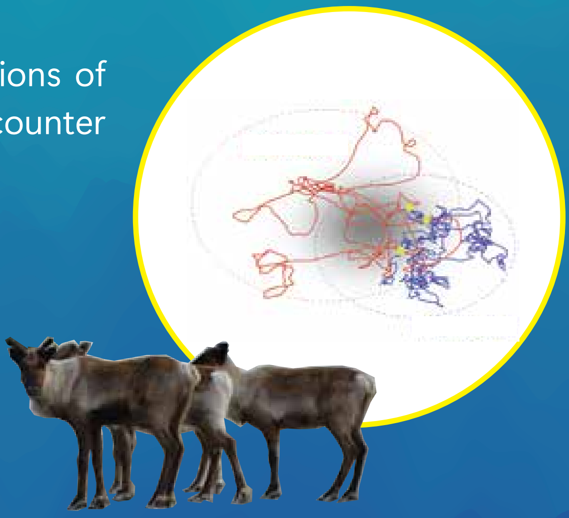
BRIN MATHEMATICS RESEARCH CENTER

Applied Stochastic Processes for Encounter Problems

February 5-9, 2024

About the Workshop

This workshop will focus on developing new theory and applications of stochastic processes, with a specific focus on so-called "encounter problems" in two space dimensions.



Organizers

Bill Fagan, University of Maryland
Ricardo Martinez-Garcia, CASUS-HZDR, Germany

Speakers

Ruth Baker, Oxford University
Justin Calabrese, CASUS-HZDR, Germany
Eduardo Colombo, CASUS-HZDR, Germany
Sarah Davidson, MPIAB (Movebank)
Natasha Ellison, Mississippi State University
Chris Fleming, University of Central Florida
Benjamin Garcia de Figueiredo, Princeton University
Luca Giuggioli, University of Bristol
Manuela Gonzalez-Suarez, University of Reading
Elie Gurarie, SUNY
Andrew Hein, Cornell University
Mark Lewis, University of Victoria
Kezia Manlove, Utah State University
Rafael Menezes , CASUS-HZDR, Germany
Joanna Mills Flemming, Dalhousie University
Michael Noonan, University of British Columbia
Gustavo Oliveira-Santos, UFMS, Brazil
Sid Redner, Santa Fe Institute
Jorge de Menezes, CASUS-HZDR, Germany
Lauren Shoemaker, University of Wyoming
Inês Silva, CASUS-HZDR, Germany
Anudeep Surendran, CASUS-HZDR, Germany
Rebecca Tyson, University of British Columbia
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DEPARTMENT OF MATHEMATICS

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Schedule at a Glance

	Monday	Tuesday	Wednesday	Thursday	Friday
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	Breakfast/Registration	Breakfast	Breakfast	Breakfast	Breakfast
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	Martinez-Garcia				
		Silva	Menezes		
10:00	Garcia de Figueiredo	Davidson	Noonan		
					Coffee Break
	Mills Flemming	Coffee Break	Coffee Break	Coffee Break	
					Wrap-Up Discussion
11:00	Coffee Break	Tyson	Working Groups: Discussion of Plans	Working Groups: Group Work	
	Oliveira-Santos	Lewis			
12:00	Lunch	Lunch	Lunch (On Your Own) and Free Afternoon	Lunch (On Your Own)	Lunch
13:00					
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Workshop Overview

This workshop will focus on developing new theory for and applications of stochastic processes, with a specific focus on so-called 'encounter problems' in two space dimensions. Encounter problems include, among other topics, the calculation of first passage times and assessments of spatial aggregation and clustering from the underlying behavior of stochastic processes. Such approaches are central to efforts seeking to scale microscopic (particle-level) representations to macroscopic (population-level) descriptions. Encounter problems for simple Brownian Motion (BM) are reasonably well understood mathematically and lead to the well-known law of mass action when scaled to the population level. However, encounter problems for more complicated stochastic processes, such as Ornstein-Uhlenbeck (OU) motion, are a persistent hot topic, and how OU encounters reflect in population dynamics remains unknown. In particular, understanding encounter problems for OU motion (particularly in a two-dimensional spatial context) is of substantial interest in mathematical biology. For example, encounter problems are central to understanding and building mathematical representations of disease spread where the focus is on contacts between infected and susceptible individuals, one or both of which can be mobile. Likewise, encounter problems for OU motion are highly relevant in ecology where the focus is on animals that occupy home ranges. Results from theoretical analyses of encounter problems have proven helpful in predicting the specific regions of space in which encounters between animal groups are expected to occur. Similarly, strong connections exist in cell biology, where concerns about 'crowded transport' problems regarding the intracellular movement of macromolecules have been explored with OU models. With this workshop, we expect to make progress in formulating and exploring 'encounter' problems for OU models and their relatives. By bringing together leading experts, we hope to make progress in at least two areas. First, we would like to explore encounter problems for OU movement processes that include realistic, biologically motivated attraction/avoidance forces. This is challenging because inclusion of such forces can result in nonlinear stochastic differential equations. Second, we would like to incorporate OU movement into epidemiological and population dynamic models. This is challenging because individuals are not indistinguishable under OU-movement assumptions, and obtaining population-level statistics requires tracking the population size and at least some features of its spatial structure over time.

Organizing committee

Bill Fagan, University of Maryland

Ricardo Martinez-Garcia, Center for Advanced Systems Understanding - HZDR, Germany

Workshop Schedule

Monday, February 5, 2024

8:30 - 9:00 Breakfast/Registration

9:00 - 9:15 Doron Levy & Bill Fagan
Opening

9:15 - 10:00 Ricardo Martinez-Garcia (Center for Advanced System Understanding - HDZR)
Stochastic Processes and Encounters: Conceptual Overview and Context for the Workshop

10:00 - 10:30 Benjamin Garcia de Figueiredo (Princeton University)
Diffusion and Interaction Processes from the Ground Up: Occupation Times and Stationarity

10:30 - 11:00 Joanna Mills Flemming (Dalhousie University)
Encounters at Sea: Aquatic Animal Tracking Data

11:00 - 11:30 Coffee Break

11:30 - 12:00 Gustavo Oliveira-Santos (Federal University of Mato Grosso do Sul)
Spatial Compartmentalization: A Nonlethal Predator Mechanism to Reduce Parasite Transmission Between Prey Species

12:00 - 2:00 Lunch

2:00 - 2:30 Luca Giuggioli (University of Bristol)
Quantifying First-Encounter and First-Transmission Events through an Analytically Exact Discrete Space-Time Formalism

2:30 - 3:00 Kezia Manlove (Utah State University)
Inferring Social Drivers and Fitness Consequences of Animal Contacts in Two Real-World Systems

3:00 - 3:30 GANDHIMOHAN VISWANATHAN (Federal University of Rio Grande do Norte)
Under What Conditions are Inverse Square Lévy Walk Searches Optimal?

3:30 - 4:00 COFFEE BREAK

4:00 - 4:30 ANUDEEP SURENDRAN (Center for Advanced System Understanding - HZDR)
How Range Residency and Velocity Correlations Impact Encounter Rates

4:30 - 5:00 MANUELA GONZALEZ-SUAREZ (University of Reading)
Wildlife Encounters with Linear Infrastructures

5:00 - 5:30 EDUARDO COLOMBO (Center for Advanced System Understanding - HZDR)
A Bottom-Up Approach to Connect Individual-Level Behavior and Home-Range Shape

5:30 - 6:30 HIGH TEA

Tuesday, February 6, 2024

8:30 - 9:00	Breakfast
9:00 - 9:30	Ruth Baker (Oxford University) *Using Mathematical Models to Unravel Cell-Cell Interactions and Provide a Link Between Genotype and Phenotype*
9:30 - 10:00	Inês Silva (Center for Advanced System Understanding - HZDR) *Understanding Vehicle-Wildlife Encounters: Insights from Animal Movement Datasets and Road Mortality Surveys*
10:00 - 10:30	Sarah Davidson (MPIAB (Movebank)) *Leveraging Community Data Platforms to Study Encounter Problems*
10:30 - 11:00	Coffee Break
11:00 - 11:30	Rebecca Tyson (University of British Columbia) *Memory-Guided Foraging and Host Spatial Arrangement Interact to Determine Pollination Services*
11:30 - 12:00	Mark Lewis (University of Victoria) *First Passage Time: Connecting Random Walks to Functional Responses*
12:00 - 1:30	Lunch
1:30 - 2:00	Natasha Ellison (Mississippi State University) *Modelling Animal Movement and Spatial Patterns to Understand the Behavior of Wild Animals for the General Wildlife Biologist*
2:00 - 2:30	Andrew Hein (Cornell University) *Data-Driven Models of Encounters and Interactions in Ecology*
2:30 - 3:00	Coffee Break
3:00 - 3:30	Chris Fleming (University of Central Florida) *Continuous-Time Encounter Measures and their Estimation*
3:30 - 4:00	Justin Calabrese (Center for Advanced System Understanding - HZDR) *A Novel, Range-Distribution-Based Estimator of Pairwise Encounter Probabilities*

4:00 - 4:30 Elie Gurarie (SUNY College of Environmental Science and Forestry)
Linking Movements to Encounters: Fundamental Frameworks, Definitions and Derivations

4:30 - 5:00 Jorge de Menezes (Center for Advanced System Understanding - HZDR)
The Monogamy Index: A Distance-Based Continuous Measure to Assess Animal Mating System

5:00 - 5:30 Sid Redner (Santa Fe Institute)
The Dynamics of Foraging and Starvation

Wednesday, February 7, 2024

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10:00 - 10:30	Michael Noonan (University of British Columbia) *Confronting Data with Theory: How Stochastic Processes Can Yield Novel Insight into Animal Movement Strategies*
10:30 - 11:00	Coffee Break
11:00 - 12:00	Working Groups: Discussion of Plans
12:00 - 5:00	Lunch (On Your Own) and Free Afternoon

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8:30 - 9:00	Breakfast
9:00 - 10:30	Working Groups: Group Work
10:30 - 11:00	Coffee Break
11:00 - 12:00	Working Groups: Group Work
12:00 - 1:30	Lunch (On Your Own)
1:30 - 3:00	Working Groups: Group Work
3:00 - 3:30	Coffee Break
3:30 - 5:00	Working Groups: Group Work
7:00 - 9:00	Conference Dinner

Friday, February 9, 2024

8:30 - 9:00	Breakfast
9:00 - 10:15	Working Groups: Group Conclusions
10:15 - 10:45	Coffee Break
10:45 - 12:00	Wrap-Up Discussion and Plans for Products
12:00 - 1:30	Lunch
1:30 - 1:45	Workshop Closing

Abstracts of talks

Stochastic Processes and Encounters: Conceptual Overview and Context for the Workshop

Ricardo Martinez-Garcia

Center for Advanced System Understanding - HDZR

Monday, February 5, 2024 @ 9:15 AM

Diffusion and Interaction Processes from the Ground Up: Occupation Times and Stationarity

Benjamin Garcia de Figueiredo

Princeton University

Monday, February 5, 2024 @ 10:00 AM

Diffusion in the presence of reactive domains has the potential to be a robust and generalizable framework for understanding how movement on larger scales can shape and constrain local contact interactions. Nevertheless, the growing literature on this subject still bears unresolved tensions on various interpretations of the distribution of encounter events. In this talk I will present some remarks on how interaction processes may be interpreted as a coupling of diffusion to point processes in the occupation time of the reactive domain. The point-process interpretation gives clear meaning to reaction constants and an immediate connection to encounters in the stationary limit. The latter observation reveals a tentative universal relationship between reaction times and first-hitting times conditioned on the stationary distribution of the diffusive motion. These ideas are illustrated in the ecological example of wildlife-vehicle collisions, which simultaneously serve as a (one dimensional) minimal case of the framework and an explicit example of how the distribution of encounter events can be interpreted directly in terms of observables of interest such as decrease in average lifespan of a population. I discuss how these notions generalize to higher-dimensions.

Encounters at Sea: Aquatic Animal Tracking Data

Joanna Mills Flemming

Dalhousie University

Monday, February 5, 2024 @ 10:30 AM

The Ocean Tracking Network (OTN) is a global aquatic research, data management and partnership platform headquartered at Dalhousie University (Halifax, Nova Scotia, Canada). For nearly two decades OTN has been utilizing state-of-the-art ocean monitoring equipment to collect data on the movement and survival of aquatic animals. The resulting telemetry data can tell us not only where animals are, but also provide information about the animals themselves (e.g., heart rate), their behaviour (e.g., spawning), and their environments (e.g., salinity). Spatiotemporal modelling frameworks for these complex data sets can improve our understanding of how animals are responding to climate change (and other anthropogenic disturbances) as well as help us obtain better estimates of population size to inform conservation and fishing policies.

Spatial Compartmentalization: A Nonlethal Predator Mechanism to Reduce Parasite Transmission Between Prey Species

Gustavo Oliveira-Santos

Federal University of Mato Grosso do Sul

Monday, February 5, 2024 @ 11:30 AM

Predators can modulate disease transmission within prey populations by influencing prey demography and behavior. Predator-prey dynamics can involve multiple species in heterogeneous landscapes; however, studies of predation on disease transmission rarely consider the role of landscapes or the transmission among diverse prey species (i.e., spillover). We used high-resolution habitat and movement data to model spillover risk of the brainworm parasite (Parelaphostrongylus tenuis) between two prey species [white-tailed deer (Odocoileus virginianus) and moose (Alces alces)], accounting for predator [gray wolf (Canis lupus)] presence and landscape configuration. Results revealed that spring migratory movements of cervid hosts increased parasite spillover risk from deer to moose, an effect tempered by changes in elevation, land cover, and wolf presence. Wolves induced host-species segregation, a nonlethal mechanism that modulated disease emergence by reducing spatiotemporal overlap between infected and susceptible prey, showing that wildlife disease dynamics may change with landscape disturbance and the loss of large carnivores.

Quantifying First-Encounter and First-Transmission Events through an Analytically Exact Discrete Space-Time Formalism

Luca Giuggioli

University of Bristol

Monday, February 5, 2024 @ 2:00 PM

The dynamics of transport processes have a long history in statistical physics starting from the early studies in the 1950s on particles and excitations moving in disordered materials such as amorphous semiconductors and molecular aggregates. The general formalism, laid out by Montroll and co-workers, using lattice random walks, (LRW) was later extended to Brownian walks. Among the statistically accessible transport quantities, the dynamics of first-passage processes (to a target) have been the focus of a large body of literature. While both the discrete and continuous representations are appropriate to model them, recent findings to describe LRW in confined space offer the advantage in providing exact analytic or semi-analytic representations, when compared to Brownian walks, which often require solving an often unwieldly boundary value problem numerically. This is particularly relevant for encounter and transmission processes whereby 'interactions' may occur at multiple target locations. In this talk I'll present the LRW formalism and its application to various first-passage problems in multiple geometries, from Euclidean lattices to hexagon and honeycomb domains, as well as in the presence of spatial disorder. If time allows, I will also show the application of LRW to first-passage dynamics when movement is persistent.

Inferring Social Drivers and Fitness Consequences of Animal Contacts in Two Real-World Systems

Kezia Manlove

Utah State University

Monday, February 5, 2024 @ 2:30 PM

Animal contact dynamics emerge in response to both biophysical and social drivers, yet the existing literature on stochastic processes of animal movement relies primarily on the former. Overlooking social drivers of contact imposes important limitations of models of animal contact, leading to either over- or under-estimation of system-wide contact patterns depending on the focal organisms social ecology. Gleaning social drivers of contact is difficult, however, due to the temporally variable nature of the social environment and limited data on known individuals. In this presentation, I will walk through two different examples where I have attempted to infuse social processes into inferences about system-wide contact dynamics, one in which animals are regularly censused, and another where social ecology can be approximated by aspects of the biophysical environment. I will consider a third possibility, where models of contact could be infused with independently measurements of spatiotemporally explicit densities. Finally, I will briefly outline ideas for how to strategically construct kernels around individual movement trajectories to capture a priori knowledge pertaining to information, gene, and pathogen transfer and facilitate connections between patterns of contact and emergent fitness.

Under What Conditions are Inverse Square Lévy Walk Searches Optimal?

Gandhimohan Viswanathan

Federal University of Rio Grande do Norte

Monday, February 5, 2024 @ 3:00 PM

Lévy walk search models were proposed in the 1990s to try to account for the observed movement patterns of real animals. A key property of these models is that Lévy walks with an inverse square power law distribution of move lengths are understood to optimize encounter rates between the searcher and the targets under certain search conditions, namely, when the randomly distributed targets can be revisited (after a short regeneration time) and when the density of targets becomes vanishingly small. These models have found application in theoretical ecology, however they remained somewhat controversial for a number of reasons. For example, it was reported recently that in dimensions d>1 Lévy walk searches are not optimal after all [Phys. Rev. Lett. 124, 080601 (2020)]. This claim led to further investigations showing that Lévy walk searches are optimal even when d>1 [Phys. Rev. Lett. 126, 048901 (2021)]. Here we give an overview of these developments in the context of foraging. Finally, we consider a simpler model whose behavior can be thought of as an approximation of Lévy walk searches. We present recent results of a Lévy walker inside 2D annuli and 3D spherical shells with absorbing boundaries. This model can be used as a proxy to understand why inverse square Lévy walk searches are optimal in any dimension.

How Range Residency and Velocity Correlations Impact Encounter Rates

Anudeep Surendran

Center for Advanced System Understanding - HZDR

Monday, February 5, 2024 @ 4:00 PM

Encounters between individuals are fundamental for many ecological processes such as mate finding, predation, and disease transmission, among others. Computing encounter rates in these scenarios provides insight into how individual movement strategies lead to population-level consequences. Many previous studies, focused on tying individual movement behavior to encounters, suggest that directionally persistent movement (ballistic movement) strategies improve encounter rates. However, these models often ignore the effect of range residency of animals, where the individuals use space non-uniformly and occupy a home range that is considerably smaller than the population range. Here we show that when we consider the range resident behavior, the ballistic movement strategy does not always result in increased encounter as previously thought. Rather, we show that the effect of ballistic movement on encounter rates is influenced by the spatial distribution of the individual home ranges. We demonstrate these features by deriving exact analytical expressions for encounter rates under the Ornstein-Uhlenbeck movement with foraging (OUF), which is a movement model that allows directional persistence (correlations in velocity) along with range residency.

Wildlife Encounters with Linear Infrastructures

Manuela Gonzalez-Suarez

University of Reading

Monday, February 5, 2024 @ 4:30 PM

Animals regularly move to find resources, locate mates, and avoid danger. Most daily movements cover regularly visited, generally small, home range areas, but some organisms move over thousands of kilometres during seasonal migrations. The frequency, distance, and path of animal movements are influenced by diverse factors, from individual condition and reproductive status to weather and social cues. However, regardless of what drives movement, in nearly all parts of the world moving animals regularly encounter human-modified habitats and infrastructures. Linear infrastructures such as roads, railways and power lines are prevalent features of most landscapes that affect impact animal movement and cause mortality. Millions of individuals are estimated to die each year due to collisions with vehicles on roads. Being able to predict where and when collisions are more likely is important for conservation, but also socially as human property and life can be impacted in these encounters. I will present previous work on the drivers of wildlife-vehicle collisions and discuss the challenges of modelling who, when and when animals encounter roads and moving vehicles.

A Bottom-Up Approach to Connect Individual-Level Behavior and Home-Range Shape

Eduardo Colombo

Center for Advanced System Understanding - HZDR

Monday, February 5, 2024 @ 5:00 PM

Living organisms establish interaction through the exchange of physicochemical signals. The cumulative effect of these exchanges cascades across scales controlling the emergence and maintenance of home-ranges and territories. Therefore, a theoretical framework aiming to elucidate the role of behavior in how animals partition the use of space must adopt a bottom-up approach, incorporating individual-level interactions. During this presentation we will discuss a potential data-driven structure for this framework. We will start by analyzing animal tracking data, looking for signatures of interactions, specifically focusing on contact-type interactions. Then, having characterized interactions, we move towards a connection between a quantified behavioral trait (e.g. level of aggressiveness among individuals) and how space use is partitioned.

Using Mathematical Models to Unravel Cell-Cell Interactions and Provide a Link Between Genotype and Phenotype

Ruth Baker

Oxford University

Tuesday, February 6, 2024 @ 9:00 AM

In vitro cell biology assays are a cornerstone of biomedical science, from basic research that aims to provide fundamental new understanding of development, disease and repair, through to pharmaceutical applications that include drug discovery and cytotoxicity testing. A widely adopted strategy is to conduct a particular in vitro assay under a range of genetic perturbation conditions and observe how cellular phenotypes change. The key challenge is to then to determine the mechanisms by which the genetic perturbations give rise to the phenotypes. In this context, mathematical modelling has huge potential to overcome the challenges of elucidating mechanisms by providing a rigorous framework to describe the nonlinear interactions between cells and quantify the variations in system parameters following genetic perturbations. However, for models to be successful in teasing apart complex mechanisms from noisy, high-throughput data, we need to calibrate them to quantitative data. I will show how to calibrate a complicated model to data from a high-throughput scratch assay experiment across many gene knockdowns to characterise the relative contributions of local cell density-dependent and -independent mechanisms of cell movement and proliferation. I will show that it is possible characterise functional subgroups, and that density-dependent interactions play a crucial role in wound closure.

Understanding Vehicle-Wildlife Encounters: Insights from Animal Movement Datasets and Road Mortality Surveys

Inês Silva

Center for Advanced System Understanding - HZDR

Tuesday, February 6, 2024 @ 9:30 AM

Wildlife-vehicle collisions are an ongoing and widespread source of biodiversity loss. Understanding how, when and why these collisions happen is a key challenge in any conservation and management efforts. Data collection with biologgers can reveal information on how animals use their environment, interact with each other, and their adaptive responses to rapid environmental changes and anthropogenic features in the landscape —including their behavioral responses to linear infrastructures. The movement ecology field is rapidly shifting as we open new avenues of research, with increased access to modern tracking technologies, collecting high-volume high-resolution movement datasets for a growing number of animal species worldwide. Using these datasets to reveal road impacts on animal behavior is fundamental, since wildlife-vehicle collisions are the second-largest source of anthropogenic mortality for many vertebrate species. We will explore empirical examples with animal tracking data, as well as information collected through road surveys, and how these can serve as crucial tools to achieve a deeper understanding of animal movement and behavior towards roads and vehicles.

Leveraging Community Data Platforms to Study Encounter Problems

Sarah Davidson

MPIAB (Movebank)

Tuesday, February 6, 2024 @ 10:00 AM

Many initiatives aggregate data on animal movements, representing government archives, research collaborations and telemetry networks. Of these, the largest is Movebank, a global platform for animal-borne sensor data used by researchers around the world, containing billions of measurements extending across more than four decades and representing behaviors of over 1,400 taxa. While these data are commonly described as "animal tracks", most data stored in Movebank are measurements from sensors that do not record geographic location, such as acceleration or temperature, that can be used to interpret fine-scale behavior or external and internal conditions. Together, these data offer a range information about animal encounters and potential approaches to investigating encounter problems. In some cases, encounters can be measured directly using high-resolution GPS tracks or proximity data for groups of tagged individuals. In others, movement patterns can be used to detect likely encounters with untagged animals (such as predation events) or the results of those encounters (such as mortality or disease transmission). Movebank's web application and APIs offer tools to discover, harmonize and automate access data for large-scale analysis. Researchers organize data independently within over 8,000 studies using a shared data model and vocabulary. They choose whether to share data publicly or with select others, and can be contacted directly to discuss proposed uses. Guidance is available to help prepare data-sharing agreements, access data securely by API, and assist data contributors with quality control. While uniform data formats and transfer protocols can greatly facilitate data acquisition and analysis, it is critical to understand sources of heterogeneity in methodologies, study design and technologies used in data collection. Joint analysis requires careful planning to account for this variation, define minimum data requirements to address a proposed question, and connect with data owners or other species experts to understand limitations and ensure biologically meaningful analysis. Where adequate data do not yet exist to address novel mathematical questions that are not the focus of traditional field studies, Movebank can be used to identify potential collaborators and plan new data collection. A partner platform, MoveApps, provides user-friendly, open-source software to streamline data analysis. Users build interactive workflows composed of "apps", written in R or Python, and can connect directly with developers and other users through sharable workflows and GitHub. Where data are streaming into Movebank, automated runs can support near-real-time reporting. For those developing novel methods, MoveApps offers a place to introduce others to your work. For leaders of meta-analyses, it could support an approach to data analysis that distributes some steps, such as data cleaning and exploration, across data contributors, increasing efficiency and engaging collaborators in the analysis.

Memory-Guided Foraging and Host Spatial Arrangement Interact to Determine Pollination Services

Rebecca Tyson

University of British Columbia

Tuesday, February 6, 2024 @ 11:00 AM

The plant-pollinator mutualisms are ubiquitous and of fundamental importance to agricultural and ecological sustainability. Pollinators do not generally forage on a single host type, so both wild and cultivated plants rely on obtaining sufficient visits from generalist pollinators. In this talk, we look at the interaction between the spatial arrangement of competing hosts, and the memory-guided behaviour of the mutualist foragers. This interaction leads to particular patterns of the pollination services accrued to the host population. Our results provide further insights into the role of memory in foraging patterns, and suggest approaches for increasing pollination services to crops in agricultural landscapes.

First Passage Time: Connecting Random Walks to Functional Responses

Mark Lewis

University of Victoria

Tuesday, February 6, 2024 @ 11:30 AM

In this talk I will outline first passage time analysis for animals undertaking complex movement patterns, and will demonstrate how first passage time can be used to derive functional responses in predator prey systems. The result is a new approach to understanding functional responses based on a random walk model. I will extend the analysis to complex heterogeneous environments to assess the effects of man-made linear landscape features on functional responses in wolves and elk. This work is joint with Hannah McKenzie, Evelyn Merrill and Ray Spiteri.

Modelling Animal Movement and Spatial Patterns to Understand the Behavior of Wild Animals for the General Wildlife Biologist

Natasha Ellison

Mississippi State University

Tuesday, February 6, 2024 @ 1:30 PM

Spatial patterns created by animal movements are driven by an intertwined network of animal interactions, memory processes and features of the environment, thus modelling can be challenging. First of all, fitting tracking devices to wild animals and later collecting these data is demanding and time consuming. Afterwards, determining the predominant spatiotemporal processes that drive the patterns by analyzing the movement paths is outside of most wildlife biologists toolboxes, often leading to movement data that is not being used to its full potential. Therefore, collaborations with mathematicians to model these stochastic processes is essential for fully understanding wild animal movement, their resulting space use and potentially the connected population level patterns. In this talk, I will discuss how mechanistic tools are used by wildlife biologists by describing popular tools and their advantages and pitfalls and using examples from my own and my collaborators research.

Data-Driven Models of Encounters and Interactions in Ecology

Andrew Hein

Cornell University

Tuesday, February 6, 2024 @ 2:00 PM

Ecosystems are complex systems that comprise not only diverse populations of organisms, but also the diverse and often ephemeral interactions among those organisms. Historically, ecologists have built mathematical models of ecosystems by either assuming simple topologies and interaction rules, or by seeking to infer these from often limited demographic data. However, as new data collection technologies come online, it is becoming possible to measure ecological interactions directly. I will discuss mathematical methods and data analysis tools for building new kinds of models of ecological interactions that are driven by data.

Continuous-Time Encounter Measures and their Estimation

Chris Fleming

University of Central Florida

Tuesday, February 6, 2024 @ 3:00 PM

Animal tracking data comprise locations sampled at discrete times, which may only provide a sparse representation of the true movement path, and where the sampled times may not be synchronous across individuals. Therefore, measures that test for encounters only at sampled times can miss encounters that occur during the observation period, and will yield differentially biased encounter-rate estimates, with more underestimation at coarser sampling rates and for more tortuous movement processes. In this talk, I discuss measures based on continuous-time stochastic process models that avoid these biases and provide uncertainty estimates that reflect imperfect observation.

A Novel, Range-Distribution-Based Estimator of Pairwise Encounter Probabilities

Justin Calabrese

Center for Advanced System Understanding - HZDR

Tuesday, February 6, 2024 @ 3:30 PM

Direct encounters, which can occur when two animals come within a threshold distance of each another, underpin many ecological processes including predation, mating, contest competition, territory formation, and disease transmission. The probability of encounter is therefore of fundamental quantity, and has historically been quantified from animal tracking data via two classes of metrics that feature contrasting strengths and weaknesses. Trajectory-based methods estimate the frequency of simultaneous location observations between two individuals that are within a threshold distance, d. In contrast, distribution-based methods use home range overlap as a proxy for encounter potential. While trajectory-based metrics directly quantify the probability of encounter, they are sensitive to the sampling frequency and yield underestimates when data are sparse. In contrast, home-range-based metrics have good statistical properties, including insensitivity to sampling frequency, but are not straightforwardly related to encounter probability. Here, we introduce a distribution-based estimator of the probability of encounter. Using mathematical arguments, simulated data, and empirical case studies, we show that, like trajectory-based methods, our metric directly and accurately estimates encounter probability, while also displaying the sampling insensitivity of methods based on home range overlap. Furthermore, our probability of encounter estimator features reliable confidence intervals, and is implemented in and fully integrated with the ctmm R package (v1.2+) for movement analysis.

Linking Movements to Encounters: Fundamental Frameworks, Definitions and Derivations

Elie Gurarie

SUNY College of Environmental Science and Forestry

Tuesday, February 6, 2024 @ 4:00 PM

Biological encounters are fundamental to many ecological processes. There is an intrinsic tension in the application of two physics-inspired models to the analysis of biological movements and encounters: The diffusion model assumes a homogeneous population of pathologically random particles, while the ideal-free-gas model, which underlies rate-type interaction models (e.g. Lotka-Volterra) assume a heterogeneous population of particles moving linearly, with hard collisions. Biological entities are clearly somewhere in between: heterogeneous populations of organisms moving in a combination of directed and random modes with probabilistic encounters. While it is difficult to reconcile these fully, I propose a framework with which to approach this problem. I note a fundamental distinction between "first encounter rates" and "mean encounter rates", which are not generally equal (depending on movement behaviors, spatial scales of encounter, spatial distribution and dynamics of targets), and a similar fundamental distinction between destructive and non-destructive encounters. Based on these considerations, I present a taxonomy of encounter processes and discuss their functional relationships. I then present a continuous-time, continuous-space framework for examining encounters between searchers and immobile (but dynamic) targets, as well as a few analytical solutions (or approximations) for more biologically realistic encounter rates. Finally, I present a few examples in which insights from a fundamental encounter theory can inform applied problems in animal movement ecology.

The Monogamy Index: A Distance-Based Continuous Measure to Assess Animal Mating System

Jorge de Menezes

Center for Advanced System Understanding - HZDR

Tuesday, February 6, 2024 @ 4:30 PM

Mating systems is a topic of ample discussion in ecology, with a diversity of measures to infer it. Among those is inference based on animal movement, under the assumption that close proximity or high home range overlap translate in a higher probability of mating. Despite its popularity, how much overlap or proximity is sufficient to classify a species as “promiscuous” or “monogamous” is still debated and dependent on the underlying metric of overlap. In this presentation, we propose a new index, the monogamy index, that eliminates this subjectivity by introducing a continuous and individual index of monogamy. This metric is also agnostic towards the distance metric, working with home-range overlap or distance. We demonstrate this index soundness in six different simulation scenarios with four different distance metrics. Further, we show our index concurs with previous qualitative results of a mating system study on Thrichomys spp. Finally, we discuss how this index has relatively small standard errors with respect to similar individuals and discuss other applications for fission-fusion groups and aggressiveness studies. We discuss and recommend its use with centroid distance at high effective sample size and with home range overlap calculated using autocorrelated kernel density estimation at low effective sample size.

The Dynamics of Foraging and Starvation

Sid Redner

Santa Fe Institute

Tuesday, February 6, 2024 @ 5:00 PM

What is the fate of a random-walk forager that depletes its environment as it wanders? Whenever the forager lands on a food-containing site, all the food is consumed and the forager becomes fully sated. However, when the forager lands on an empty site, it moves one time unit closer to starvation. If the forager wanders S steps without encountering food, it starves to death. We show that the lifetime of this starving random walk forager scales linearly with S in one dimension by solving an underlying non-Markovian first-passage problem. In greater than two dimensions, we present evidence that the lifetime grows quasi-exponentially in S. We also investigate the role of greed, in which the forager preferentially moves towards food when faced with a choice of hopping to food or to an empty site in its local neighborhood. Paradoxically, the forager lifetime can have a non-monotonic dependence on greed, with different senses to the non-monotonicity in one and in two dimensions. In one dimension, the forager lifetime exhibits a huge peak when greed is negative, while in two dimensions the maximum lifetime occurs for positive, but not perfect, greed. Finally, we briefly discuss the role of frugality and myopia on foraging dynamics. Frugality means that the forager does not eat until it is nutritionally depleted beyond a specified level. Myopia means that the forager sometime does not "see" food at its current site and leaves the food undisturbed. Both attributes are surprisingly effective in extending the forager lifetime.

Stochasticity in Species Interaction Neighborhoods Increases the Potential for Coexistence

Lauren Shoemaker

University of Wyoming

Wednesday, February 7, 2024 @ 9:00 AM

Coexistence and the maintenance of species diversity depends jointly on species responses to the environment and interactions among species. As such, variability in the density and identity of species that reside within an individual's local neighborhood can impact the focal individuals fecundity and thus the probability of coexistence among multiple species.Here, I overview previous and ongoing research from my lab using theoretical mathematical models that explain how stochasticity in interaction neighborhoods predicts pairwise species coexistence. I additionally discuss empirical work quantifying neighborhood stochasticity, its impact on species interaction strengths, and coexistence potential within annual plant communities in both California USA and Western Australia.

Combining Spatial Dynamics and Movement Models to Explore the Demographic Consequences of Movement: A Logistic Model with Range Residency

Rafael Menezes

University of São Paulo

Wednesday, February 7, 2024 @ 9:30 AM

In this presentation, I introduce a novel modeling framework incorporating realistic movement into models of population and community dynamics. Traditionally, Spatial Moment Dynamics (SMD) and Individual Based Models (IBMs) are two complementary tools to investigating the dynamics of populations and communities in space. While IBMs can easily incorporate complex interactions and movement, SMD provides an analytical framework for investigating the outcome of the IBM simulations. I demonstrate that by representing realistic movement as a stochastic process and incorporating it into an IBM, it is possible to explore the ultimate consequences of organism behavior on population demographic patterns. The resulting model can be analyzed analytically and numerically, using SMD and stochastic simulation algorithms. To show the potential of this approach, we employ it to analyze the factors influencing the carrying capacity of a population of range-resident organisms, including home range (HR) size, HR crossing times, dispersal, and competition ranges. Beyond the complex dependency on these scales and rates, we show that the asymptotic abundance is strongly related to the spatial distribution of organisms. We use the Ornstein-Uhlenbeck (OU) movement model to represent the movement of organisms with range residency, which allows for a diverse range of movement behaviors – from sessile organisms with vanishingly small home ranges to roaming organisms with home ranges as large as the environment. In these two limits, our results are consistent with those produced by previous models for sessile organisms and well-mixed populations.

Confronting Data with Theory: How Stochastic Processes Can Yield Novel Insight into Animal Movement Strategies

Michael Noonan

University of British Columbia

Wednesday, February 7, 2024 @ 10:00 AM

Ecologists have long been interested in linking individual behavioural decisions with higher-level processes (e.g., predator-prey dynamics, disease transmission, optimal foraging strategies, etc). Stochastic processes and encounter theory provide a rich set of tools for understanding and making predictions about such relationships, however, due to their technical nature, they are rarely used in more applied settings. Thus, although the impact that different movement strategies might have on encounter rates is well recognized from a theoretical standpoint, a generalized understanding of how they may shape general patterns in animal movement is lacking. Rapid advances in the capacity to collect and work with movement data, however, are enabling stochastic process models to be fit to data from a broad range of species. Here I present a number of case studies that highlight how stochastic processes can be used to show how the optimization of encounter rates shape patterns in animal movement strategies. First I describe how stochastic processes fit to GPS data from >3,000 individuals across hundreds of species of terrestrial mammals and birds reveal the trade-offs that animals appear to make while searching for resources. I next describe how such models can be used to provide novel insight into the social behaviour of giant anteaters. I then show how encounter theory can provide novel insight into the way we think about human-wildlife conflict. Finally, I describe how we can use stochastic processes to refine our thinking about how ecological processes might respond to changing environmental conditions due to anthropogenic disturbance. These case studies demonstrate how stochastic process models, and their parameters, permit the estimation of encounter related metrics that can be used to describe ecological process in new ways, allowing researchers to confront trends in empirical movement data with predictions from the rich field of encounter theory, yield novel insight, and test new questions. Further bridging the divide between theory and data is promising avenue for future research.

The Brin Mathematics Research Center

The Brin Mathematics Research Center is a research center that sponsors activity in all areas of pure and applied mathematics and statistics. The Brin MRC was funded in 2022 through a generous gift from the Brin Family. The Brin MRC is part of the Department of Mathematics at the University of Maryland, College Park.

Activities sponsored by the Brin MRC include long programs, conferences and workshops, special lecture series, and summer schools. The Brin MRC provides ample opportunities for short-term and long-term visitors that are interested in interacting with the faculty at the University of Maryland and in experiencing the metropolitan Washington DC area.

The mission of the Brin MRC is to promote excellence in mathematical sciences. The Brin MRC is home to educational and research activities in all areas of mathematics. The Brin MRC provides opportunities to the global mathematical community to interact with researchers at the University of Maryland. The center allows the University of Maryland to expand and showcase its mathematics and statistics research excellence nationally and internationally.

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