3	$\forall x \in [0, 2500]$	speed reduction with 2 sections
	$v_{m,1}$	5	$\forall x \in [0, 2500]$	
	$v_{m,2}$	4	$\forall x \in [0, 2500]$	
	n_l	3	$\forall x \in [2500, 5000]$	
	$v_{m,1}$	3	$\forall x \in [2500, 5000]$	
	$v_{m,2}$	3	$\forall x \in [2500, 5000]$	
S4	n_l	3	$\forall x \in [0, 2000]$	speed reduction with 3 sections
	$v_{m,1}$	5	$\forall x \in [0, 2000]$	
	$v_{m,2}$	4	$\forall x \in [0, 2000]$	
	n_l	3	$\forall x \in [2000, 3750]$	
	$v_{m,1}$	4	$\forall x \in [2000, 3750]$	
	$v_{m,2}$	4	$\forall x \in [2000, 3750]$	
	n_l	3	$\forall x \in [3750, 5000]$	
	$v_{m,1}$	3	$\forall x \in [3750, 5000]$	
	$v_{m,2}$	3	$\forall x \in [3750, 5000]$	

Table 2: (b) Characteristics of road sections in scenarios S3 and S4.

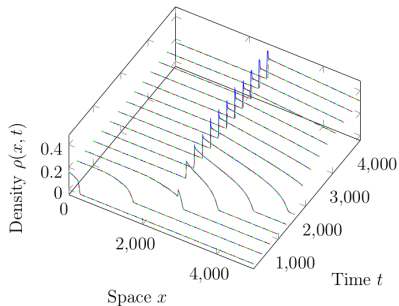


Figure 7. Road change from 5 to 3 maximum speed: red dashed line corresponds to S3-a, blue solid line corresponds to S3-b, dashed green corresponds to S3-c, see table 1.

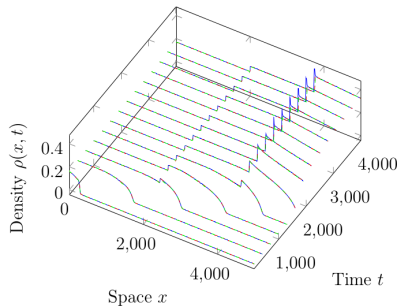


Figure 8. Road change from 5 to 4 and 4 to 3 maximum speed: red dashed line corresponds to S4-a, blue solid line corresponds to S4-b, dashed green corresponds to S4-c, see table 1.

- 1 Introduction
- 2 LBM method
- 3 Results
- 4 Conclusion**

- LBM is a fast and efficient method,
- it yields results comparable at macro-scale,
- the introduced mesoscopic fluctuation could help to capture more realistic behaviour,
- it has the advantage to be more computational efficient over the microscopic simulations
- In perspectives, this work should be extended to a large set of incoming vehicle density to better characterize the critical flows

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