Workshop on R and movement ecology:

Hong Kong University, Jan 2018

Eric Dougherty, Dana Seidel, Wayne Getz

Lecture 5

Behavioral analysis:
FME, CAM, and movement syndromes

Spatio-temporal scales of movement analysis

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  - break movement down into mechanistic elements
  - e.g., time taken and distance moved to complete one stride, one trot, one gallop sequence, one wingflap, one hop, jump or leap, etc.
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What is a movement syndrome?

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In animals: movement syndromes will allow for the identification of both personality and movement types

As with behavioral syndromes, movement syndromes can be integrative in linking the nature (genetics) and nuture (environment) aspects of individual (physiology, behavior) and communal (ecology, evolution) processes.

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FMEs and related stereotypical behavioral sequences

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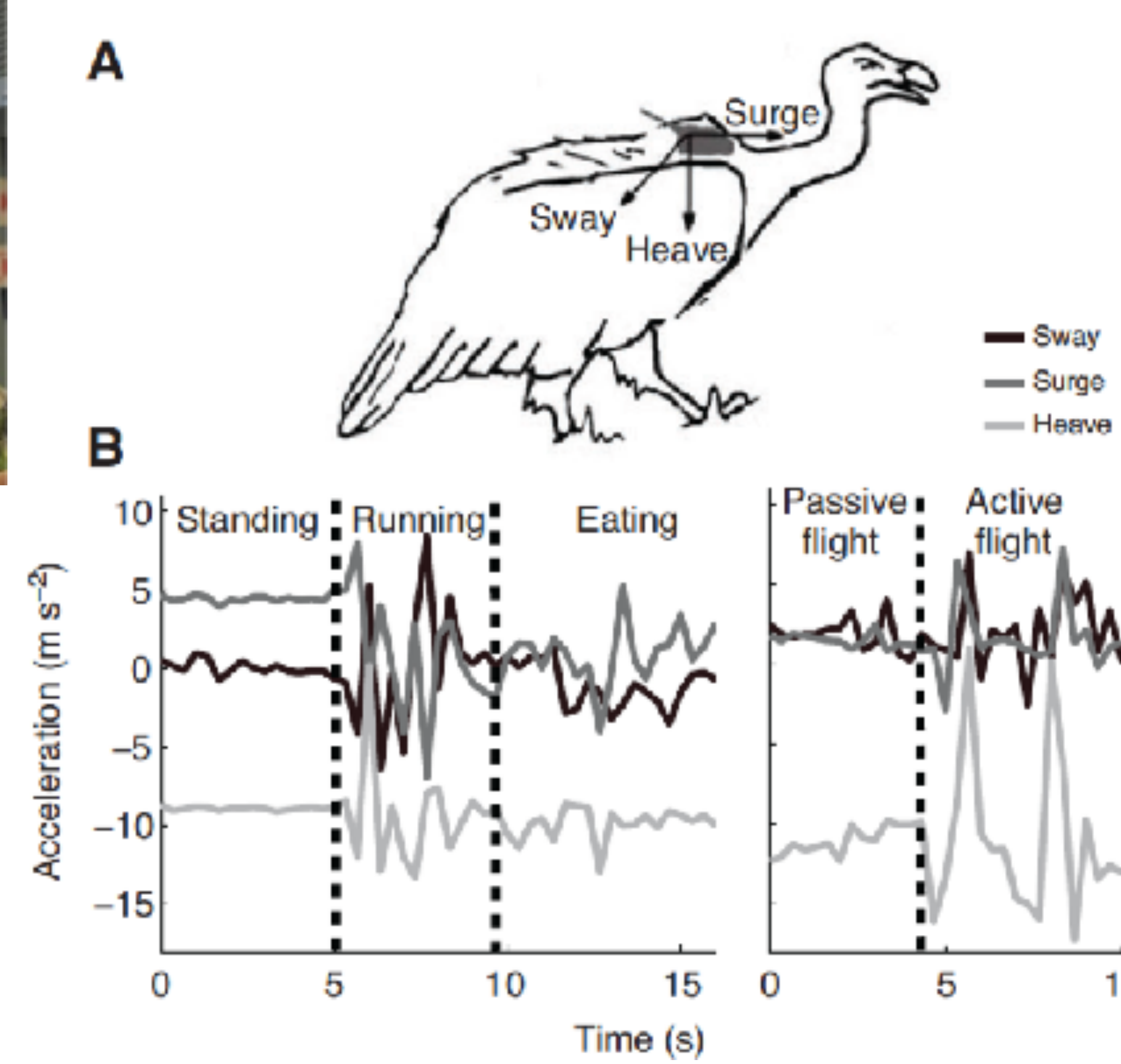
- input data: CAMS (duration, mix, sequencing, auxilliary env. data)
- Syndrome output: categorization of a point located in a region of processed input data space (region demarcated using: state identification methods—hidden Markov models or HMM; machine learning methods)

FME/short CAM Machine learning

Machine learning algorithm	Accuracy Mean	s.d.	95% confidence interval
ANN	84.81	1.92	84.27, 85.36
CART	85.95	2.02	85.38, 86.53
LDA	86.74	1.27	86.38, 87.10
RF	90.88	1.46	90.47, 91.30
SVM	87.01	1.61	86.55, 87.47

ANN, artificial neural network; CART, classification and regression trees; LDA, linear discriminant analysis; RF, random forest; SVM, support vector machine.
N=50 runs.



Using tri-axial acceleration data to identify behavioral modes of free-ranging animals: general concepts and tools illustrated for griffon vultures

Ran Nathan, Orr Spiegel, Scott Fortmann-Roe, Roi Harel, Martin Wikelski, Wayne M. Getz

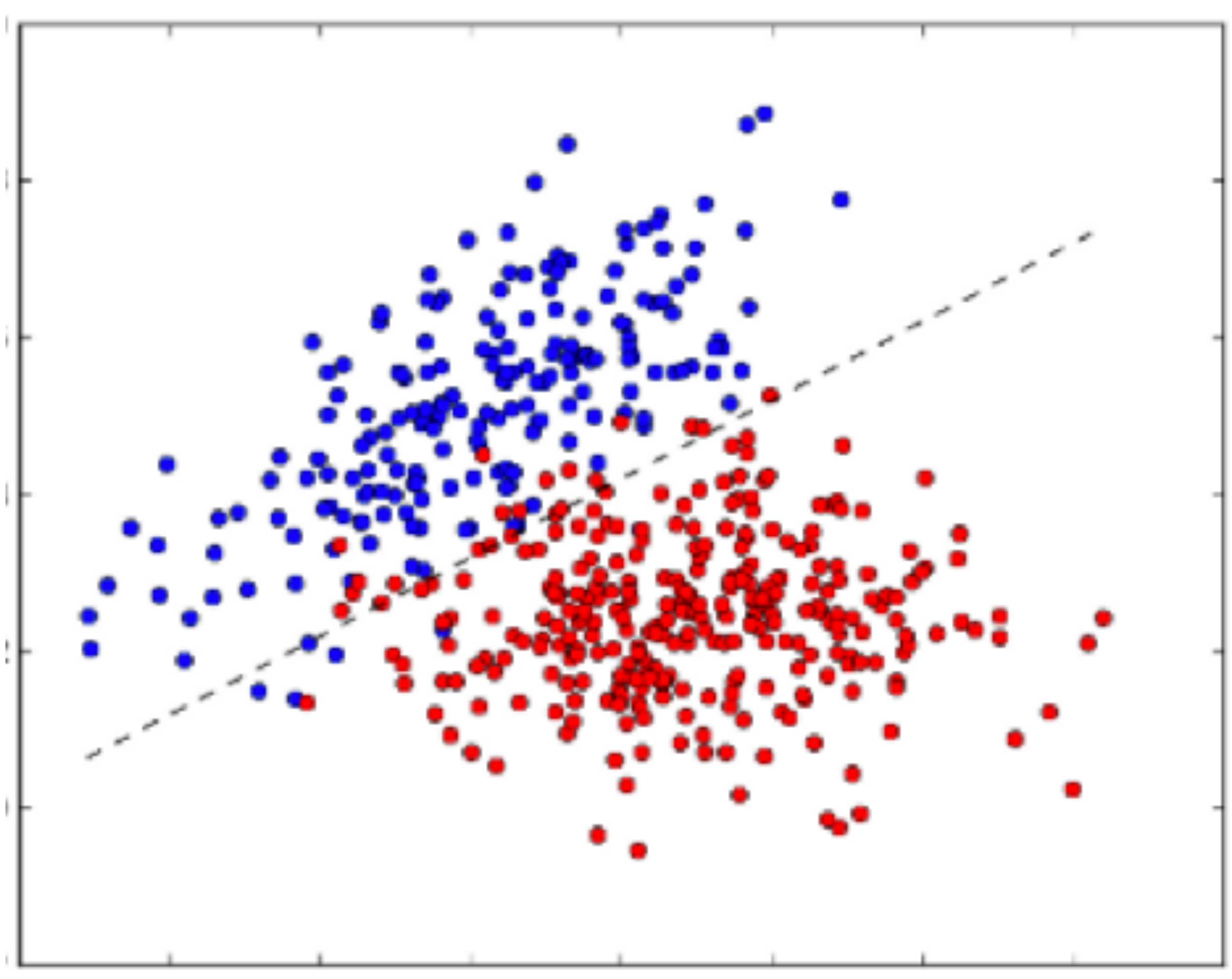
Journal of Experimental Biology 2012 215: 986-996;
doi: 10.1242/jeb.058602

Pattern (Machine) Learning Algorithms

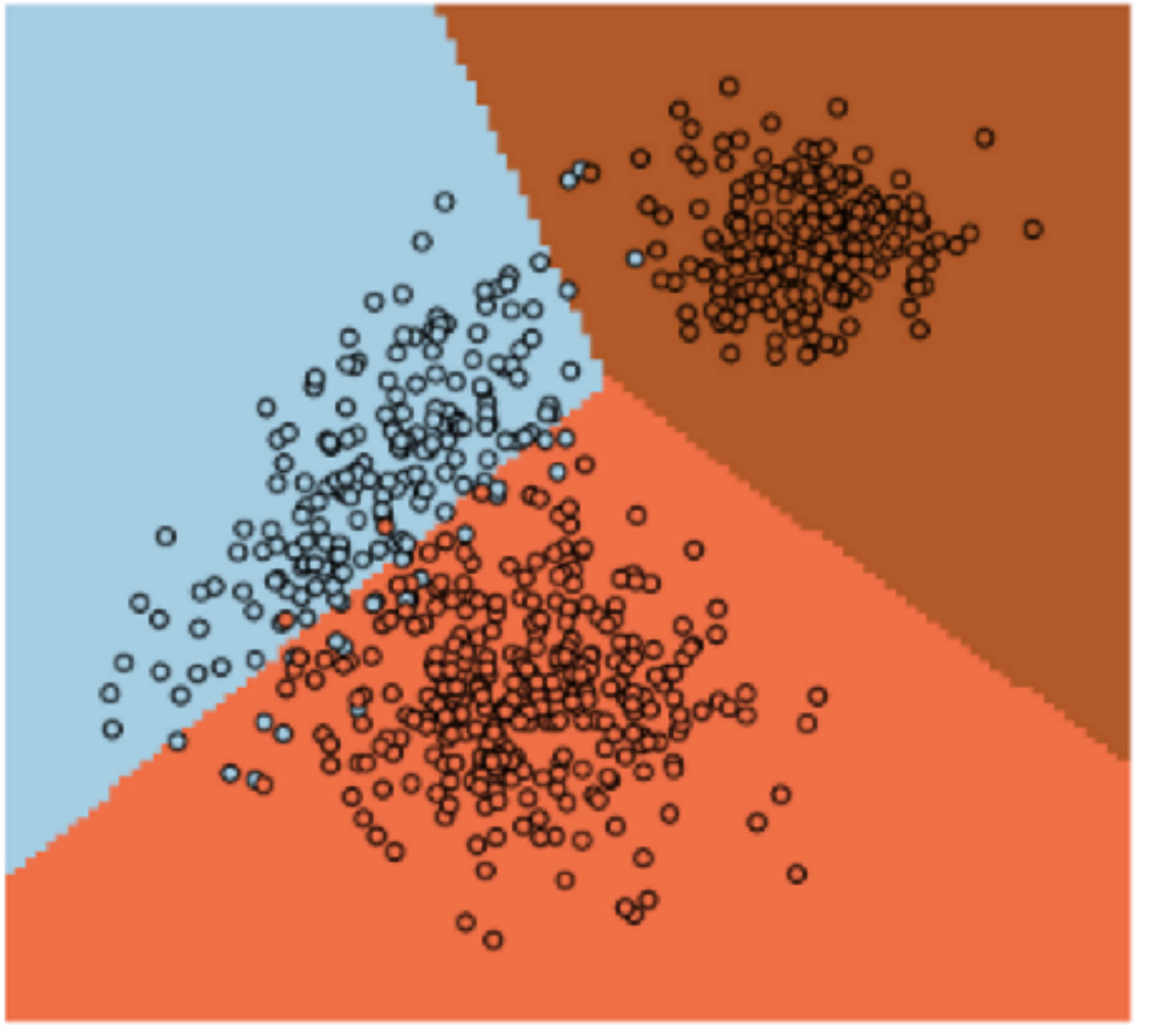
Linear discriminant analysis (LDA)

- reduces dimensionality while minizing variance
- parametric assumption of Gaussian distribution of classes
- typically avoids overfitting (i.e. produces fewer more general categories

Two categories
one separator equation

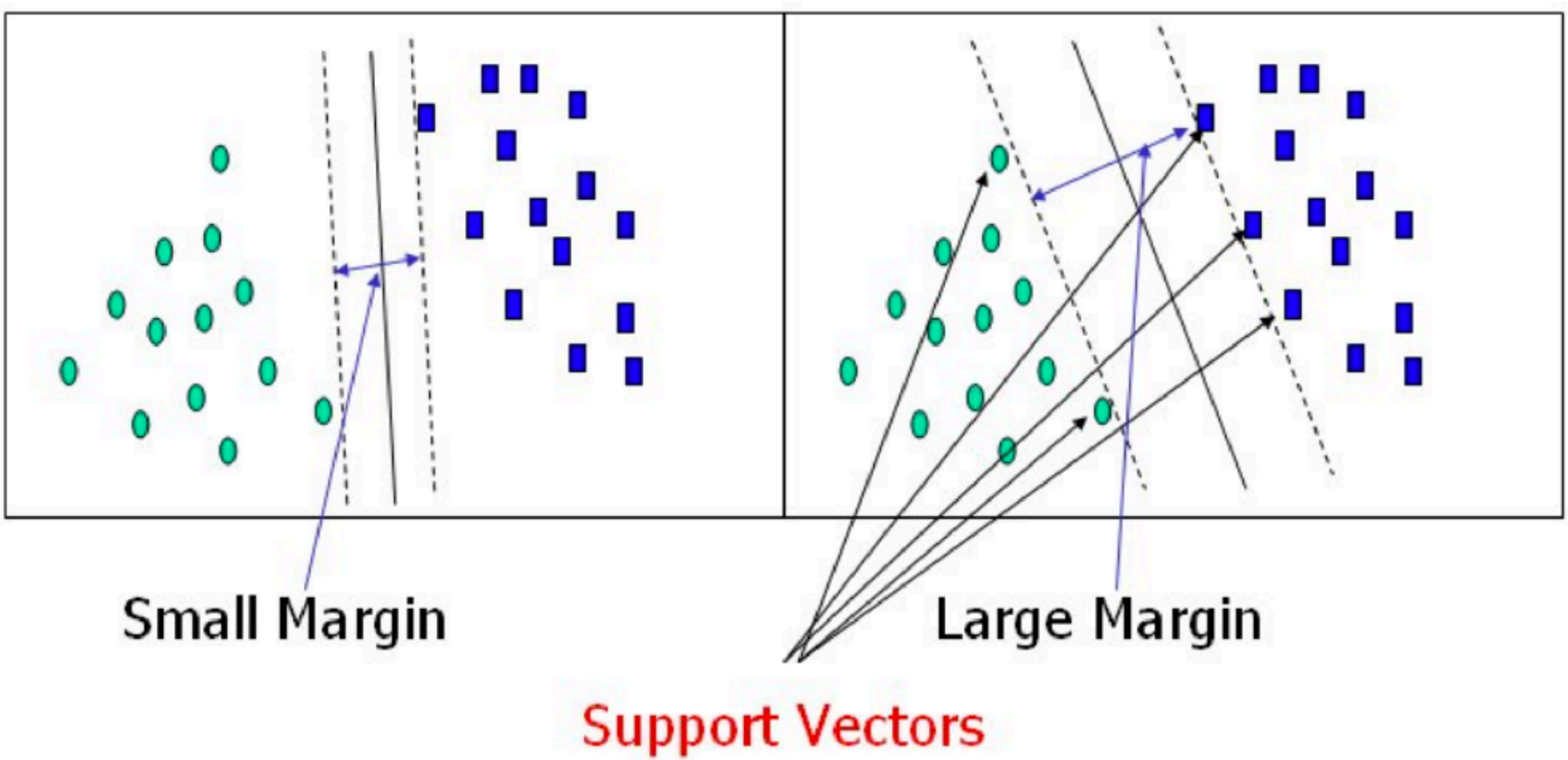


There categories
three separator equations



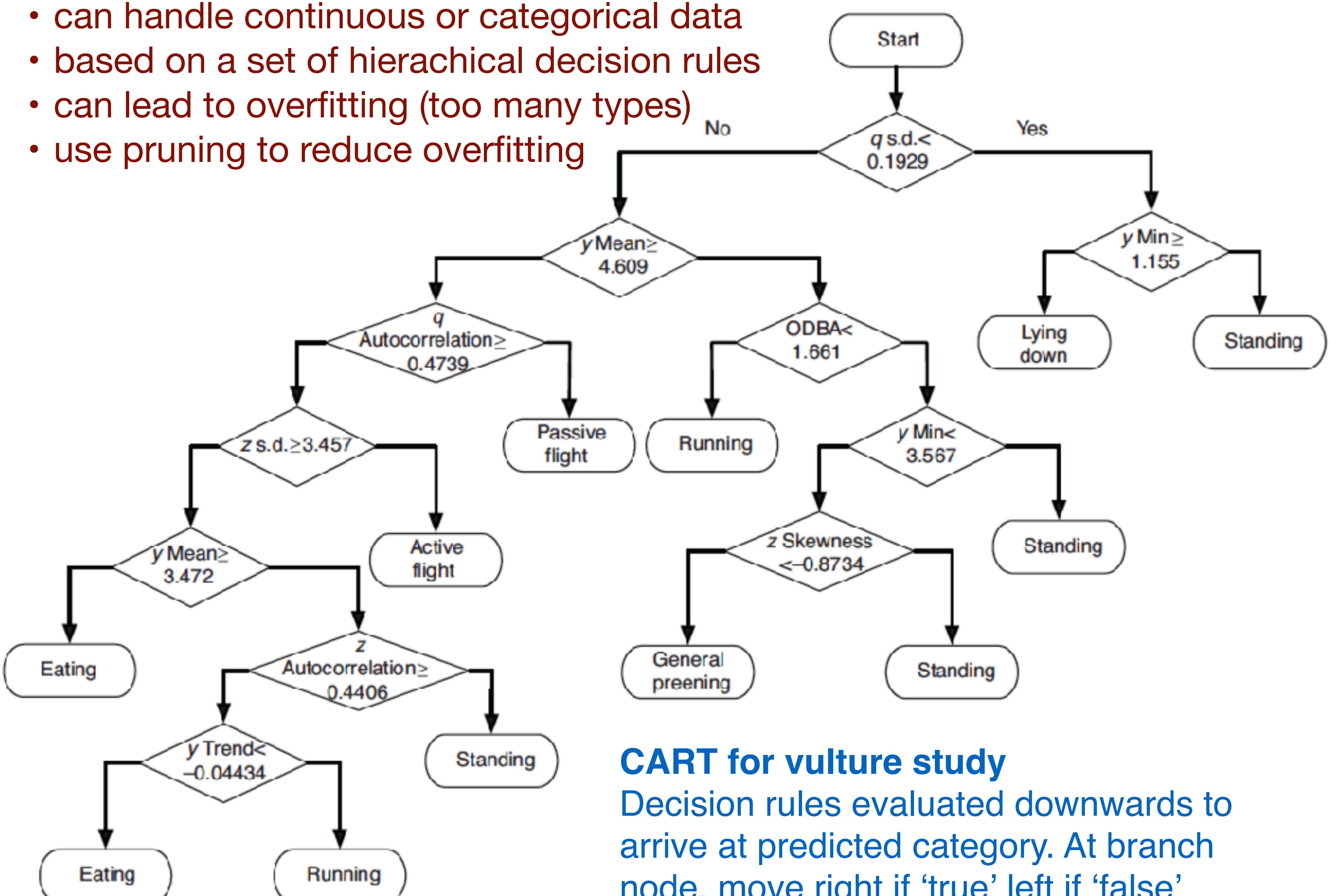
Support vector machines (SVM)

- essentially binary: group of interest versus the rest
- maximize distance of group from separating hyperplane
- repeat several times: for different groups to get multiple groups
- computationally intensive



Classification and Regression Trees (CART)

- can handle continuous or categorical data
- based on a set of hierachical decision rules
- can lead to overfitting (too many types)
- use pruning to reduce overfitting

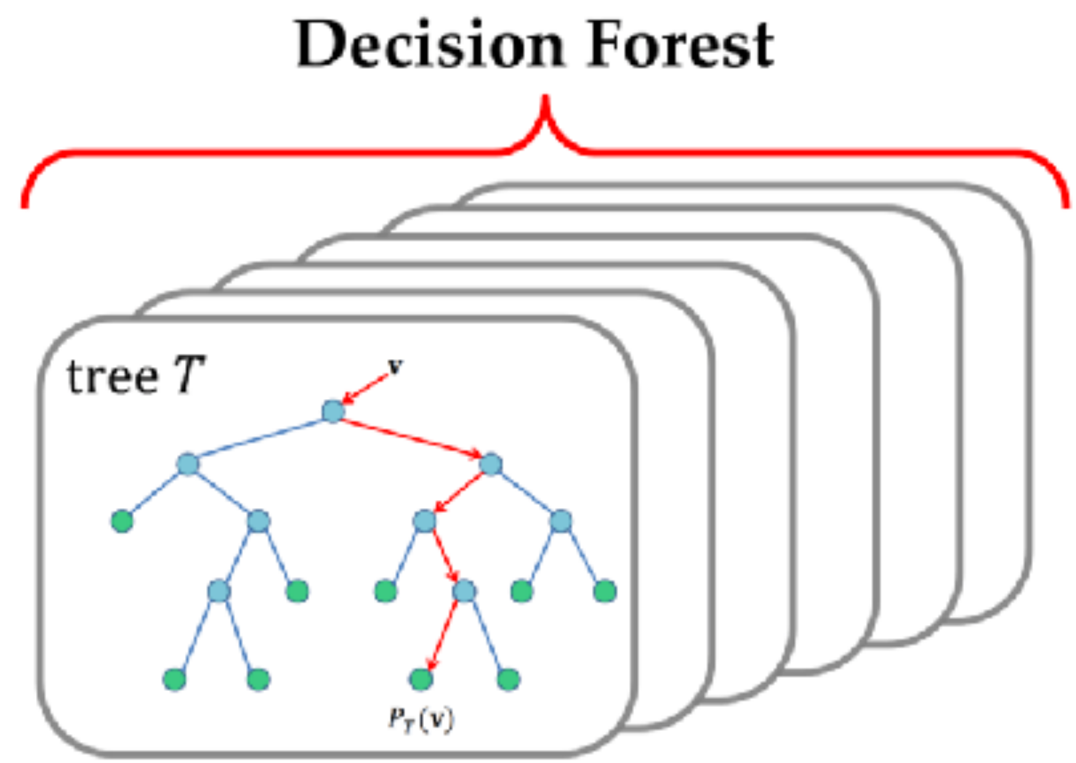


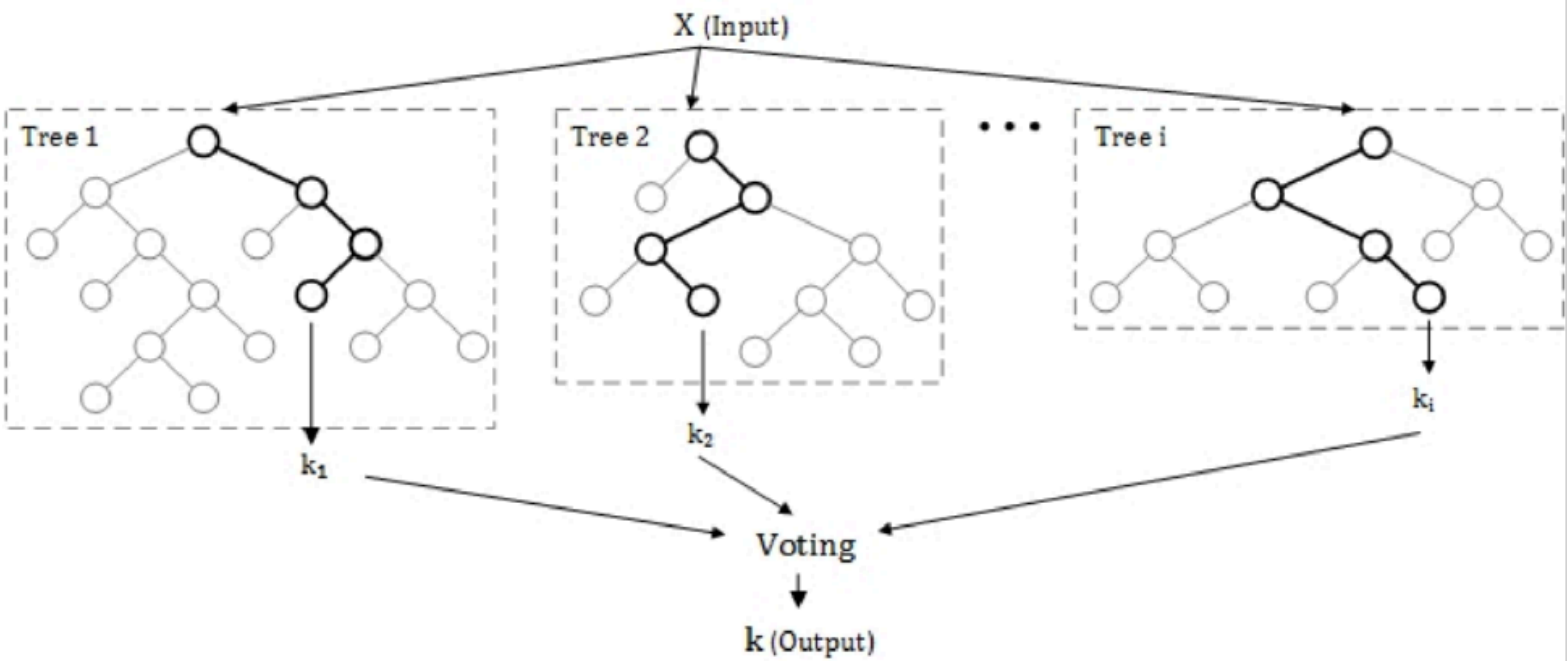
CART for vulture study

Decision rules evaluated downwards to arrive at predicted category. At branch node, move right if ‘true’ left if ‘false’

Random Forests (RF)

- ensemble of decision classifiers
- each classifer similar to CART
- output classification is the mode
- computationally intensive, but more reliable than CART

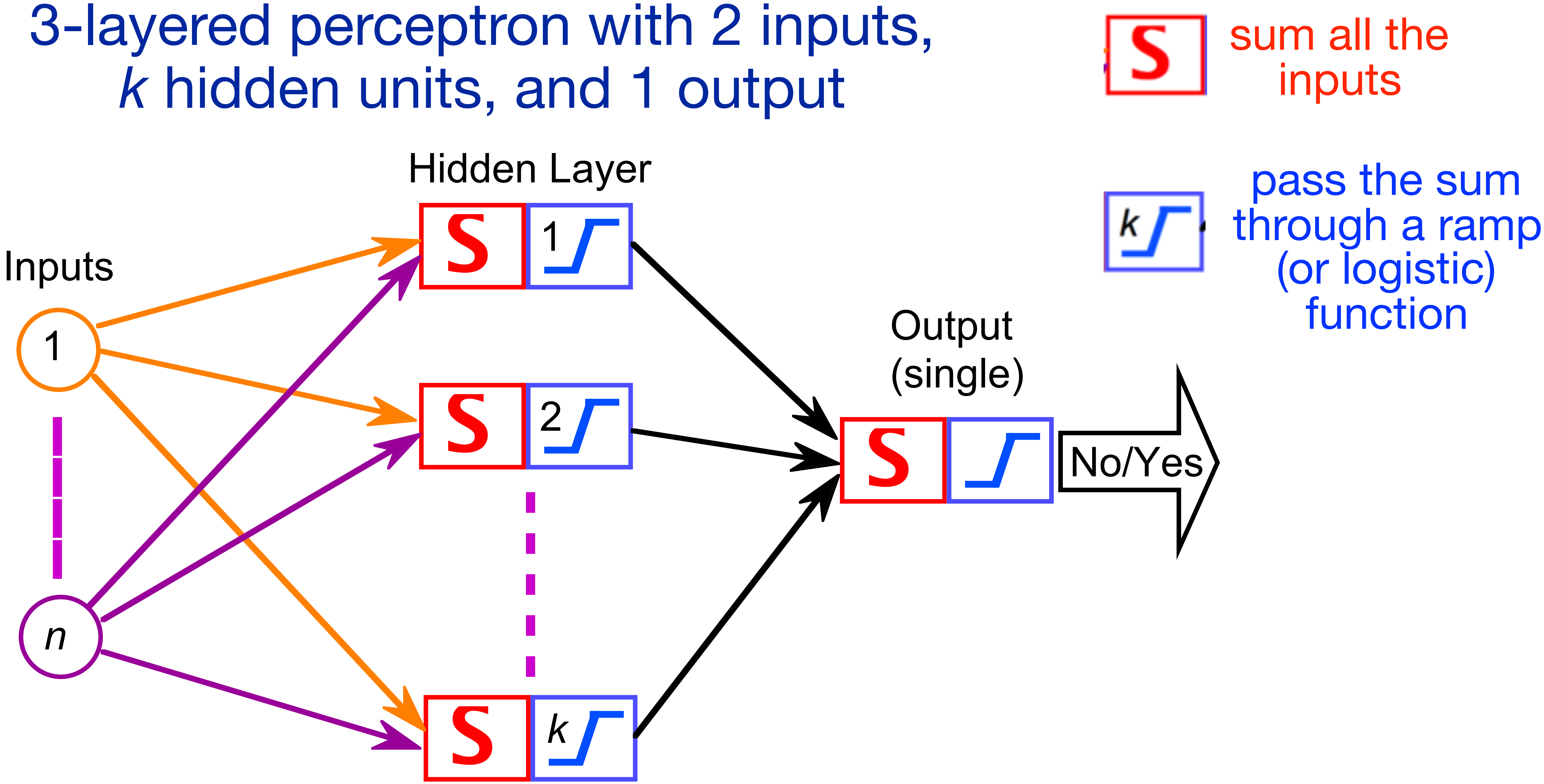




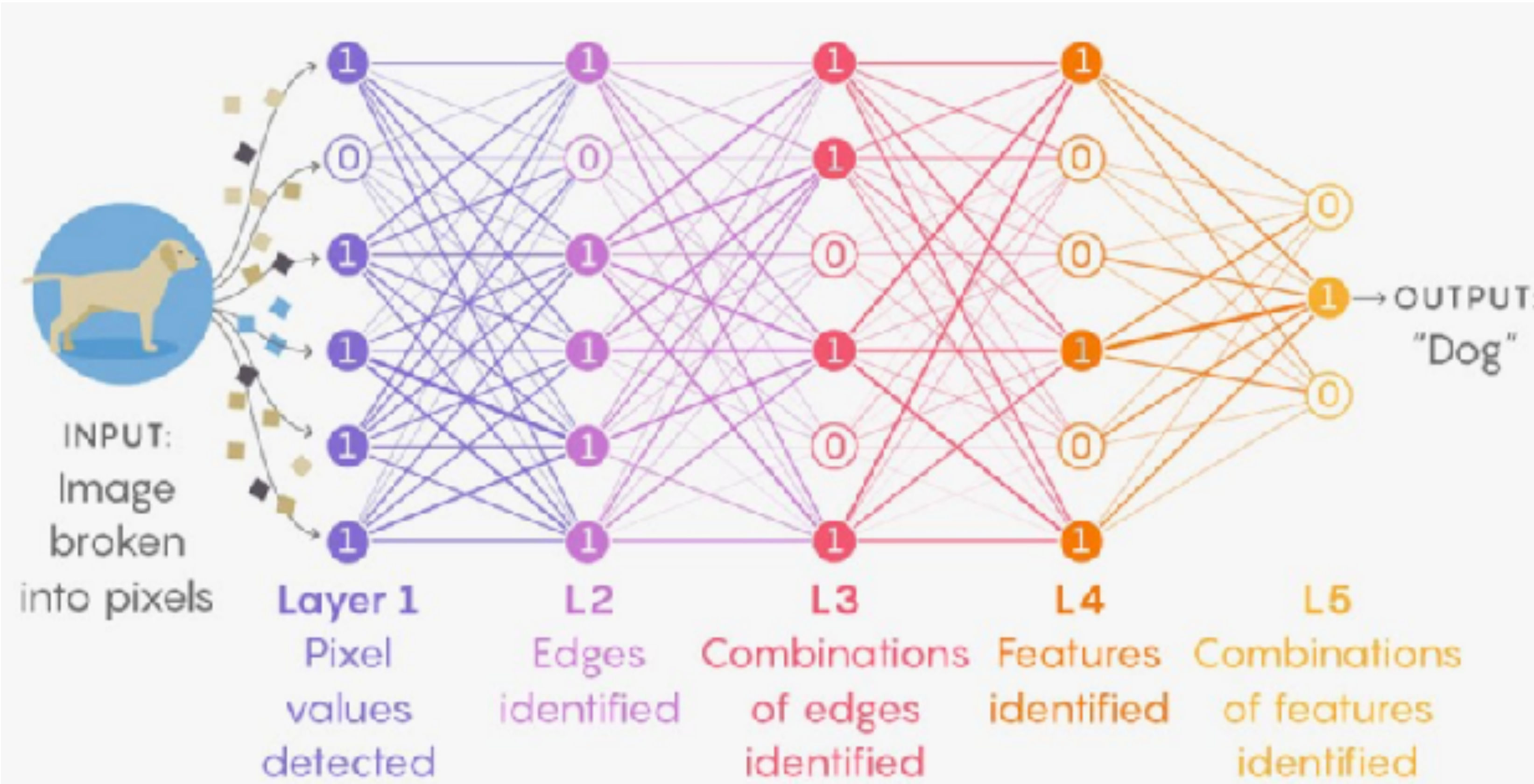
Artificial neural networks (ANNs)

- Simplest is three layer perceptron: input, hidden, output.
- More complicated have several hidden layers
- Deep learning uses outputs from several different hidden layers rather than just the final hidden layer

3-layered perceptron with 2 inputs, *k* hidden units, and 1 output

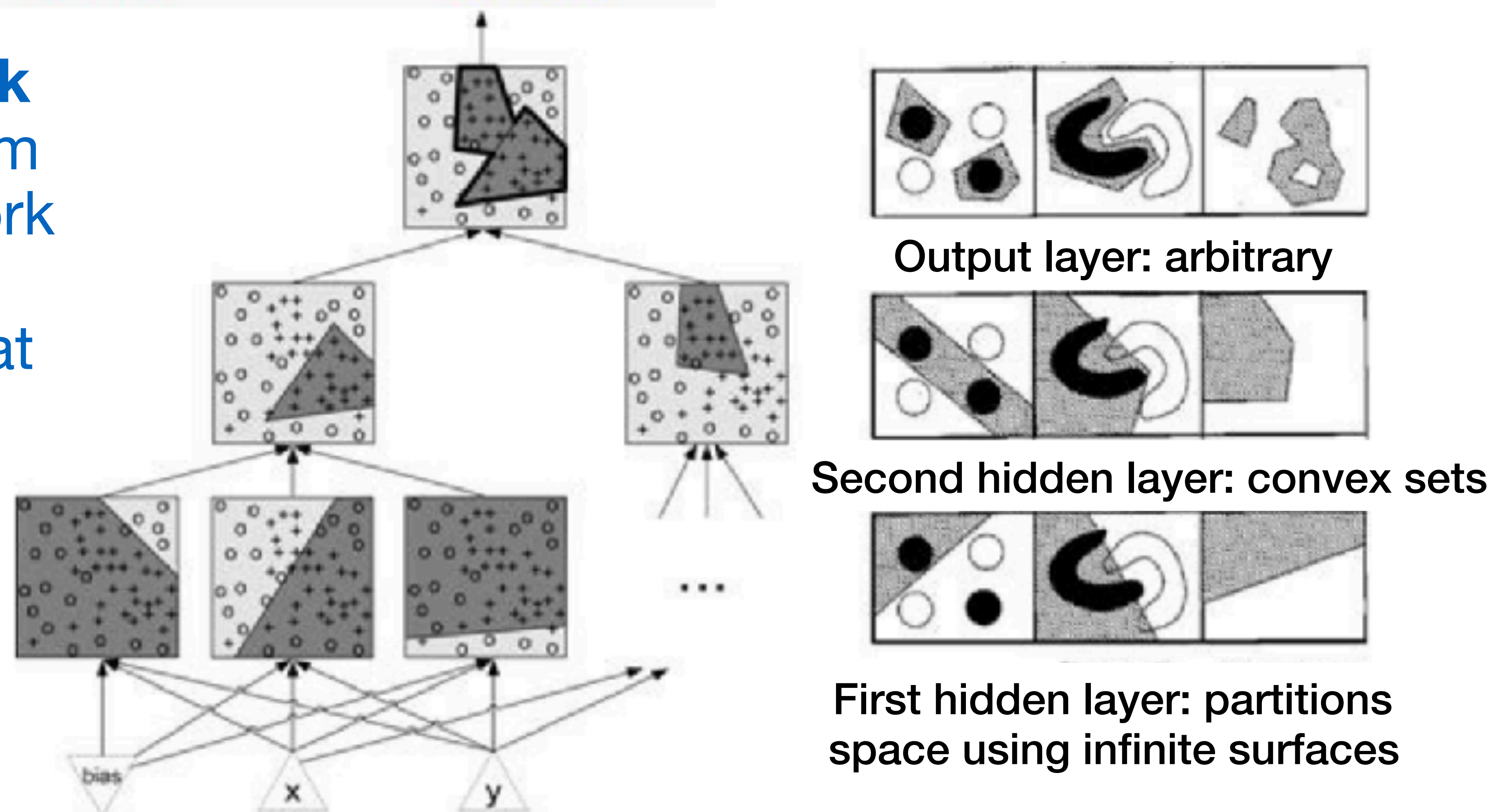


Deep learning using multilayer perception networks



This is in **feedforward** mode after training has occured has occurred: computations are purely algebraic

Training requires **back propogation** algorithm which turns the network into an adaptive dynamical system that changes over time



Identifying behavioral states needed to extract CAMs

Journal of Animal Ecology 2016, **85**, 69–84 doi: 10.1111/1365-2656.12379

SPECIAL FEATURE: STUCK IN MOTION? RECONNECTING QUESTIONS AND TOOLS IN MOVEMENT ECOLOGY

What is the animal doing? Tools for exploring behavioural structure in animal movements

Eliezer Gurarie[1,2]*, Chloe Bracis[3], Maria Delgado[4,5], Trevor D. Meckley[6], Ilpo Kojola[7] and C. Michael Wagner[6]

Table 1. Summary table of four broad categories of behavioural movement analysis methods. The four methods implemented in this paper and the most directly relevant references are bold faced. All of the entries in the last category can be considered multistate random walks, hidden Markov models or state space models

Category	Method	References
Metric-based	Fractal analysis	Fritz, Said & Weimerskirch (2003), Laidre *et al.* (2004)
		Nams & Bourgeois (2004); Tremblay, Roberts & Costa (2007)
	Tortuosity measures	Bovet & Benhamou (1988); Benhamou (2004)
	First passage time (FPT)	**Fauchald & Tveraa (2003)**
	Residence time (RT)	Barraquand & Benhamou (2008)
Classification and segmentation	Penalized contrasts	Lavielle (2005), Calenge (2006)
	Bayesian partitioning (BPMM)	**Calenge (2006)**
	k-clustering	van Moorter *et al.* (2010)
	RT (segmentation step)	Barraquand & Benhamou (2008)
Phenomenological time-series analysis	Autocorrelation functions	Boyce *et al.* (2010)
	Change point analysis (BCPA)	**Gurarie, Andrews & Laidre (2009), Gurarie (2013)**
		Kranstauber *et al.* (2012)
	Wavelet	Polansky *et al.* (2010)
Mechanistic movement modelling	**Multistate random walk (MRW)**	**Morales *et al.* (2004)**
	Ignoring location error	Forester *et al.* (2007), Langrock *et al.* (2012)
		Patterson *et al.* (2008), McClintock *et al.* (2012)
	Accounting for error	Jonsen *et al.* (2013), Breed *et al.* (2012)

Hidden Markov Models (HMMs) for identifying behavioral states (needed to extract CAMs)

$Q = q_1 q_2 \ldots q_N$	a set of N **states**
$A = a_{11} a_{12} \ldots a_{n1} \ldots a_{nn}$	a **transition probability matrix** A, each a_{ij} representing the probability of moving from state i to state j, s.t. $\sum_{j=1}^{n} a_{ij} = 1 \quad \forall i$
$O = o_1 o_2 \ldots o_T$	a sequence of T **observations**, each one drawn from a vocabulary $V = v_1, v_2, \ldots, v_V$
$B = b_i(o_t)$	a sequence of **observation likelihoods**, also called **emission probabilities**, each expressing the probability of an observation o_t being generated from a state i
q_0, q_F	a special **start state** and **end (final) state** that are not associated with observations, together with transition probabilities $a_{01} a_{02} \ldots a_{0n}$ out of the start state and $a_{1F} a_{2F} \ldots a_{nF}$ into the end state

Hidden Markov Models (HMMs) for identifying behavioral states (needed to extract CAMs)

Figure 9.3 shows a sample HMM for the ice cream task. The two hidden states (H and C) correspond to hot and cold weather, and the observations (drawn from the alphabet $O = \{1, 2, 3\}$) correspond to the number of ice creams eaten by Jason on a given day.

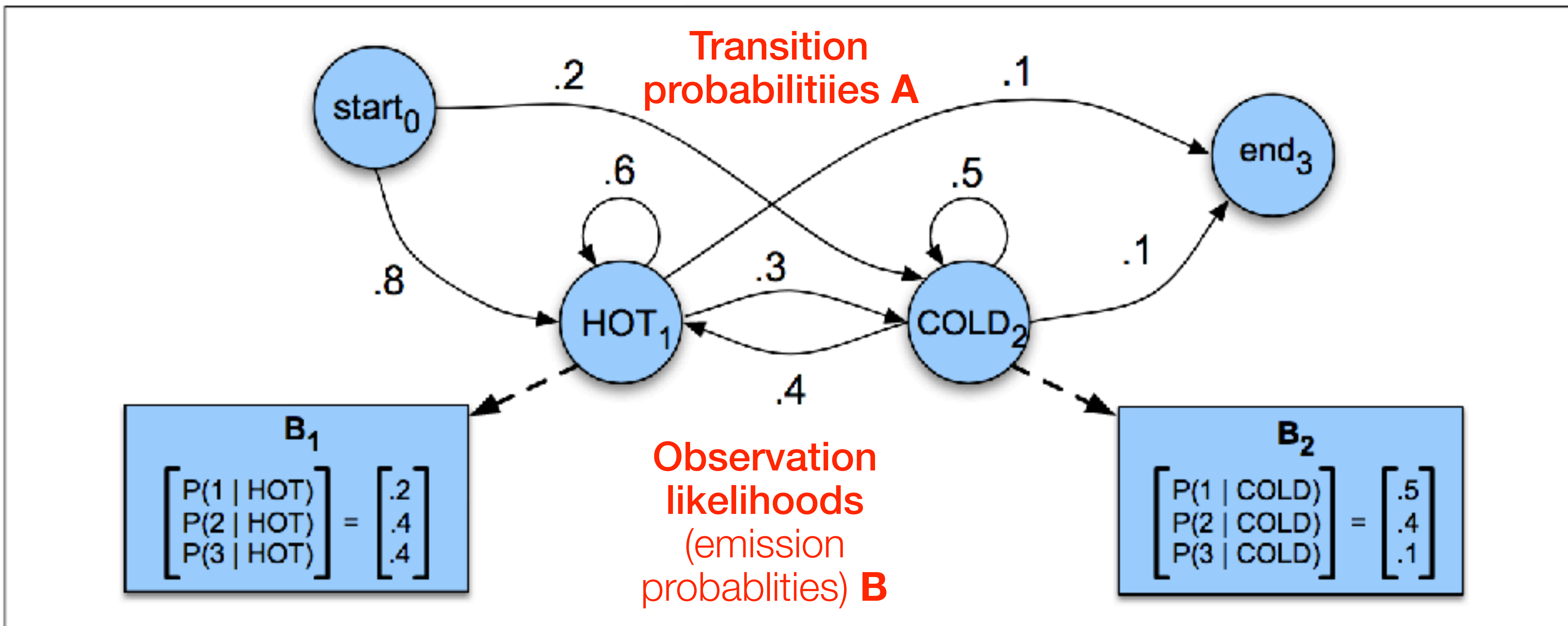


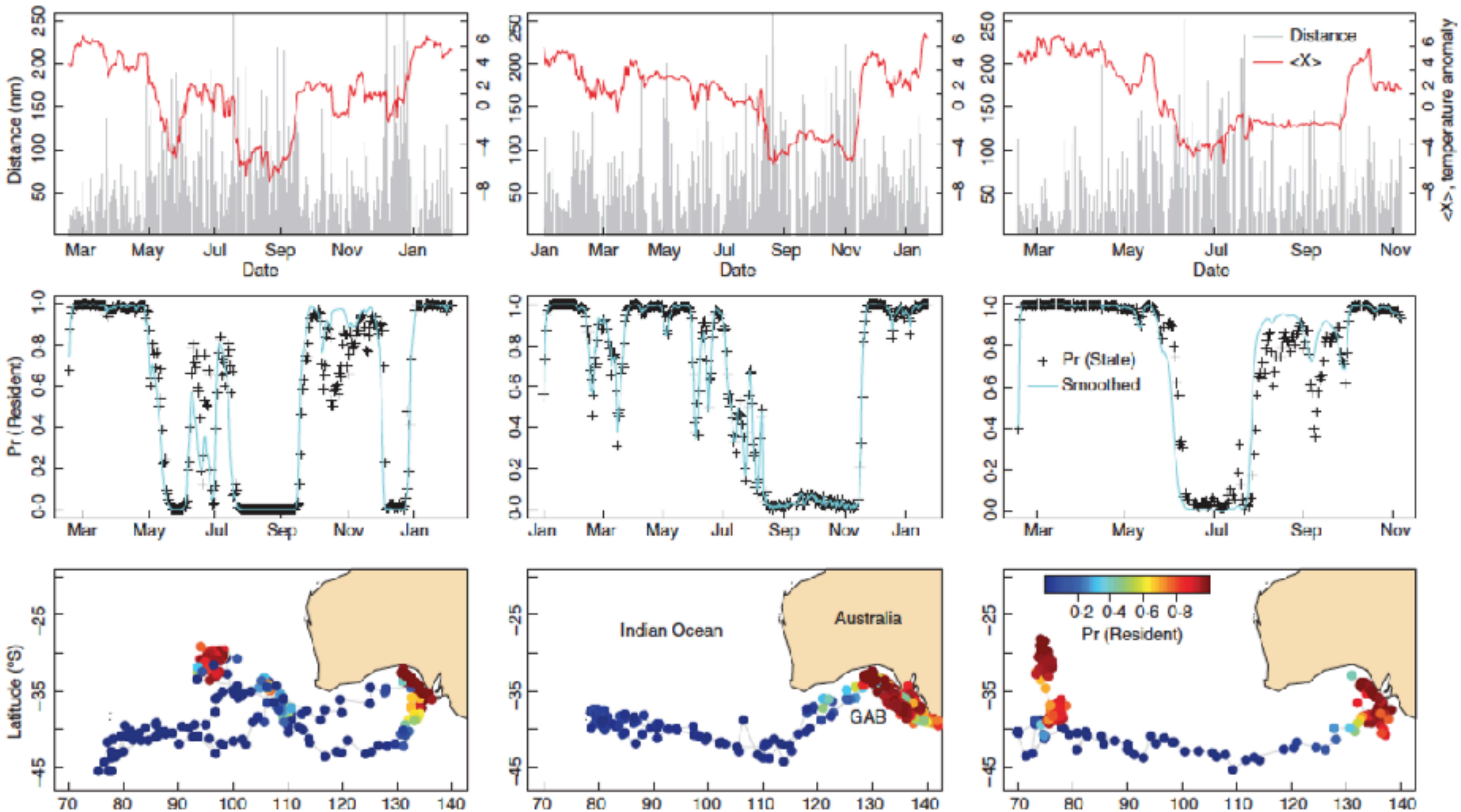
Figure 9.3 A hidden Markov model for relating numbers of ice creams eaten by Jason (the observations) to the weather (H or C, the hidden variables).

Journal of Animal Ecology 2009, 78, 1113–1123 doi: 10.1111/j.1365-2656.2009.01583

Toby A. Patterson[1,2]*, Marinelle Basson[1], Mark V. Bravington[3] and John S. Gunn[1]

Classifying movement behaviour in relation to environmental conditions using hidden Markov models

Two states: resident or migratory



Simple metrics reveal common movement syndromes across diverse vertebrate taxa and environments

Briana Abrahms, Dana P. Seidel, Eric Dougherty, Elliott L. Hazen, Steven J. Bograd, Alan M. Wilson, J. Weldon McNutt, Daniel P. Costa, Stephen Blake, Justin S. Brashares and Wayne M. Getz

Movement Ecology 2017 5:12

https://doi.org/10.1186/s40462-017-0104-2 |

Species	*number of individuals*
African buffalo	5
African elephant	8
African wild dog	13
Black-backed jackal	15
California sea lion	15
Cheetah	5
Galapagos	8
Galapagos tortoise	8
Lion	9
N. elephant seal	15
Plains zebra	9
Springbok	10
White-backed	10

Data

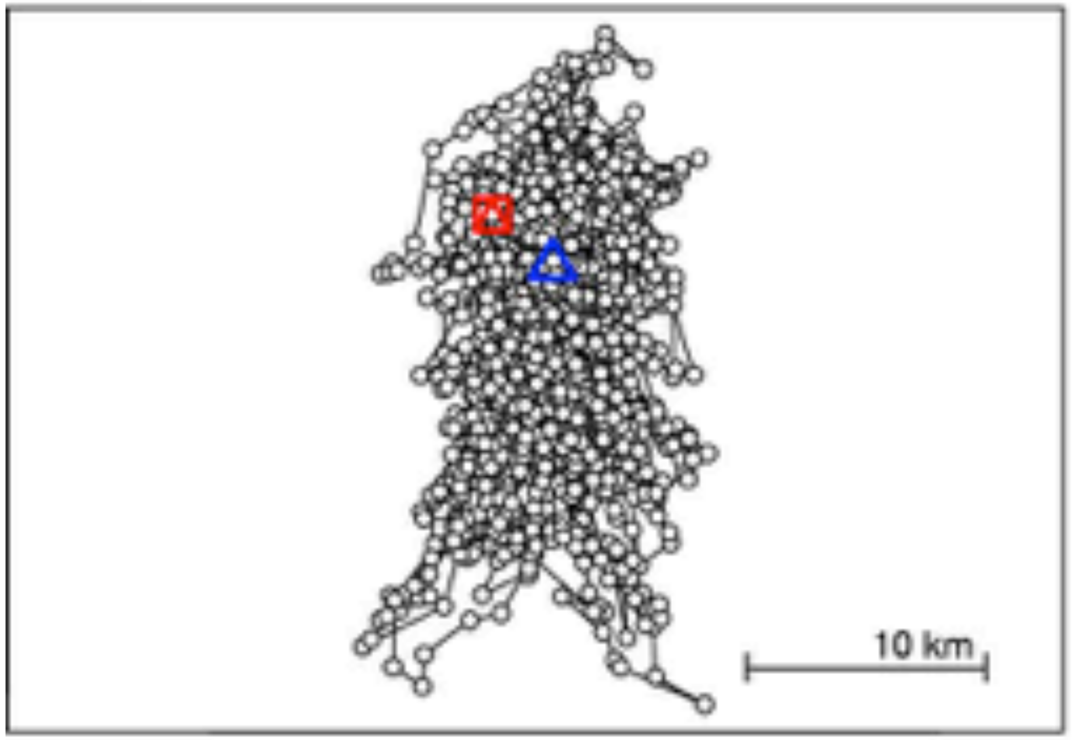
1. All one-hour frequency resolution, except 1.5 hours for the albatross (repeated at 3 hour resolution)
2. Metrics calculated over a range of time scales: hour, day, month, and lifetime of trajectory

Metrics

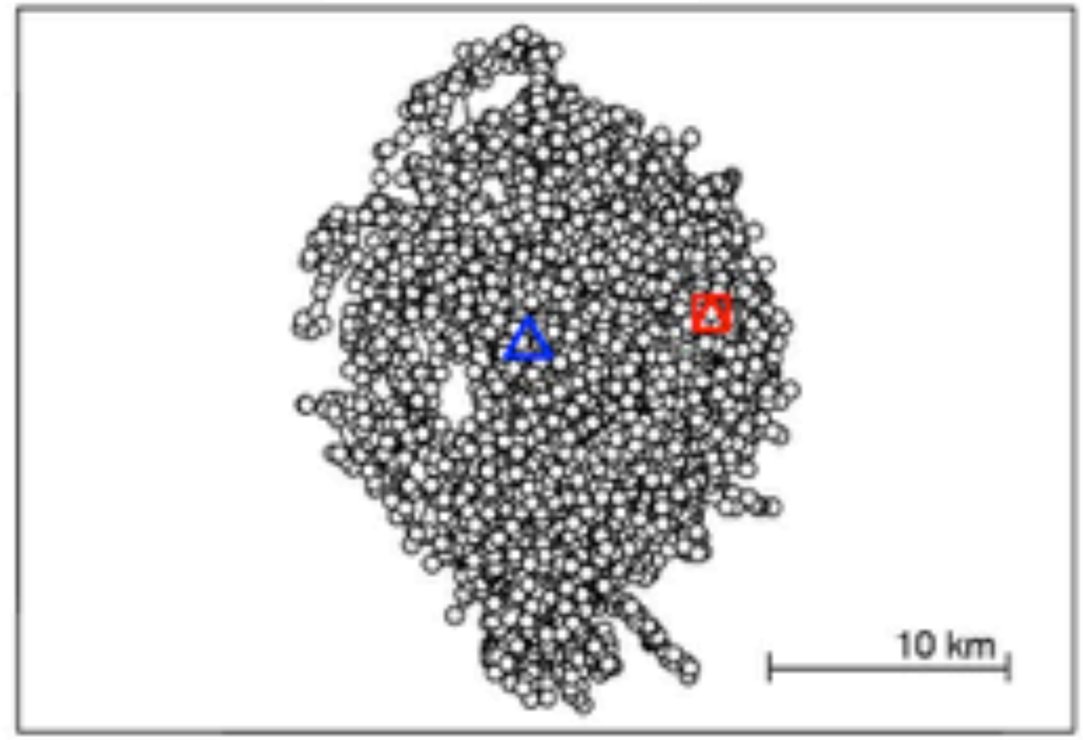
1. Mean turning angle correlation (TAC)
2. Residence time (RT): within fixed radius
3. Mean time to return (T2R): to within fixed radius after leaving for more than 12 & 24 hours
4. Mean volume of intersection (VI): between monthly 95% kernel density home ranges
5. Maximum net-squared-displacement (MNSD): scaled by smallest MNSD for species.

Simulated archetypes

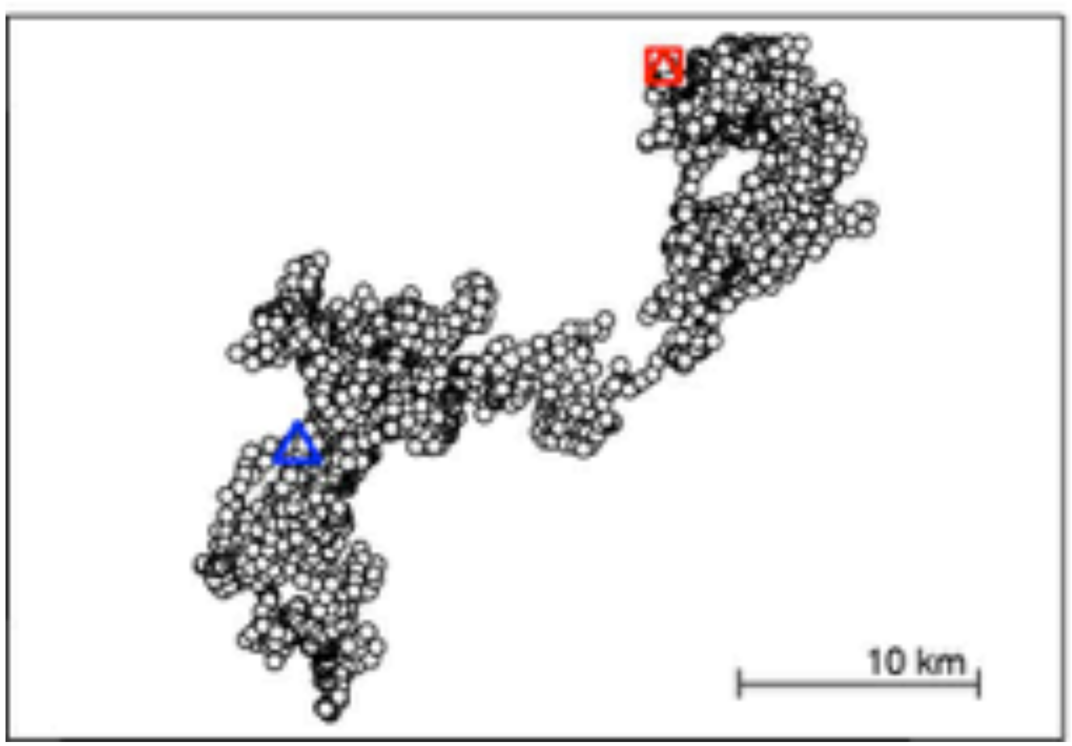
Central place forager



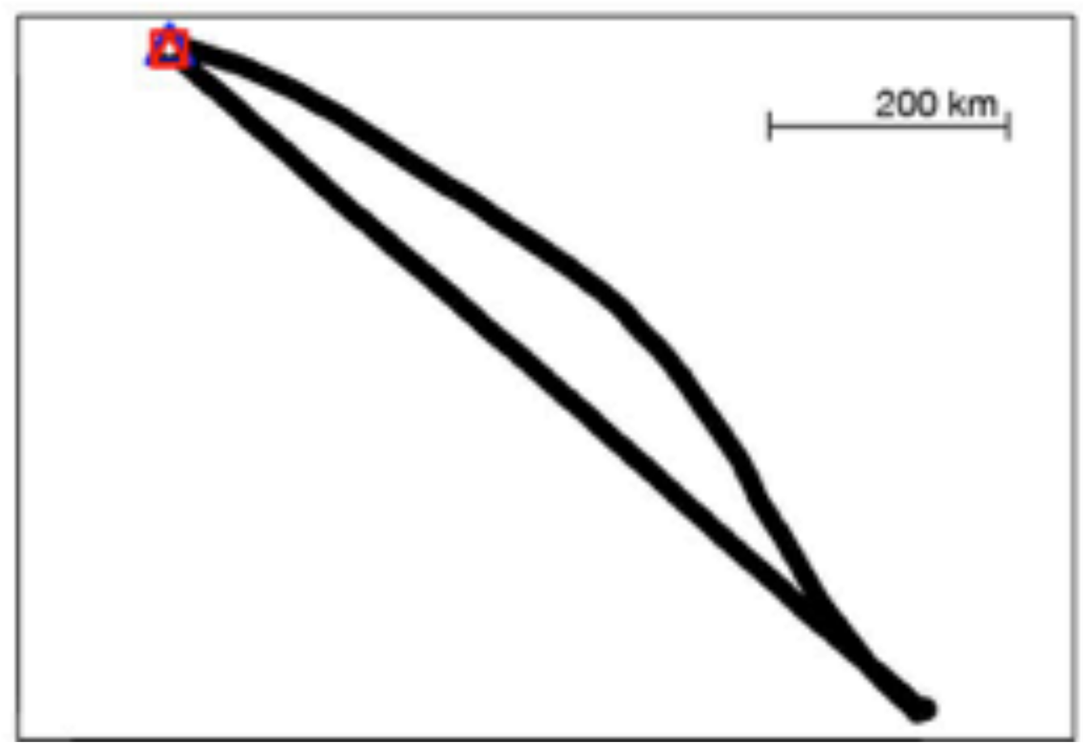
Territorial



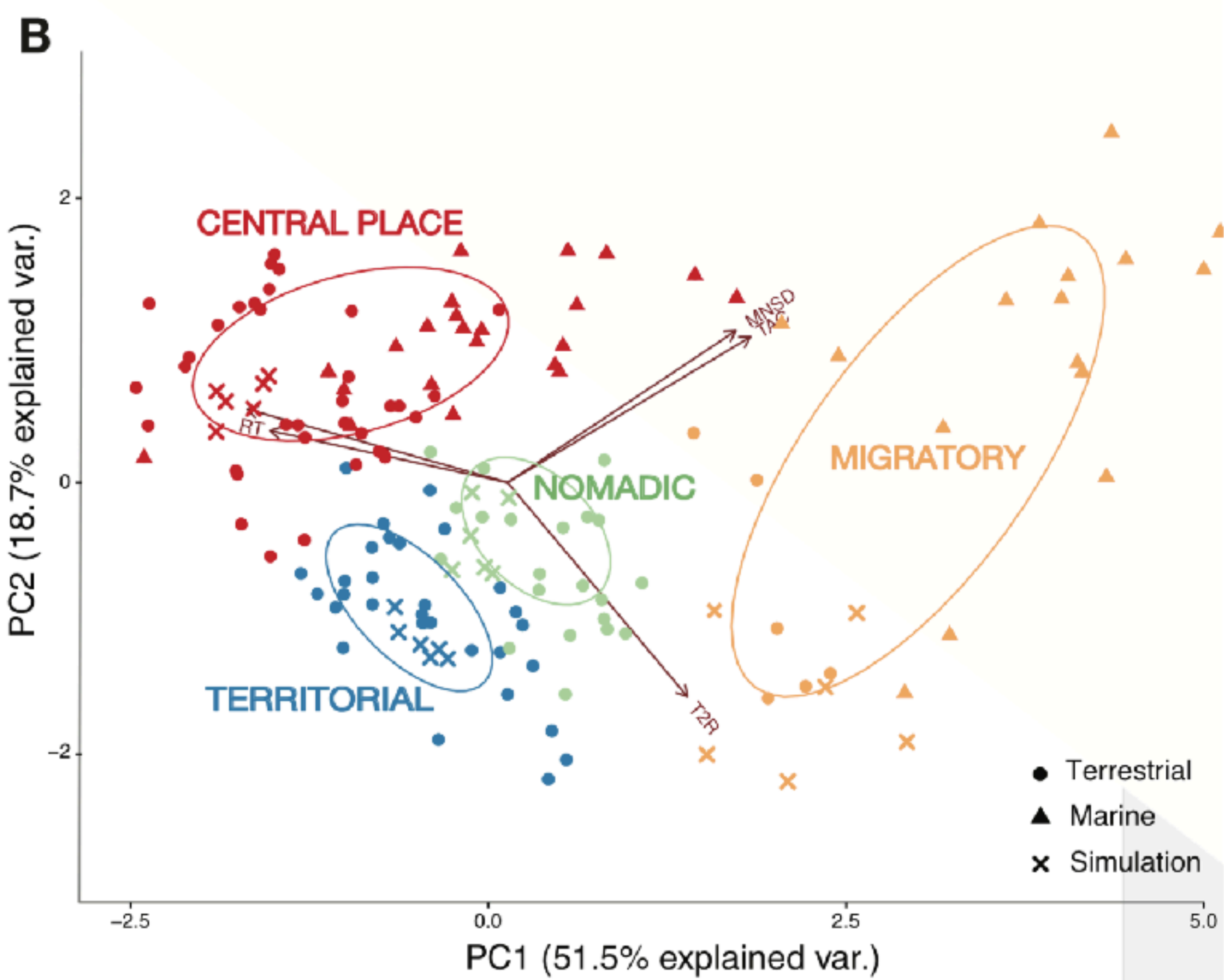
Nomad



Migrant



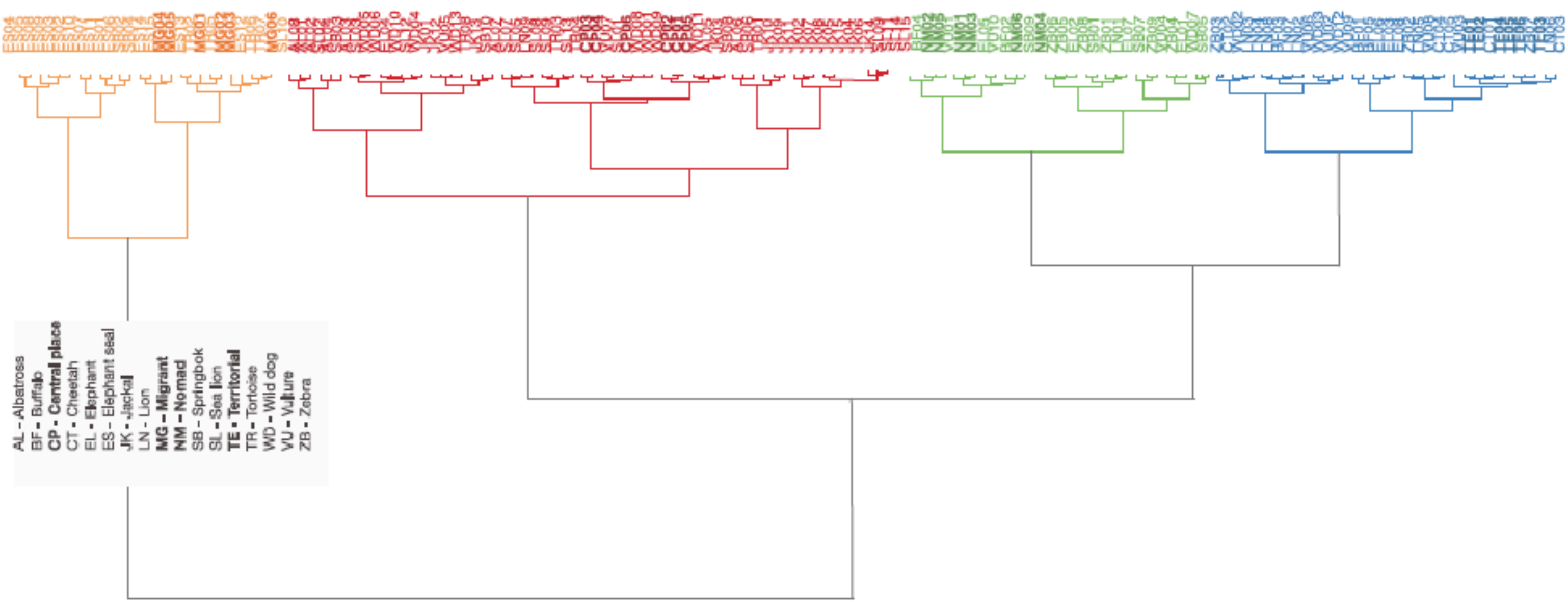
Cluster analysis (Ward's method)



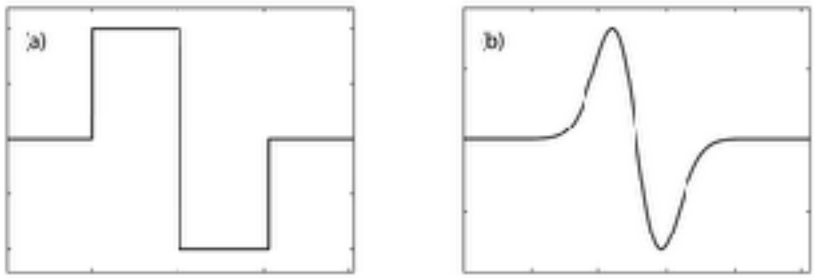
Cluster Dendrogram

Table 2. Summary of 130 individuals within 13 species analyzed into cluster classifications.

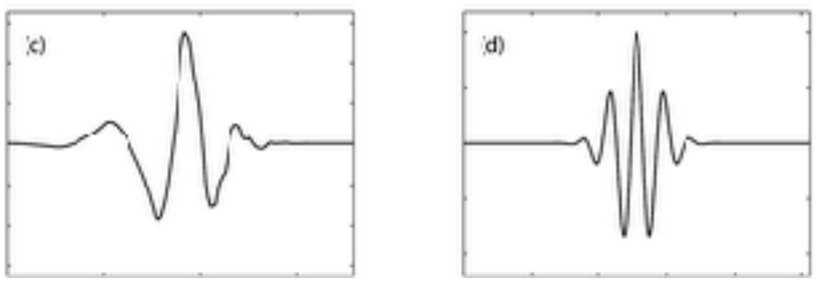
Species	*N individuals*	Migratory	Central place	Nomadic	Territorial
African buffalo	5	-	-	2	3
African elephant	8	-	1	4	3
African wild dog	13	-	9	1	3
Black-backed jackal	15	-	15	-	-
California sea lion	15	1	14	-	-
Cheetah	5	-	-	-	5
Galapagos albatross	8	-	8	-	-
Galapagos tortoise	8	4	4	-	-
Lion	9	-	1	1	7
N. elephant seal	15	15	-	-	-
Plains zebra	9	-	-	6	3
Springbok	10	2	4	4	-
White-backed vulture	10	-	2	3	5



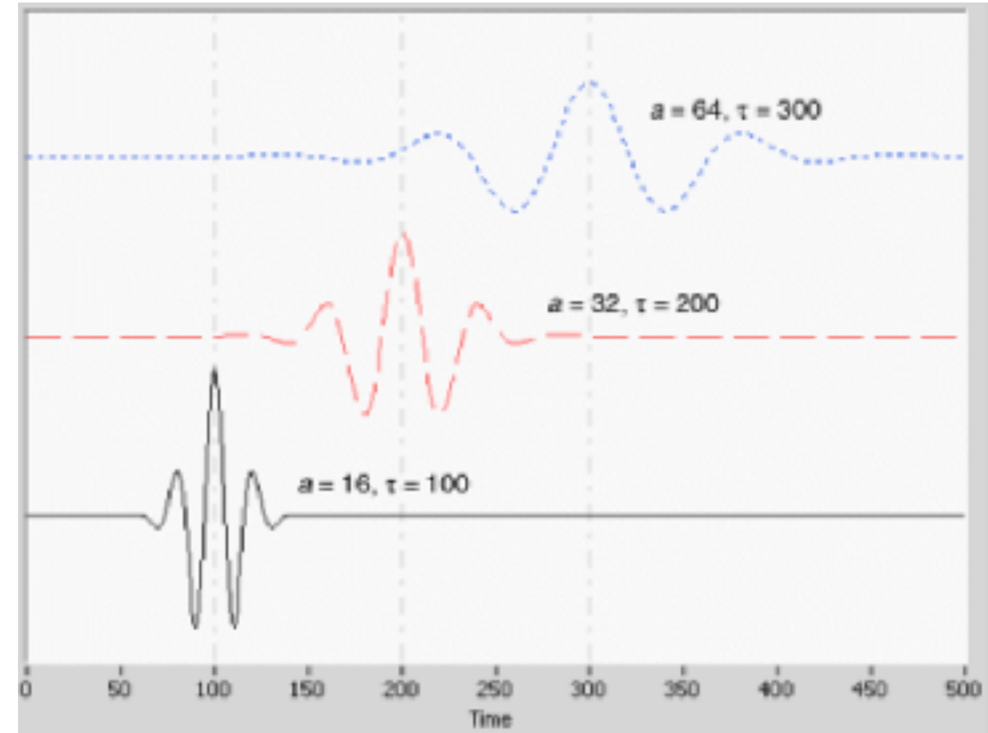
Wavelet analysis



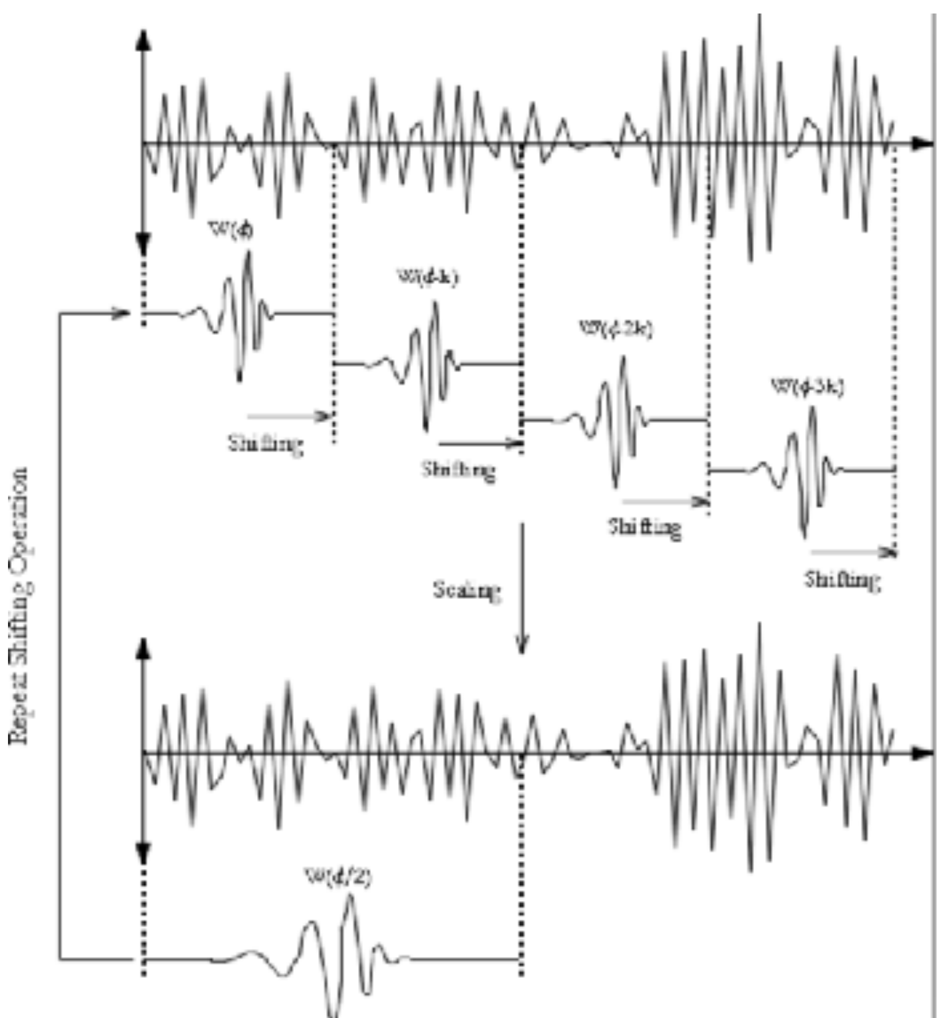
examples of wavelets



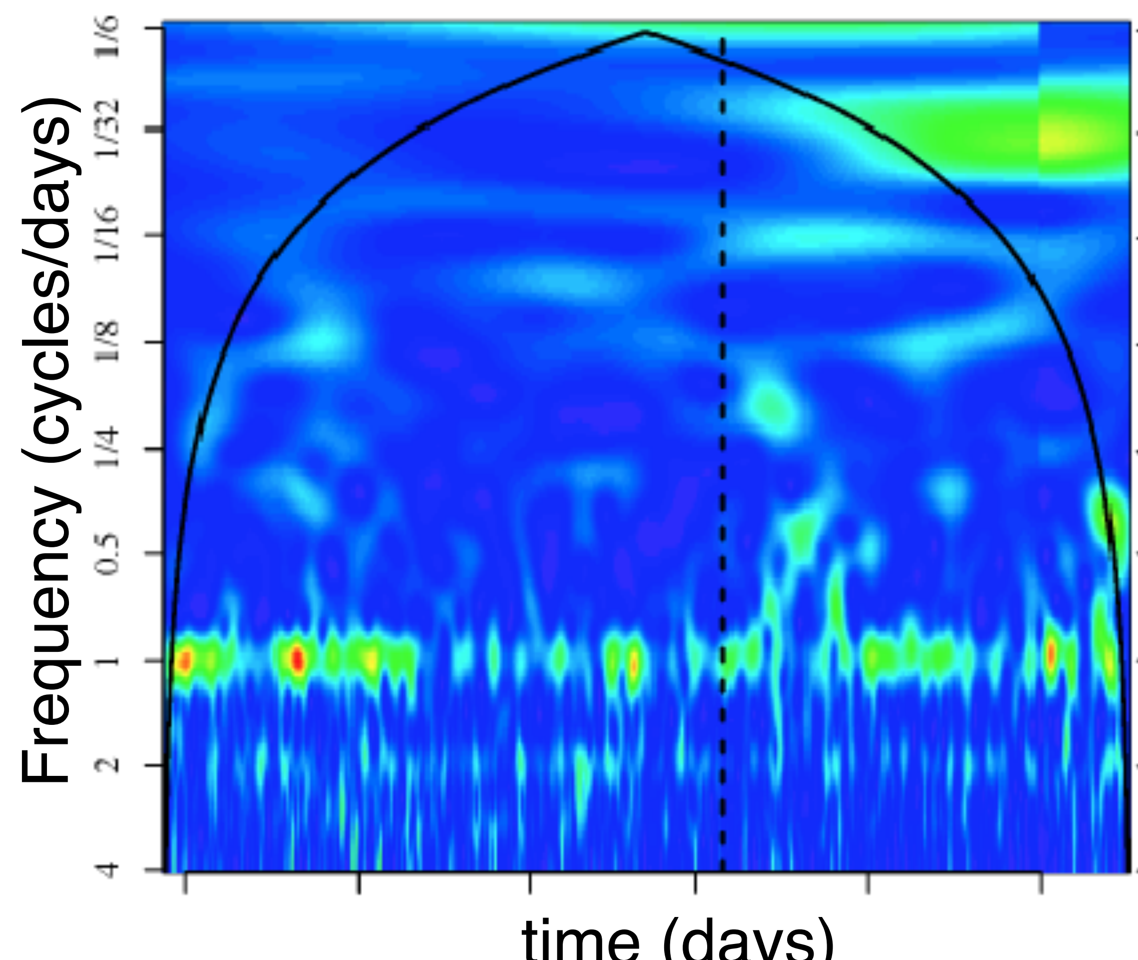
frequency doubling of wavelets



pass wavelets of different frequencies over raw signal and record amount of overlap



Raw signal: Averaged modulus values of wavelet scalograms of 3-hourly net displacement time series



Elephants of Samburu

George Wittemyer

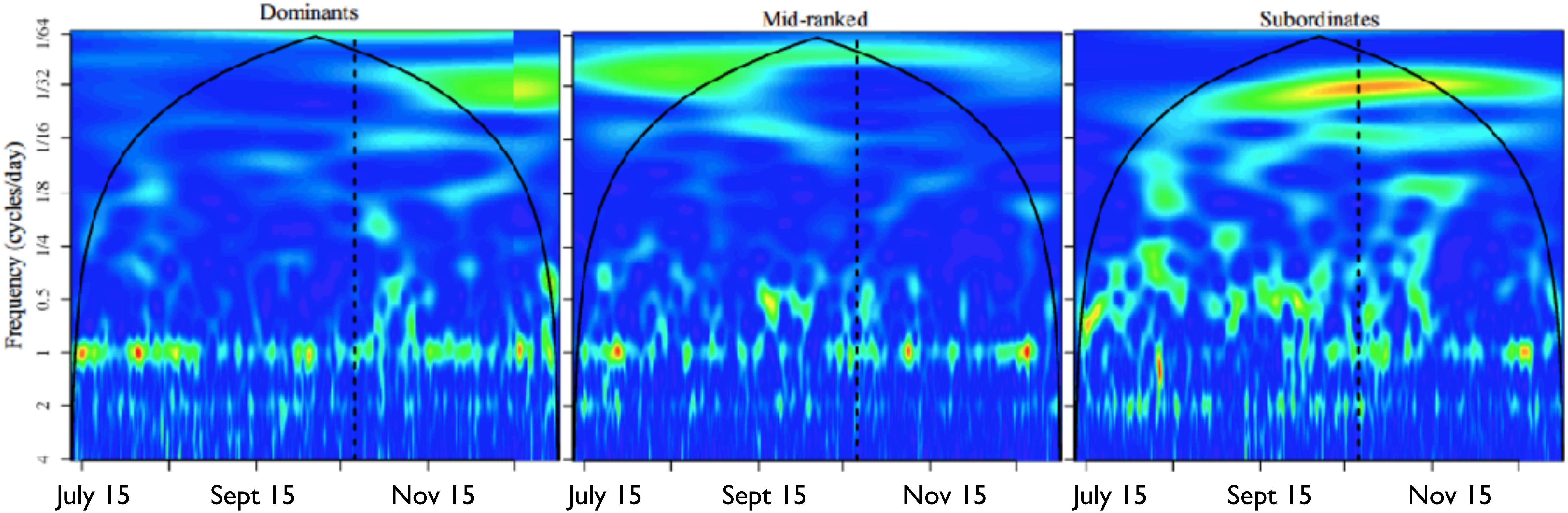
Leo Polansky

Elephant movement patterns: wavelet analysis

Disentangling the effects of forage, social rank, and risk on movement autocorrelation of elephants using Fourier and wavelet analyses

19108–19113 | PNAS | December 9, 2008 | vol. 105 | no. 49

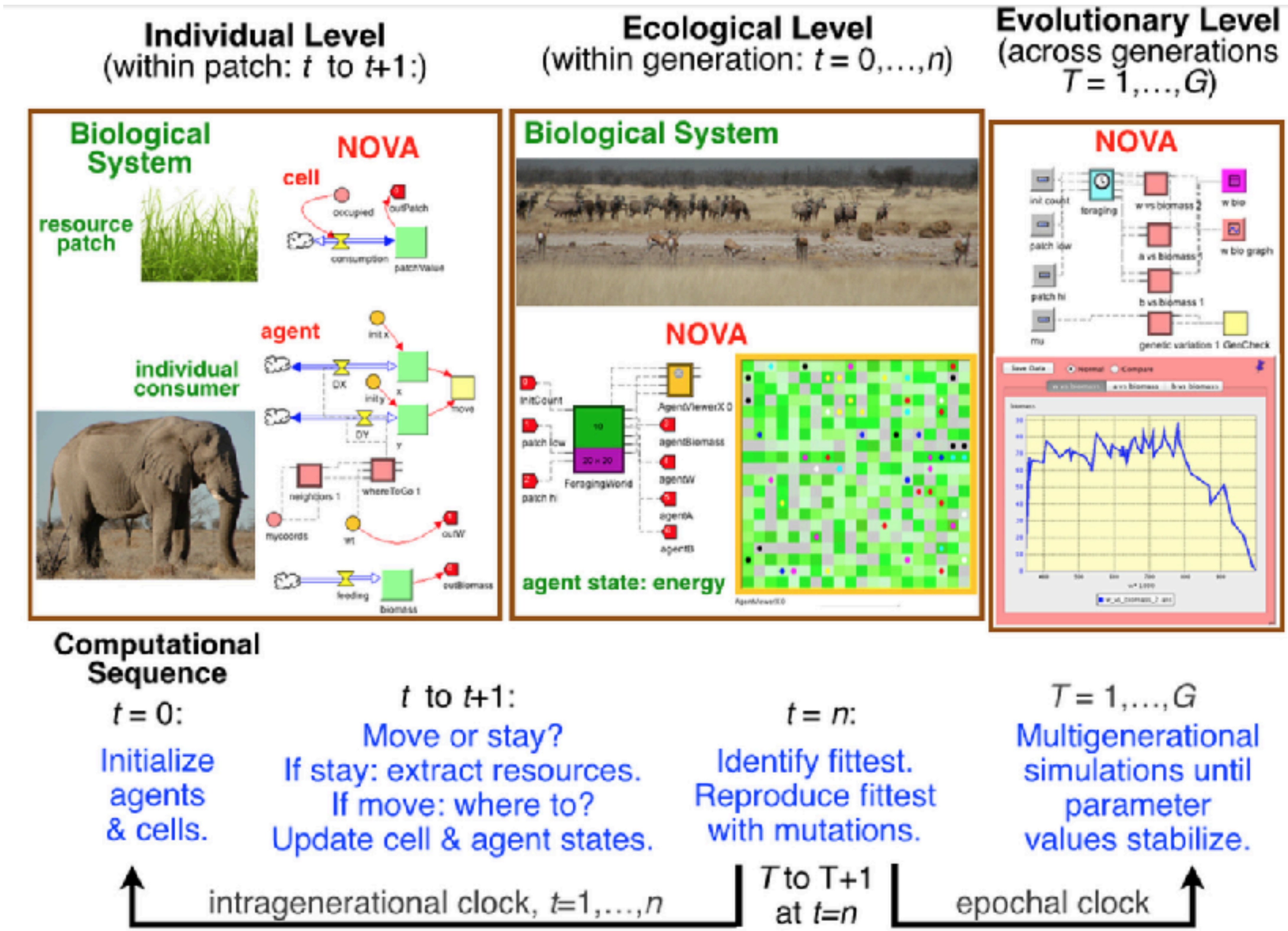
George Wittemyer[a,b,c,1,2], Leo Polansky[b,2], Iain Douglas-Hamilton[c,d], and Wayne M. Getz[b,e]



Dominant individuals made regular forays to water on a 24 hour cycle, subordinate individuals visited water on 2-4 day cycles, depending on the season

Why we expect syndromic groups to evolve

Citation: Getz WM, Salter R, Lyons AJ, Sippl-Swezey N (2015) Panmictic and Clonal Evolution on a Single Patchy Resource Produces Polymorphic Foraging Guilds. PLoS ONE 10(8): e0133732. doi:10.1371/journal.pone.0133732



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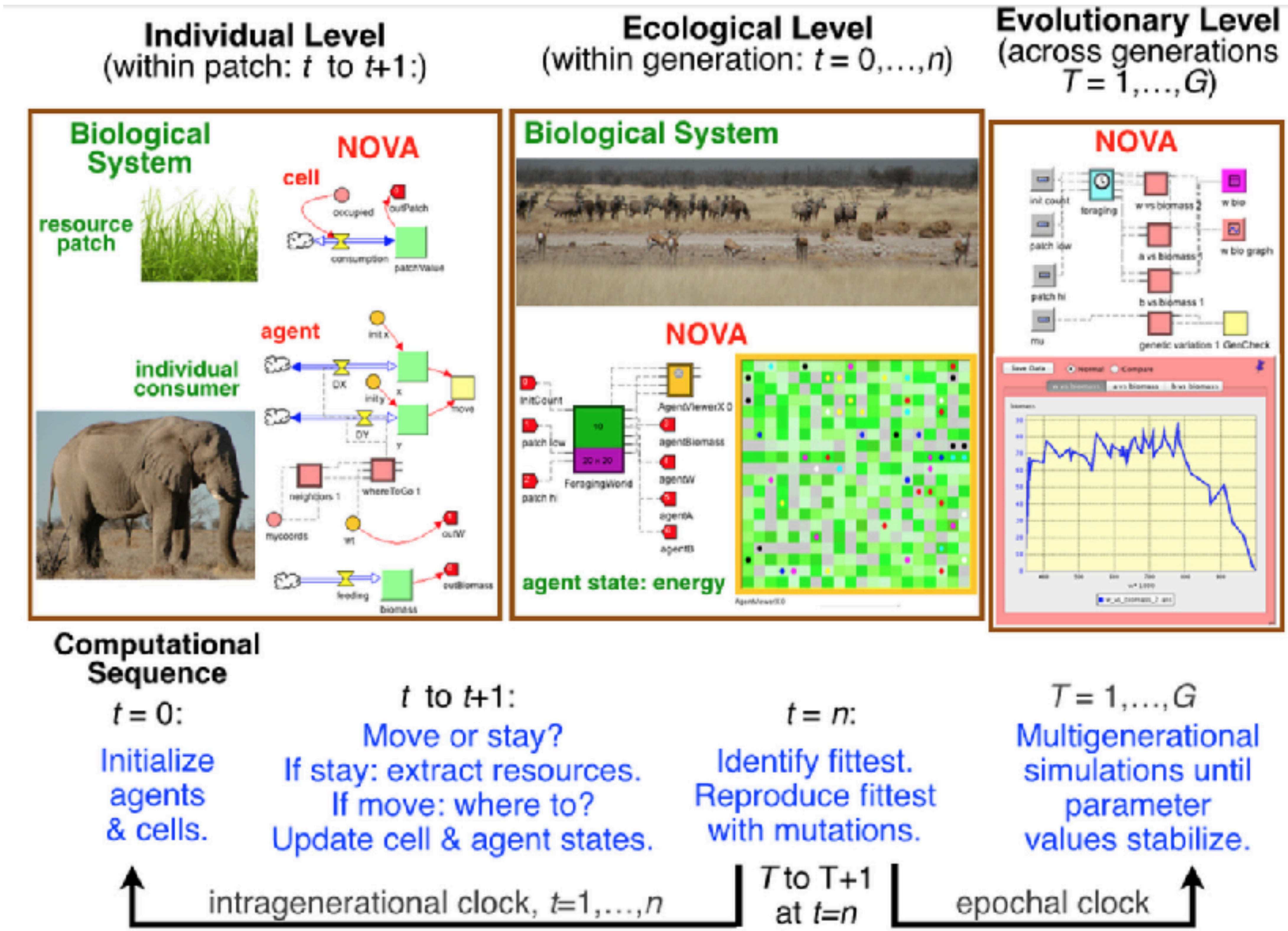
Three strategy foraging model



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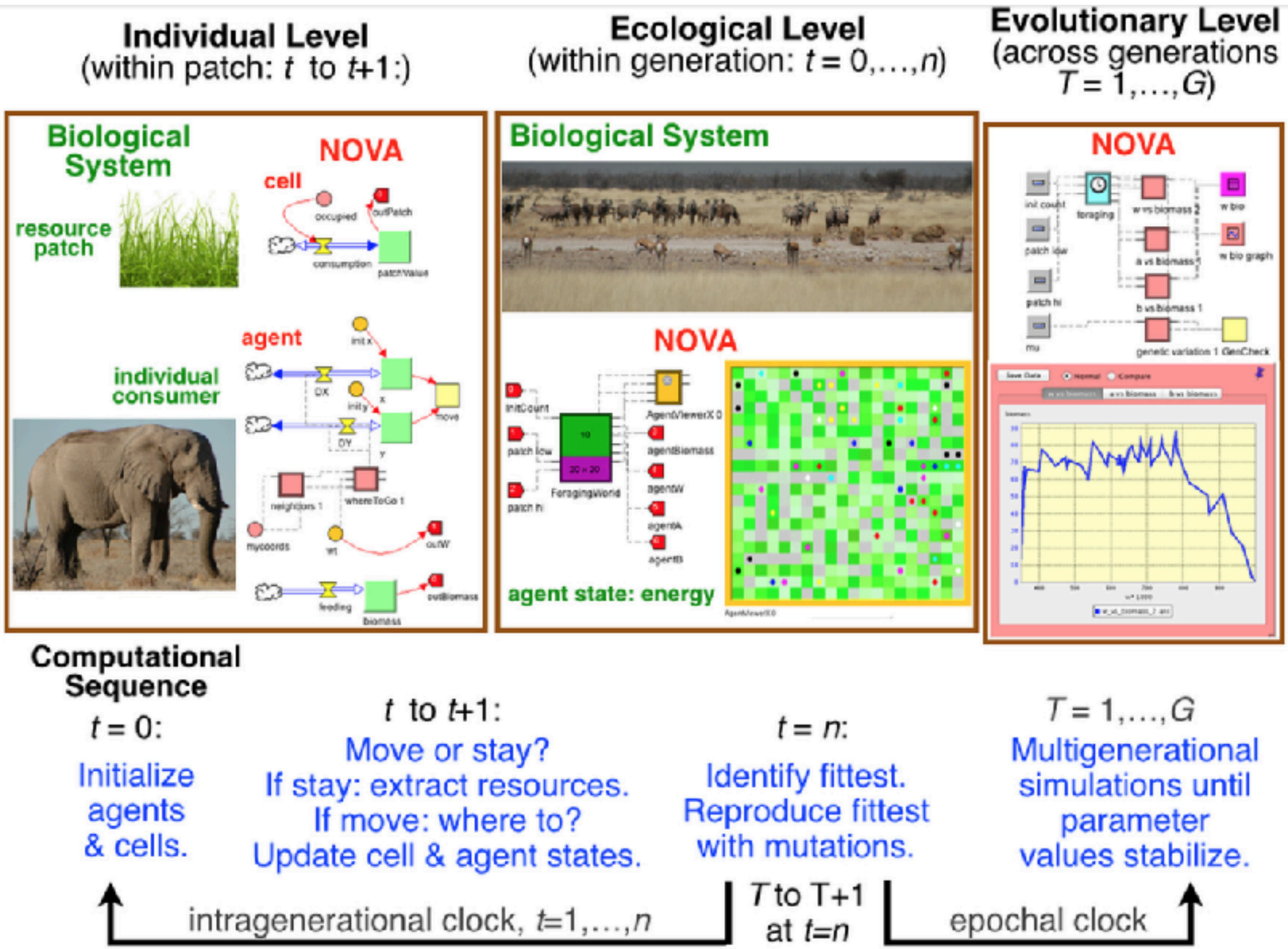
Three strategy foraging model

- movement threshold for local resource depletion (*rho*)



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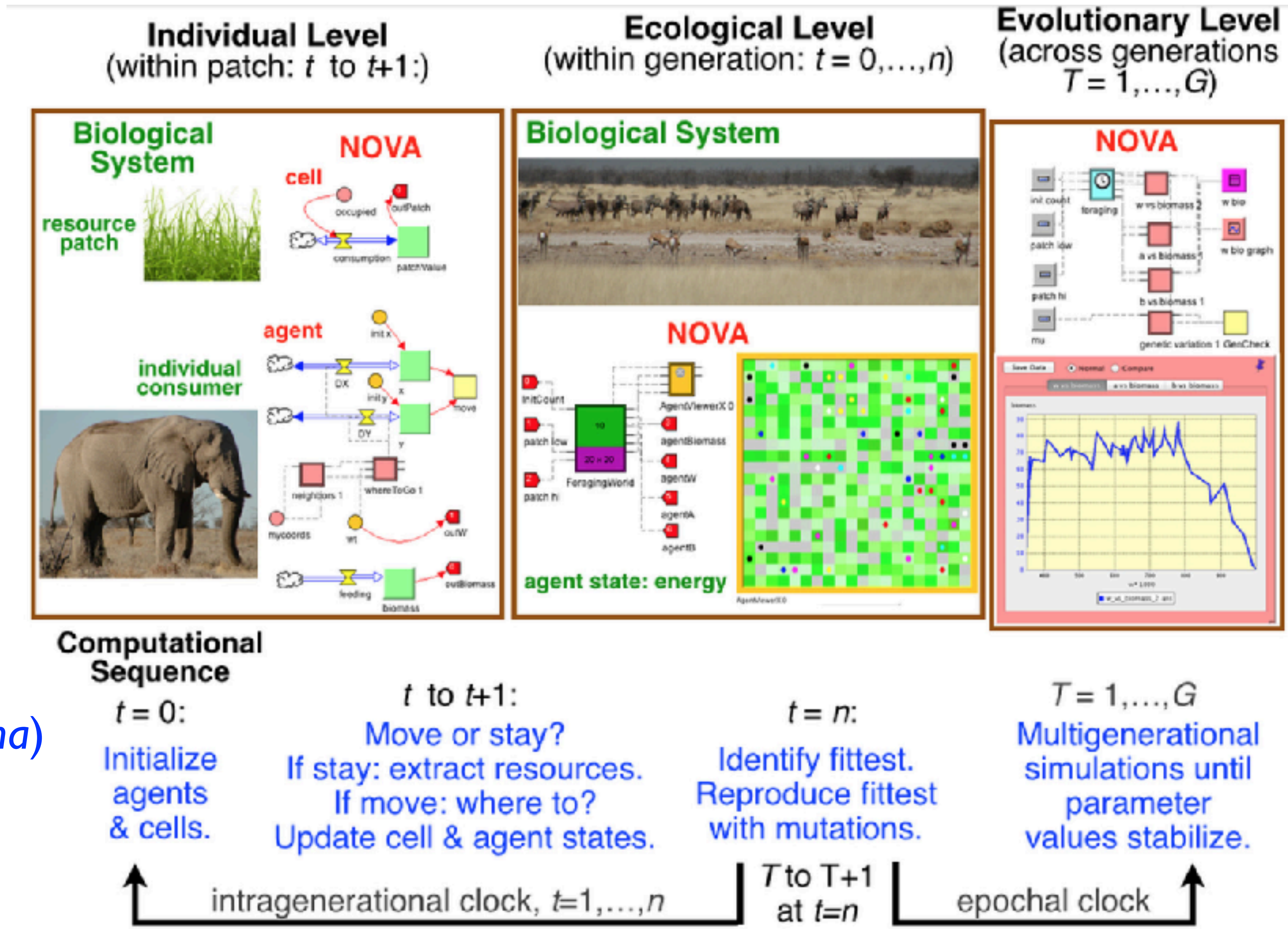

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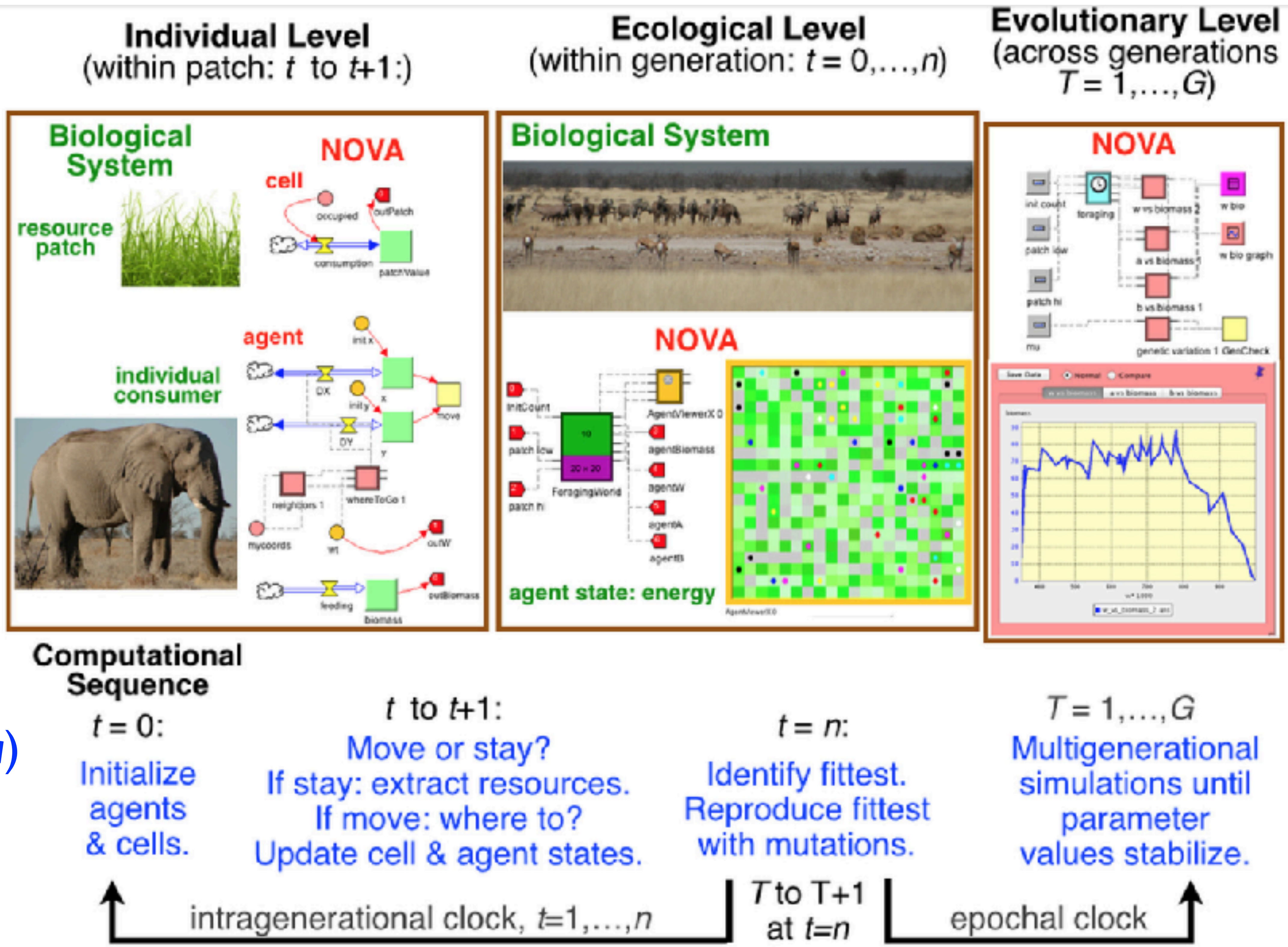
Three strategy foraging model

- movement threshold for local resource depletion (*rho*)
- degree of competition avoidance (*alpha*)
- strategy-tactic trade-off (*delta*)



Syndromic groups emerge!

- movement threshold for local resource depletion (*rho*)
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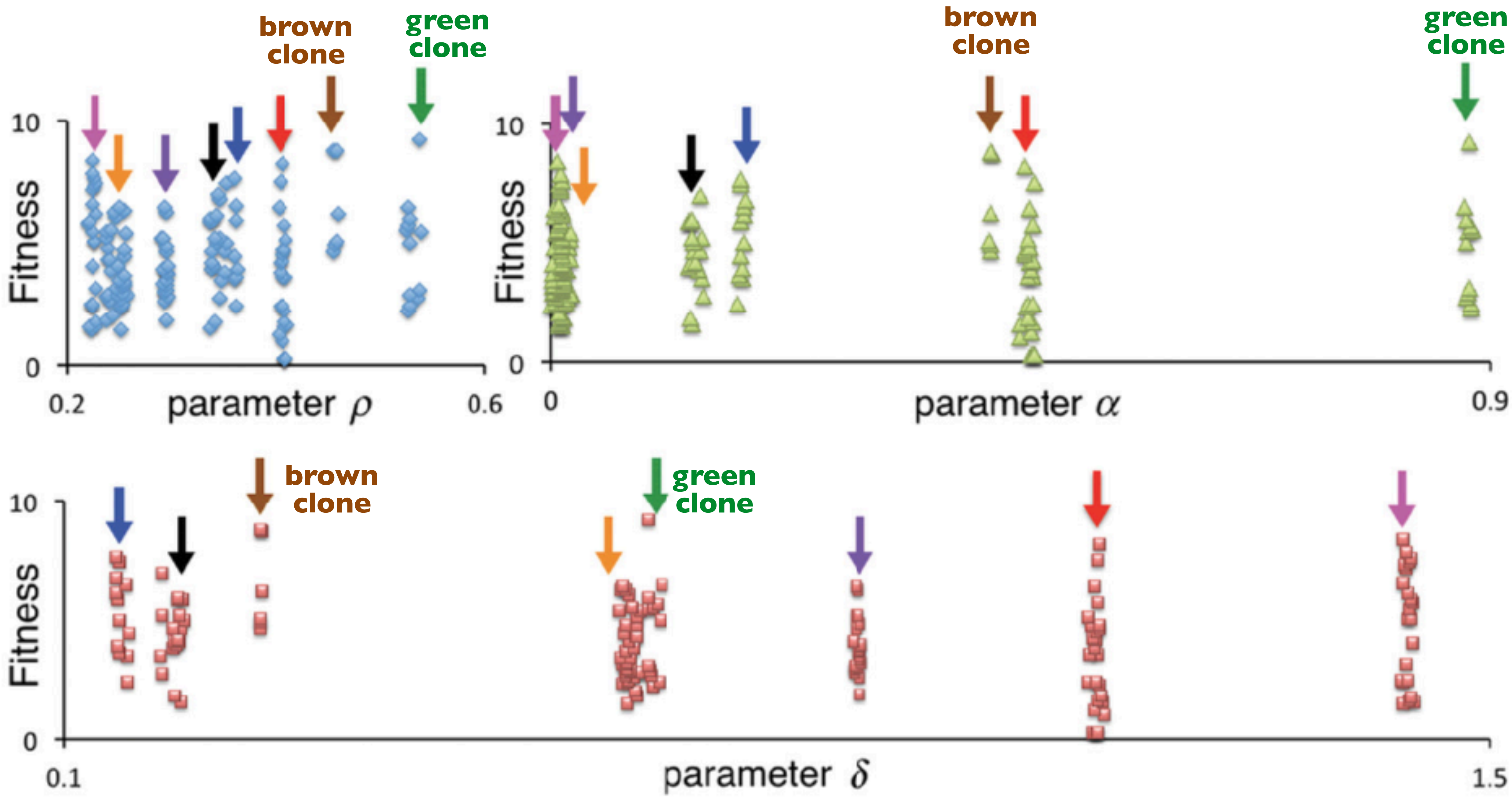


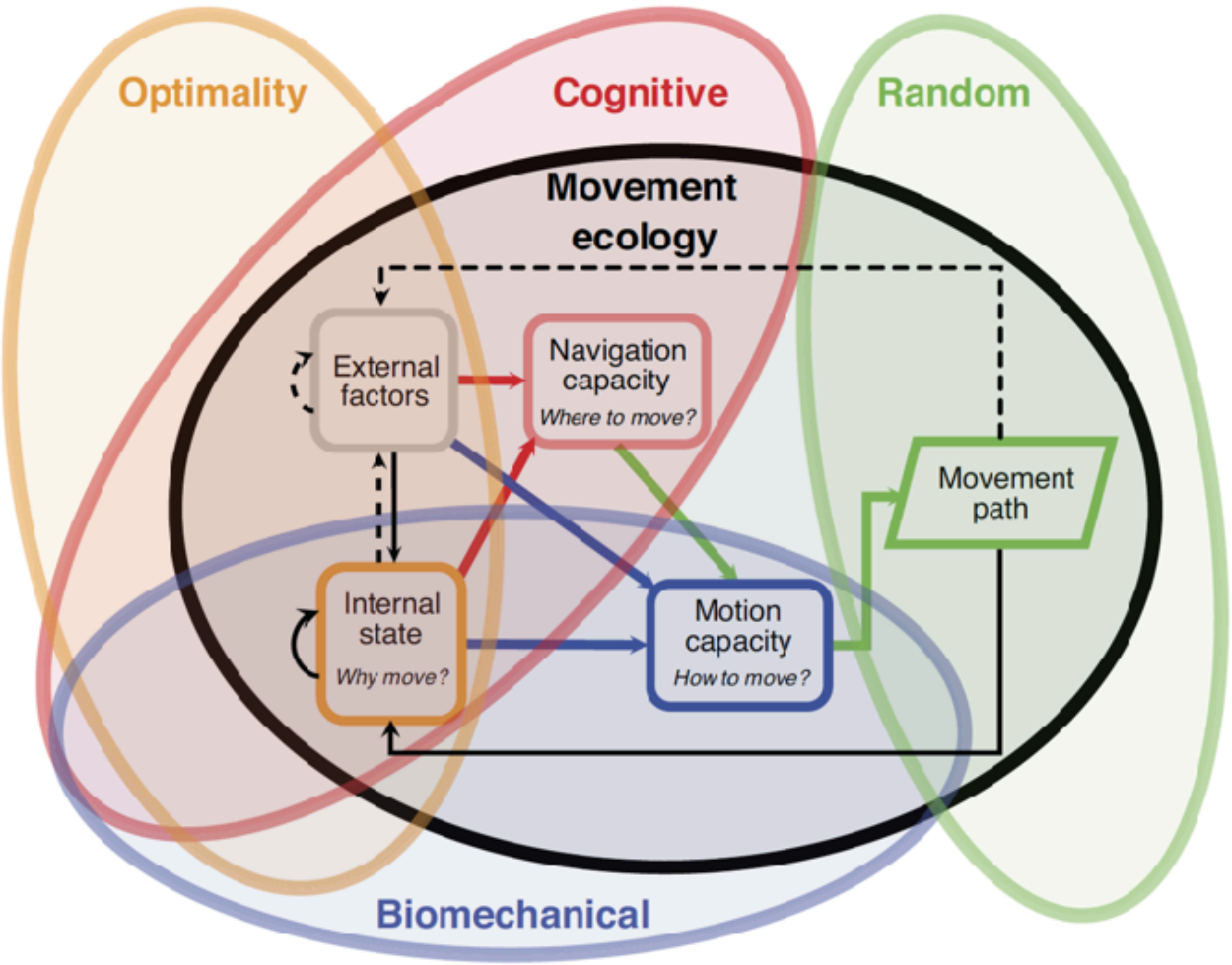
Moving beyond

A movement ecology paradigm for unifying organismal movement research

19052–19059 | PNAS | December 9, 2008 | vol. 105 | no. 49

Ran Nathan[a,1], Wayne M. Getz[b], Eloy Revilla[c], Marcel Holyoak[d], Ronen Kadmon[a], David Saltz[e], and Peter E. Smouse[f]

Individual level



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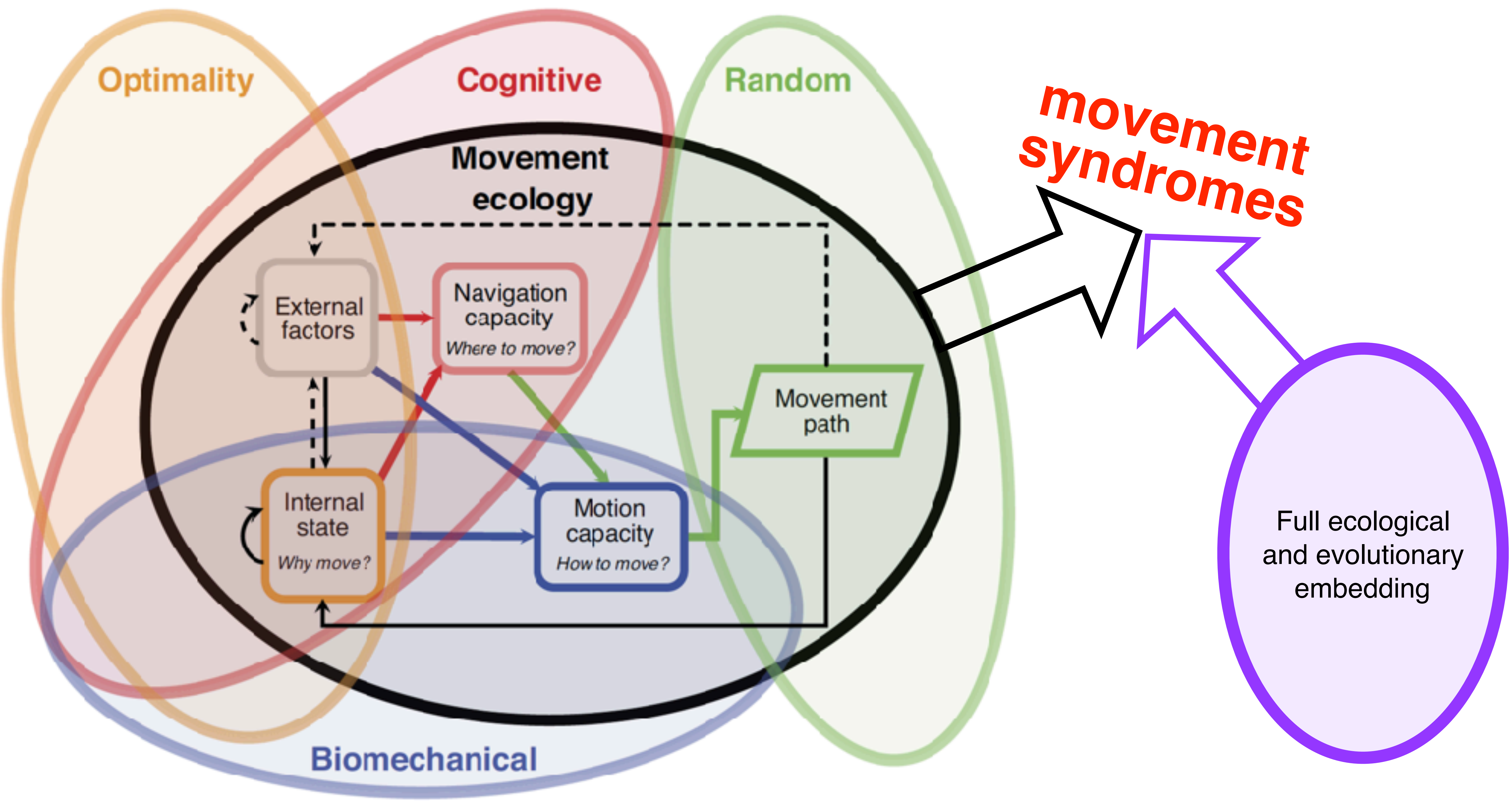
Individual level **Group level**



Thank you

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- *2015-2018: NSF EEID Spatio-temporal explicit estimation of R0 for pathogens with environmentally-mediated transmission.*
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- *2009-2013: BSF Grant 2008255, Movement and foraging efficiency of vultures.*
- *2009-2011: NSF Grant MCINS-20091291, Dissertation Research (Pauline Kamath): The role of host adaptive genetics in the variable patterns of anthrax occurrence across Southern Africa.*
- *2008-2009: USDI Fish & Wildlife Service 98210-8-G745: Etosha elephants: movement, anthrax, and demography in a declining population*
- *2008-2012: NIH Grant GM083863: The ecology of environmentally maintained episodic anthrax in Etosha, Namibia.*

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