(integrated) Step-Selection Analysis

Tal Avgar

Introduction

Habitat Selection (Probability) Function: a phenomenological model of the probability that an available discrete spatial unit will be used given its habitat type/value

- Availability varies over time and space:
  - Environments change: depletion, phenology, temperature, light, etc.
  - Cognitive processes: sensory perception, learning, and memory
  - Movement: position in geographical space dictates availability in environmental space
- Case-control design: matching used positions with a set of available positions based on spatial and/or temporal proximity

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Step-Selection Analysis

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- Use conditional logistic regression to obtain maximum likelihood parameter (B) estimates:

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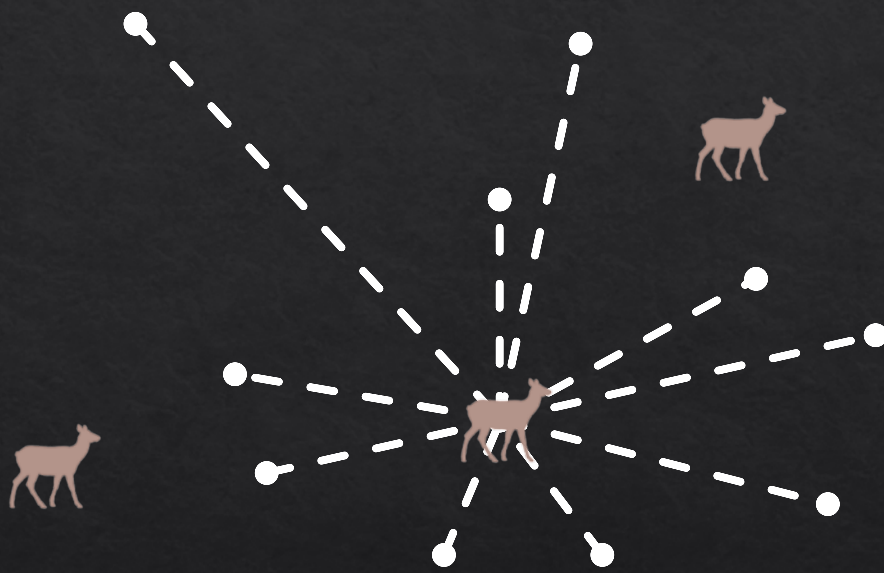
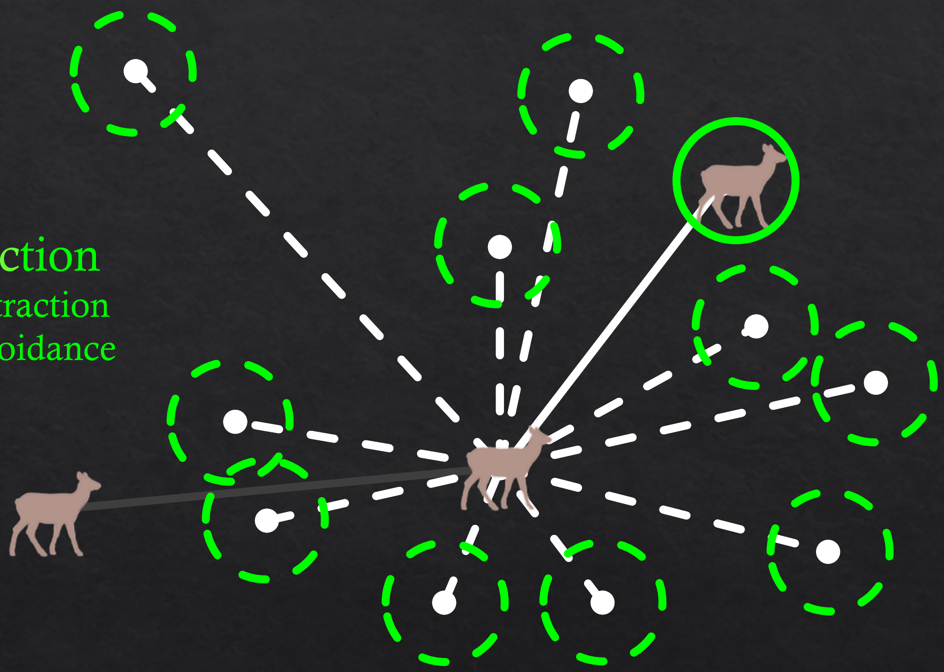
Step-Selection Analysis



graphics adapted from Prokopenko 2016

Step-Selection Analysis

selection
- attraction
- avoidance



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2. Define observed ('used') steps: pairs of fixes taken at a <u>constant time interval</u>
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4. Attribute all steps with environmental covariates, measured either at the step's endpoint, or 'along' the step
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6. Gain inference: estimate the *Relative Selection Strength* for the various environmental covariates

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Path geometry

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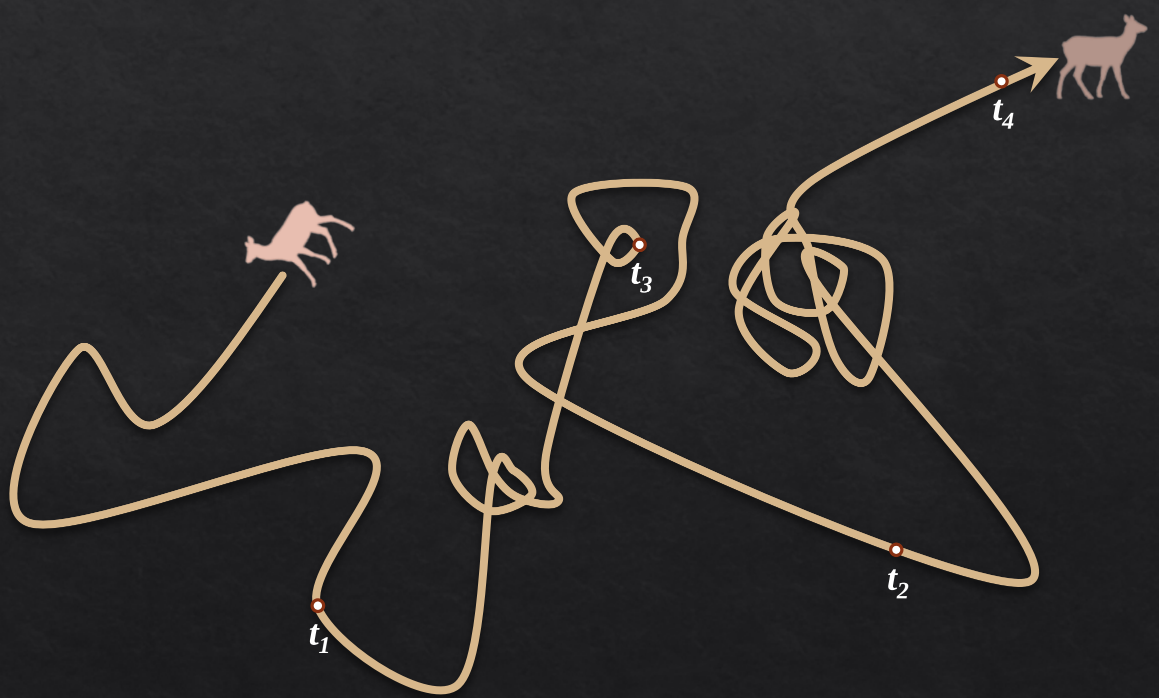
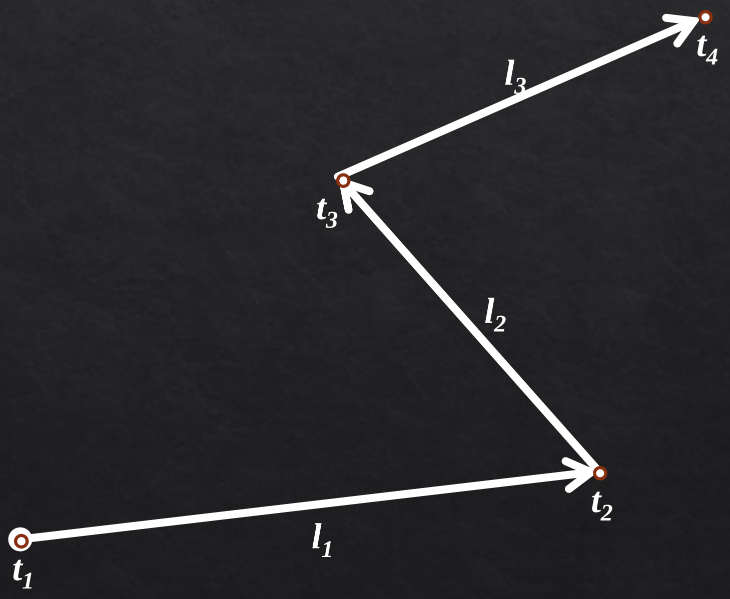


$$(t_4 - t_3) = (t_3 - t_2) = (t_2 - t_1)$$

Path geometry

- Step length: l



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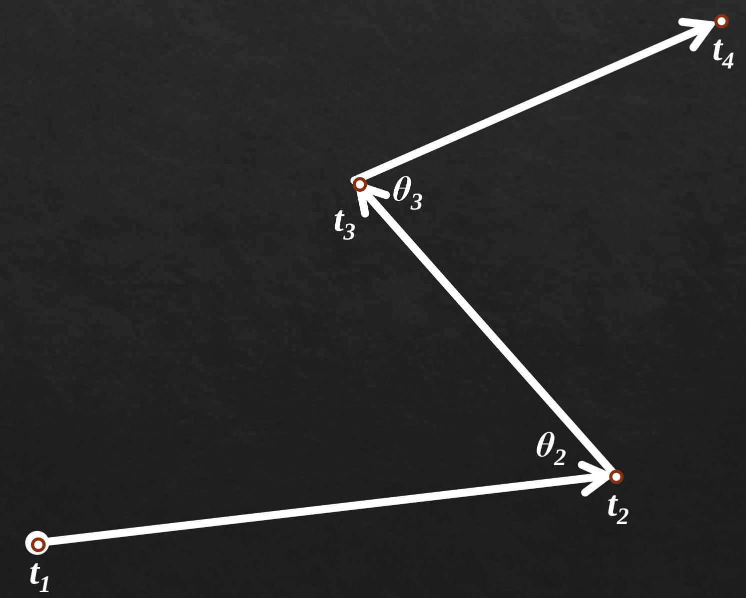
Path geometry

- Step length: l
- Directional correlation: $cos(\theta)$



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Step-Selection Analysis

- In SSA, habitat-selection inference is conditional on movement, whereas movement (steps sampled from the empirical distribution) is assumed independent of habitat selection
- Include 'step length' as a covariate to control for the effect of movement and reduce bias in habitat-selection inference

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integrated Step-Selection Analysis

- In iSSA, available step are sampled from explicitly defined theoretical distributions
- Step length and turn angles are then included as covariates, with associated ‘selection coefficients’ that correspond to the parameter vector
- Use conditional logistic regression to simultaneously obtain maximum likelihood parameter estimates for habitat selection and movement:

$$L(\mathrm{B}(\tau), \mathrm{A}(\tau) | x_1, \ldots, x_t, \ldots, x_T) = \prod_{t=1}^{T} \frac{exp[\mathrm{B}(\tau) \cdot H(x_t, \tau) + \mathrm{A}(\tau) \cdot f(x_{t-2\tau}, x_{t-\tau}, x_t)]}{\sum_{i=1} exp[\mathrm{B}(\tau) \cdot H(x_{t,i}, \tau) + \mathrm{A}(\tau) \cdot f(x_{t-2\tau}, x_{t-\tau}, x_{t,i})]}$$

Duchesne, T., Fortin, D. & Rivest, L. (2015). Equivalence between step selection functions and biased correlated random walks for statistical inference on animal movement. *PLoS ONE*, 10, e0122947.

Avgar, T., Potts, J.R., Lewis, M.A. & Boyce, M.S. (2016). Integrated step selection analysis: bridging the gap between resource selection and animal movement. *Methods Ecol. Evol.*, 7, 619–630.

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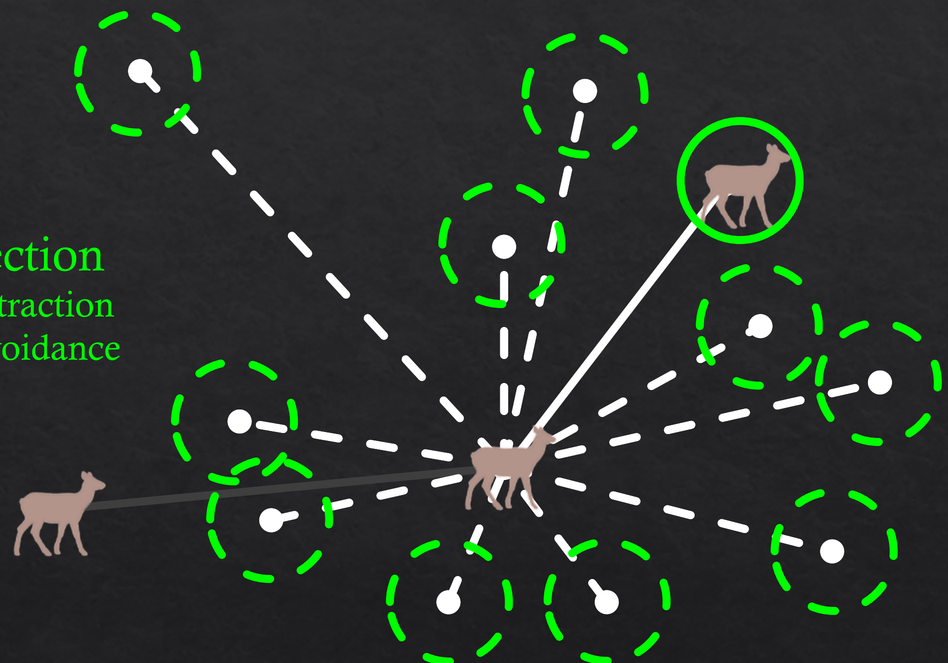
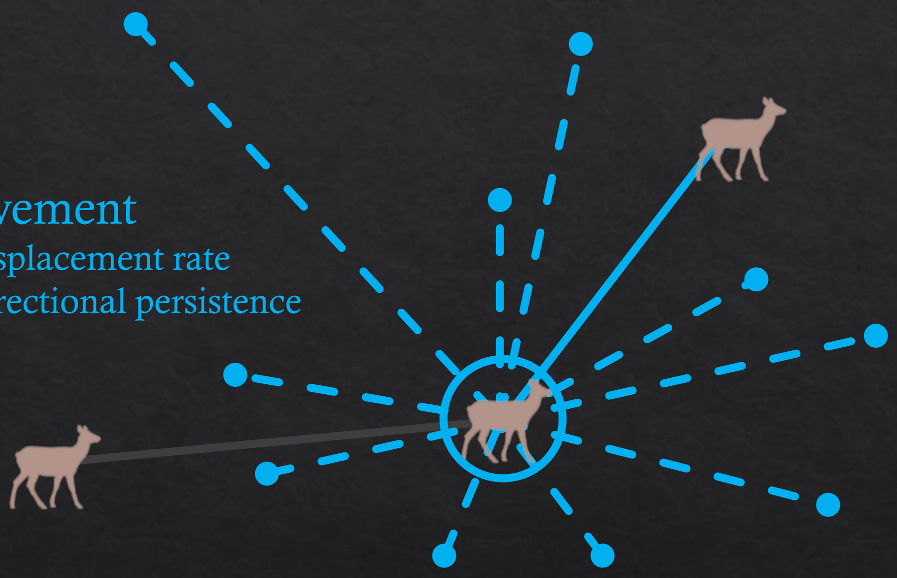


integrated Step-Selection Analysis

movement
- displacement rate
- directional persistence



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1. Obtain individual positional data
2. Define observed ('used') steps: pairs of fixes taken at a <u>constant time interval</u>
3. Match each observed steps with a random set of 'available' steps, sampled from tentative analytical distributions of step-lengths and turn-angles
4. Attribute all steps with environmental covariates, measured either at the step's endpoint, or 'along' the step, and the step's length ($l, ln(l), l^2, ln(l)^2$) and turn angle ($cos(\theta)$)
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Random (‘control’ or ‘available’) steps are sampled from:

step length

- Exponential: $ln\left(f_{\text{exponential}}(l|\lambda)\right) = \ln(\lambda) - \lambda l$
- Half-Normal: $ln(f_{\text{halfNormal}}(l|\sigma)) = -\ln\left(\frac{\sqrt{2}}{\sigma\sqrt{\pi}}\right) - \frac{1}{2\sigma^2} l^2$
- Log-Normal: $ln\left(f_{\text{logNormal}}(l|\sigma,\mu)\right) = \left(-ln(\sigma\sqrt{2\pi}) - \frac{\mu^2}{2\sigma^2}\right) - \left(\frac{\mu}{\sigma^2} - 1\right) ln(l) - \frac{1}{2\sigma^2} ln(l)^2$
- Gamma: $ln\left(f_{\text{gamma}}(l|k,q)\right) = -ln(\Gamma(k)q^{\kappa}) - \frac{1}{q} l + (k-1) ln(l)$

directional bias

- von Mises: $ln(f_{\text{vonMises}}(\theta|\nu,\mu = 0)) = \nu cos(\theta) - ln[2\pi I_0(\nu)]$

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iSSA: calculating ‘selection-free’ movement parameters

- Exponential rate parameter: $\hat{\lambda} = \lambda_0 - \beta_l$
- half-Normal scale parameter: $\hat{\sigma} = \sigma_0 / \sqrt{1 - 2\sigma_0 \beta_{l^2}}$
- log-Normal mean: $\hat{\mu} = [\mu_0 - \sigma_0 \beta_{ln(l)}] / [1 - 2{\sigma_0}^2 \beta_{ln(l)^2}]$
- log-Normal standard deviation: $\hat{\sigma} = \sigma_0 / \sqrt{1 - 2{\sigma_0}^2 \beta_{ln(l)^2}}$
- Gamma shape parameter: $\hat{k} = k_0 + \beta_{ln(l)}$
- Gamma scale parameter: $\hat{q} = 1 / \left(\frac{1}{q_0} - \beta_l\right)$
- von Mises concentration parameter: $\hat{\nu} = \nu_0 + \beta_{cos(\theta)}$

iSSA FAQs

- Can I compare results from data sampled at different frequencies?
- Can I test effects of covariates that do not vary within a cluster?
- How many available steps do I need for each used step?
- How do I calculate the expected ‘selection-free’ speed based on my iSSA results?
- How do I interpret interactions?
- Can I estimate a Directional Bias (rather than Directional Correlation)?