Inferring animal movement & behaviour in continuous time from irregular & noisy GPS observations

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Animal movement modelling special edition
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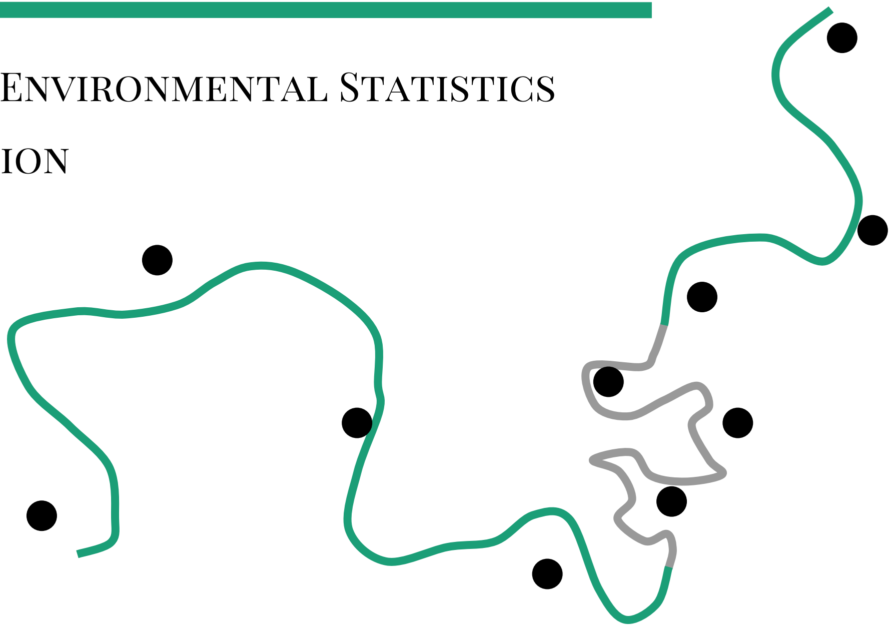

Alison Parton & Paul G. Blackwell
The University of Sheffield
Glasgow, December 2017

Movement model

Inference

Simulation examples

Two-state elk movement

Noisy reindeer observations

Discrete Time

Morales, et al. 2004 Ecology
McClintock, et al. 2012 Ecol. Monogr.
Langrock, et al. 2012 Ecology

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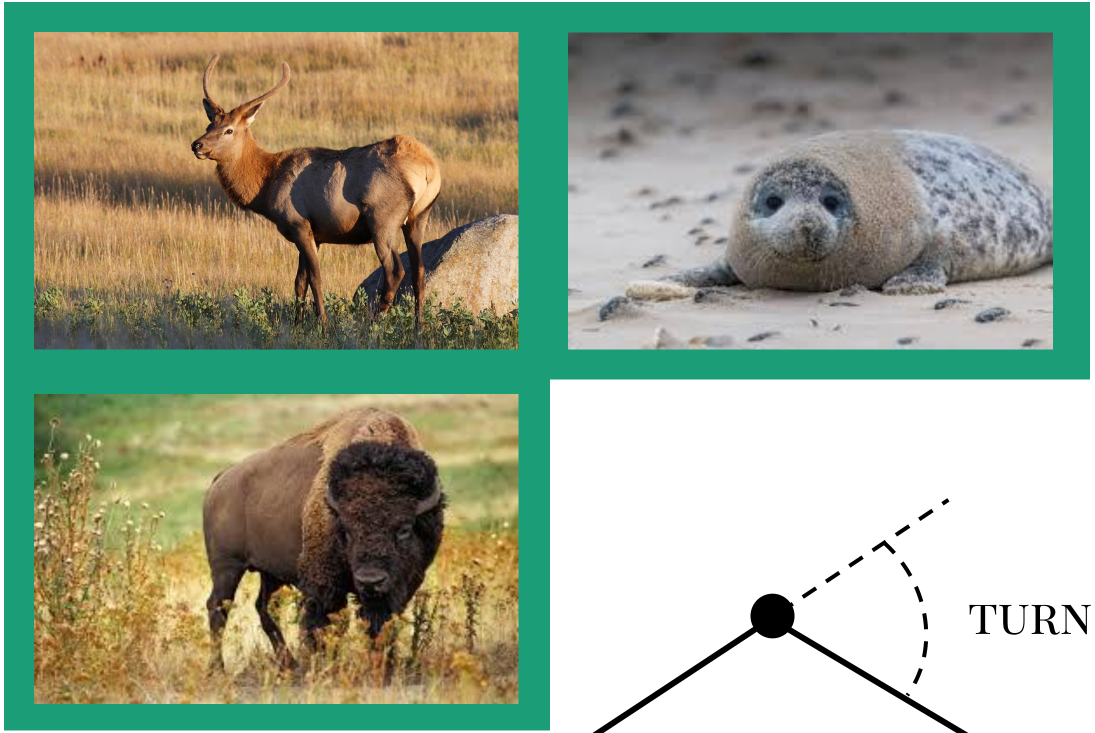

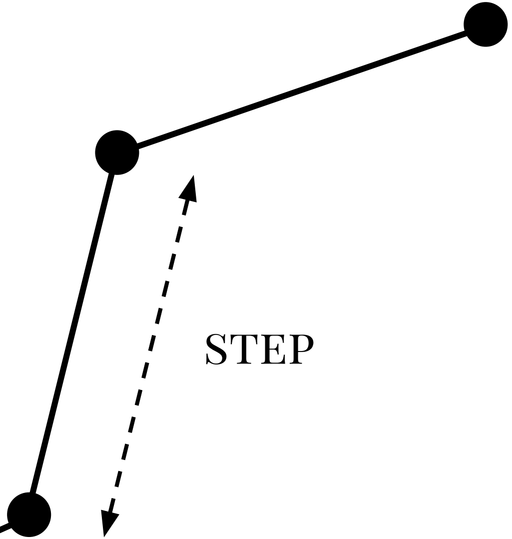

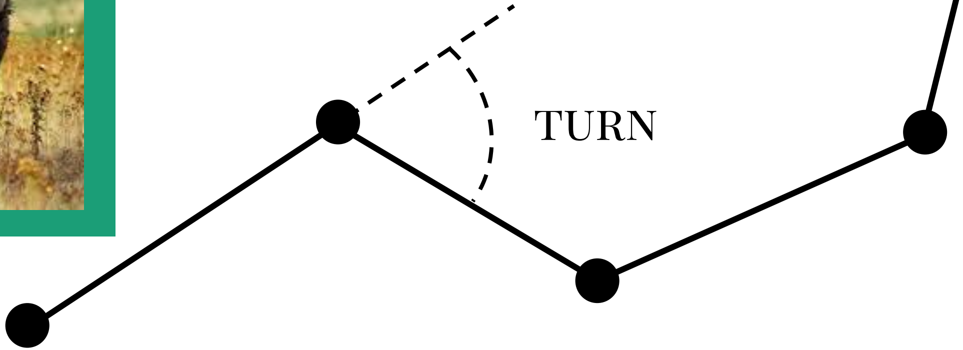

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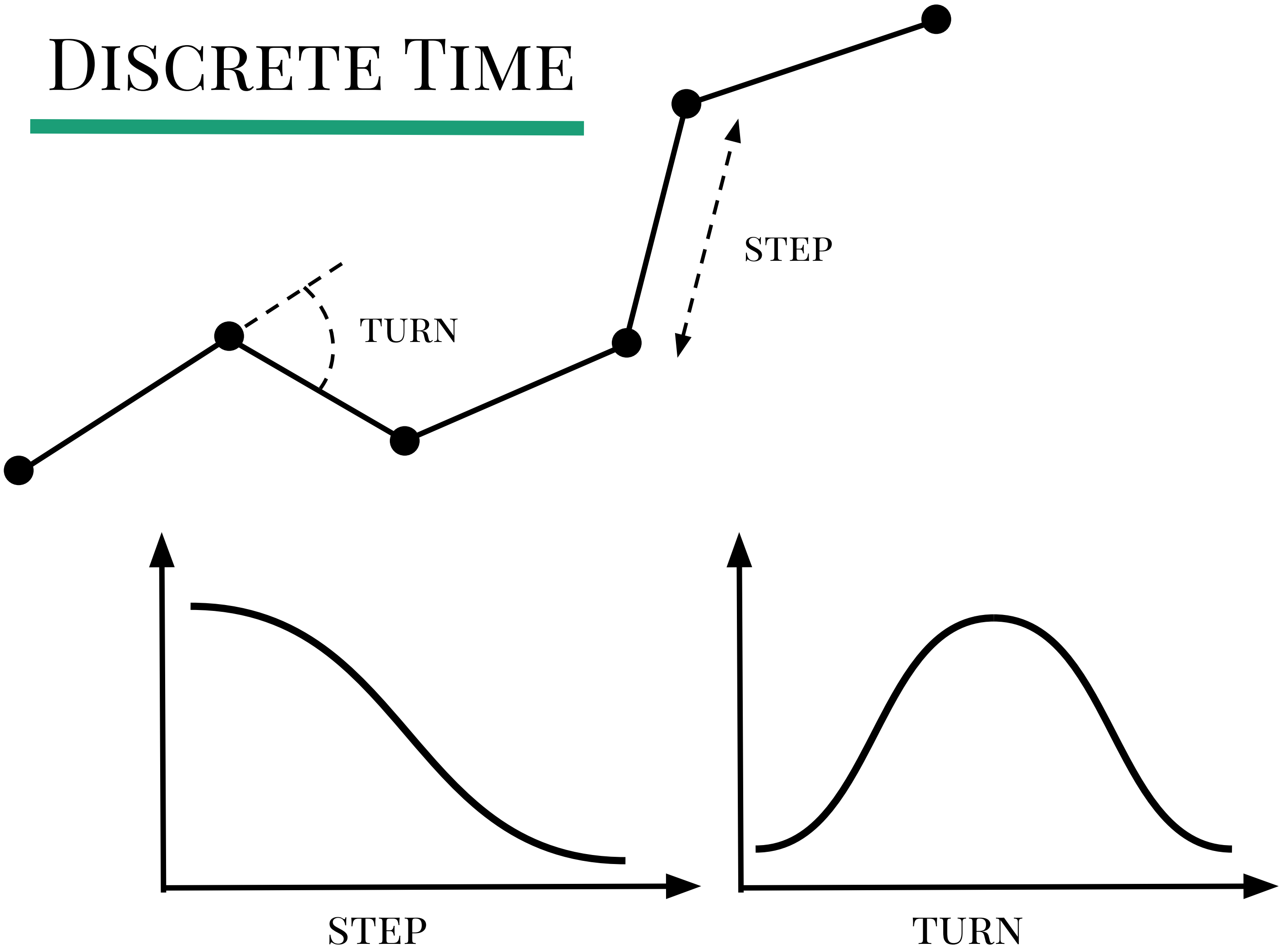

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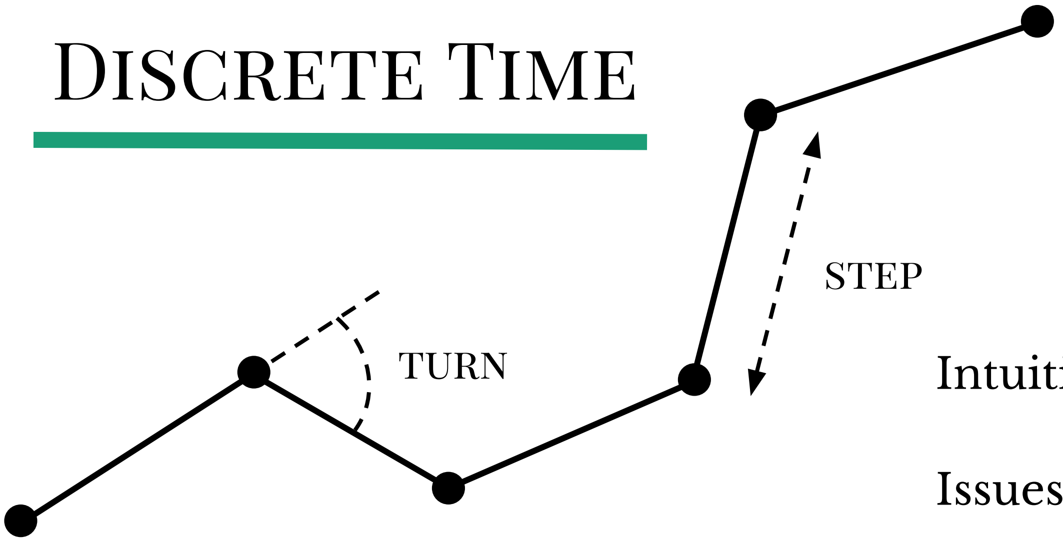
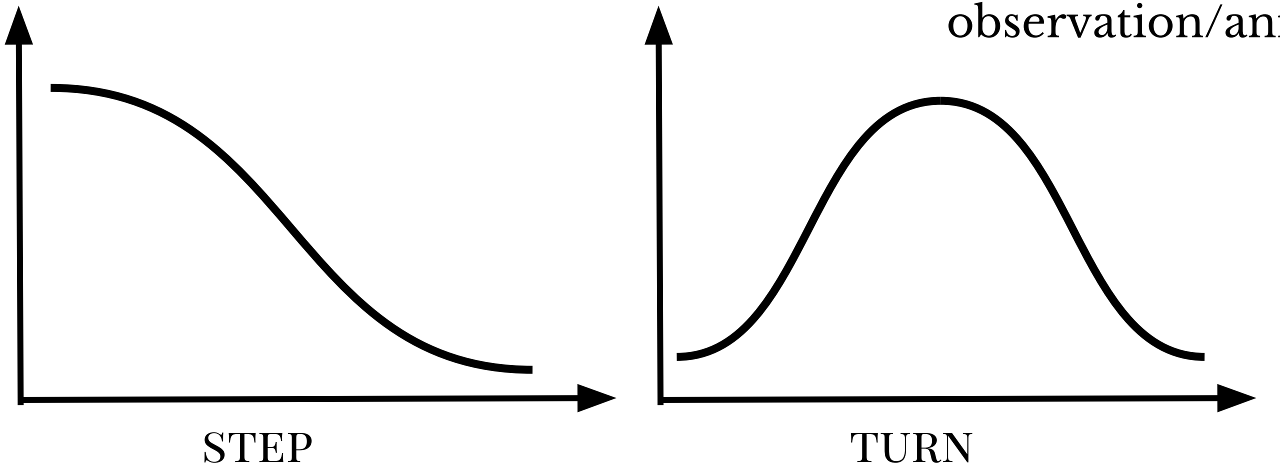
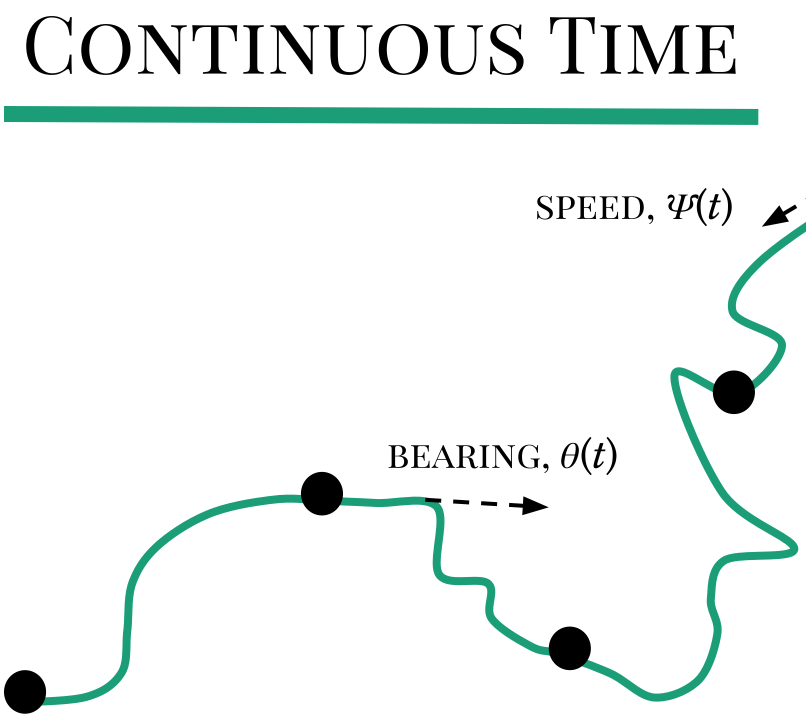


Intuitive parameterisation of movement.

Issues: irregular/missing observations,
combine/compare data/analyses,
observation/animal time scale.



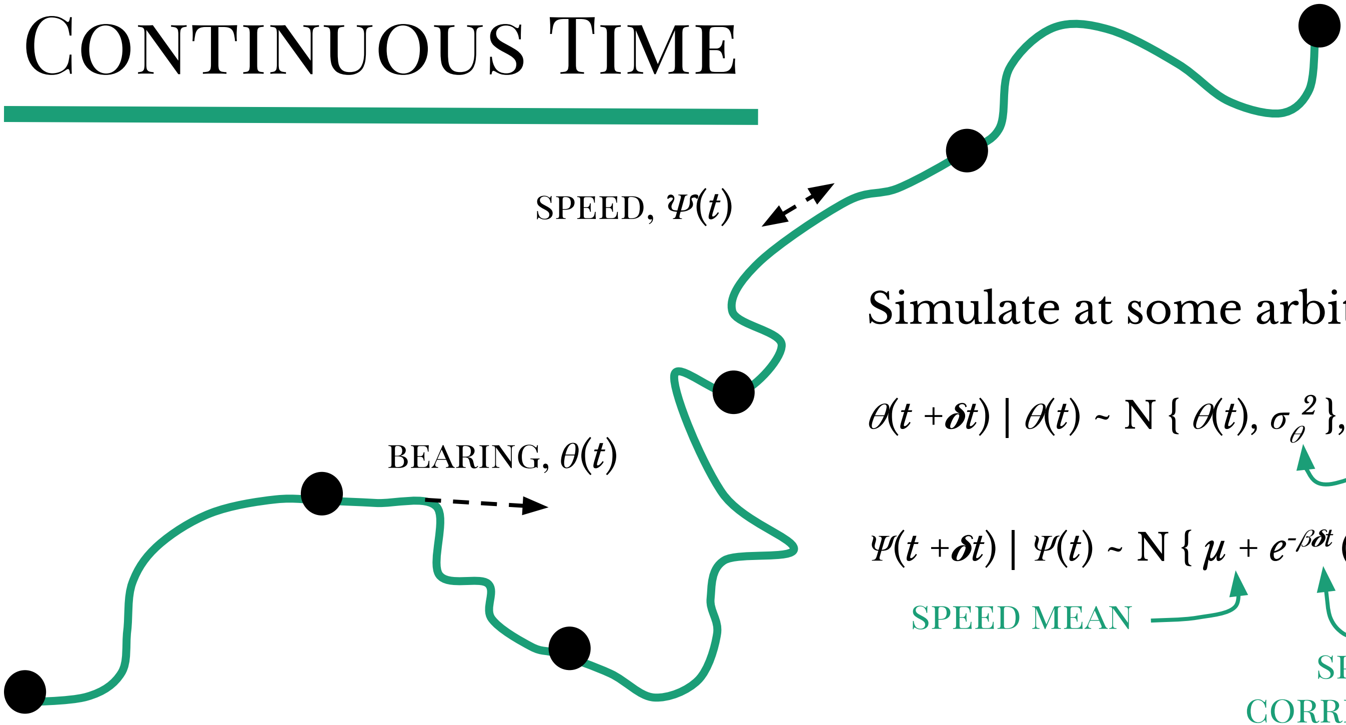
CONTINUOUS TIME



$\theta(t)$ ~ Brownian motion.
Parameter σ_{θ}^{2}.
Persistent movement, travel in similar direction over short time period.

$\Psi(t)$ ~ Ornstein-Uhlenbeck process.
Parameters μ, β, σ_{Ψ}^{2}.
Attracted to long-term mean speed, but includes correlation.

Continuous Time



Simulate at some arbitrarily fine time scale:

TURN VARIANCE

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

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

SPEED MEAN

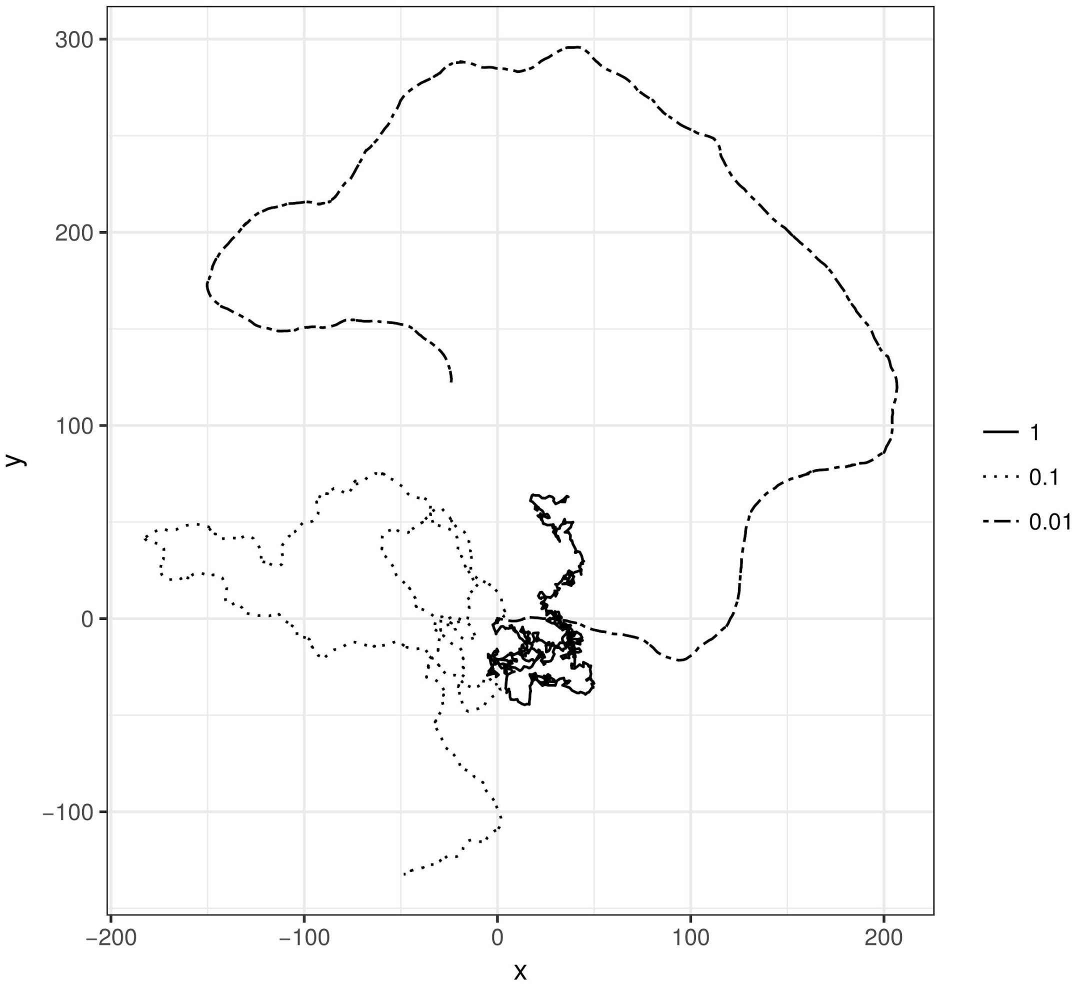
SPEED CORRELATION

SPEED VARIANCE

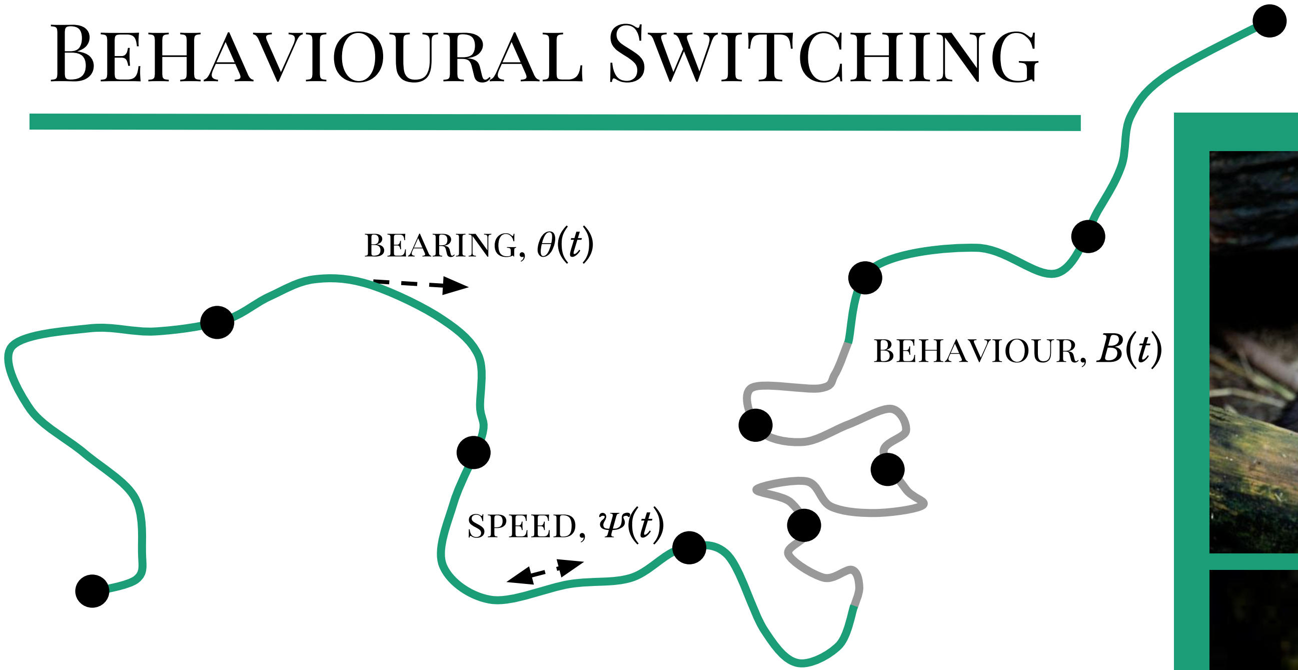
Recover the notion of 'steps' from the speed at this approximation:

$$v(t) = \Psi(t)\boldsymbol{\delta} t.$$

Continuous Time

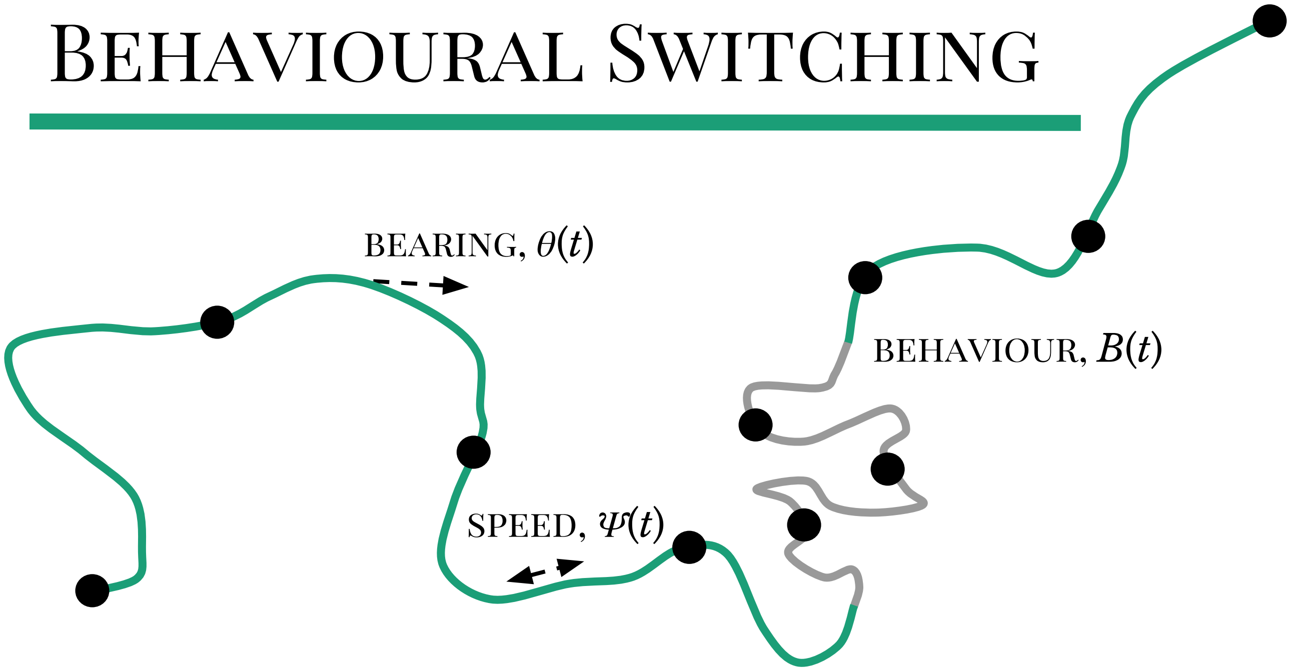


Behavioural Switching



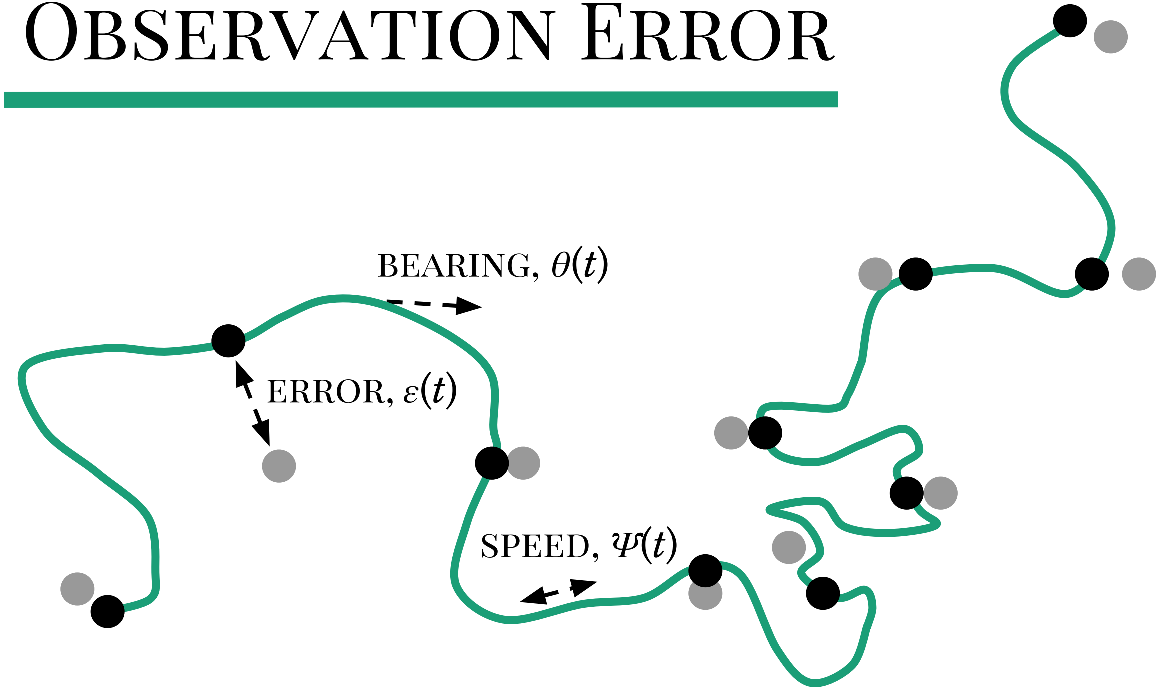
Blackwell, et al. 2015 Methods in Ecology and Evolution

Behavioural Switching

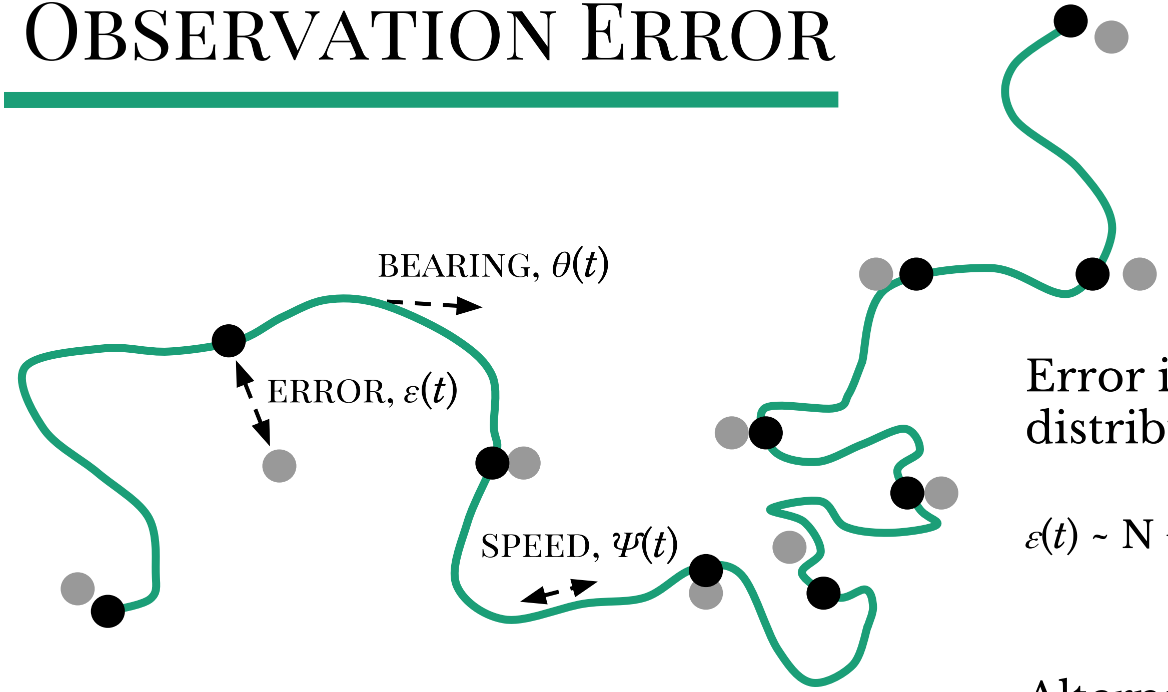


Behaviour follows continuous time Markov chain.
Finite (known) number of states.
Switching rates λ and probabilities q.
Set of movement parameters for each state.

Observation Error



OBSERVATION ERROR



Error independent and identically distributed in space and time

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

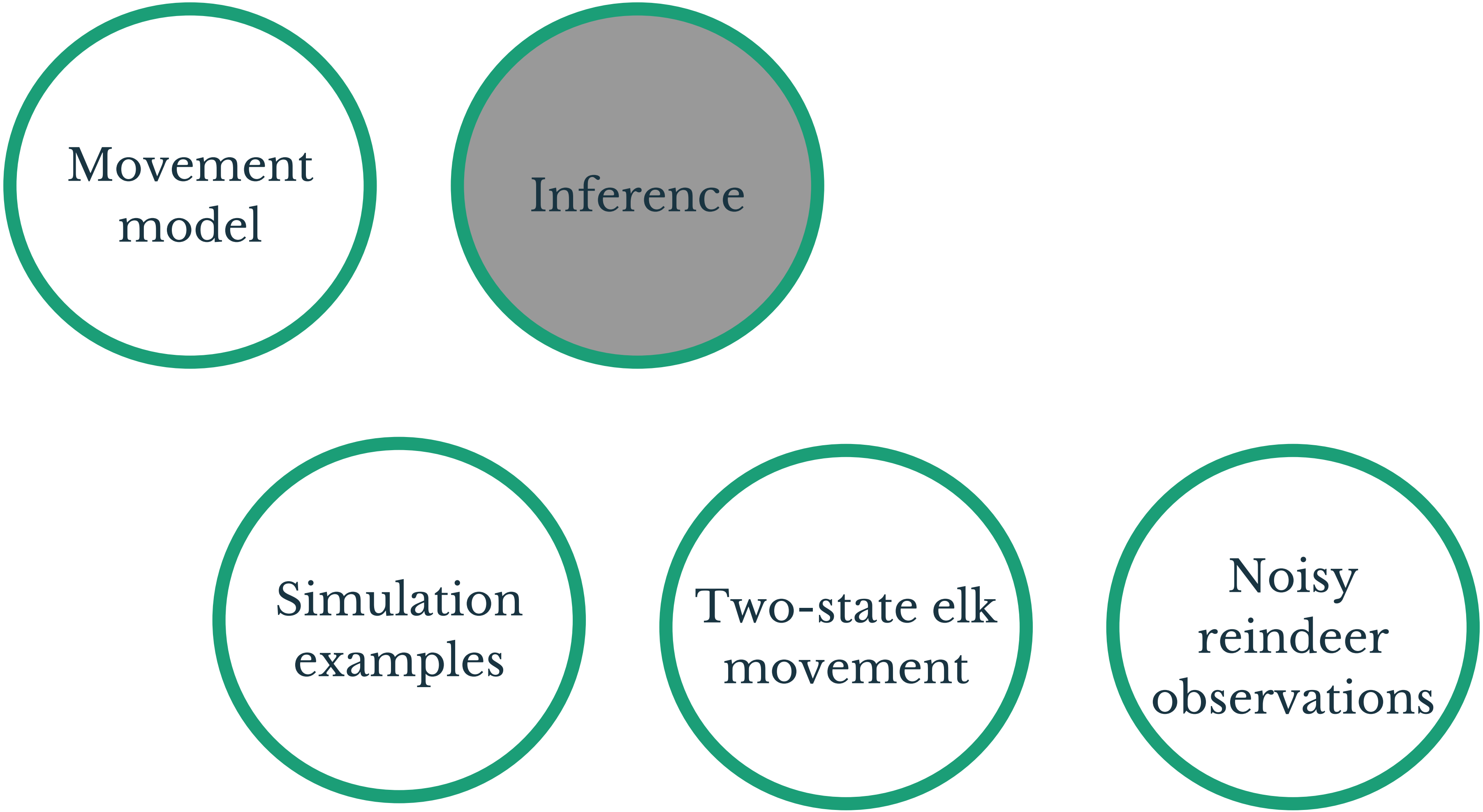
ERROR VOLATILITY

Alternatively, correlated error process, with correlation decaying with time

$$\varepsilon(t) \mid \varepsilon(s) \sim \mathrm{N}\{\, \varepsilon(s) e^{-\kappa(t-s)},\ \sigma_{\varepsilon}^{2}(1 - e^{-\kappa(t-s)}) \,\}$$

ERROR CORRELATION

ERROR VOLATILITY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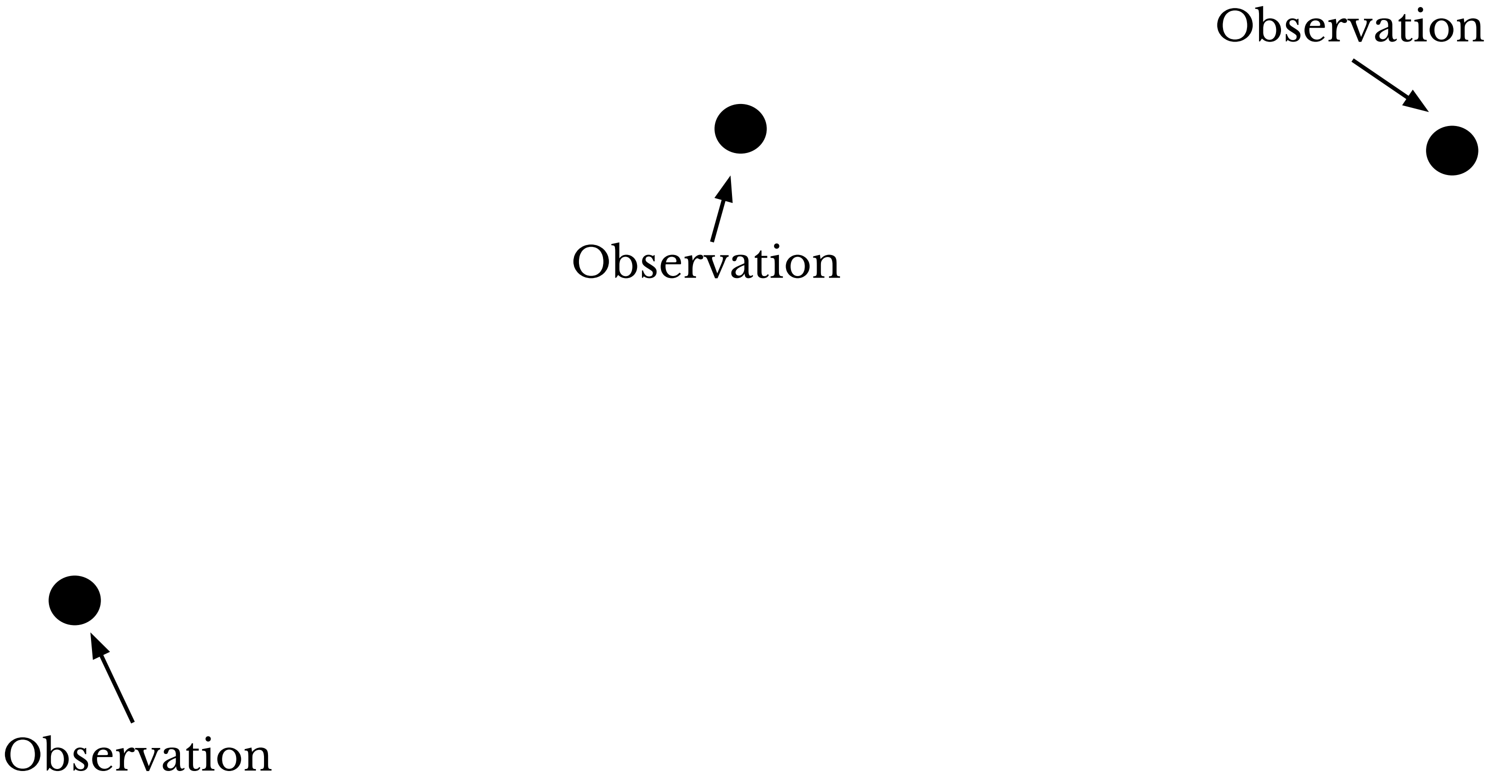
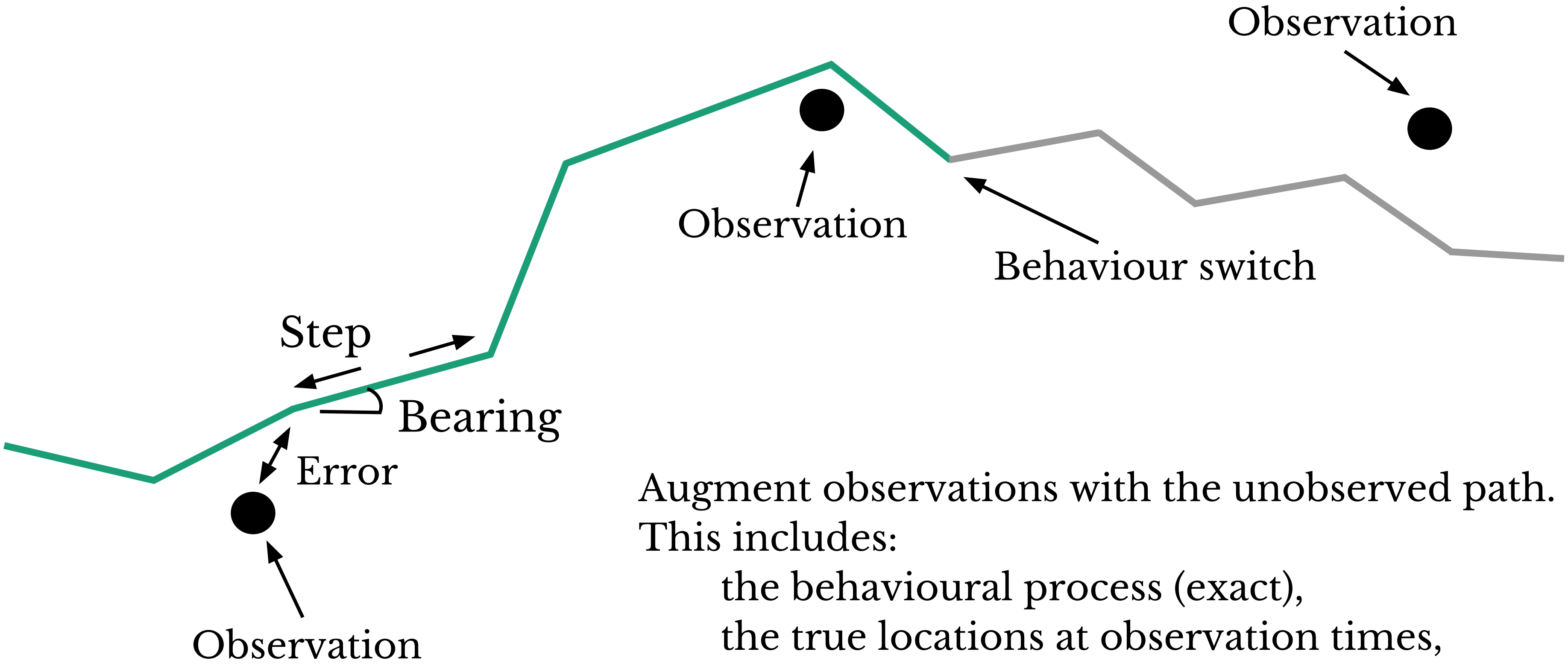
Bayesian Inference by Augmentation



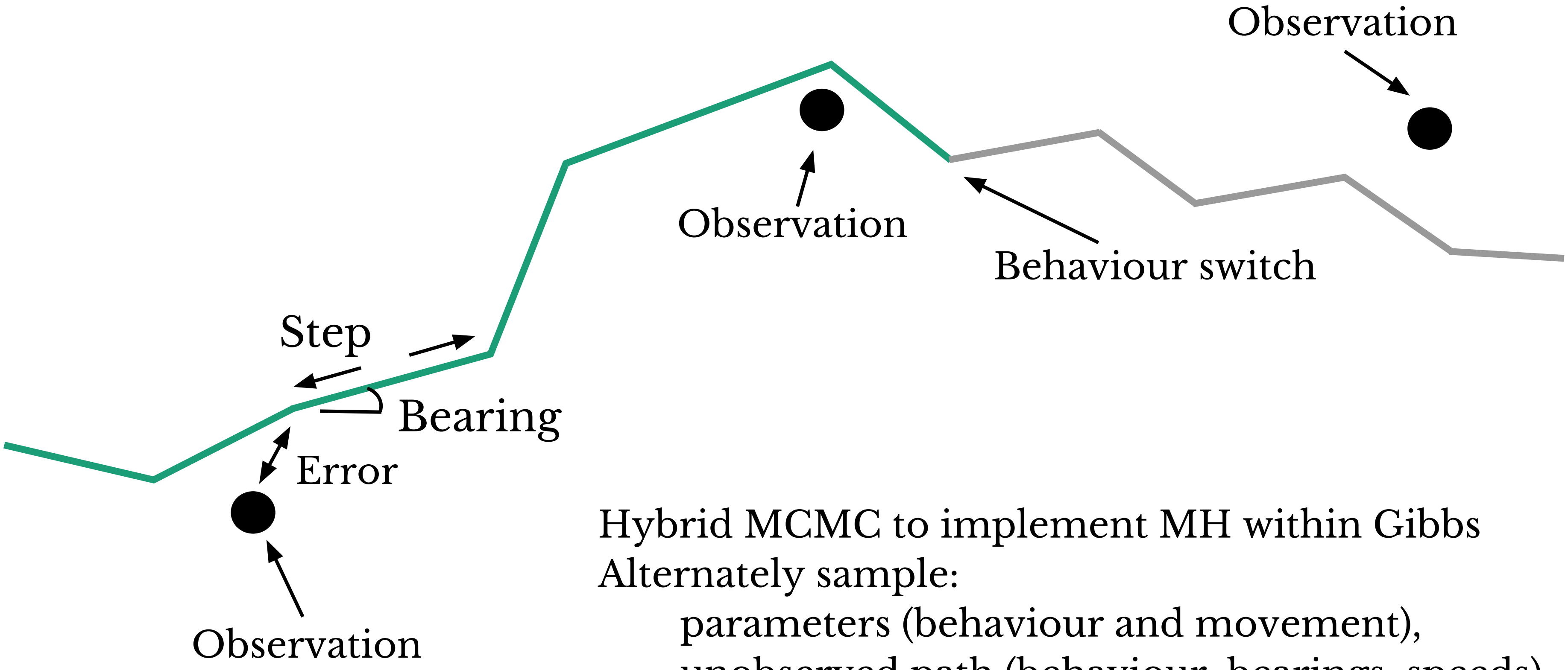
Bayesian Inference by Augmentation



Augment observations with the unobserved path.
This includes:

- the behavioural process (exact),
- the true locations at observation times,
- the movement (at approx. time scale).

Bayesian Inference by Augmentation



Hybrid MCMC to implement MH within Gibbs
Alternately sample:

parameters (behaviour and movement),
unobserved path (behaviour, bearings, speeds).

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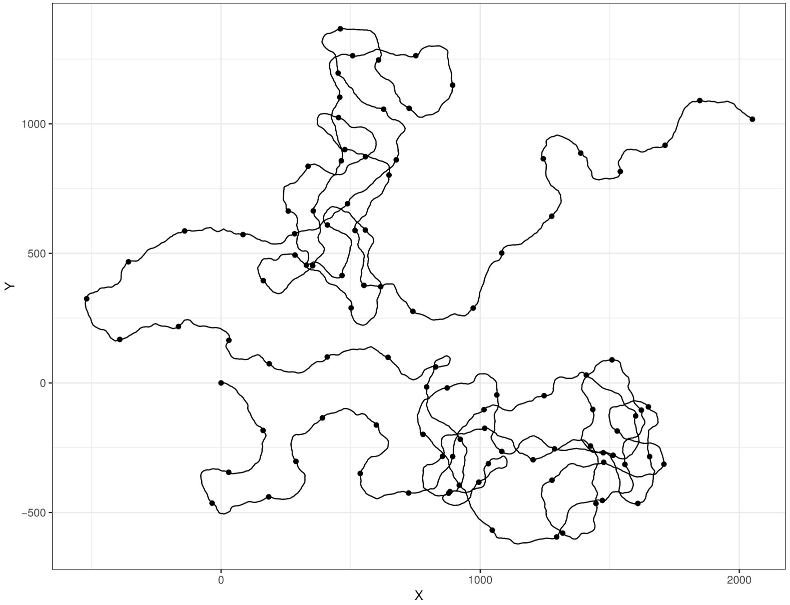
SIMULATIONS



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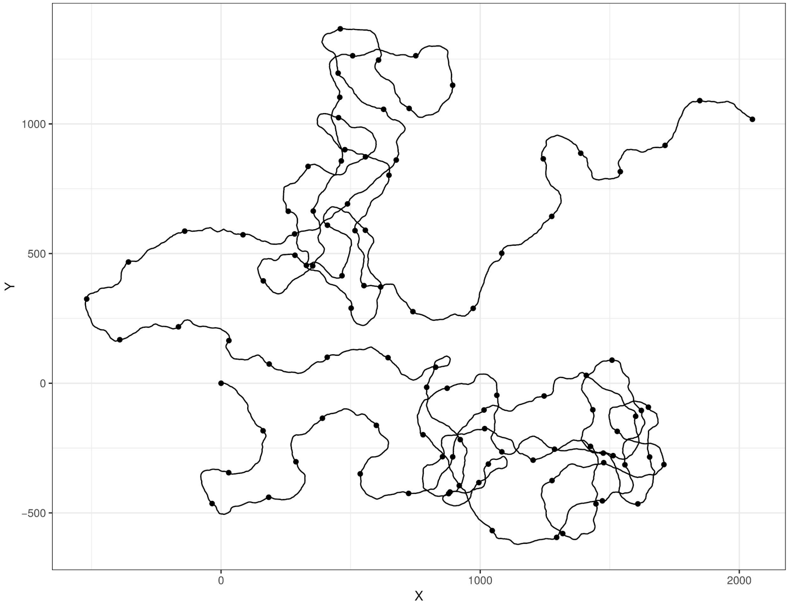

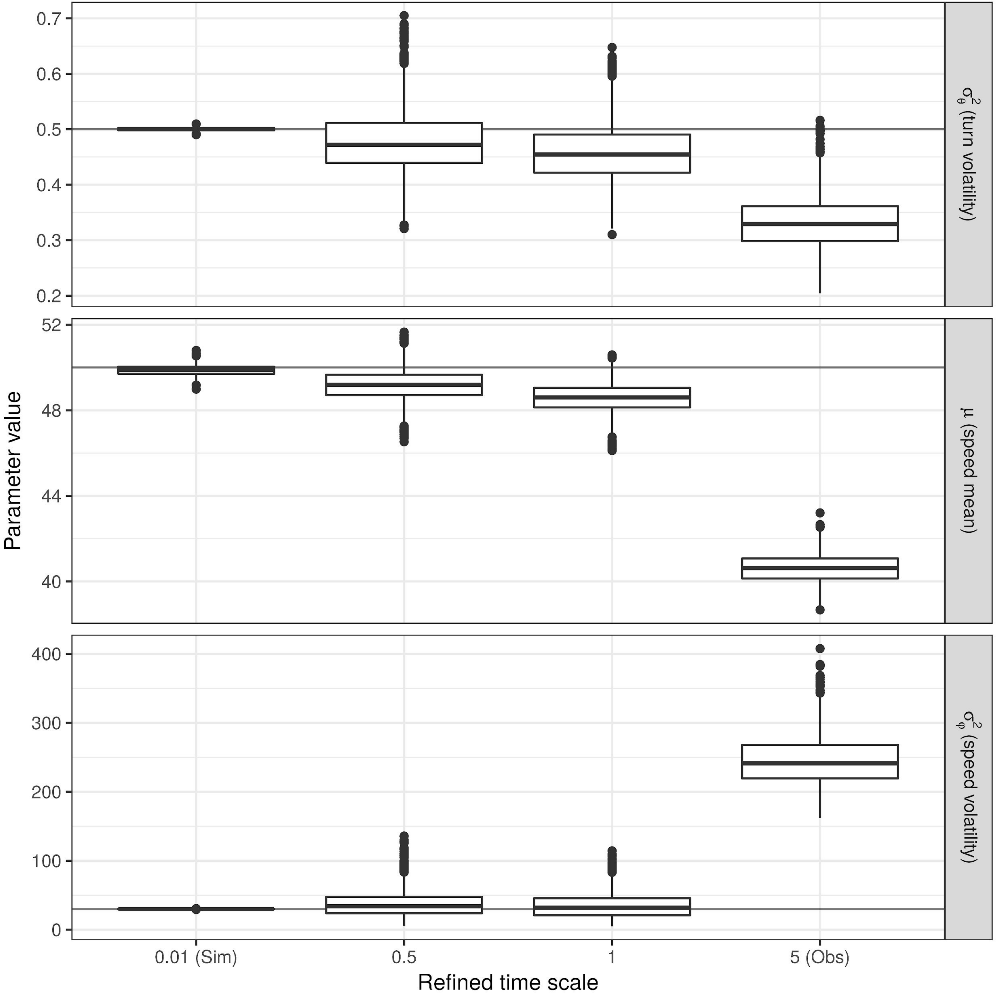

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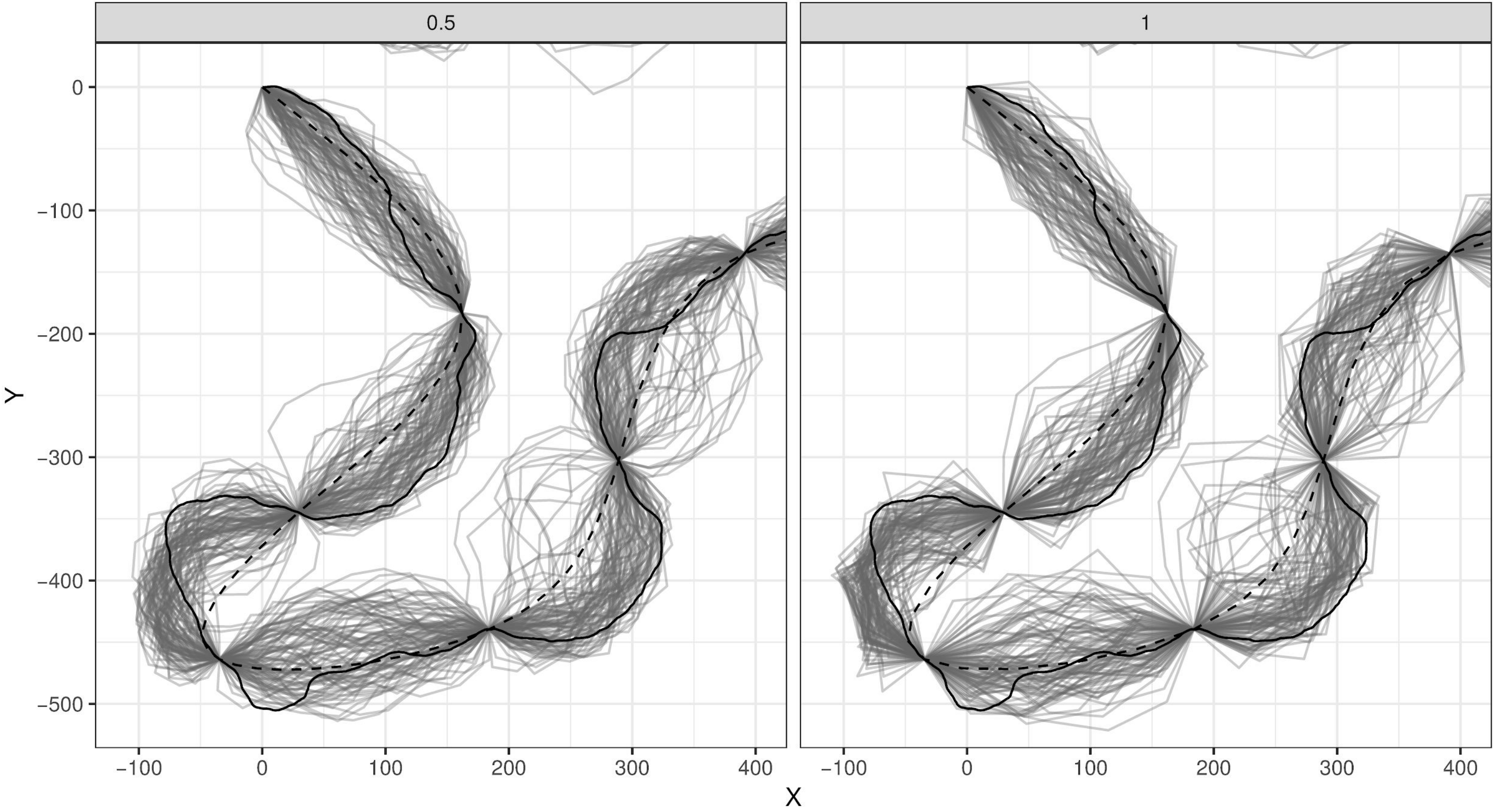

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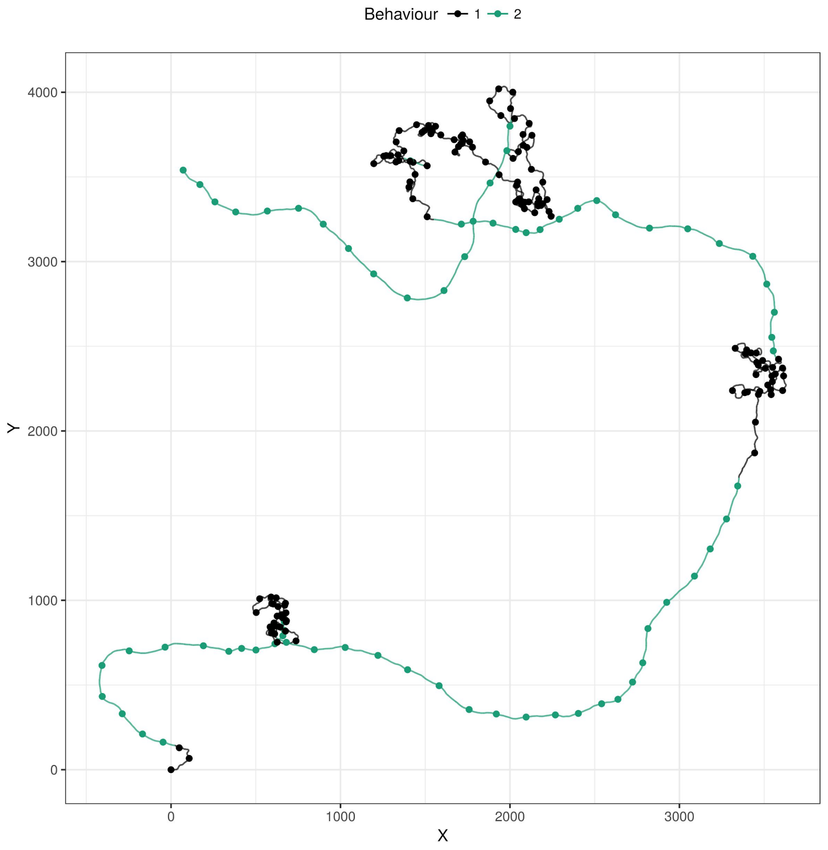

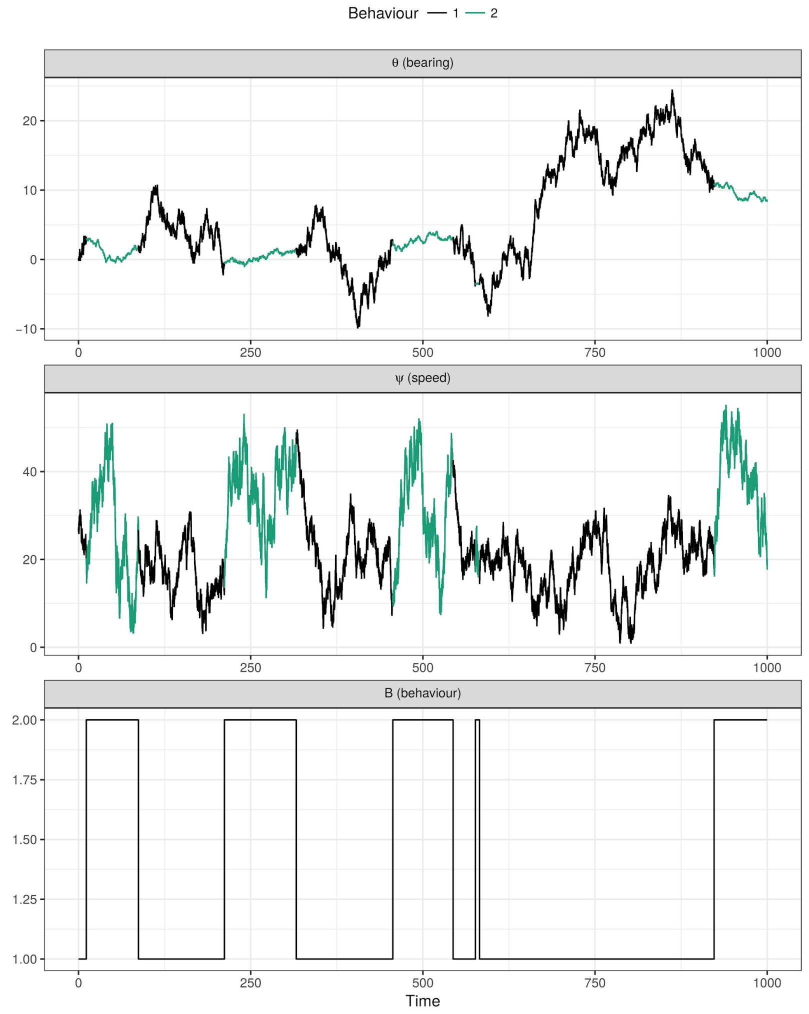

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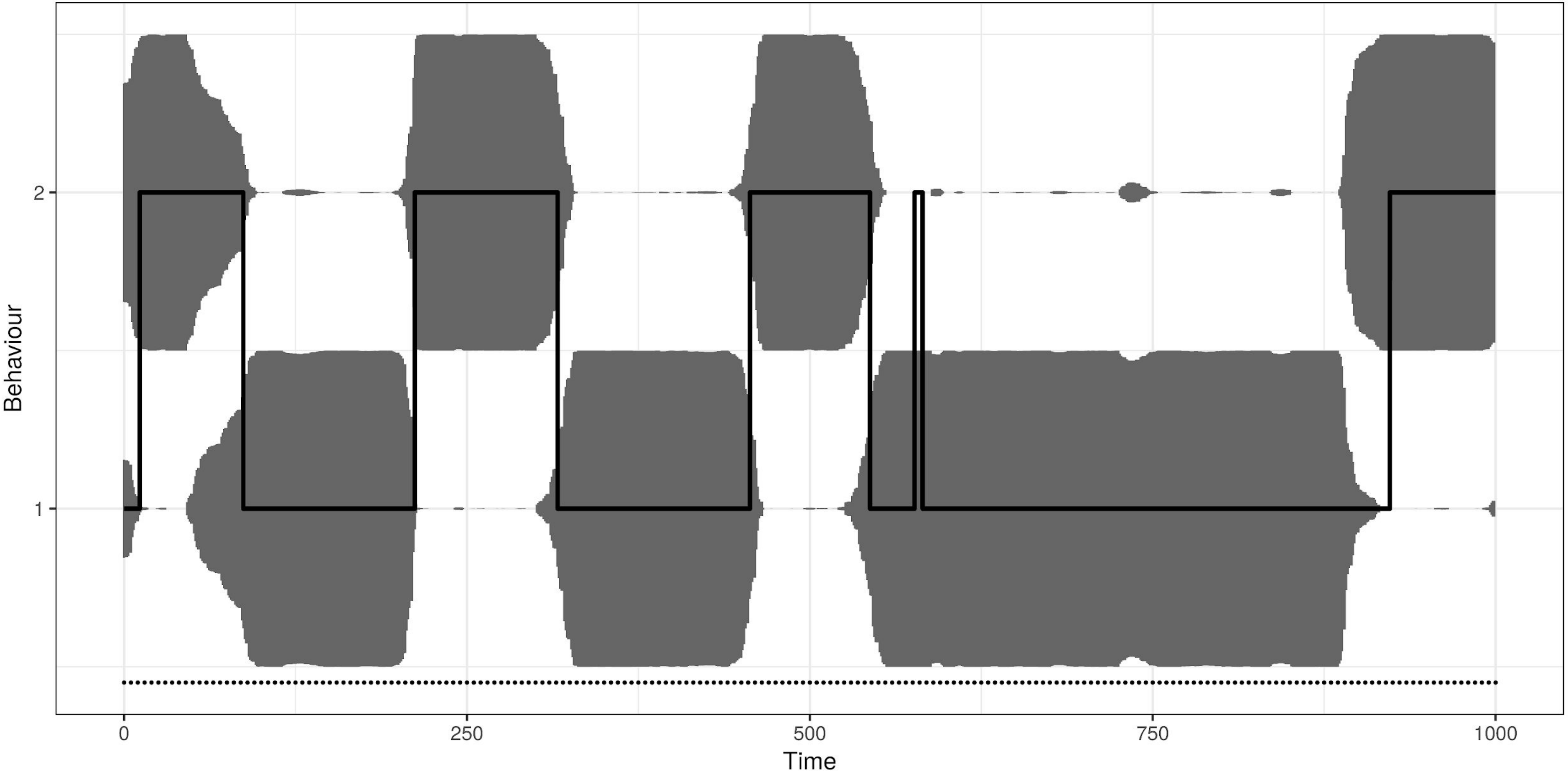

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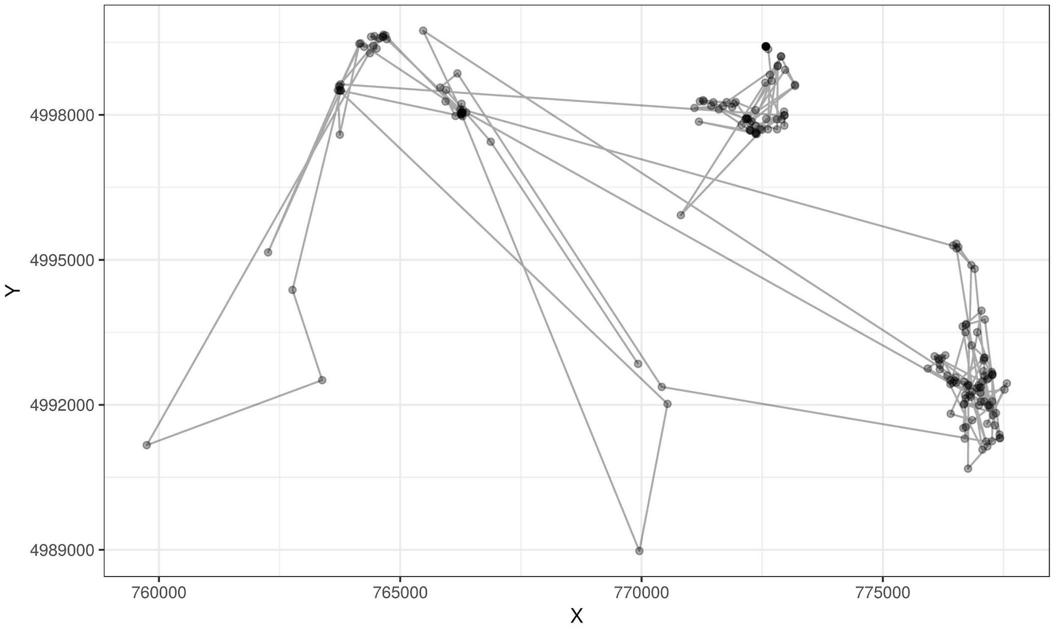
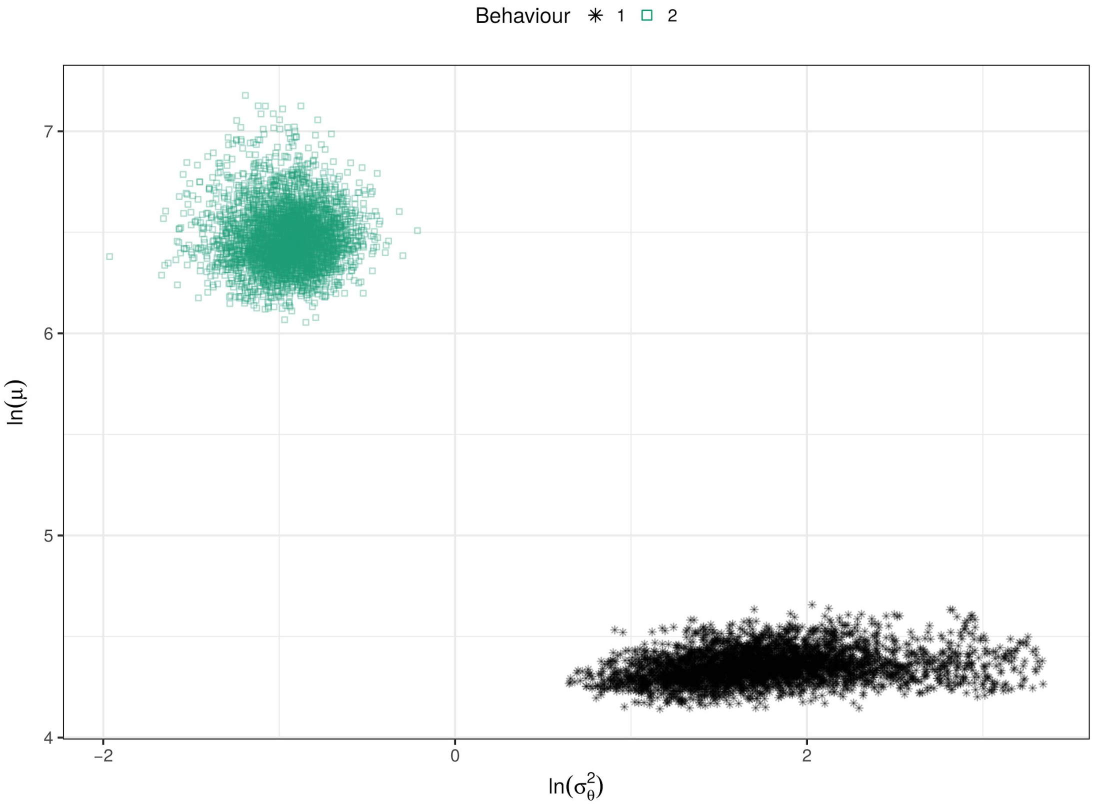
Two State Movement in Elk



Data from Morales, et al. 2004 Ecology

Two State Movement in Elk



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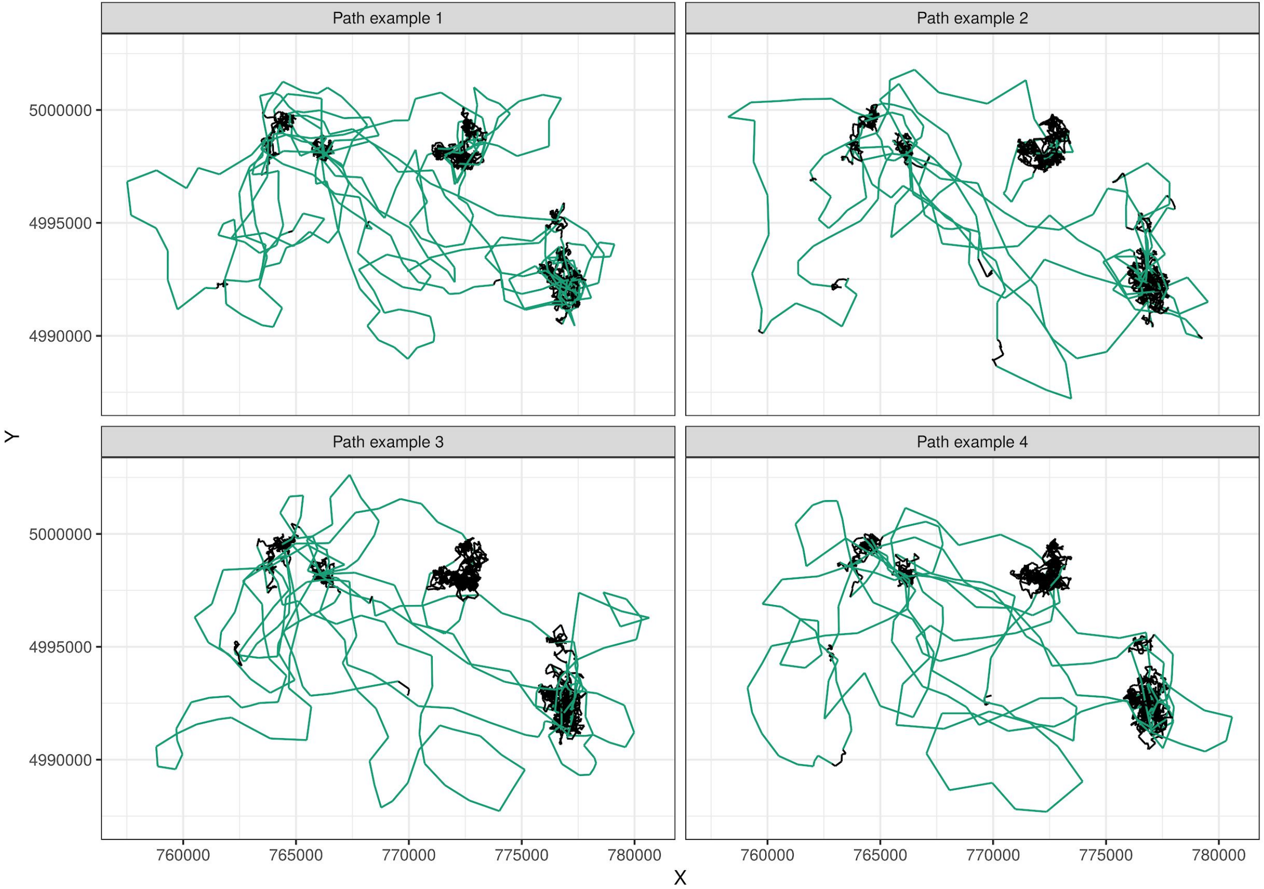

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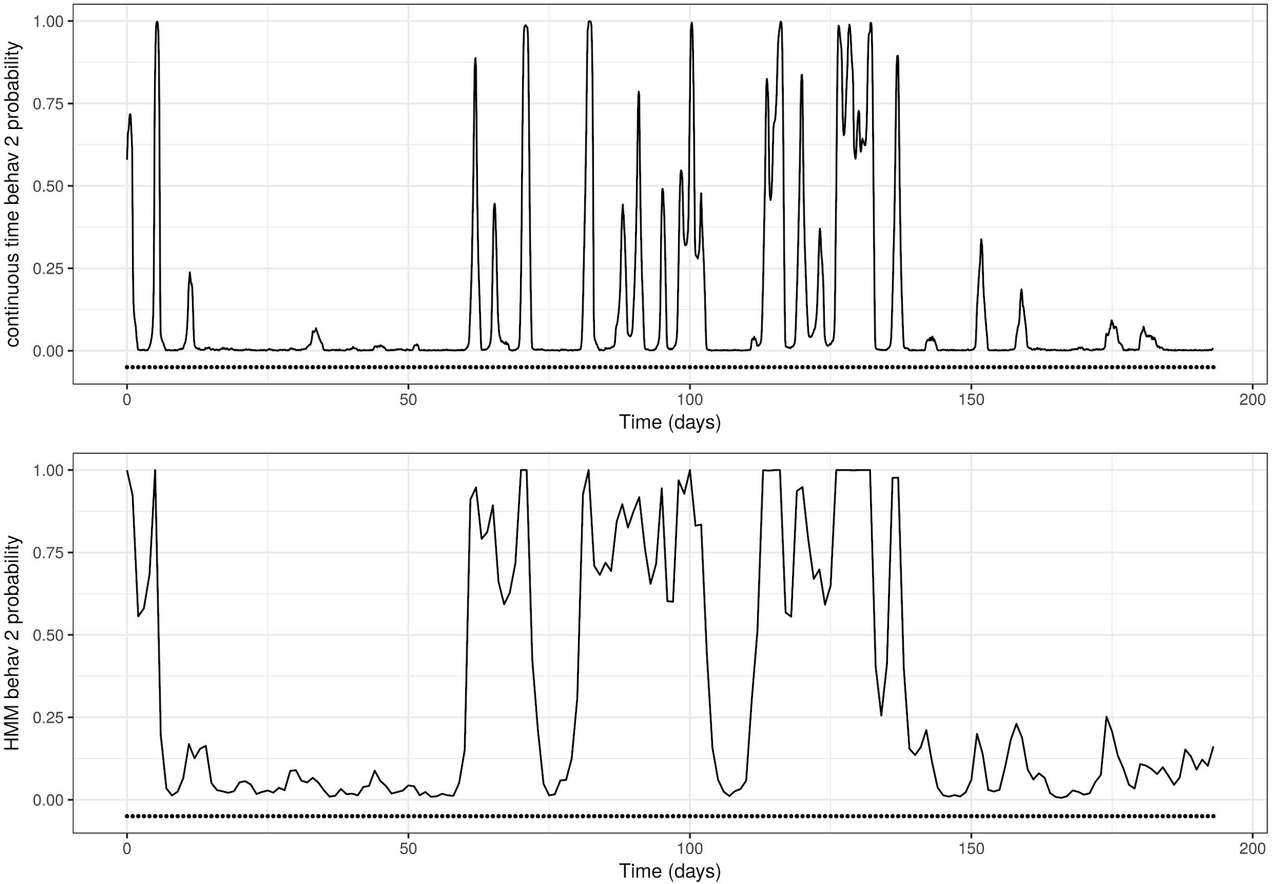

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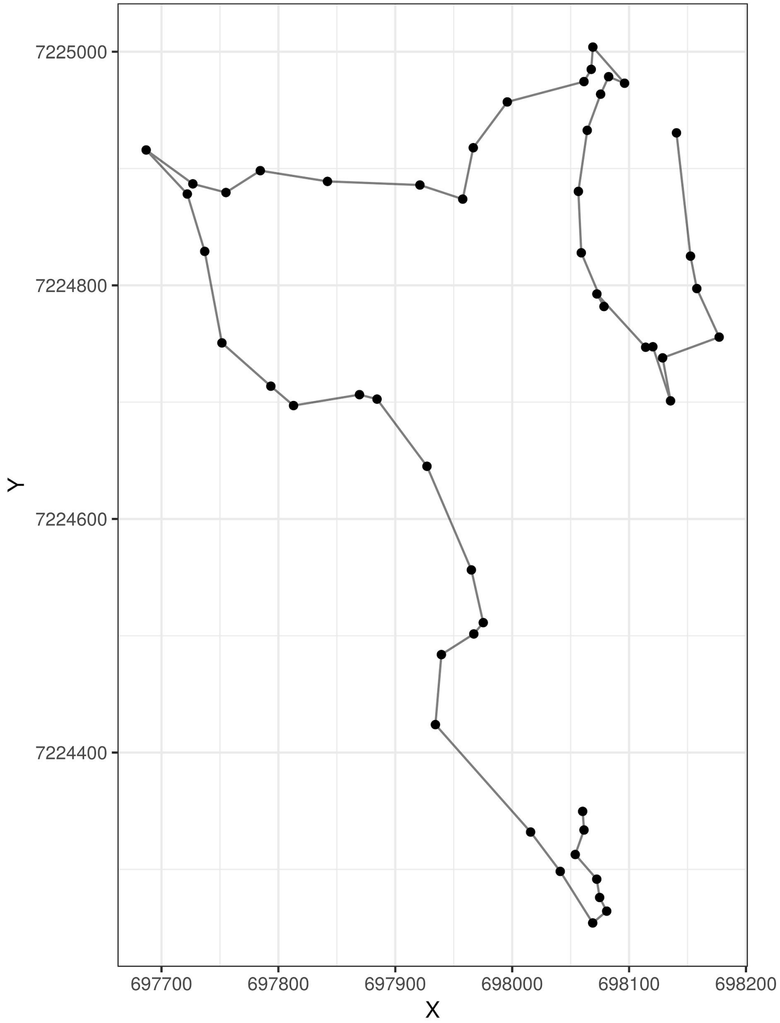
Noisy Reindeer Data

Data and image courtesy of
Anna Skarin, SLU



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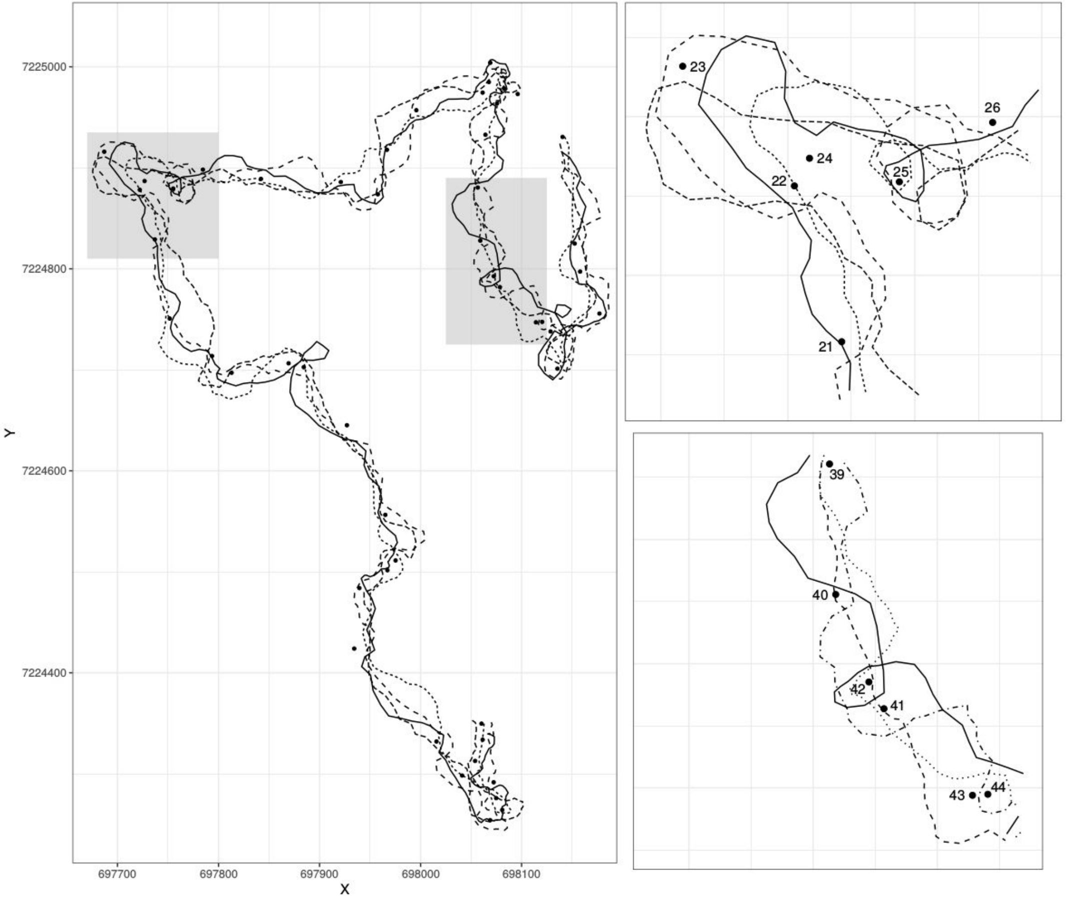

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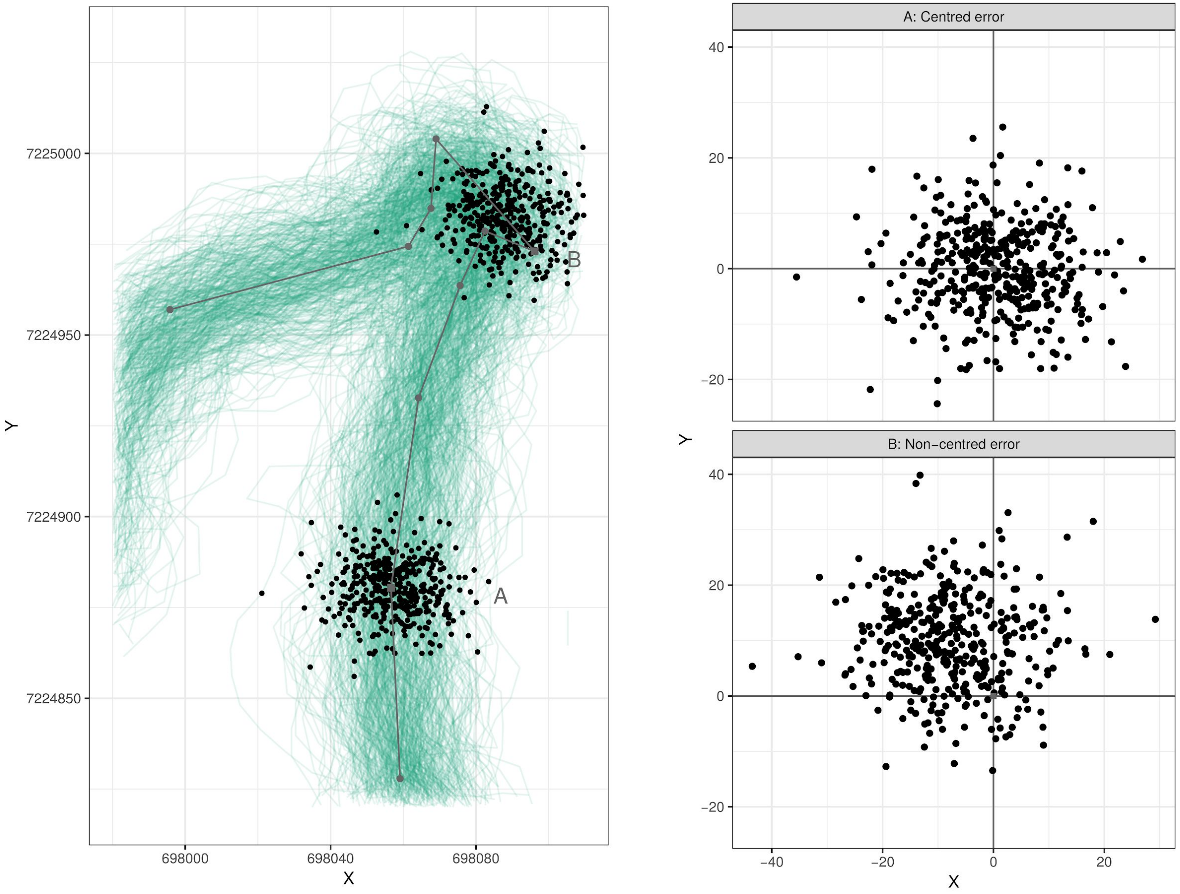
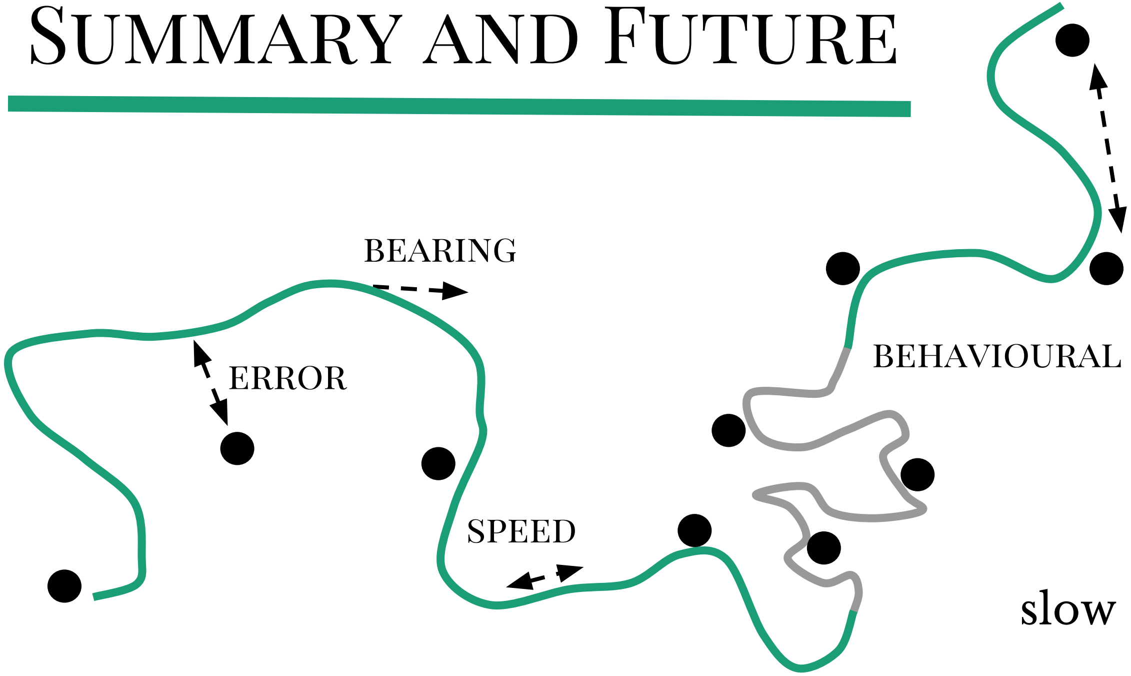


Summary and Future



Extensions:

directed/attracted movement
environmental dependence
slow decaying memory in behaviour

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APARTON2@SHEFFIELD.AC.UK @ALISON_PARTON