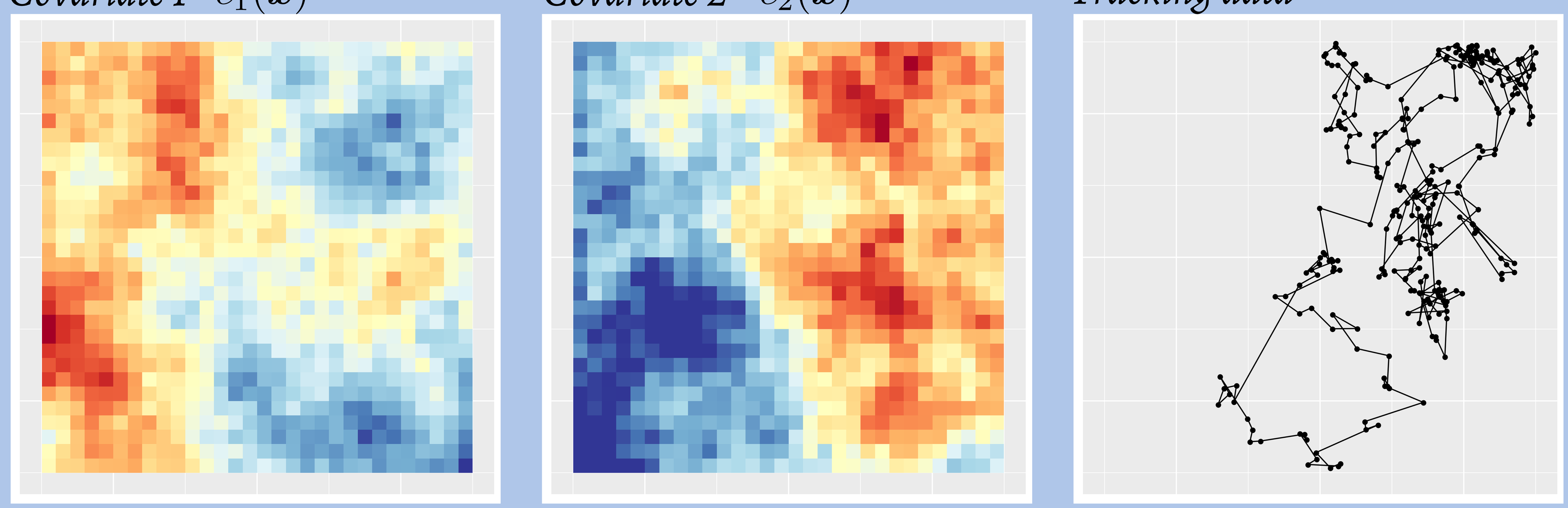
Can animals do MCMC?

Linking resource selection and step selection models

Théo Michelot* (tmichelot1@sheffield.ac.uk), Paul Blackwell*, Jason Matthiopoulos**

*University of Sheffield, UK, **University of Glasgow, UK

The problem: SSFs are not RSFs



What is the effect of the covariates on the animal's movements?

How to estimate $\beta_1, \beta_2, \dots$, in $w(\boldsymbol{x}) = \exp(\beta_1 c_1(\boldsymbol{x}) + \beta_2 c_2(\boldsymbol{x}) + \dots)$, where $w(\boldsymbol{x})$ measures preference for a location $\boldsymbol{x}$?

Resource selection function (RSF)

Model the distribution of locations in terms of the covariates:

$$\pi(\boldsymbol{x}) \propto w(\boldsymbol{x})$$

probability of using $\boldsymbol{x}$ *(utilisation distribution)*

"proportional to" (π is normalized)

Step selection function (SSF)

Model the distribution of steps in terms of the covariates:

$$p(\boldsymbol{x} \to \boldsymbol{y}) \propto \phi(\boldsymbol{x} \to \boldsymbol{y}) w(\boldsymbol{y})$$

probability of a step from x to y

movement in the absence of covariates

But step selection models do not make it possible to estimate the utilisation distribution (Barnett & Moorcroft, 2008).

Can we design a step selection (movement) model with a known utilisation distribution (UD) $\pi(\boldsymbol{x}) \propto w(\boldsymbol{x})$?

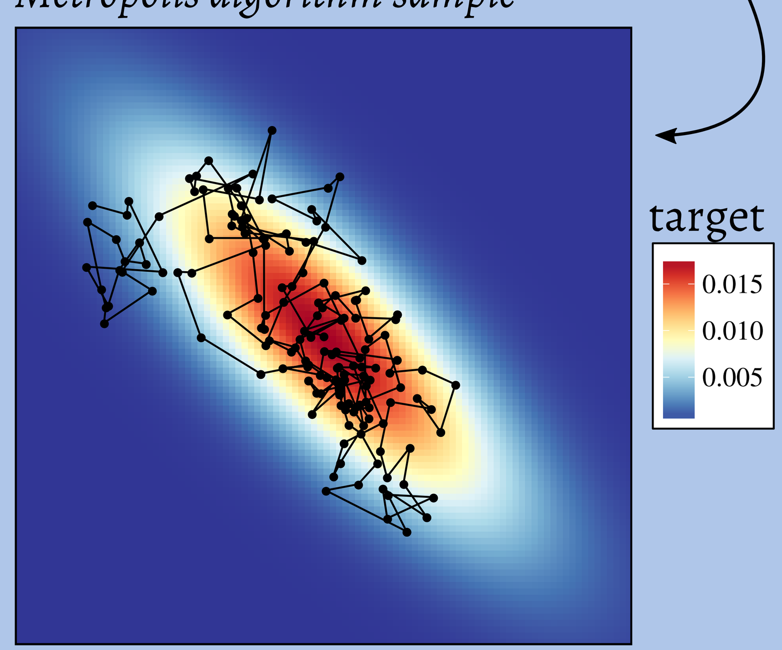
MCMC as a movement model?

A Markov chain Monte Carlo (MCMC) algorithm is a general method to sample points from a given probability distribution, called the target distribution.

the Metropolis algorithm is a widely used MCMC sampler

It describes a way to generate steps in a parameter space, such that the long-term distribution of sampled points coincides with the target distribution.

Metropolis algorithm sample



Similarly, an animal takes steps in geographical space, such that the long-term distribution of locations is the utilisation distribution.

We consider a MCMC algorithm with target distribution $\pi(\boldsymbol{x}) \propto w(\boldsymbol{x})$. It defines a step selection model with known utilisation distribution.

We propose the local Gibbs sampler, a rejection-free MCMC algorithm, to model animal movement.
For any point $\boldsymbol{x}$, let $D_r(\boldsymbol{x})$ be the disc of centre $\boldsymbol{x}$ and radius $r > 0$.

Local Gibbs algorithm

Start from $\boldsymbol{x}_1$. Then, for $t = 1, 2, \dots$,

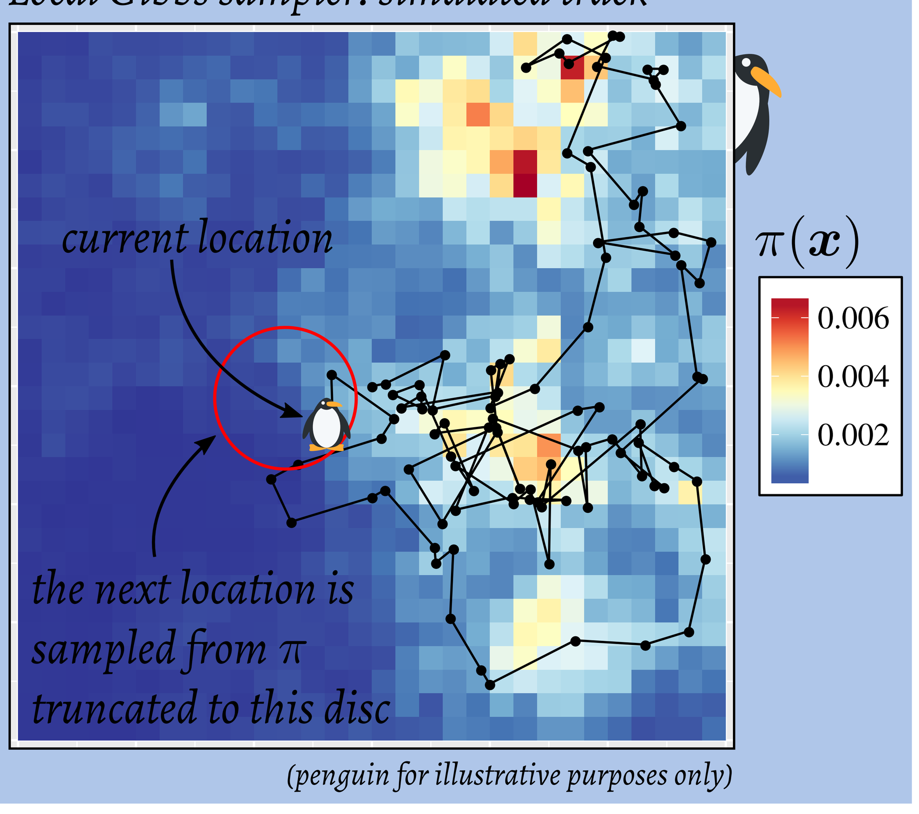
1. Generate a point $\boldsymbol{z}$ uniformly from $D_r(\boldsymbol{x}_t)$.
2. Define

$$\tilde{\pi}(\boldsymbol{x}) \propto \begin{cases} \pi(\boldsymbol{x}) & \text{in } D_r(\boldsymbol{z}), \\ 0 & \text{elsewhere,} \end{cases}$$

the utilisation distribution truncated and scaled on $D_r(\boldsymbol{z})$.

3. The next location $\boldsymbol{x}_{t+1}$ is drawn from $\tilde{\pi}$.

Local Gibbs sampler: simulated track



(penguin for illustrative purposes only)

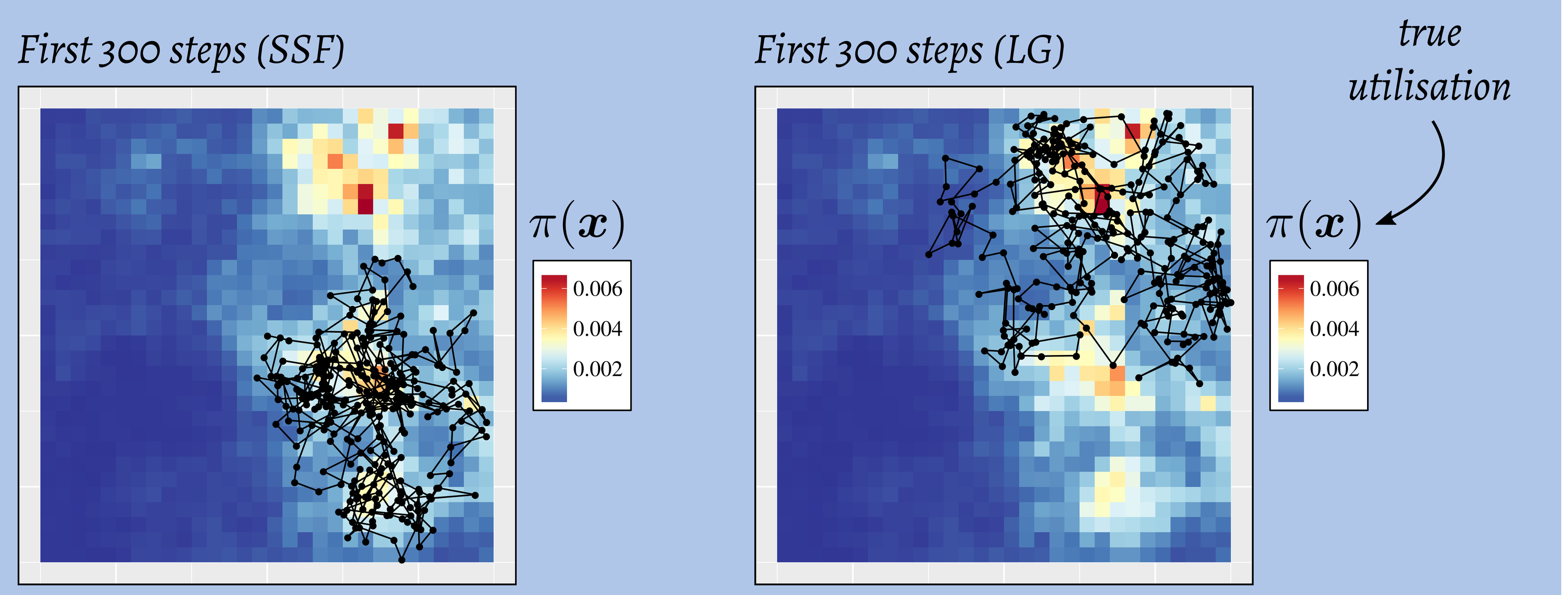
Simulations and results

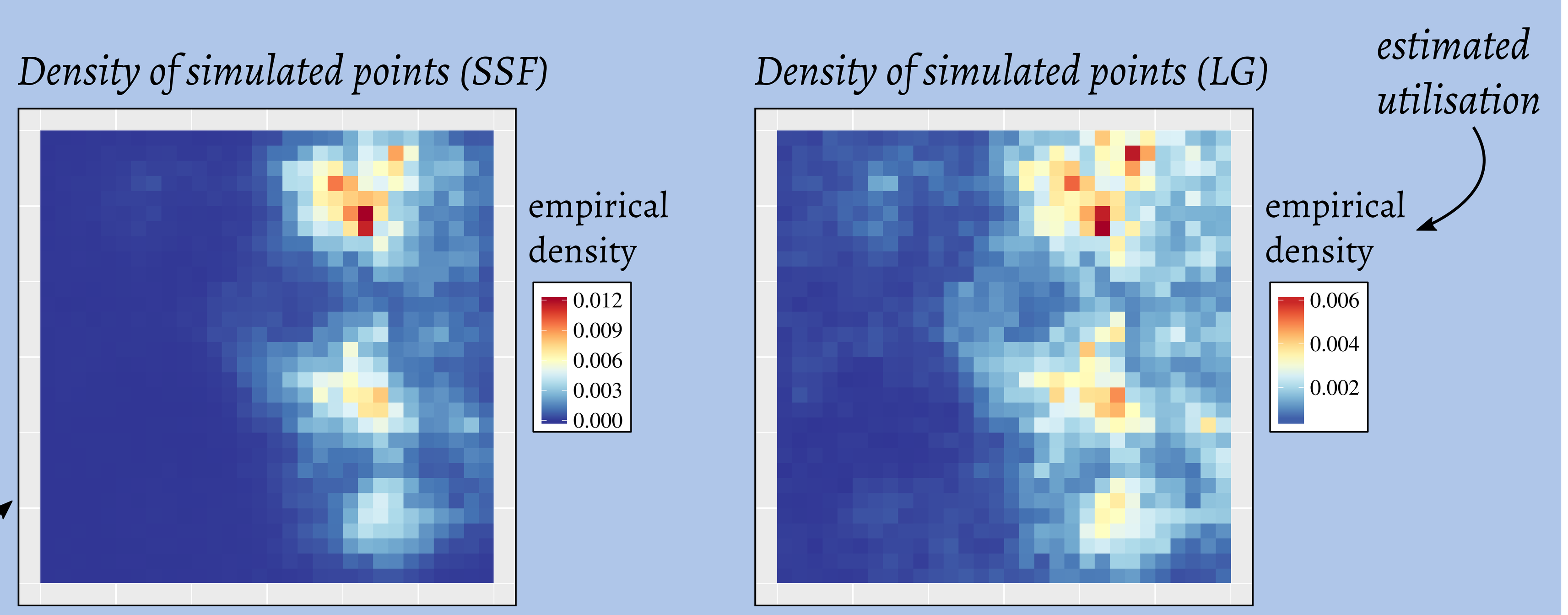
We sampled 500,000 locations for a known utilisation distribution, using

- a standard step selection model (SSF);
- the local Gibbs sampler (LG).

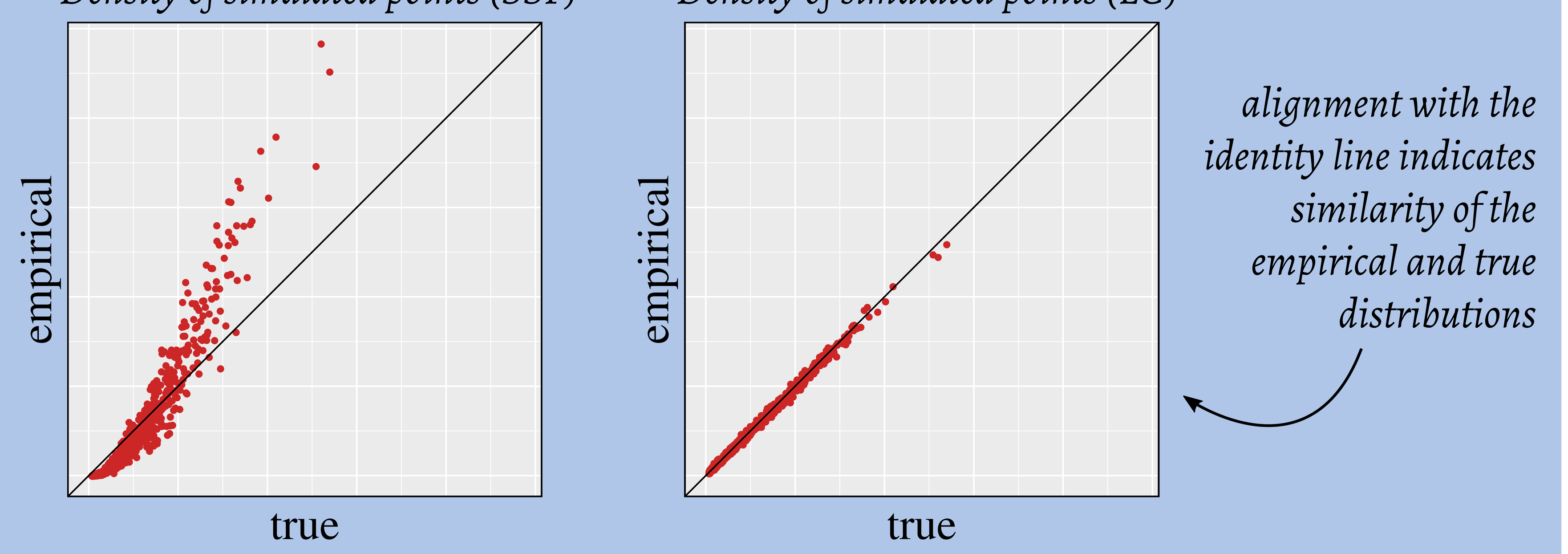
(the uniform sampling model of Forester et al., 2009)

We compare the distribution of simulated locations to the true UD:





Areas where $\pi(\boldsymbol{x})$ is high are used disproportionately by the SSF model.



Unlike standard step selection models, the local Gibbs algorithm produces samples from a known utilisation distribution, proportional to the RSF $w(\boldsymbol{x})$.

Estimating space use from data

This framework allows us to estimate the resource selection coefficients $(\beta_1, \beta_2, \dots)$ from observed telemetry data, as well as parameters of the movement (the parameters of the MCMC sampler).
Using a MCMC algorithm with transition kernel $p(\boldsymbol{x}_t \to \boldsymbol{x}_{t+1})$, the likelihood of observations $\boldsymbol{x}_1, \dots, \boldsymbol{x}_T$ can be obtained as:

$$\mathcal{L} = \prod_{t=1}^{T-1} p(\boldsymbol{x}_t \to \boldsymbol{x}_{t+1})$$

We are currently working on likelihood-based methods to estimate all parameters of $p(\boldsymbol{x}_t \to \boldsymbol{x}_{t+1})$ in the local Gibbs model.

References

- Michelot, T., Blackwell, P.G., & Matthiopoulos, J. (preprint). *Linking resource selection and step selection models for habitat preferences in animals.* arXiv:1708.08426.
- Barnett, A. H., & Moorcroft, P. R. (2008). *Analytic steady-state space use patterns and rapid computations in mechanistic home range analysis.* Journal of mathematical biology.
- Forester, J. D., Im, H. K., & Rathouz, P. J. (2009). *Accounting for animal movement in estimation of resource selection functions: sampling and data analysis.* Ecology.