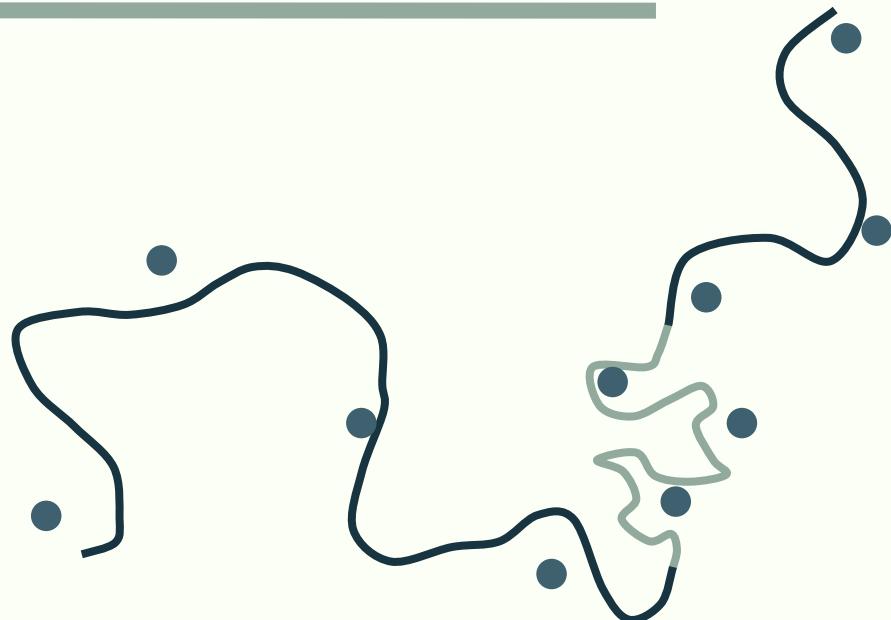


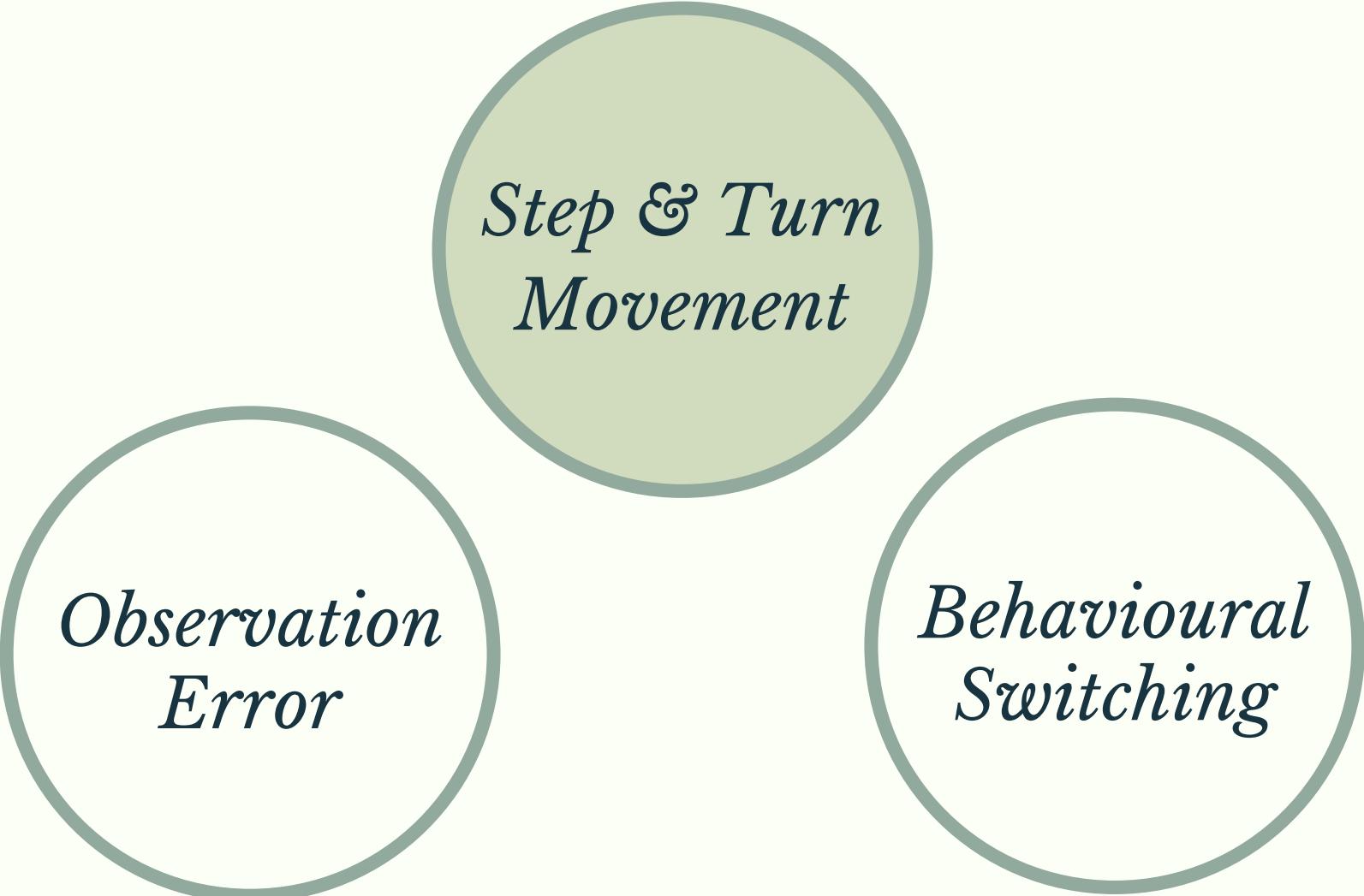
Inferring Animal Movement & Behaviour in Continuous Time from Irregular & Noisy GPS Observations

Alison Parton & Paul G. Blackwell

The University of Sheffield

EURING, Barcelona, July 2017



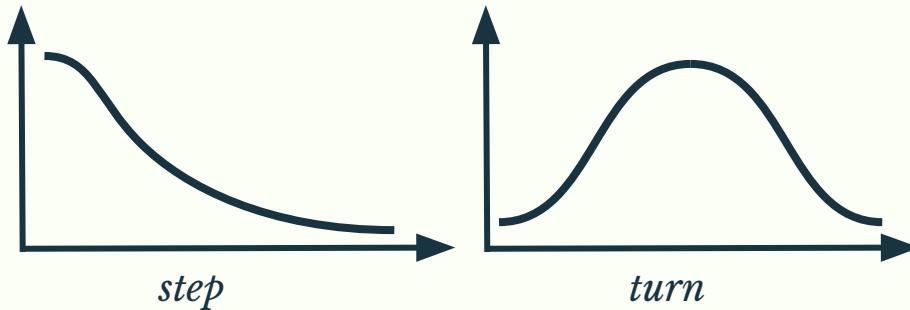


*Step & Turn
Movement*

*Observation
Error*

*Behavioural
Switching*

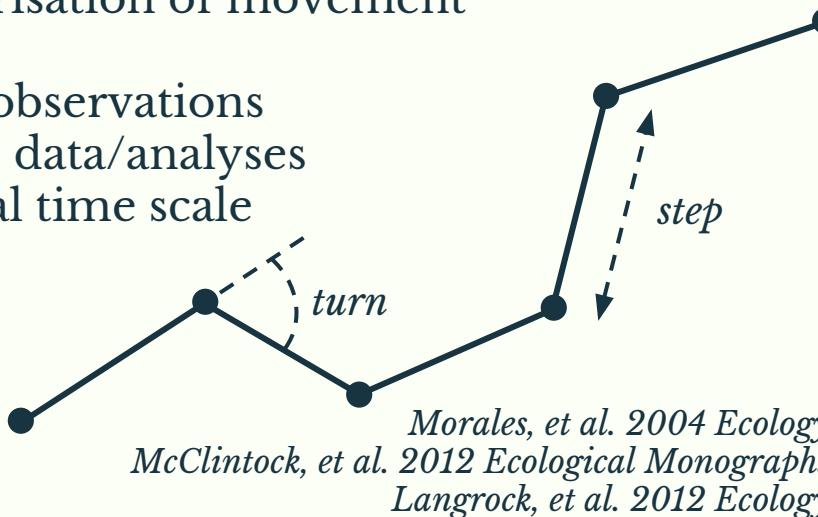
Discrete Time



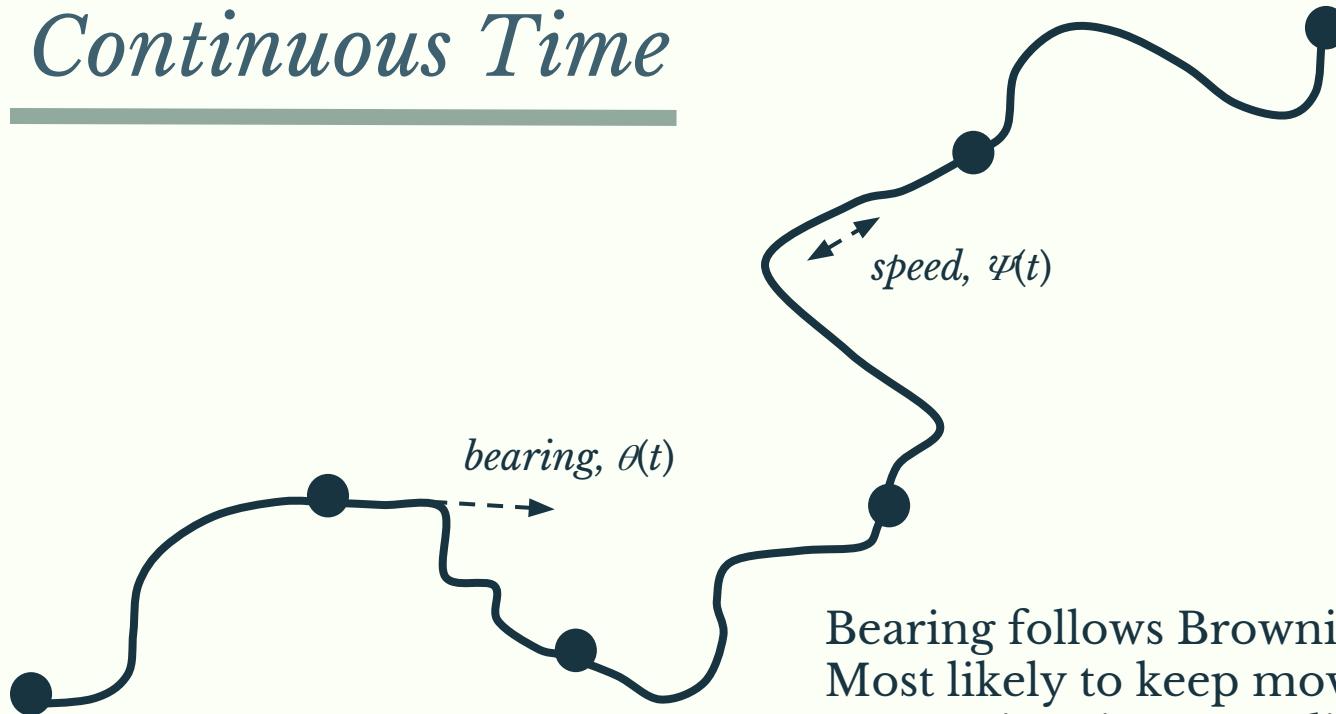
Intuitive parameterisation of movement

Issues:

- irregular/missing observations
- combine/compare data/analyses
- observation/animal time scale



Continuous Time



Bearing follows Brownian motion
Most likely to keep moving in same direction
Uncertainty increases linearly with time

Speed follows Ornstein Uhlenbeck process
Long term mean speed and variance
Attracted to mean, but correlated in time

Continuous Time

Simulate at some arbitrarily fine time scale

$$\theta(t + \delta t) | \theta(t) \sim N \{ \theta(t), \sigma_\theta^2 \}$$

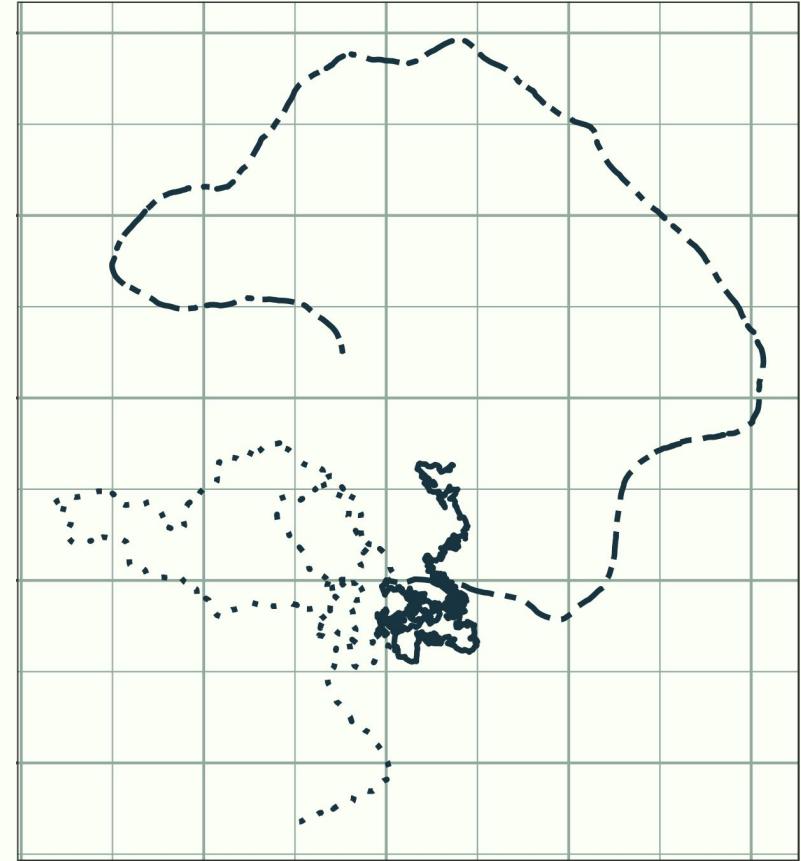
turn volatility

$$\Psi(t + \delta t) | \Psi(t) \sim N \{ \mu + e^{-\beta \delta t} (\Psi(t) - \mu), \sigma_\Psi^2 (1 - e^{-\beta \delta t}) \}$$

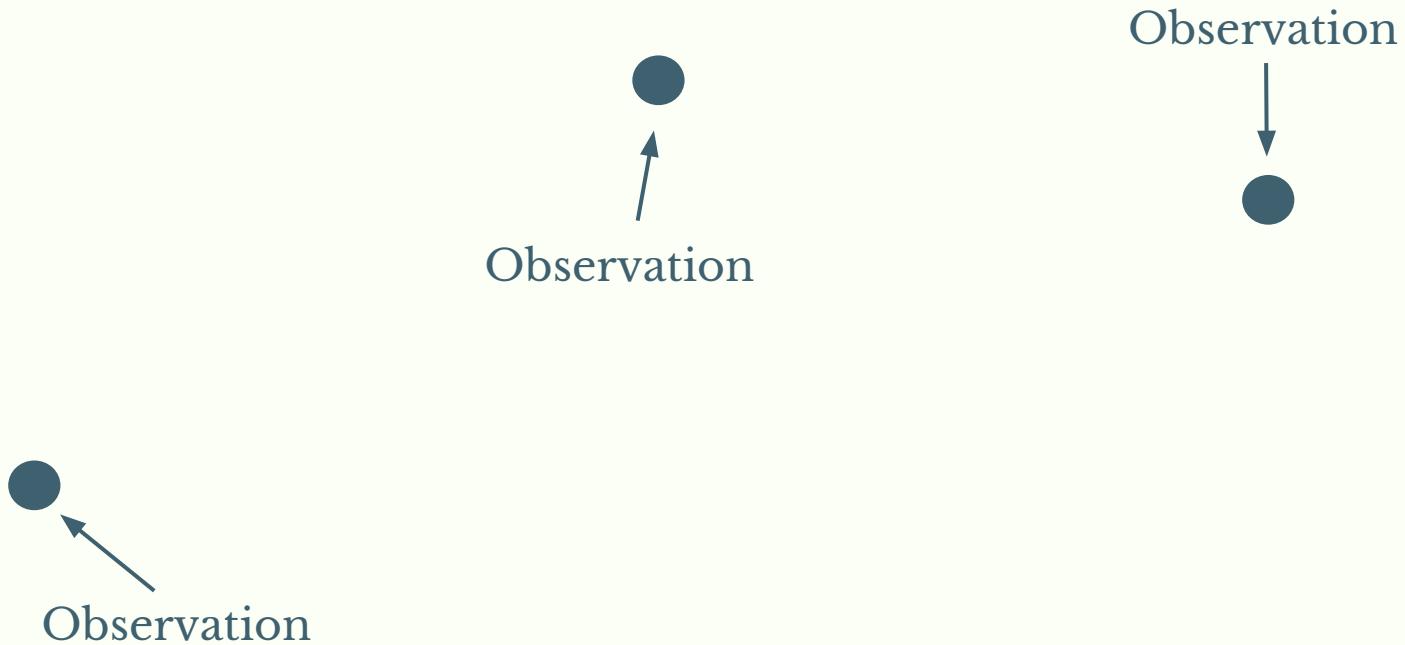
speed mean *speed correlation* *speed volatility*

Recover the notion of ‘steps’ from the speed at this approximation

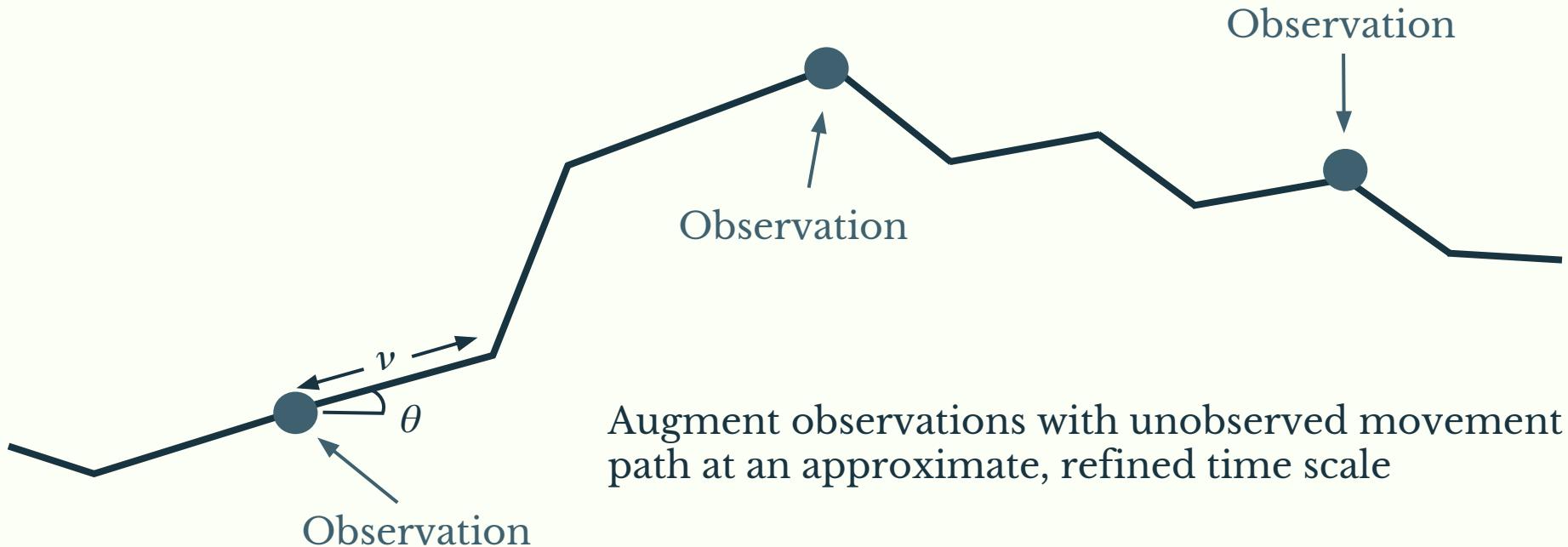
$$v(t) = \Psi(t) \delta t$$



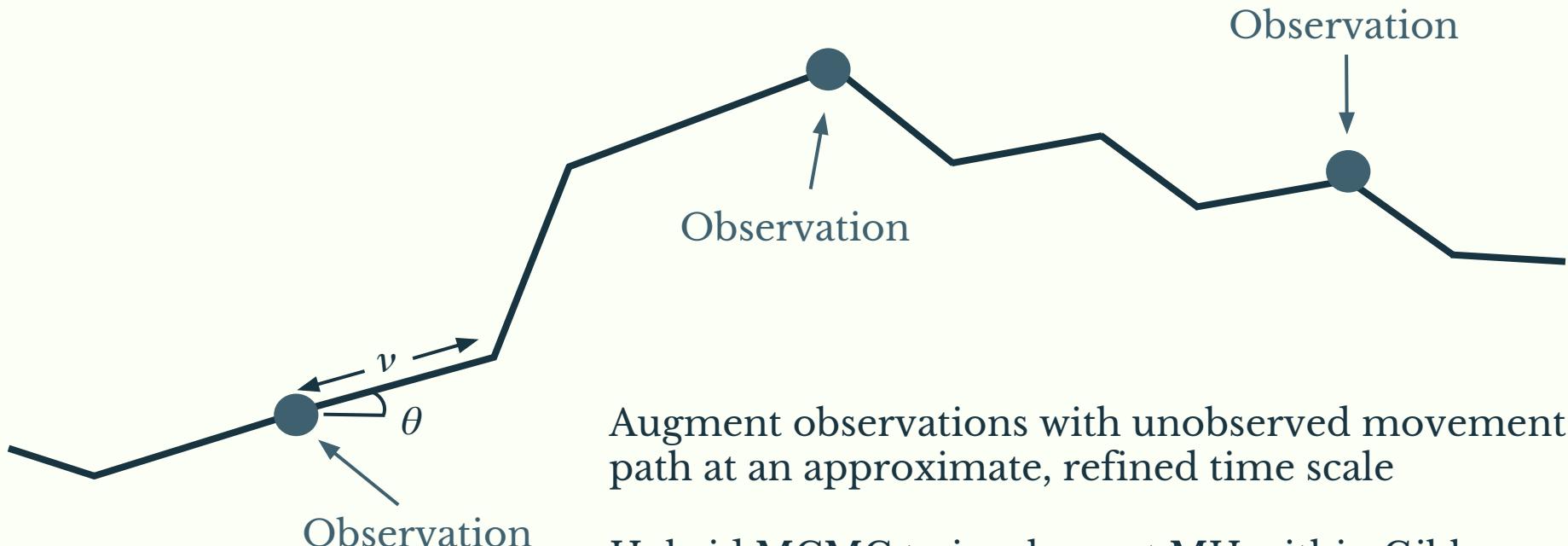
Bayesian Inference by Augmentation



Bayesian Inference by Augmentation



Bayesian Inference by Augmentation



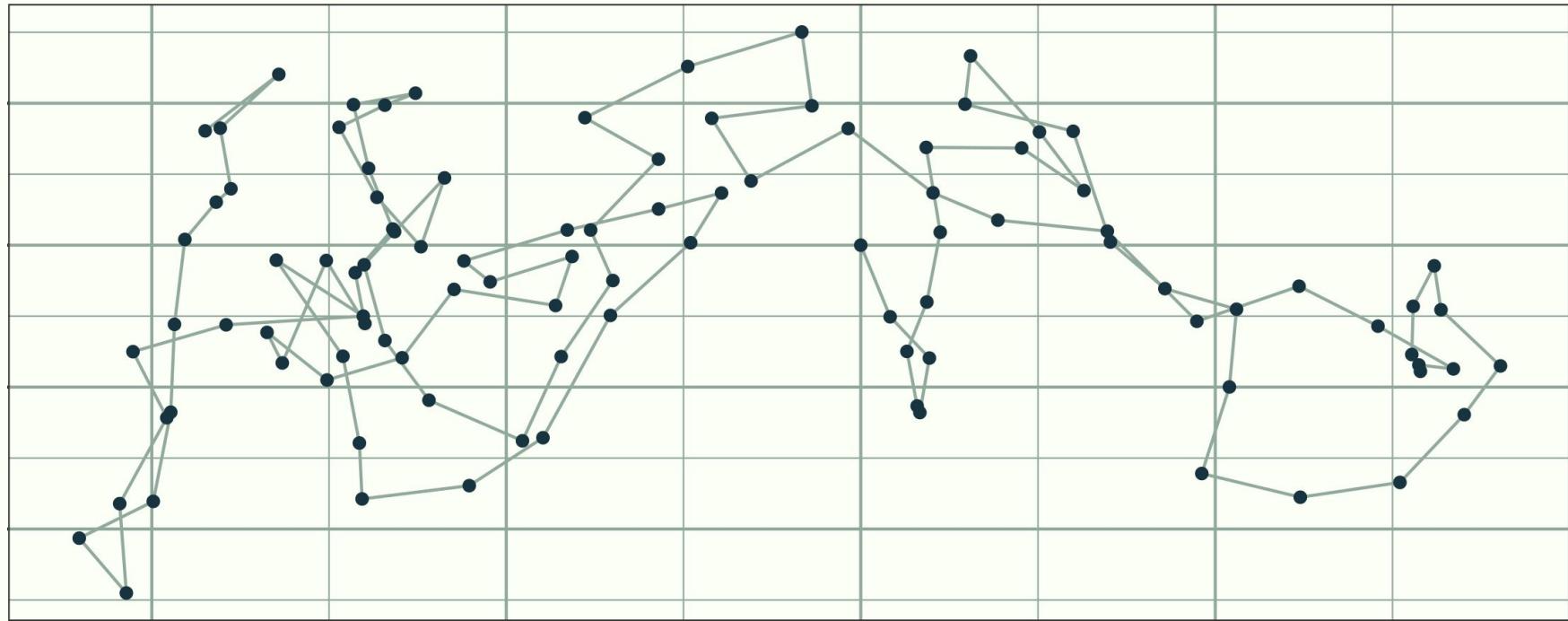
Augment observations with unobserved movement path at an approximate, refined time scale

Hybrid MCMC to implement MH within Gibbs
Alternately sample:

Parameters

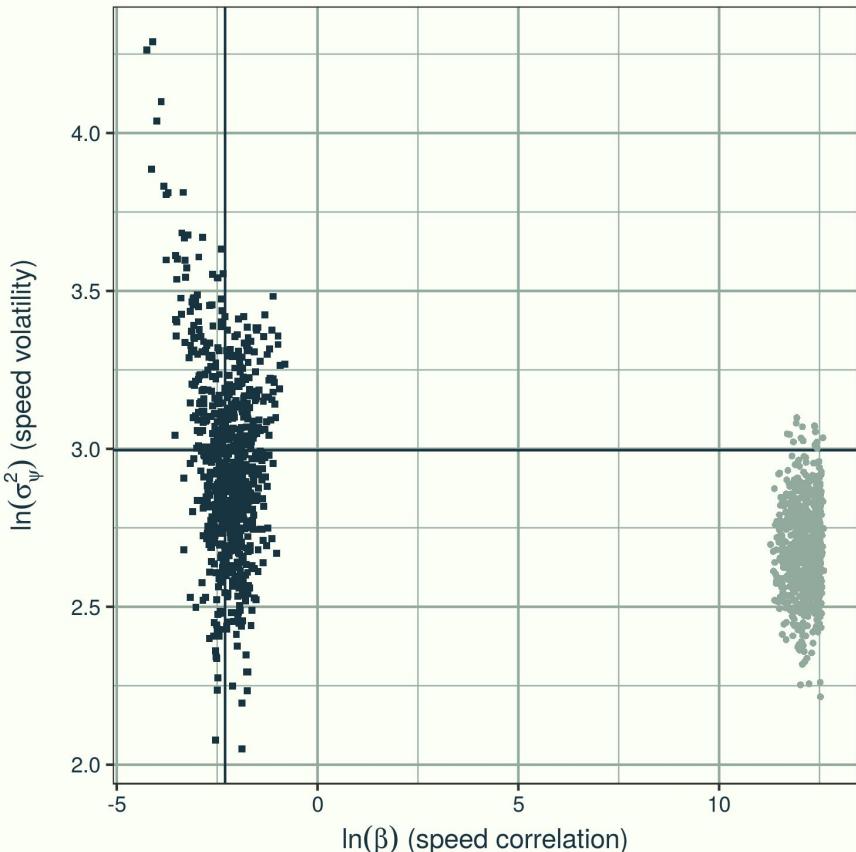
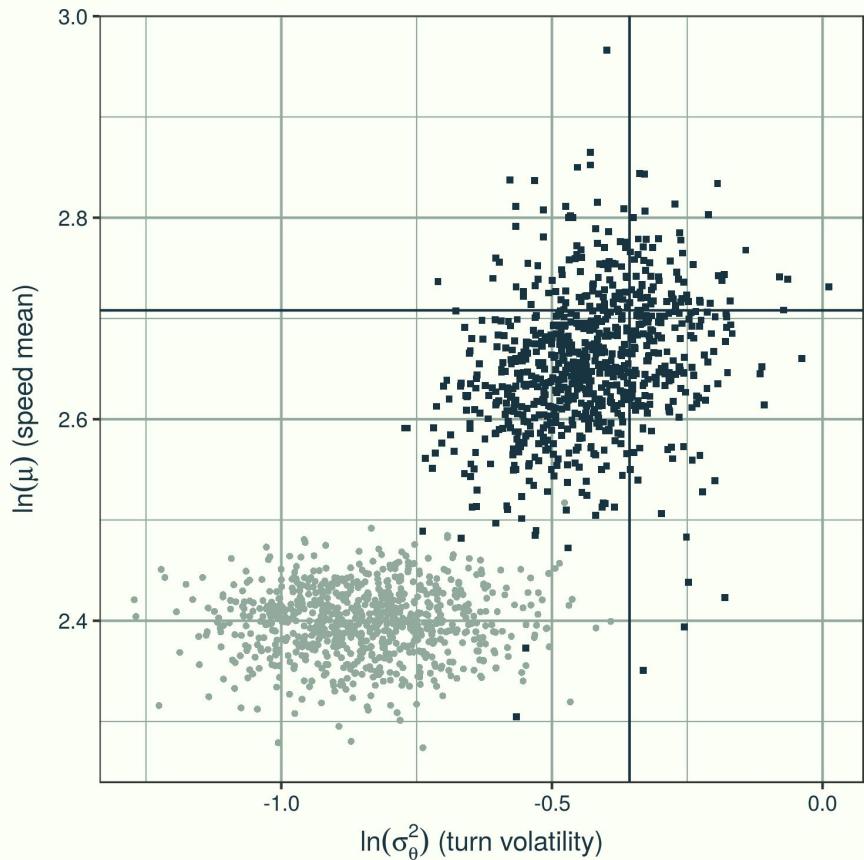
Unobserved refined path (bearings, speeds)

Simulated Example: Observations



Parameter Estimation

— True ● Discrete time ■ Continuous time

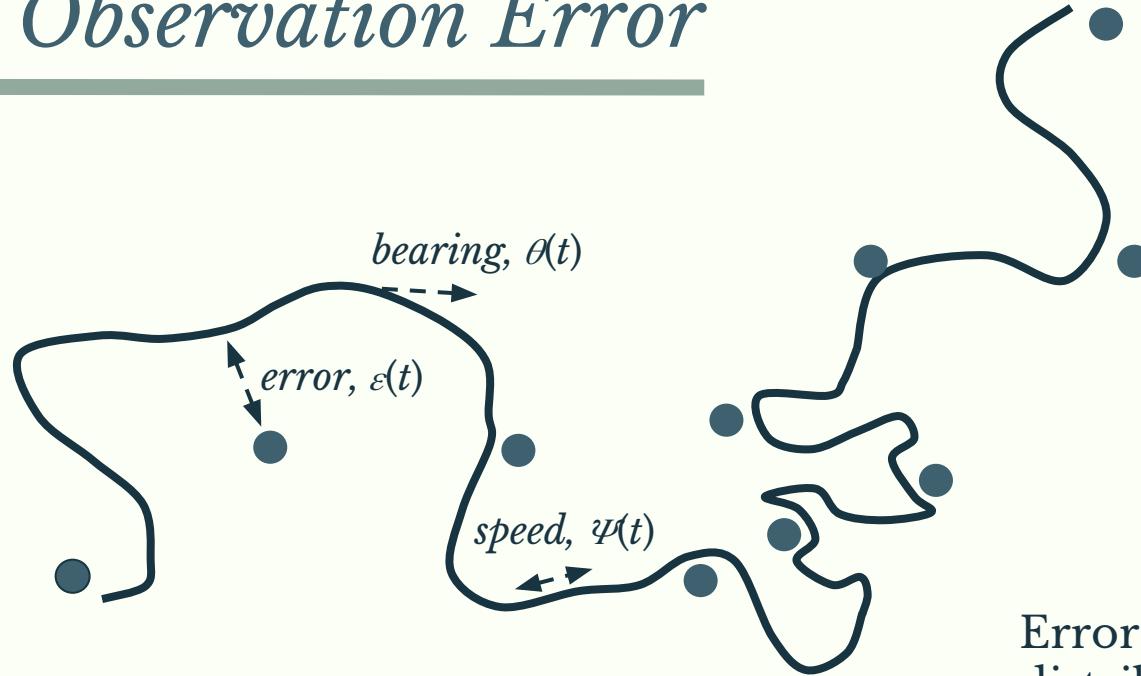


*Step & Turn
Movement*

*Observation
Error*

*Behavioural
Switching*

Observation Error

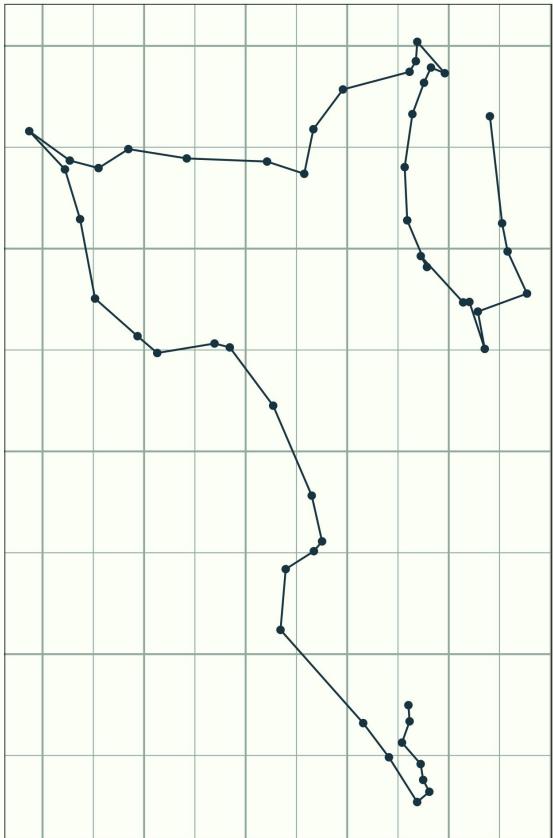


Error independent and identically distributed in space and time

$$\varepsilon(t) \sim N \{ 0, \sigma_\varepsilon^2 \}$$

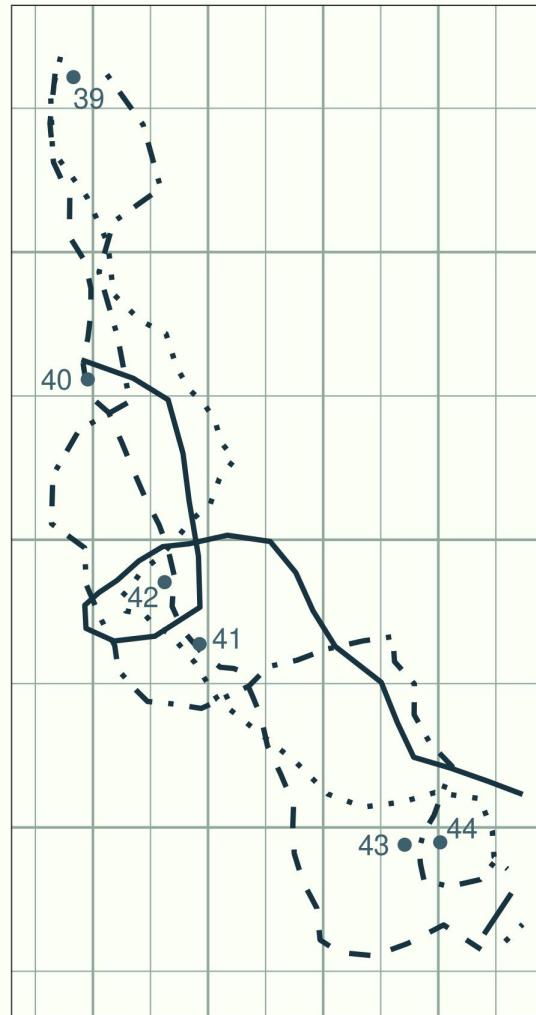
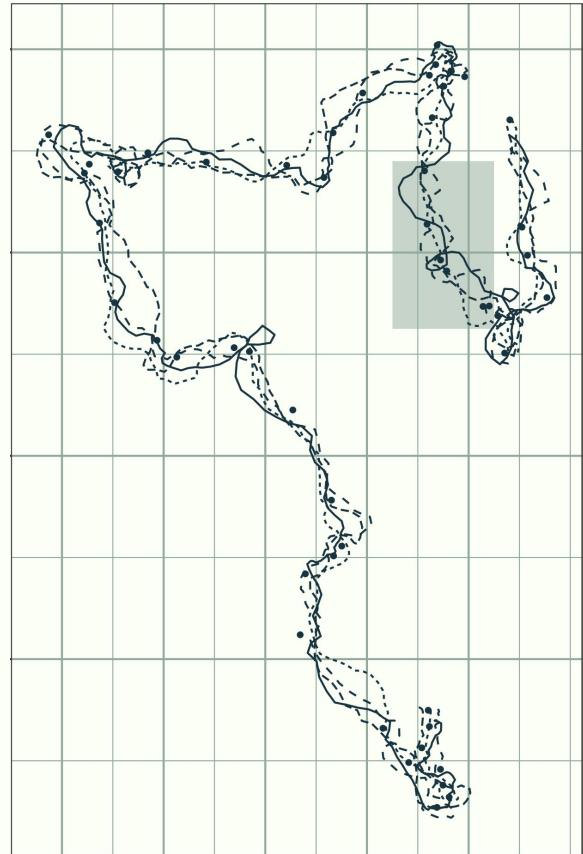
error volatility

Noisy Reindeer Data

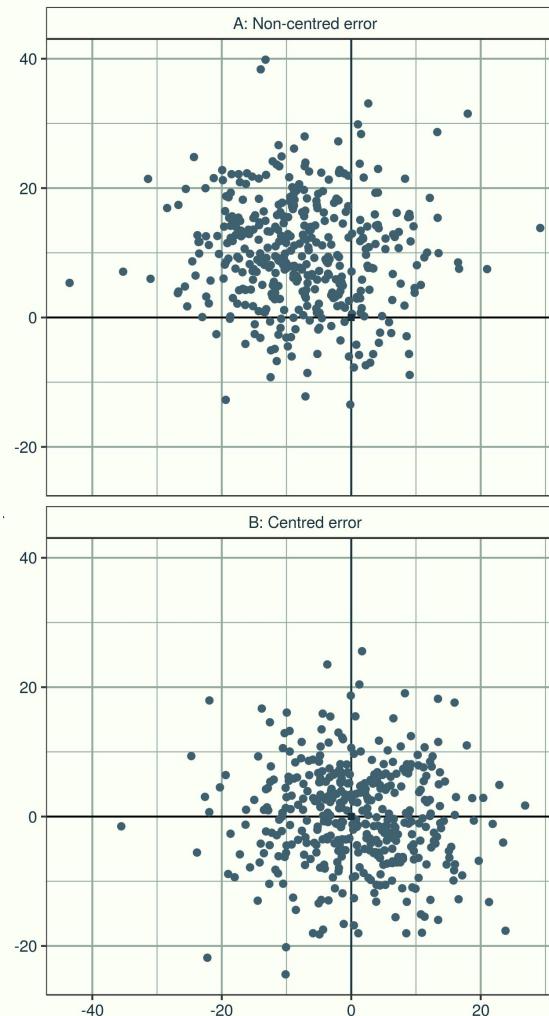
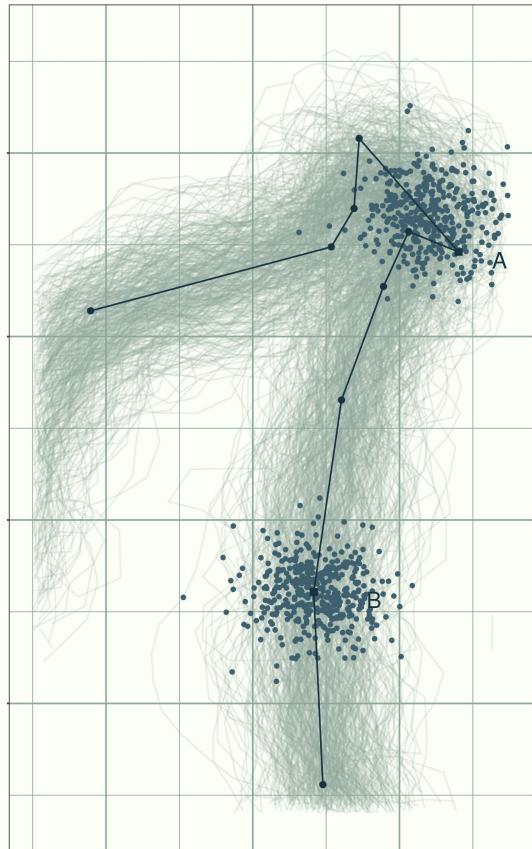


*Data and image courtesy of Anna Skarin,
Swedish University of Agricultural Sciences*

Smoothing π Turns



True location estimation

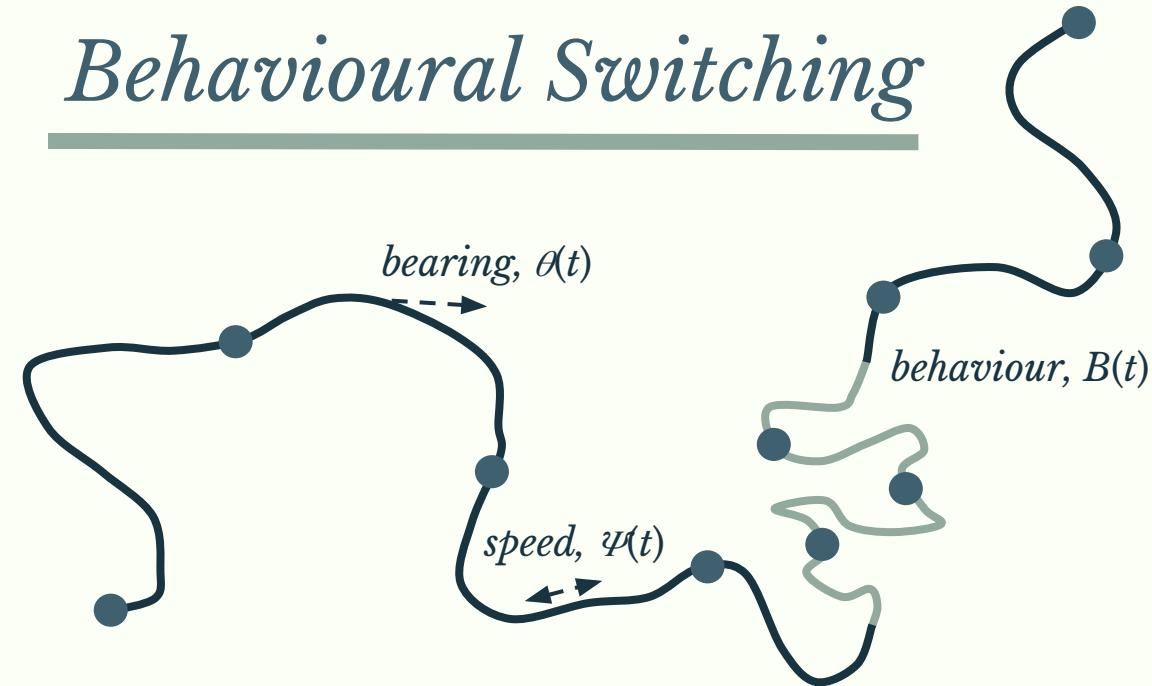


*Step & Turn
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Switching*

Behavioural Switching

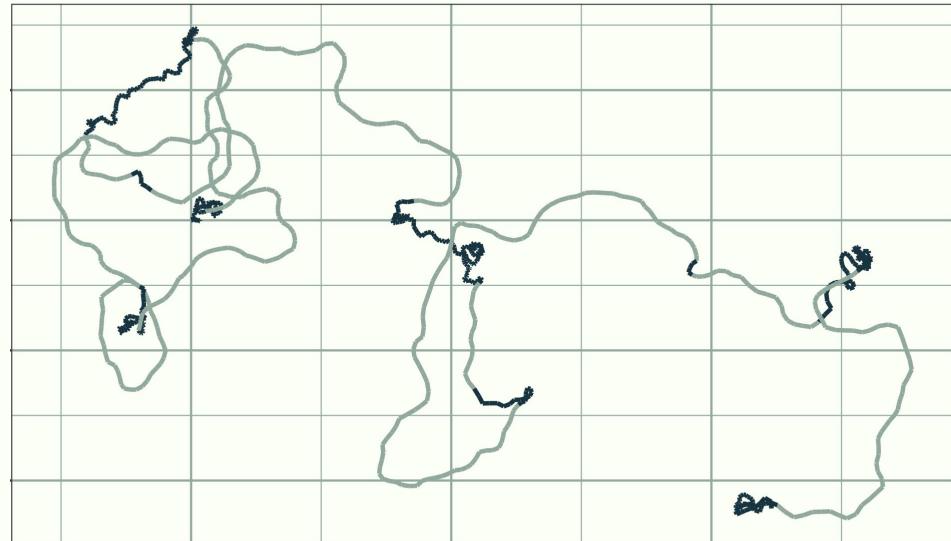
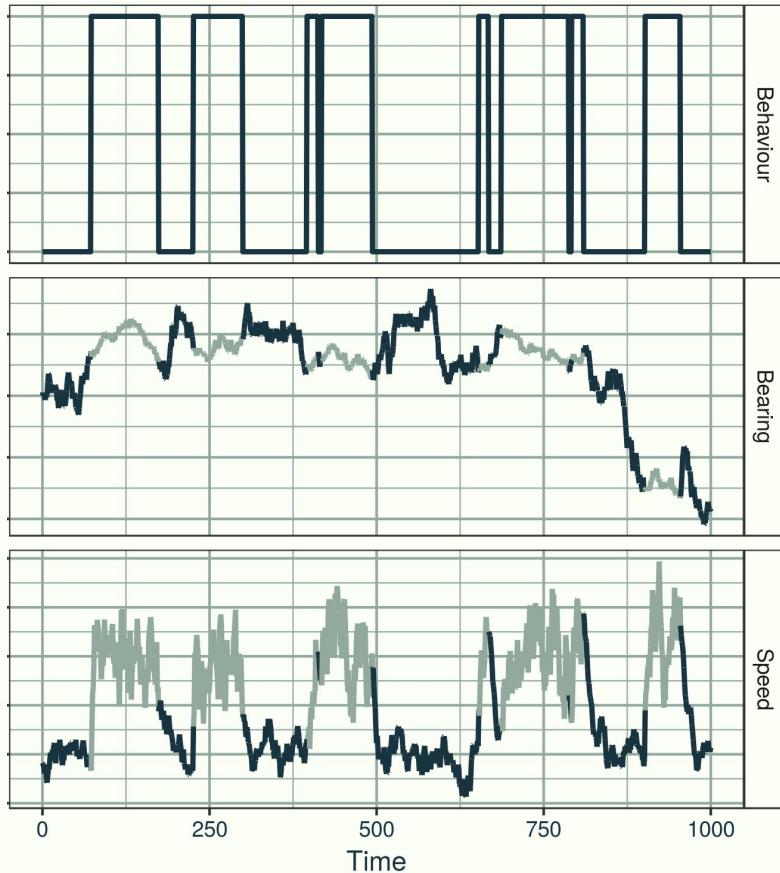


Behaviour follows continuous time Markov chain
Finite (known) number of states
Switching rates λ and probabilities q
Set of movement parameters for each state

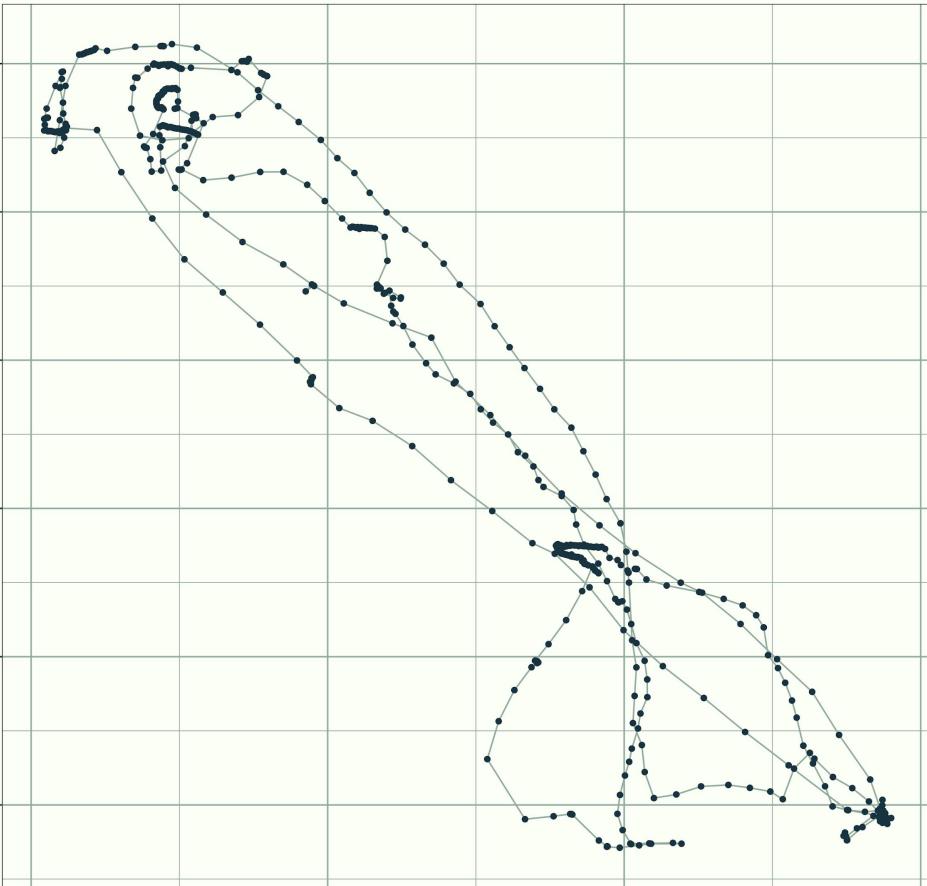
Blackwell, et al. 2015 Methods in Ecology and Evolution



Multistate Simulation Example



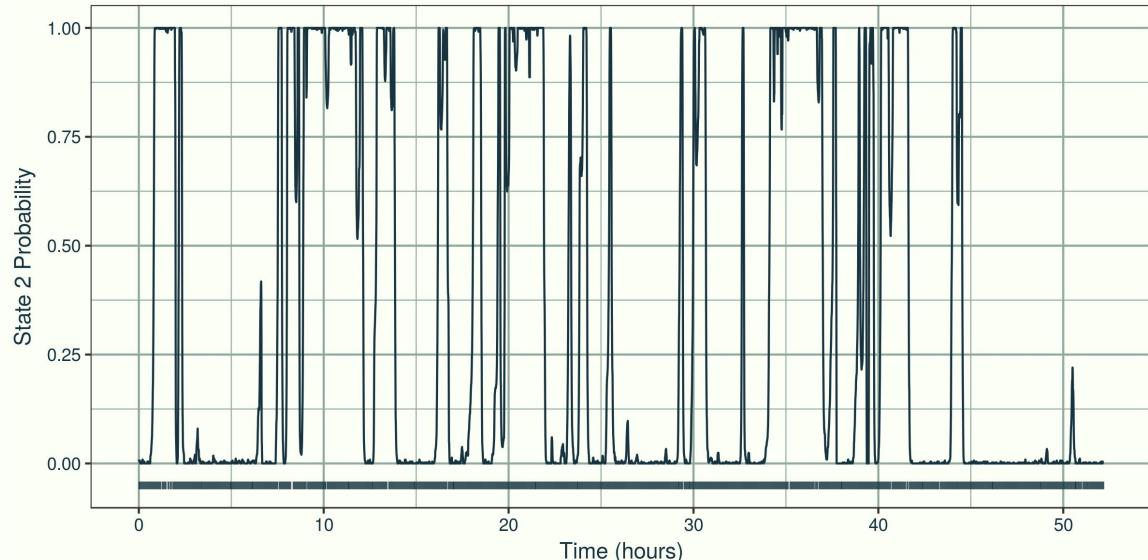
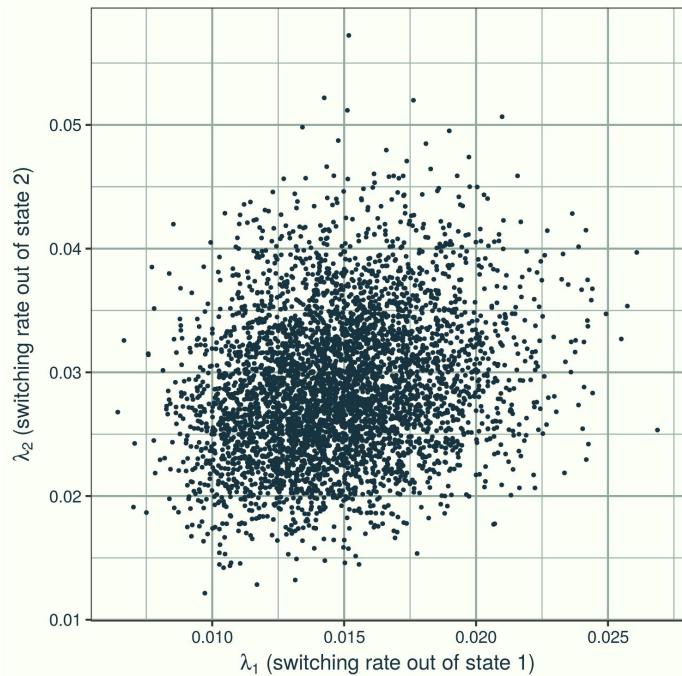
Two State Gull Data



Lesser black-backed gull

3-5 min sampling frequency
1000 observations
>2 days

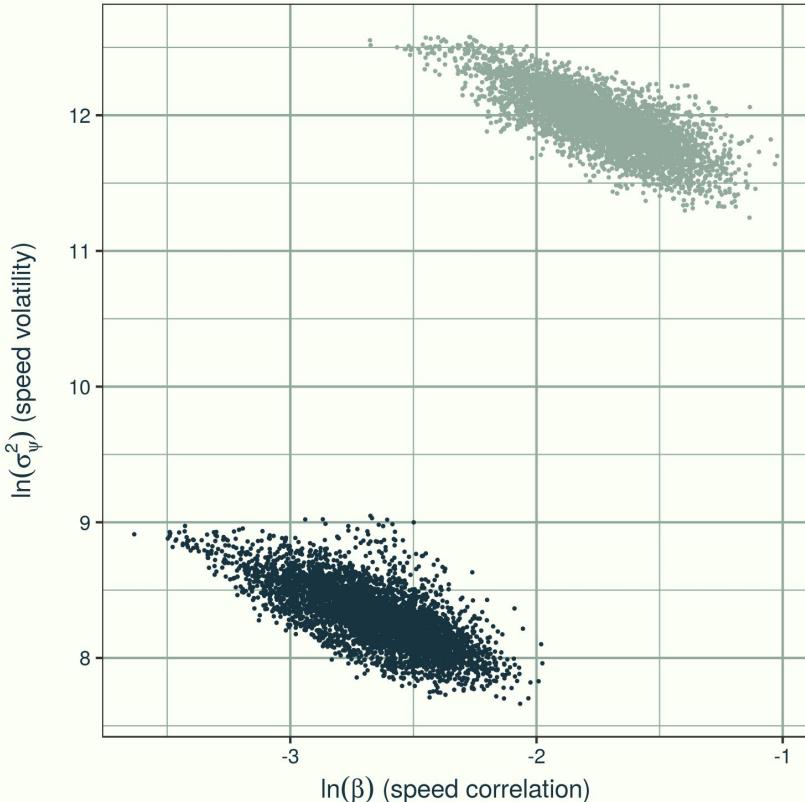
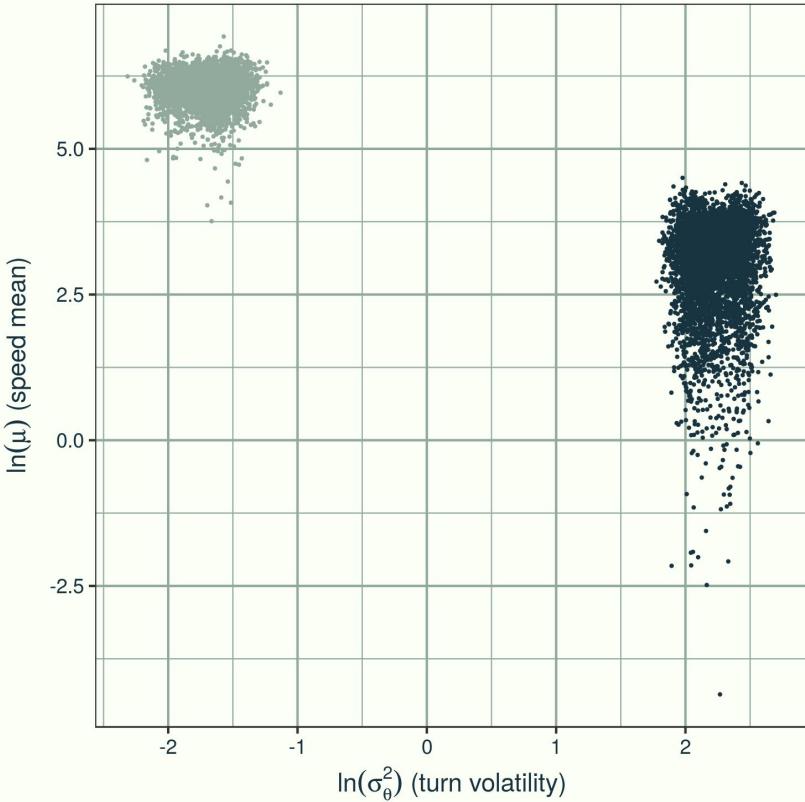
Estimated Behavioural Process



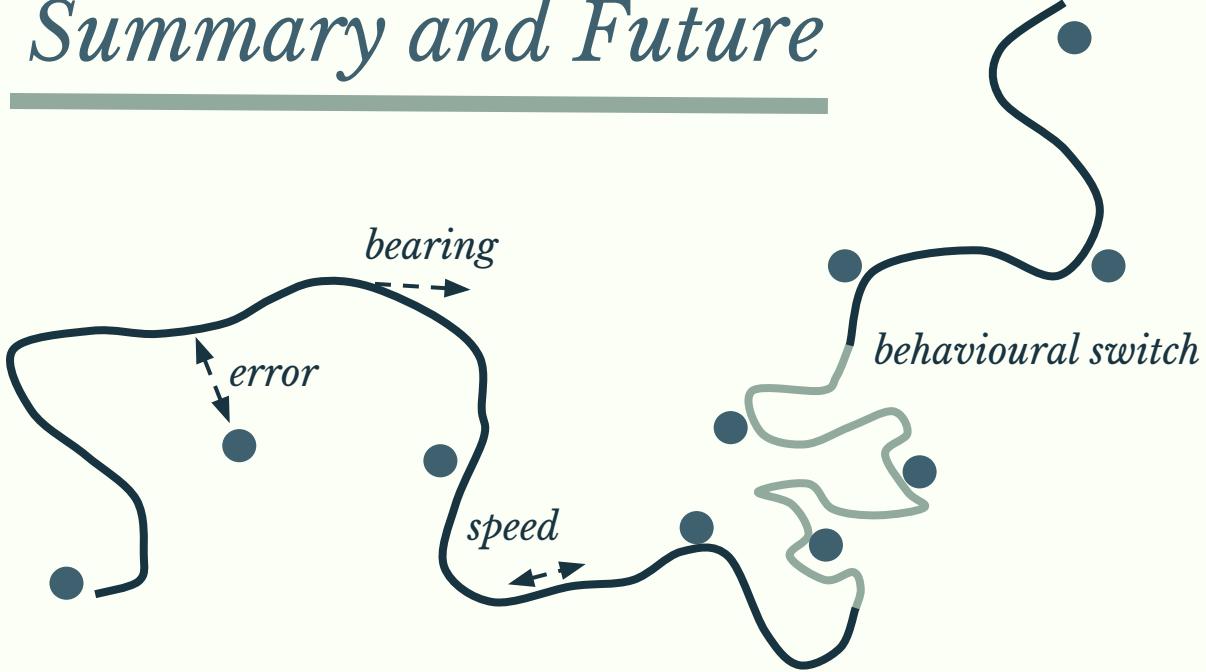
*State 1 (slower and correlated, tortuous)
State 2 (faster and volatile, persistent)*

Parameter Estimation

- State 1 (slower and correlated, tortuous)
- State 2 (faster and volatile, persistent)



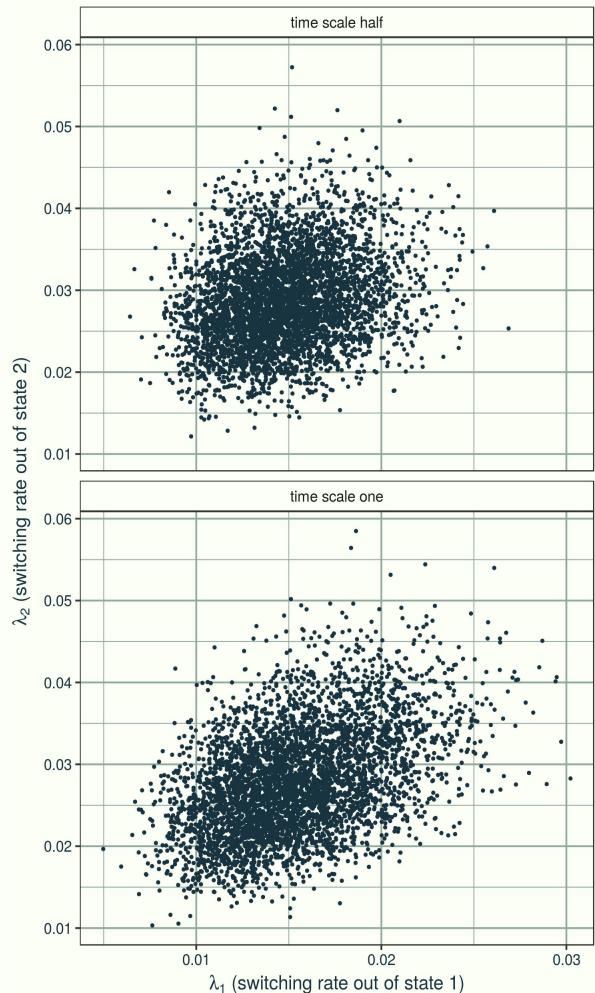
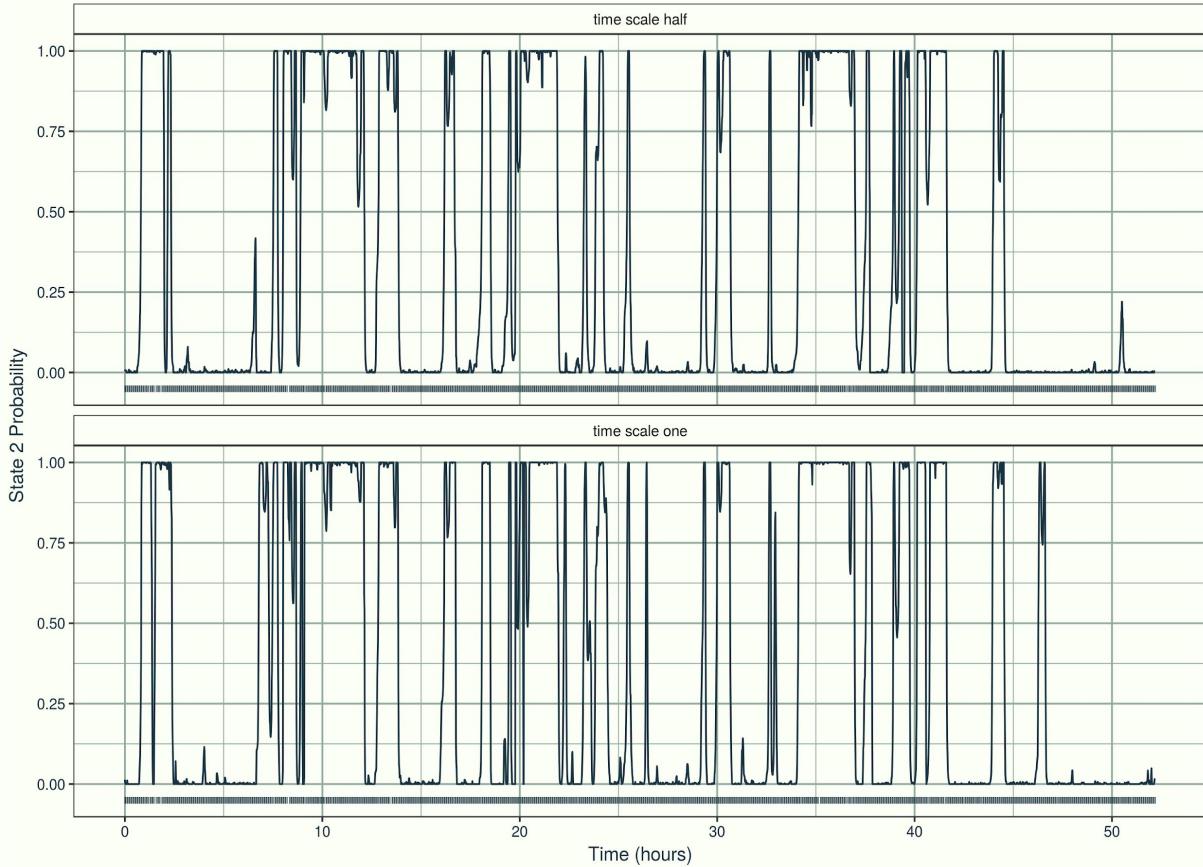
Summary and Future



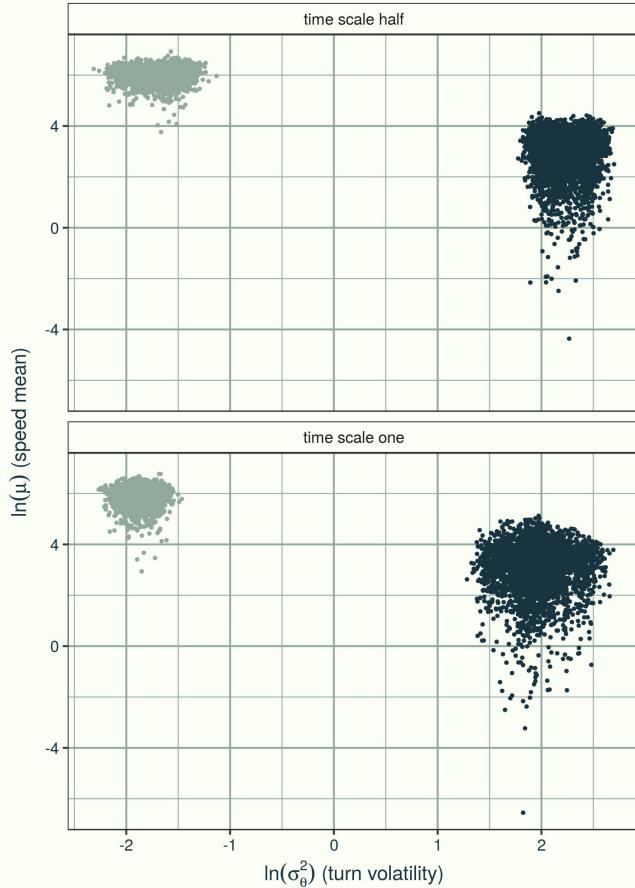
Extensions:

- directed/attracted movement
- correlated observation error
- environmental dependence
- speeding up inference - filtering methods

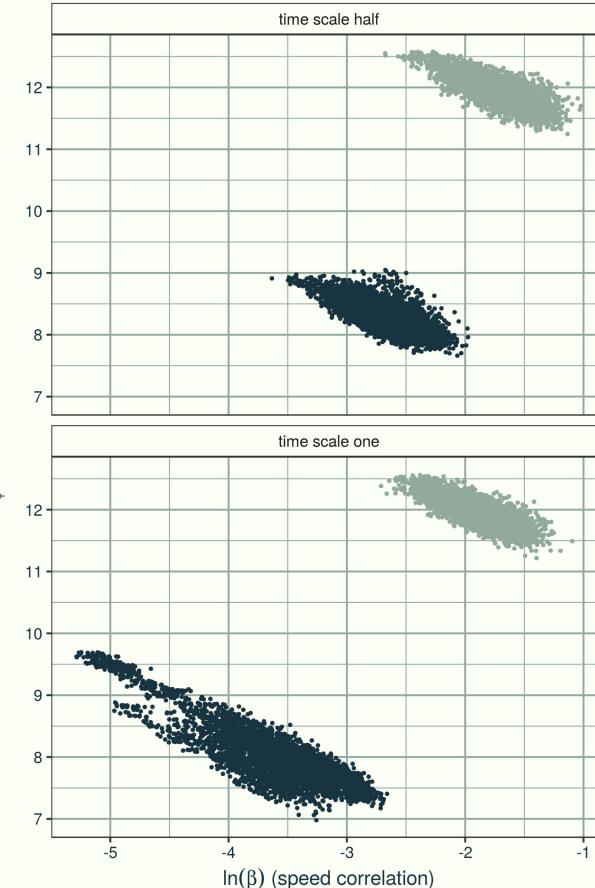
Estimated Behavioural Process



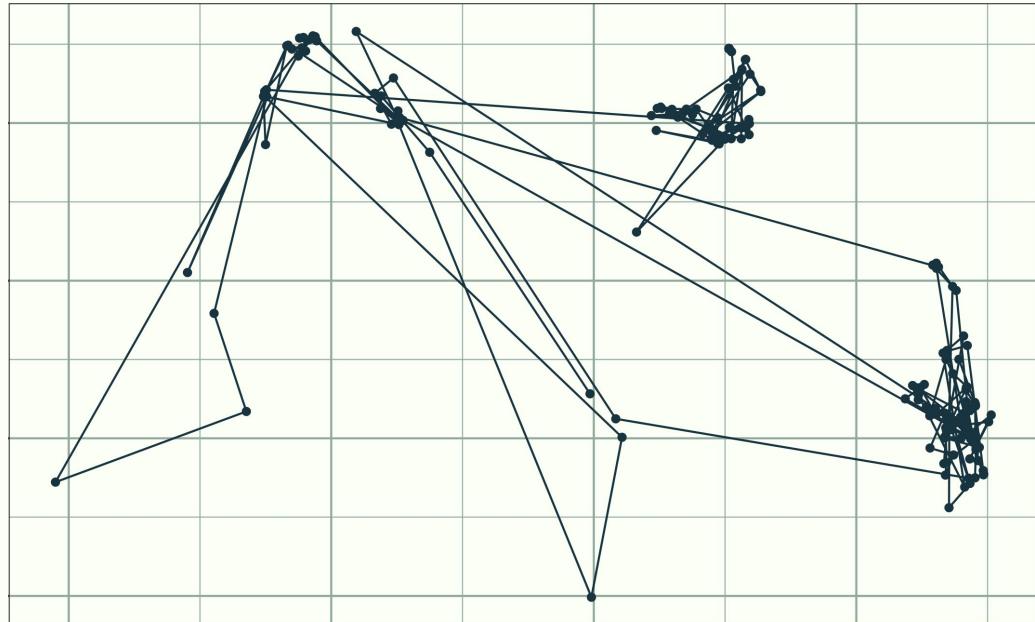
Parameter Estimation



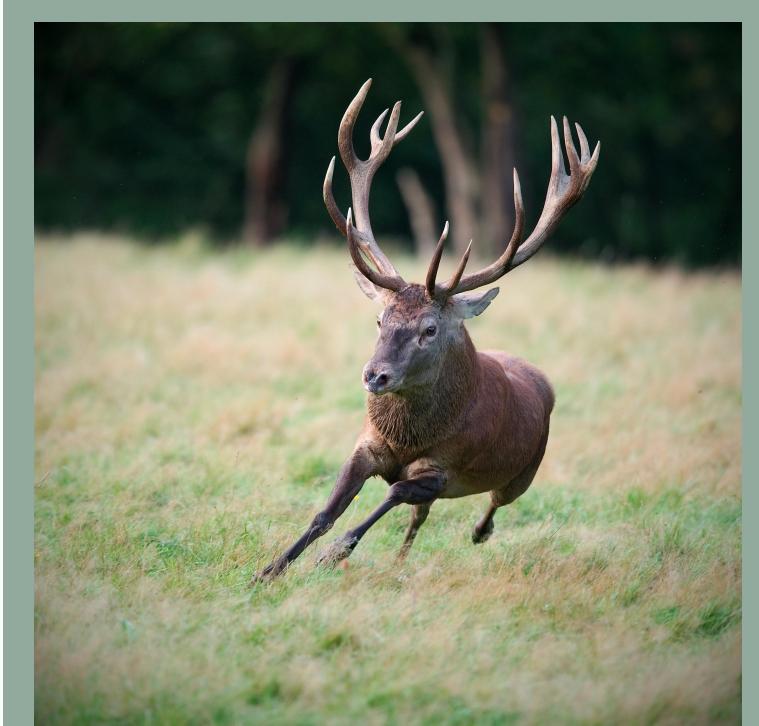
- State 1 (slower and correlated, tortuous)
- State 2 (faster and volatile, persistent)



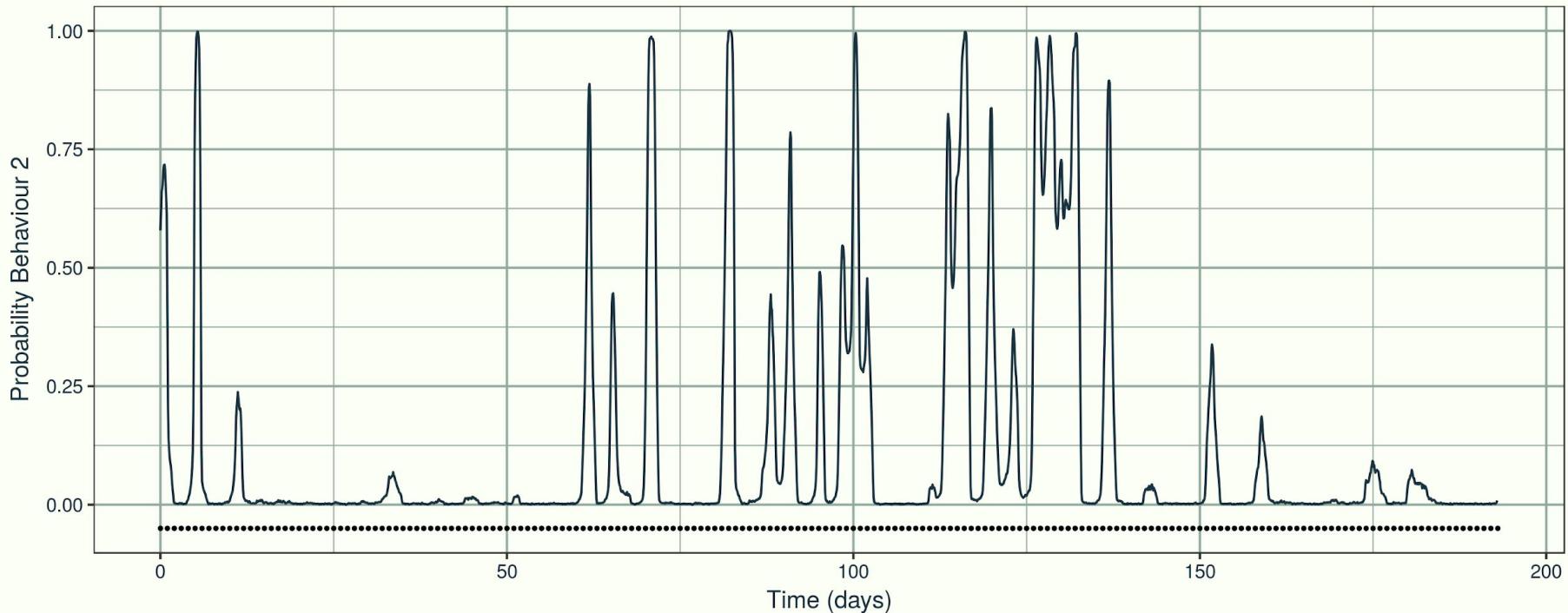
Two State Elk Data



Data from Morales, et al. 2004 Ecology



Estimated Behavioural Process



Parameter Estimation

■ State 1 (slow, tortuous) ● State 2 (fast, persistent)

