When is a bottleneck a bottleneck?

Johannes Schmidt, Vladislav Popkov,
Andreas Schadschneider

Institut für Theoretische Physik

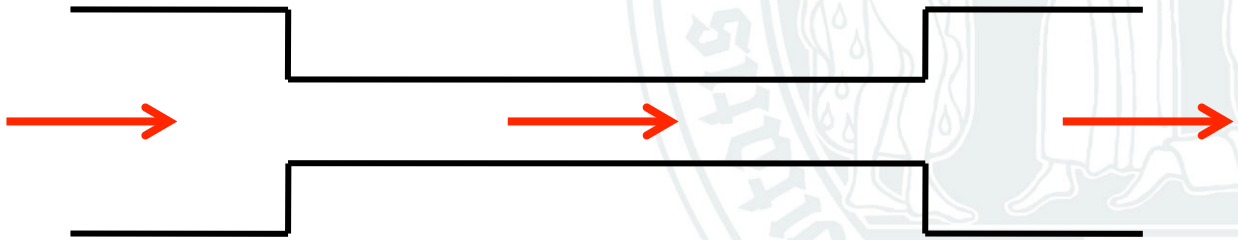
Universität zu Köln, Germany

www.thp.uni-koeln.de/~as

Introduction

bottleneck = (local) flow limitation

(e.g. lane reduction, speed limit, narrow corridors, …)



When does a bottleneck lead to a traffic jam?
Is there a critical bottleneck strength?

here:

- theoretical (physics) point of view
- minimal model: generic nature of bottleneck transitions

Asymmetric Simple Exclusion Process

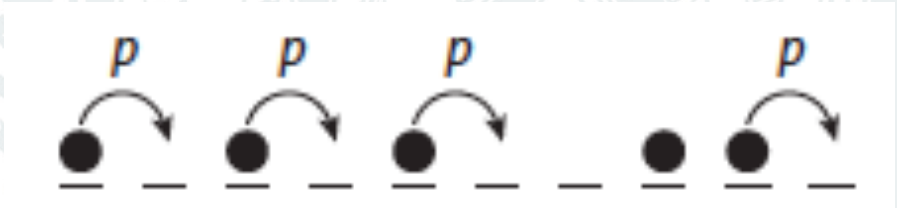
Toy model for traffic:

1. directed motion
2. volume exclusion
3. stochastic dynamics

For applications: different modifications necessary

ASEP = **NaSch model** with $v_{max}=1$

bulk dynamics:

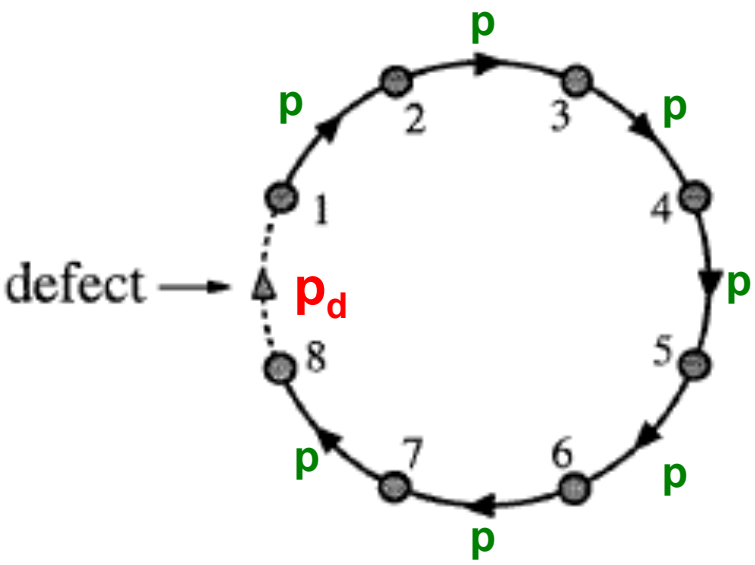


Asymmetric Simple Exclusion Process (ASEP)

particles hop with probability p to right neighbor site if this is empty!

Captures generic aspects of traffic, well-understood, many rigorous results exist

Bottleneck: ASEP with defect



realization of **bottleneck** scenario by a "**defect**"

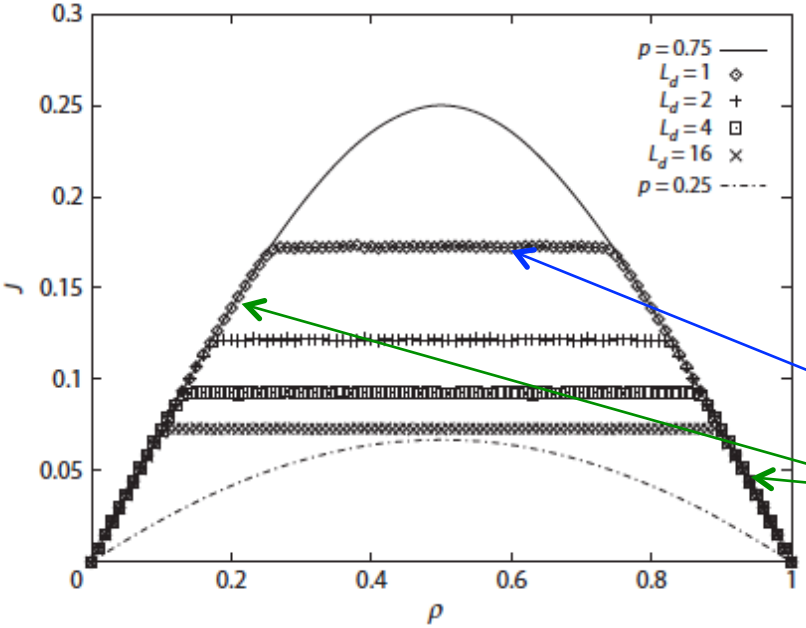
at **defect**: reduced hopping rate $p_d < p$ (slow bond)

defect strength: $\Delta p := \dfrac{p - p_d}{p}$

Bottleneck: fundamental diagram

Effect on fundamental diagram?

Flow can not exceed the maximal defect current!



ASEP (p=0.75) with reduced hopping probability p_d=0.25 at L_d consecutive defect sites (period. BC)

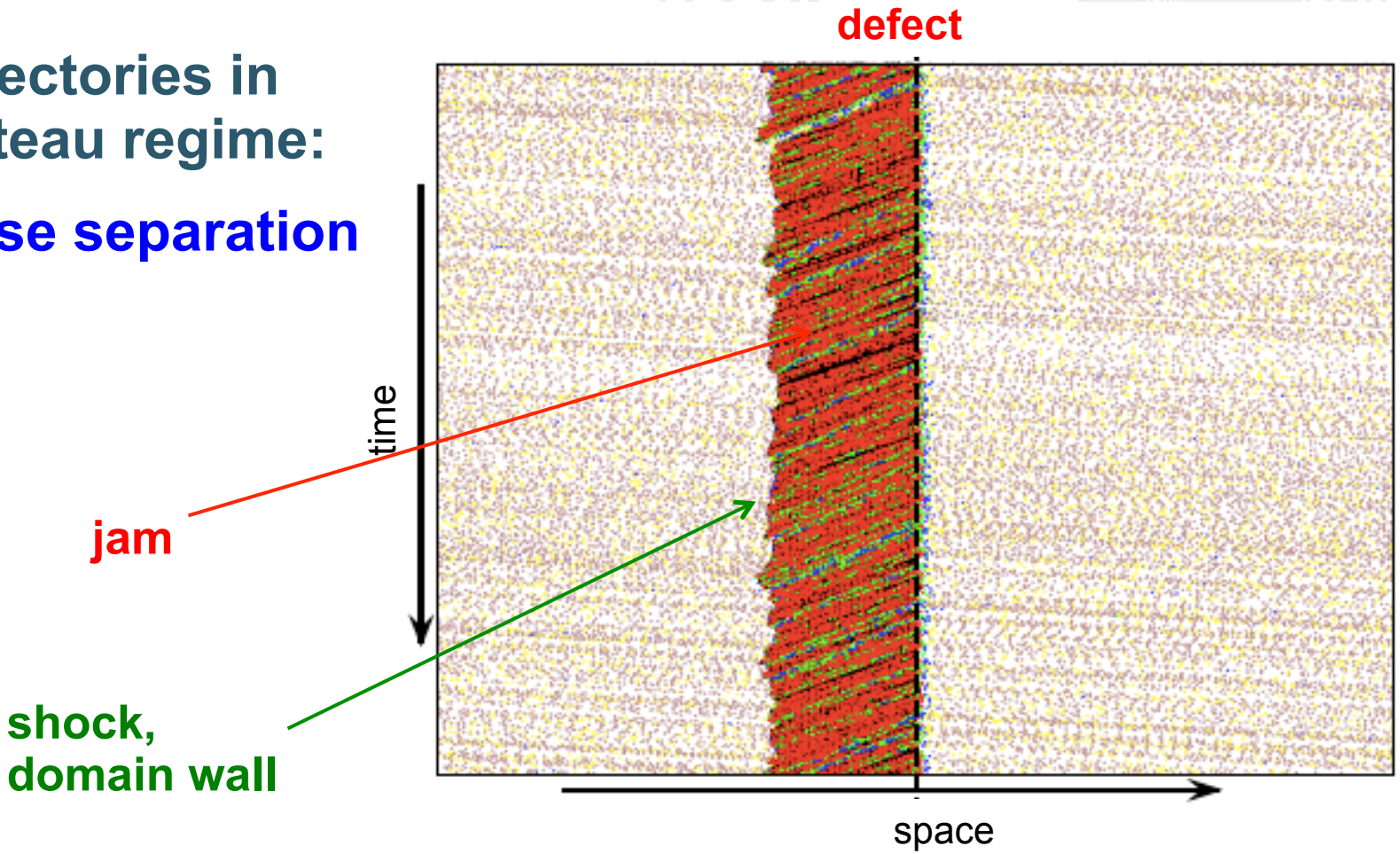
typical:

- plateau at intermediate densities
- no influence for low and high densities

Bottleneck (NaSch model)

trajectories in plateau regime:

phase separation

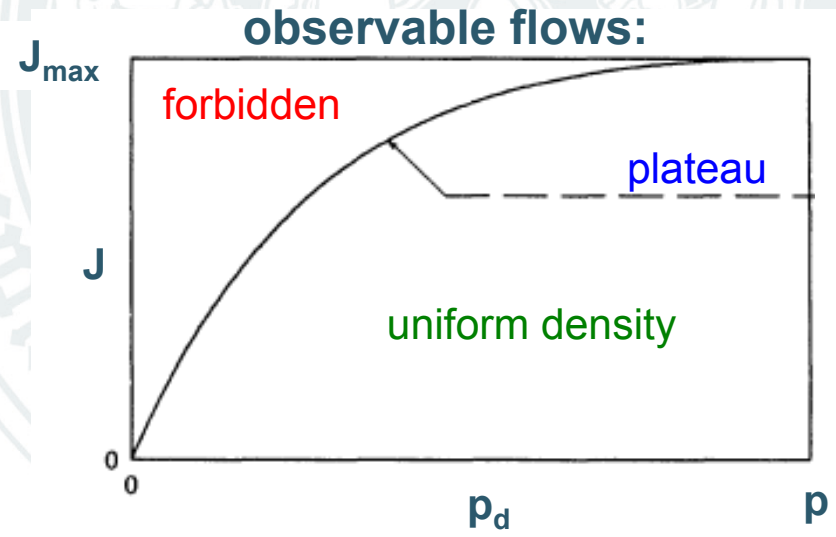


Bottleneck: Theory

Mean-field approach: (Janowsky & Lebowitz, '92)

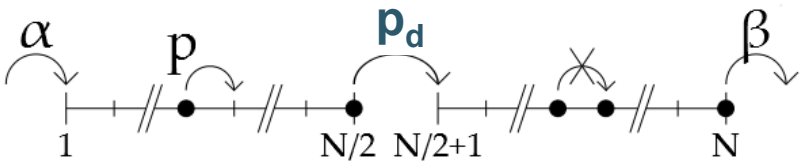
arbitrarily weak defect leads to flow reduction, i.e. formation of a plateau in the fundamental diagram:

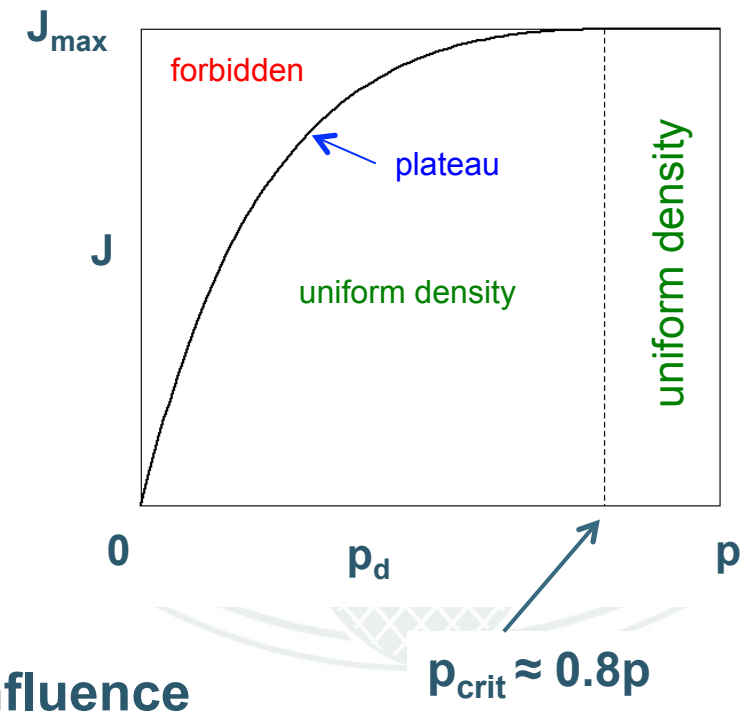
$$\Delta p_{crit} = 0$$



⟹ **Every bottleneck leads to jam formation!**

Bottleneck: Simulations





Monte Carlo simulations:

(Ha, Timonen, den Nijs, 2003)

$$\Delta p_{crit} \approx 0.2$$

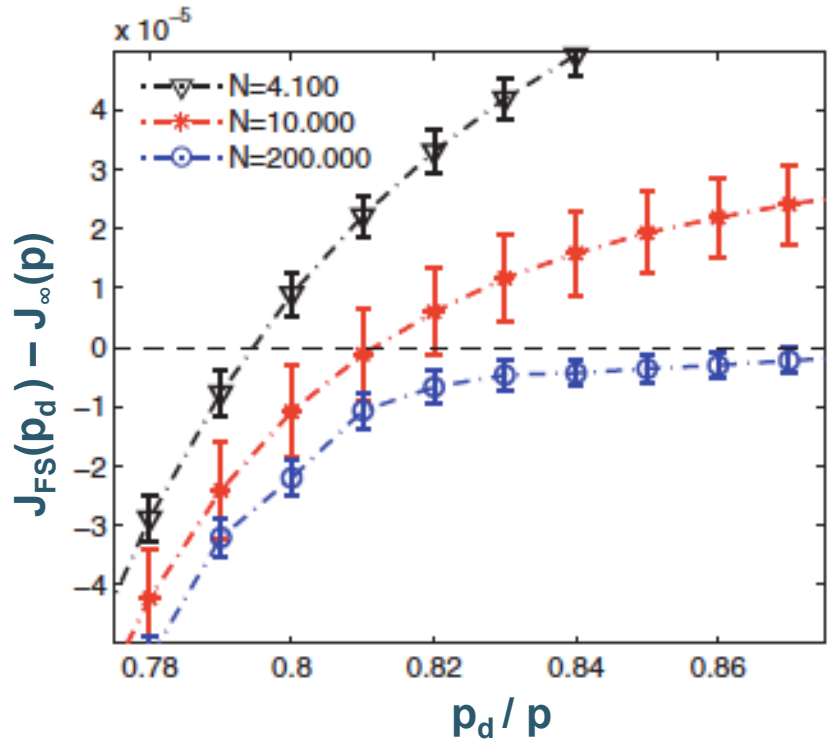
→ **weak bottlenecks: no (global) influence (on bulk density, flow) !???**

Bottleneck: New simulations

Effects on current:

- **strong finite-size corrections**
- **good statistics necessary (dependence on choice of random number generator!)**

$$\Delta p_{crit} < 0.14$$



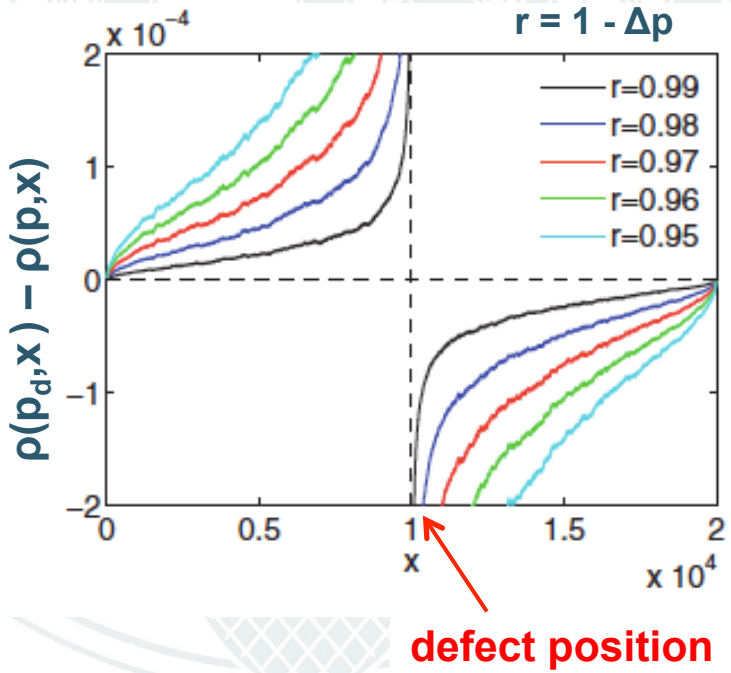
(Schmidt, Popkov, Schadschneider 2015)

Bottleneck: New simulations

Effects on density profile:

Improving statistics by

- **simulating pure system and defect system with identical random numbers**
- **measuring difference of density profiles (small fluctuations for weak defects!!)**
- **open boundary conditions**



defect has non-local effects, effects density profile in whole system

$$\Delta p_{crit} < 0.01$$

(Schmidt, Popkov, Schadschneider 2015)

Bottleneck: Mathematics

Meanwhile:

Mathematical proof for $\Delta p_{crit} = 0$ announced:

Basu, Sidoravicius, Sly (arXiv:1408.3464)

Results are expected to be generic for traffic models, not ASEP-specific

Relevance for empirical results

Bottleneck effects easily lost in fluctuations!

What is the best observable to identify a bottleneck?

Interpretation of flow values difficult, subtle effects, even in model setting only observable for excellent statistics!

Collective Dynamics

New Journal

Collective Dynamics

– open access and free of charge for authors –

The journal Collective Dynamics (CD) focuses on research in the field of pedestrian dynamics, vehicular traffic and other systems of self-driven particles, such as molecular motors, animal groups or agents. The journal is a forum for all scientists working on fundamental (empirical as well as theoretical) research or concrete applications. Articles should be written in a way that makes them accessible to a wide range of scientific disciplines. As a peer-reviewed journal, Collective Dynamics publishes scientific papers that should reflect original, previously unpublished work, but may also report on systematic reviews of published research and other pedagogical articles (e.g. lecture notes).

It offers an opportunity especially for those researchers who have problems to find a suitable journal due to the interdisciplinary nature of their work.

Andreas Schadschneider & Armin Seyfried

Submission by Email to
info@collective-dynamics.eu