Jamology

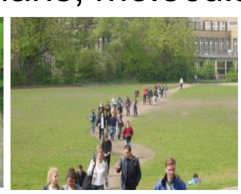
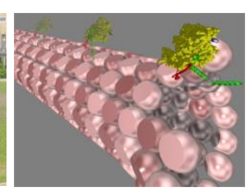
traffic jams of self-driven particles

Katsuhiro Nishinari
The University of Tokyo

What are self-driven particles (SDP)?

- Vehicles, ants, pedestrians, molecular motors…



- Non-Newtonian particles,
  which do not satisfy Newton's laws of motion.
  ex. 1) Action $\neq$ Reaction,
  → "force" is psychological
  2) Sudden change of motion

D. Helbing, Rev. Mod. Phys. vol.73 (2001) p.1067.
D. Chowdhury, L. Santen and A. Schadschneider,Phys. Rep. vol.329 (2000) p.199.

Methods for studying SDP

Conventional mechanics cannot be directly applicable due to the break of the Newton's laws.

1) Introduction of imaginary forces

e.g. Social force model (Helbing, et al)

Differential equations of motion

2) Rule-based approach (CA model, Multi Agent)

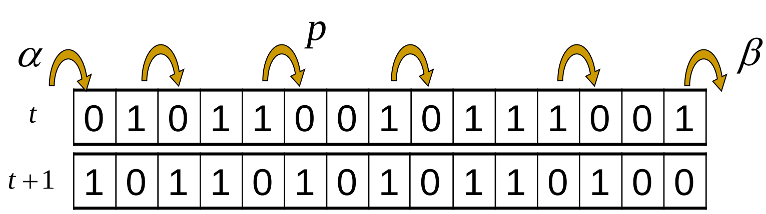
→ { Numerical approach

Exactly solvable models (e.g. ASEP)

ASEP=The simplest model for SDP

ASEP（Asymmetric Simple Exclusion Process）

Rule：move forward if the front is empty

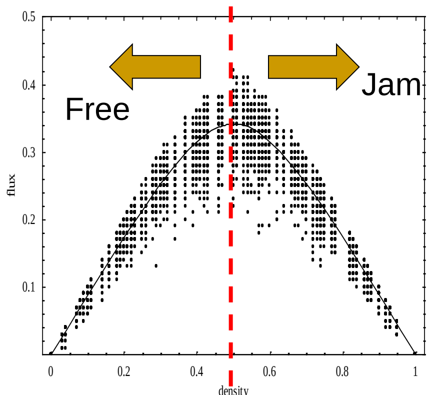


This is an exactly solvable model, i.e., we can calculate density distribution and flux in the stationary state.

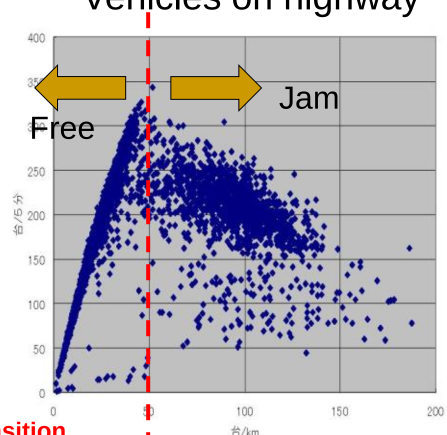
This is a base model for all sorts of jamming phenomena!

Fundamental Diagram

ASEP



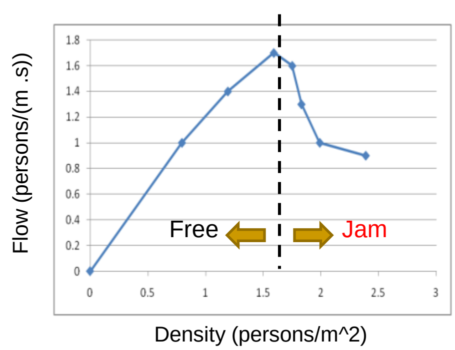
Vehicles on highway



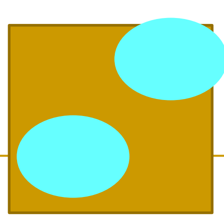
Critical density **Phase transition** Critical density

This curve is common among various kinds of SDP!

Pedestrian flow

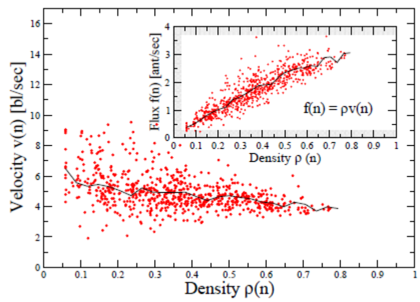


1m



Critical density
= 1.8 persons/m^2

No jams in ants on trails!

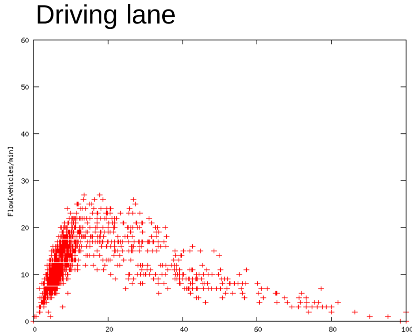


There is no high density state (> 0.7) in the observed data.
Ants move with constant velocity up to 0.7 density.

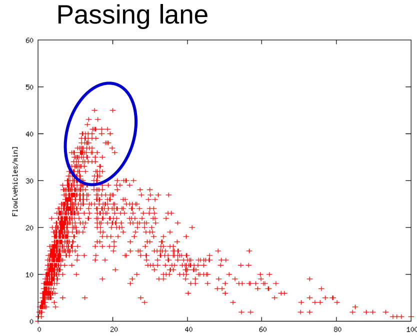
“Traffic-like collective movement of ants on trails: absence of jammed phase” Phys.Rev.Lett. vol.102 (2009) p.108001

“Metastability” is crucial for traffic jam

Driving lane



Passing lane



Observed data taken from Tokyo Metropolitan highway

Existence of "Metastable state"

New Journal of Physics
The open-access journal for physics

Traffic jams without bottlenecks—experimental evidence for the physical mechanism of the formation of a jam

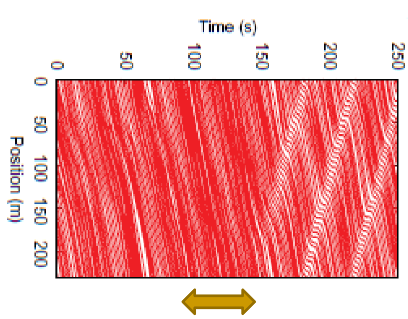
Best Paper Award (2008)

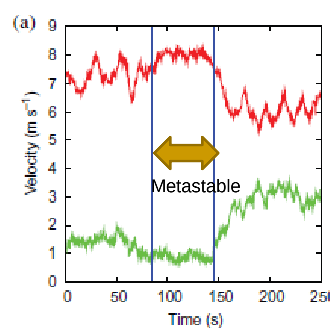
Yuki Sugiyama[1,10], Minoru Fukui[2], Macoto Kikuchi[3], Katsuya Hasebe[4], Akihiro Nakayama[5], Katsuhiro Nishinari[6,7], Shin-ichi Tadaki[8] and Satoshi Yukawa[9]

[1] Department of Complex Systems Science, Nagoya University, Nagoya 464-8601, Japan
[2] Nakanihon Automotive College, Sakahogi 505-0077, Japan
[3] Cybermedia Center, Osaka University, Toyonaka 560-0043, Japan
[4] Aichi University, Miyoshi 470-0296, Japan
[5] Faculty of Science and Technology, Meijo University, Nagoya 468-8502, Japan
[6] Department of Aeronautics and Astronautics, The University of Tokyo, Bunkyo 113-8656, Japan
[7] PRESTO, Japan Science and Technology Agency
[8] Computer and Network Center, Saga University, Saga 840-8502, Japan
[9] Department of Earth and Space Science, Osaka University, Toyonaka 560-0043, Japan
E-mail: sugiyama@phys.cs.is.nagoya-u.ac.jp

New Journal of Physics **10** (2008) 033001 (7pp)
Received 14 November 2007
Published 4 March 2008

Existence of metastable state just before the emergence of jam





Average velocity（red）
Variance of velocity (green)

Modeling of metastability by CA

OV (optimal velocity) model

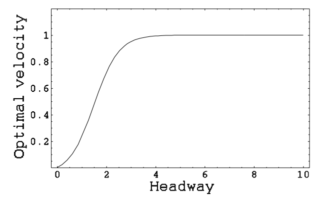
$$\frac{d^2 x_n}{dt^2} = a\left(V(x_{n+1} - x_n) - \frac{dx_n}{dt}\right)$$

$V(h)$ **OV function**

h **headway**

$a = 1/\tau$ **sensitivity**

x_n x_{n+1}



OV model and its discretization

$$\ddot{x}_i = a(V(x_{i+1} - x_i) - \dot{x}_i)$$

Difference equation (coupled map lattice)

Step 1

$$v_i^{t+1} = v_i^t + a(V(x_{i+1}^t - x_i^t) - v_i^t)$$

$$= (1-a)v_i^t + aV(x_{i+1}^t - x_i^t)$$

Step 2

$$x_i^{t+1} = x_i^t + v_i^{t+1}$$

Yukawa et al, JPSJ, 64 (1995) p.35

CA model with metastable states

Stochastic OV model

$$v_i^{t+1} = (1-a)v_i^t + aV(x_{i+1}^t - x_i^t)$$

$$a \in [0,1] \quad v, V \in [0,1] \quad x \in \mathbf{Z}$$

Velocity = hopping probability

$$x_i^{t+1} = x_i^t + 1 \quad \text{w.p.} \quad v_i^{t+1}$$ **(if the front is empty)**

Stochastic OV model（SOV）

M.Kanai, K.Nishinari, T.Tokihiro, *Phys. Rev. E*vol.72 (2005) p.035102(R).

SOV includes ASEP and Zero Range Process

$$v_i^t \to (1-a)v_i^t + aV(x_{i+1}^t - x_i^t)$$

$$v_i^{t+1} = v_i^t = q$$ **ASEP**

Exactly solvable

$a \to 0$

Low sensitivity

SOV

$a \to 1$

High sensitivity

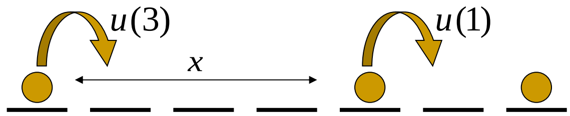
$$v_i^{t+1} = V(x_{i+1}^t - x_i^t)$$ **ZRP**

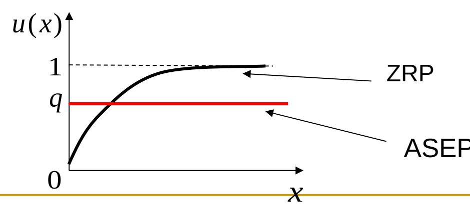
Exactly solvable

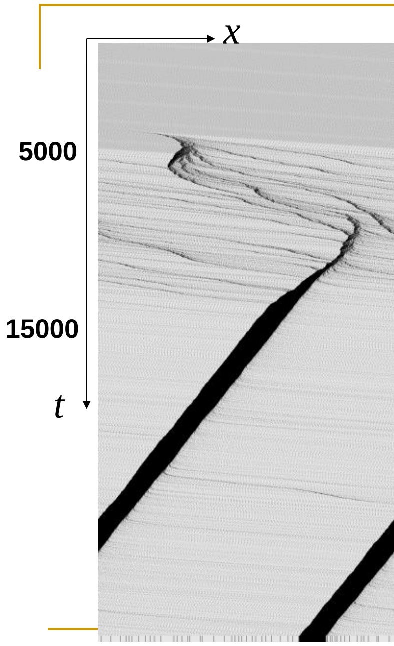
Zero Range Process (ZRP)

- **Exactly solvable stochastic model**
- **A generalization of ASEP**

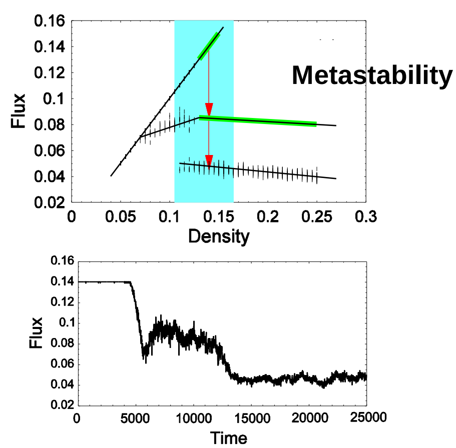
Hopping probability $u(x)$ = arbitrary function of gap distance







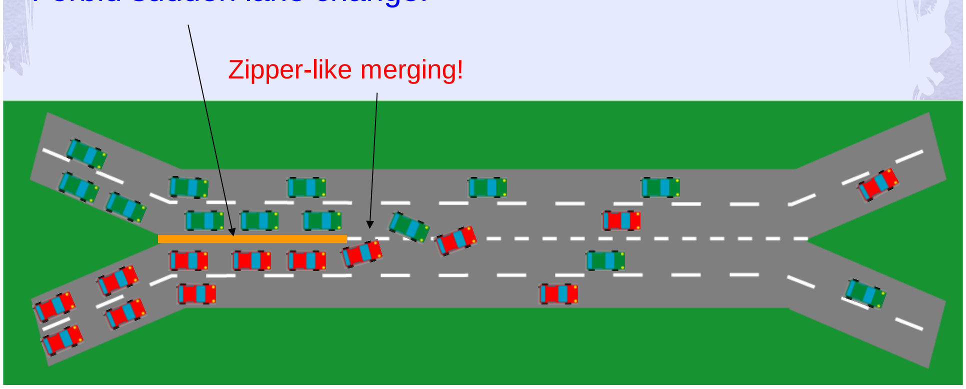
Small "a" case (a<0.05)



Metastable flow
= unstable due to perturbations

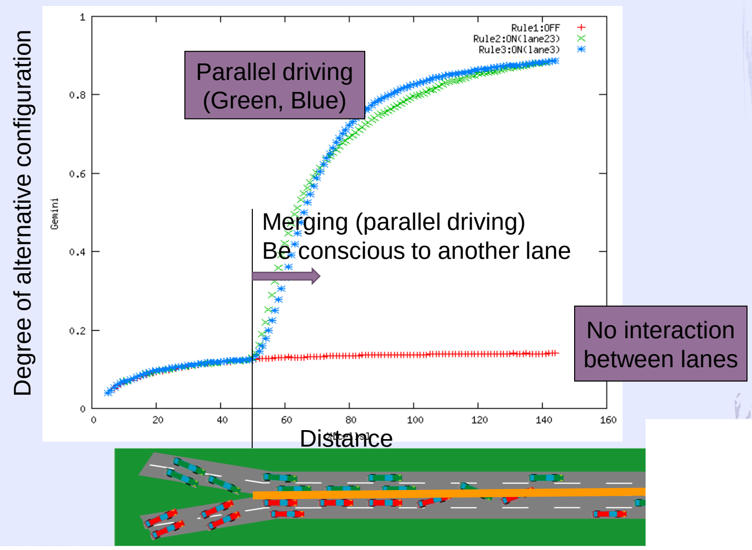
Jams in Junctions

Solution
=Forbid sudden lane change!



Simulation by SOV model

R. Nishi, H. Miki, A. Tomoeda and K. Nishinari, Phys. Rev. E 79, 066119 (2009)



Pedestrian dynamics

Floor field CA Model

Pedestrians motion
 = herding behavior
 = long range interaction

For computational efficiency, can we describe the behavior of pedestrians by using local interactions only?

Idea: **Footprints = Feromone**

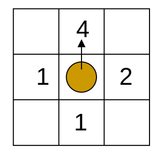
Long range interaction is imitated by local interaction through „memory on a floor“.

Dymanic FF (DFF)

Number of footprints on each cell

- Leave a footprint at each cell whenever a person leave the cell
- Store global information to local cells
- Herding behaviour =

  choose the cell that has more footprints



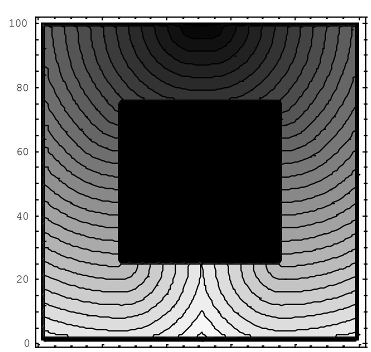
- Dynamics of DFF

  dissipation＋diffusion

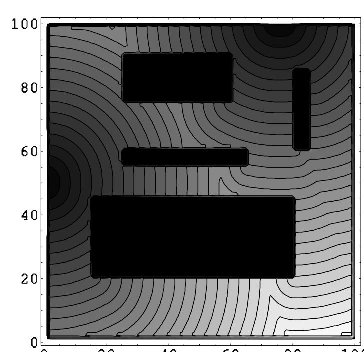
  dissipation･･･α diffusion･･･β

Static FF (SFF) = Dijkstra metric

- Distance to the destination is recorded at each cell



One exit with a obstacle

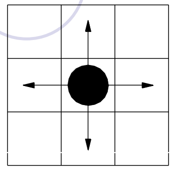


Two exits with four obstacles

This is done by Visibility Graph and Dijkstra method.

K. Nishinari, A. Kirchner, A. Namazi and A. Schadschneider, IEICE Trans. Inf. Syst., Vol.E87-D (2004) p.726.

Probability of movement



0	$p_{-1,0}$	0
$p_{0,-1}$	$p_{0,0}$	$p_{0,1}$
0	$p_{1,0}$	0

$$p_{ij} \approx \exp(k_D D_{ij}) \exp(-k_s S_{ij})$$

S_{ij} Distance between the cell (i,j) and a door.

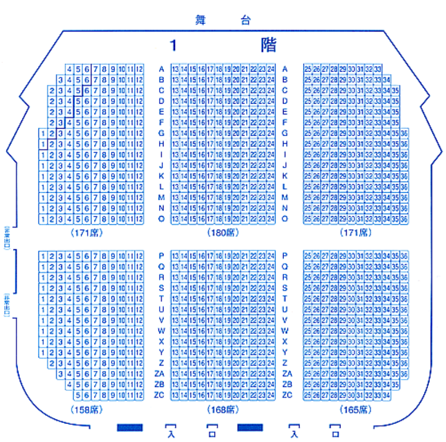
D_{ij} Number of footprints at the cell (i,j).

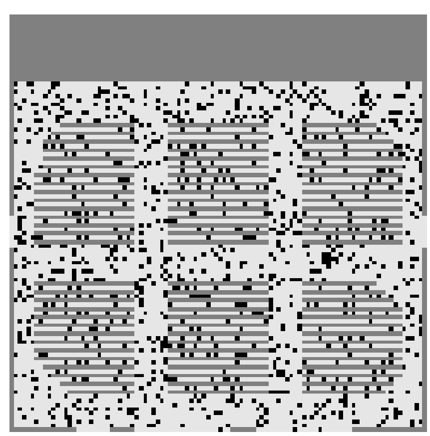
$k_S \to \infty$ Normal

$k_D \to \infty$ Panic

k_D / k_S Panic degree (panic parameter)

Simulation Example:
Evacuation at a concert hall





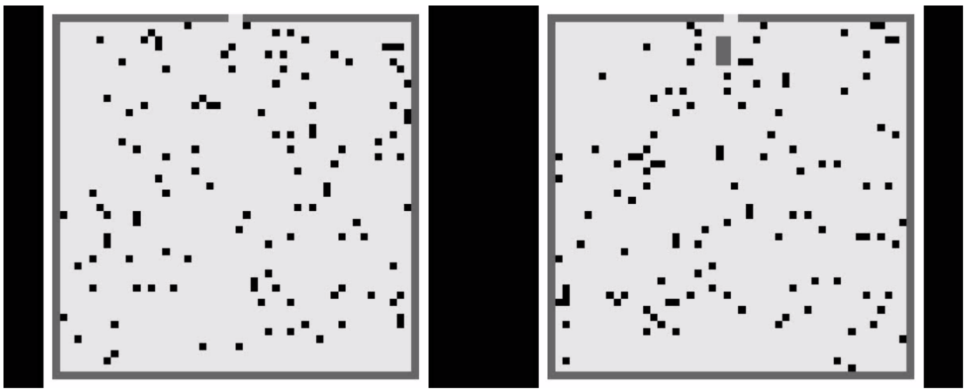
Jams near exits.

Effect of obstacles near an exit

D.Helbing, I.Farkas and T.Vicsek, Nature, vol.407 (2000) p.487.

A.Kirchner, K.Nishinari, and A.Schadschneider,Phys. Rev. E, vol.67 (2003) p.056122.

Absence of obstacle **Presence of obstacle**



Total evacuation time 62[s](Absence) 55[s](Presence)

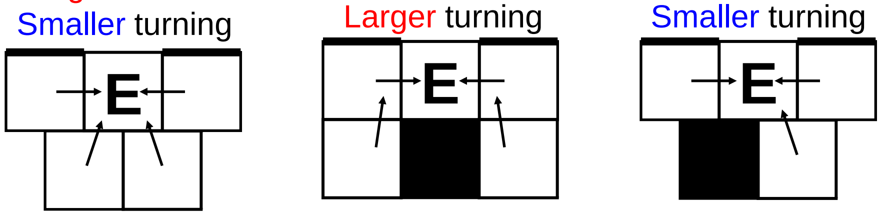
Size of the room 25m × 25m, 125 persons

Total evacuation time is reduced by an obstacle!

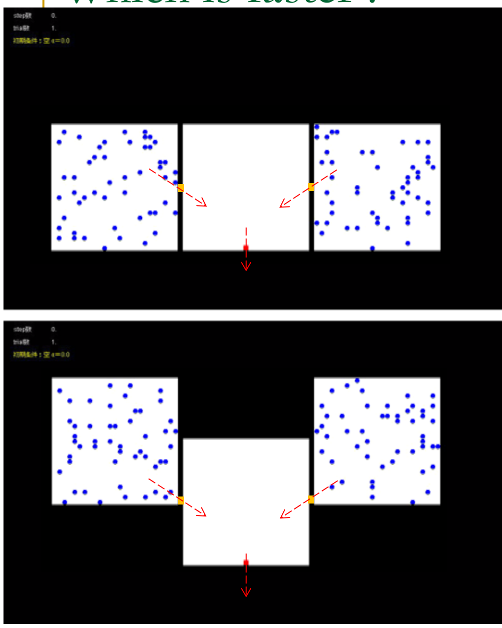
Interpretation: Conflict and Turning

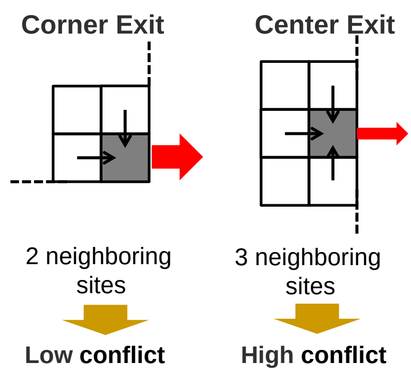
D. Yanagisawa and K. Nishinari, Phys. Rev. E, vol.76 (2007) p.061117.

No obstacle	**Center obstacle**	**Shifted obstacle**
High conflict	Low conflict,	Medium conflict,
Smaller turning	Larger turning	Smaller turning



Which is faster ?

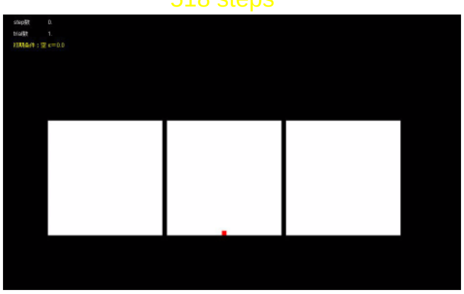




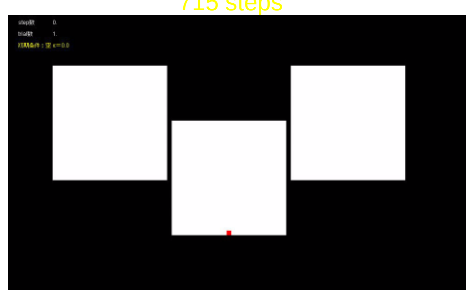
Local bottlenecks may improve the outflow

T. Ezaki, D. Yanagisawa and K. Nishinari, Phys. Rev. E 86, 026118 (2012).

518 steps



715 steps



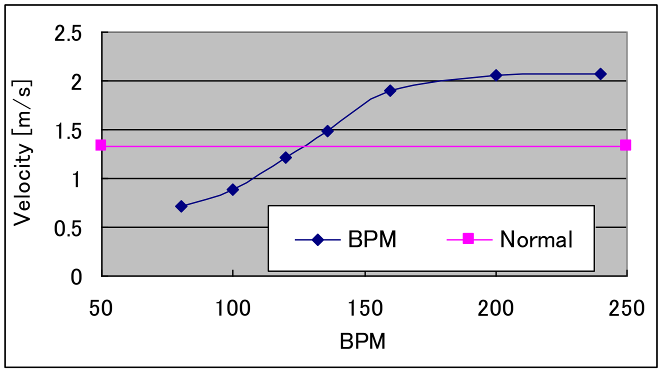
High conflicts at the first bottlenecks.

Low conflicts at the second bottleneck.

Low conflicts at the first bottlenecks.

High conflicts at the second bottleneck.

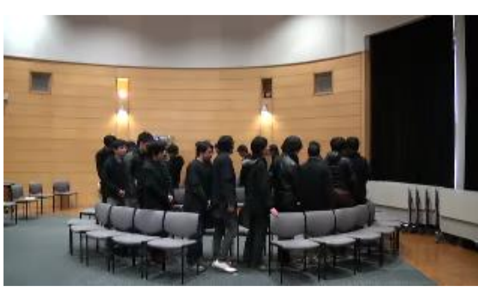
Single Pedestrian Walking with Rhythm



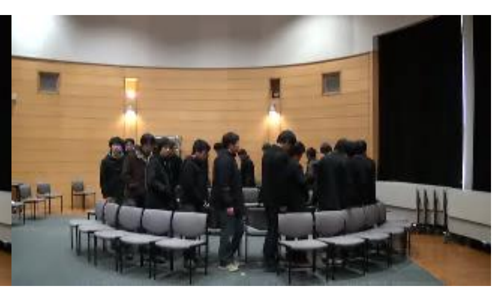
BPM (Beet per Minutes) in the normal walking is about 130.

Without v.s. With 70 BPM sound (Number = 24, Density = 1.86 [1/m])

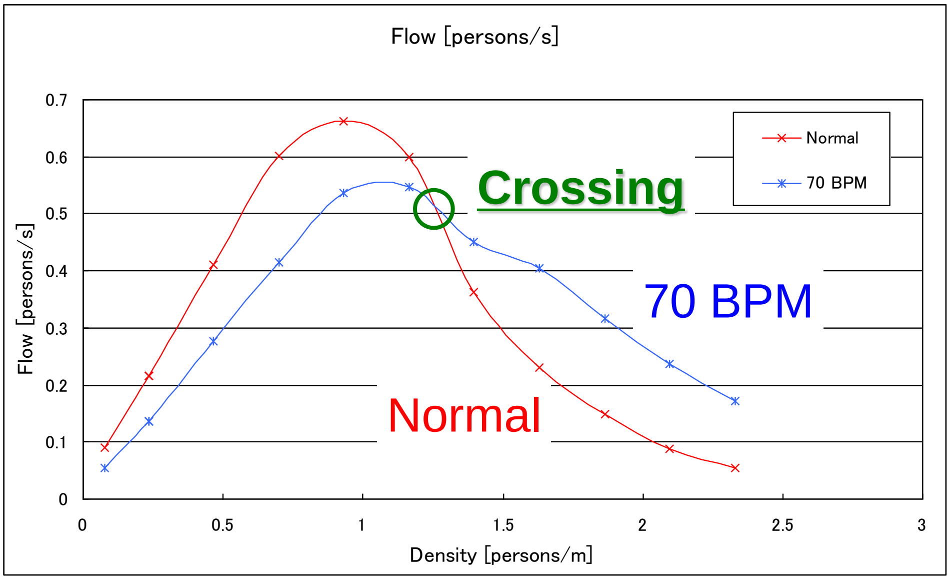
Without sound



With sound



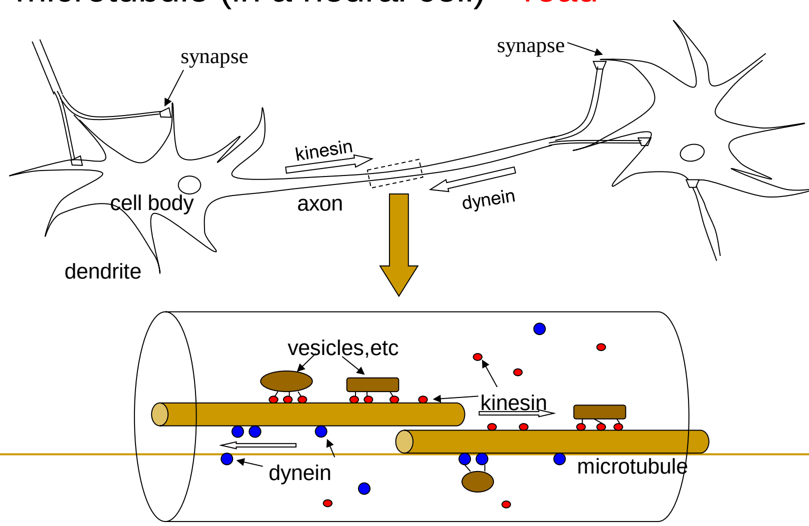
Result of the Flow



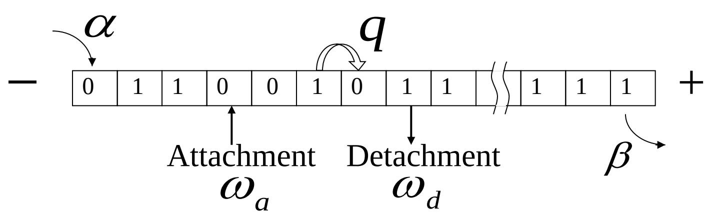
Yanagisawa, et al, Phys. Rev. E 85, 016111 (2012)

Jam in neural cell

Active transportation of molecular motors=car
microtubule (in a neural cell)＝road



A simple model of motor traffic

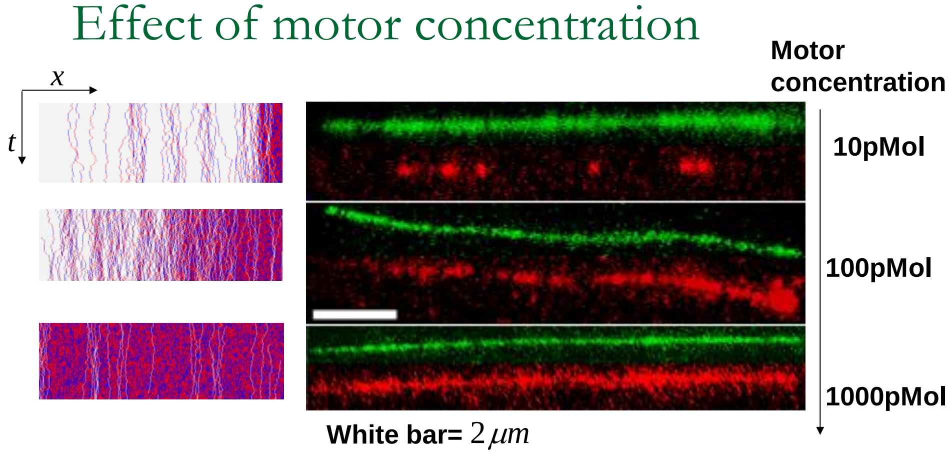


Rule

1)attach	0 ⟶ 1	ω_a	Langmuir kinetics
2)detach	1 ⟶ 0	ω_d	Langmuir kinetics
3)move	10 ⟶ 01	q	⟶ ASEP

Parmegianni, Franosch and Frey, *Physical Review Letters* (2003) p.086601

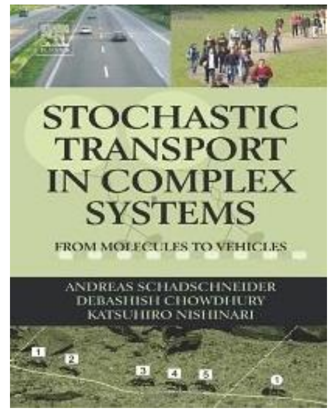
Simulations versus Experiment
Effect of motor concentration



Jam formation at the high concentration of motors!

K.Nishinari, Y.Okada, D.Chowdhury and A.Schadschneider,
Physical Review Letters, vol. 95 (2005) p.118101.

Books of "Jamology"



Original Japanese version
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Elsevier Science
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Science Publication Award in Japan

Collaboration with
Schadschneider, Kirchner (Cologne)
Schreckenberg, Kluepfel, Krez (Duisburg)
D.Helbing (Dresden, Zurich)
Chowdhury, Ambarash (IIT)
Armin Seyfried (Wuppertal)
Rui Jiang (China)
S.Bandini, G.Vizzari (Milano)





Review articles:
Phys. Life Rev. vol.2 pp.318-352 (2005)
Phase Transitions, vol.77 pp.601-624 (2004)

See also our home page
http://park.itc.u-tokyo.ac.jp/tknishi

email: tknishi@mail.ecc.u-tokyo.ac.jp