Statistical Methods Webinar Series

March 2022

Integrated Step-Selection Analysis

Brian Smith & Tal Avgar

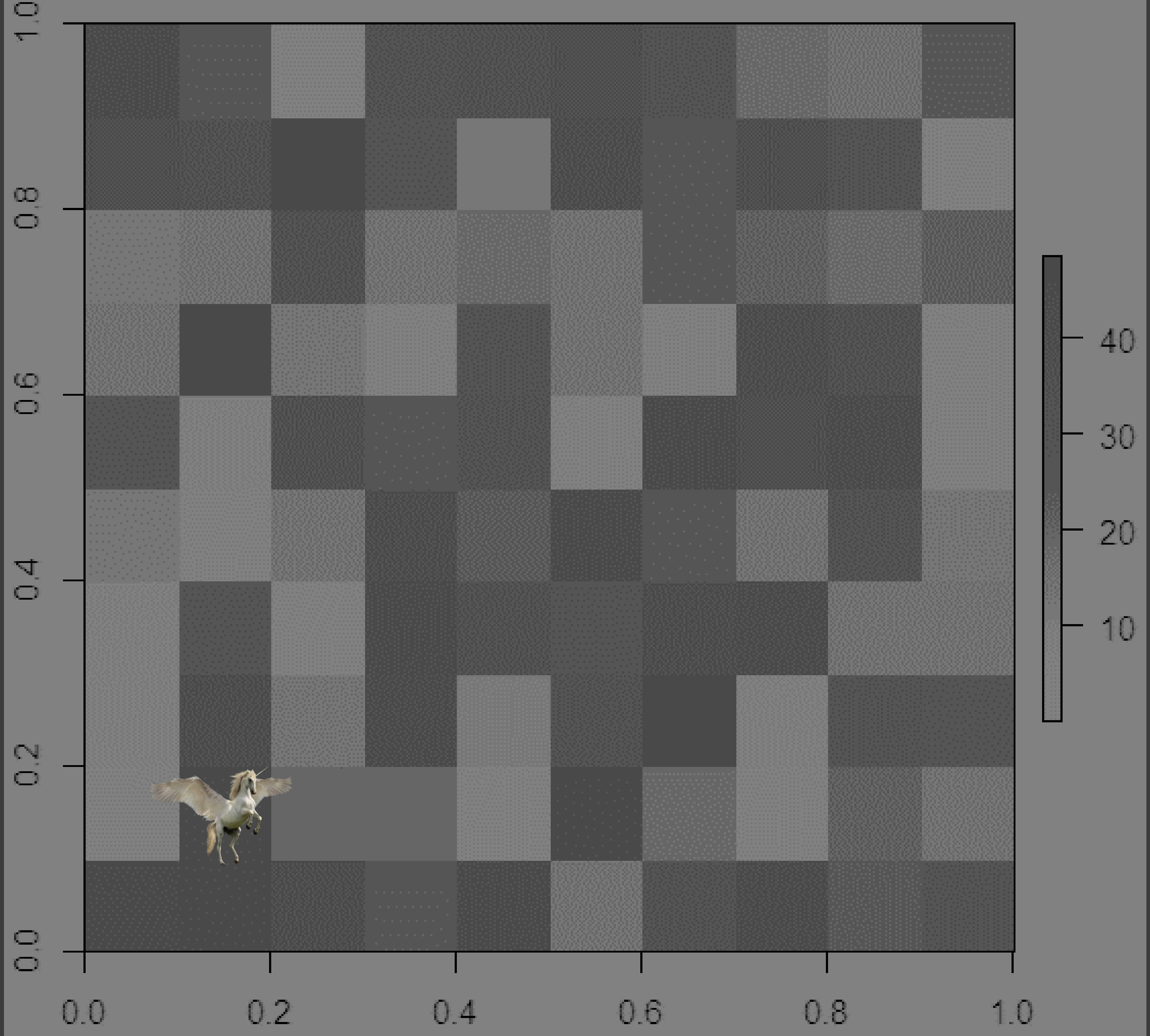
Land Acknowledgment

Utah State University Logan, Utah, resides on the ancestral, traditional, and contemporary lands of the Northwestern Band of the Shoshone Nation. The university resides on land ceded in the 1863 Treaty at Fort Bridger and other lands within our state. Today we recognize Utah's eight federally recognized Native nations, historic Indigenous communities in Utah, Indigenous individuals and communities past and present. In offering this land acknowledgment, we affirm Indigenous sovereignty, history, and experiences

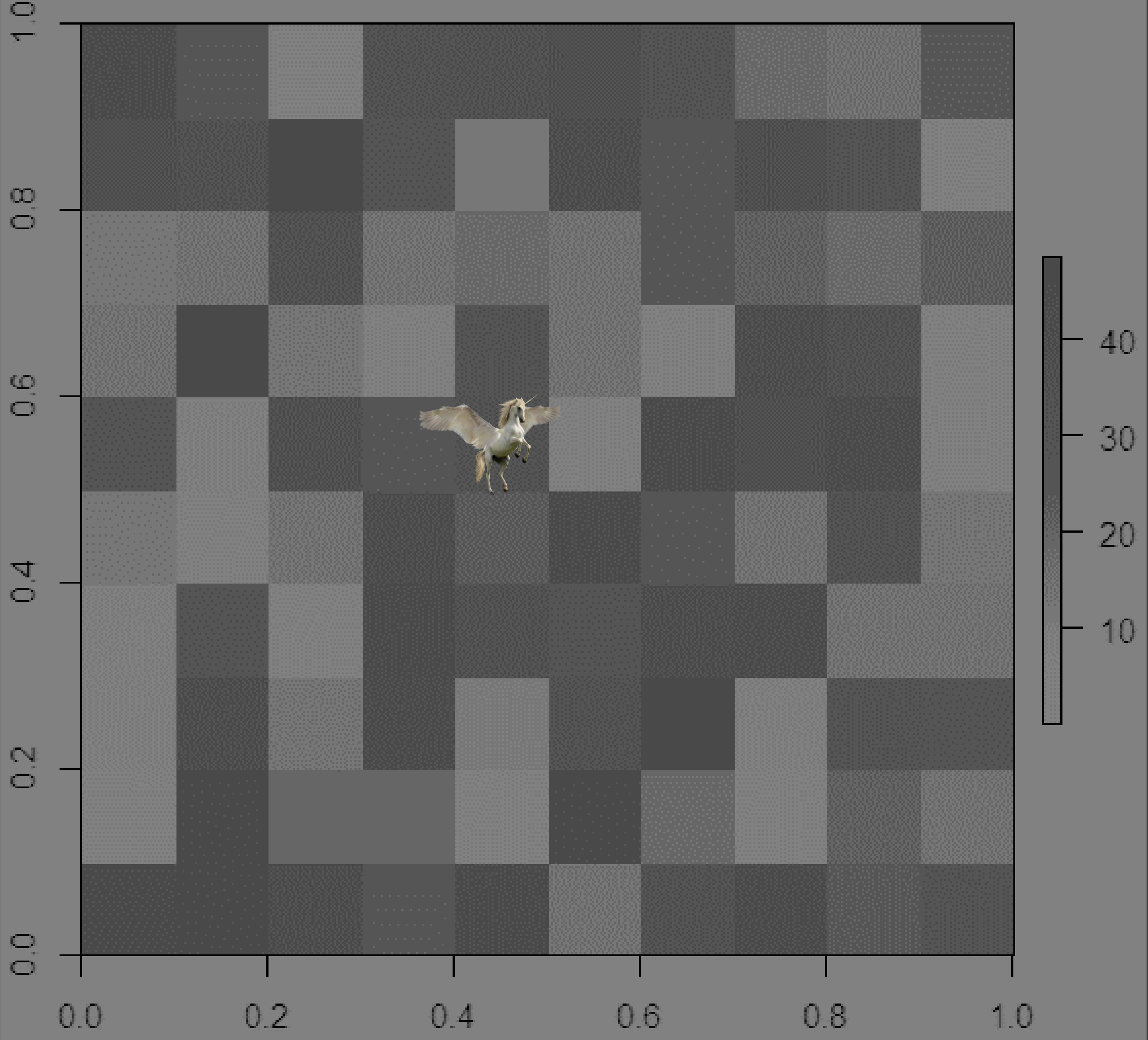
Locally Biased Correlated Random Walk

- A *discrete-time positional-jump process*

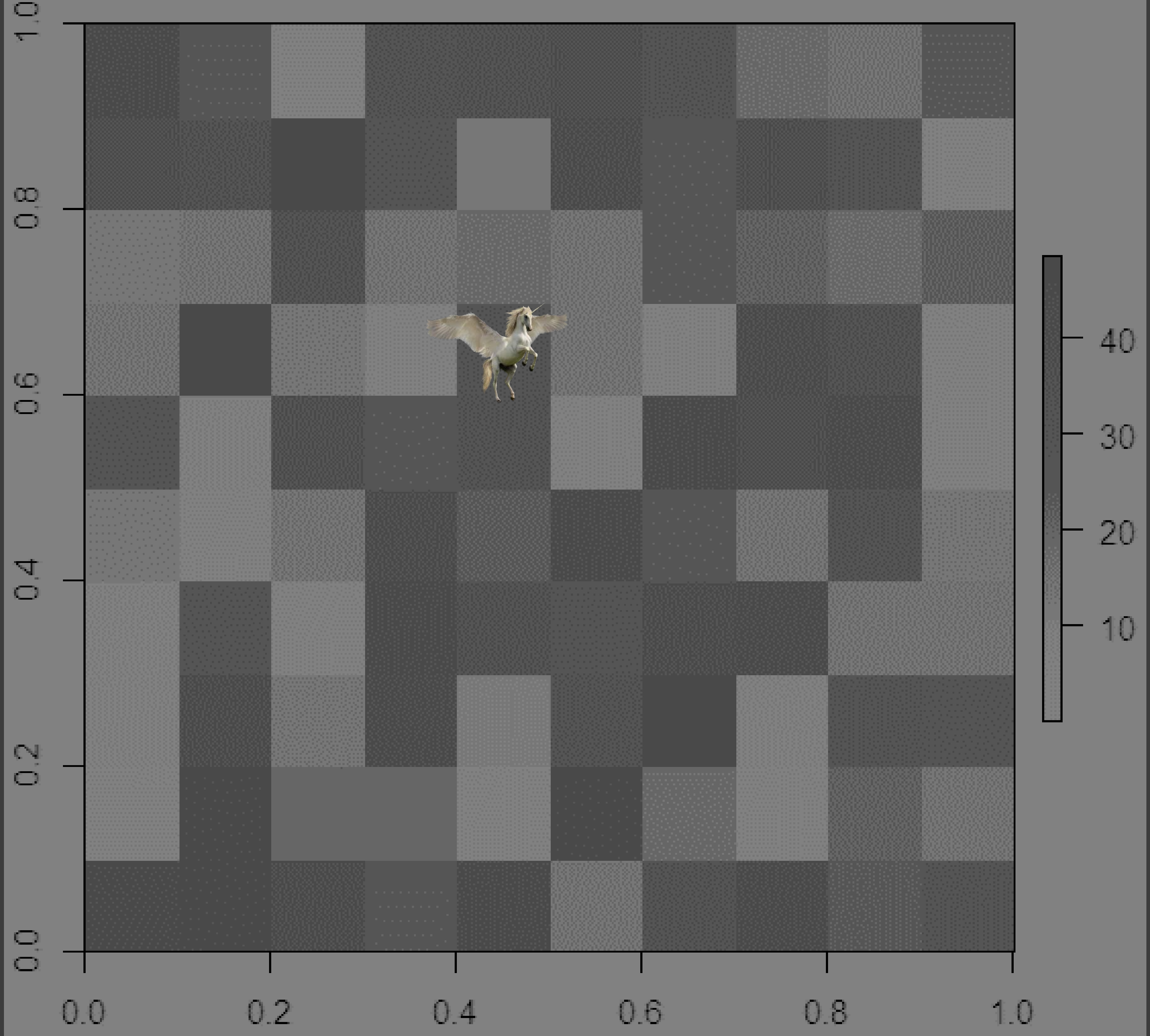
$t = 1$



$t = 2$



$t = 3$



Locally Biased Correlated Random Walk

- A *discrete-time positional-jump process*
- Jump (*step*) length is a random variable drawn from a parametric *step-length* distribution, with parameters that may depend on space (due to environmental conditions at the step's start-point; e.g., due to deep snow), time (e.g., due to circadian rhythm), and/or the previous step's length

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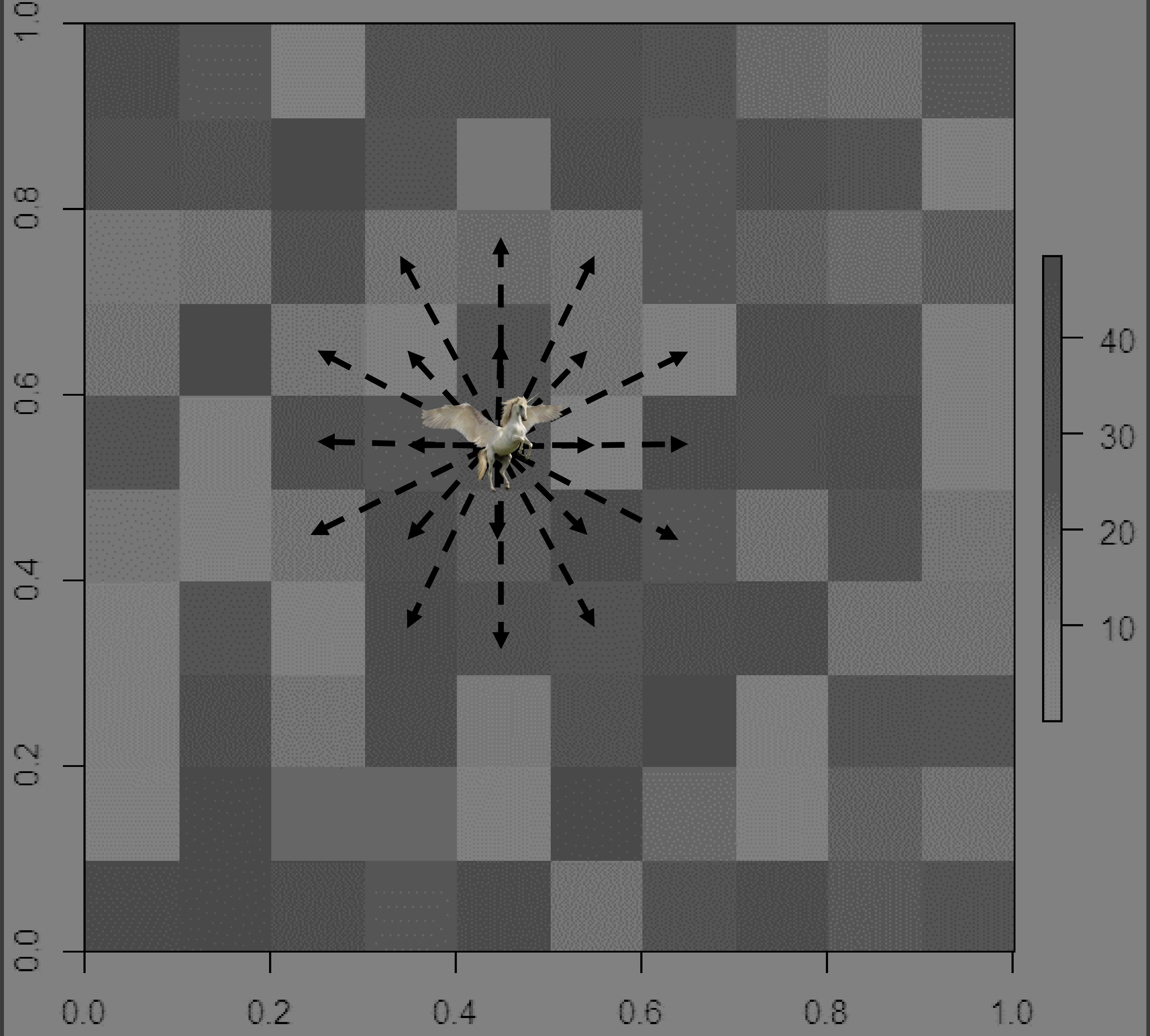

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- Angular deviation between the step's heading and the previous step's heading is a random variable drawn from a parametric *turn-angle* distribution, with parameters that may depend on space, time, and/or step length

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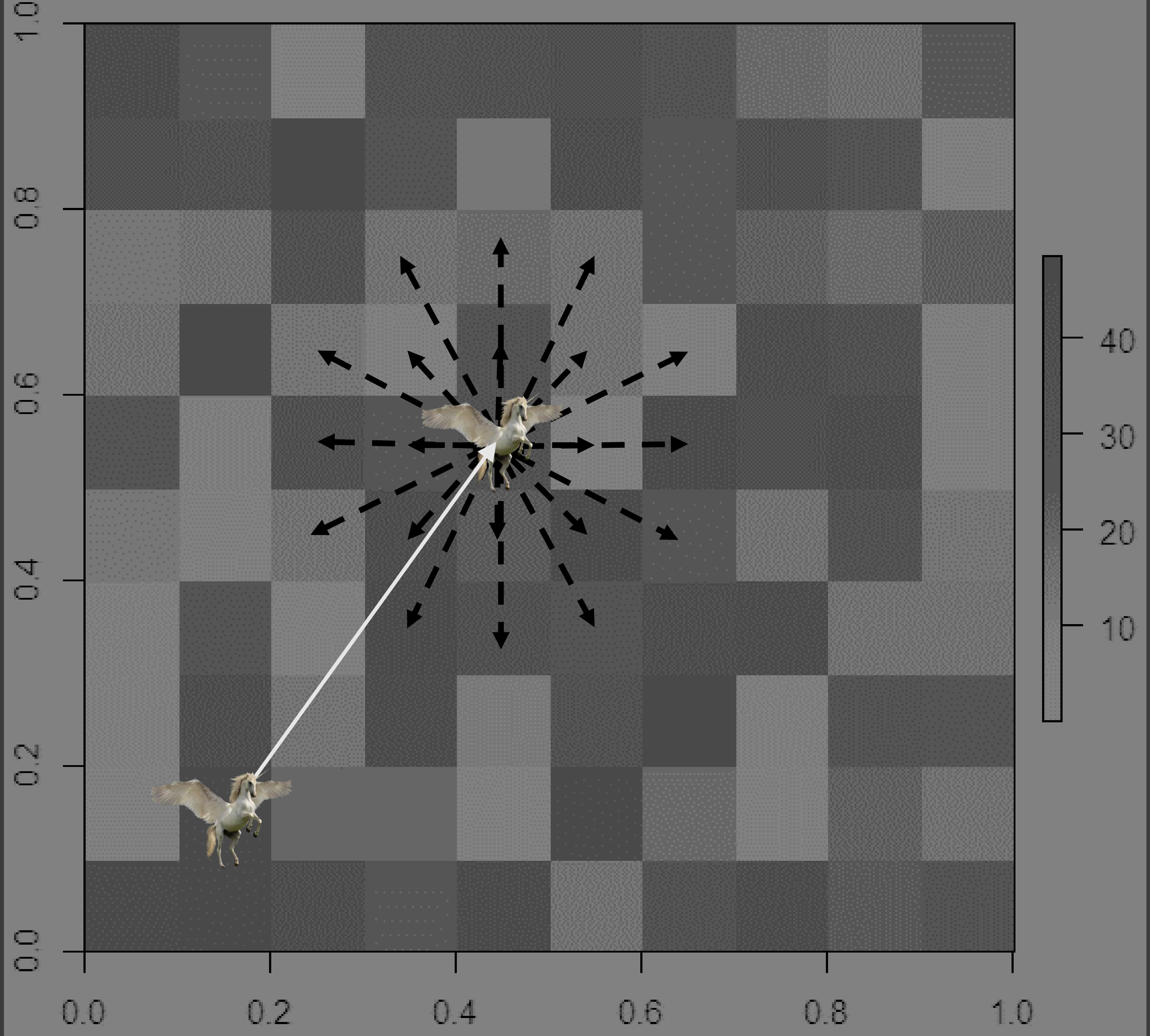

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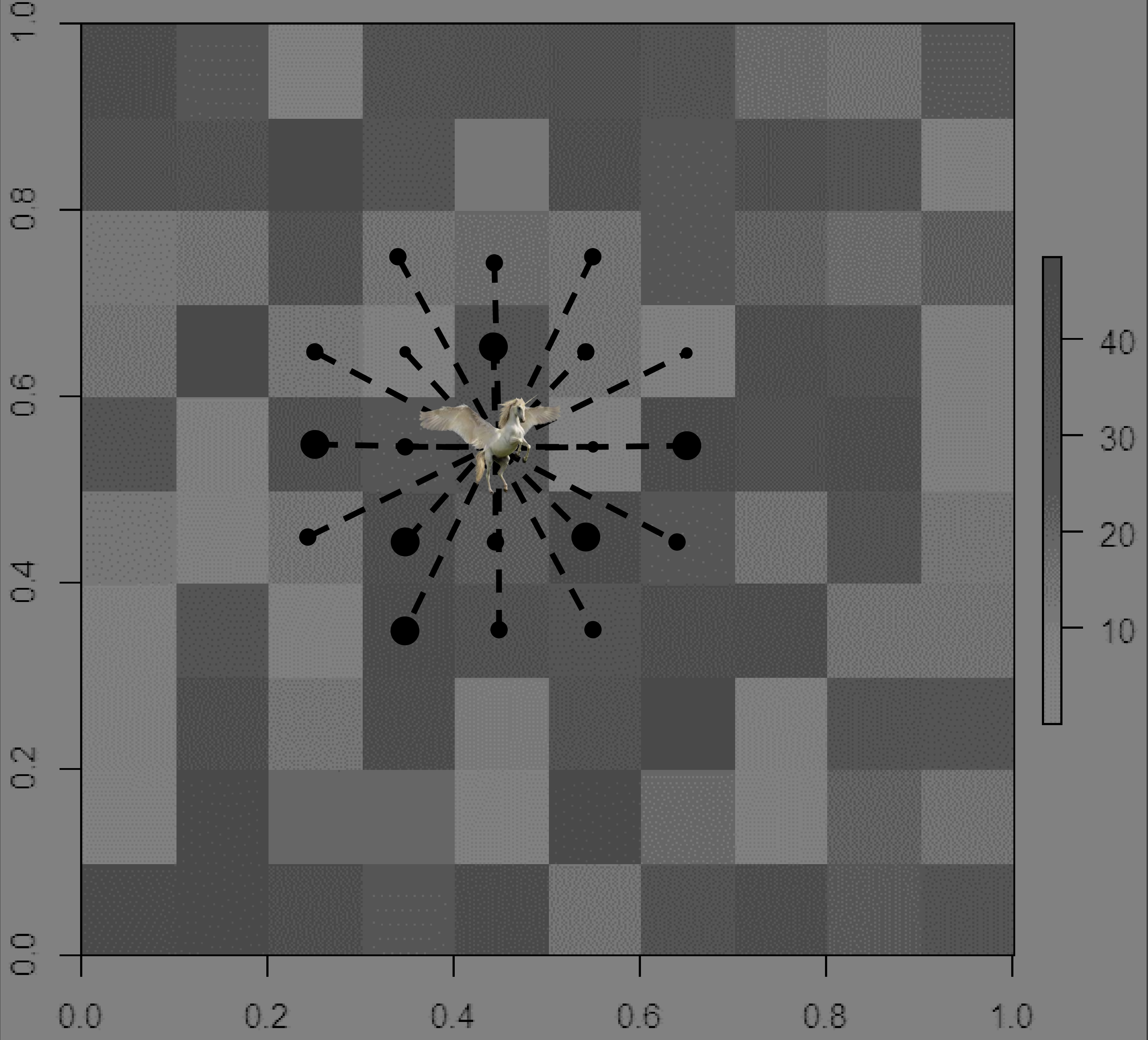
- Angular deviation between the step's heading and the previous step's heading is a random variable drawn from a parametric *turn-angle* distribution, with parameters that may depend on space, time, and/or step length
- The step's end-point position in *environmental space* (the *habitat*) is a random variable drawn from a selection-weighted distribution of available habitats. *Habitat selection strength* may vary in space and/or time

$t = 2$



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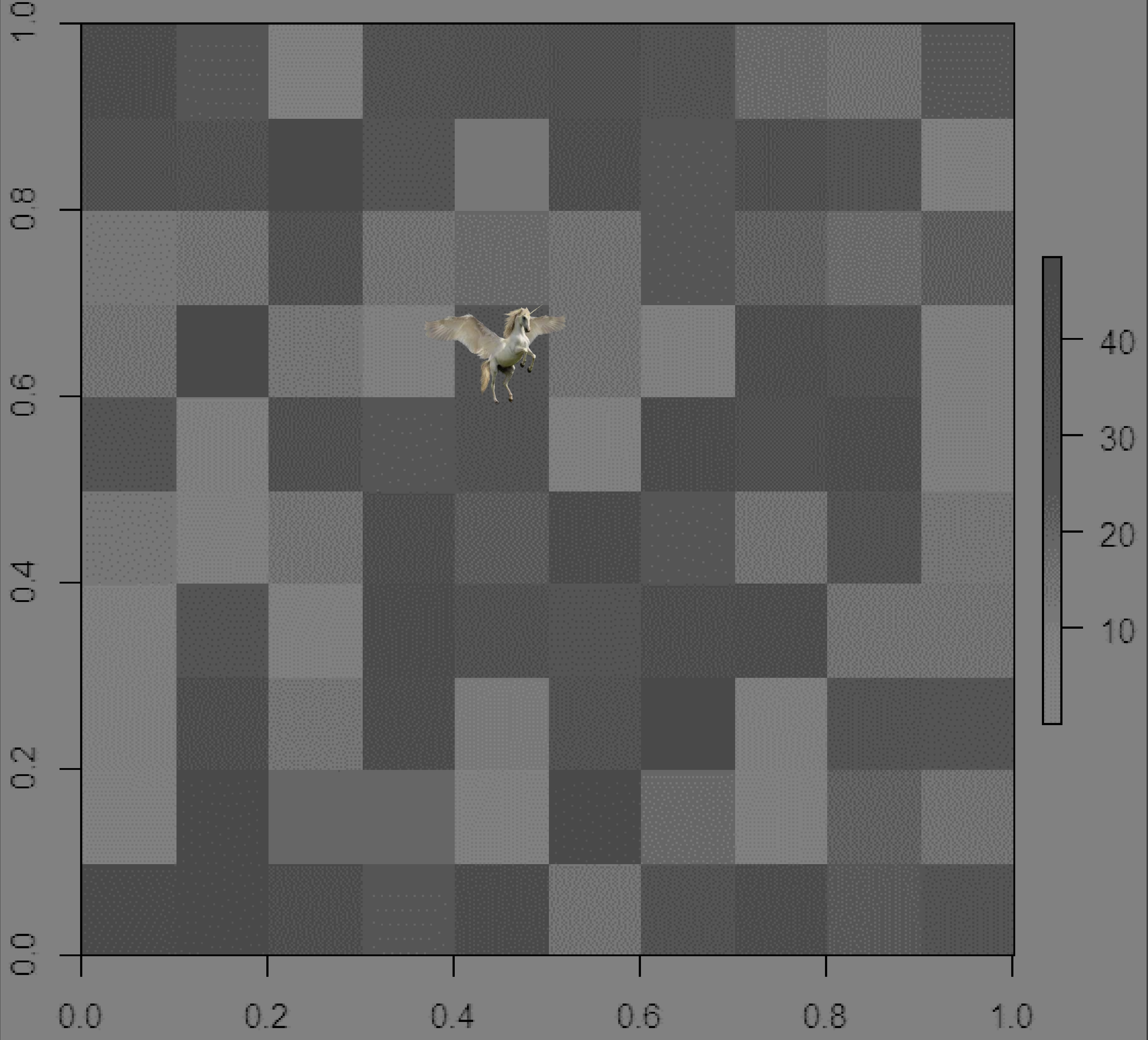

Locally Biased Correlated Random Walk

selection-free movement kernel

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iSSA

Question: how does one go about parametrizing a locally Biased Correlated Random Walk?

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Answer: integrated Step-Selection Analysis (iSSA)

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.

integrated Step-Selection Analysis (iSSA)

- Simultaneously estimating movement and habitat selection using conditional-logistic regression

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- Habitat availability emerges from the movement process

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- Simultaneously estimating movement and habitat selection using conditional-logistic regression
- Habitat availability emerges from the movement process
- Resolves statistical issues with temporal autocorrelation (typical in animal movement data)
- Straightforward hypotheses evaluation, including complex temporal dynamics
- Efficient parametrization of a mechanistic movement model (a locally Biased Correlated Random Walk): allows predicting dynamical space-use patterns

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iSSA in practice

1. **Sample**
2. **Attribute**
3. **Analyze**
4. **Infer**
5. **Predict**

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Fieberg, J, Signer, J, Smith, B, Avgar, T. (2021) A 'How to' guide for interpreting parameters in habitat-selection analyses. *J Anim Ecol*, 90, 1027–1043.

iSSA in practice

1. Sample
2. Attribute
3. Analyze
4. Infer
5. Predict

- Clean your data (

)
- Make sure all steps used in the analysis have the <u>same step duration</u>
- Consider removing ‘non-movement’ steps

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iSSA in practice

1. **Sample:** create *clusters* by matching each *used step* with a set of *available steps*' randomly sampled from tentative analytical distributions of step-lengths and turn-angles; these clusters (AKA *strata*) form the basic units of replication

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- ❑ Four possible step-length distributions
  - Exponential (include $step\ length$ as a covariate)
  - Half-Normal (include $[step\ length]^2$)
  - Log-Normal (include $\mathrm{LOG}[step\ length]^2$ and possibly $\mathrm{LOG}[step\ length]$)
  - Gamma (include $step\ length$ and/or $\mathrm{LOG}[step\ length]$)

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   - ❑ Four possible step-length distributions
   - ❑ Turn-angle distribution: von Mises (include $\cos[turn\ angle]$ as a covariate)

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   - ❑ The tentative parameters of these distributions (e.g., the Exponential *rate parameter* or the von Mises *concentration parameter*) could be estimated from the data (from the observed step lengths and turn angles)

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   - ❑ There is no 'right' number of available steps; at least one, the more the merrier

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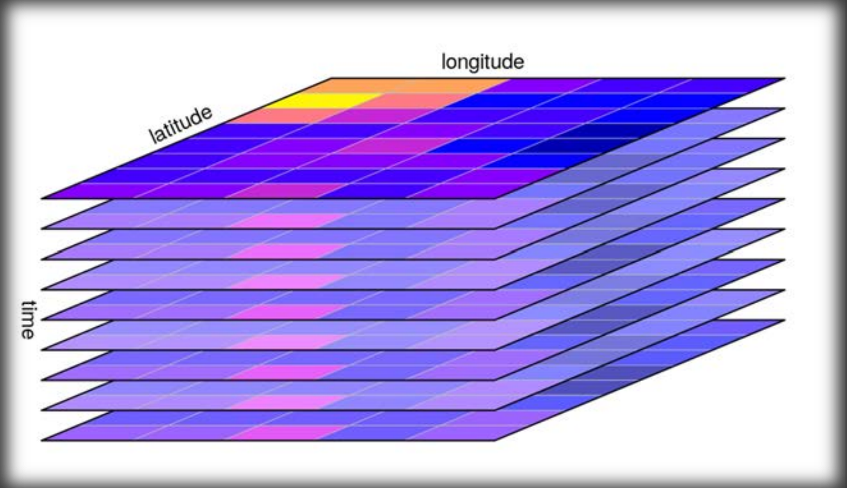
iSSA in practice

1. **Sample**
2. **Attribute:** for each step (used and available) extract and append the step's length (and possibly its turn angle), as well as any covariates of interest (including temporally dynamic covariates)



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   - Possible movement attributes: $step\ length$, $\mathrm{LOG}[step\ length]$, $[step\ length]^2$; $\mathrm{LOG}[step\ length]^2$, $\mathrm{COS}[turn\ angle]$

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   - ❑ Habitat selection is quantified in relation to the values of environmental covariates <u>at the step's end-point (matched in time and space)</u>

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   - ❑ Habitat selection is quantified in relation to the values of environmental covariates at the step's end-point (matched in time and space)
   - ❑ Attributes that are extracted at the step's start-point (and hence do not vary among steps within a cluster; including temporal covariates) can still be used as interactions with movement and/or habitat-selection covariates

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iSSA in practice

1. **Sample**
2. **Attribute**
3. **Analyze:** contrast attributes of used ($y = 1$) and available ($y = 0$) steps using a conditional-logistic regression (with cluster ID as *strata*), including appropriate interactions

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   - ❑ Prediction: when the animal moves fast, it also moves straight
     Interaction: $\mathrm{LOG}[step\ length] \times \mathrm{COS}[turn\ angle]$
   - ❑ Prediction: rough terrain inhibits movement
     Interaction: $[step\ length]^2 \times roughness$_start
   - ❑ Prediction: selection for water increases when it is hot
     Interaction: $temperature\_start \times water\_end$

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iSSA in practice

1. **Sample**
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4. **Infer:** use standard inferential tools to evaluate hypotheses regrading habitat selection and/or movement

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iSSA in practice

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3. **Analyze**
4. **Infer**: use standard inferential tools to evaluate hypotheses regrading habitat selection and/or movement
   - P-values, standard errors, AIC, likelihood ratio
   - Concordance (the probability that a used step is ranked higher than an available step; within-cluster ROC AUC)
   - Likelihood-based pseudo R^2 (requires an appropriate null model; no such thing as an 'intercept only' conditional-logistic regression)

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iSSA in practice

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4. **Infer**: use standard inferential tools to evaluate hypotheses regrading habitat selection and/or movement
   - ❑ Cross-validation is tricky
   - ❑ Used-Habitat Calibration Plots [Fieberg, J.R., Forester, J.D., Street, G.M., Johnson, D.H., ArchMiller, A.A. and Matthiopoulos, J. (2018) Used-habitat calibration plots: a new procedure for validating species distribution, resource selection, and step-selection models. *Ecography*, 41, 737-752]

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iSSA in practice

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3. **Analyze**
4. **Infer**: use standard inferential tools to evaluate hypotheses regrading habitat selection and/or movement
   - It is highly recommended to use *Relative Selection Strength* (RSS) when interpreting and plotting results. RSS is the relative intensity of use of two equally available habitat units belonging to different sectors of environmental space (categorical), or that differ by one unit along one environmental dimension (continuous) [Avgar, T., Lele, S.R., Keim, J.L., Boyce, M.S. (2017) Relative Selection Strength: Quantifying effect size in habitat- and step-selection inference. *Ecol Evol*, 7, 5322-5330]

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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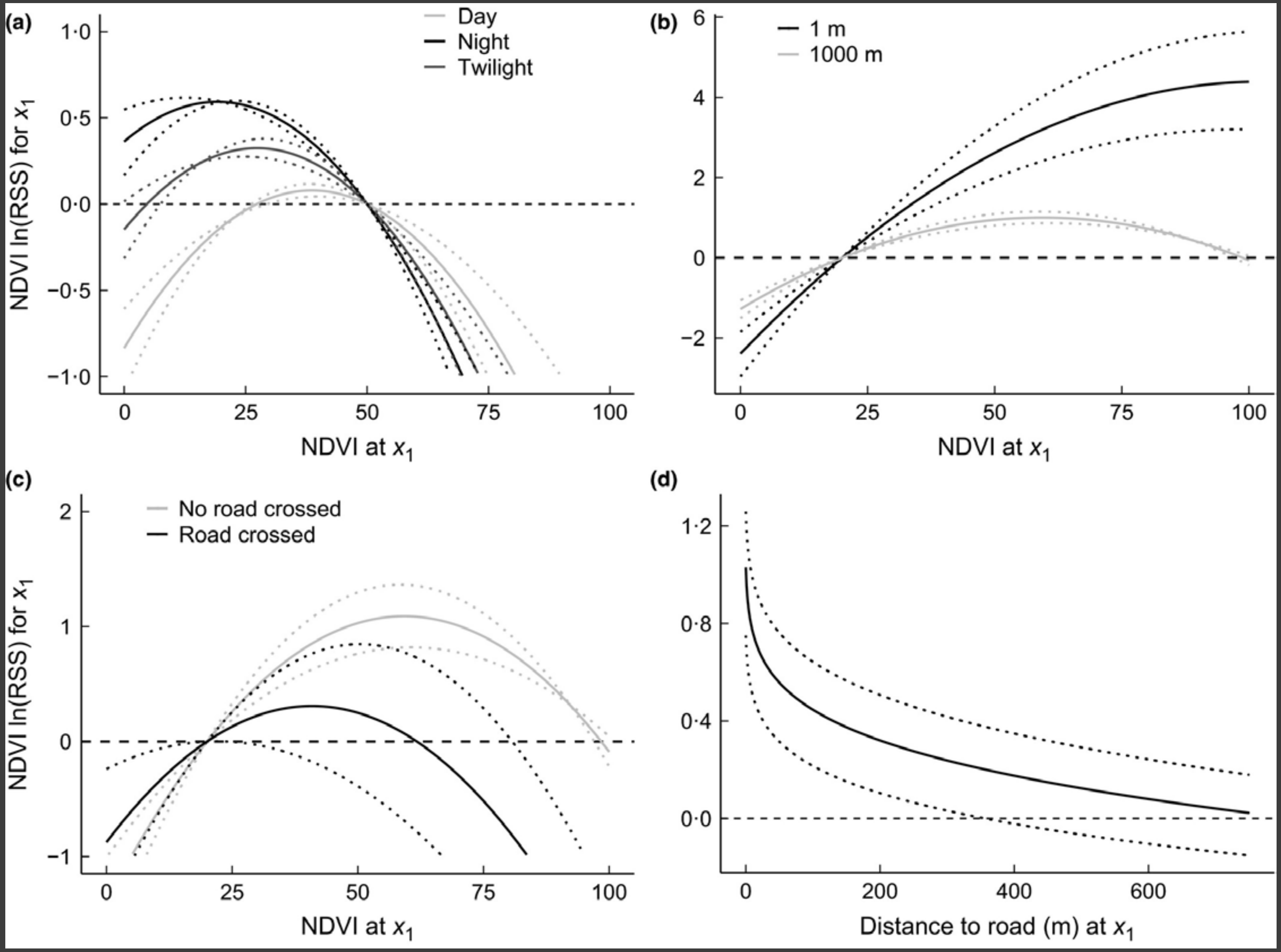
Example: log RSS for NDVI



(a) RSS for selecting location x_1 over x_2 (NDVIx_2 = 50%)

(b) RSS for x_1 over x_2 (NDVIx_2 = 20%, x_1 and x_2 are equidistance from a road)

(c) RSS for x_1 over x_2 (NDVIx_2 = 20%) for steps that did or did not cross a road

(d) RSS of location x_1 over x_2 (NDVIx_2 = 20%, NDVIx_1 = 50%)

Prokopenko, C.M., Boyce, M.S. and Avgar, T. (2017) Characterizing wildlife behavioural responses to roads using integrated step selection analysis. *J Appl Ecol*, 54: 470-479.

iSSA in practice

1. **Sample**
2. **Attribute**
3. **Analyze**
4. **Infer**: use standard inferential tools to evaluate hypotheses regrading habitat selection and/or movement
   - The *selection-free movement kernel* is obtained by updating the tentative step-length and turn-angle distributions using the corresponding iSSA coefficient estimates

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If available step lengths were sampled from an exponential distribution with tentative rate parameter λ_0, and the step length (l) was included as a covariate in the analysis, with resulting coefficient estimate β_l, the adjusted (selection-free) step length Exponential rate parameter is given by:

$$\hat{\lambda} = \lambda_0 - \beta_l$$

If available step lengths were sampled from a half-Normal distribution with scale parameter (standard deviation) σ_0, and the squared step length (l^2) was included as a covariate in the analysis, with resulting coefficient estimate β_{l^2}, the adjusted (selection-free) step length half-Normal scale parameter is given by:

$$\hat{\sigma} = \frac{\sigma_0}{\sqrt{1 - 2\sigma_0 \beta_{l^2}}}$$

If available step lengths were sampled from a log-Normal distribution with tentative mean μ_0 and standard deviation σ_0, and the log-transformed step length ($\ln[l]$) and its square ($\ln[l]^2$) were included as covariates in the analysis, with resulting coefficient estimates $\beta_{\ln[l]}$ and $\beta_{\ln[l]^2}$ (respectively), the adjusted (selection-free) step length log-Normal mean and standard-deviation parameters are given by:

$$\begin{cases} \hat{\mu} = \dfrac{\left(\mu_0 - \sigma_0 \beta_{\ln[l]}\right)}{\left(1 - 2{\sigma_0}^2 \beta_{\ln[l]^2}\right)} \\ \hat{\sigma} = \dfrac{\sigma_0}{\sqrt{1 - 2{\sigma_0}^2 \beta_{\ln[l]^2}}} \end{cases}$$

If available step lengths were sampled from a gamma distribution with tentative shape k_0 and scale q_0, and the step length (l) and its log-transform ($\ln[l]$) were included as covariates in the analysis, with resulting coefficient estimates β_l and $\beta_{\ln[l]}$ (respectively), the adjusted (selection-free) step length gamma shape and scale parameters are given by:

$$\begin{cases} \hat{k} = k_0 + \beta_{\ln[l]} \\ \hat{q} = \dfrac{1}{\left(\dfrac{1}{q_0} - \beta_l\right)} \end{cases}$$

If available turn angles were sampled from von Mises distribution with tentative concentration parameter ν_0, and the cosine of the turn angle ($\cos[\theta]$) was included as a covariate in the analysis, with resulting coefficient estimate $\beta_{\cos[\theta]}$, the adjusted (selection-free) von Mises concentration parameter is given by:

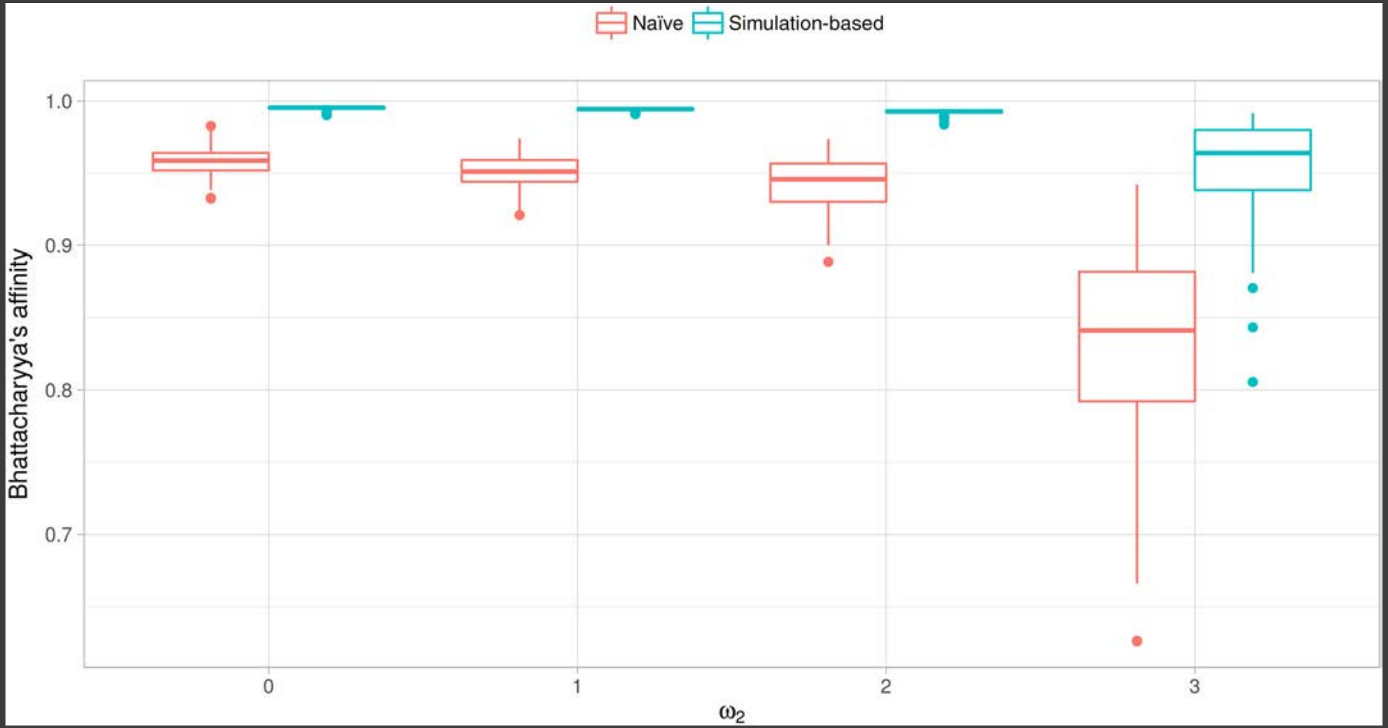
$$\hat{\nu} = \nu_0 + \beta_{\cos[\theta]}$$

iSSA in practice

1. Sample
2. Attribute
3. Analyze
4. Infer

Predict: simulate trajectories

Agreement between the true *utilization distribution* and its estimates using the 'naïve' and 'simulation-based' approaches



Signer, J., Fieberg, J., and Avgar, T. (2017) Estimating utilization distributions from fitted step-selection functions. *Ecosphere,* 8, e01771.

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iSSA FAQs

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What does it mean if the parameters of the *selection-free movement kernel* (the adjusted shape/scale/concentration of the step-length or turn-angle distributions) come out negative?

- ❑ If the von Mises concentration parameter is negative, the adjusted turn angle distribution is centred at π ($180°$) rather than 0 (negative directional autocorrelation; the animal is more likely to turn back)
- ❑ If any of the parameters of the step-length distribution is negative, the model is ill-fitted
  - Try a different step-length distribution
  - Include an interaction between step-length and turn-angle (e.g., $\mathrm{LOG}[step\ length] \times \mathrm{COS}[turn\ angle]$)
  - Include additional step-length interactions (e.g., $[step\ length]^2 \times\ roughness$_start)
  - Remove ‘non-movement’ steps (e.g., based on a step-length threshold)
  - Resample the data to a coarser temporal resolution (longer step duration)

iSSA FAQs

How can I combine data from multiple individuals?

- If all you want is 'population-level' inference, include the same number of clusters from each individual in a single model
- Mixed-effects approach: tricky in conditional logistic regression, use a Poisson regression instead [Muff, S., Signer, J., Fieberg, J. (2020) Accounting for individual-specific variation in habitat-selection studies: Efficient estimation of mixed-effects models using Bayesian or frequentist computation. *J Anim Ecol*. 89, 80-92]
- "Two-step" approach: first conduct independent iSSA for each individual, then summarize across individual coefficient estimates using weighted bootstrapping [e.g., using AIC weights, as in Scrafford, M.A., Avgar, T., Heeres, R., Boyce, M.S. (2018) Roads elicit negative movement and habitat-selection responses by wolverines (*Gulo gulo luscus*), *Behav Ecol*, 29, 534-542], or linear models with inverse-variance weights [as in Dickie, M., McNay, S.R., Sutherland, G.D., Cody, M., Avgar, T. (2020) Corridors or risk? Movement along, and use of, linear features varies predictably among large mammal predator and prey species. *J Anim Ecol*, 89, 623-634]

iSSA FAQs

Can iSSA account/test for directional bias (rather than just directional persistence)?

- Yes. Given a hypothetical preferred direction, each step can be characterised by its angular deviation from this preferred direction, and the coefficient associated with the cosine of this angular deviation is an estimator of the concentration parameter of the corresponding von Mises distribution [the larger it is, the stronger the bias; Duchesne, T., D. Fortin, and L-P. Rivest (2015) Equivalence between Step Selection Functions and Biased Correlated Random Walks for statistical inference on animal movement. *PLoS ONE,* 10(4): e0122947]

iSSA FAQs

Can I (and should I) combine iSSA with behavioral-state assignment or path segmentation analysis (e.g., a Hidden Markov Model)?

- Yes and yes [e.g., as in Picardi, S., Coates, P.S., Kolar, J., Mathews, S.R., O’Neil, S., Dahlgren, D.K. (2022) Behavioral state-dependent habitat selection and implications for animal translocations. *J Appl Ecol*, 59, 624-635]

Thank you!


ARE THERE ANY QUESTIONS? FEEL FREE TO ASK ANY-THING AT ALL.
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IF SOMEONE GIVES YOU A WEDGIE AT THE MOMENT YOU DIE, WILL YOU HAVE IT FOR ETERNITY?