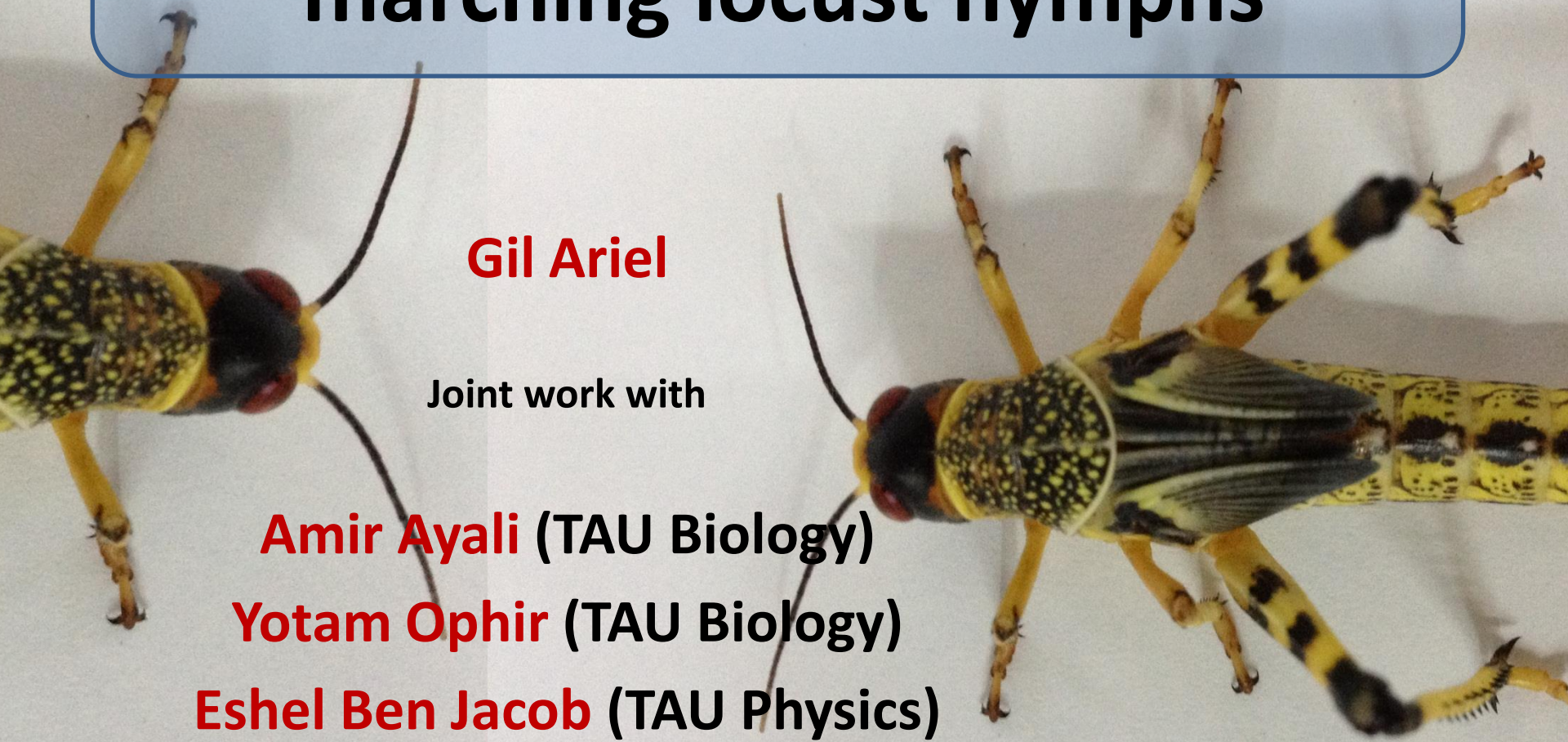
Multiscale dynamics of marching locust nymphs



Gil Ariel

Joint work with

Amir Ayali (TAU Biology)

Yotam Ophir (TAU Biology)

Eshel Ben Jacob (TAU Physics)

Sagi Levi (BIU Math)

Oren Rimer (BIU Math)

Israeli desert 2013

Questions

Micro-scale
Details
Animal locomotion
Interactions

Macro-scale
Coarse graining
Swarm dynamics

Control?

"The locusts have no king, yet go they forth all of them by bands" Proverbs 30:27

What makes the system switch between ordered and disordered states?

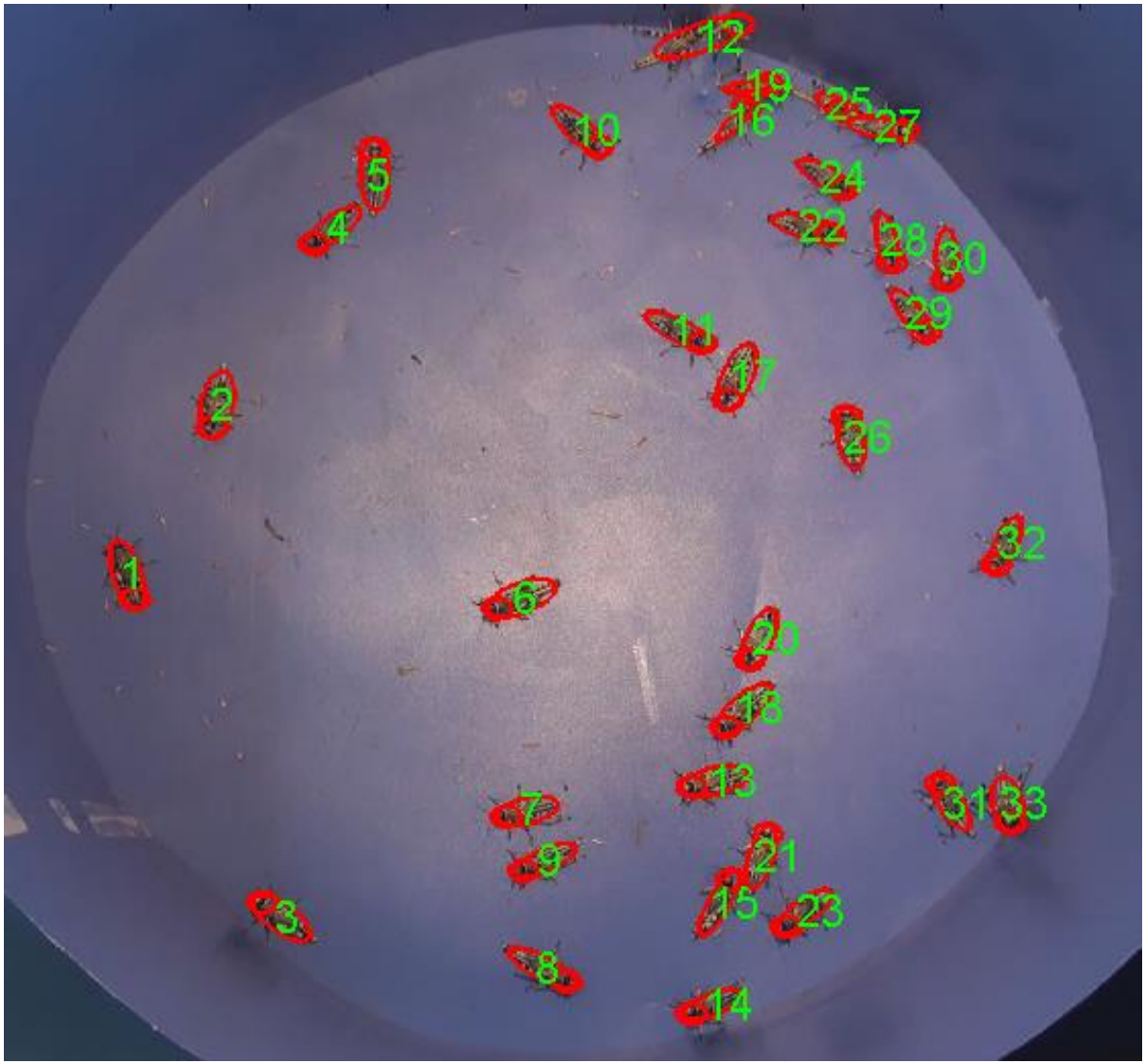
Experiments

Previous experiments: single animals, tactile interactions, global averages

[Couzin, Simpson, Buhl et al 2006, Bazazi et al 2012]

[movie]

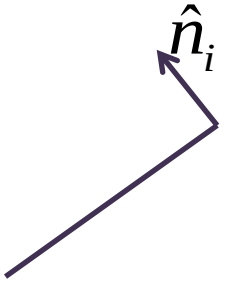
Experiments



[movie]

Macroscopic dynamics

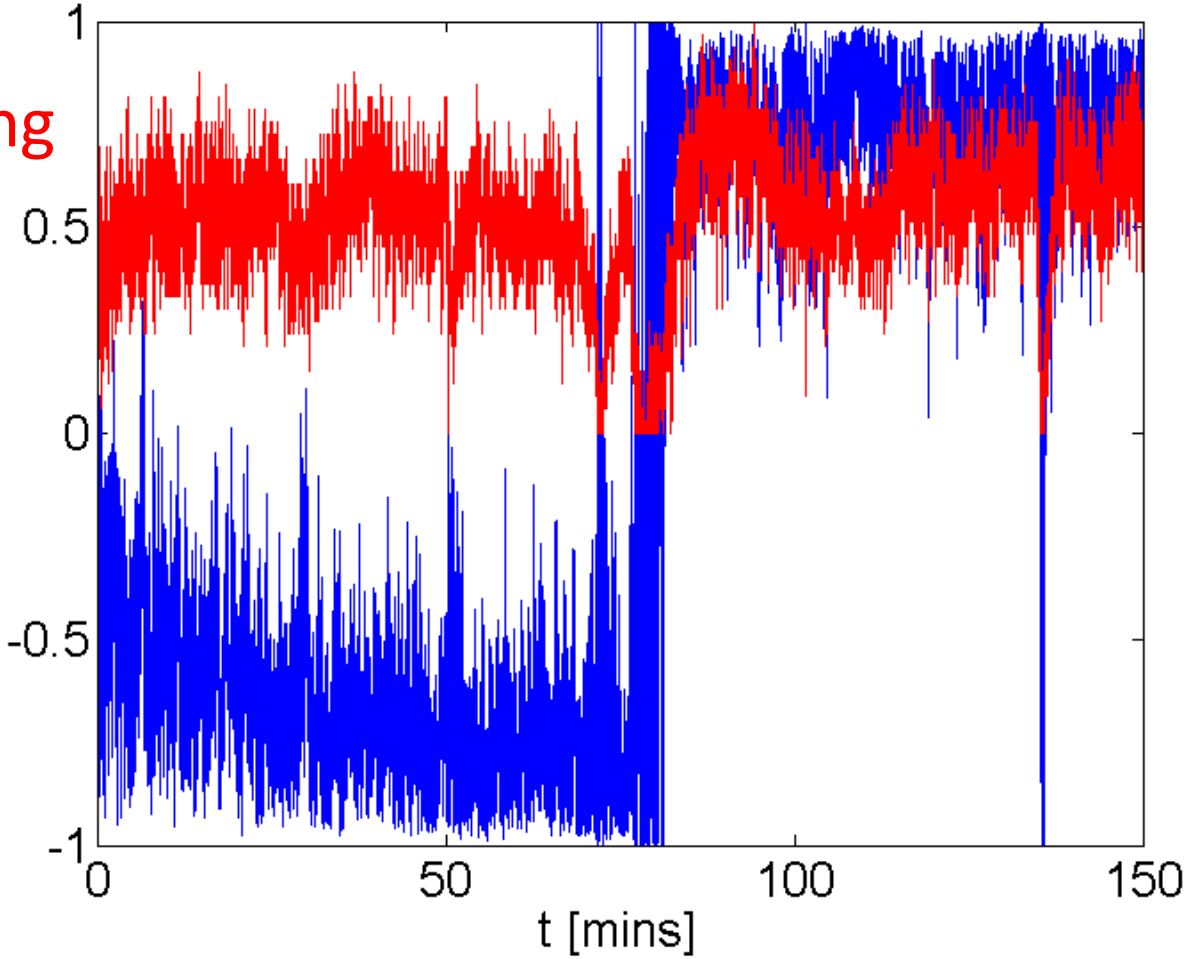
Order parameter $\phi = \frac{1}{n_{\text{walking}}} \sum_{\text{walking animals}} v_i \cdot \hat{n}_i$



Fraction of walking animals

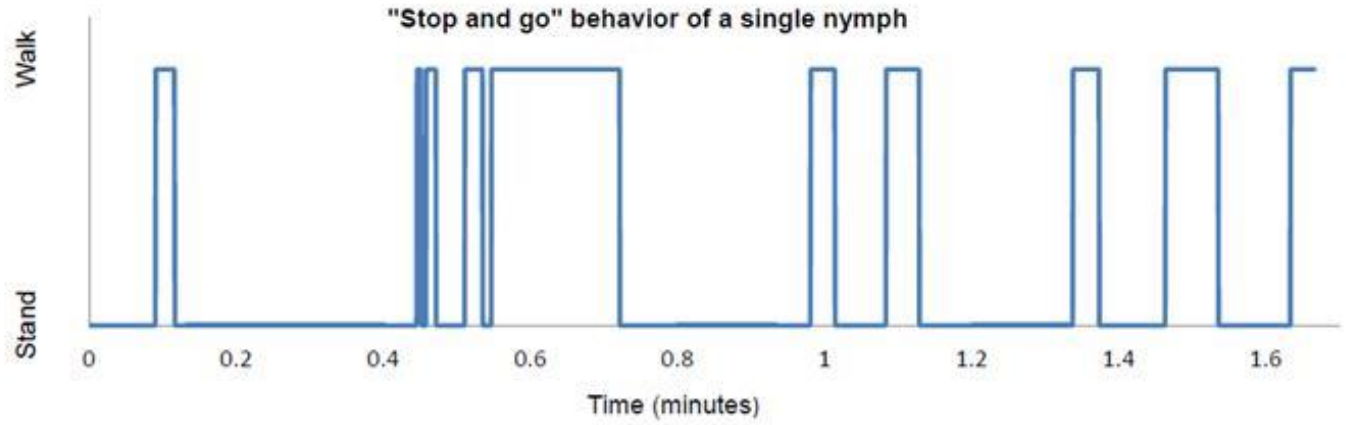
Order parameter

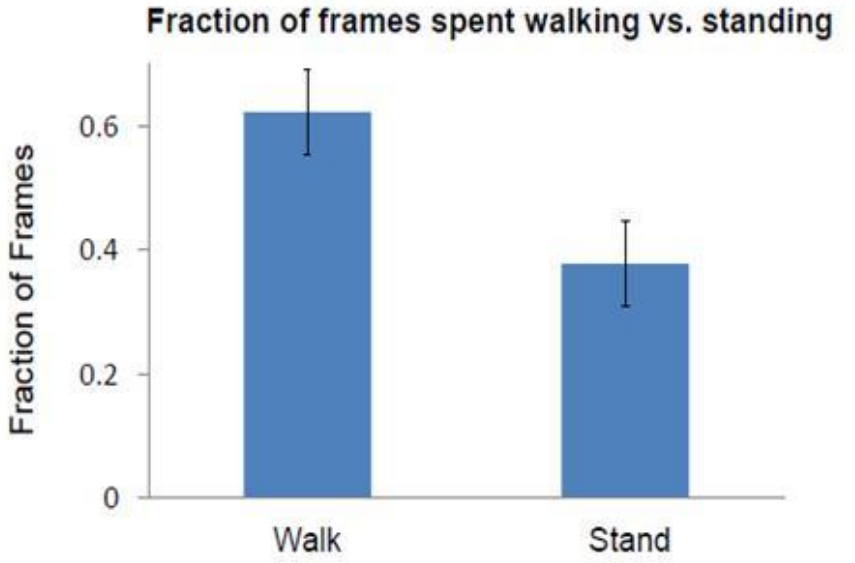
Correlation=0.4



Microscopic dynamics

Stop and go motion

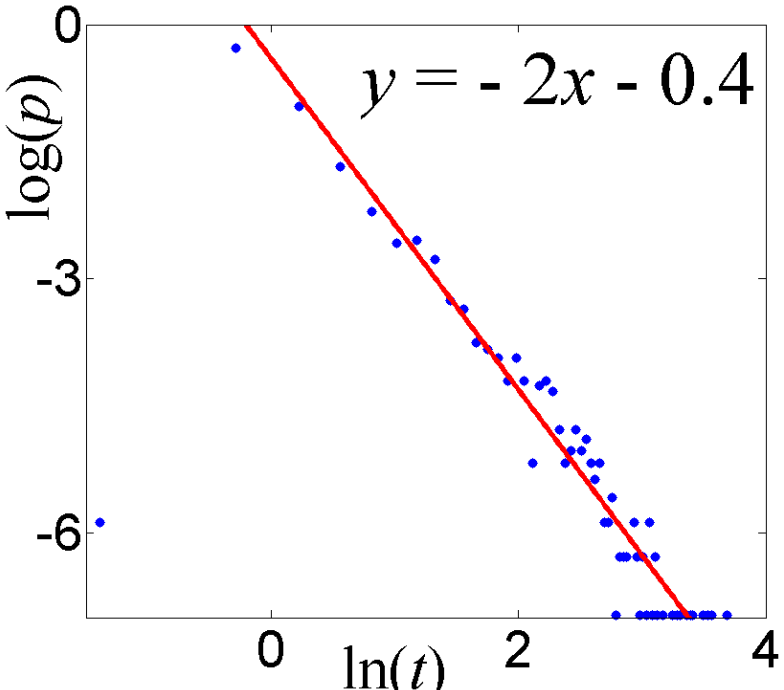




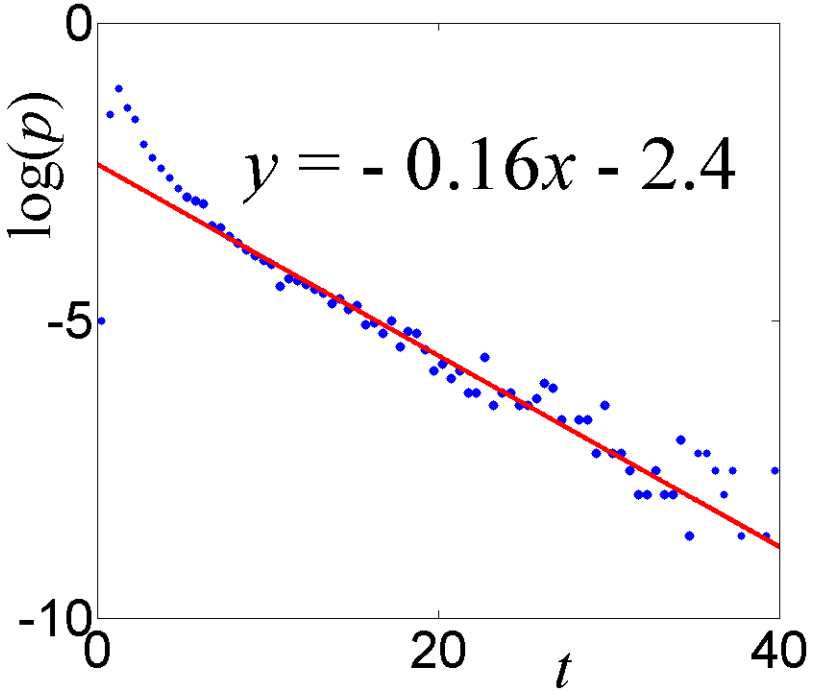
The key "decision" is when to start/stop moving and in which direction

Microscopic dynamics

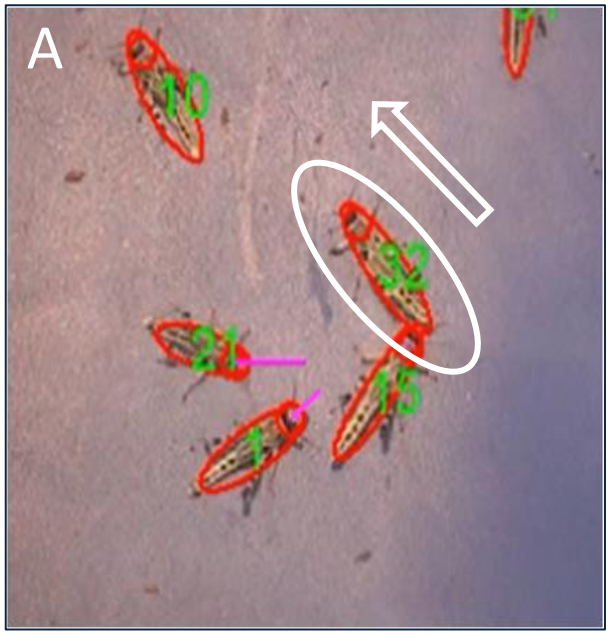
rest durations

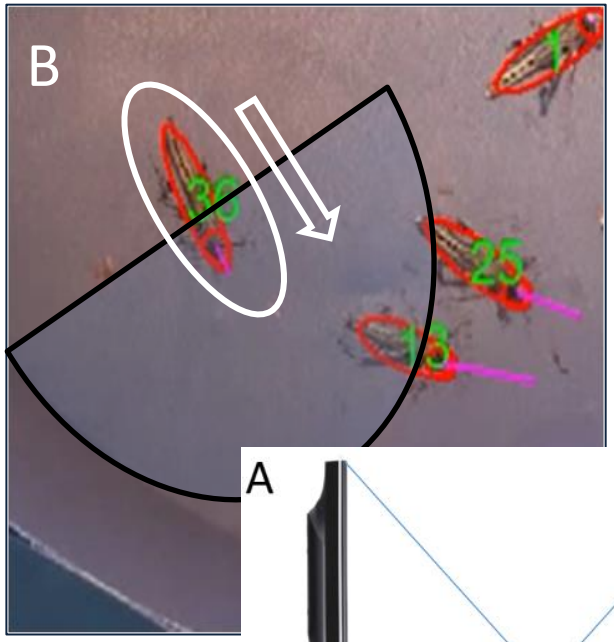


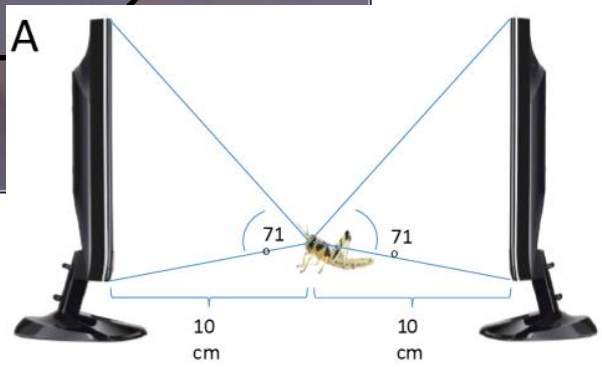
walk durations

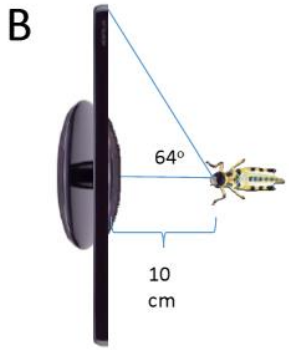


Walking initiations









Visual\tactile triggers for walking and turning

Ariel et al, 2013

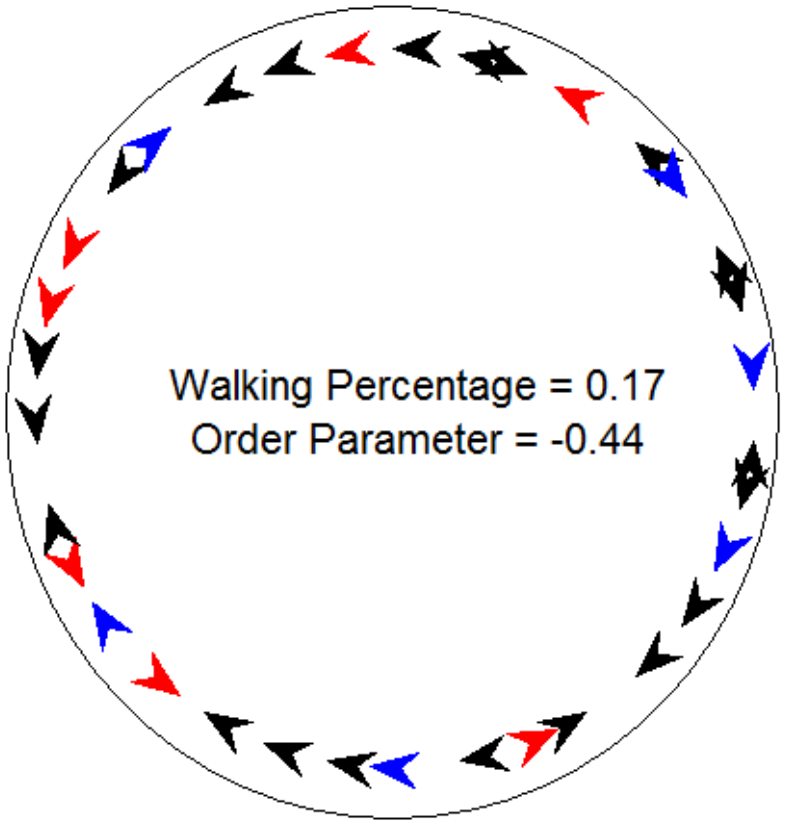
Realistic model

Stop and go

No free parameters!

1D (for now)

- **Start walking**
  - Touch
  - Vision stimulus
  - Spontaneous
- **Stop walking**
  - Touch
  - Spontaneous
- **Turn.** Only when starting to walk.
  - Depends on global ϕ



|movie|

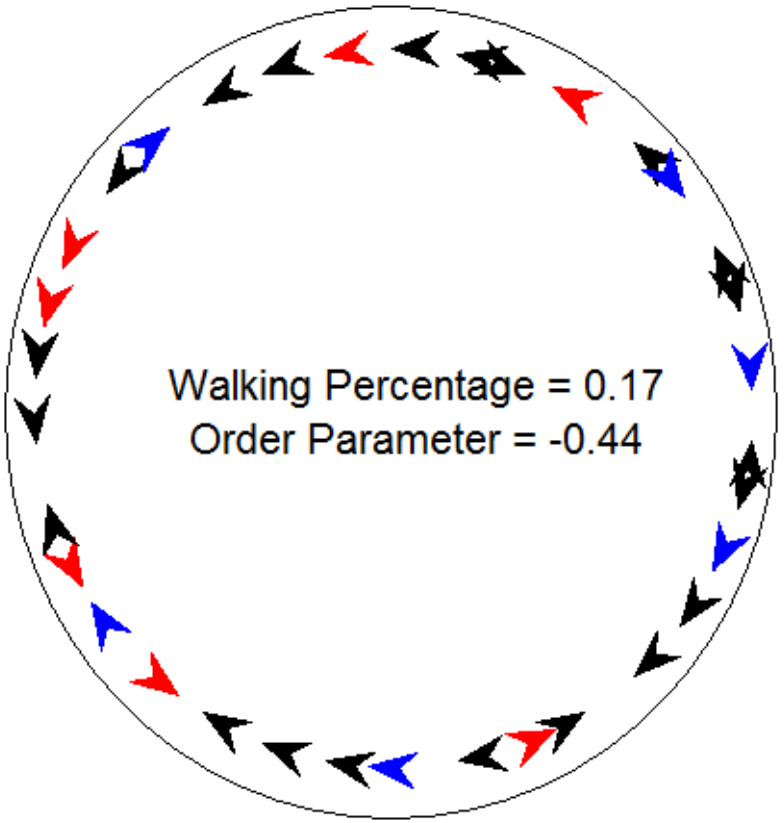
Simplified model

Stop and go

Local

1D (for now)

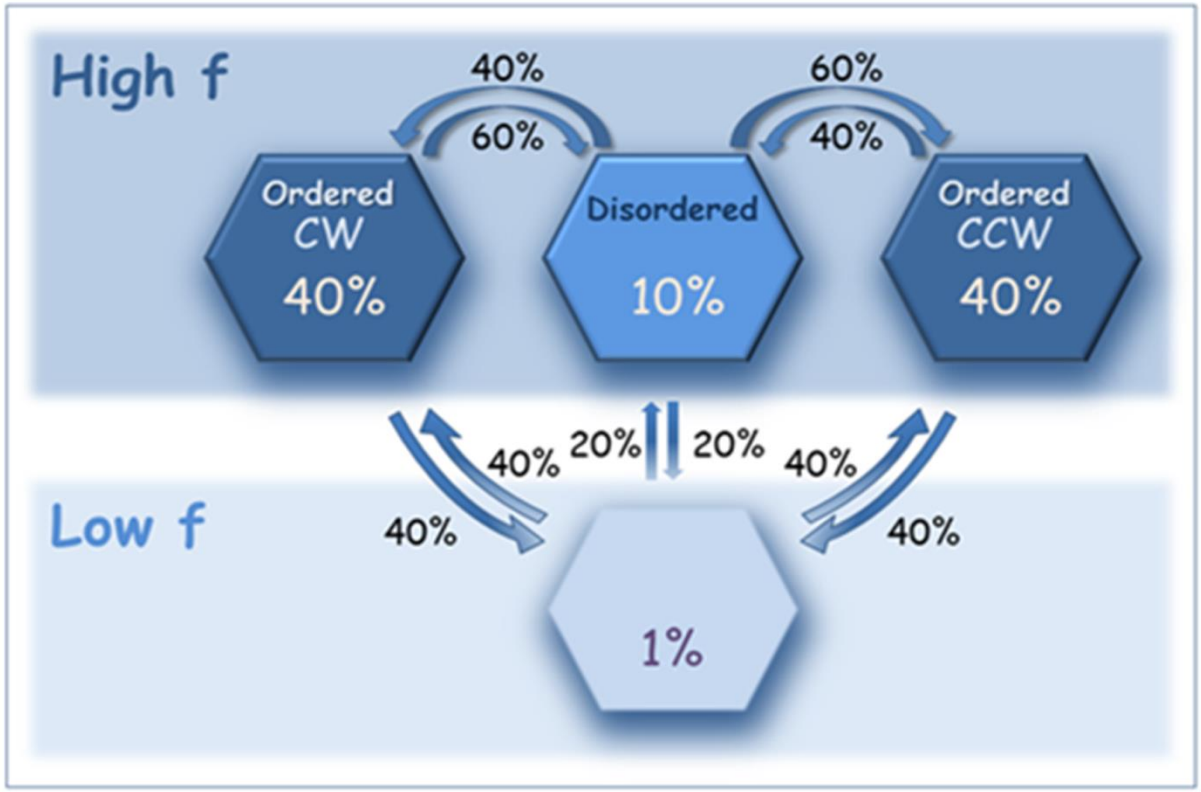
- **Start walking**
  Increased local movement
  Spontaneous
- **Stop walking**
  Spontaneous
- **Turn** Positive feedback with local ϕ

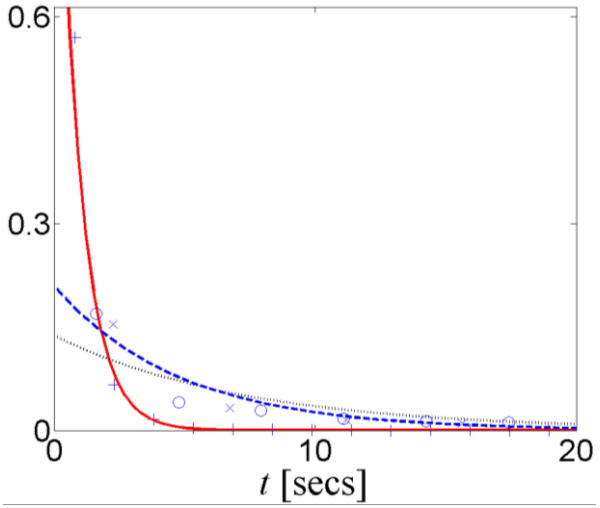


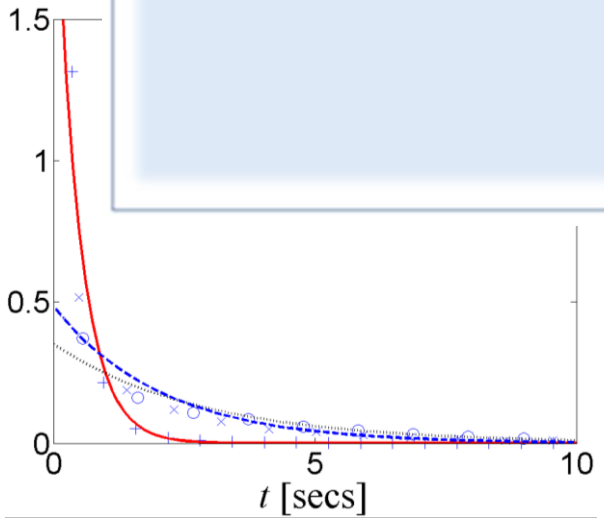
[movie]

CTMC approximation

Coarse variables: f and ϕ







CTMC approximation

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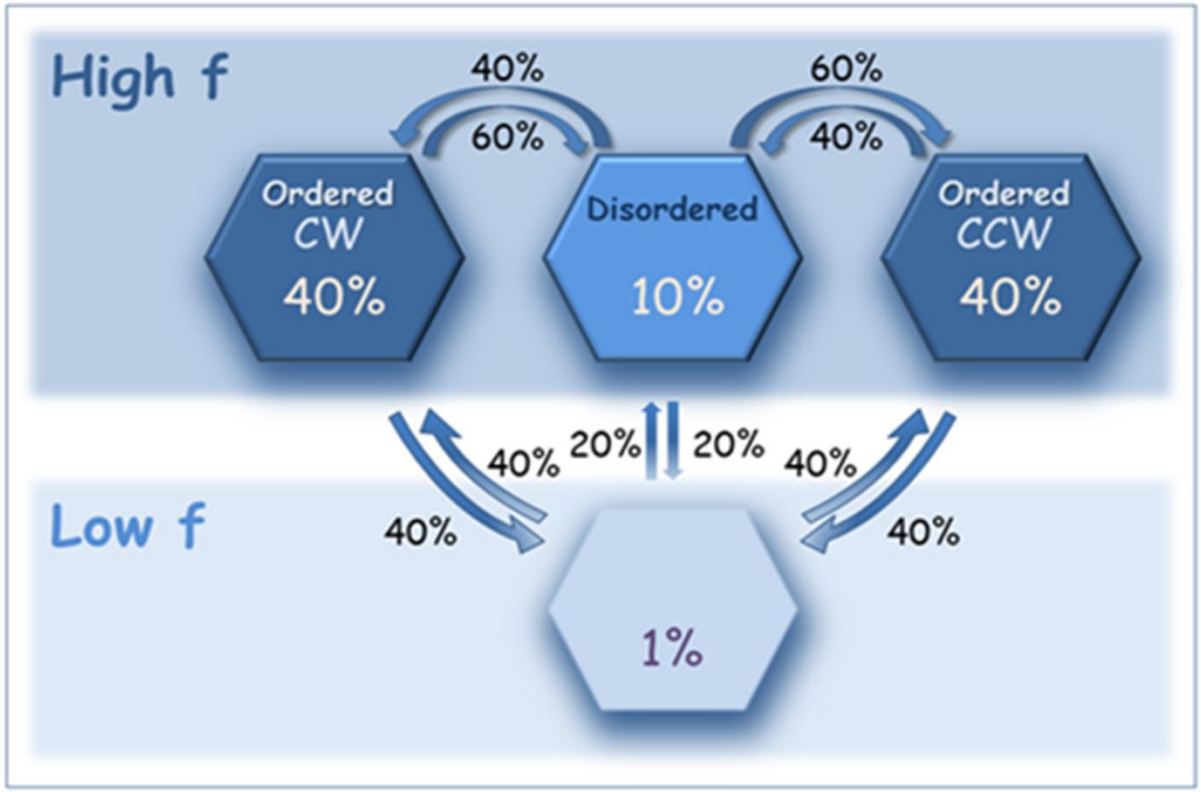


Most directional switches are through the low f state.

Multiscale analysis

[Yates et al ’09]

Coarse grained coordinates:

the order parameter

Central limit theorem

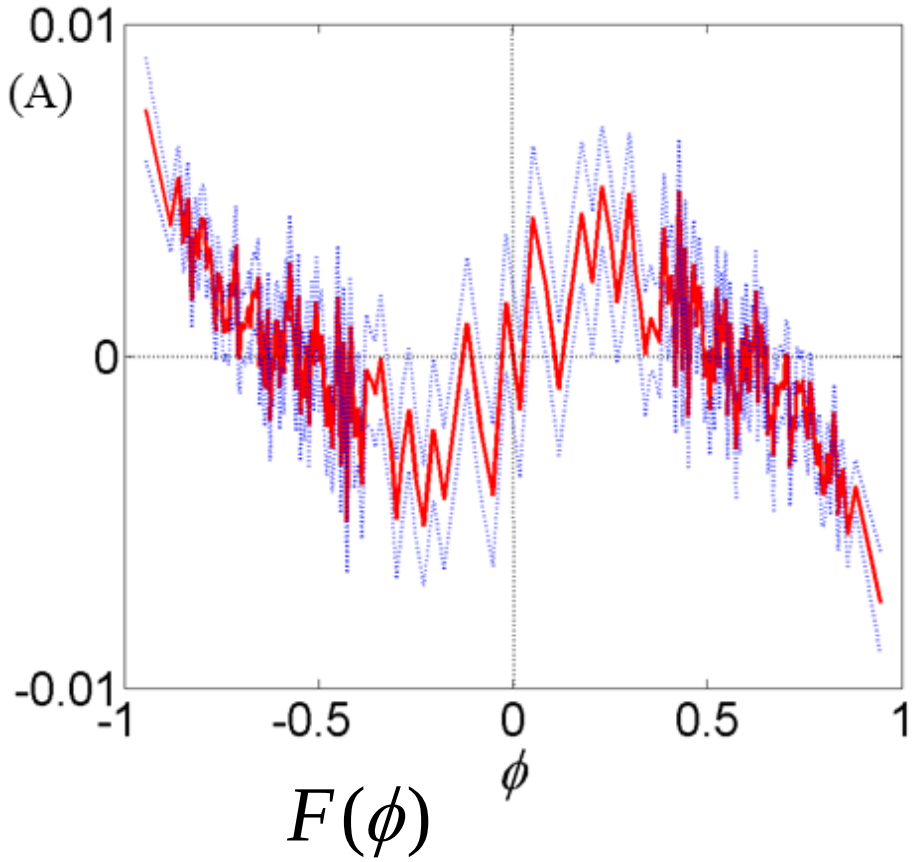
$$d\phi_t = F(\phi)dt + \sqrt{D(\phi)}dB_t$$

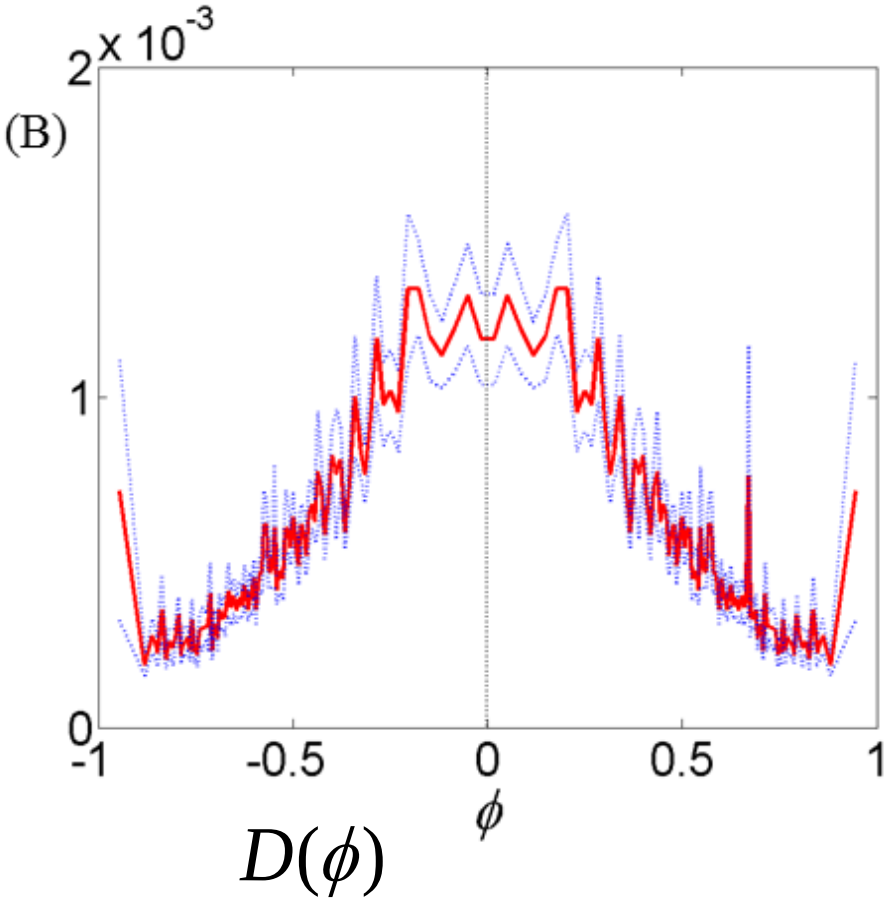
$$F(\phi) = \left\langle \frac{\phi_{t+\Delta t} - \phi_t}{\Delta t} \right\rangle$$

$$D(\phi) = \frac{1}{2}\left\langle \frac{(\phi_{t+\Delta t} - \phi_t)^2}{\Delta t} \right\rangle$$

Multiscale analysis

experiment

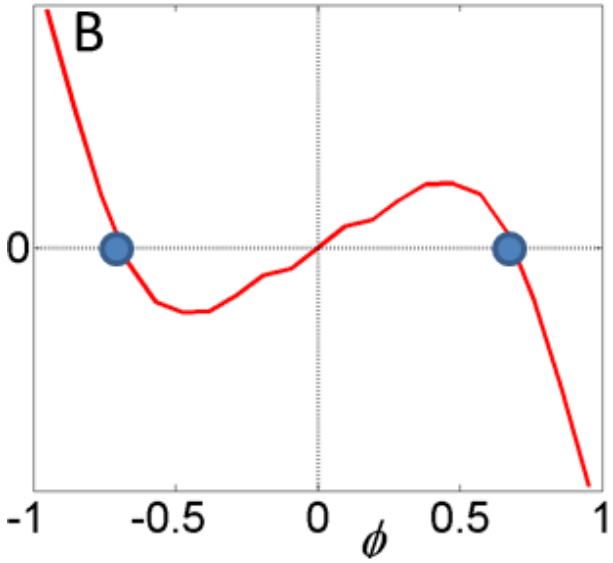




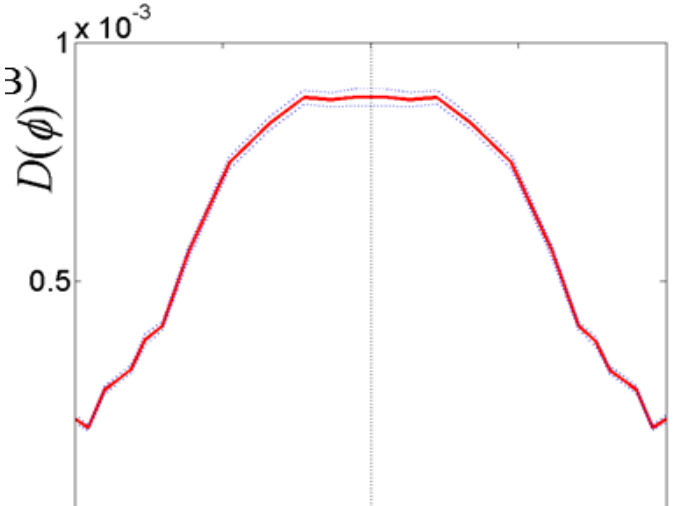
zeros of f = fixed points (stable or unstable)

Multiscale analysis

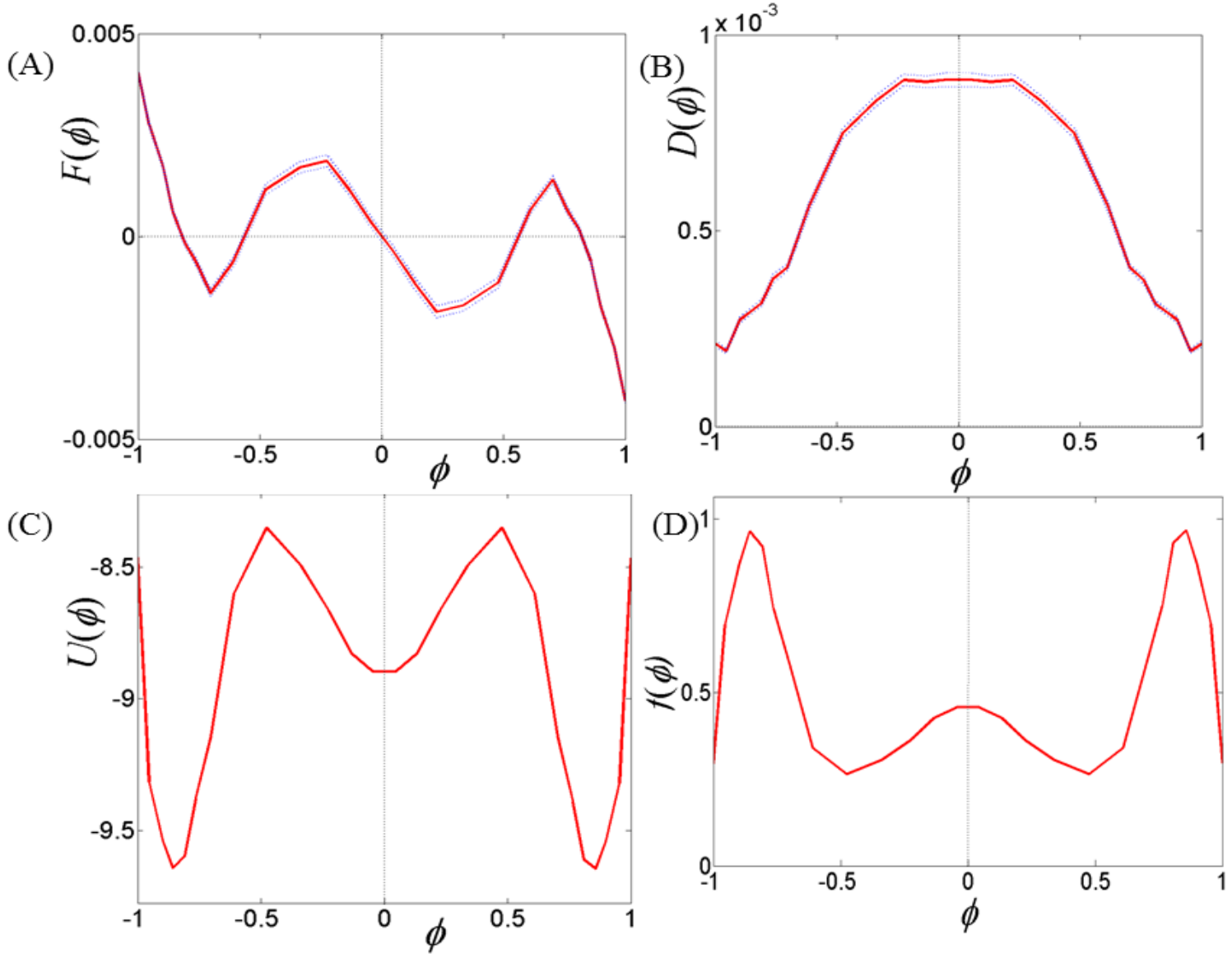
[Yates et al ’09]
1D Viscek. *D*=const. Ad hoc correction.



[Bode et al ’10. *D*=const. Asynchronous update



Realistic model



Multiscale analysis

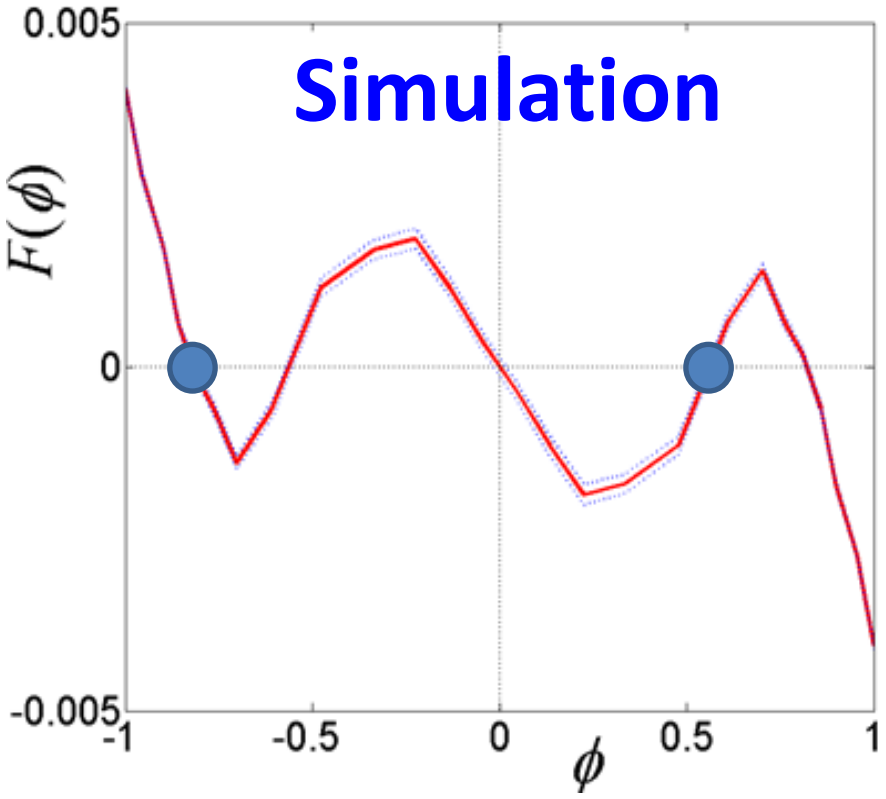
At large $|\phi|$ the probability to turn with or against ϕ is larger Than against ϕ.

f: fraction of walkers

N: number of animals

$$\sum v_i = Nf$$

$$\phi = \frac{1}{Nf}\sum v_i = 1$$



Multiscale analysis

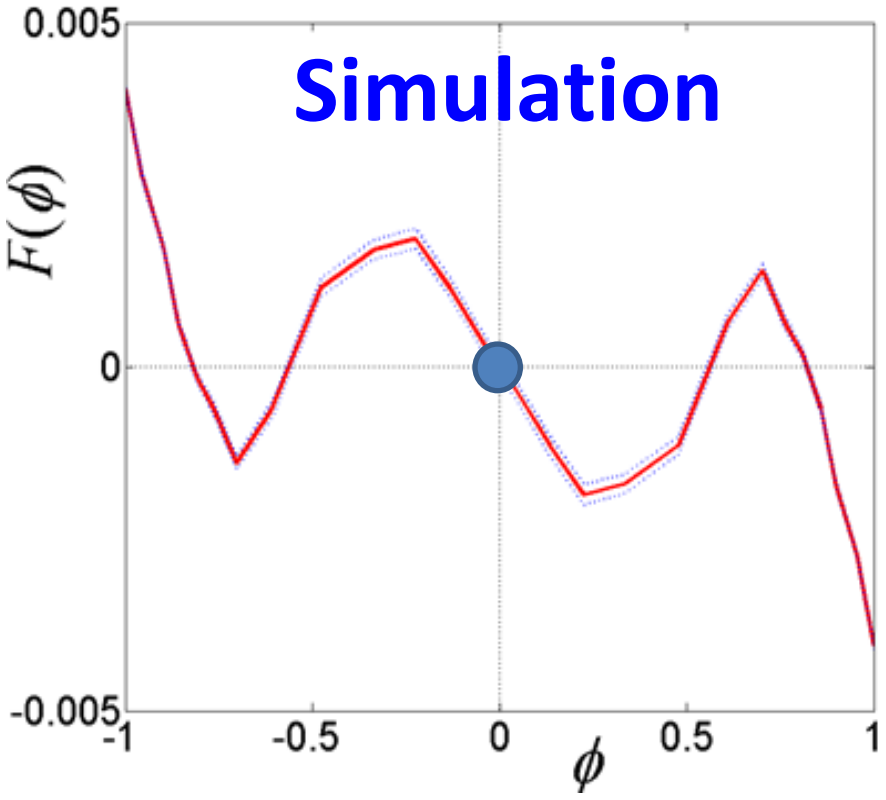
At small $|\phi|$ the probability to turn with or against ϕ is almost equal.

f: fraction of walkers
N: number of animals

$$\sum v_i = \sqrt{Nf}$$
$$\phi = 1/\sqrt{Nf}$$

But $\phi \sim f$.

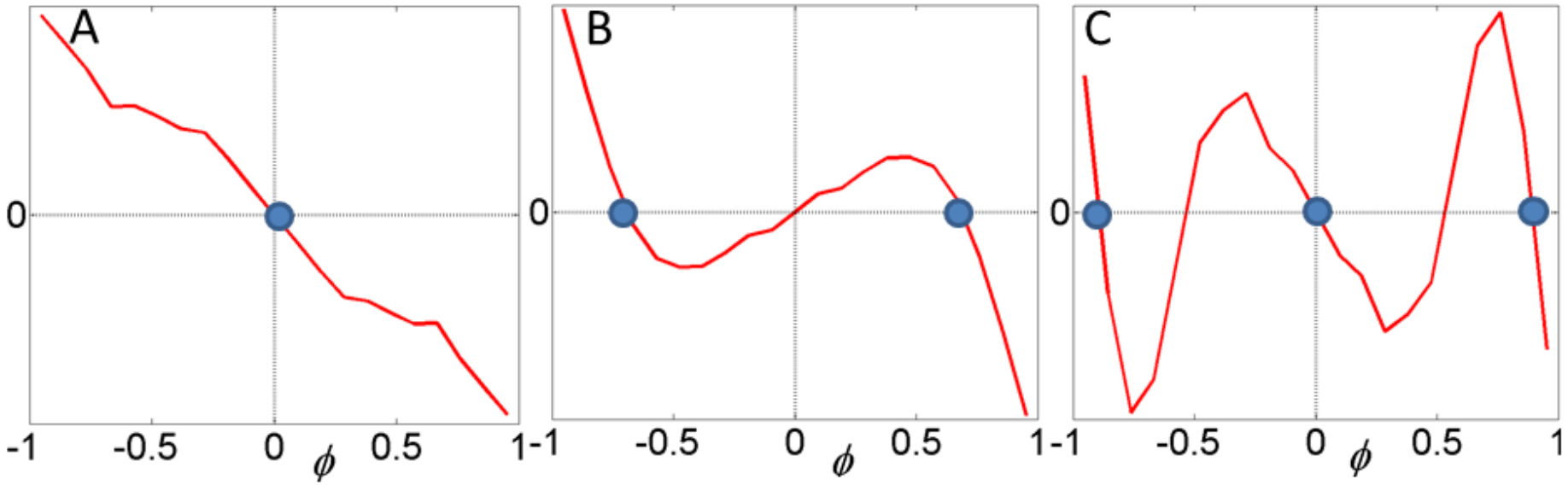
$$\phi^{3/2} \sim N^{-1/2}$$
$$\phi \sim N^{-1/3}$$



With N=34, ϕ=0.3. Fluctuations dominate -> $\phi \rightarrow 0$

Local model

Effective drift with different U-turn probability

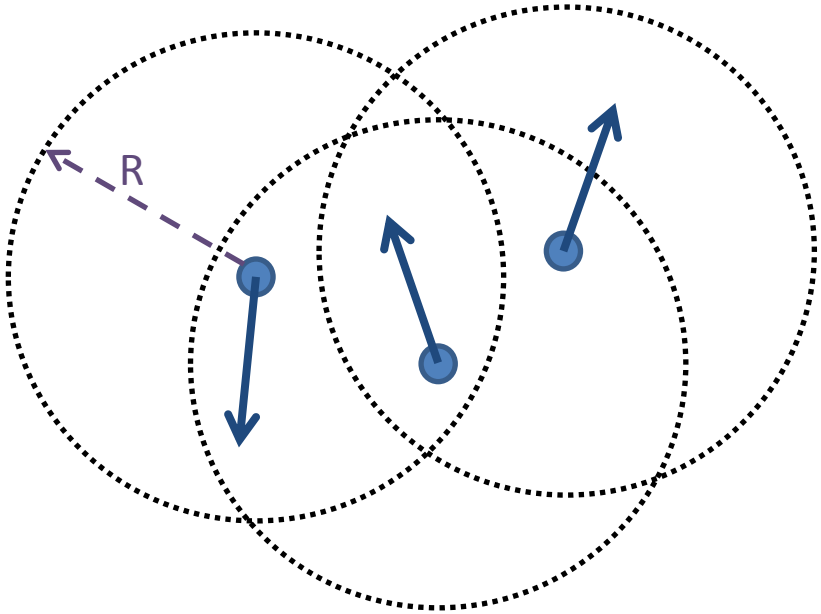


$F(\phi)$

Ariel et al, 2013

2D stop-and-go model

- Viscek et al ’96
  stat phys. approach. XY model + movement.



- Particle density *f.* 2D Torus.
- Constant speed
- Every step: align with local average + noise.

Order parameter

$$\phi = \frac{1}{N}\sum \boldsymbol{v}_i$$

2D stop-and-go model

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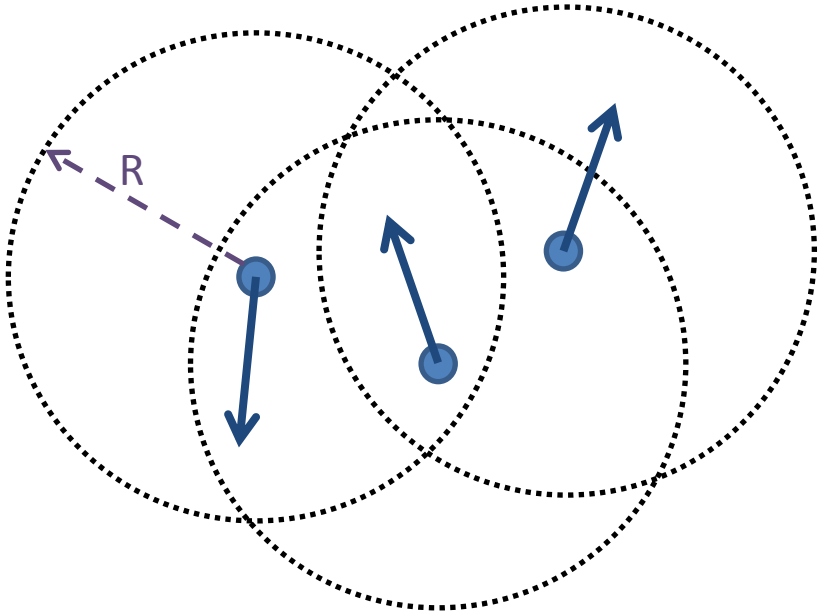

- Particle density *f.* 2D Torus.
- Constant speed\stop
- Every step: align with local average + noise\do nothing

Order parameter

$$\phi = \frac{1}{N_{\text{walk}}} \sum_{i \text{ is walking}} v_i$$

- The prob. To start walking depends on local movement.
- The prob. to align depends on local order.

  Motivation: dynamic switching between phases

2D stop-and-go model

- Viscek et al ’96
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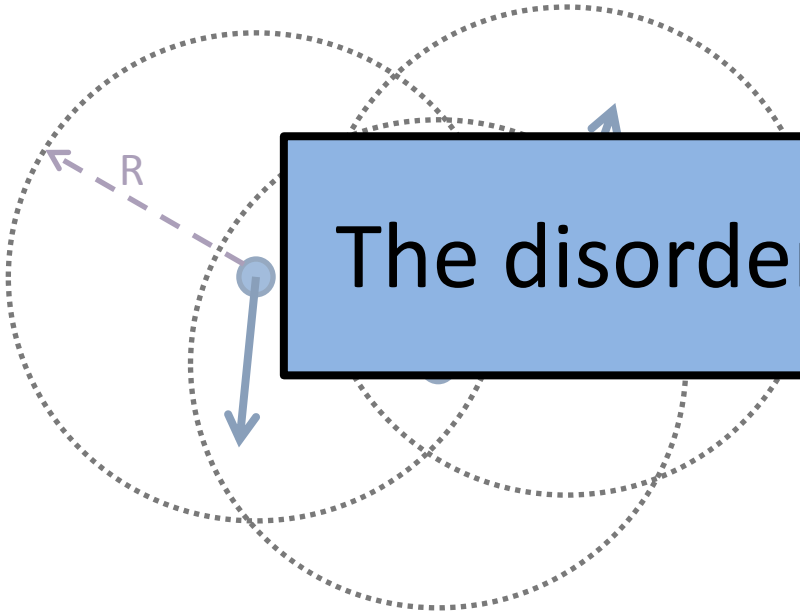


- Particle density *f*
- Constant speed\stop
- al
- ing

The disordered state is not stable

Order parameter

$$\phi = \frac{1}{N_{\text{walk}}} \sum_{i \text{ is walking}} v_i$$

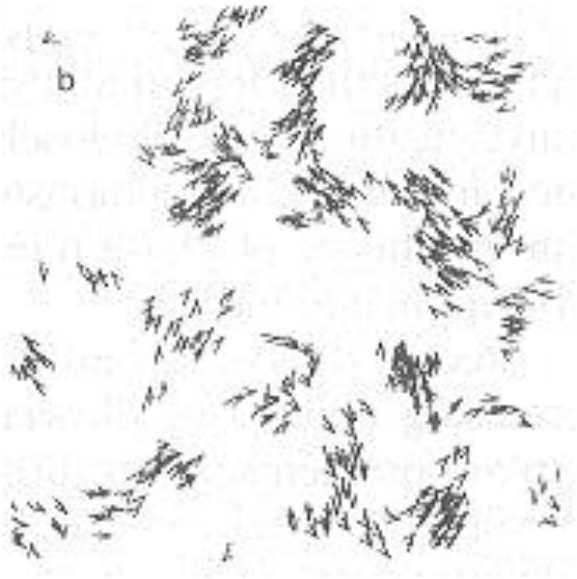
- The prob. To start walking depends on local movement.
- The prob. to align depends on local order.
  Motivation: dynamic switching between phases

2D stop-and-go model

Particles form clusters.

Local properties are different than global.

Difference between 1D and 2D.



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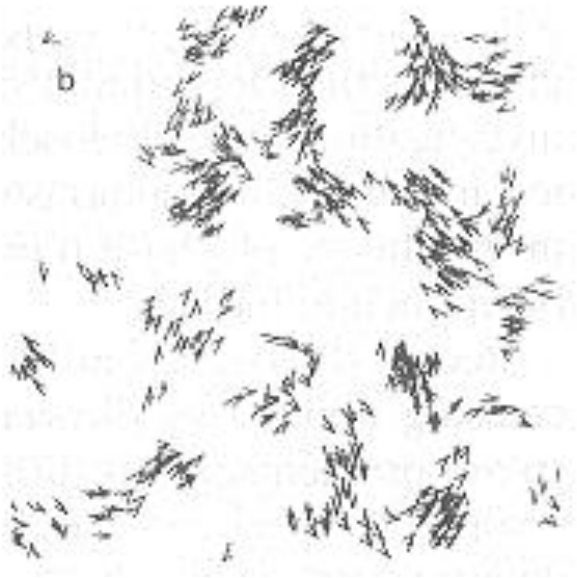
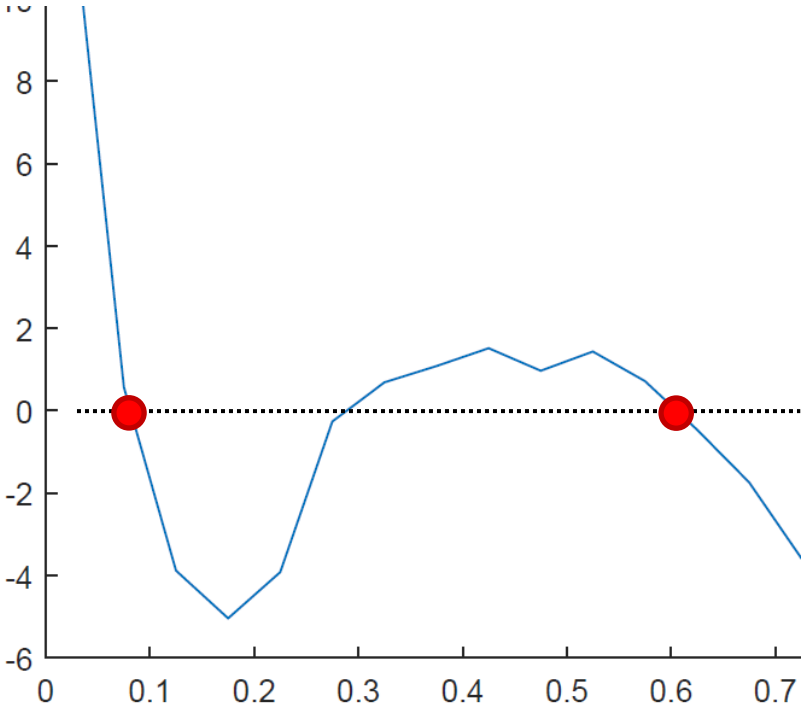


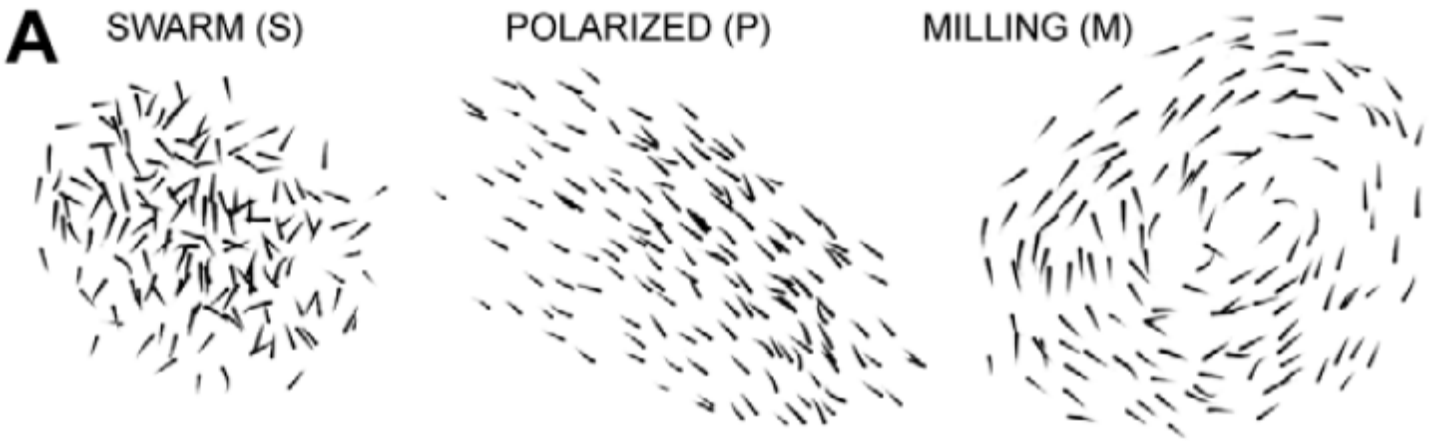
Solution: add memory

The drift



Intermittent motion

Fish: float and coast



Tunstrom et al, 2013

Conclusions

A generic principle

- Stop and go motion
- Positive feed back with order

Three meta-stable states:

2 ordered and 1 disordered

Not a phase transition

Modelling locust collective motion: a review.
Ariel and Ayali. Under review.

Thank you