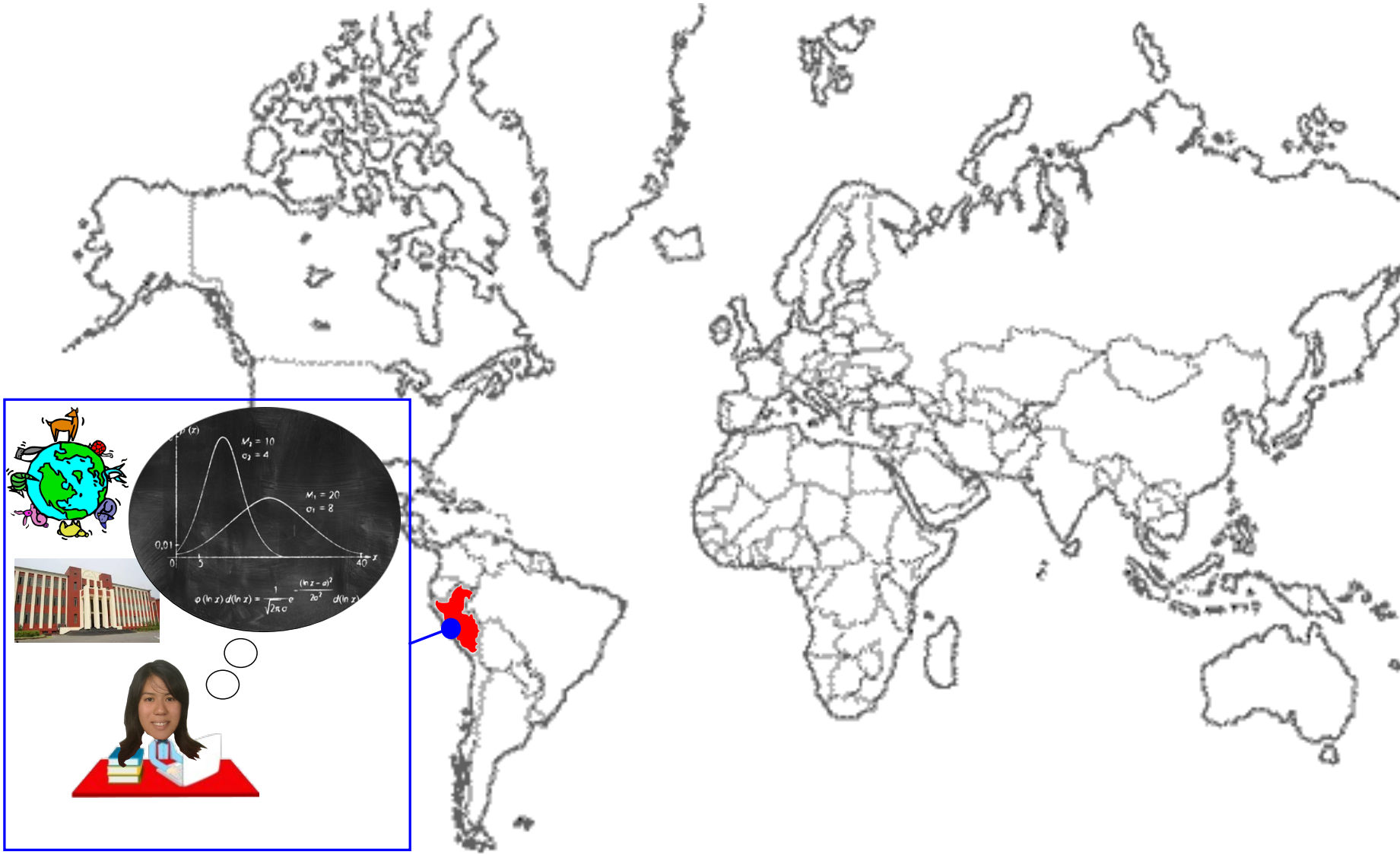
Movement ecology and trajectometry: stories from the sea

Rocío Joo

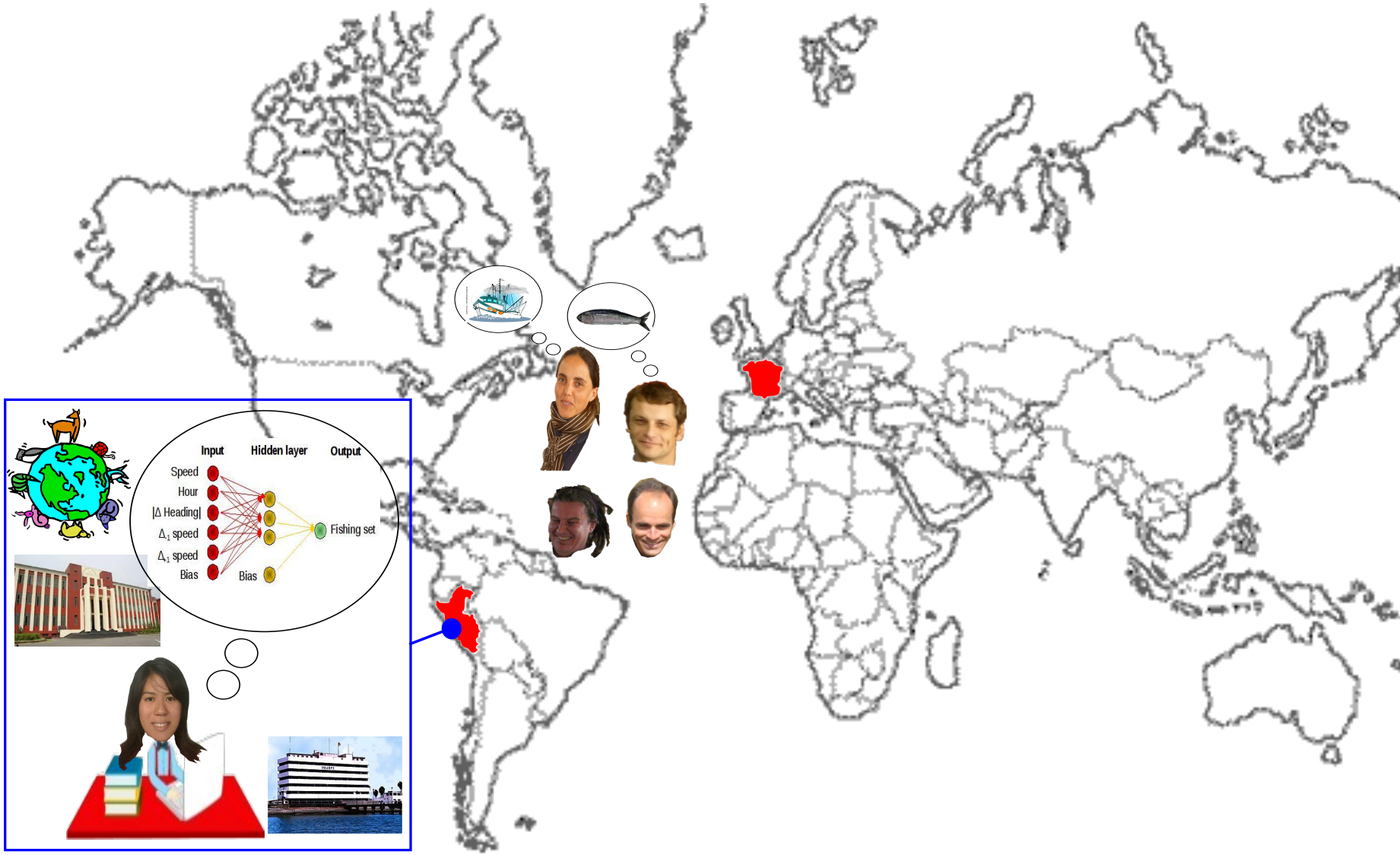
Cocha Cashu

October 2017

My movement...



My movement...


Input
Hidden layer
Output
Speed
Hour
|Δ Heading|
Δ1 speed
Δ1 speed
Bias
Bias
Fishing set

My movement...

My movement...

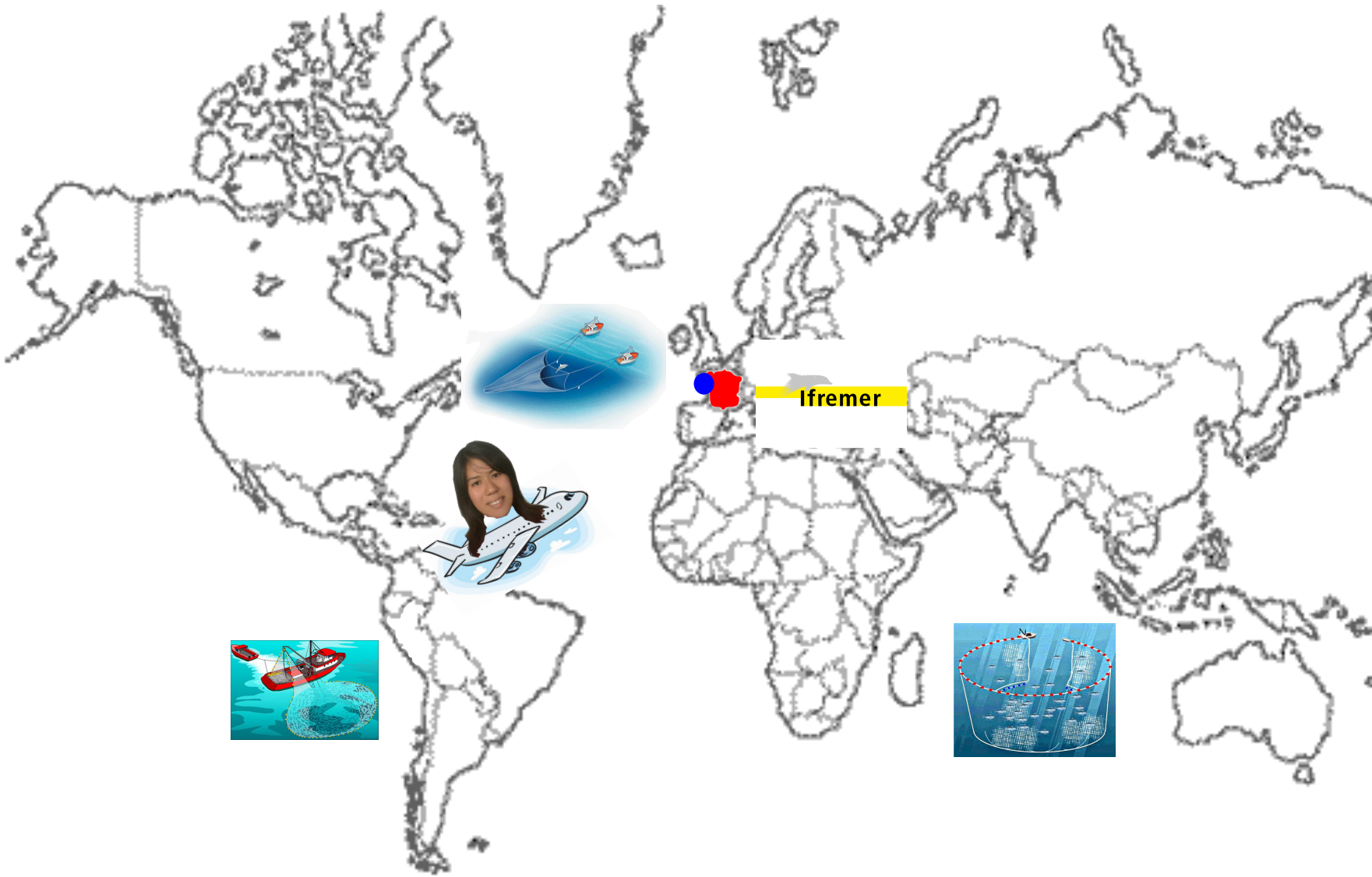

TELECOM
Bretagne
IRD
Institut de recherche
pour le développeme

My movement...

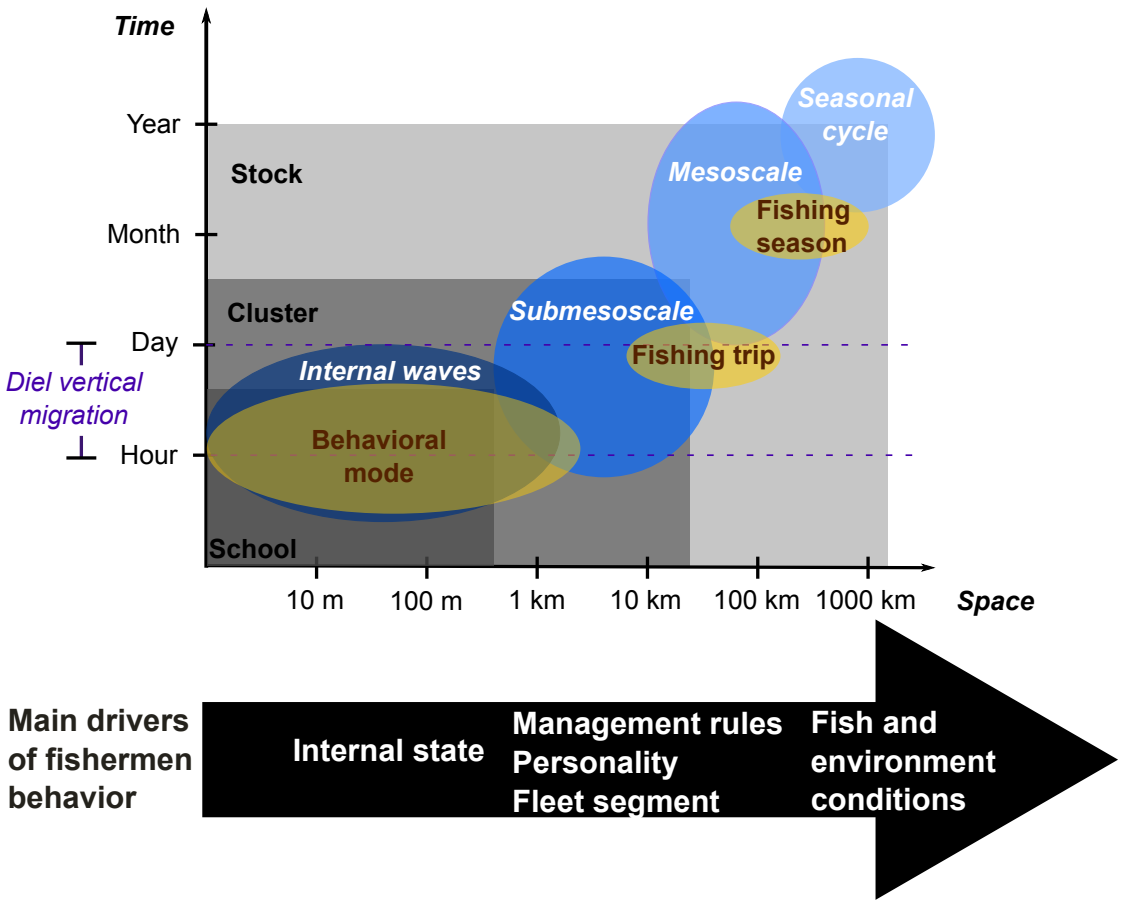
My movement...


INSTITUTO DE
FOMENTO
PESQUERO
Universidade Federal de Sergipe
Nelson Mandela
Metropolitan
University
for tomorrow
Port Elizabeth & George

My movement...



A quantitative approach to the movement ecology of fishers



Research subject

A quantitative approach to the movement ecology of fishers

- Movement ecology
- Random walks
- Behavioral modes
- Spatial behavior and other ecosystem components
- Predator to prey maps
- Collective behavior

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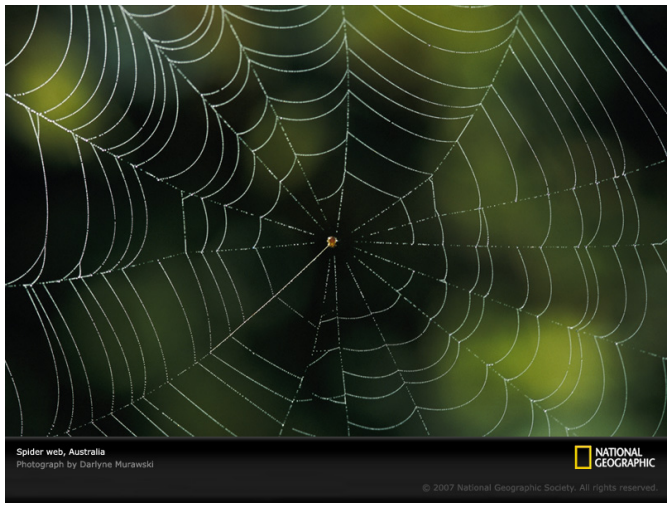
Movement ecology

Behavior ← expressed through movement

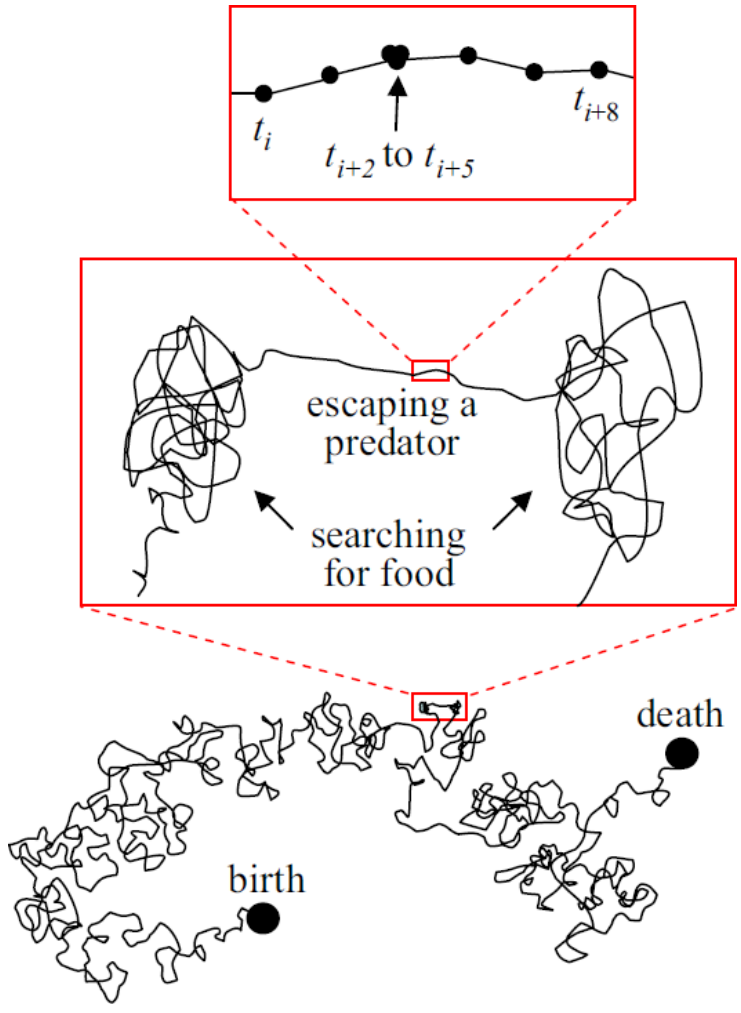


Movement ecology

Behavior ← expressed through movement

Movement ecology

- Behavior ← expressed through movement
- Movement path → Behavioral units
- What internal and external factors condition individuals' Behavior?
- Multiple scales



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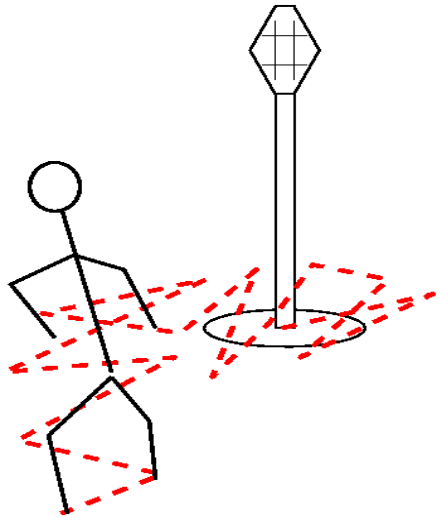
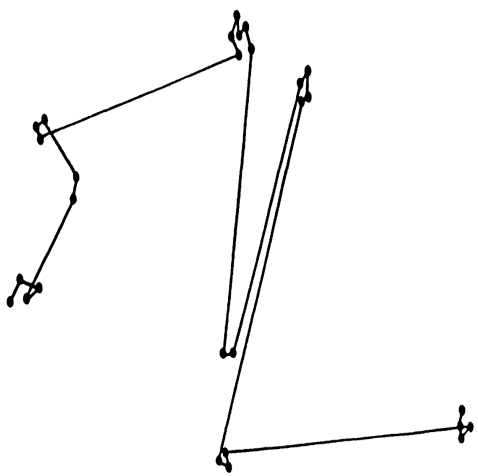
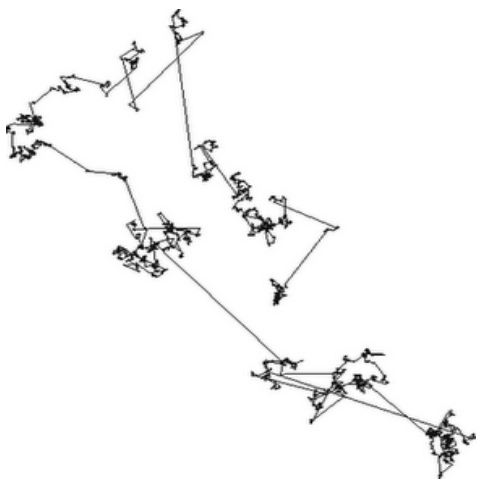
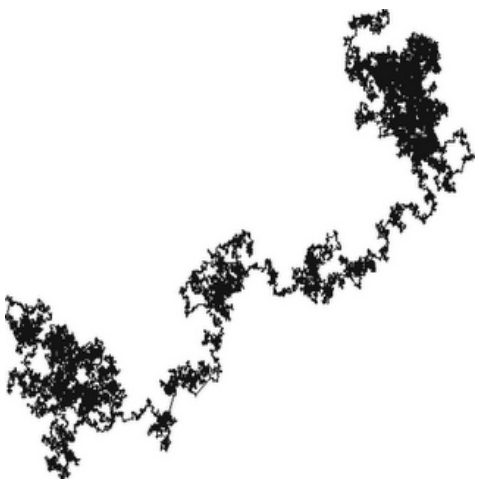
Random walks: what are they?

Mathematical formalisation of a trajectory that consists of taking successive random steps.









Random walks: which one is better?

- Brownian motion
- Lévy flights / walks
- Correlated RWs
- Biased RWs
- Biased-correlated RWs

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Part of the debate: methodology for fit and selection

- Move: variable-length step reflecting a behavior. How to define it?

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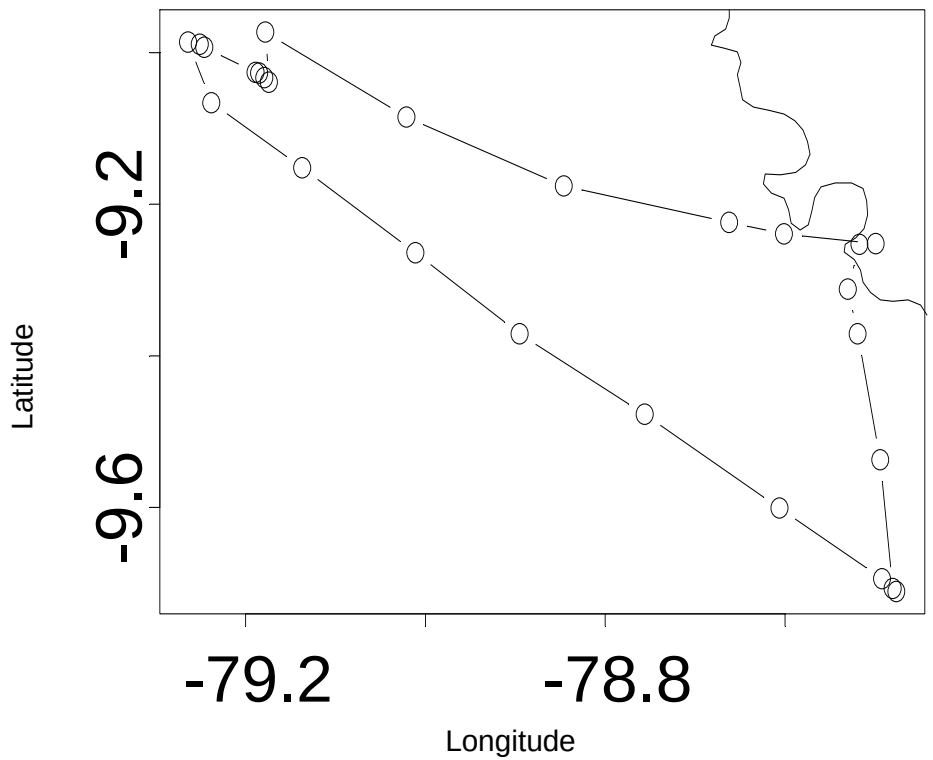

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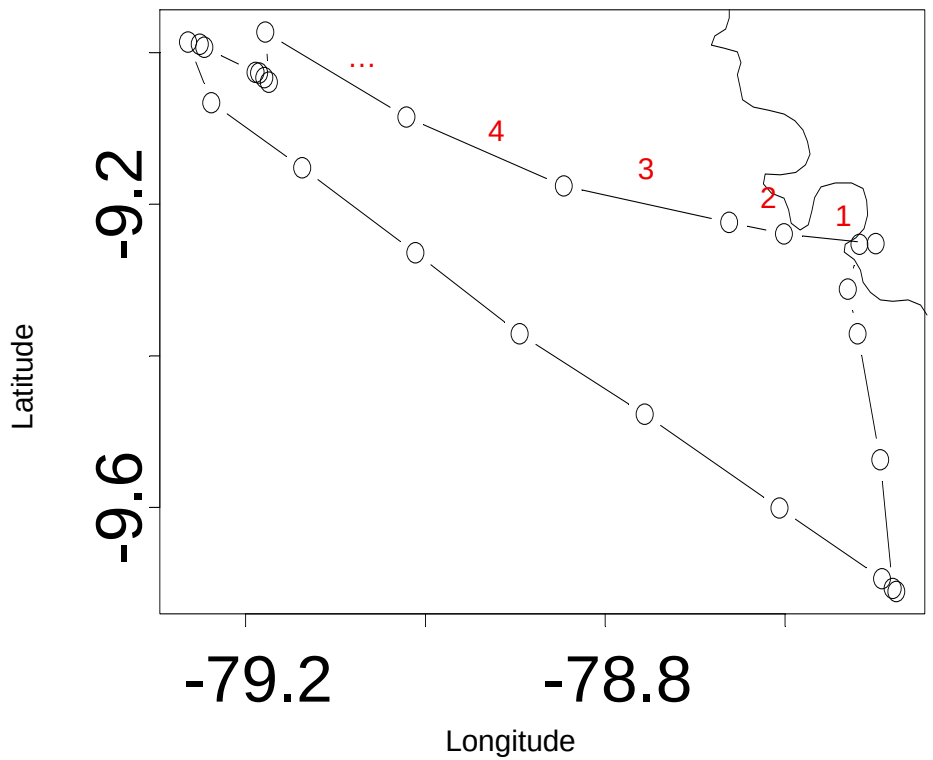

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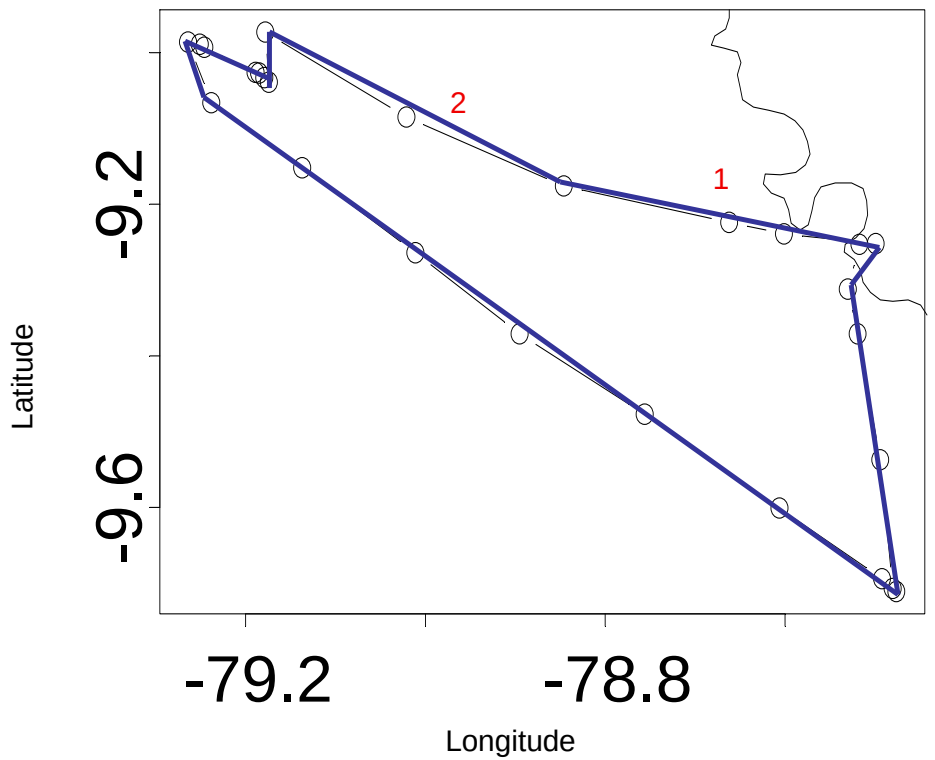
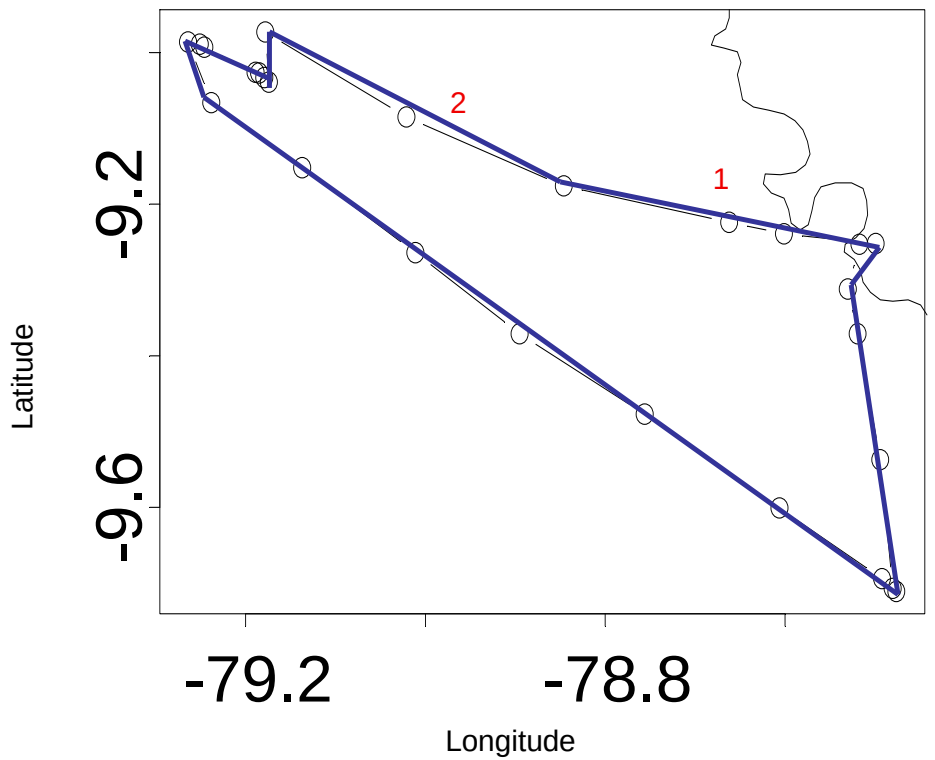


Random walks: which one is better?

Part of the debate: methodology for fit and selection

- Move: the tail of the distribution of its length is associated to a certain RW

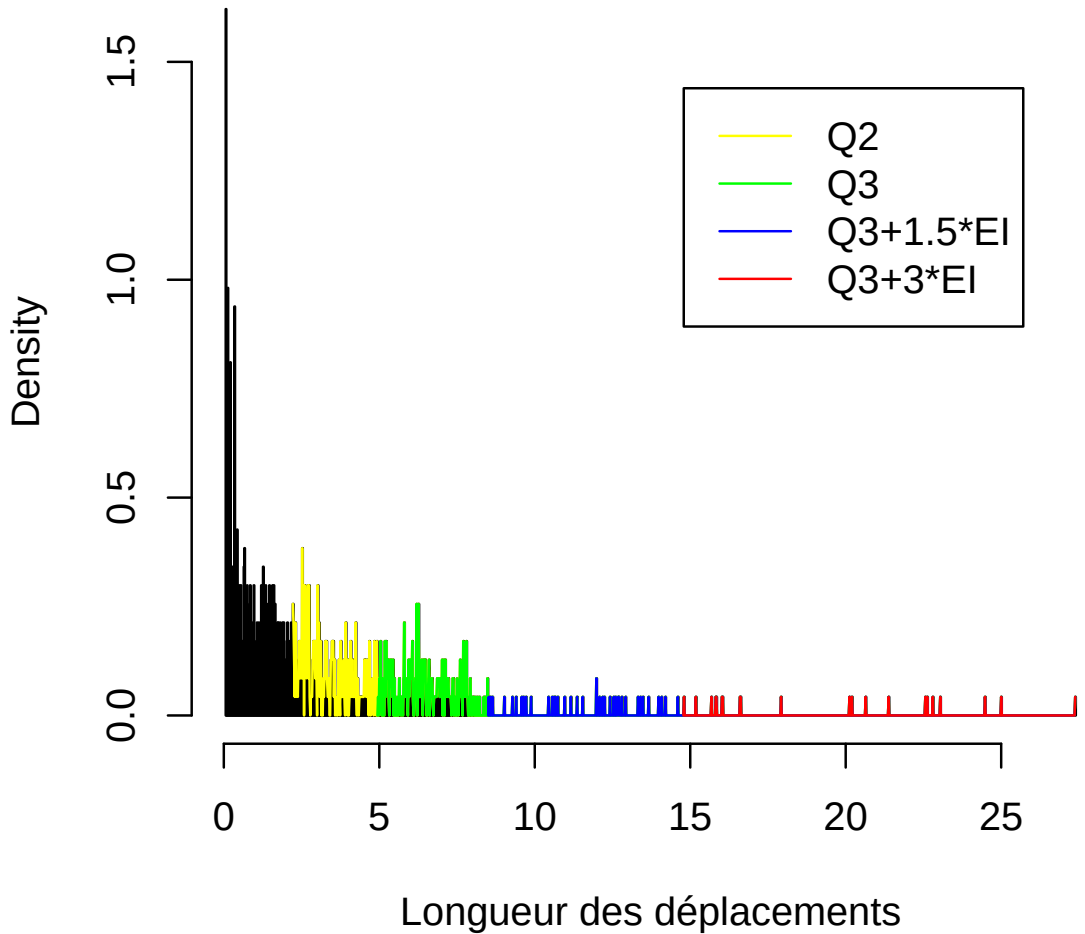


Where does the tail start?

Random walks: which one is better?

Part of the debate: methodology for fit and selection

- Move: Where does the tail start?



Random walks: which one is better?

Part of the debate: methodology for fit and selection

- Gof tests and selection criteria

Random walks: which one is better?

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- Gof tests and selection criteria

Sayyareh (2007):

Gof tests

- Truth or falseness of a hypothesis
- Find a well-specified model

Selection criteria

- Proximity to the truth
- Choose the best among a non specified set

Random walks: which one is better?

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Sayyareh (2007):

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$\subset$

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Random walks: which one is better?

Part of the debate: methodology for fit and selection

- Generalized Pareto distribution

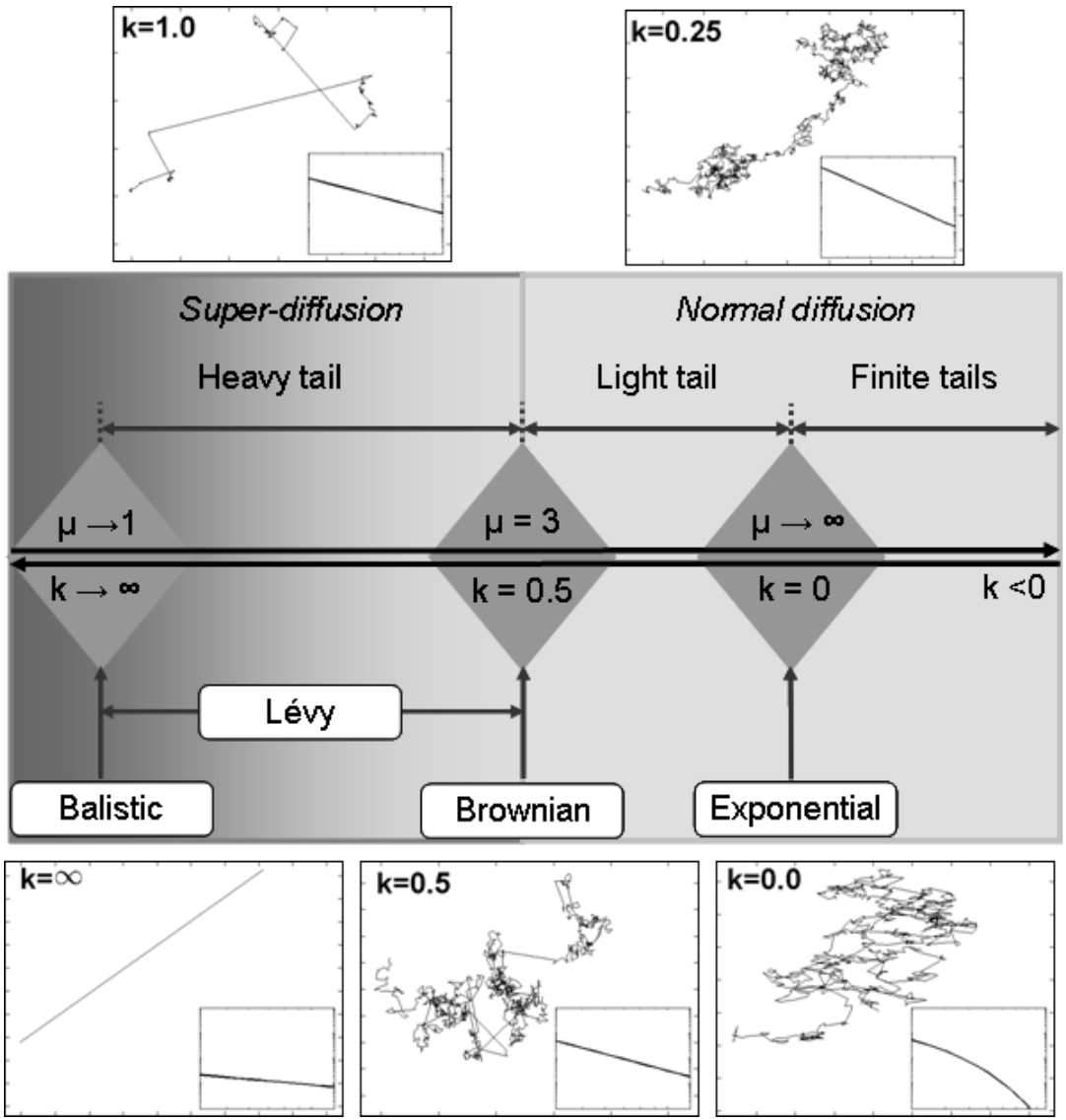
$$F_{\sigma,\kappa}(x) = \begin{cases} 1 - \left(1 + \frac{\kappa x}{\sigma}\right)^{-1/\kappa}, & \kappa \neq 0 \\ 1 - \exp\left\{-\frac{x}{\sigma}\right\}, & \kappa = 0 \end{cases}$$

where $\sigma > 0$ and $-1 < \kappa < 1$ are the scale and shape parameters; the domain of x is $[\theta, 1[$ when $\kappa > 0$ or $[\theta, \sigma]$ when $\kappa \leqslant 0$; θ is the start of the tail of the distribution.

Random walks: which one is better?

Part of the debate: methodology for fit and selection

- Generalized Pareto distribution



(Bertrand et al 2015)

Random walks: which one is better?

Part of the debate: ethological

- What kind of RWs do animals actually perform?
- Do they walk randomly?
- What is randomness?

Random walks: which one is better?

Instead, practical pattern-oriented perspective

Models → interpret movement (via model properties)

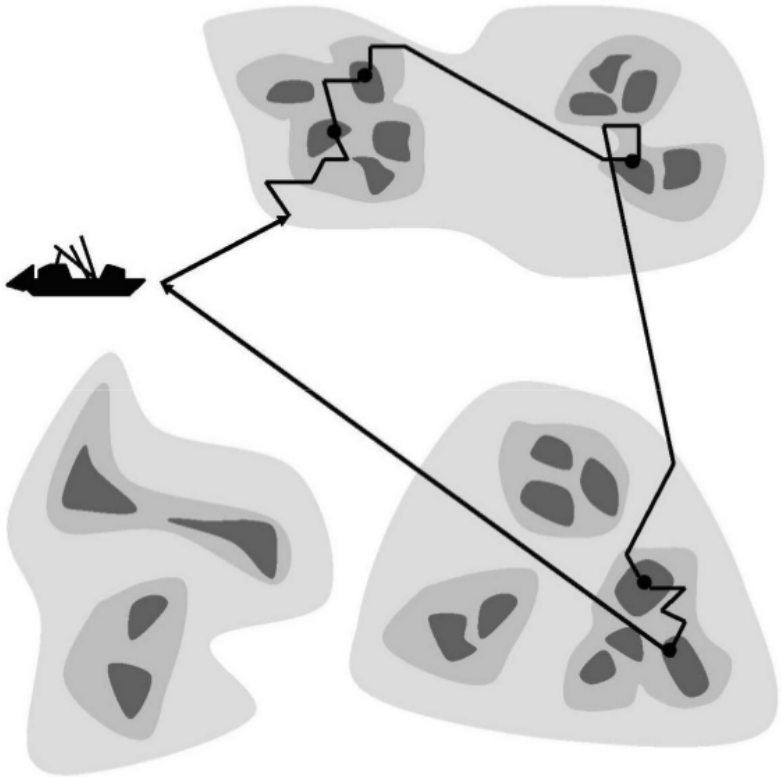
E.g., Generalized Pareto

$$F_{\sigma,\kappa}(x) = \begin{cases} 1 - \left(1 + \frac{\kappa x}{\sigma}\right)^{-1/\kappa}, & \kappa \neq 0 \\ 1 - \exp\left\{-\frac{x}{\sigma}\right\}, & \kappa = 0 \end{cases}$$

- κ: parameter inversely related to diffusion parameter μ of Lévy ($\mu = 1 + 1/\kappa$)
- σ: scale parameter

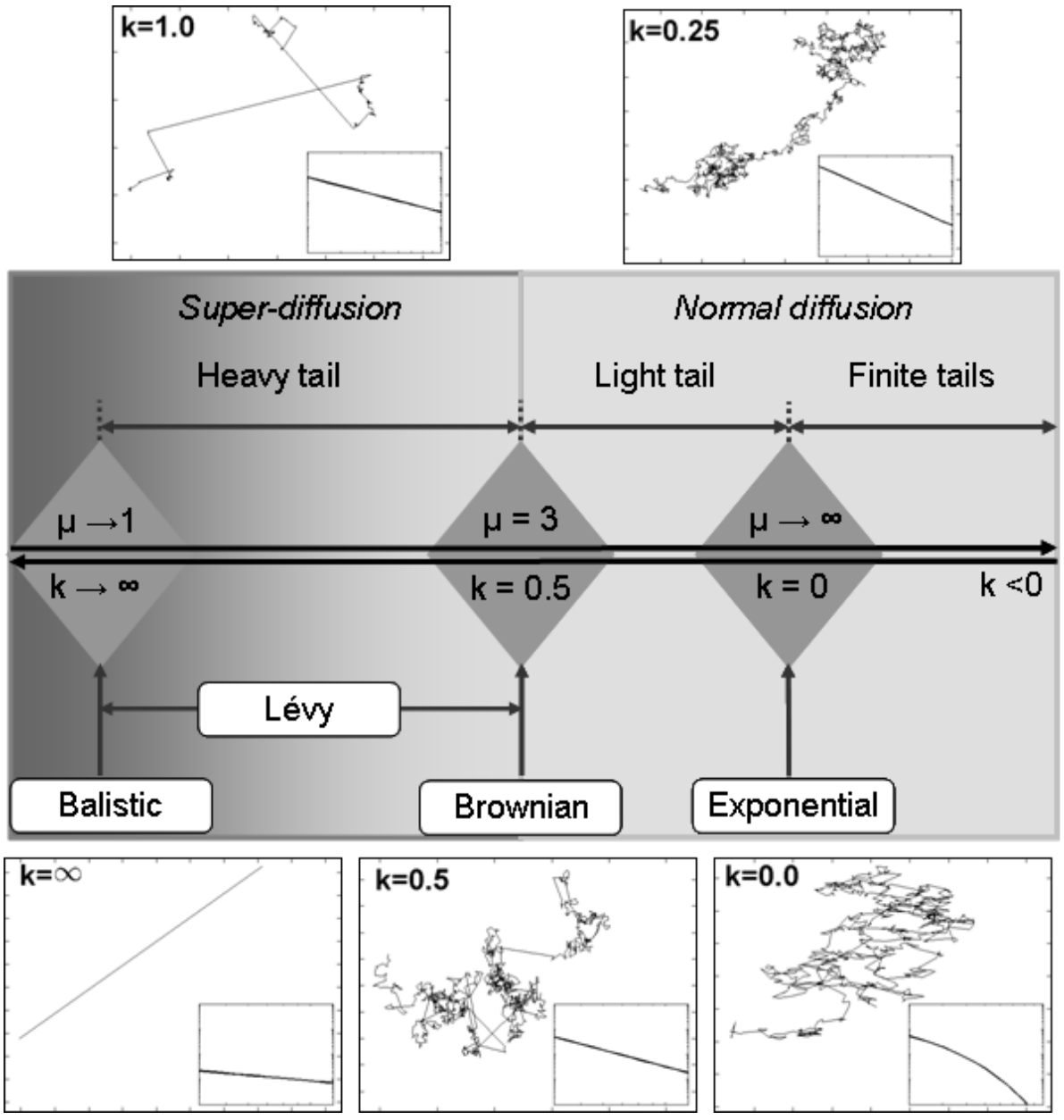
Random walks: which one is better?

Interpreting diffusion



	+ Dif	- Dif
Nb. short mov.	+	−
Time within patches	+	−
Nb. long mov.	−	+
Nb. visited patches	−	+

Random walks: which one is better?



(Bertrand et al 2015)

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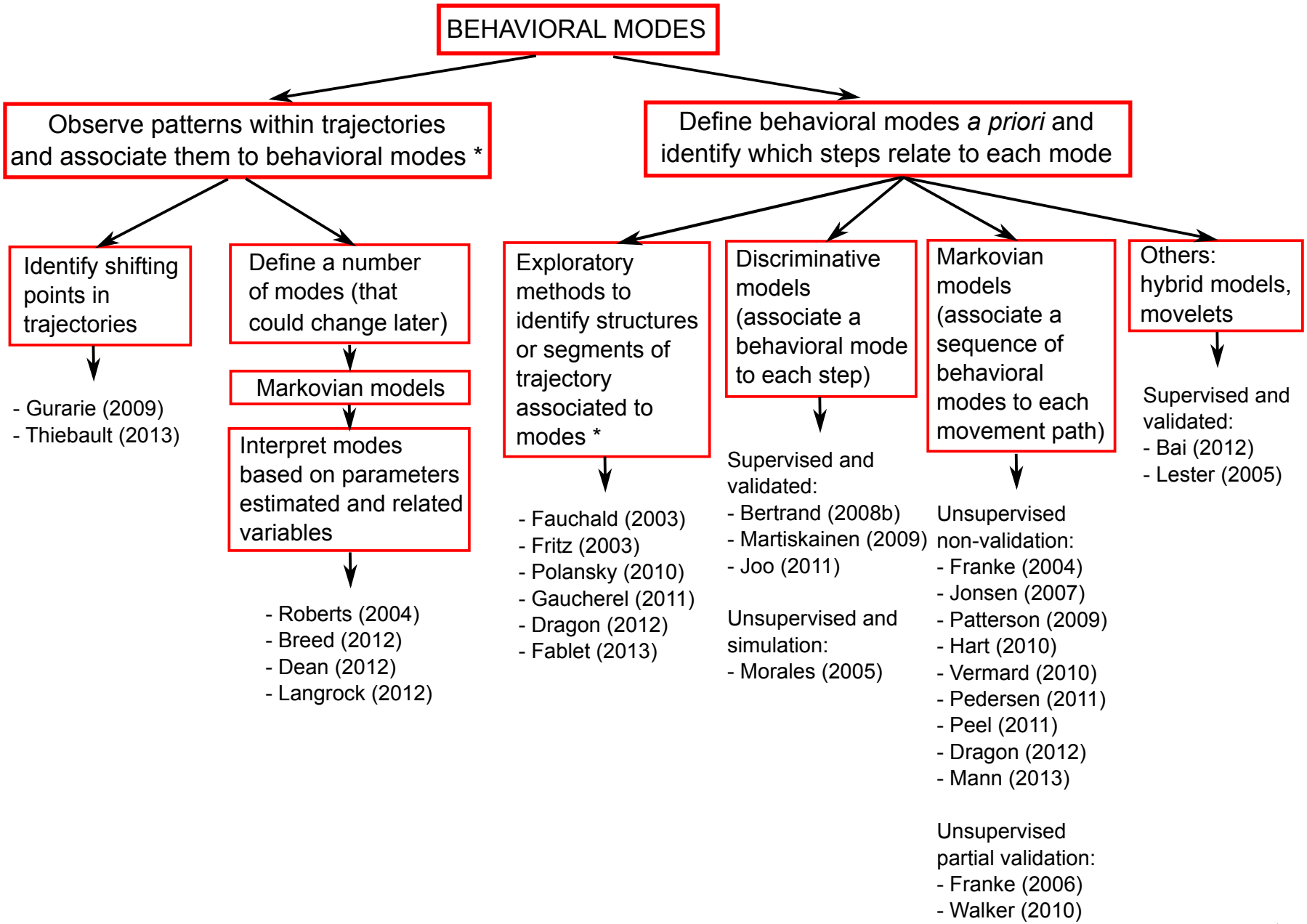
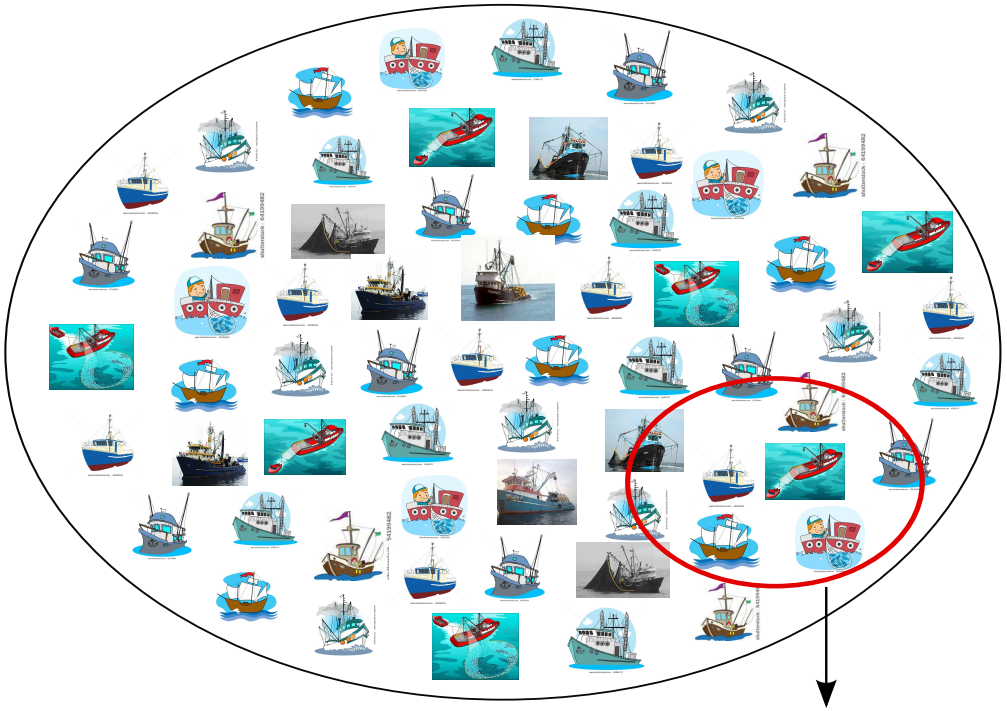
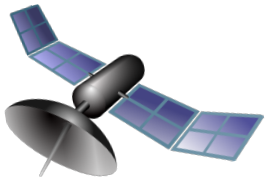
Behavioral modes: a typology



Behavioral modes: an example

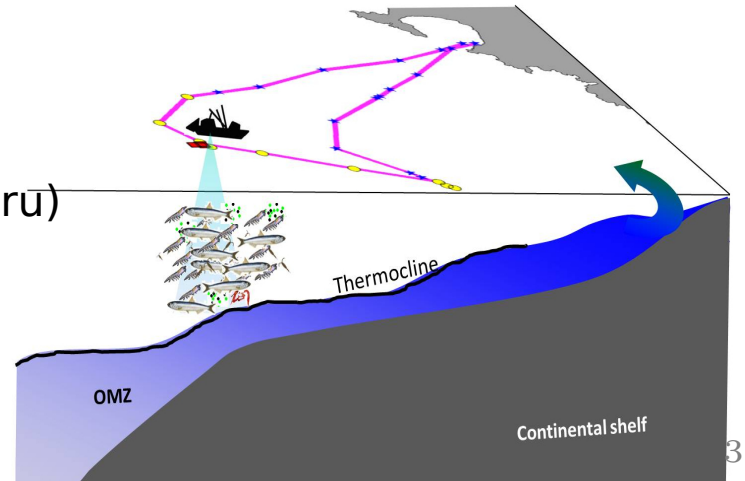
Fisheries application





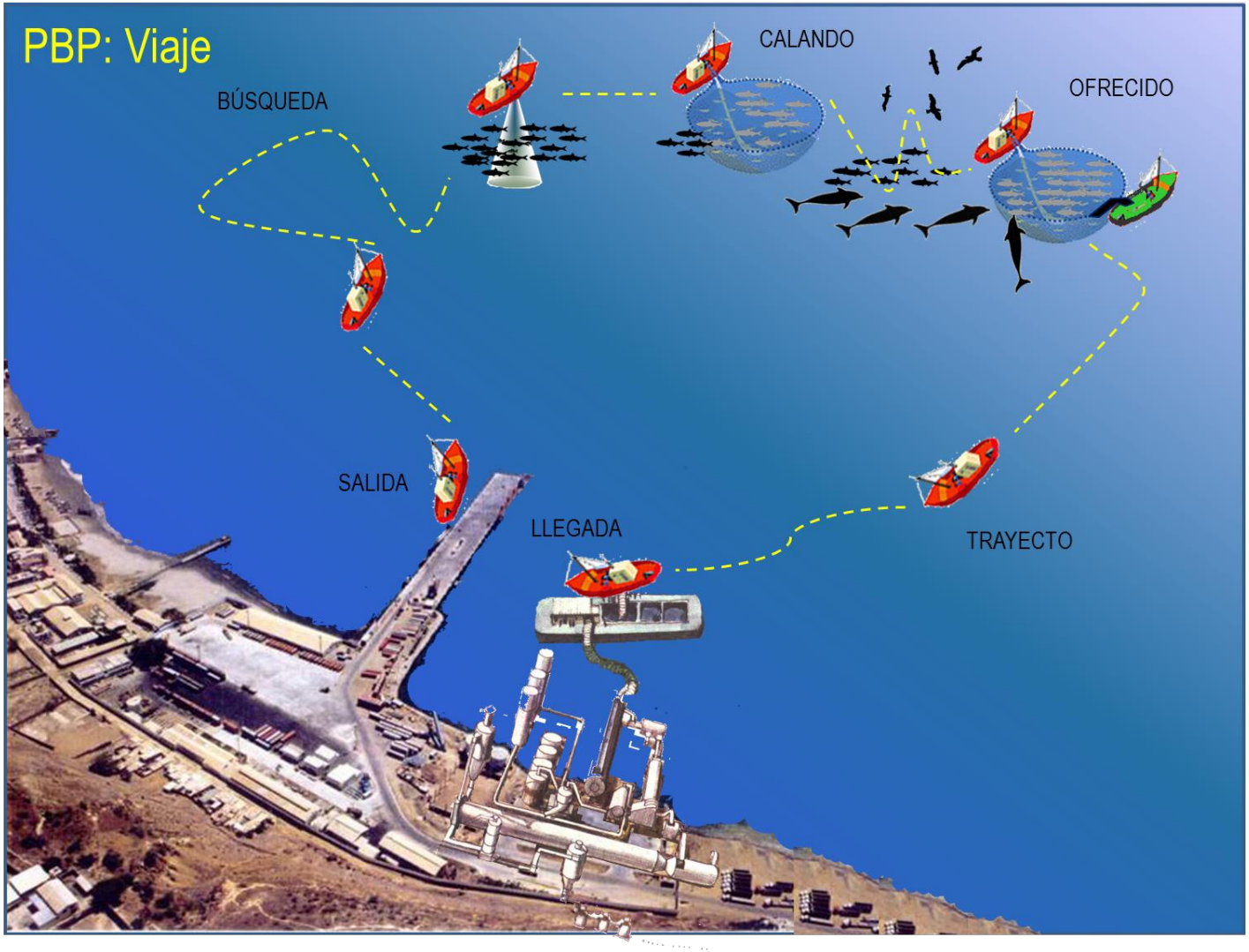
VMS
(lon,lat)
~ 1 record/hour
100% trips
~50000 (Peru)

OBSERVERS
(lon,lat,**activity**)
< 1% trips
~ 200 x year (Peru)

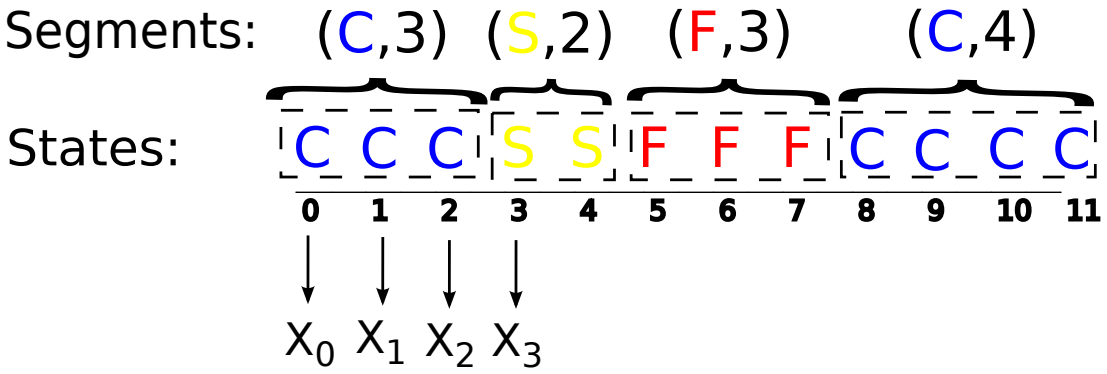


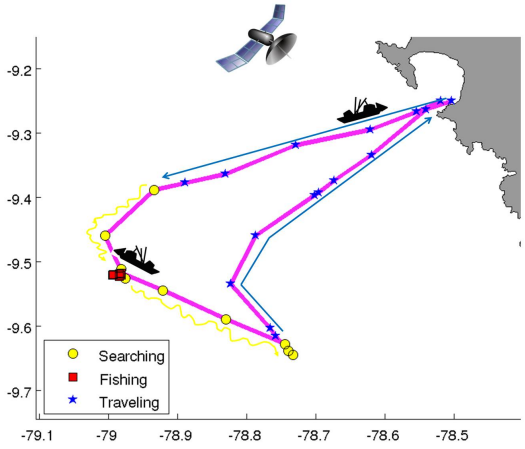
Fishers -> ecosystem indicators

Behavioral modes: an example



Behavioral modes: hidden Markov & semi-Markov





HMM

$$\Pi_C \times p_{CC} \times p_{CC} \times p_{CS} \times p_{SS} \times p_{SF} \times p_{FF} \times p_{FF} \times p_{FC} \times p_{CC} \times p_{CC} \times p_{CC}$$

HSMM

$$\Pi_C \times d_C(3) \times p_{CS} \times d_S(2) \times p_{SF} \times d_F(3) \times p_{FC} \times D_C(4)$$

Behavioral modes: hidden Markov & semi-Markov

$P(S_0 = s_0)$ $\quad \Pi = \begin{matrix} \mathbf{S} & \mathbf{F} & \mathbf{C} \\ [0 & 0 & 1] \end{matrix}$

$P(S_{T-1} = s_{T-1})$ $\quad \Omega = \begin{matrix} \mathbf{S} & \mathbf{F} & \mathbf{C} \\ [0 & 0 & 1] \end{matrix}$

$P(S_t = j \mid S_{t-1} = i)$ $\quad p_{ij} =$ inferred from training data

$P(X_t = x_t \mid S_t = j)$ $\quad b_j(x_t) =$ distributions fitted from training data

$P(S_{t+u+1} \neq j, S_{t+2}^{t+u} = j \mid S_{t+1} = j, S_t \neq j)$ $\quad d_j(u) =$ distributions fitted from training data

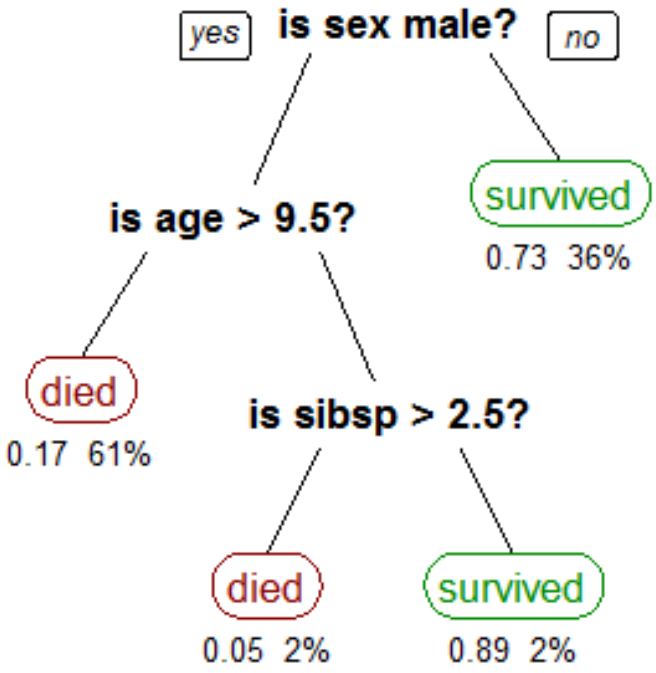
Behavioral modes: Discriminative models

- Classify observed variable patterns into states
- States are independent (no past, no future).

Used for this study:

- Random Forests (RF)
- Support Vector Machines (SVM)
- Artificial Neural Networks (ANN)

Behavioral modes: Random forests

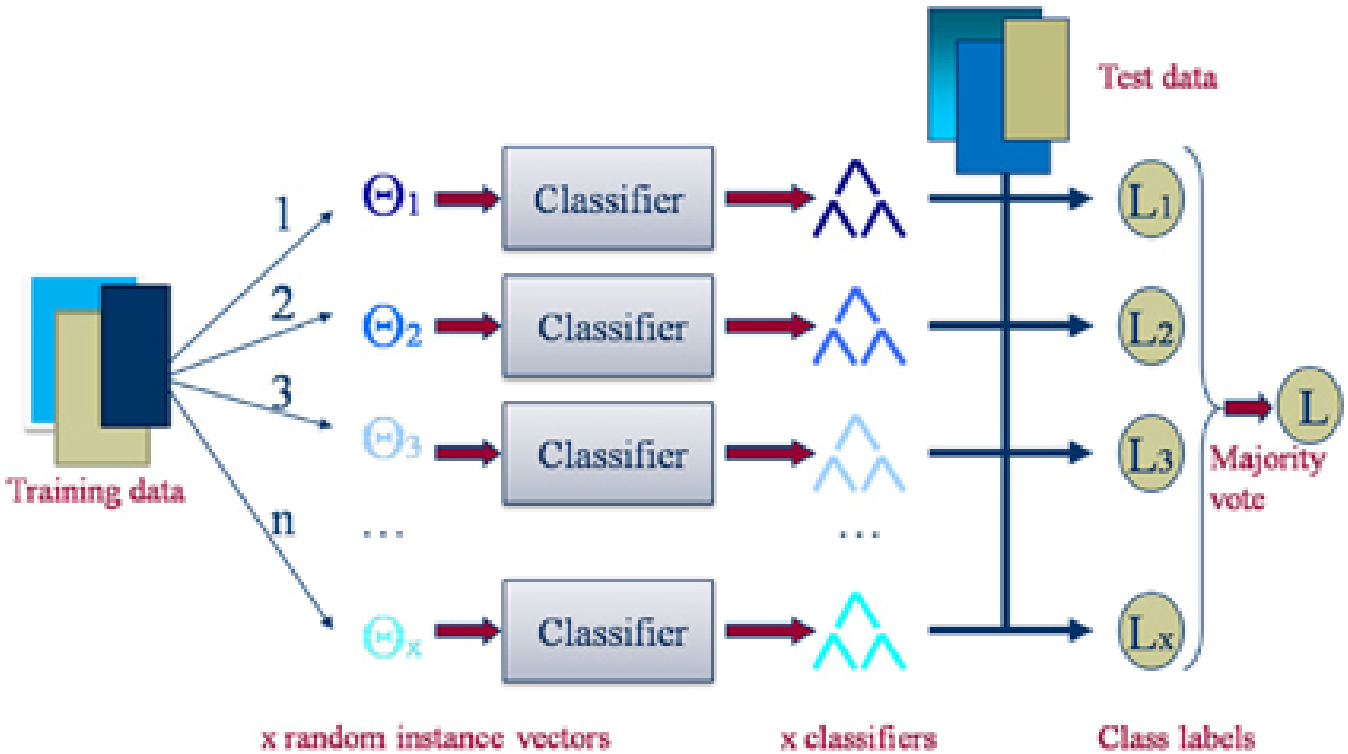


Iterative algorithm:

- Separation of data at each node
- Test every possible way to split each feature
- Optimize separation by variance criterion
- Iterate until nodes have data from one class only

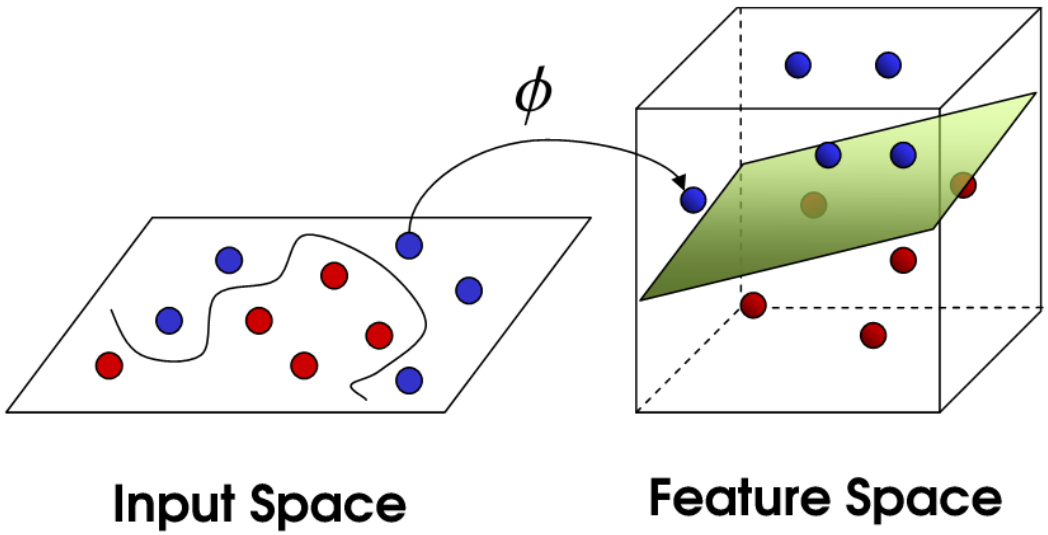
Behavioral modes: Random forests

Several trees: random selection of sample of data and characteristics

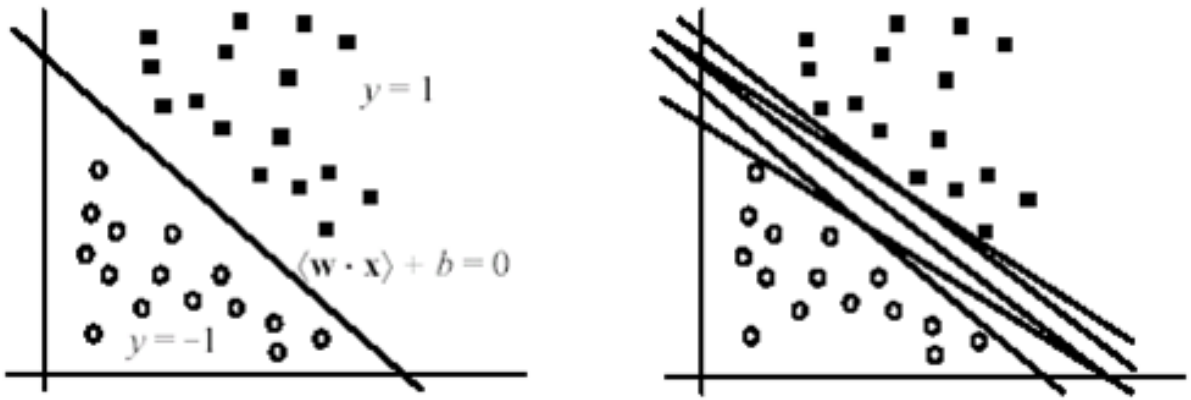


Parameters: number of trees, number of features considered at each node, ...

Behavioral modes: Support vector machines



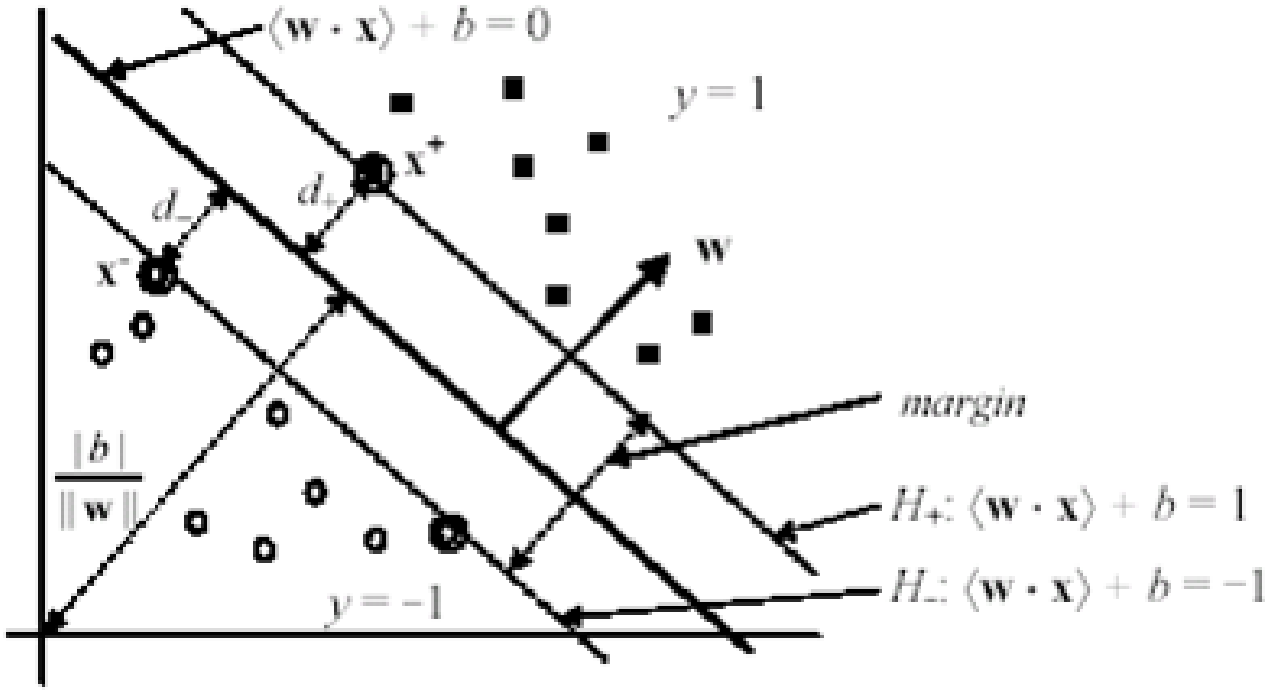
How to choose the hyperplane?



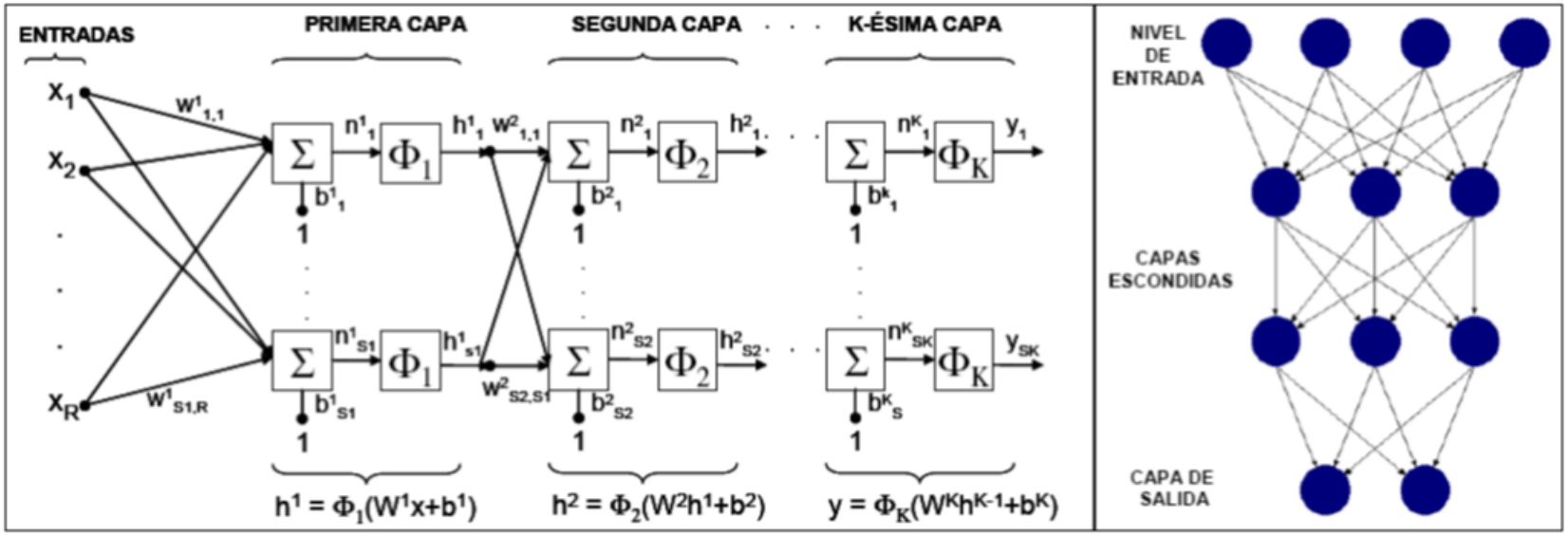
Hyperplane equation: $< w.x > +b = 0$

Behavioral modes: Support vector machines

Margin maximizing separation between classes.



Behavioral modes: Artificial neural networks



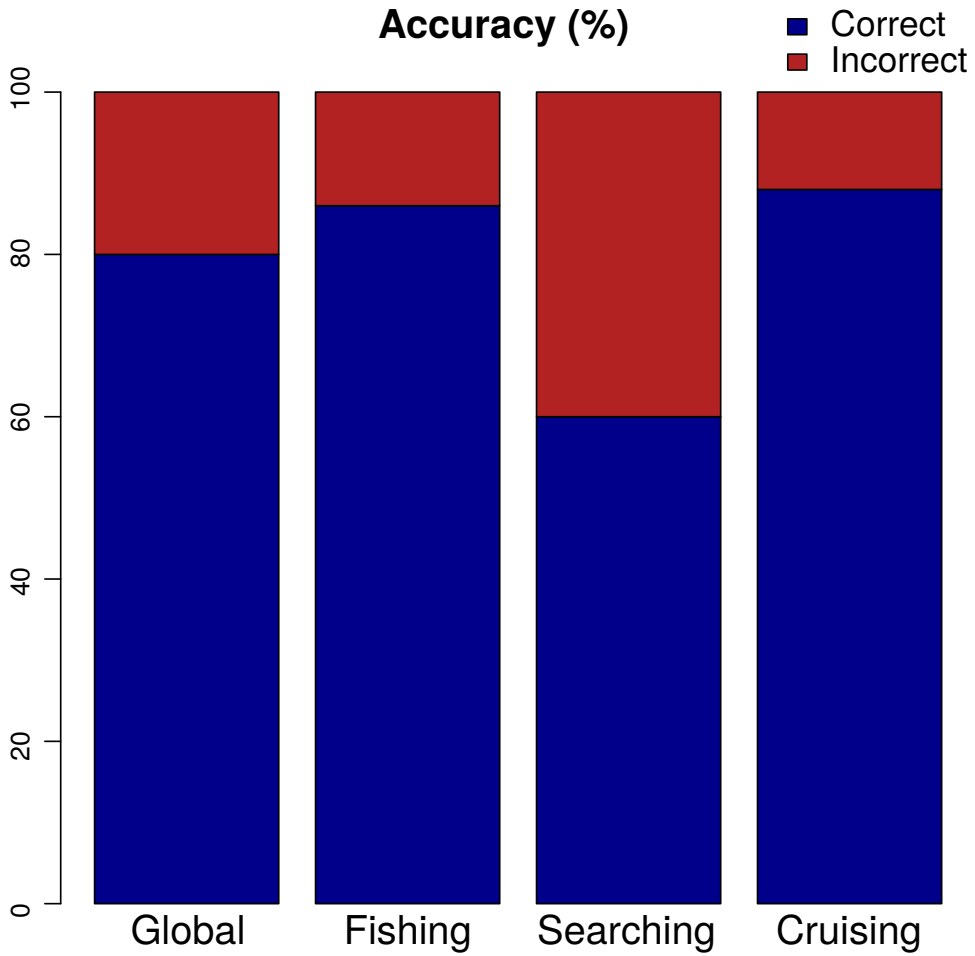
$$input_i = \sum w_{ij} \times output - preceding - note_j + b_i$$
$$h_i = \sum w_{ij} \times + b_i$$
$$y_k = \phi_2 b_k + \sum_j w_{jk} \phi_1((b_j + \sum_i w_{ij} x_i)$$

Parameters: activation functions, number of nodes, ...

Behavioral modes: method comparison

Joo et al. 2013 (PlosONE)

- Discriminative
  - Artificial neural networks (ANN)
  - Support vector machines (SVM)
  - Random forests (RF)
- Markovian
  - Hidden Markov models (HMM)
  - **Hidden semi-Markov models (HSMM)**
- Hybrid Markovian-discriminative



Behavioral modes: method comparison

Other applications of some of the methods:

- Artisanal fishery in Mexico (RF) **(Torres et al 2014, Small-scale fisheries)**
- Artisanal fishery in Brazil (HSMM) **(Da Silva 2017, BSc. thesis)**
- Fish aggregating devices in the Indian Ocean (RF and hybrid models) **(Maufroy et al 2015, Plos ONE; Maufroy PhD thesis)**

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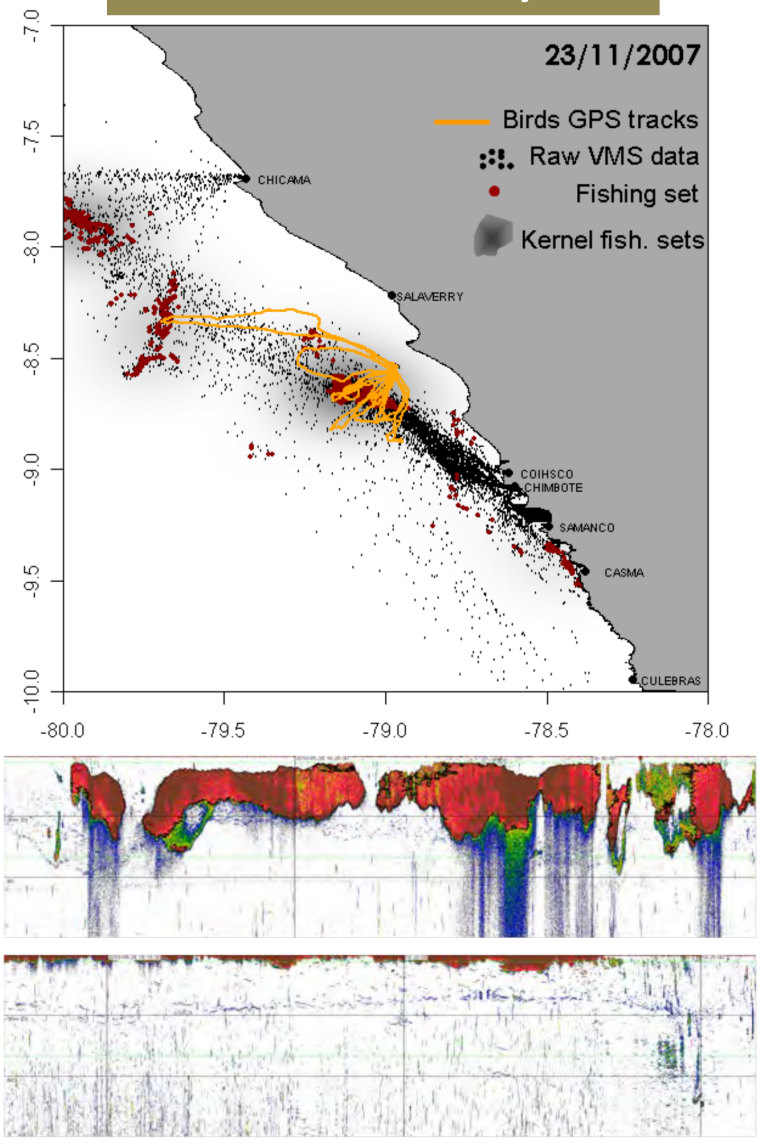
Spatial behavior & ecosystem

Humboldt Current System



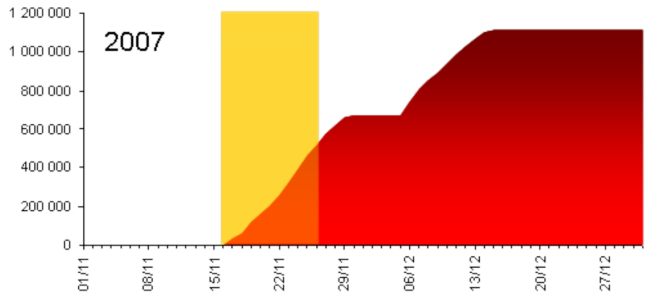
Bertrand et al. (2012) JAE

Tracking at the opening of fishing season

Seabird foraging effort increase day after day, seabirds forage farther from vessels

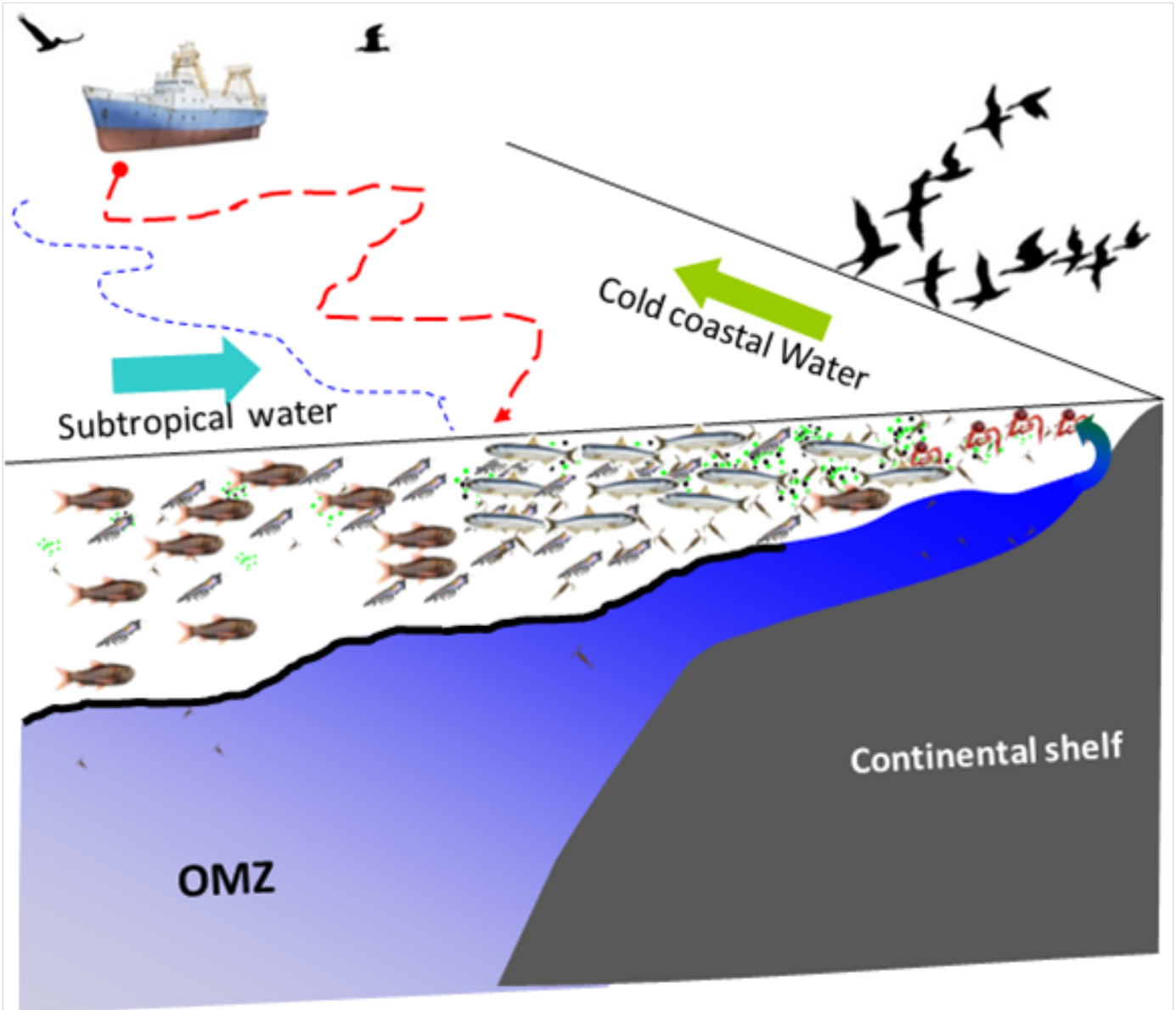
Mixed effect models:
Main effect from the local depletion generated by the fishery removals

Seabird needs: ~ 200 $t.d^{-1}$
Fishery removals: ~ 50 000 $t.d^{-1}$



Competition seabirds / fishery
Localized depletions

Spatial behavior & ecosystem

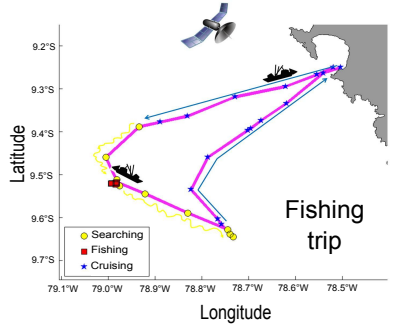


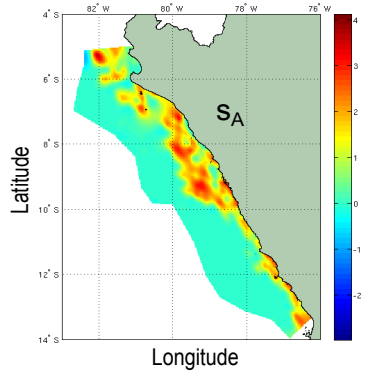
Spatial behavior & ecosystem

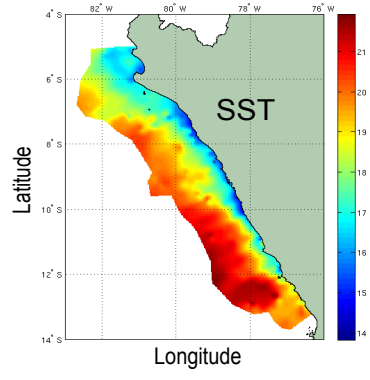
Ecosystem conditioning fisher spatial behavior?

- Fishermen:
  - $[800, 16000]$ trips per season: fishing, searching, cruising, duration, distance, maximum distance to coast, diffusion
- Anchovy:
  - 1 value per season: global and local biomass, spatial occupation, distance to coast
- Environment:
  - weekly/monthly data: SST, CHL, oxycline

Challenges: **data** (nature & resolution)
Strategy: averaging, grouping, multivariate exploration

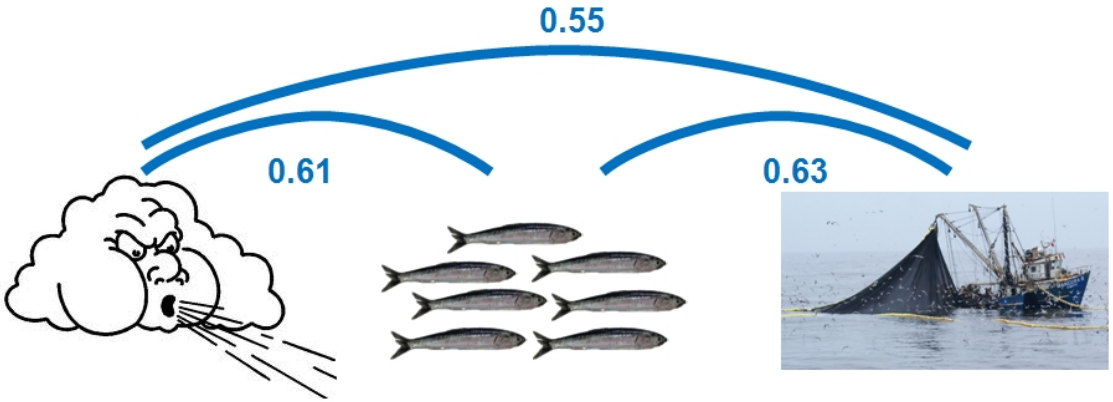


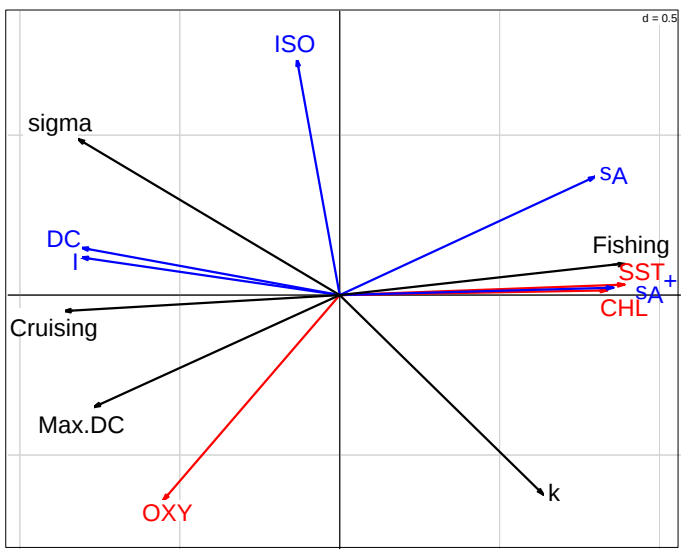


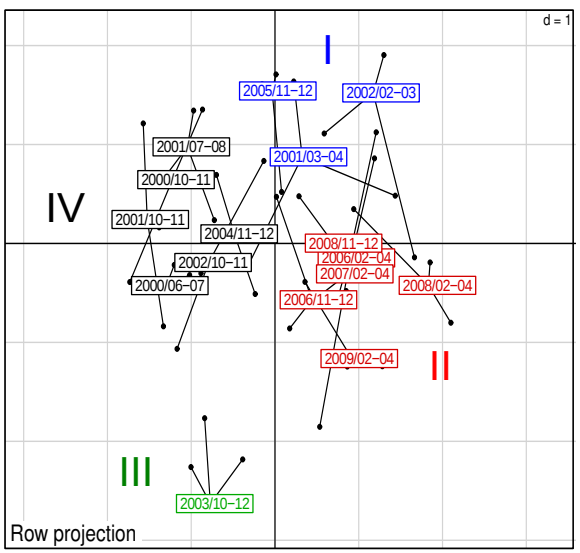


Spatial behavior & ecosystem

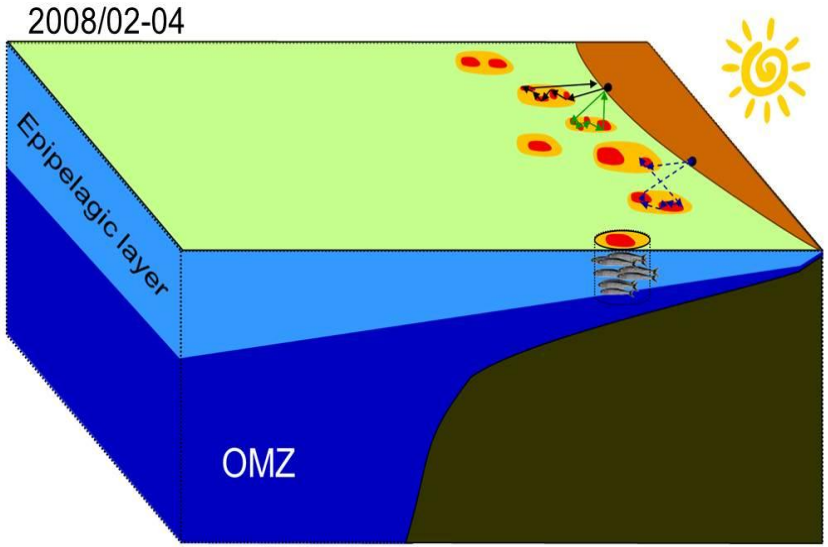
- Associations → environment and anchovy condition fisher behavior
- Stronger associations for direct links

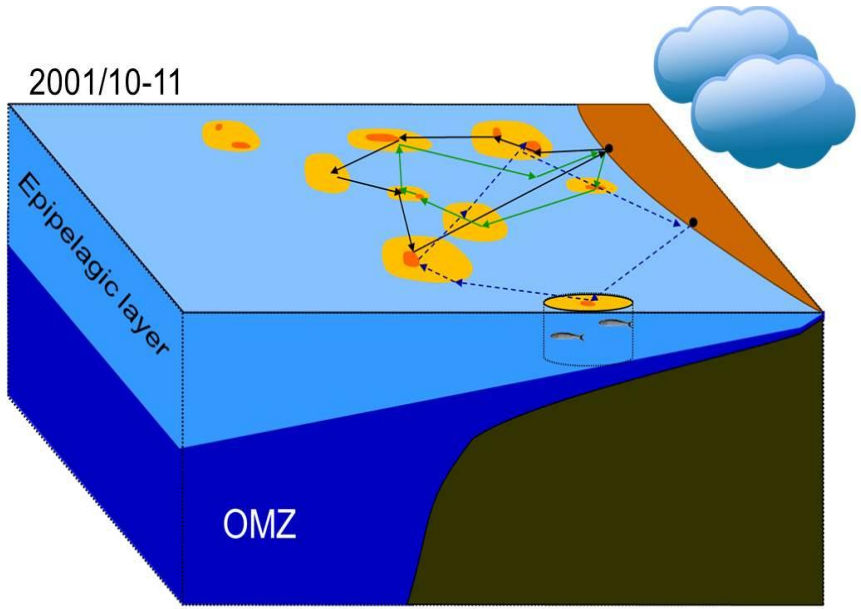






Spatial behavior & ecosystem





- Warm, productivity, superficial oxycline
- Abundant, concentrated, coastal
- Coastal, fishing, diffusive

- Cold, low productivity, deep oxycline
- Scarce, spare, far
- Far, cruising, low diffusion

(Joo et al. 2014)

Research subject

A quantitative approach to the movement ecology of fishers

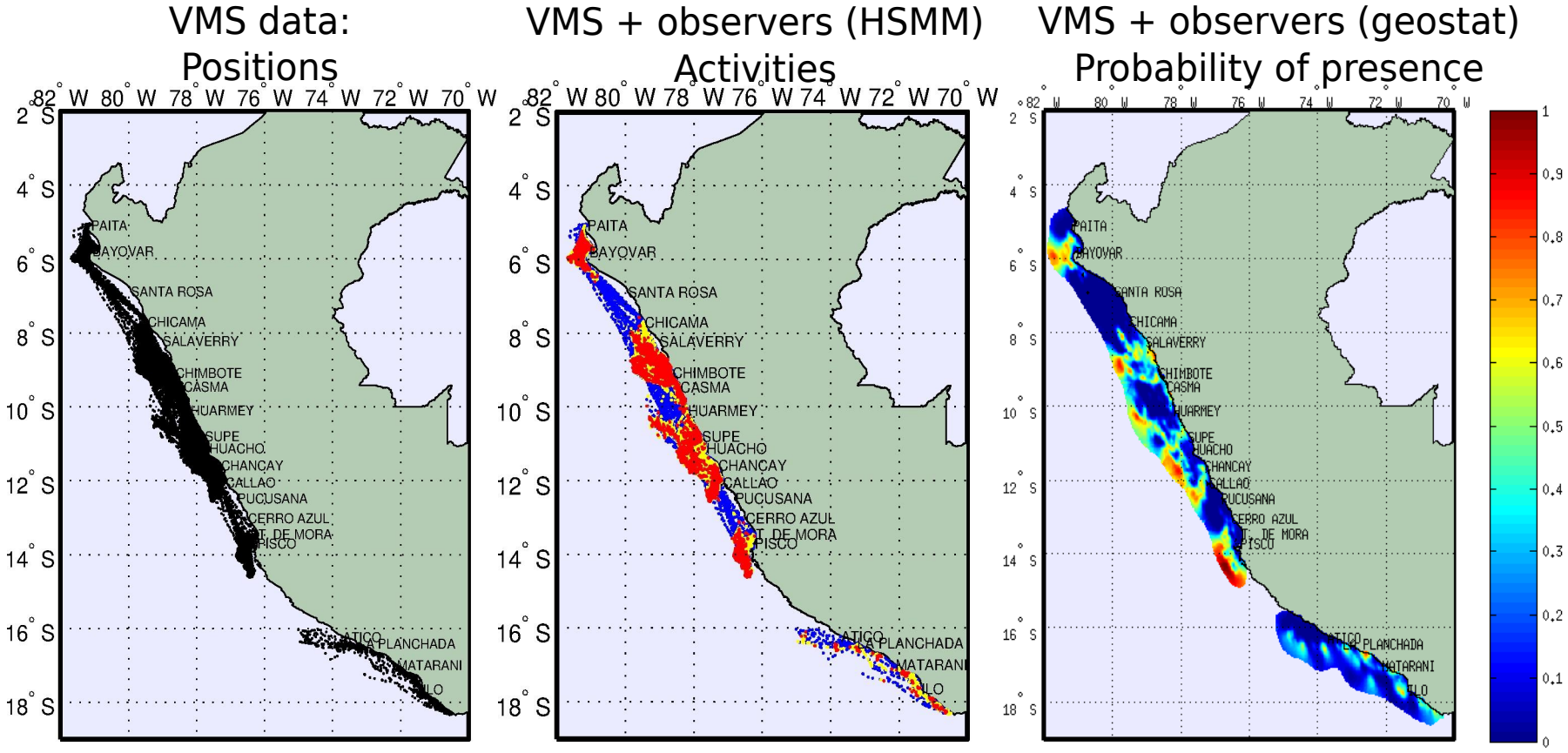
- Movement ecology
- Random walks
- Behavioral modes
- Spatial behavior and other ecosystem components
- Predator to prey maps
- Collective behavior

Predator to prey maps

Spatial patterns: what can they tell us?

Predator to prey maps

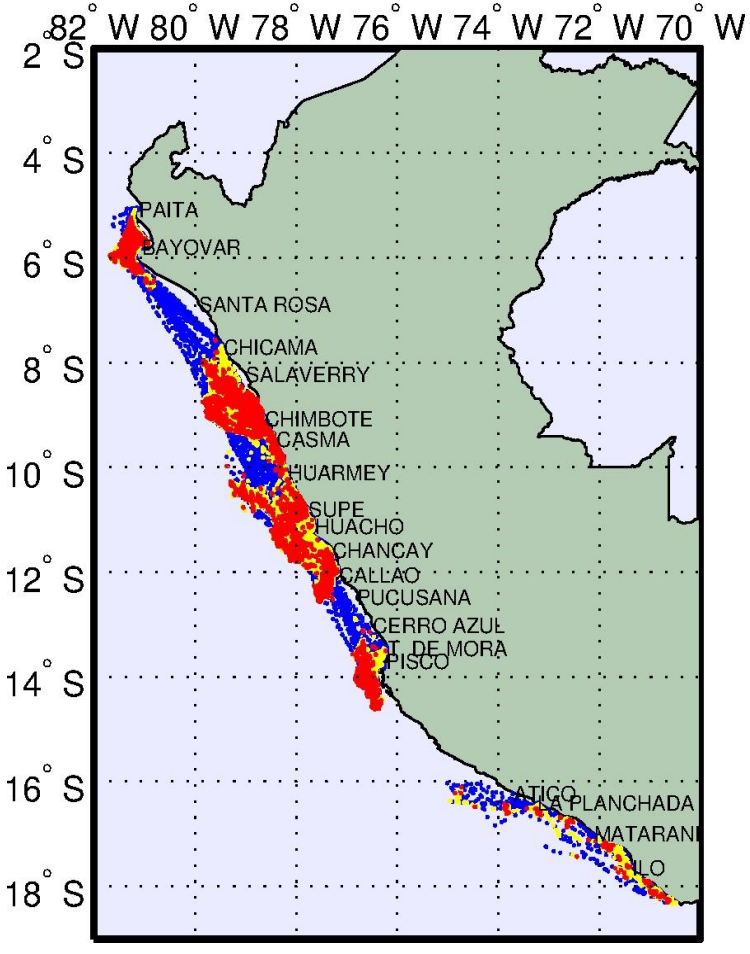
Spatial behavior as a proxy of fish presence?



1) Build VMS-based presence proxy

2) Compare it with acoustic-based presence proxy from same period

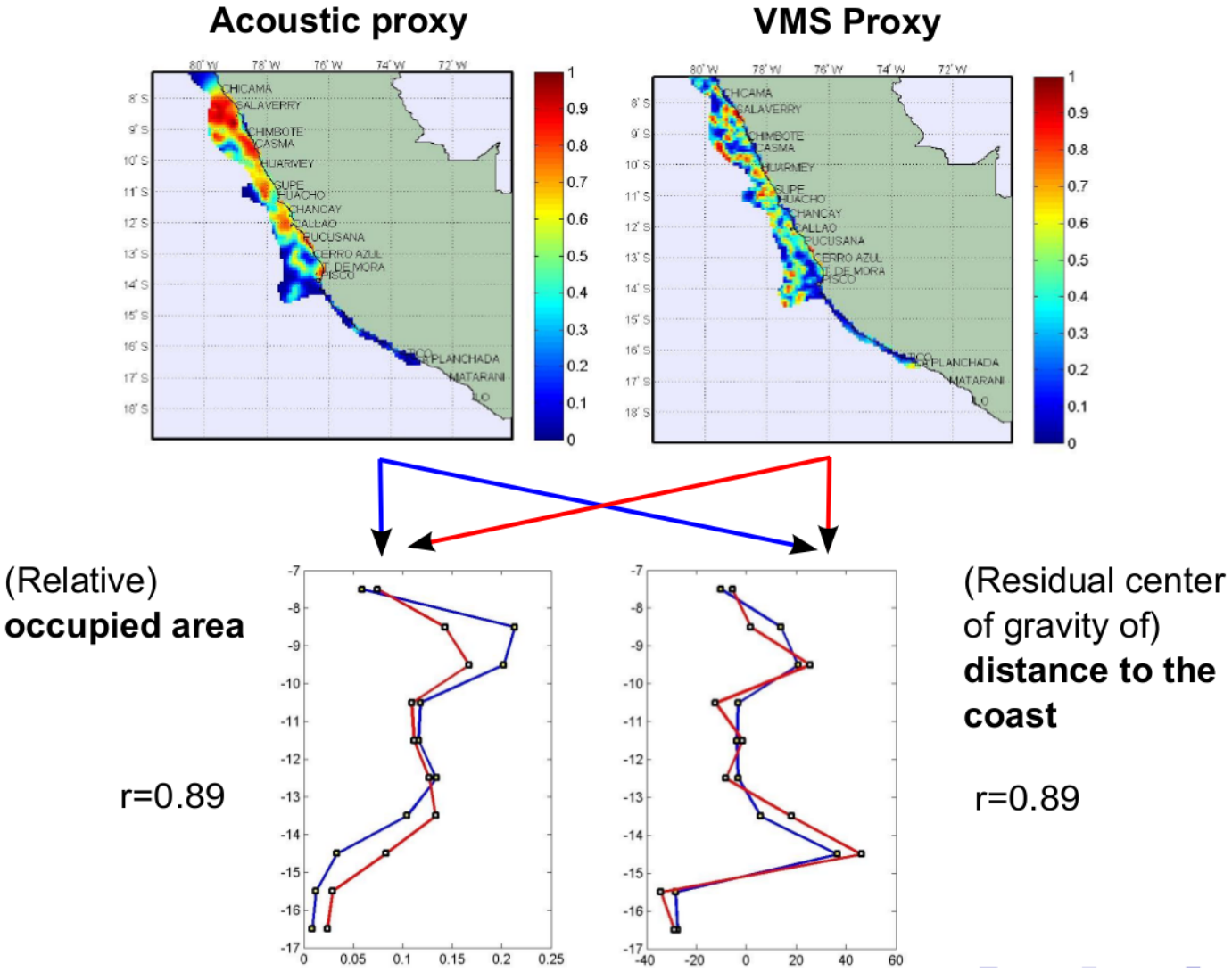
Predator to prey maps



- Grid cells of 5 km x 5 km
- For each cell: $\mathrm{P} = \frac{(\sharp F \times 1) + (\sharp S \times 0.75) + (\sharp C \times 0.3)}{\sharp F + \sharp S + \sharp C}$
  - $\sharp F$: number of **fishing** locations;
  - $\sharp S$: number of **searching** locations;
  - $\sharp C$: number of **cruising** locations
- $Z_V = \frac{(P - P_{min})}{P_{max} - P_{min}}$; $Z_V \in [0, 1]$
- Variogram model and ordinary kriging

Predator to prey maps

Similar spatial patterns?

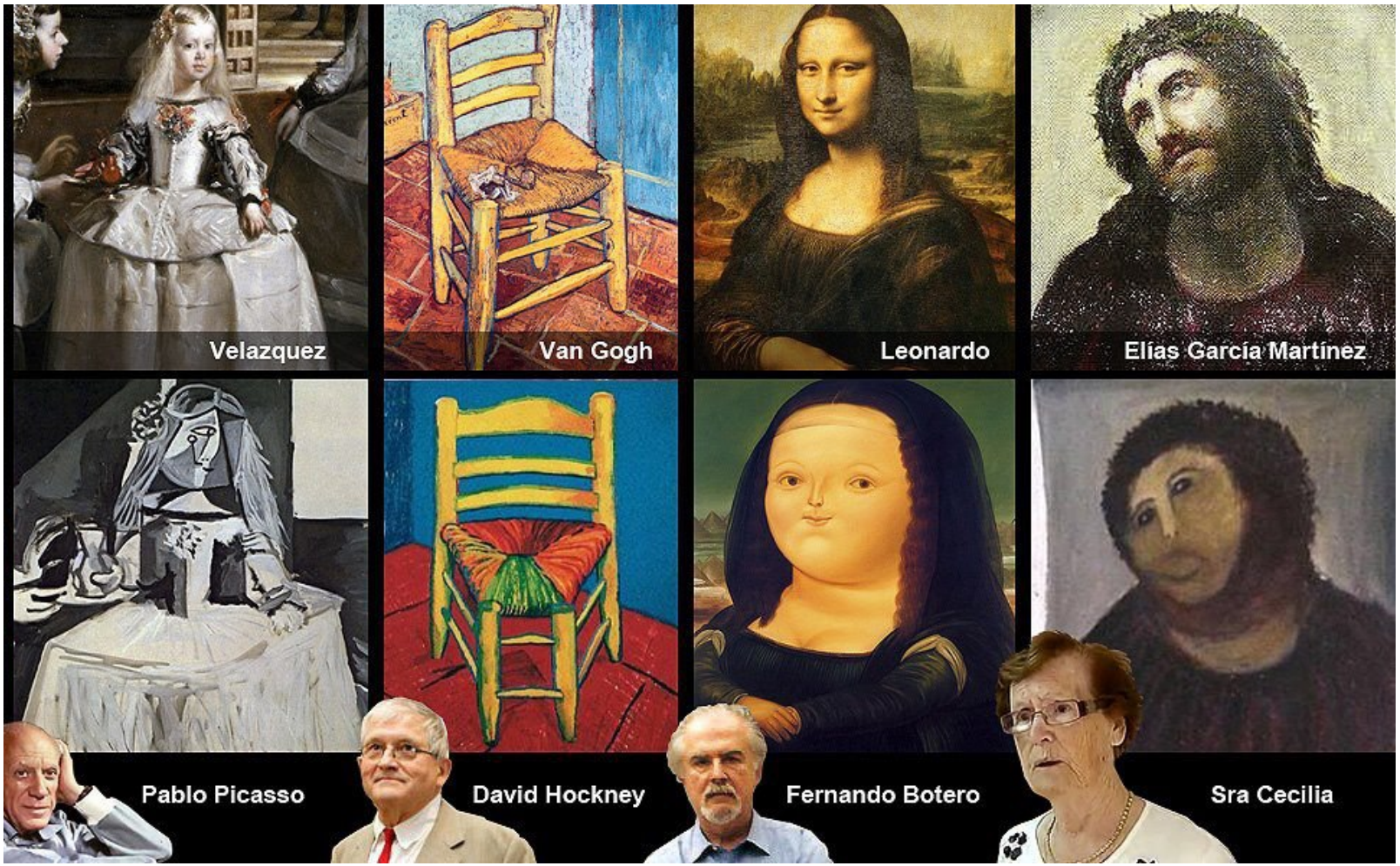


Predator to prey maps

Two sides of the same coin?

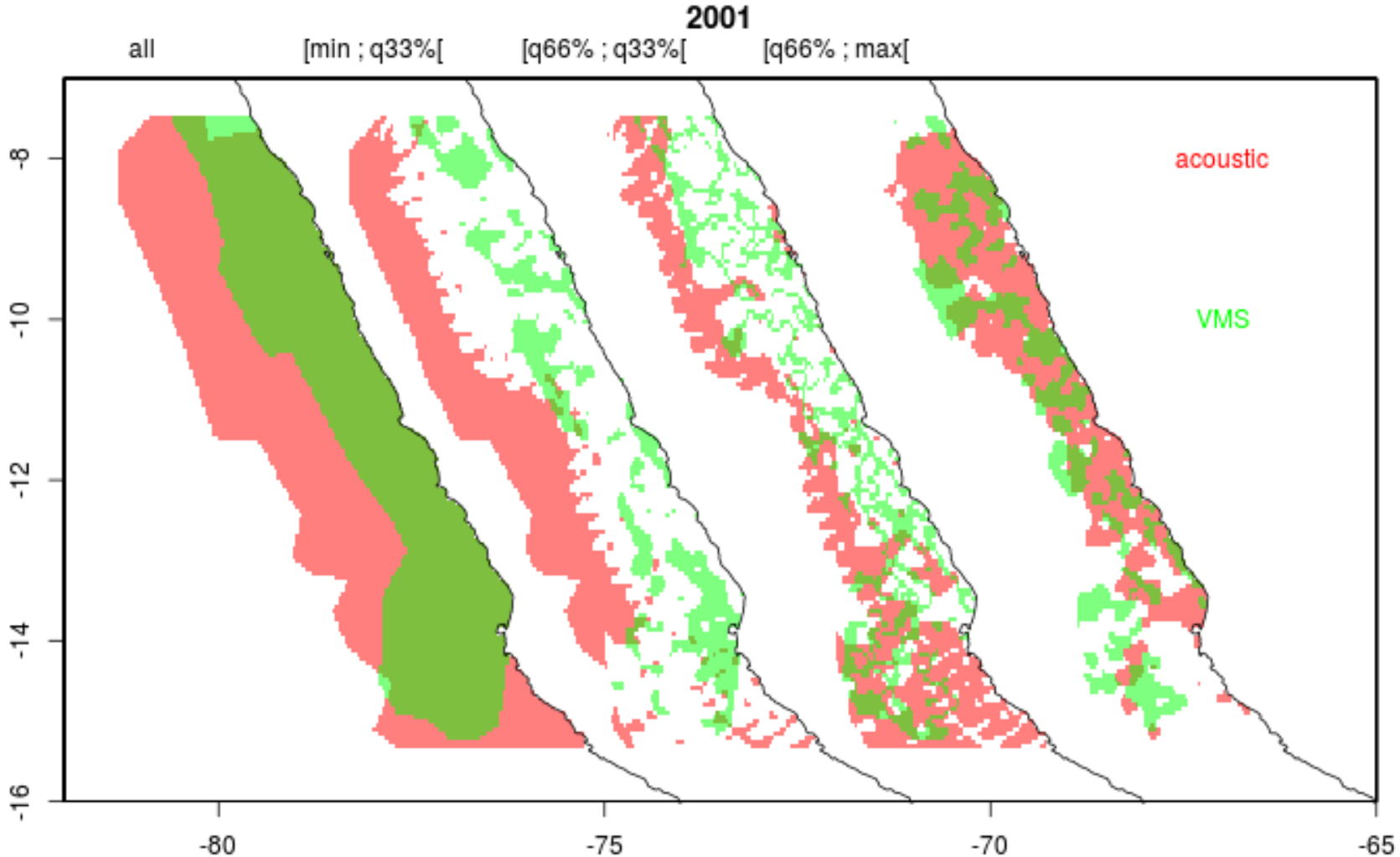
Predator to prey maps

Two sides of the same coin? Or not?

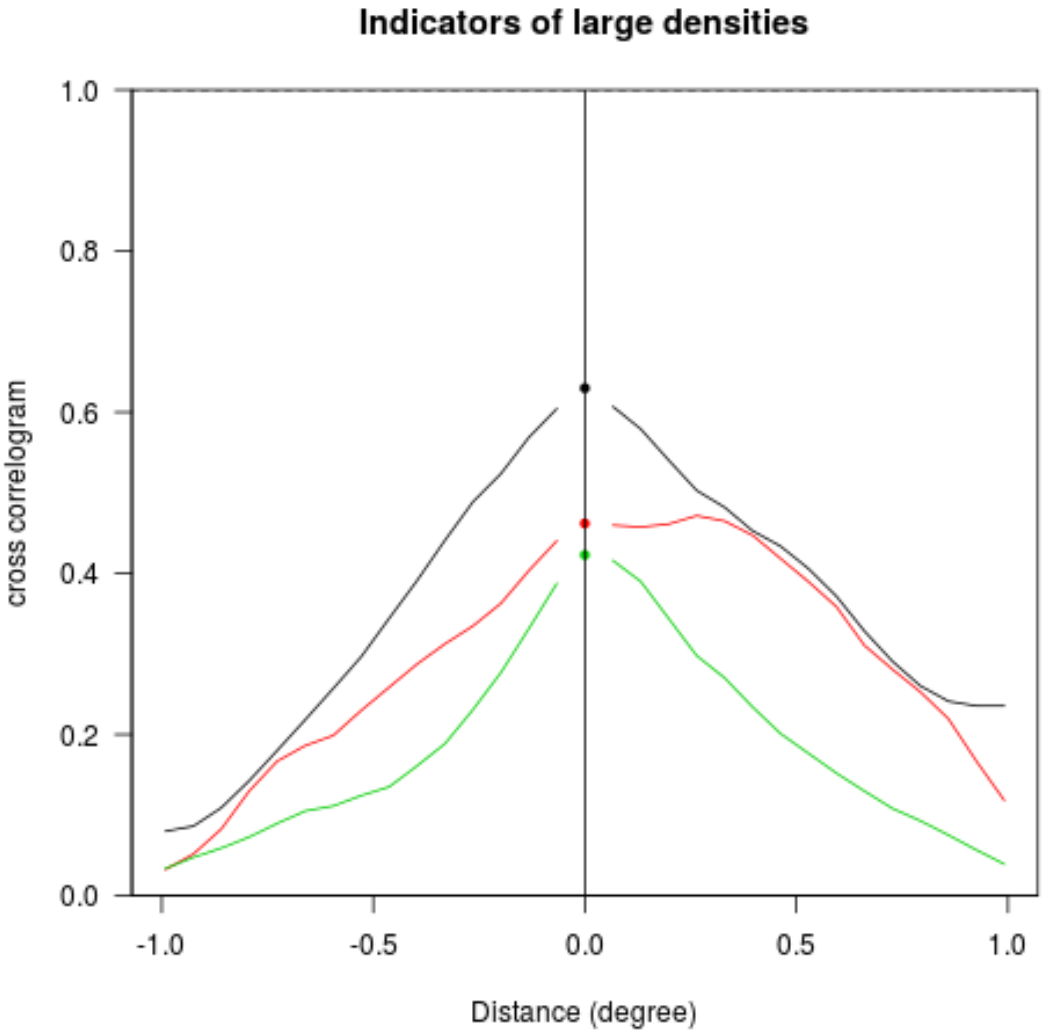


Predator to prey maps

Differences in sampling effort



Predator to prey maps



- 2001: $> 60\%$ coherence between dense VMS and acoustic zones.
- 2008 and 2009: $> 40\%$ coherence.

to be continued...

Research subject

A quantitative approach to the movement ecology of fishers

- Movement ecology
- Random walks
- Behavioral modes
- Spatial behavior and other ecosystem components
- Predator to prey maps
- Collective behavior: joint movement

How to characterize collective behavior from trajectories?

- Focus on joint-movement: how to assess it?



- Dyadic movement: 2 paths, same length
- Indices **review** and **proposals**: typology and criteria

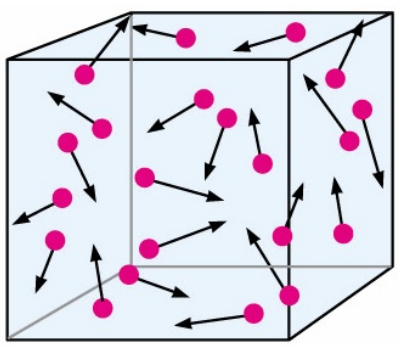
Joint movement

Criteria (related to desirable properties of indices):

1. Concreteness
2. Feasibility
3. Dyad invariance
4. Parameter tuning
5. Assumption dependence
6. Sensitivity
7. Range
8. Reference points
9. Computational cost
10. Modeling appeal

Joint movement

Indices from animal ecology, sports, medicine, physics, psychology, music and new ones!



Joint movement: Indices

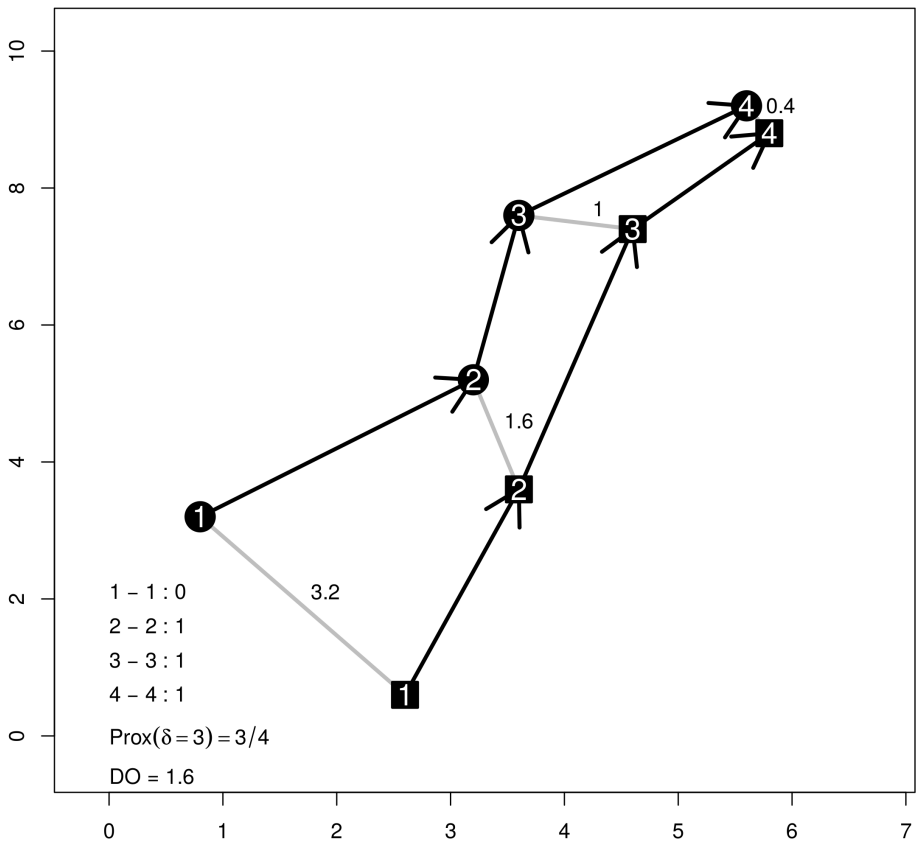
- Proximity
  1. Prox
  2. Cs1 & *Cs2*
  3. *LixnT: coefficient of interaction*
  4. *HAI: half-weight association index*
  5. jPPA: *joint potential path area*
- Coordination
  1. r: *correlation*
  2. DI
  3. *CSEM: cross sampled entropy*
  4. *RPm: relative phase*
  5. WCavg (from wavelet coherence)
  6. WCmax
  7. WCavglss
  8. WCmaxlss

Joint movement: Proximity indices

$$Prox = \Big(\sum_{t=1}^{T} K_\delta(t) \Big) / T$$

$$K_\delta(t) = \mathbb{1}\{dist(A_t, B_t) < \delta km\}$$

- proportion of simultaneous fixes that are proximal
- min: 0 (no proximity)
- max: 1 (always close)
- Issue: δ

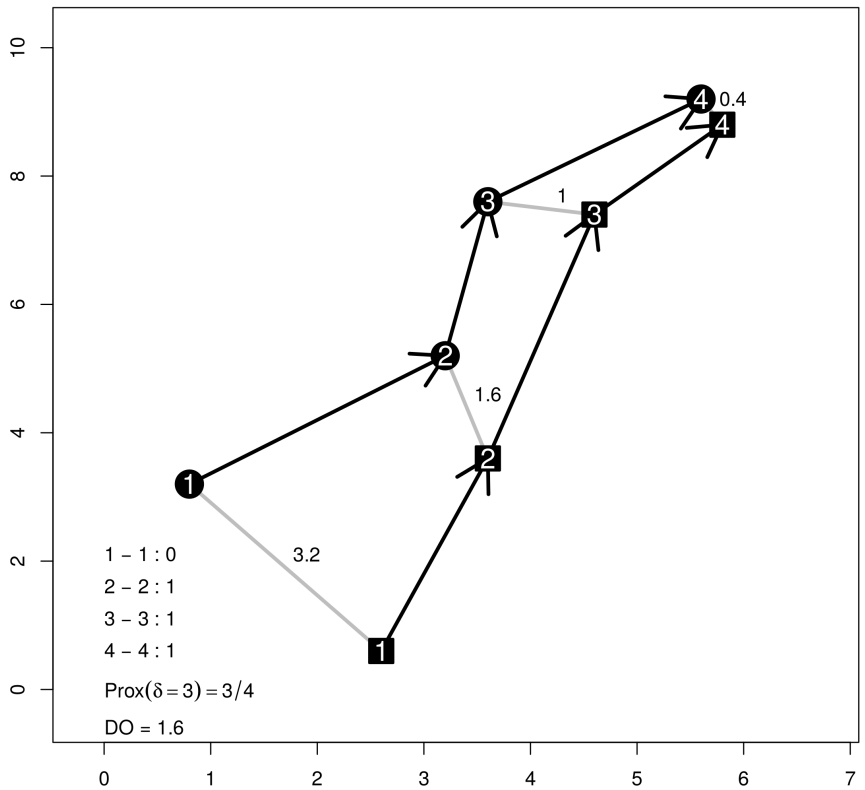


Joint movement: Proximity indices

Cs: coefficient of sociality

$$Cs = \frac{D_E - D_O}{D_E + D_O}$$

- D_O: average of observed distances
- D_E: average of expected distances
- min: -1 (avoidance)
- max: 1 (attraction)
- Issues:
  - D_E not plausible
  - Not covering whole spectrum $[-1, 1]$



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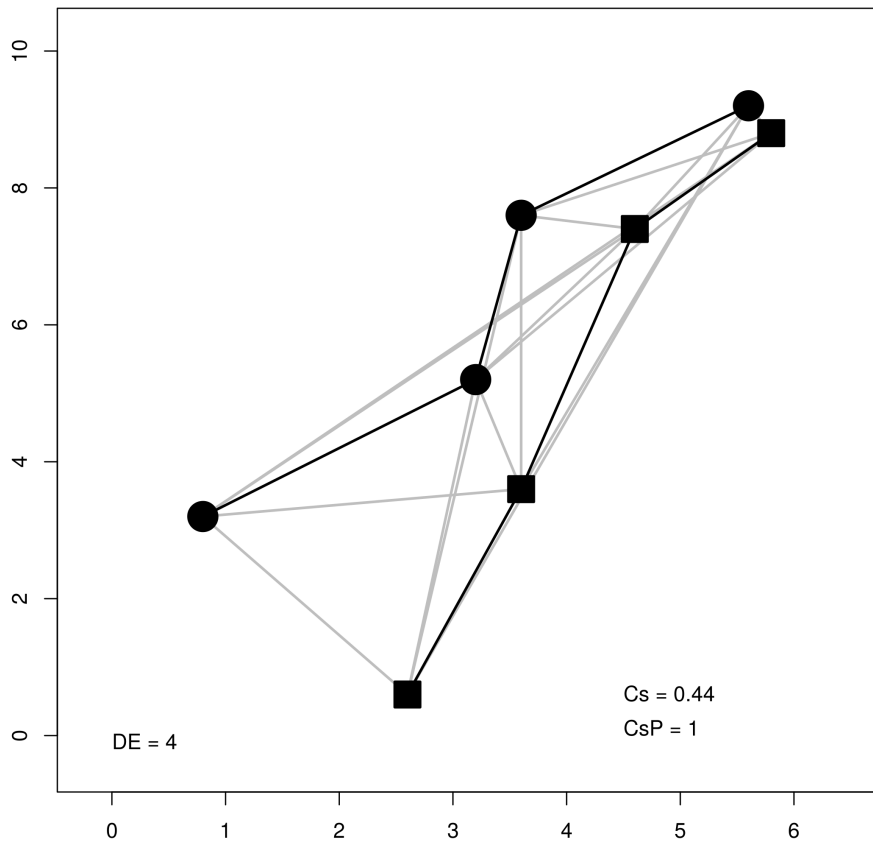


Joint movement: Coordination

DI: dynamic interaction

- Displacement:

$$g_t = 1 - \left(\frac{| d_t^A - d_t^B |}{d_t^A + d_t^B} \right)^{\delta}$$

DI_d: mean(g_t)

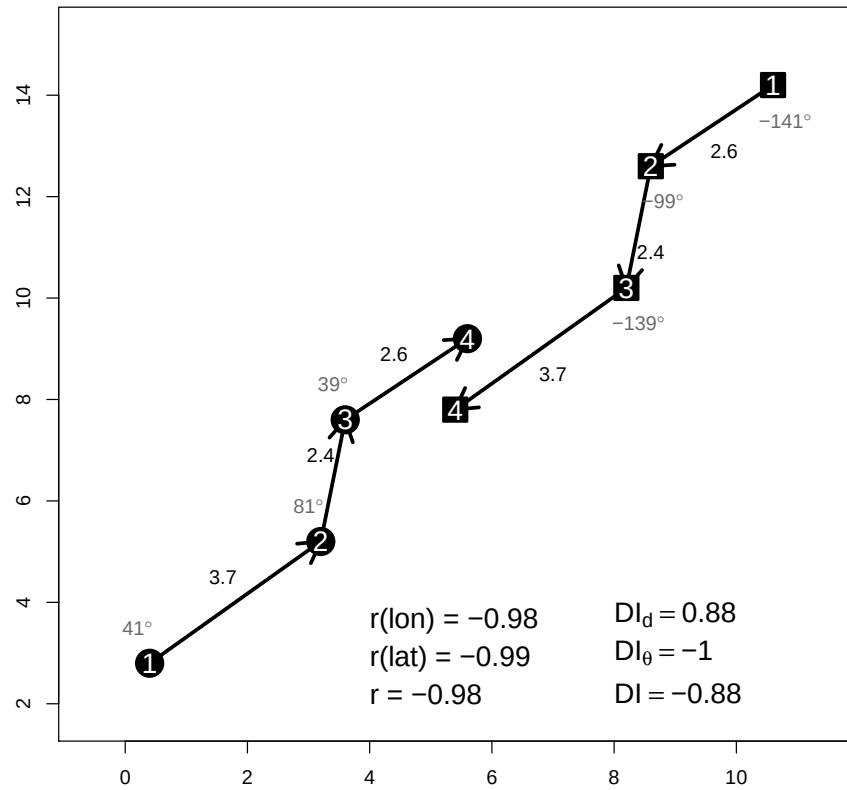
- min: 0 (no coord.)
- max: 1 (perf. coord.)

- Azimuth:

$$f_t = \cos(\theta_t^A - \theta_t^B)$$

DI_θ: mean(f_t)

- min: −1 (opp. direct.)
- max: 1 (same orient.)

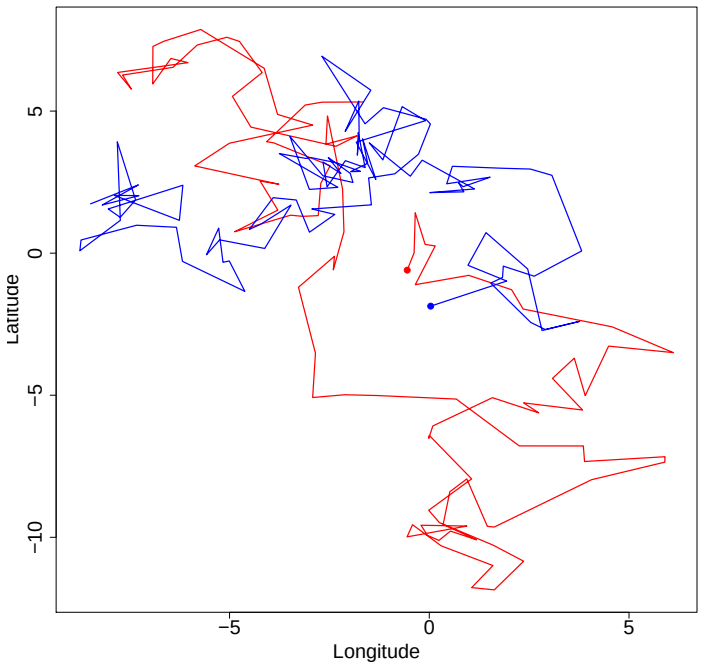


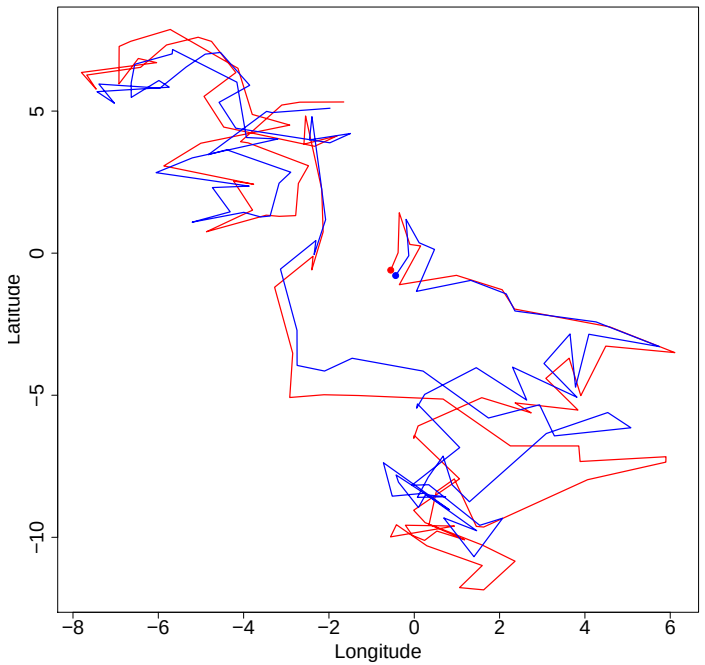
DI: mean($g_t \times f_t$)

- min: −1 (opposed mov.)
- max: 1 (cohesive mov.)

Joint movement: Dyad simulation

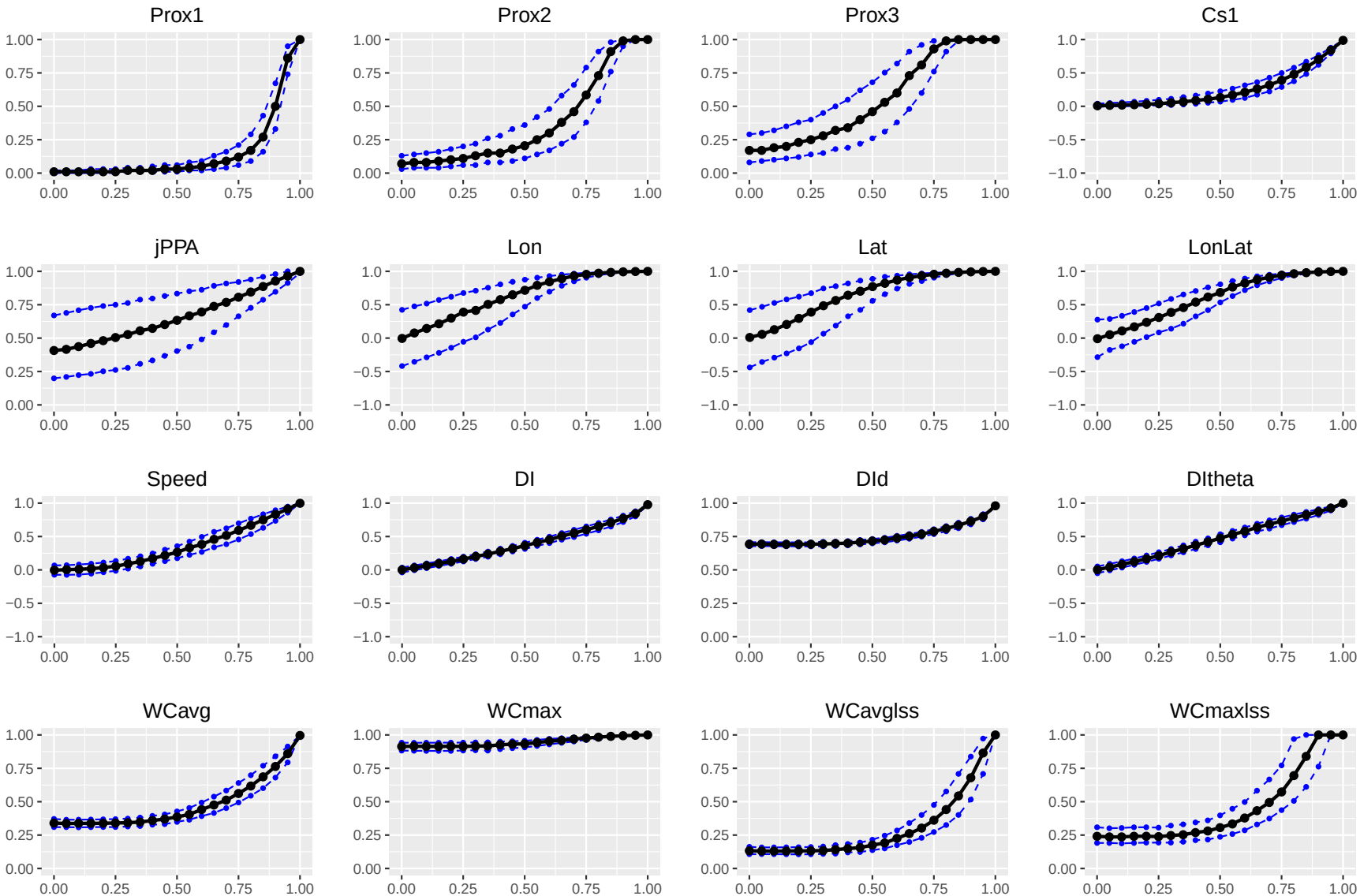
- Indices properties independent from model
- A: $X_t^A \sim X_{t-1}^A + \mathcal{N}(0, 1)$ (Brownian)
- B:
  $X_t^B \sim [w_t \times (X_t^A + \mathcal{U}(-0.05, 0.05))] + [(1 - w_t) \times \mathcal{N}(0, 1)]$
- $w = \{0, 0.05, ..., 0.95, 1\}$ (from independent to joint movement)



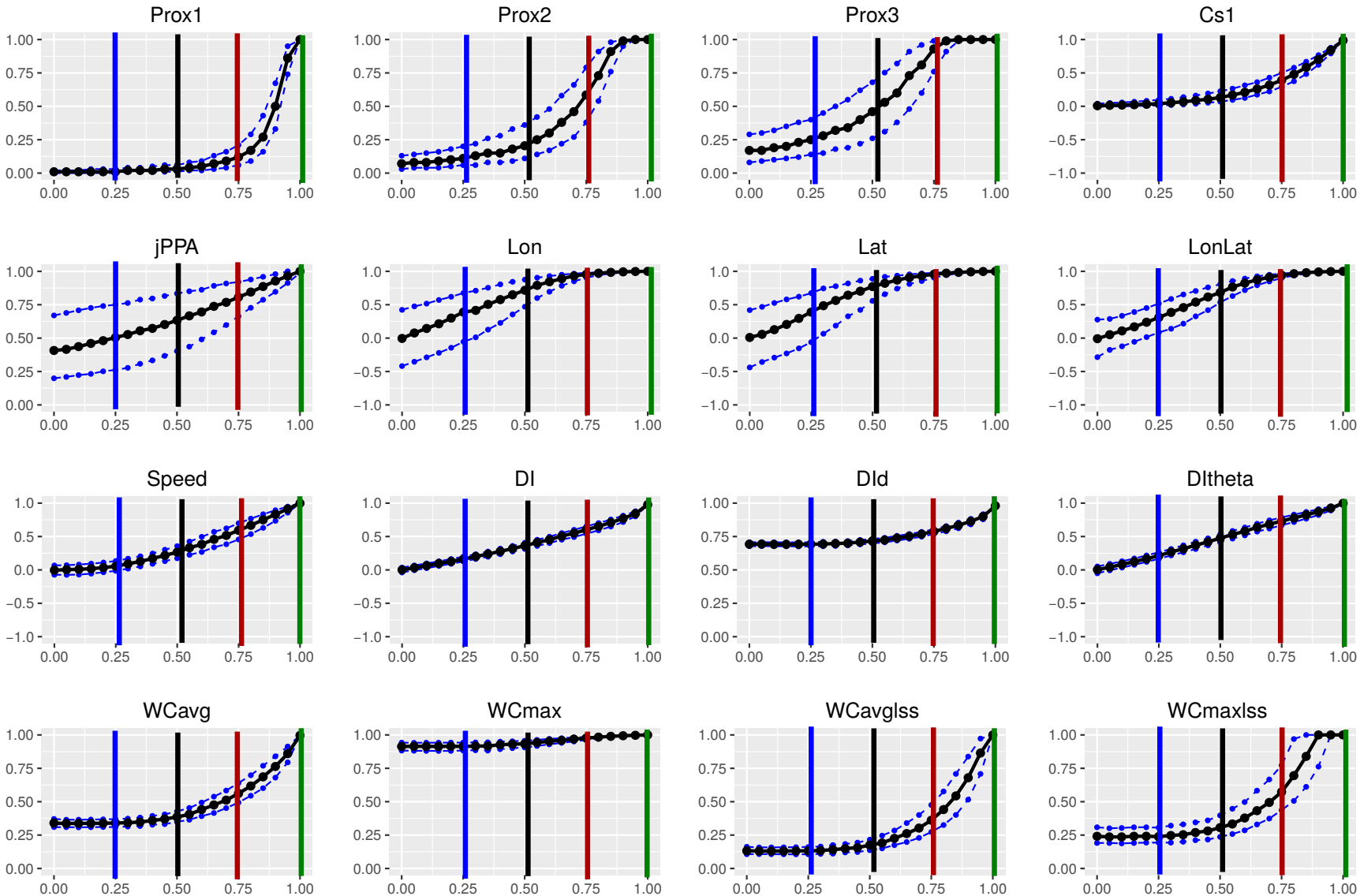


- 1000 replicas
- Compute indices on each dyad

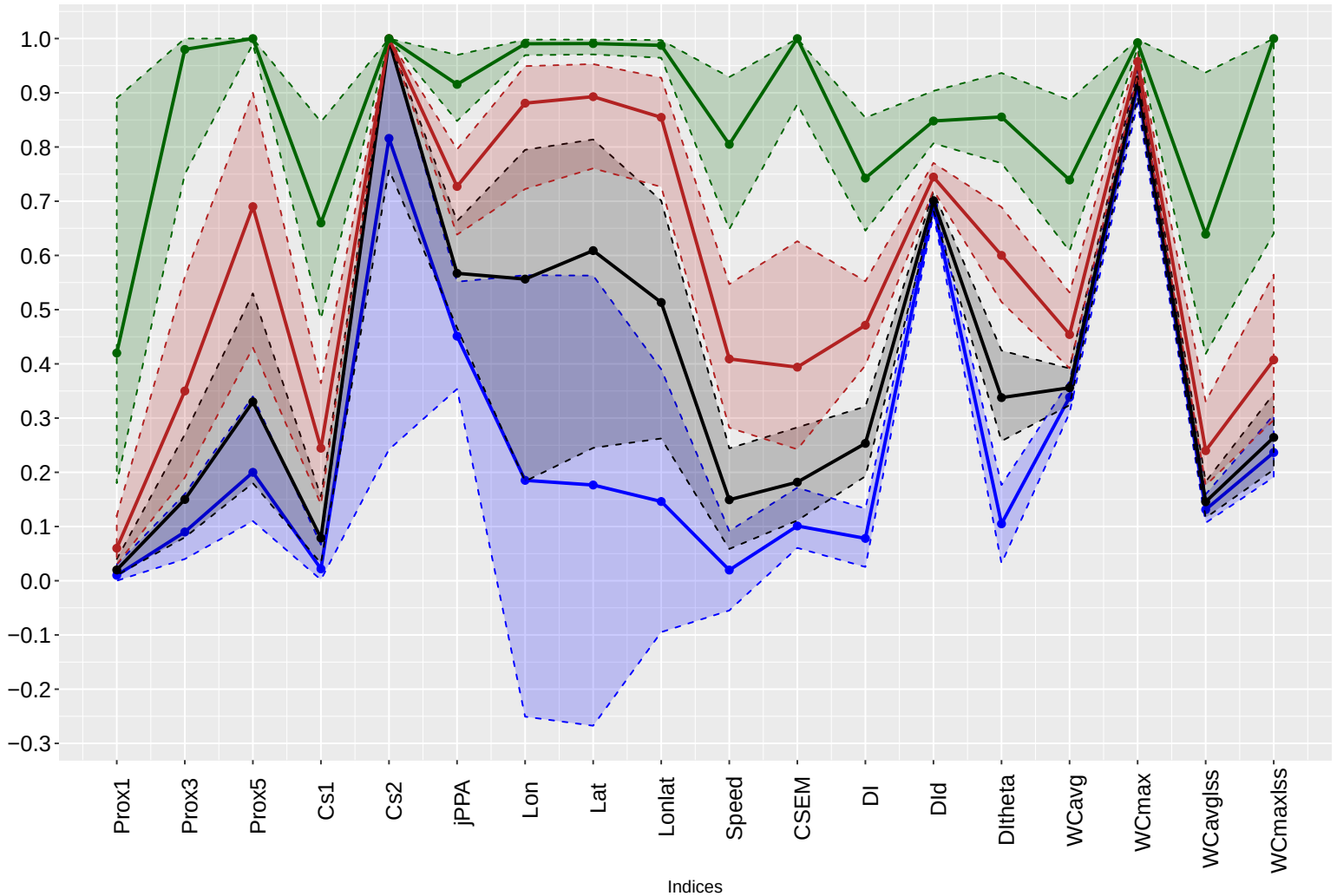
Joint movement: Dyad simulation



Joint movement: Dyad simulation



Joint movement: Dyad simulation

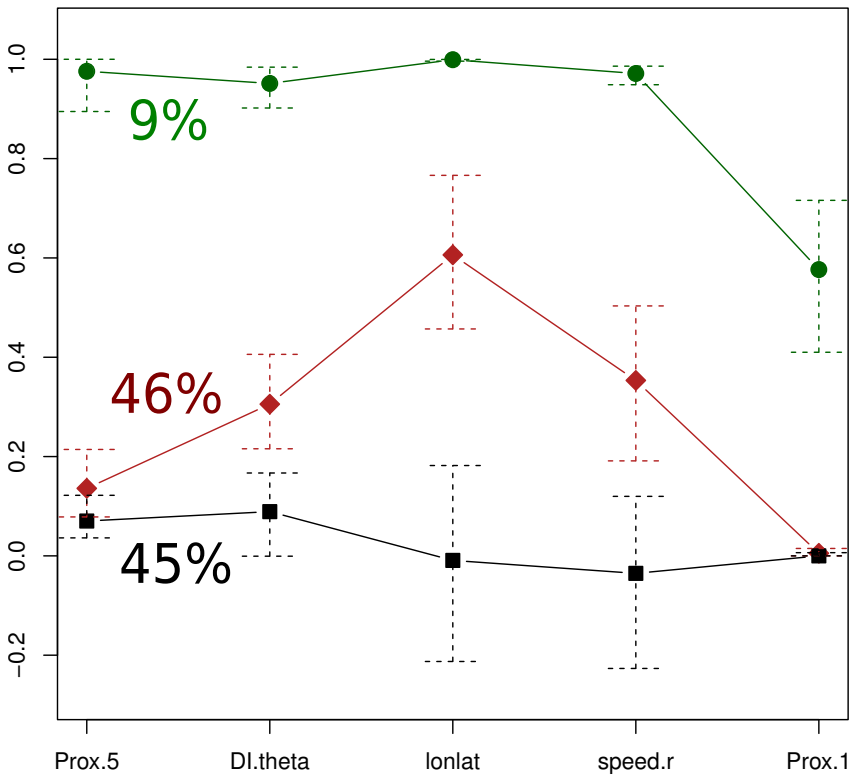


- 'Green group' discriminated by almost all.
- 'Blue group' discriminated by DI_θ, DI, r (Speed)

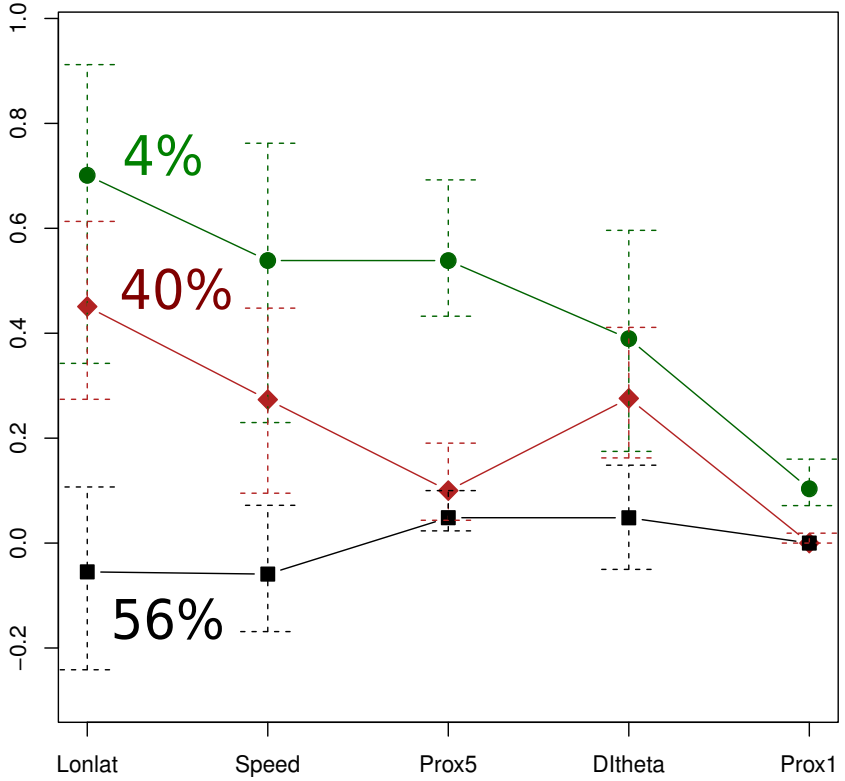
(Joo et al. MEE, in review)

Joint movement: Real data

Are there different levels of joint movement among fleets?



pelagic trawlers

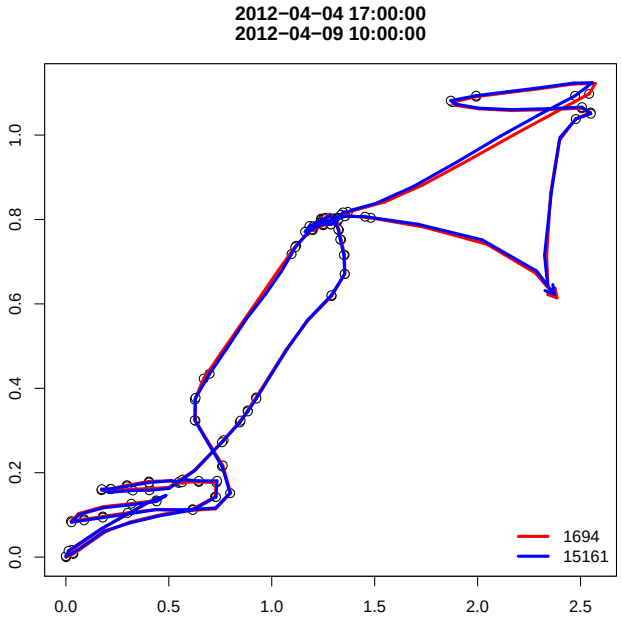


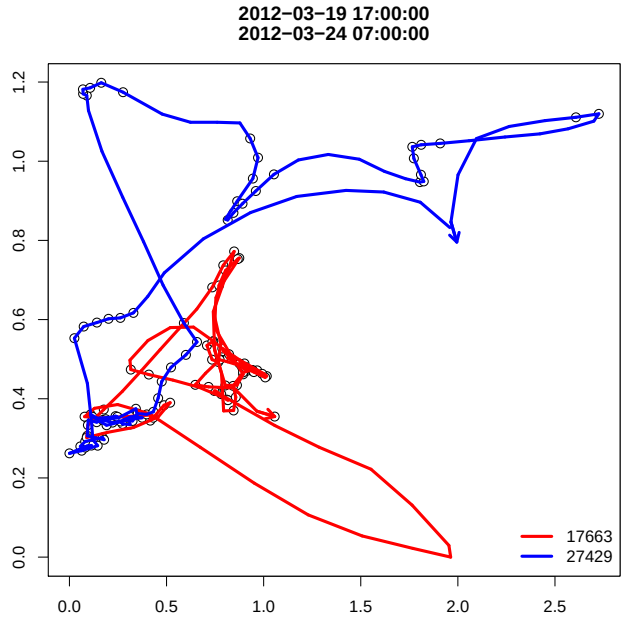
bottom trawlers

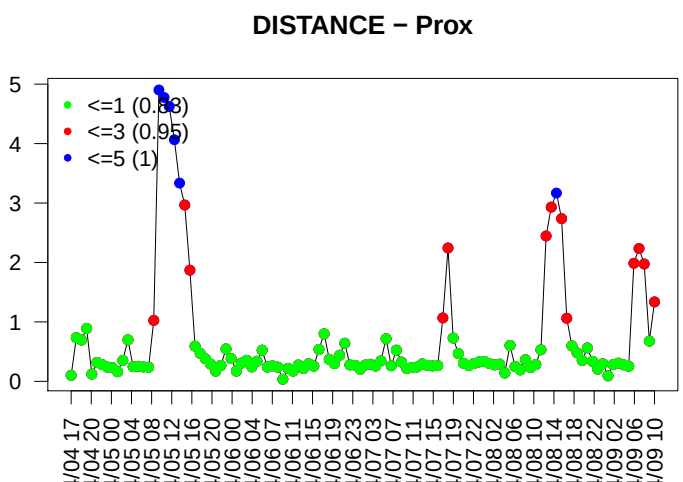
- Several levels of joint movement
- Few dyads move together

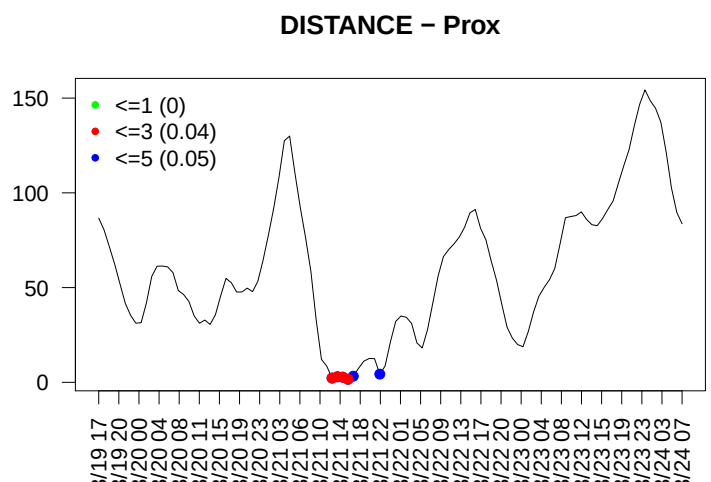
Joint movement: Real data

High vs. low joint movement



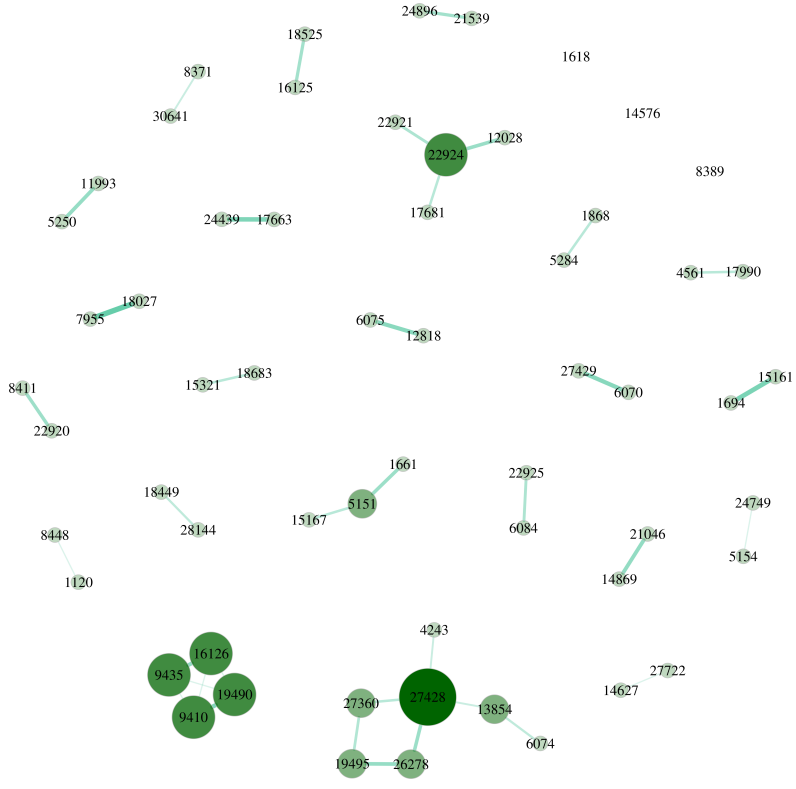




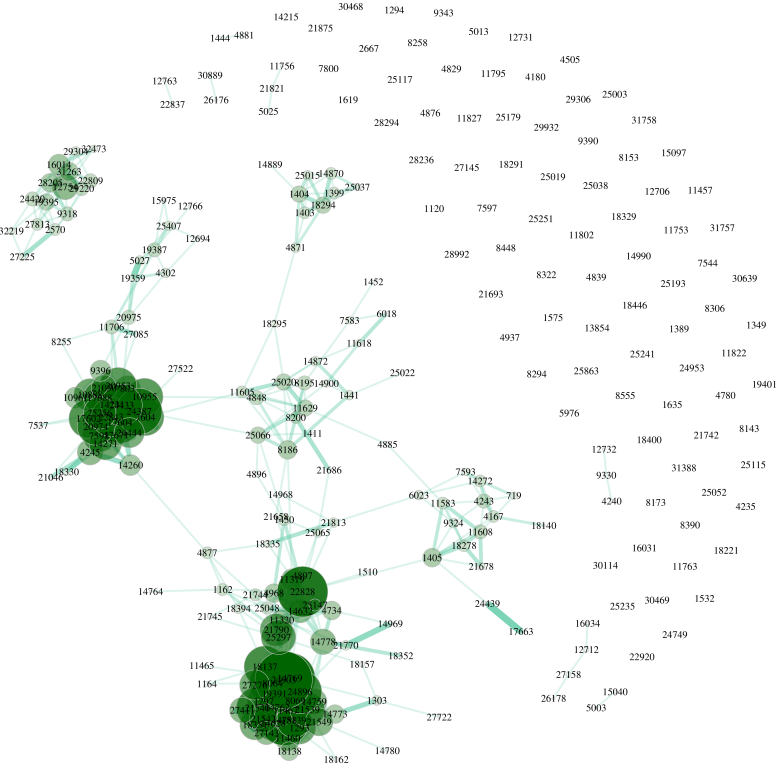


Joint movement: Real data

High joint movement among fleets: pelagic vs. bottom



Loyalty: 0.80



Loyalty: 0.16

Joint movement: Real data

- Indicators → different joint-movement patterns among dyads
- Small percentages of dyads moving together
- Different gears → movement strategies?
- Indices $\Longrightarrow$ movement models?