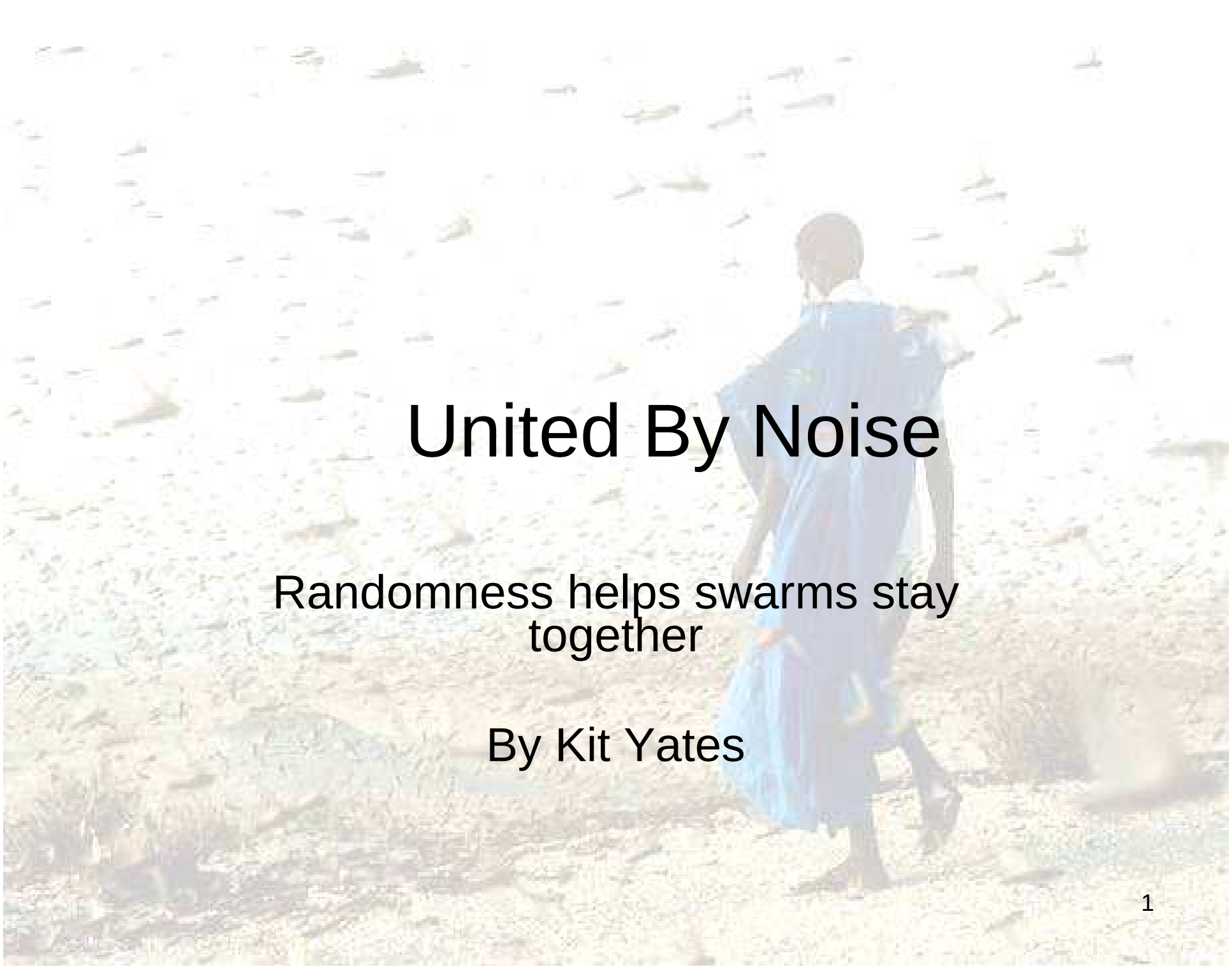


United By Noise

Randomness helps swarms stay together

By Kit Yates

Biblical Proportions

“The locusts came up over all the land of Egypt and settled in all the territory of Egypt; they were very numerous. There had never been so many locusts, nor would there be so many again. For they covered the face of the whole earth, so that the land was darkened; and they did eat every herb of the land, and all the fruit of the trees which the hail had left: and there remained not any green thing in the trees, or in the herbs of the field, through all the land of Egypt. ” Exodus(10:14-15)

Background

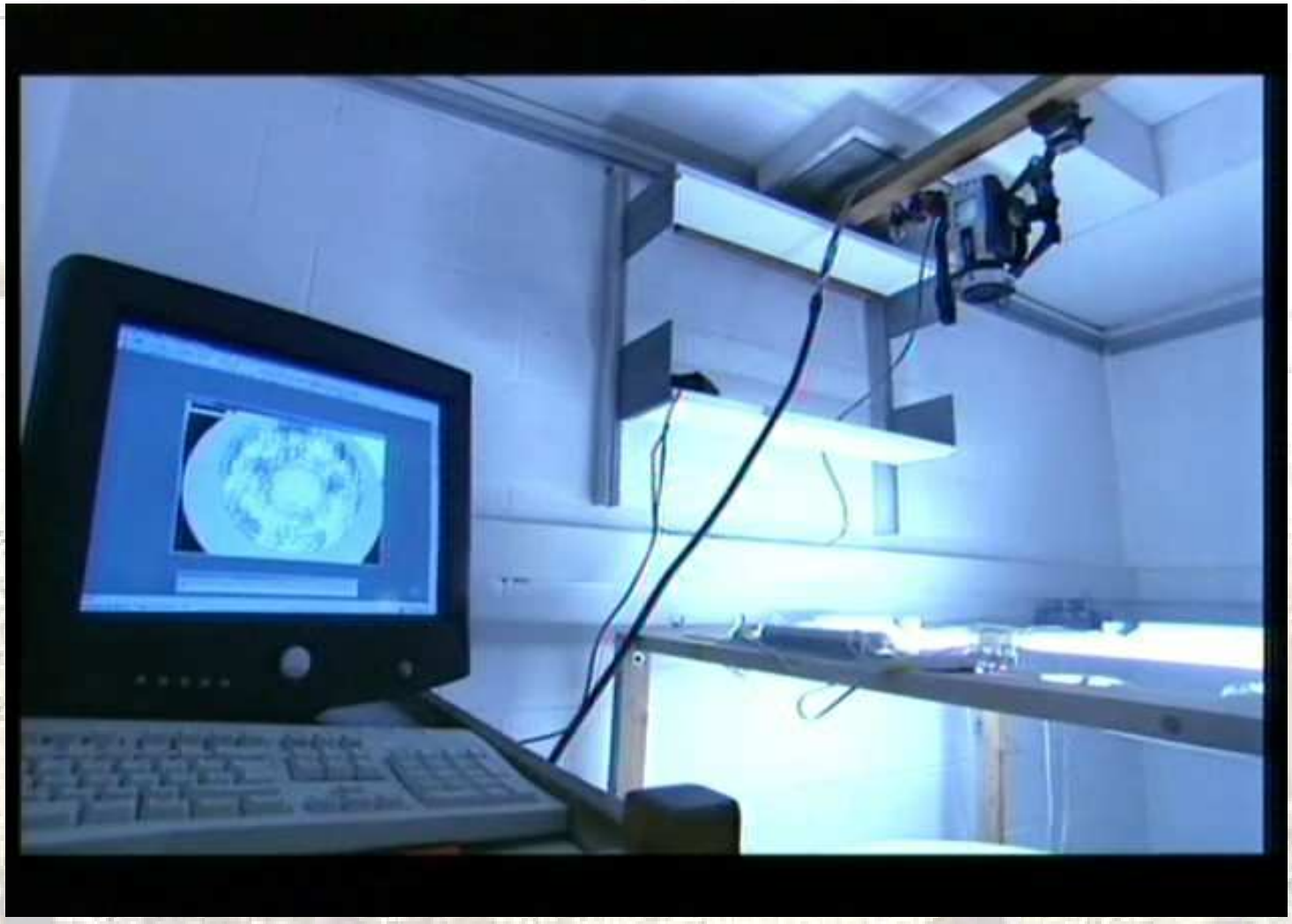
Plagues:

- 60 countries
- 29 million square kilometres
- 20% of the total land surface of the world
- 10% of the world's population

Traffic accidents

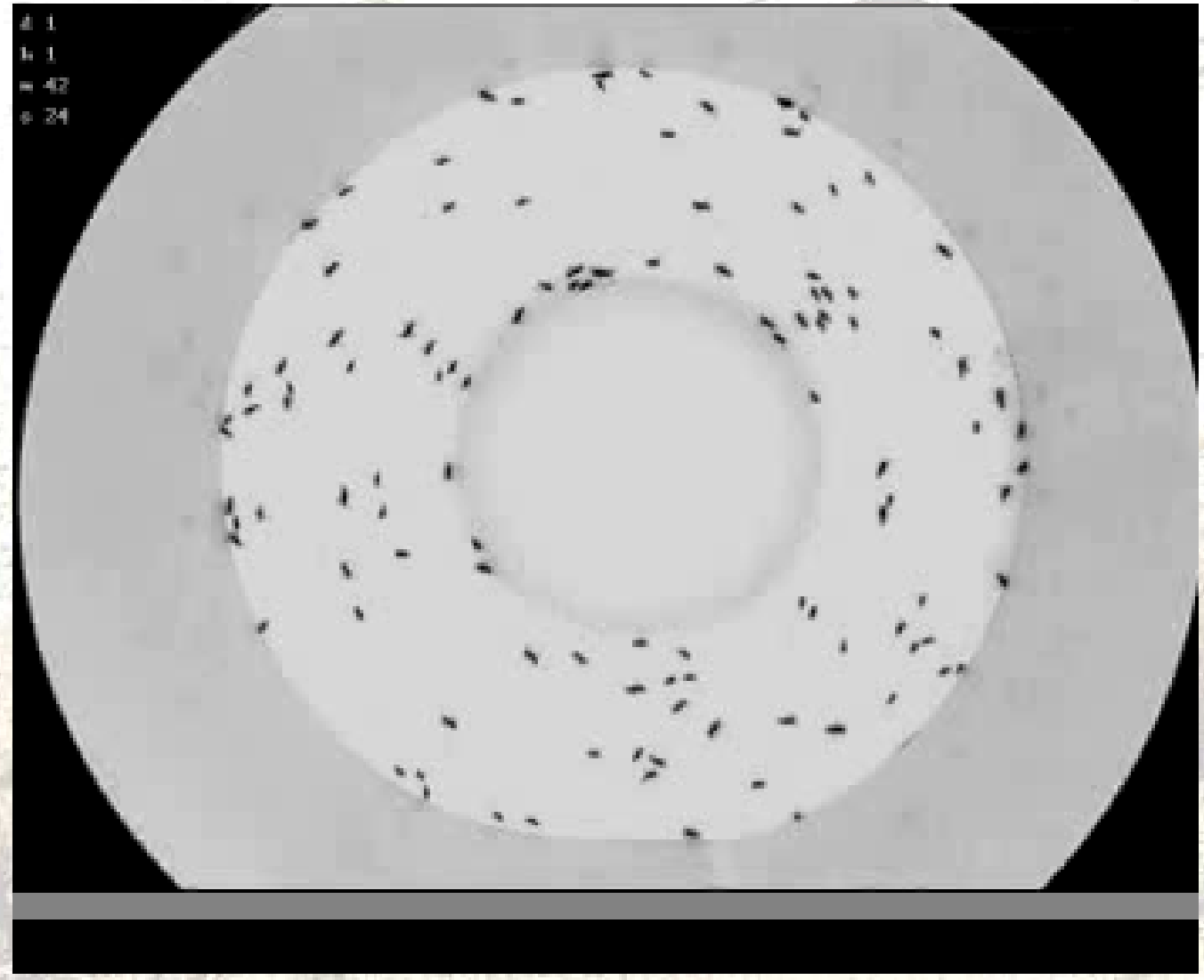
House Eating

The Experiments



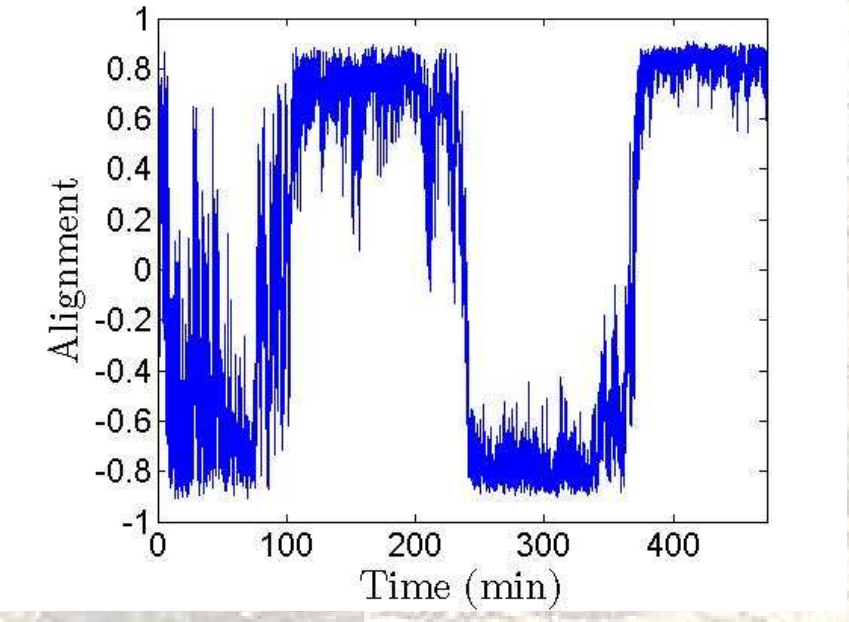
Buhl et al. (2006) From Disorder to Order in Marching Locusts. Science, 312:1402-1406.

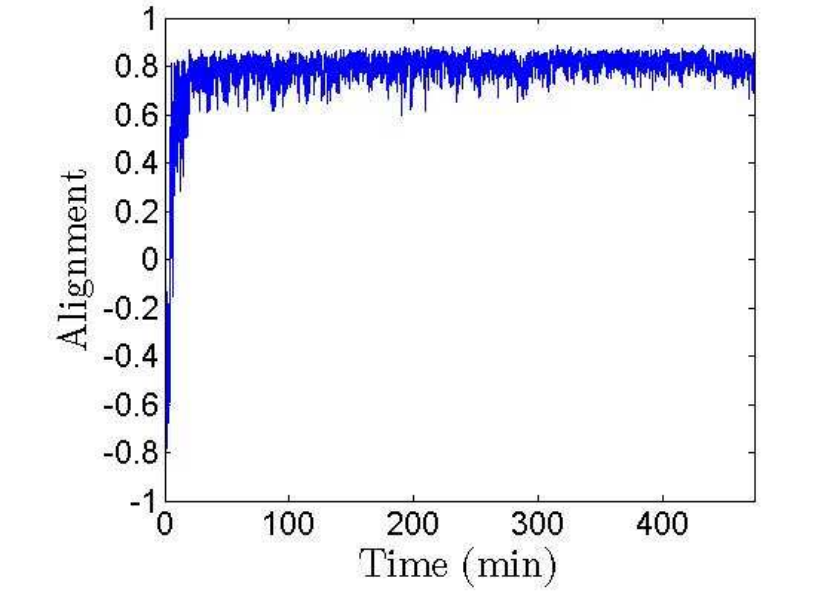
Movie



Experimental Results

- Collective motion
- Switching between two steady states: Clockwise and Anticlockwise
- Noisy/Stochastic process





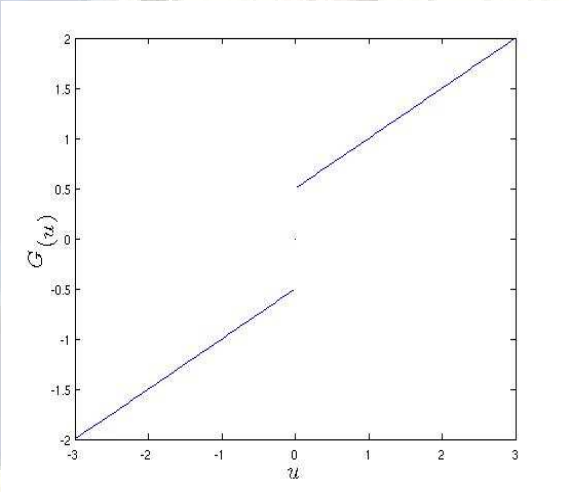
The model

$$\Delta x_i = u_i \Delta t,$$

$$\Delta u_i = \left\{ G\left(\bar{u}_i^{loc}\right) - u_i(t) \right\} \Delta t + \Delta Q \eta\left(\bar{u}_i^{loc}\right),$$

$$\text{where } \bar{u}_i^{loc} = \frac{1}{n_i(t)} \sum_{j \in \mathcal{J}_i^R} u_j(t)$$

$$\text{and } G(z) = \frac{1}{1+\beta}\{z + \beta \text{sign}(z)\}.$$



Czirok et al. (1999) Collective Motion of Self-Propelled Particles: Kinetic Phase Transition in One Dimension. PRL 82(1):209-212.

Stochastic Differential Equations (SDEs)

Typical SDE

$$U(t+dt) = U(t) + F(U(t))dt + \sqrt{2D(U(t))}dW$$

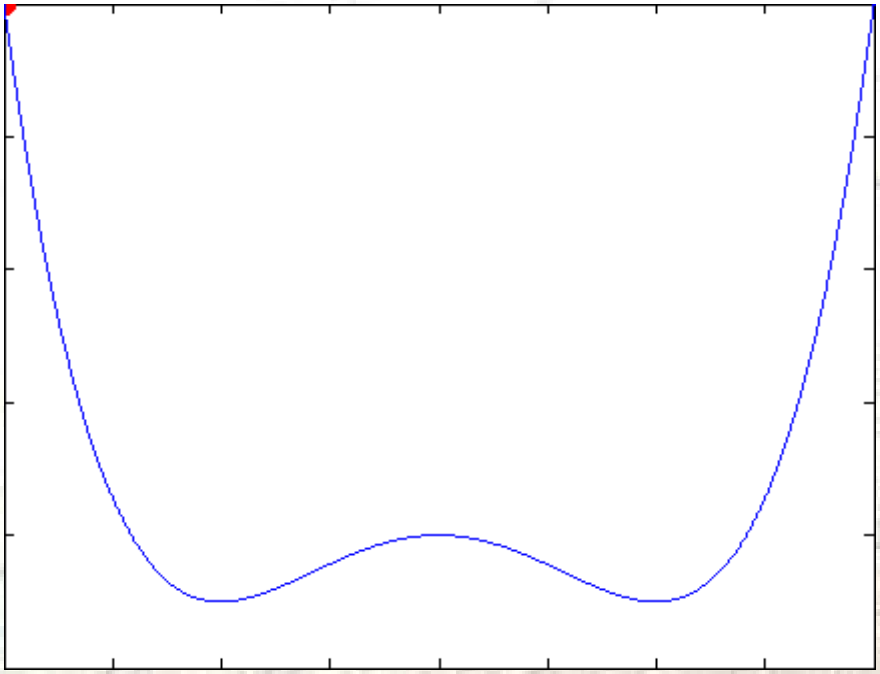
drift, F, diffusion D and $dW \sim \sqrt{dt}N(0,1)$,

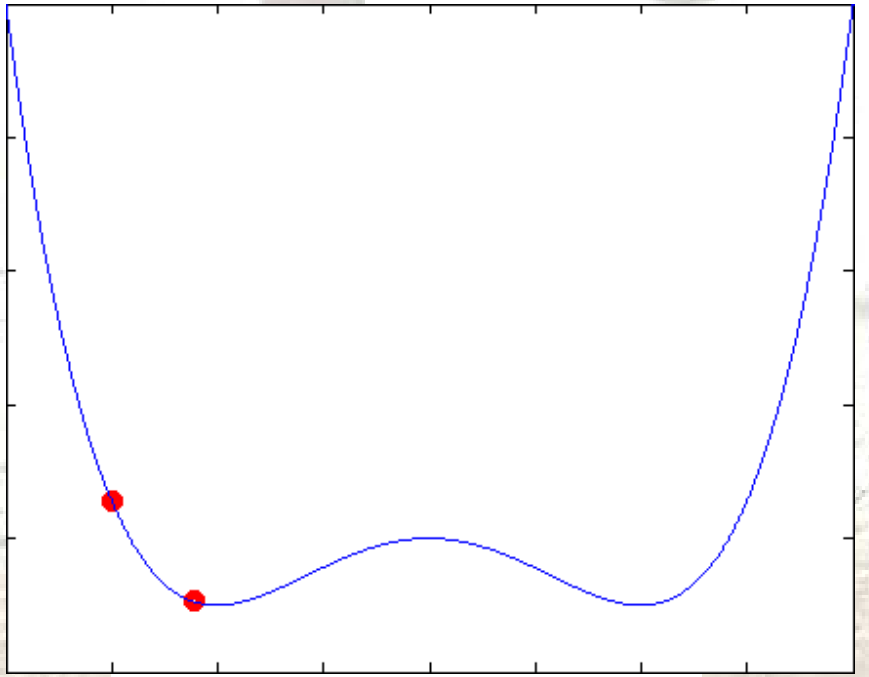
the standard Wiener process.

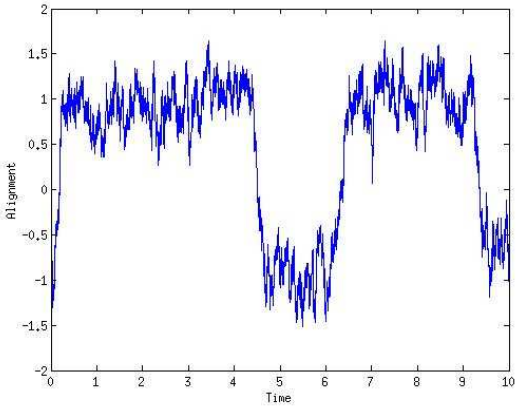
Find F and D then find potential ϕ:

$$\phi(U) = -\int_0^U \frac{F(s)}{D(s)}ds + \ln(D(U)).$$

The Difference Between an ODE and an SDE







Equation-Free Analysis

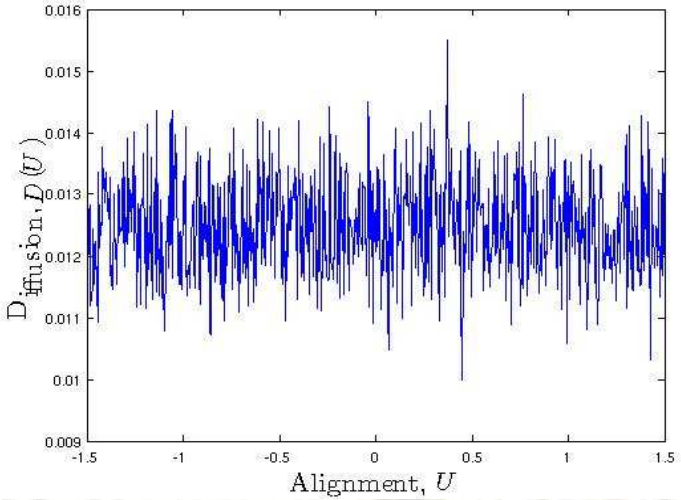
$$F(U) \approx \left\langle \frac{U(t+dt)-U(t)}{dt} \right\rangle,$$

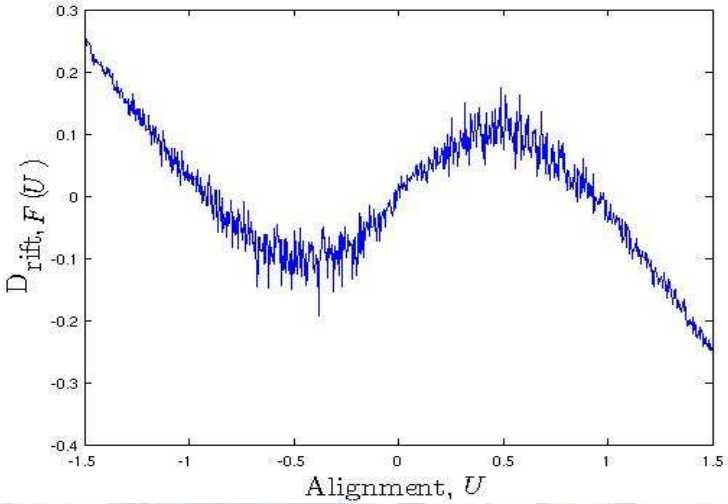
$$D(U) \approx \frac{1}{2} \left\langle \frac{[U(t+dt)-U(t)]^2}{dt} \right\rangle,$$

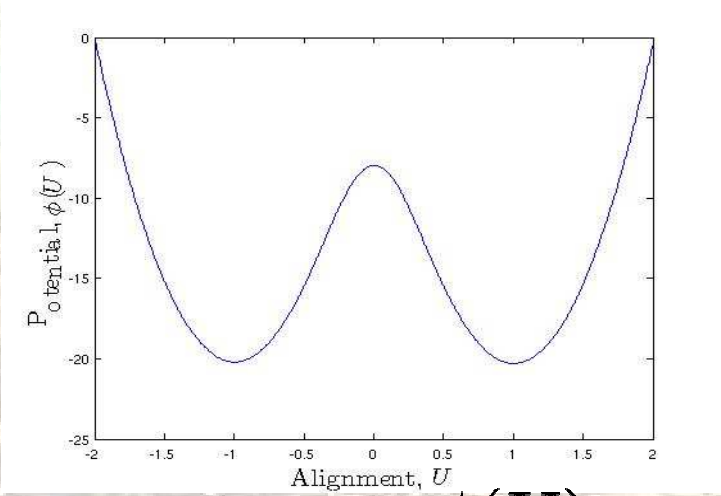
Recall the SDE:

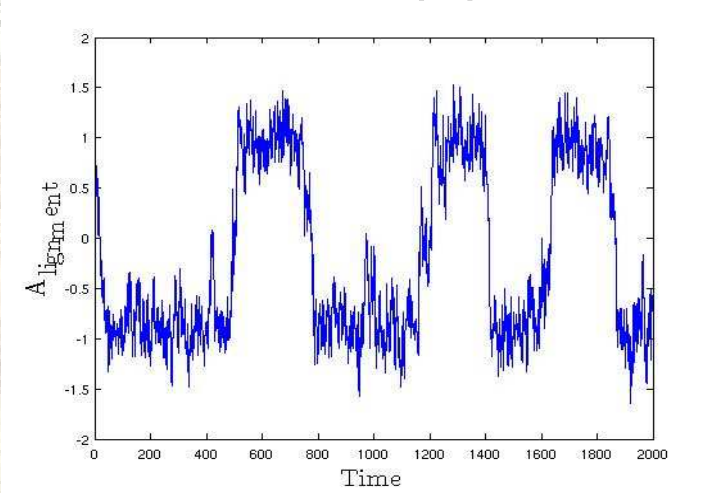
$$U(t+dt) - U(t) = F(U(t))dt + \sqrt{2D(U(t))}dW$$

Model Results

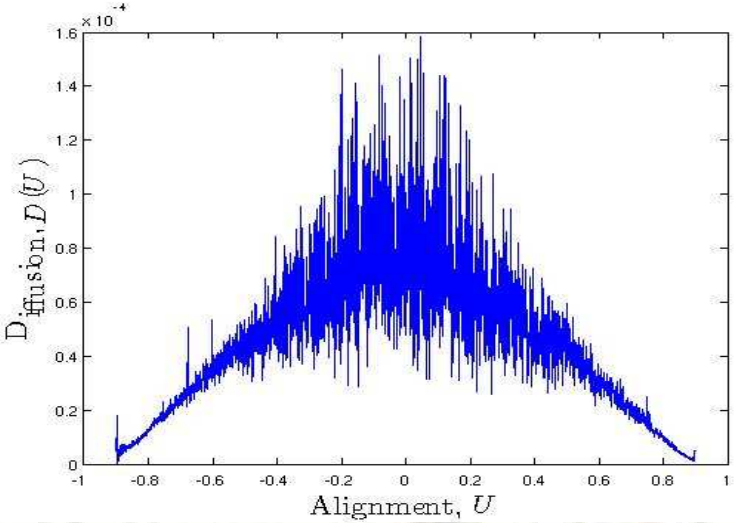


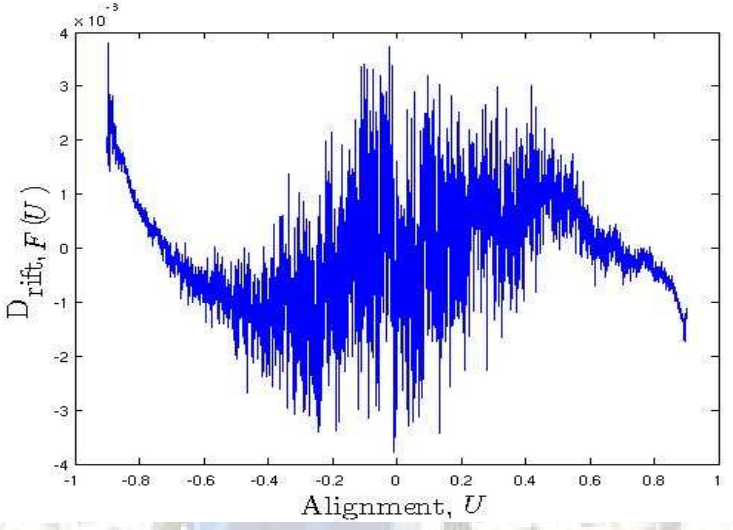


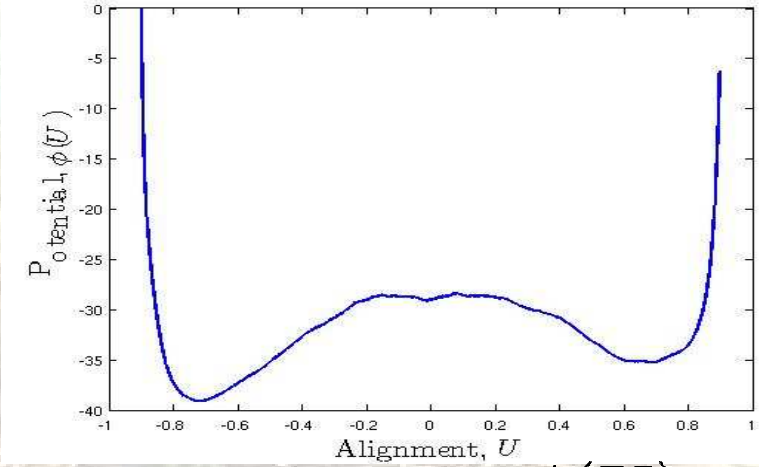


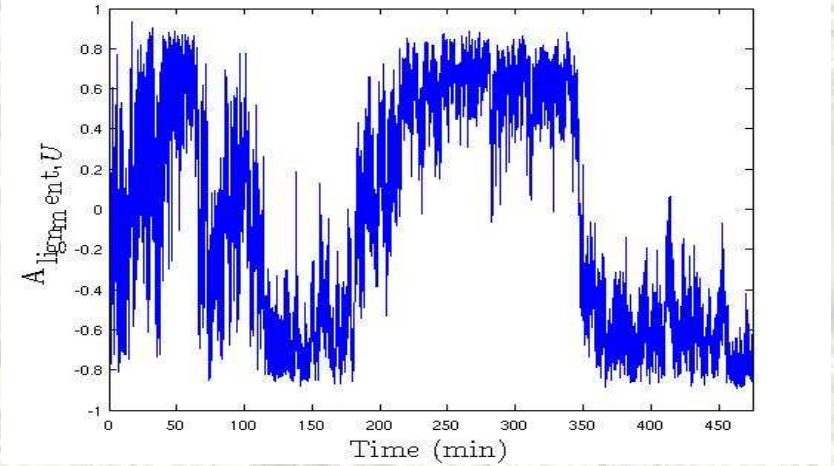


Data Analysis









Model Revision

Recall the velocity update equation,

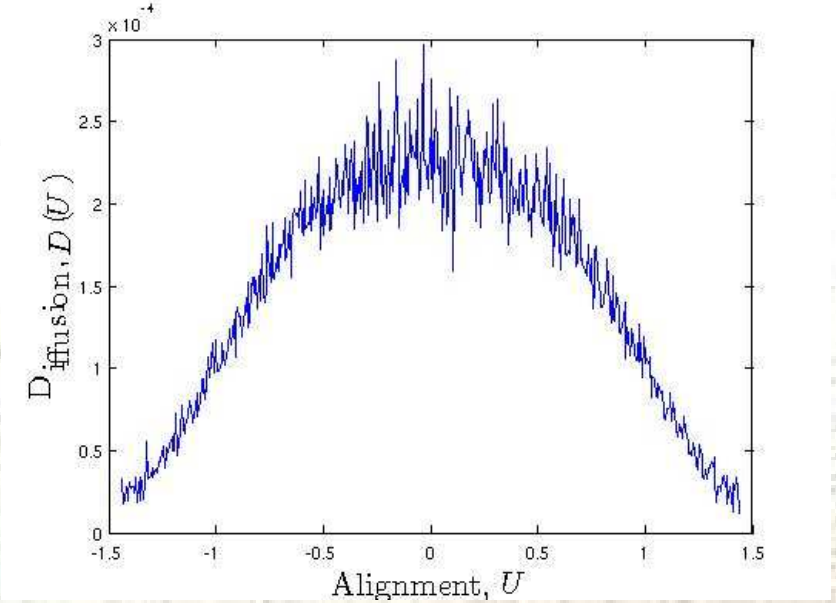
$$\Delta u_i = \left\{ G\left(\bar{u}_i^{loc}\right) - u_i(t) \right\} \Delta t + \Delta Q \eta\left(\bar{u}_i^{loc}\right).$$

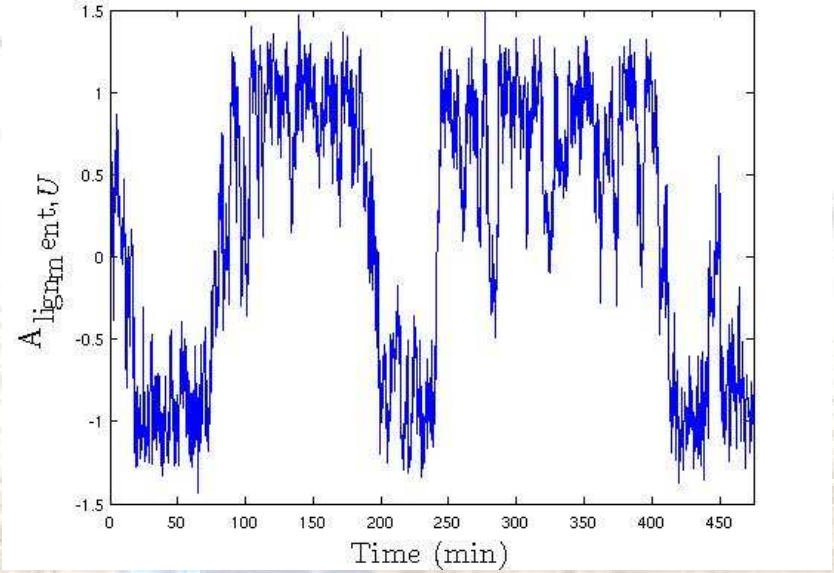
Previously $\eta\left(\bar{u}_i^{loc}\right) \equiv 1$.

We now make $\eta\left(\bar{u}_i^{loc}\right) = \frac{3}{2}\left\{1 - \left(\frac{\bar{u}_i^{loc}}{|\bar{u}_i^{loc}|_{max}}\right)^2\right\}$,

where $|\bar{u}_i^{loc}|_{max}$ is the maximum of the absolute value of the mean local velocity.

Revised Model Results

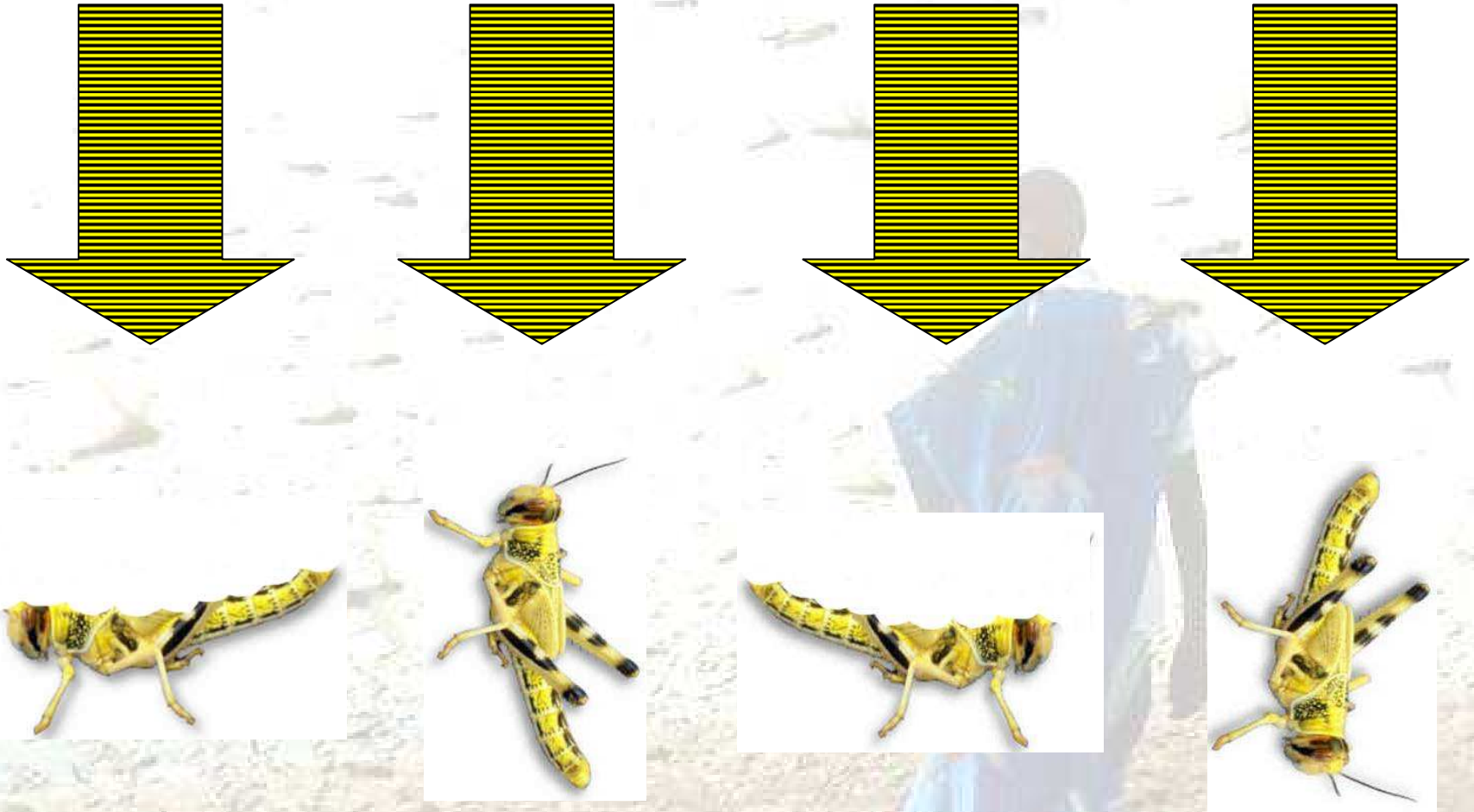




Diffusion, D(U)

Alignment Time Series

- When group becomes unaligned individuals increase the randomness of their motion.



Bazazis et al. (2008) Collective Motion and Cannibalism in Locust Migratory Bands Current Biology 18, 735–739.

Conclusions

Explanations

- Evolution - Alignment increase harvesting efficiency and reduce predation
- Cannibalism – Dangerous to fall out of line as sides are more vulnerable

Increased individual randomness when unaligned help the swarm stay together.

For more details see: Yates et al. (2009) Inherent noise facilitates cohesive behaviour in swarms. Under Review, PNAS.

Acknowledgement

- Supervisors: Radek Erban, David Sumpter and Carlos Escudero.
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