



Award# 1853681

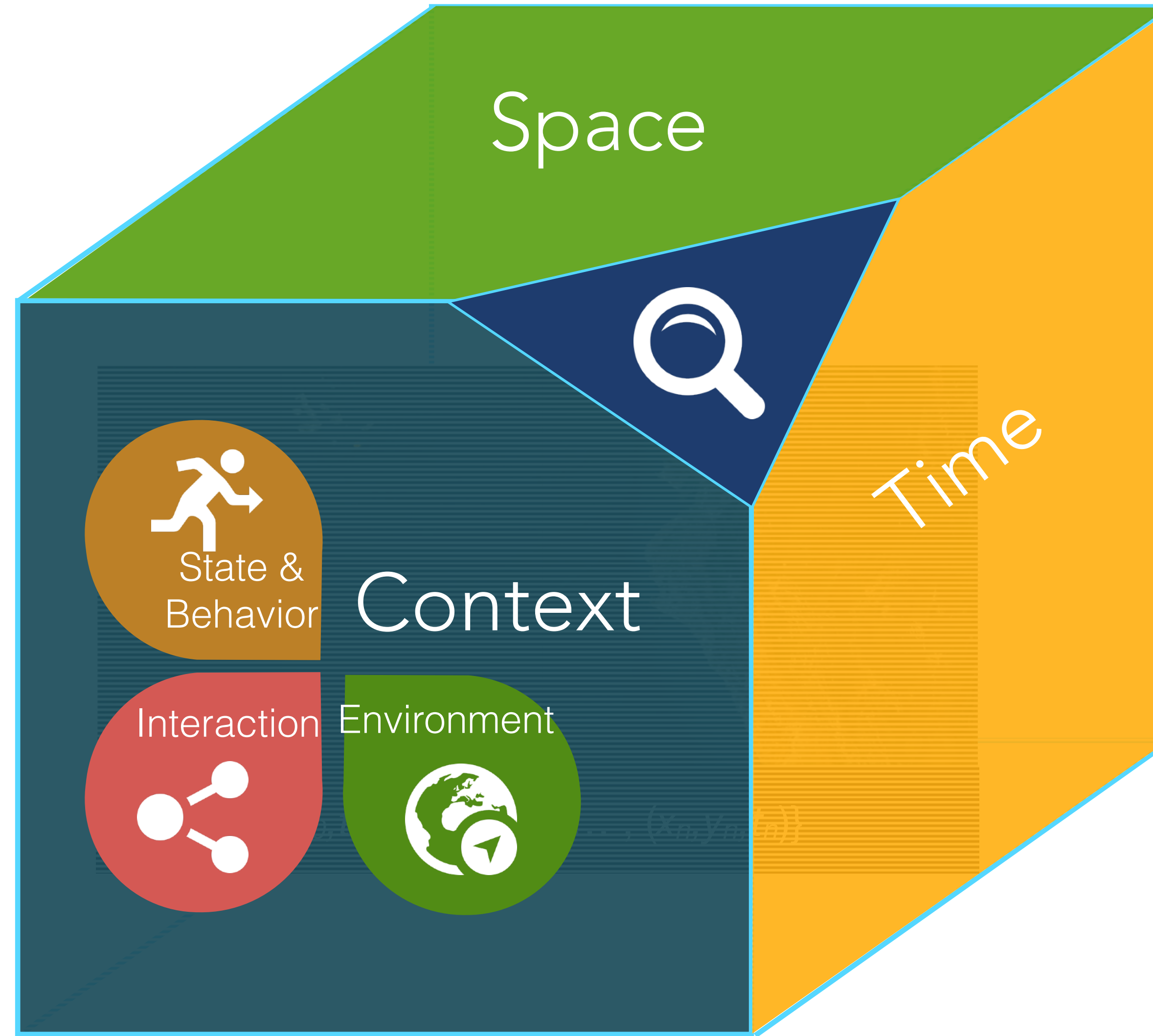
**WhereNext:**

## **Towards a Cartographic Framework for Movement**

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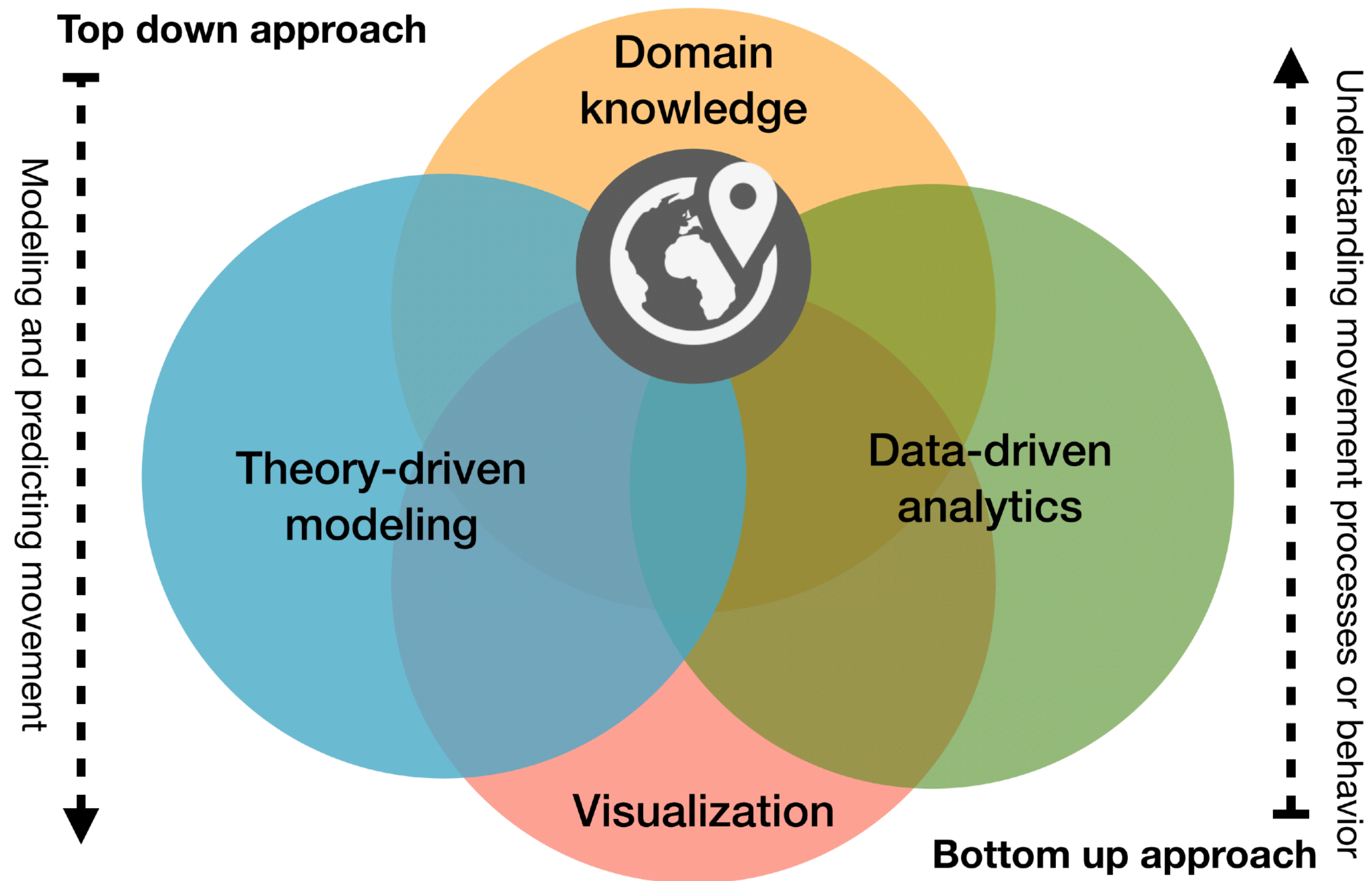
MOVE Lab: <http://move.geog.ucsb.edu/>

Department of Geography  
University of California Santa Barbara

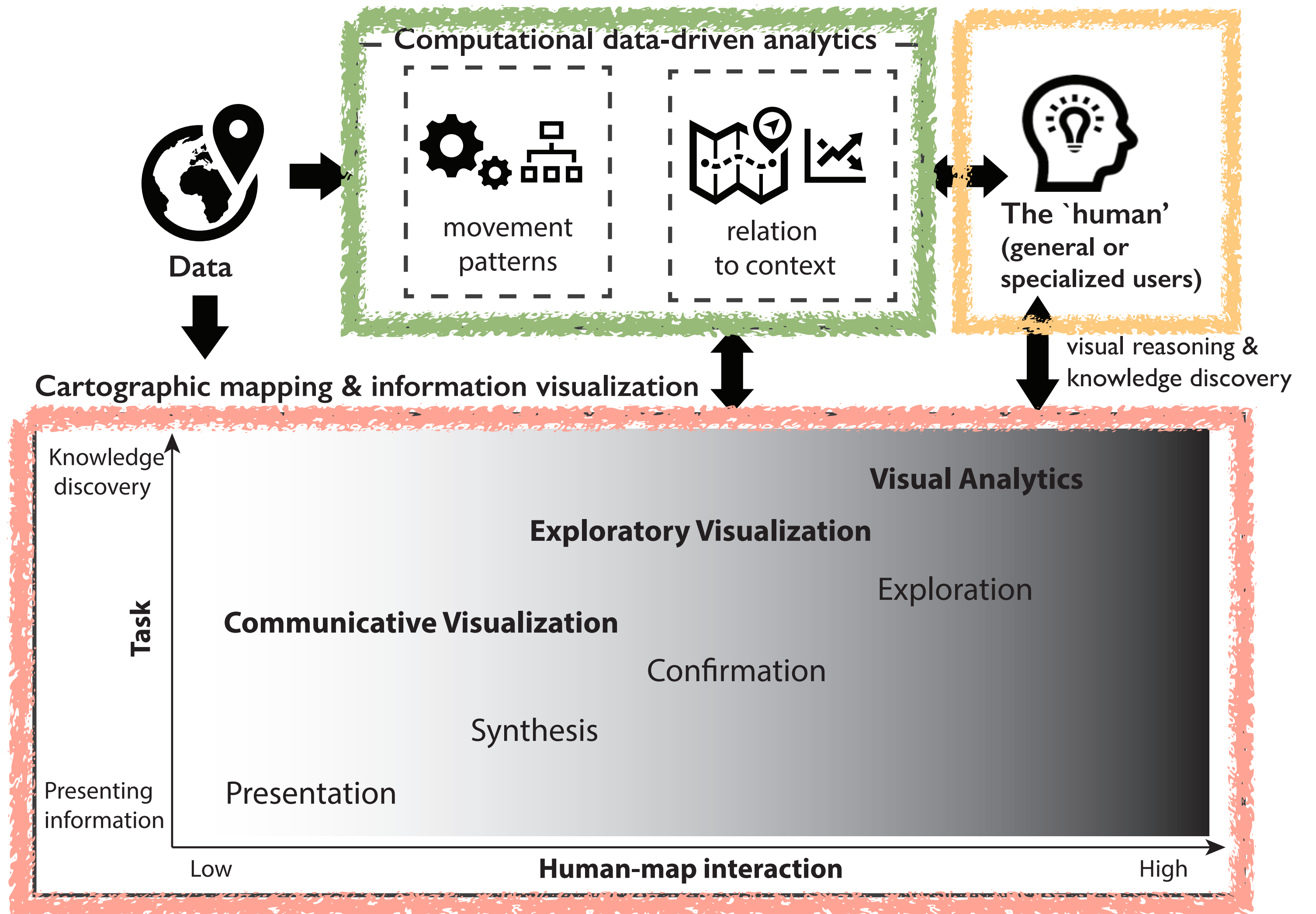
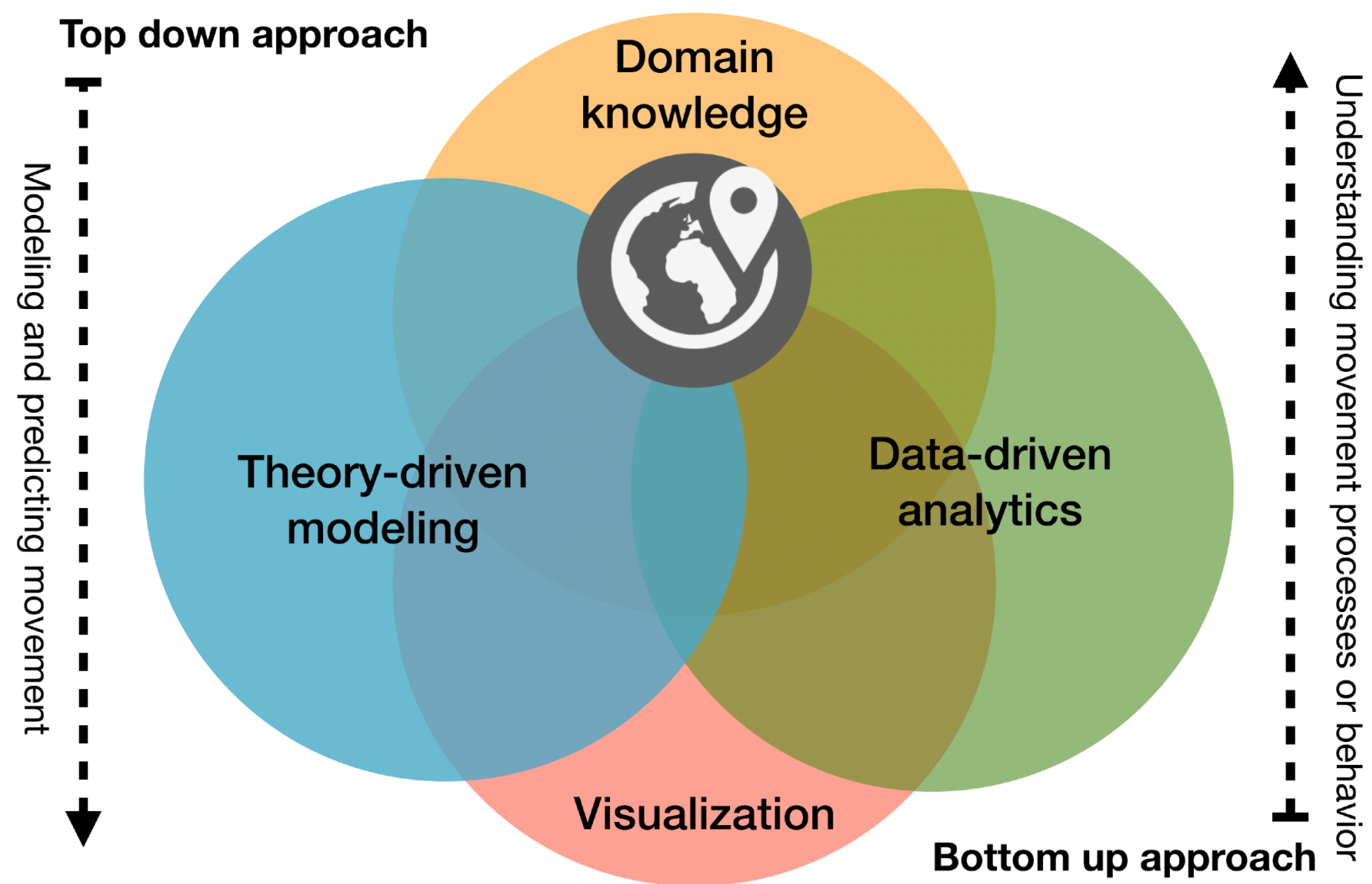


**Movement is multidimensional: space, time, context**

# Human-Centered Data Science Approach to Movement Analytics



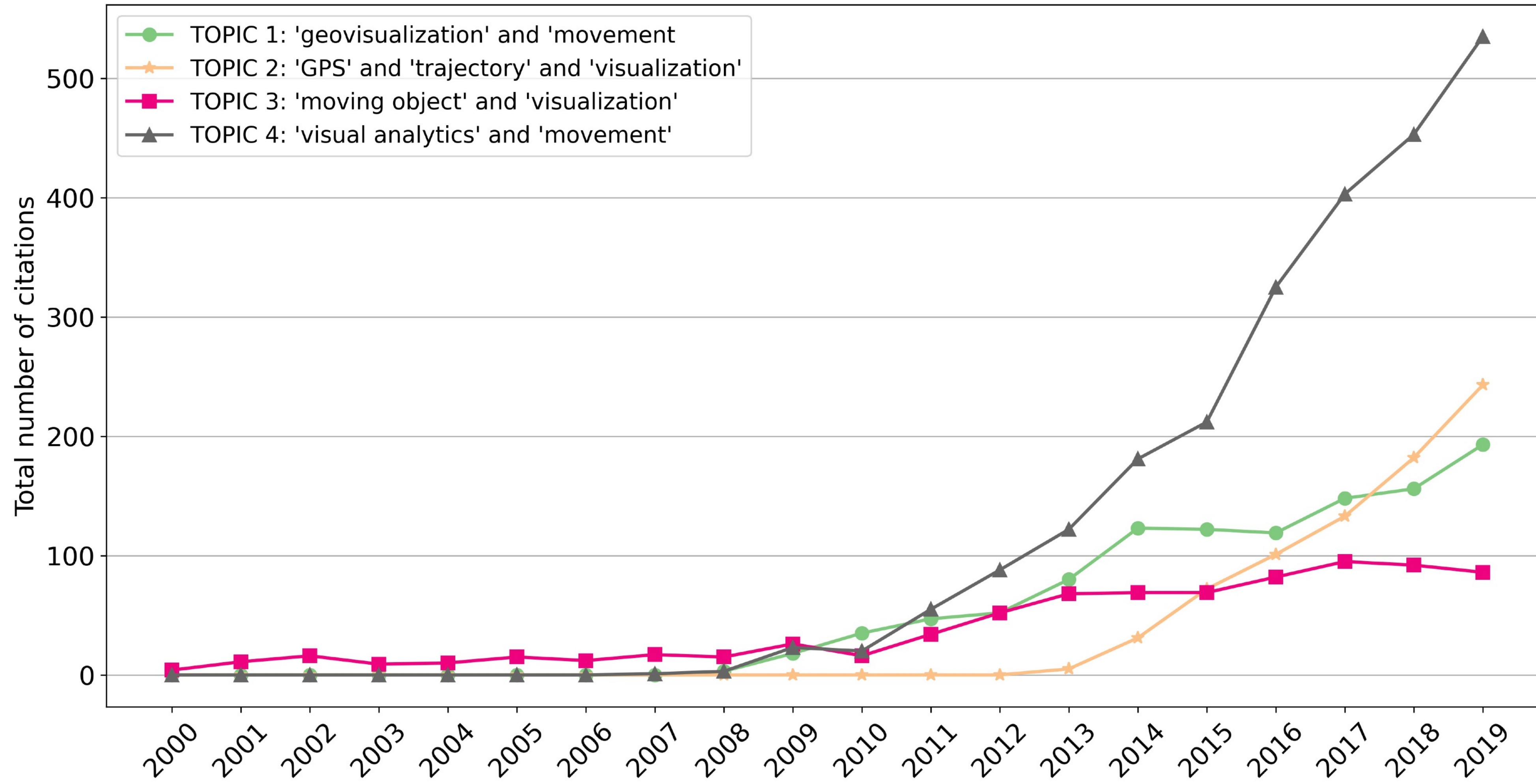
# Human-Centered Data Science Approach to Movement Analytics



Dodge & Noi (in review)

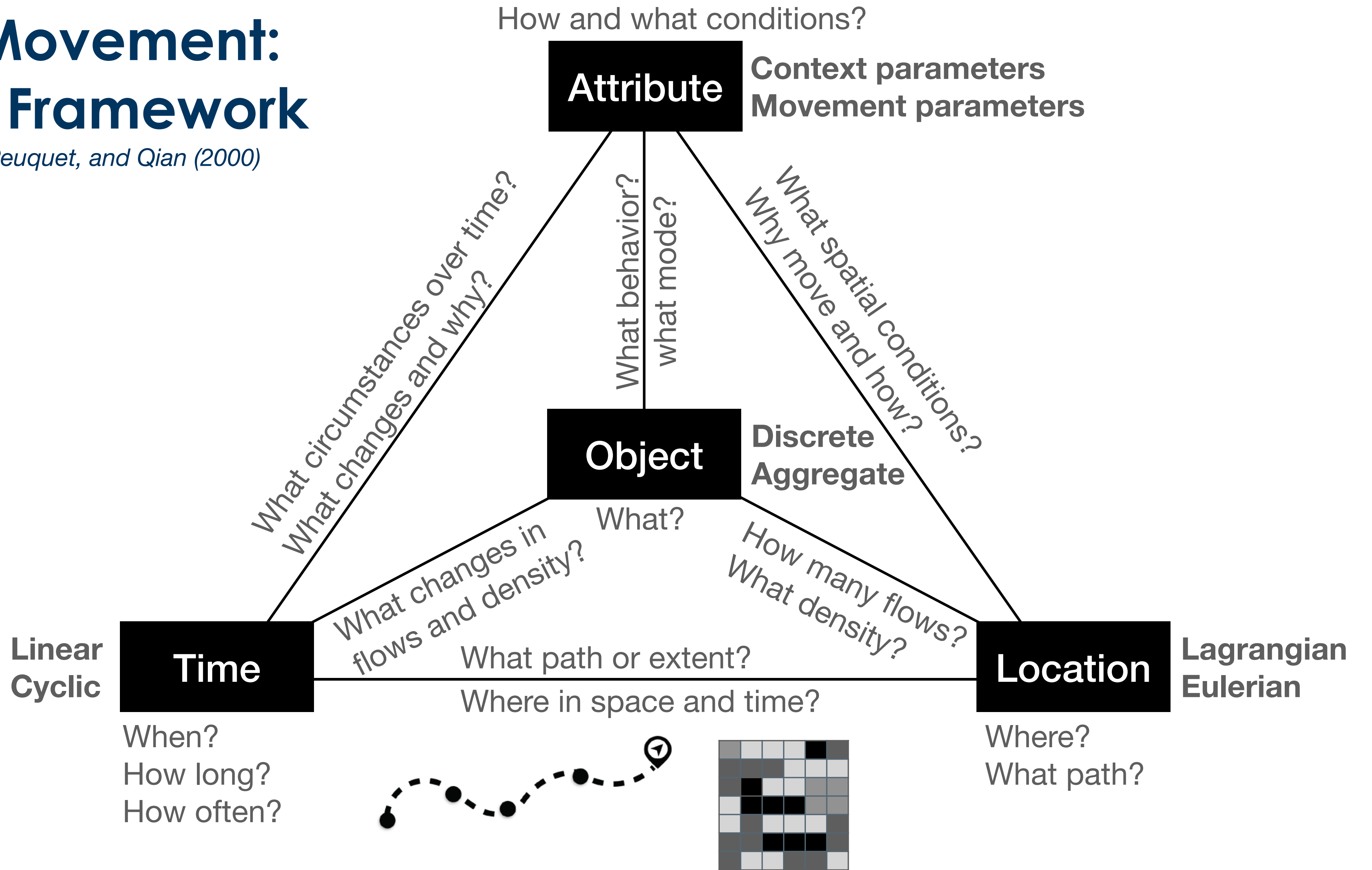
# Visualization of Movement

Web of Science



# Mapping Movement: A Pyramid Framework

*Kraak (2014), Mennis, Peuquet, and Qian (2000)*



# Elements of the Cartographic Framework for Movement

Source: Dodge and Noi (in review) CaGIS

## VISUAL ELEMENTS

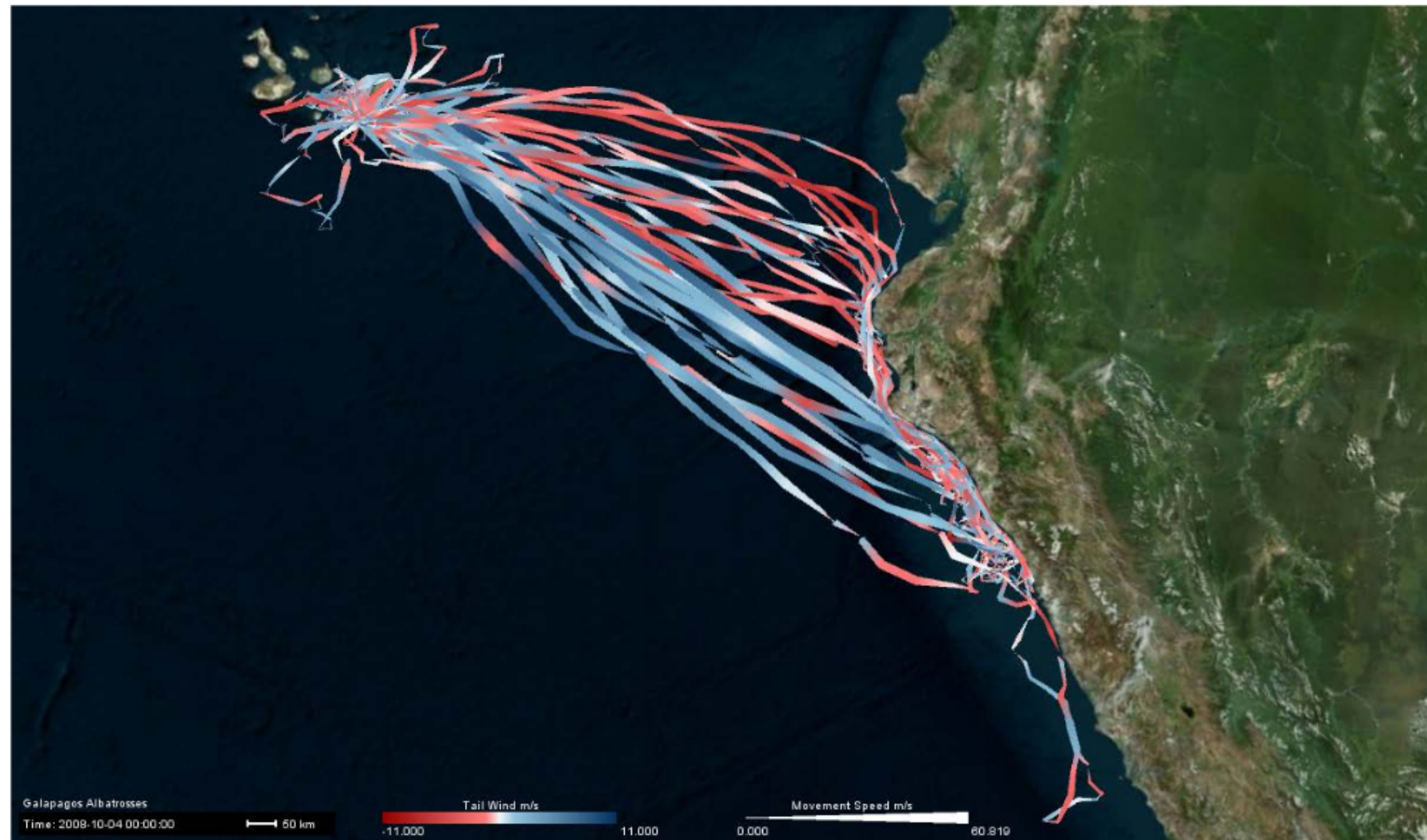
1	Vector	binary
2	Raster	binary
3	Lagrangian	binary
4	Eulearian	binary
5	Discrete	binary
6	Aggregate	binary
7	2D	binary
8	3D	binary
9	Static	binary
10	Dynamic	binary
11	Location	binary
12	Time	binary
13	Movement parameters	binary
14	Context parameters	binary

## FUNCTIONAL ELEMENTS

13	Multiple coordinated views (MCV)	binary
15	Dynamic querying	binary
16	Public users	binary
17	Private users	binary
18	Knowledge construction	binary
19	Knowledge presentation	binary
20	Interaction	categorical
21	Flexibility	categorical

# Movement Data

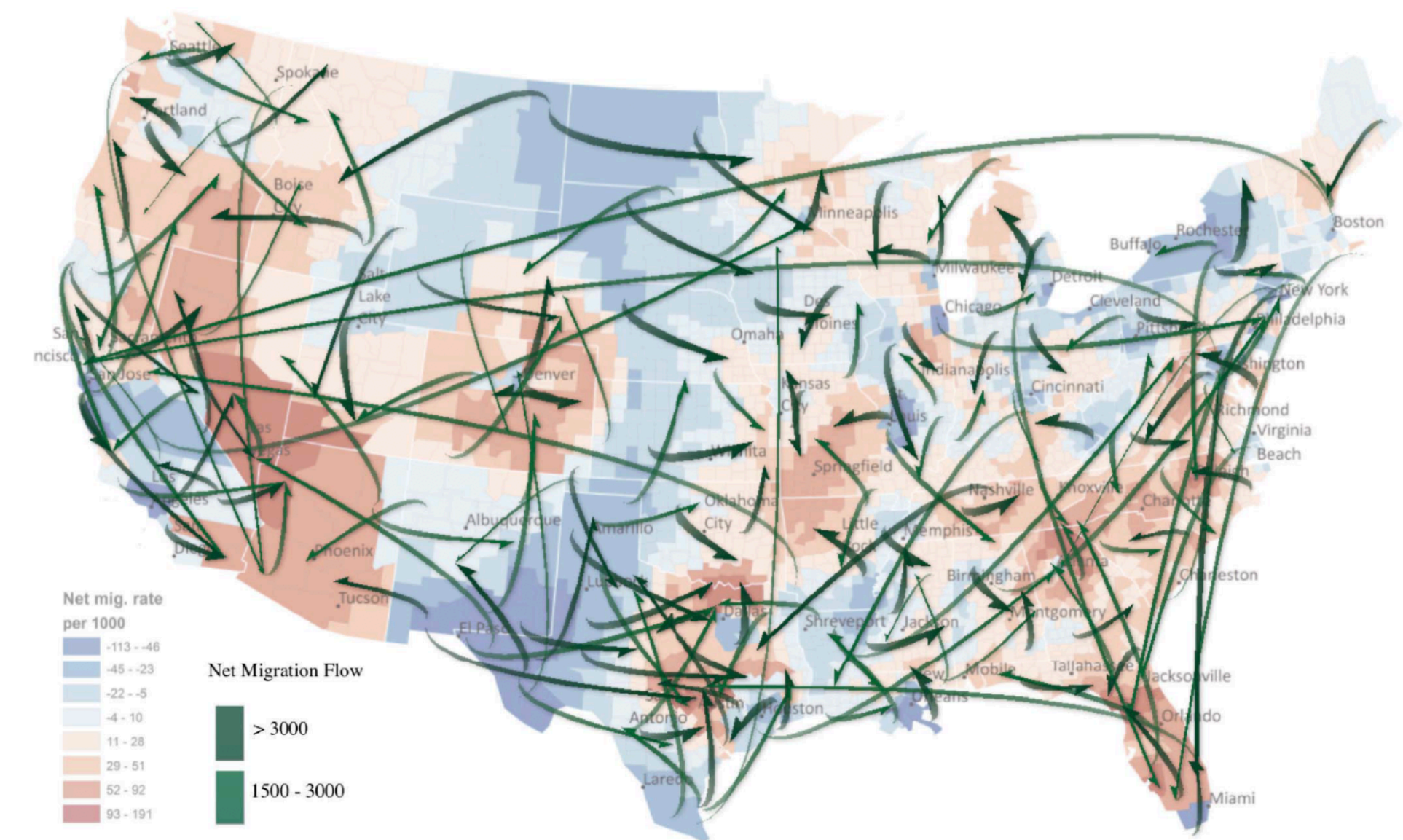
## Trajectories (discrete)



*Xavier & Dodge (2014)*

GPS Trajectories of 9 adult albatrosses (90 min resolution), annotated with wind speed (m/s) and wind direction, 6-hour, 2.5°, U/V-wind components NCEP Reanalysis 2 using Env-DATA

## O-D flows (discrete and aggregate)



*D. Guo (2014)*

US Migration: “Smoothed net migration flows for age 25-29, with population threshold = 1,000,000. The background map shows the net migration rate for age group 25-29.” Guo, 2014

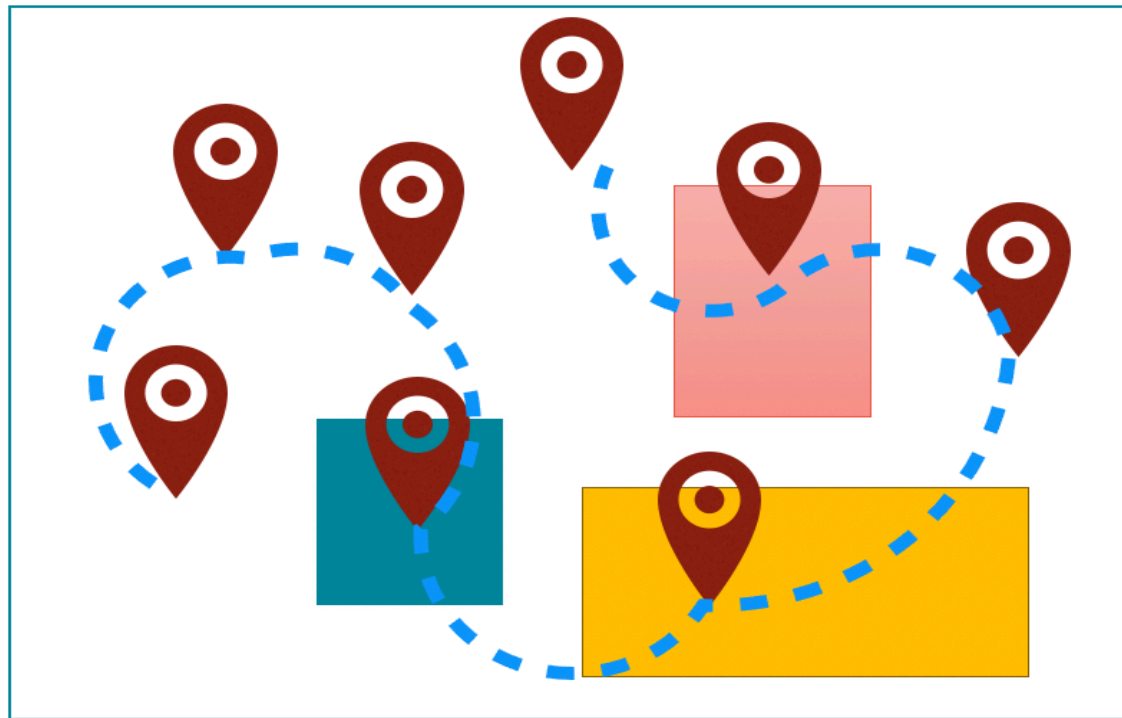
Movement of humans, vehicles, animals, diseases, natural phenomena, etc.



# Data Collection vs Representation Perspectives

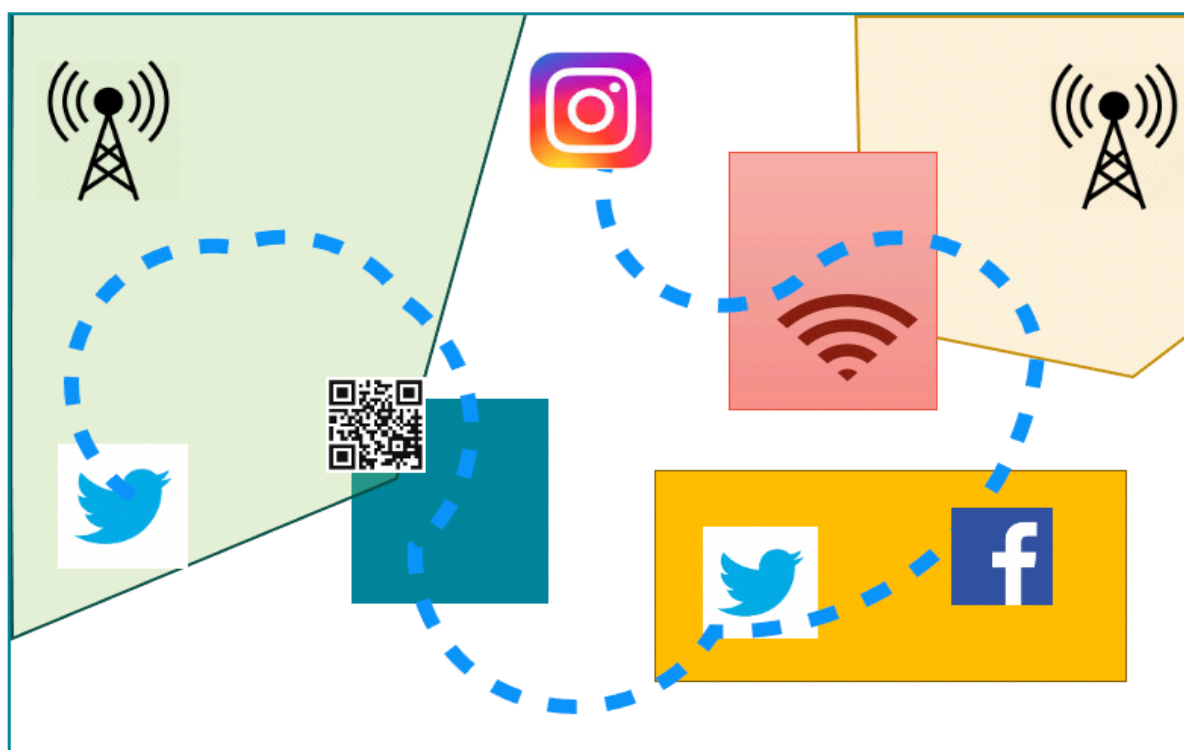
## Lagrangian perspective:

Observing movement from the perspective of the moving entity; following the entity along its track over time



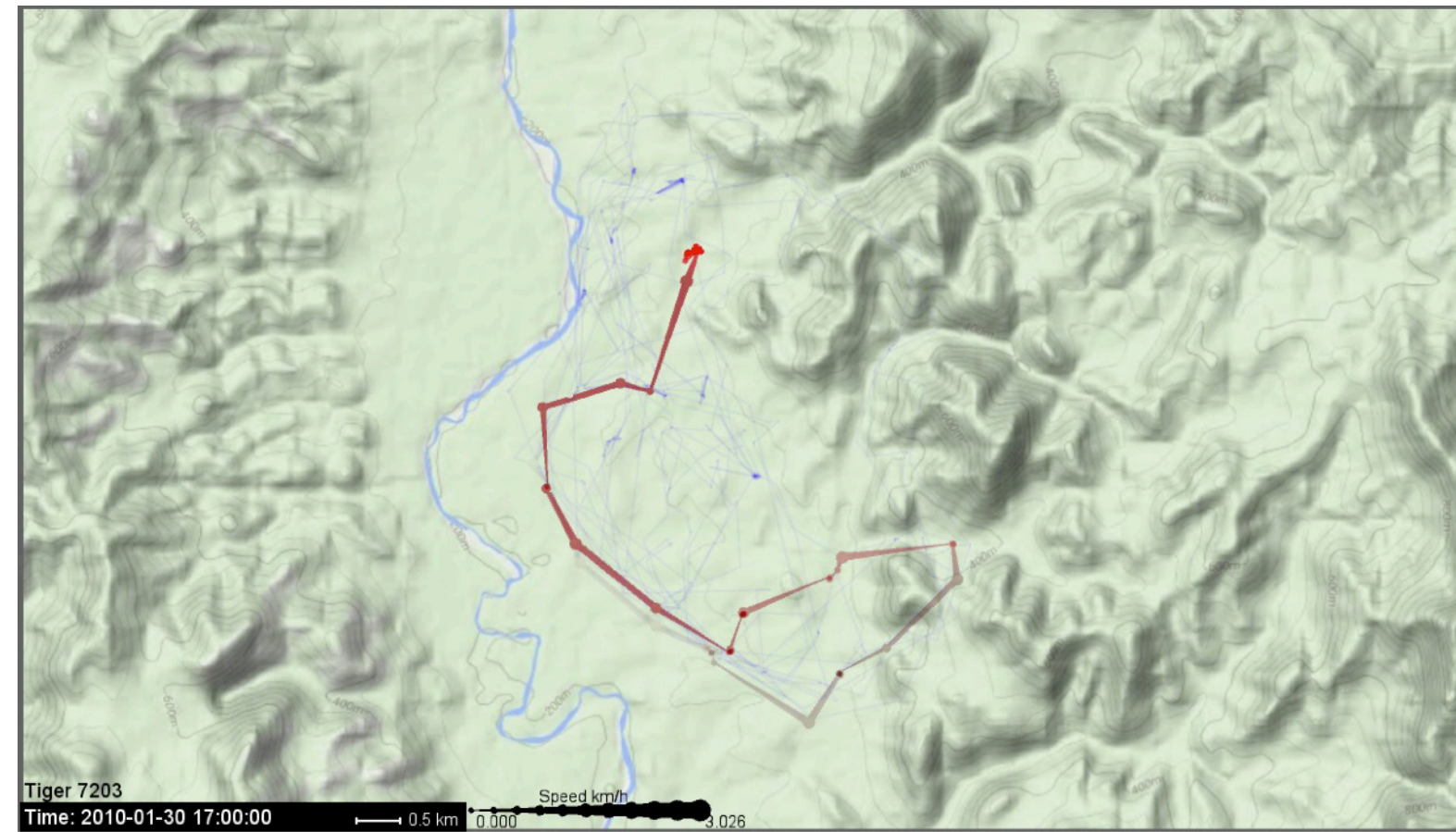
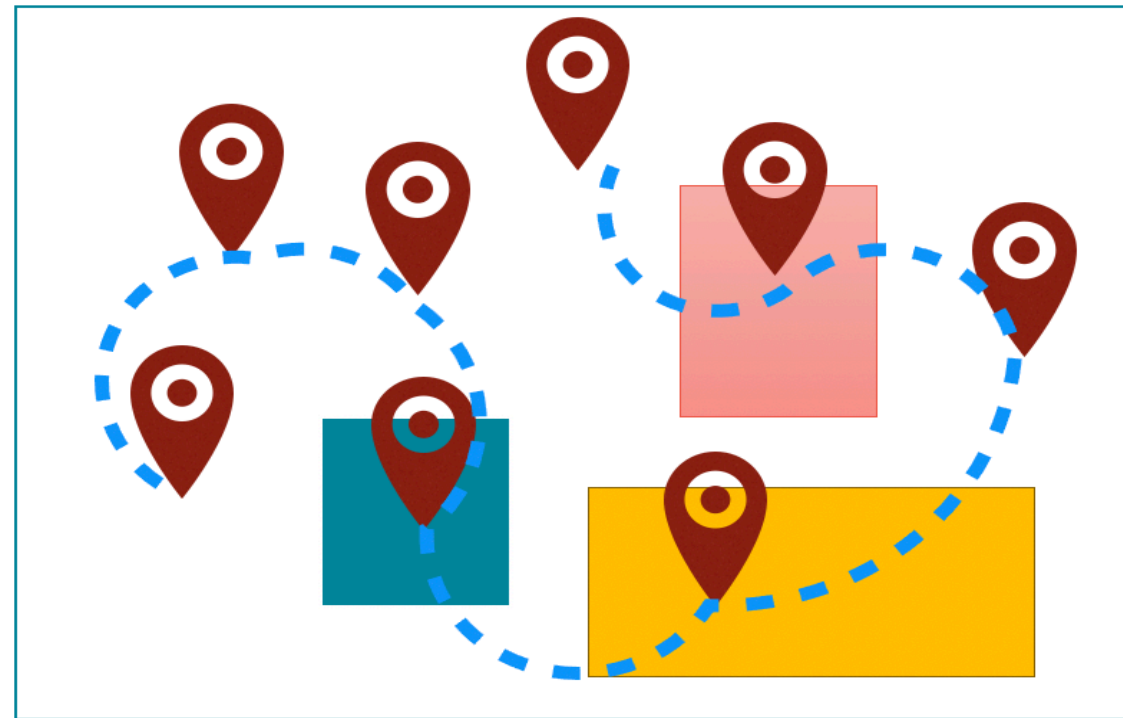
## Eulerian perspective:

Observing movement at fixed locations; recording presence of moving entities at certain locations over time



# Data Collection vs Representation Perspective

Lagrangian perspective:

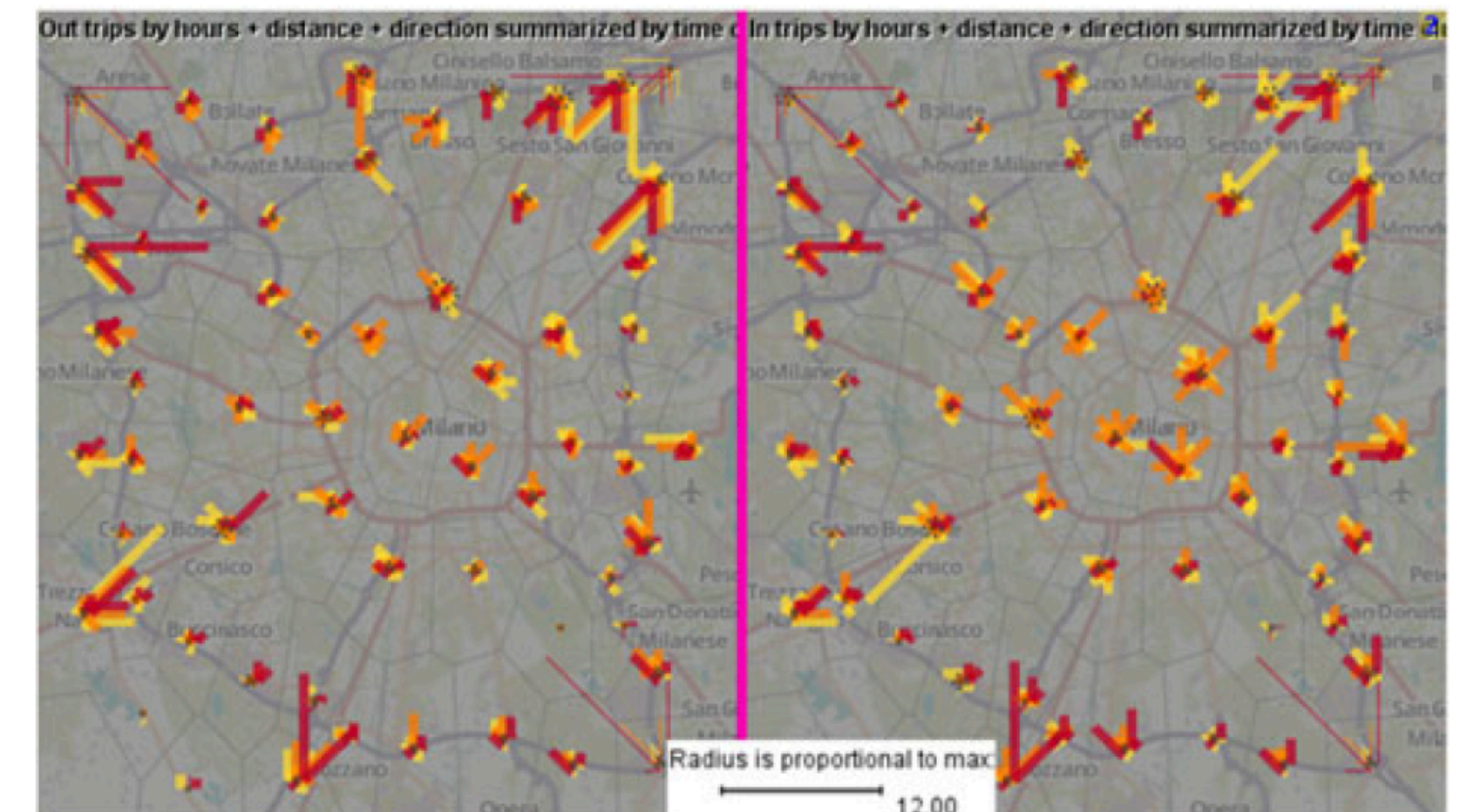


A female tiger trajectory between Dec 2009 – July 2010 (4874 GPS points)



Tiger activity at different temperature

*Collaboration with Esri, N. Shephard*

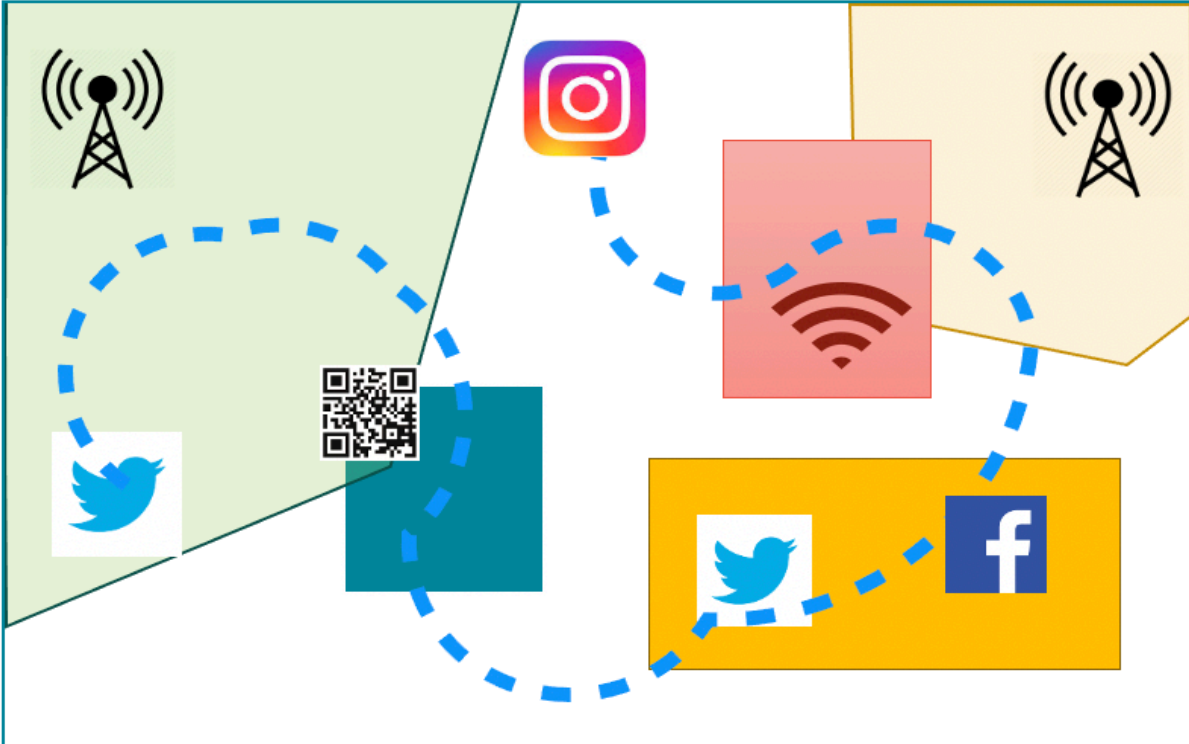


Car Trips in Milan (O-D flows)

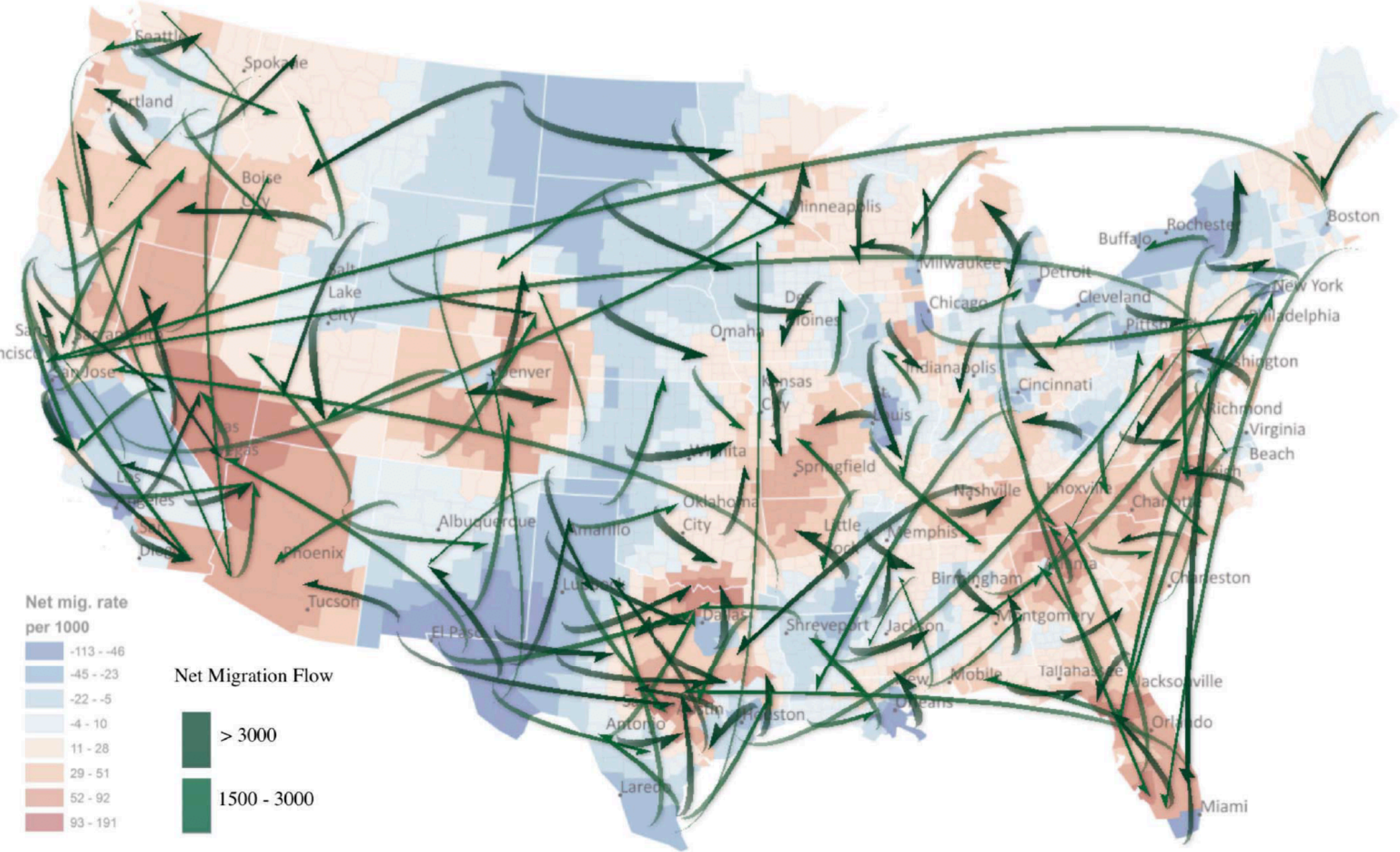
*Andrienko et al (2017)*

# Data Collection vs Representation Perspective

### Eulerian perspective:



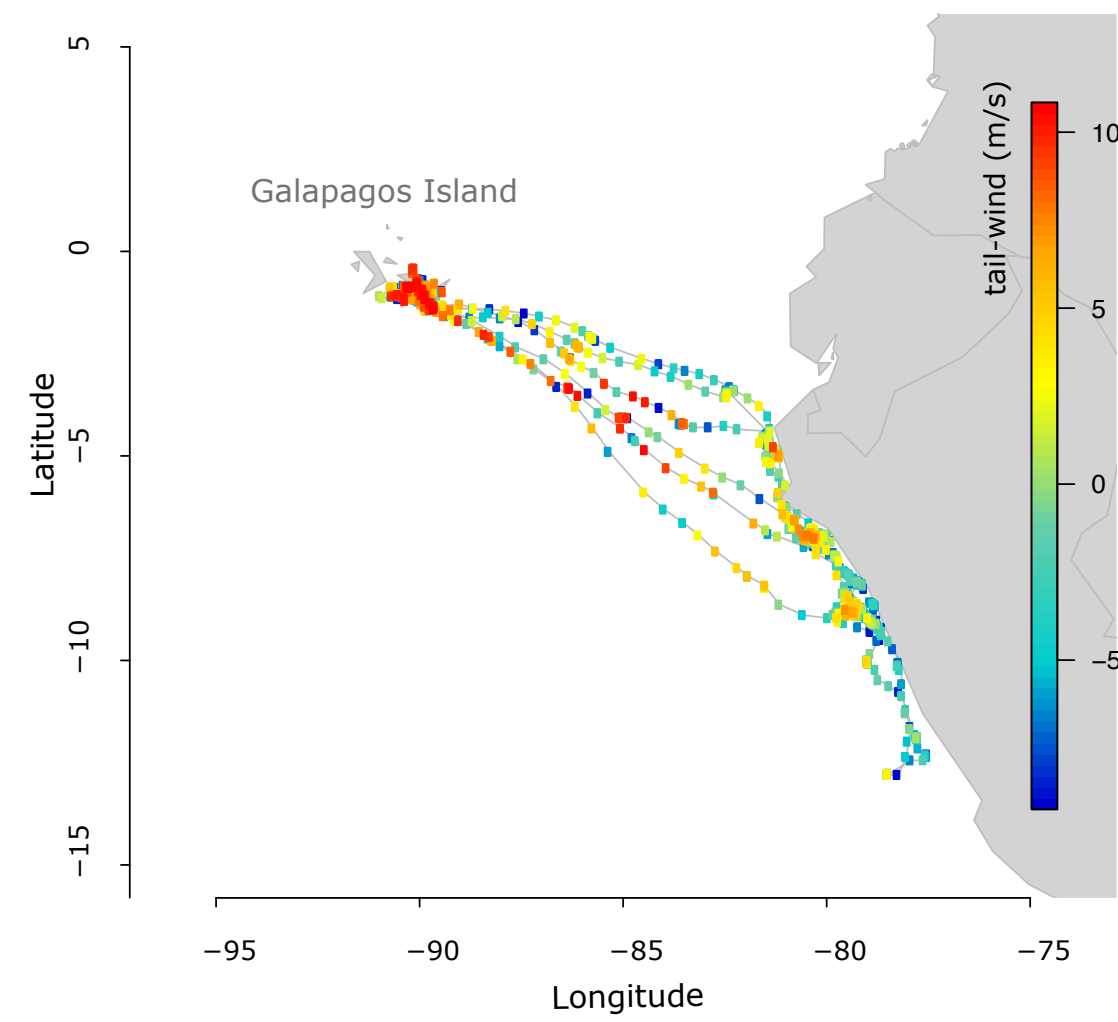
Dodge (2019), Laube (2014)



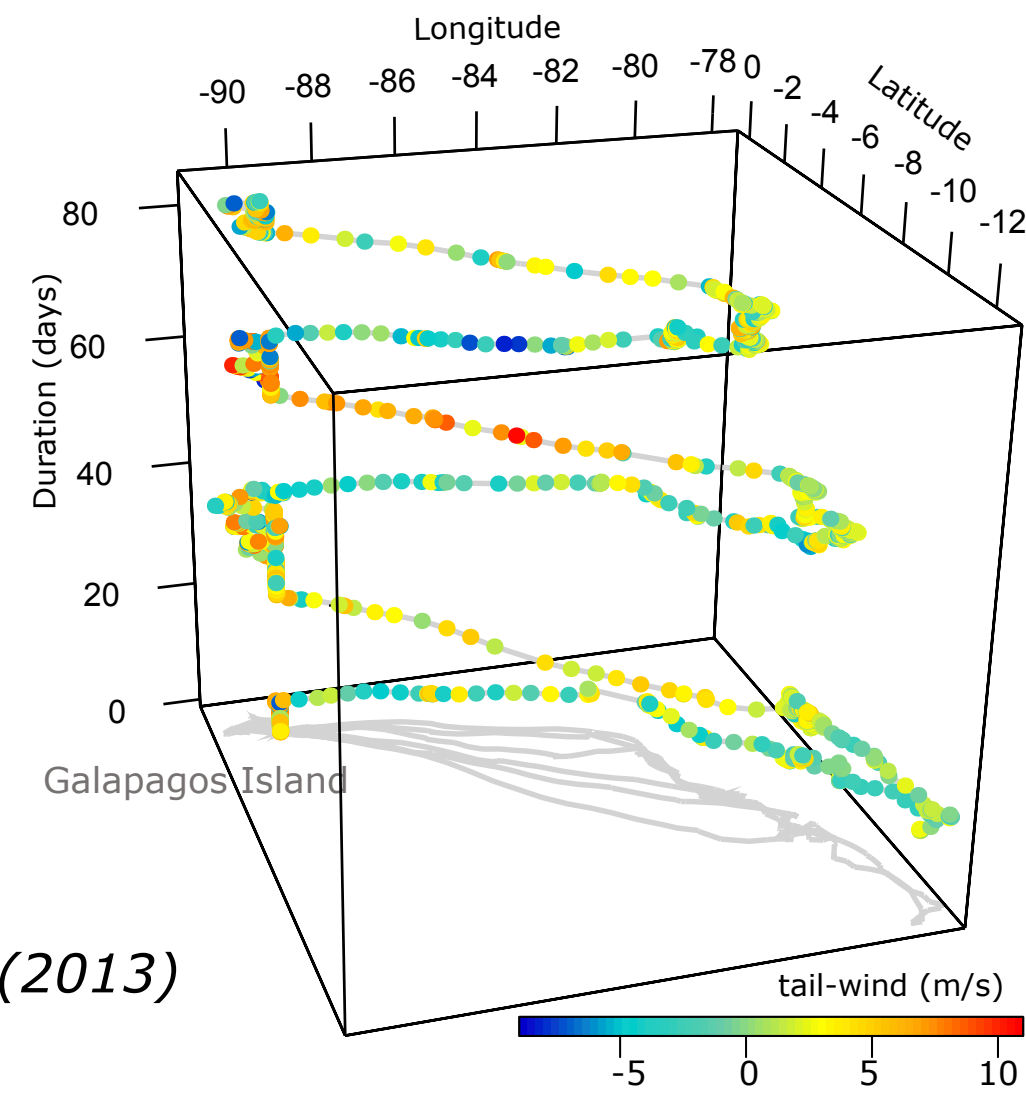
US Migration: “Smoothed net migration flows for age 25-29, with population threshold = 1,000,000. The background map shows the net migration rate for age group 25-29.” Guo, 2014

D. Guo (2014)

# Mapping Movement – Location

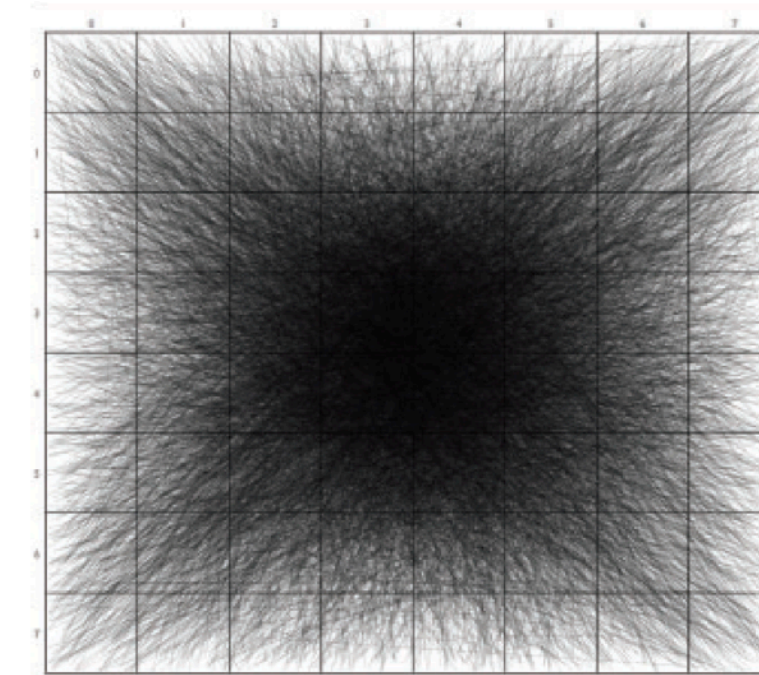


*Dodge et al (2013)*

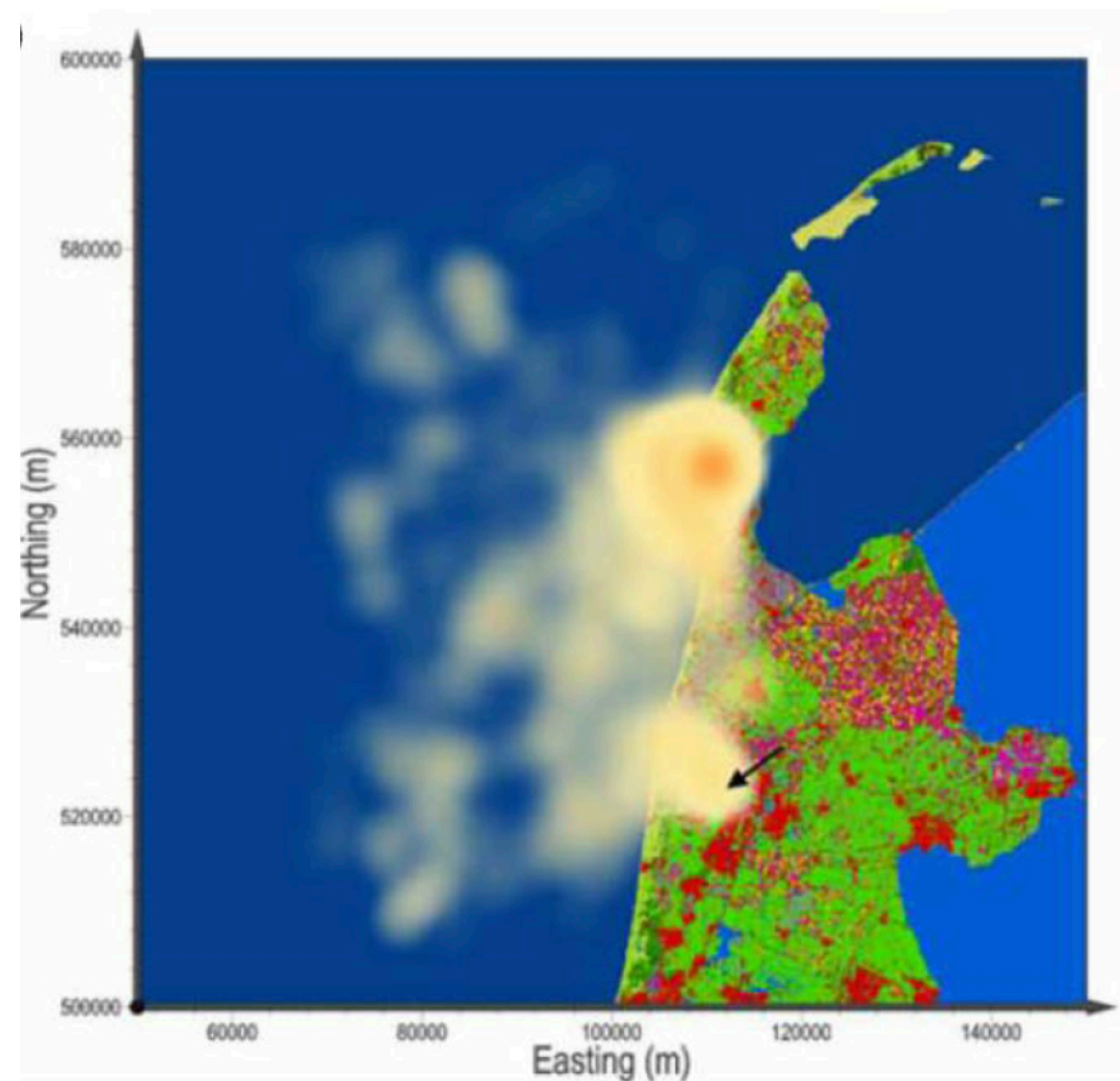


## Vector representation:

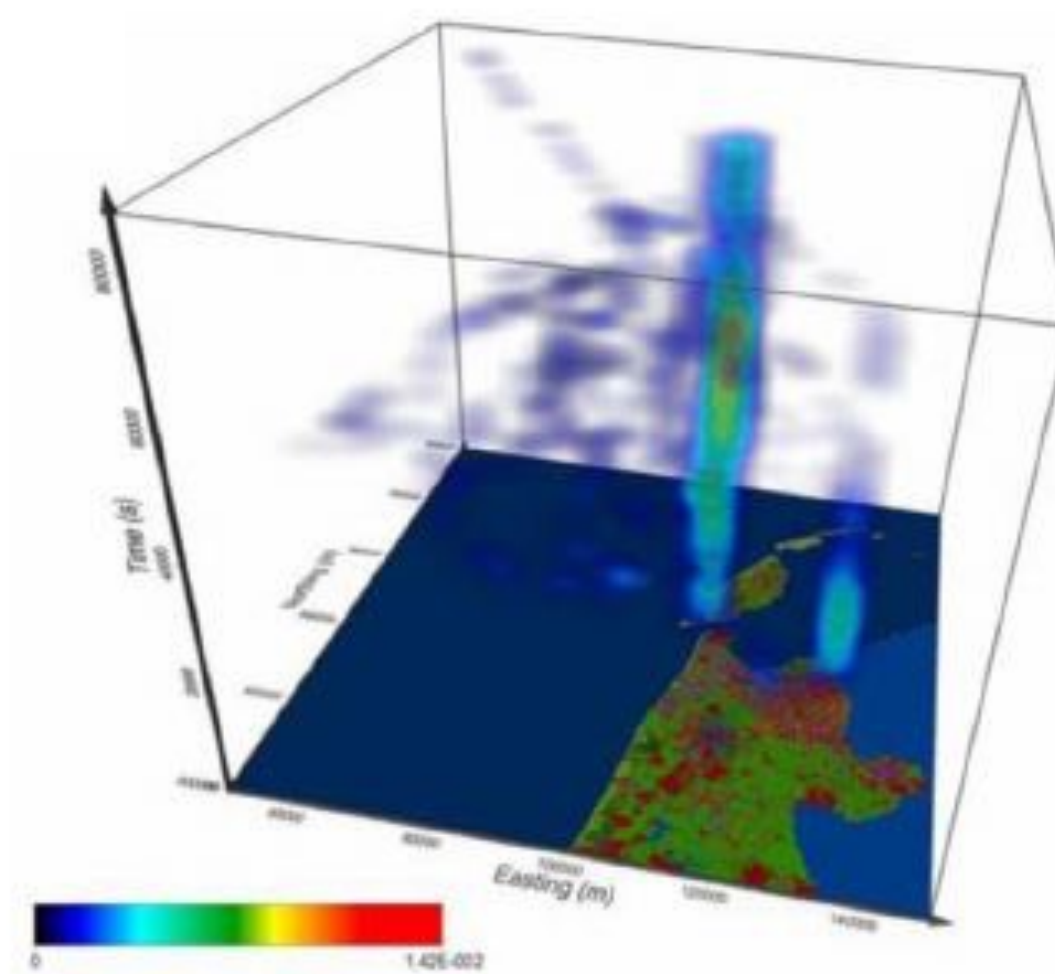
Often for discrete movement and flow lines



*Wood et al (2010)*

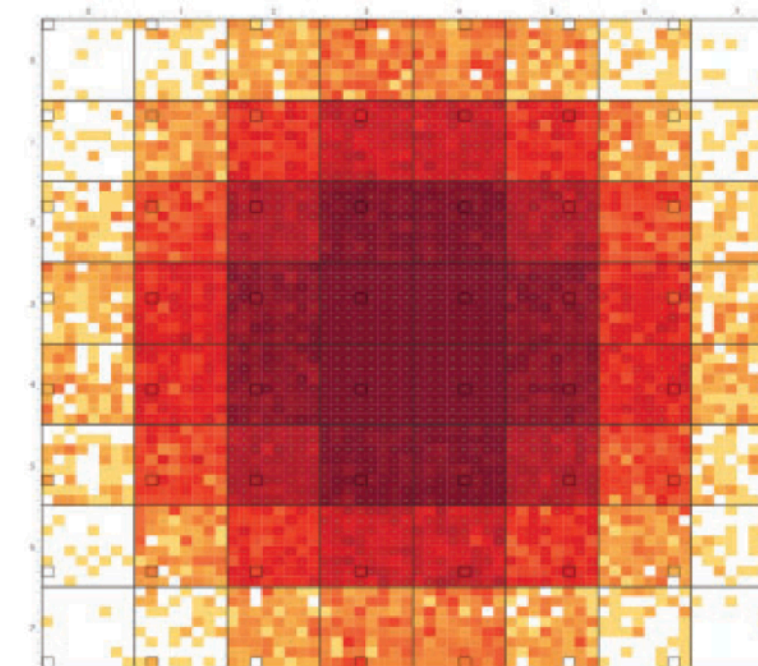


*Demsar et al (2014)*



## Raster representation:

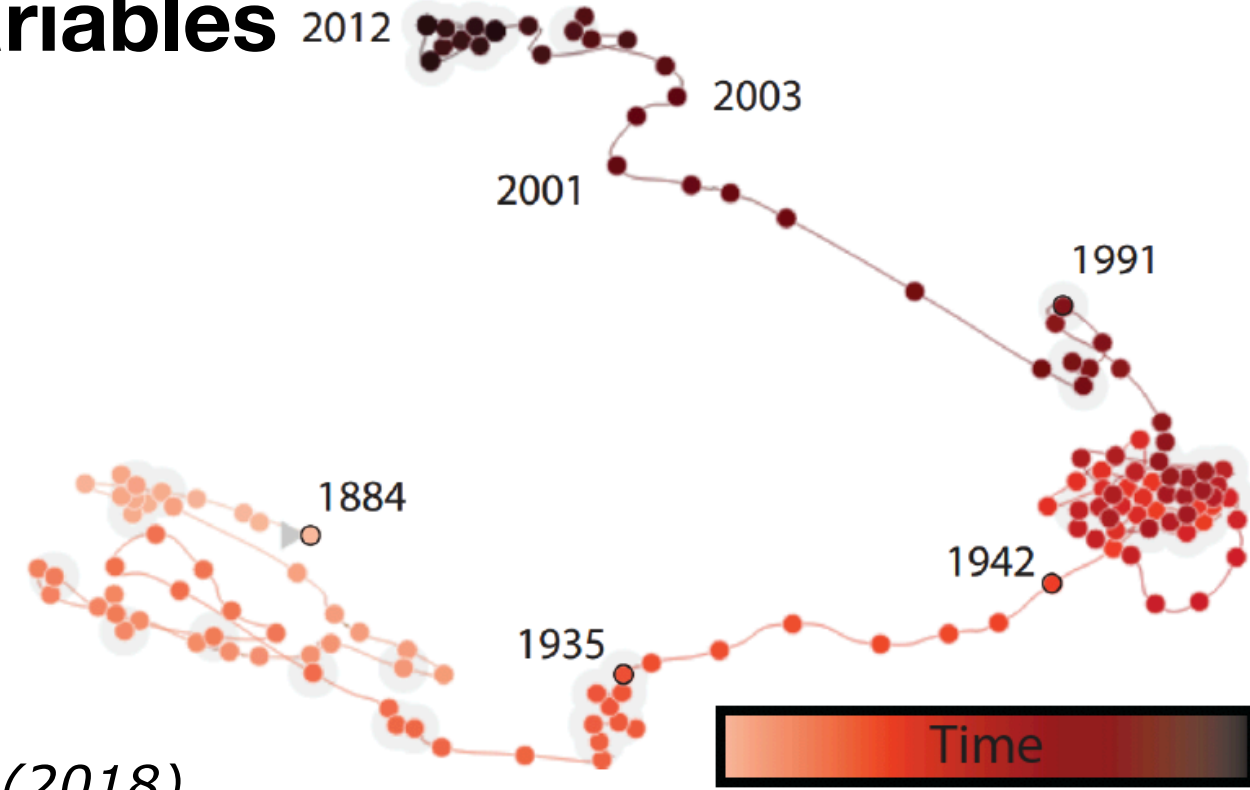
Commonly for aggregate movement and flow density



*Wood et al (2010)*

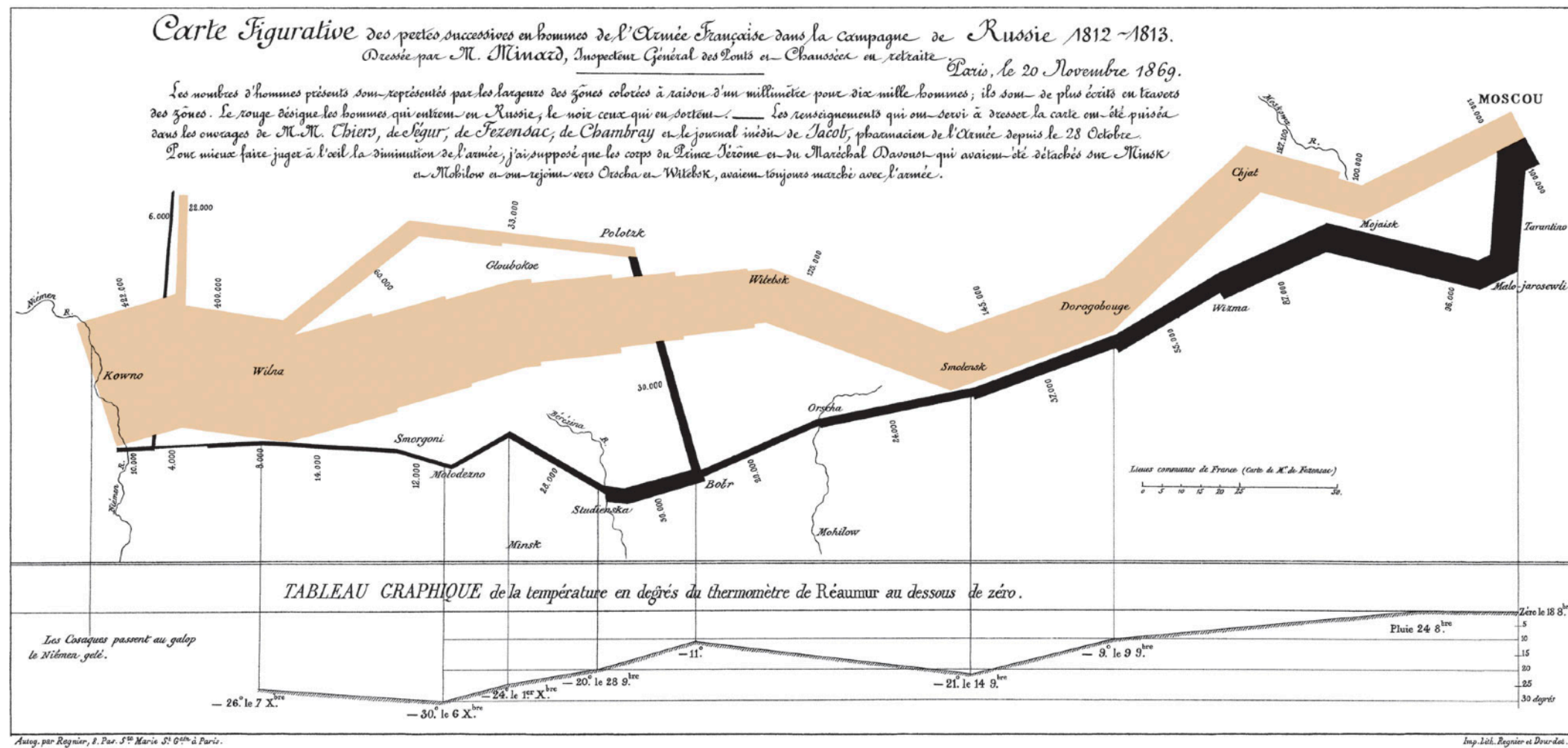
# Mapping Movement – Time

Attribute presentation using visual variables



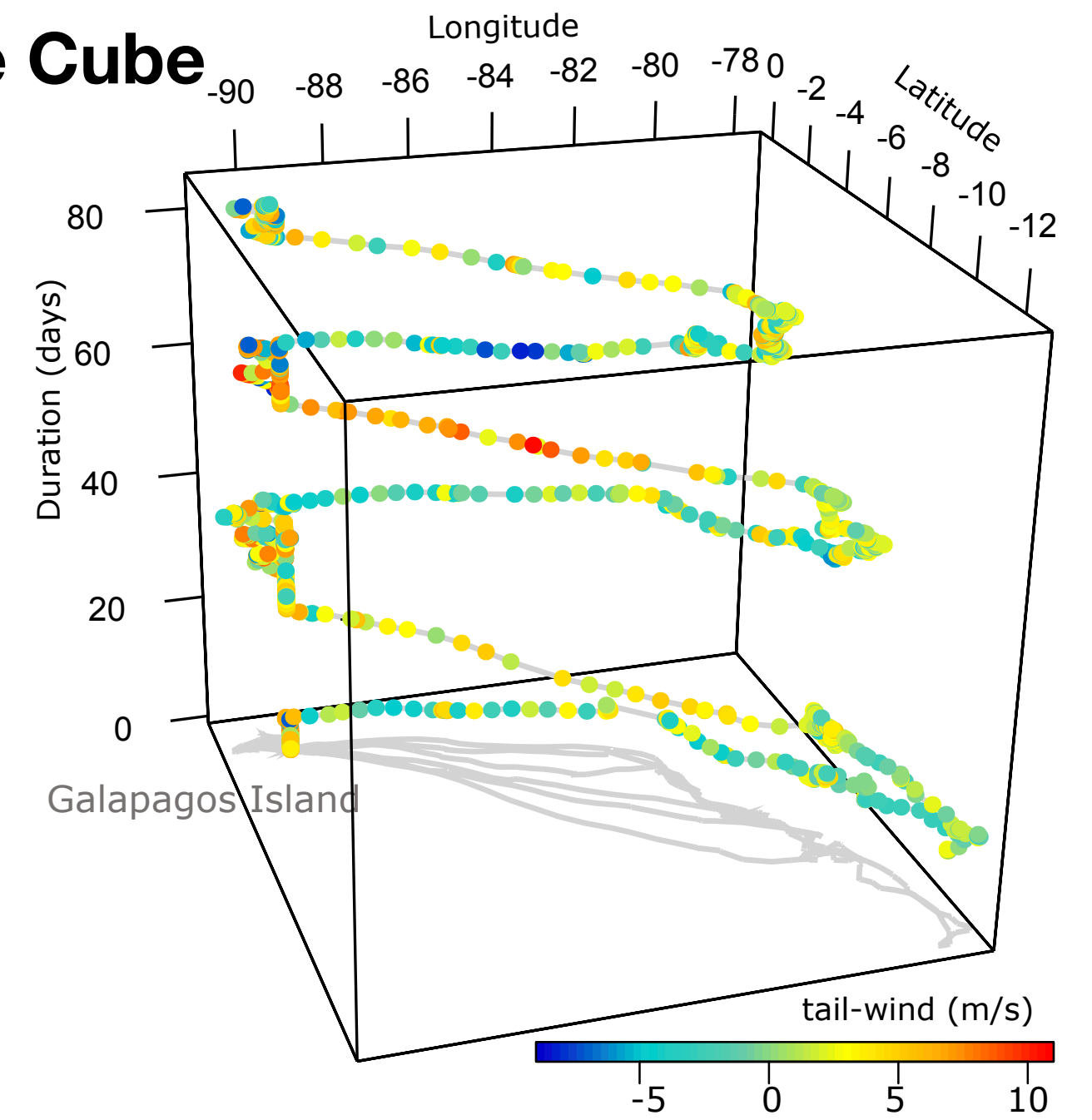
Perin et al. (2018)

Time line Kraak (2014)

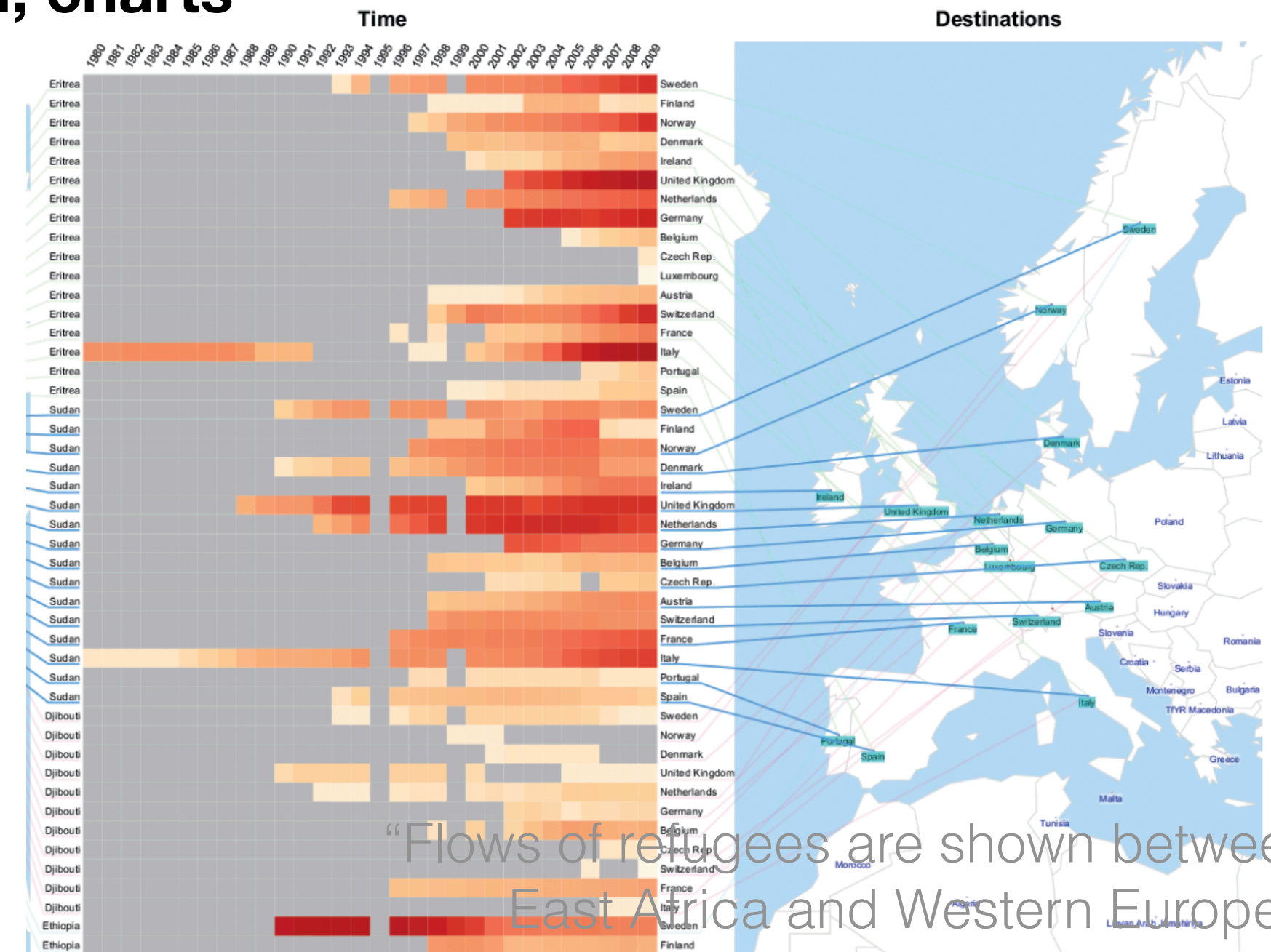


## Space-Time Cube

Animation



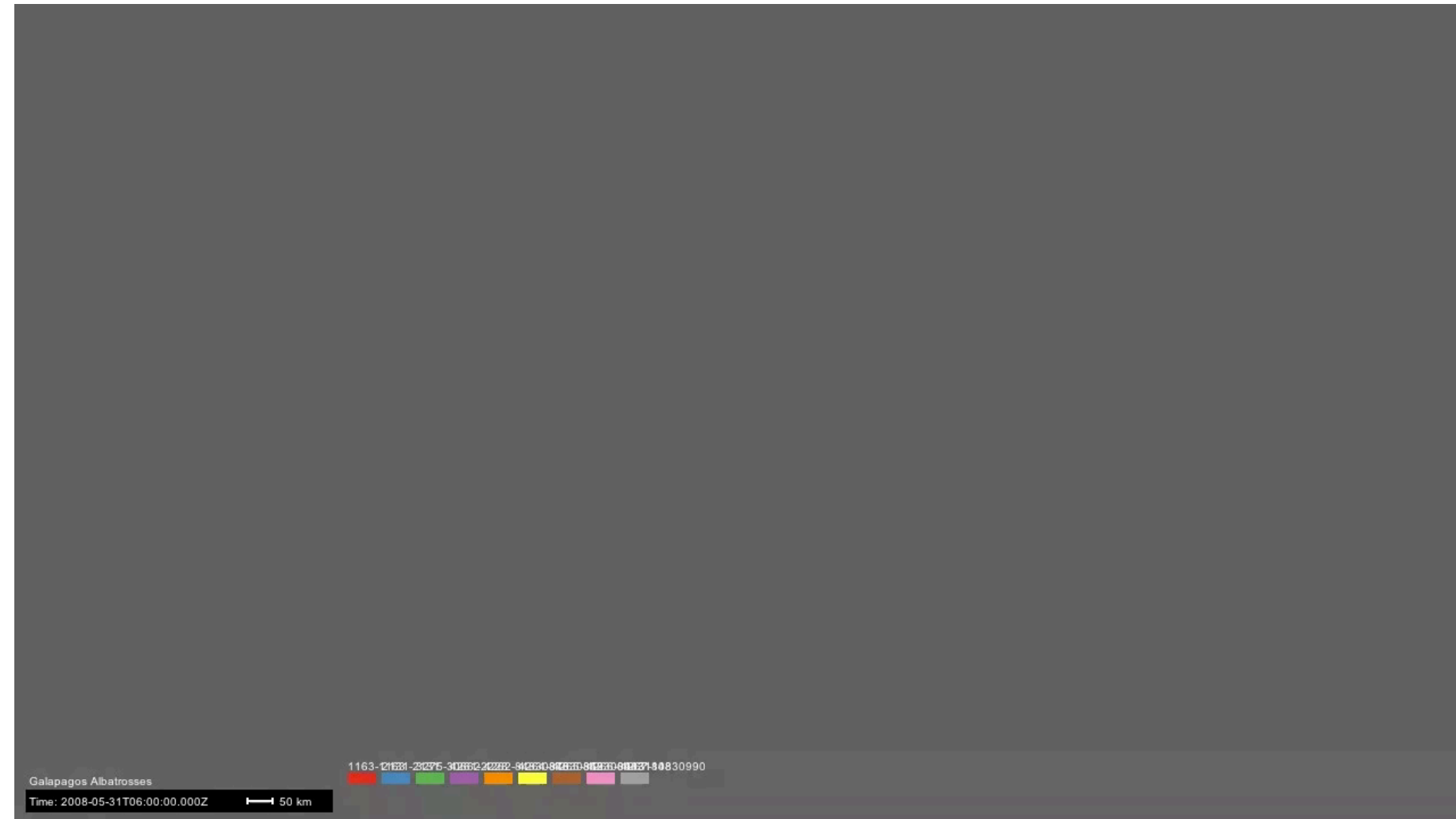
Time profile, diagram, charts



Boyandin et al. (2011)

“Flows of refugees are shown between East Africa and Western Europe.”

# Mapping Movement – Location, Time, Attributes



**Location and time**

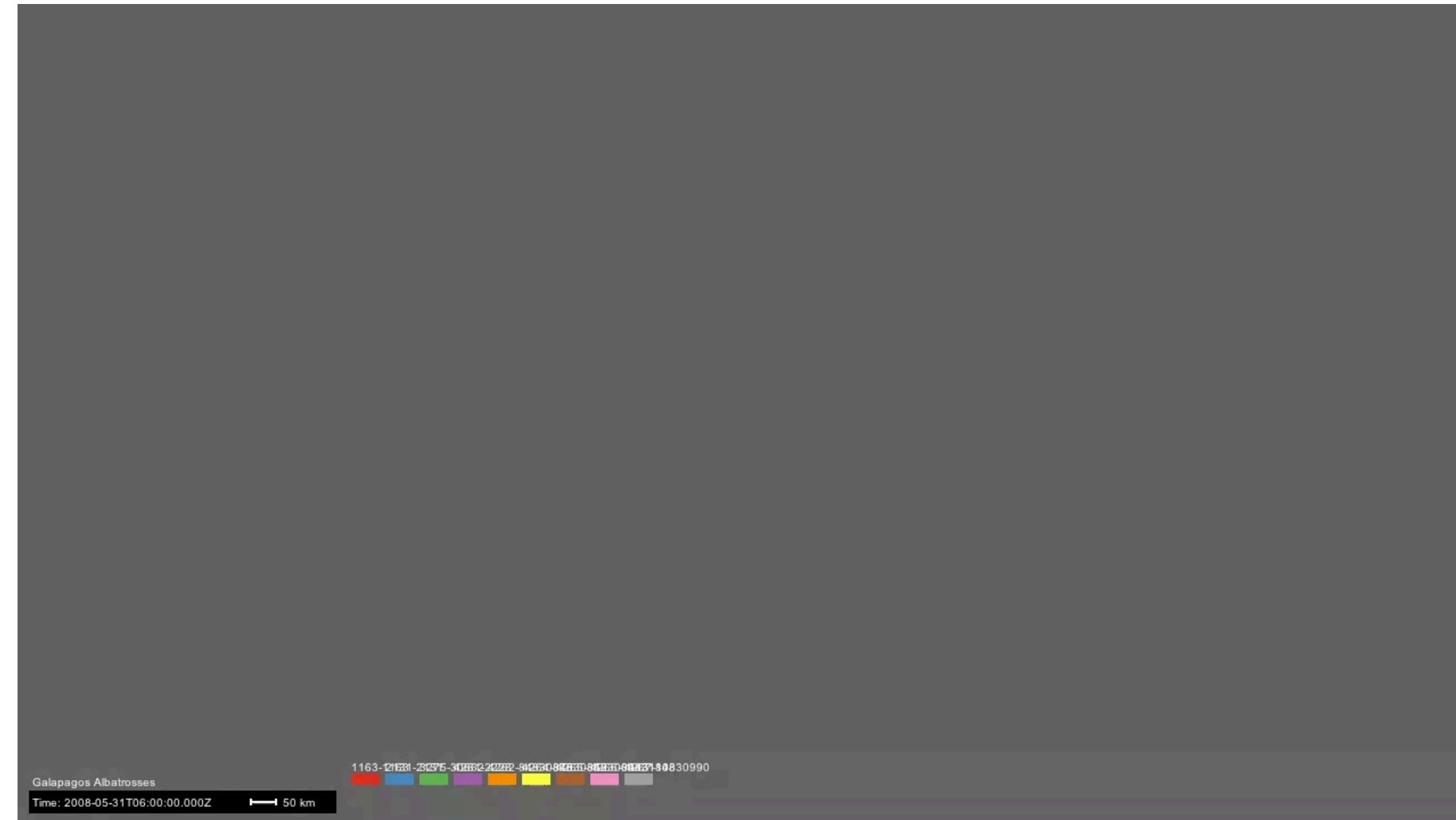
**Movement parameters:**

speed, acceleration, turn angle, etc.

**Context parameters:**

The condition and circumstances of movement, environment, geography, behavior, mode, interactions, etc.

# Location, Time, Attributes



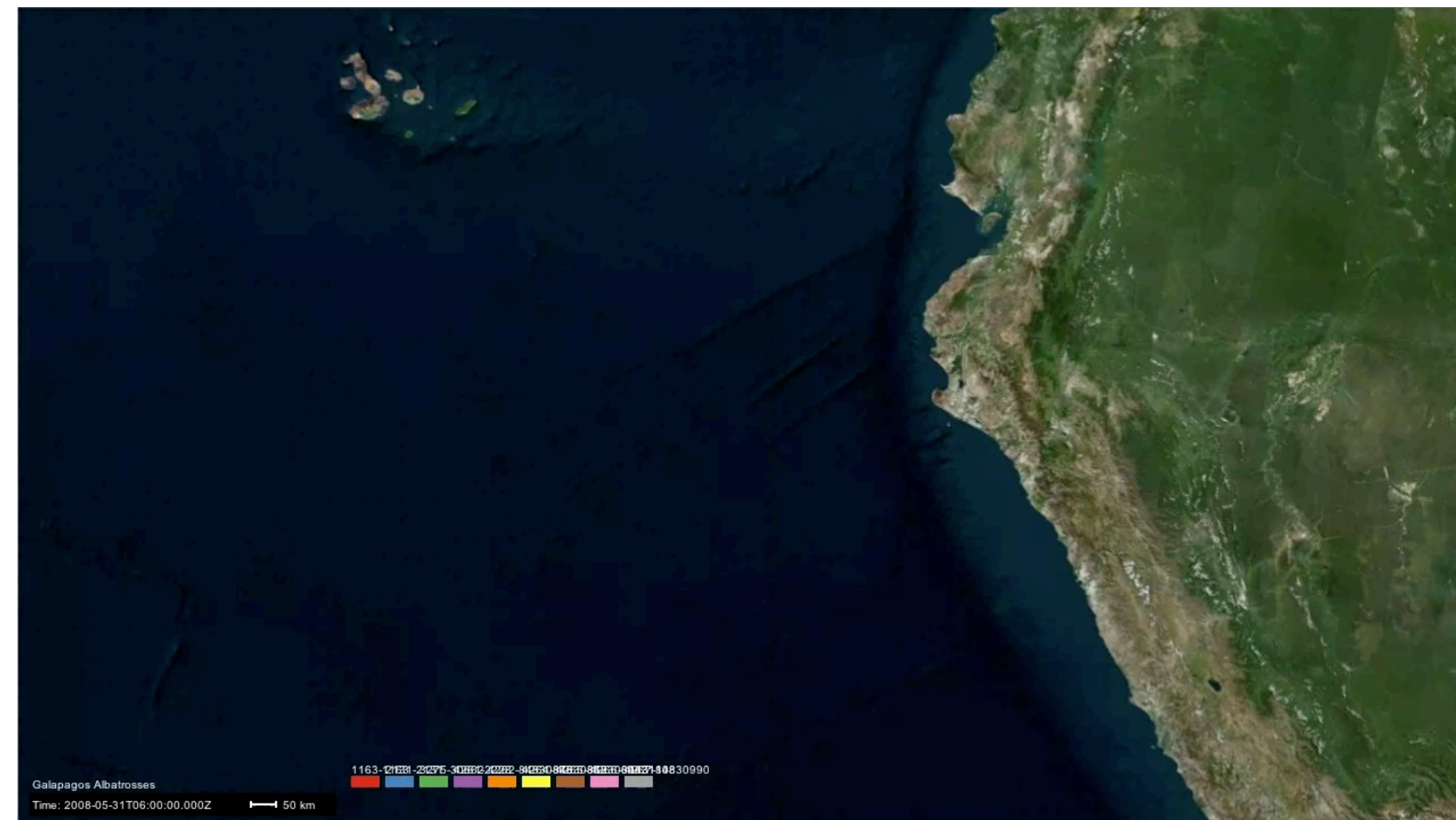
## Location and time

### Movement parameters:

speed, acceleration, turn angle, etc.

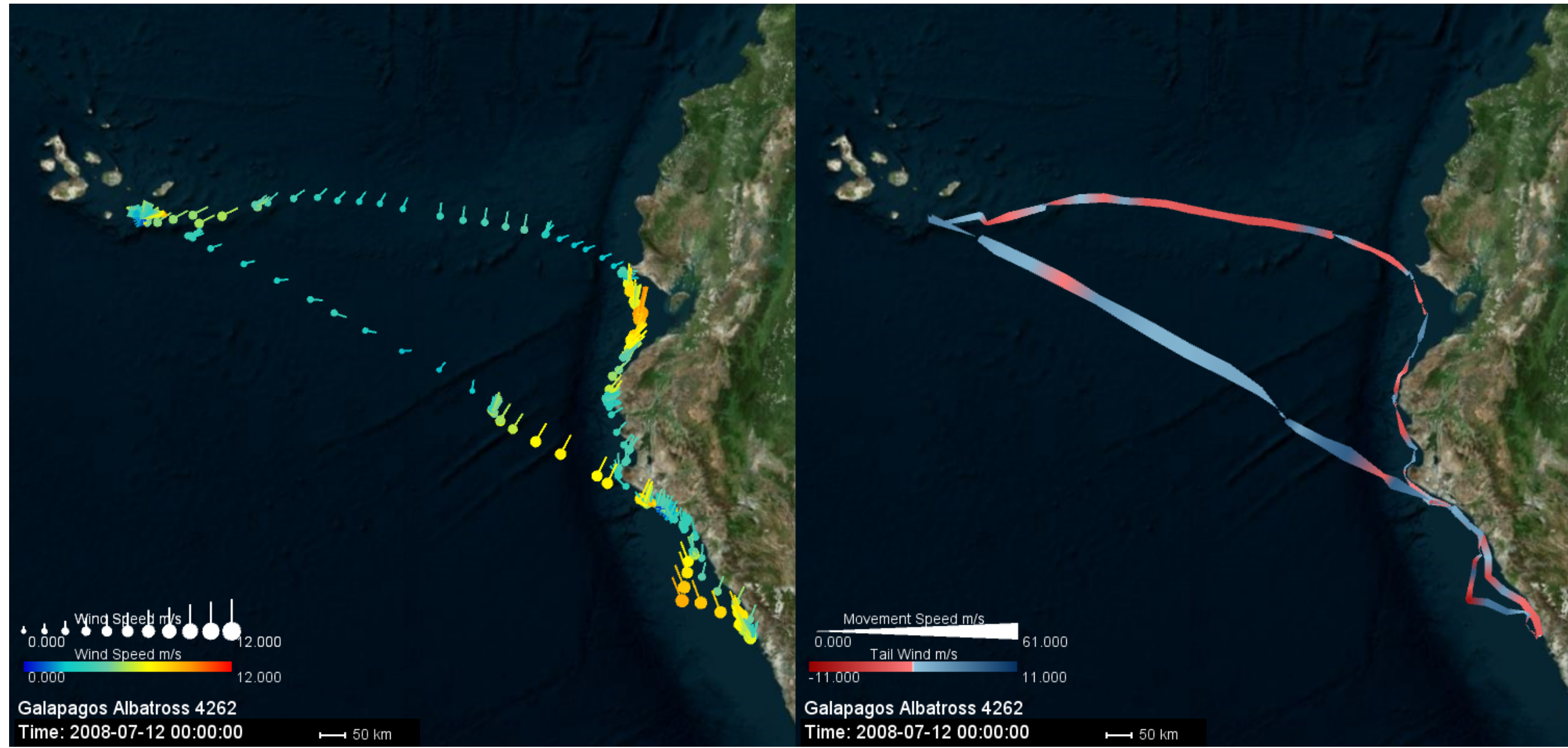
### Context parameters:

The condition and circumstances of movement, environment, geography, behavior, mode, interactions, etc.



# Location, Time, Attributes

## Bertin's Visual Variables

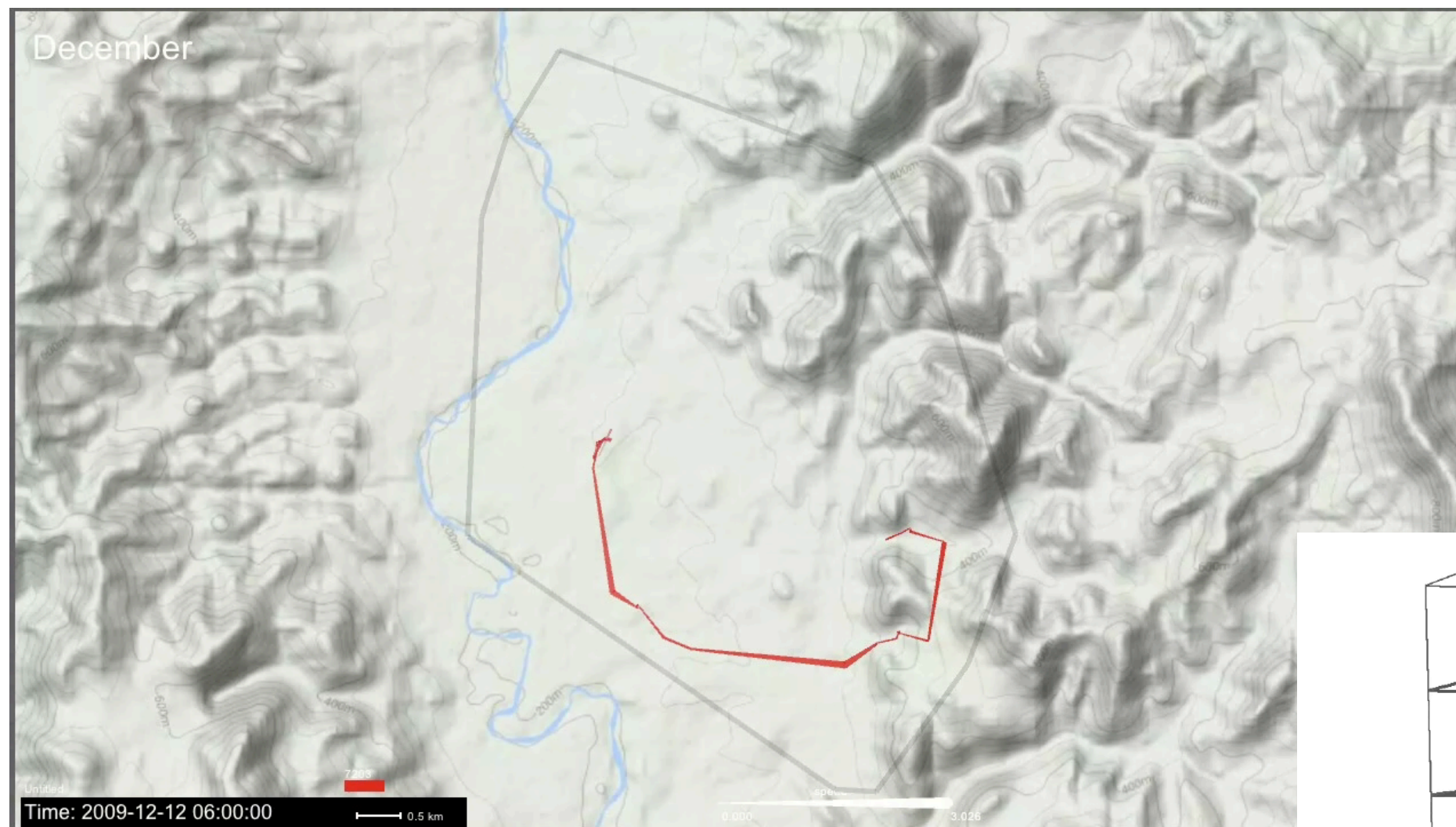


Visual variables	Moving points		Trajectory	
	2D space (x,y)   3D space-time (x,y,t)		2D space (x,y)   3D space-time (x,y,t)	
position				
size				
orientation				
shape				
color hue				
color value				
texture	does not apply			
color saturation				
crispness				
transparency				

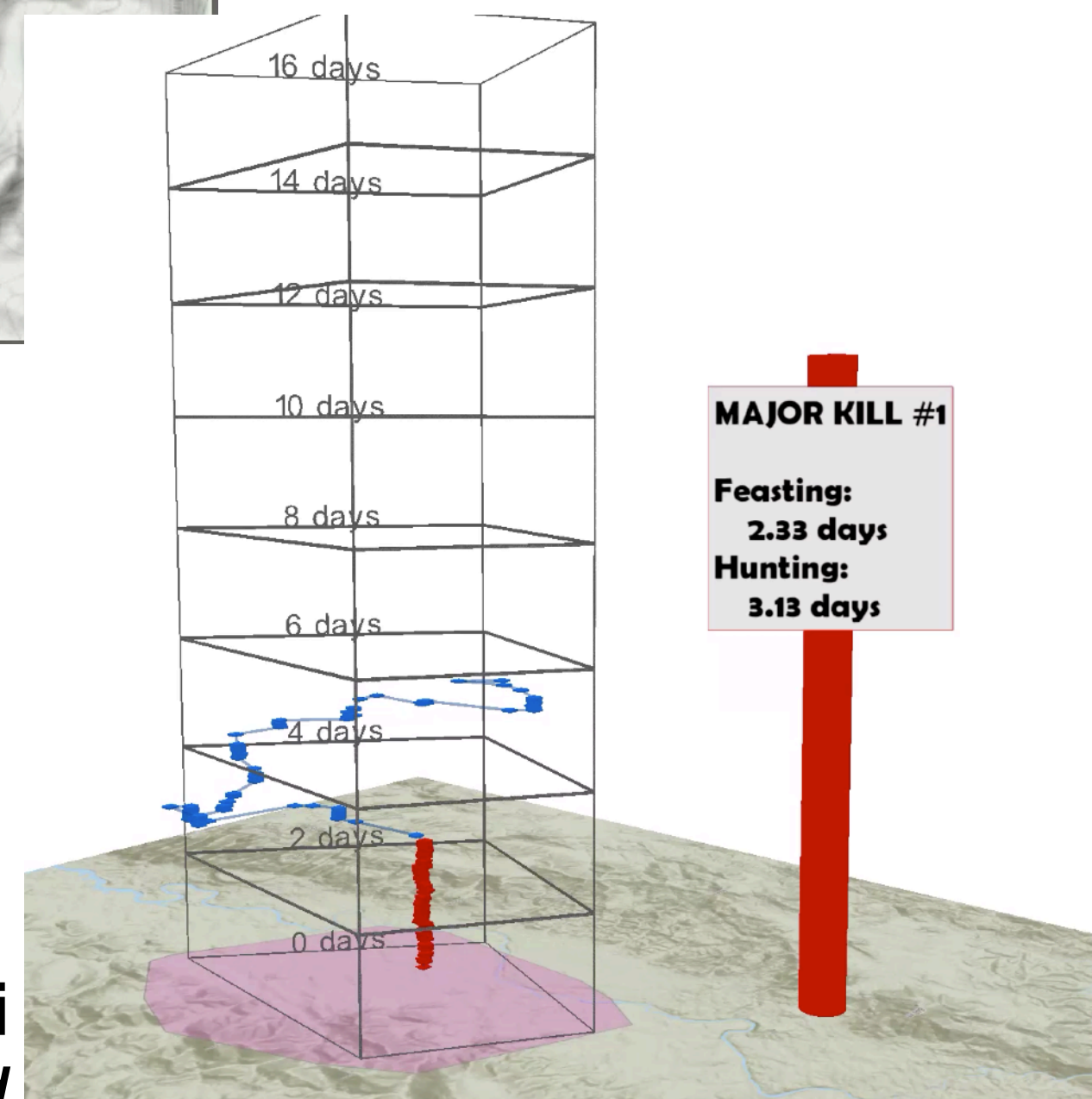


# Other Cartographic Elements: Visual Variables, highlighting, dynamic displays, 2D/3D environments

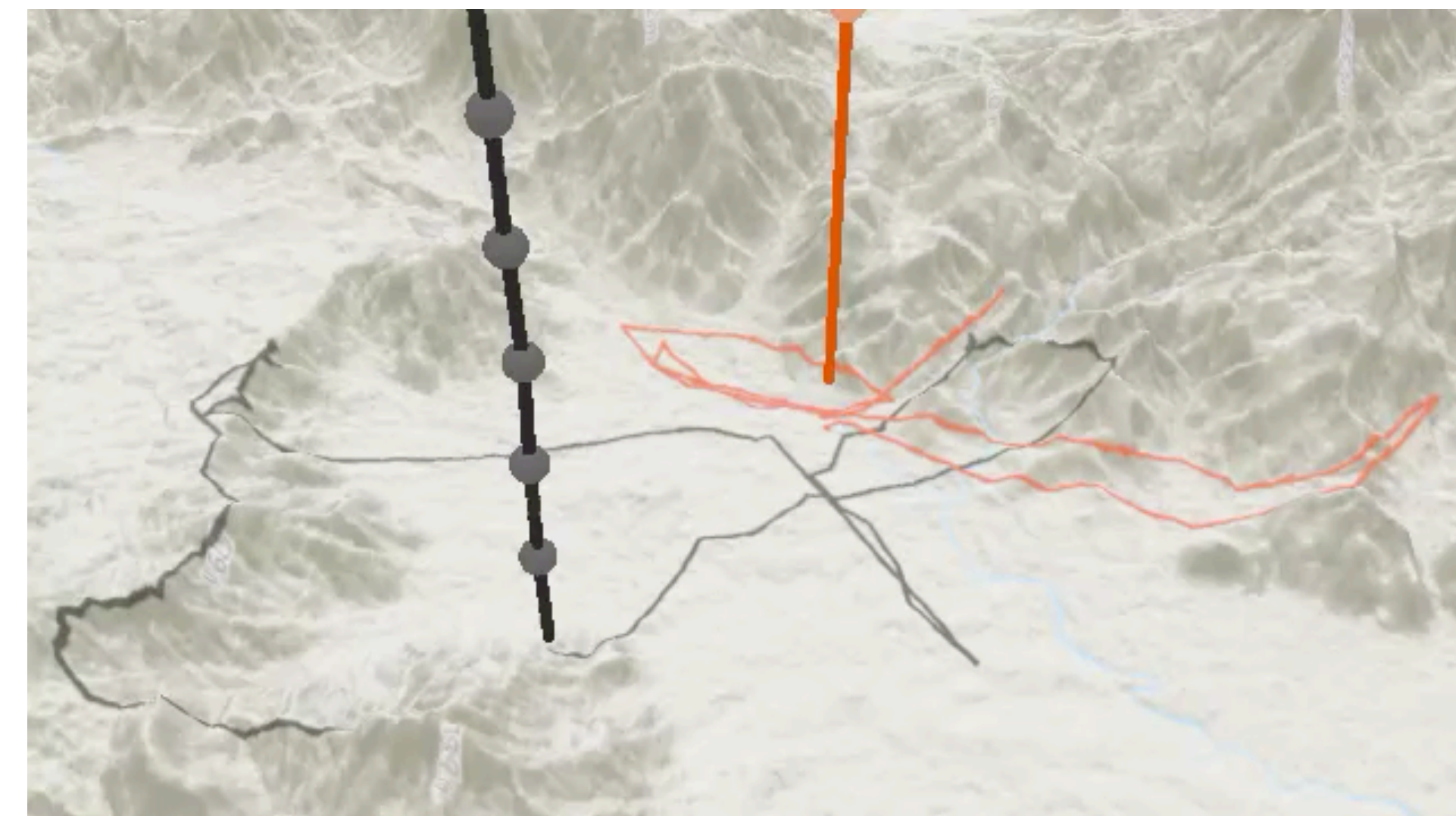
Tiger patrolling pattern



Tiger hunting frequency



Tiger-tiger interaction

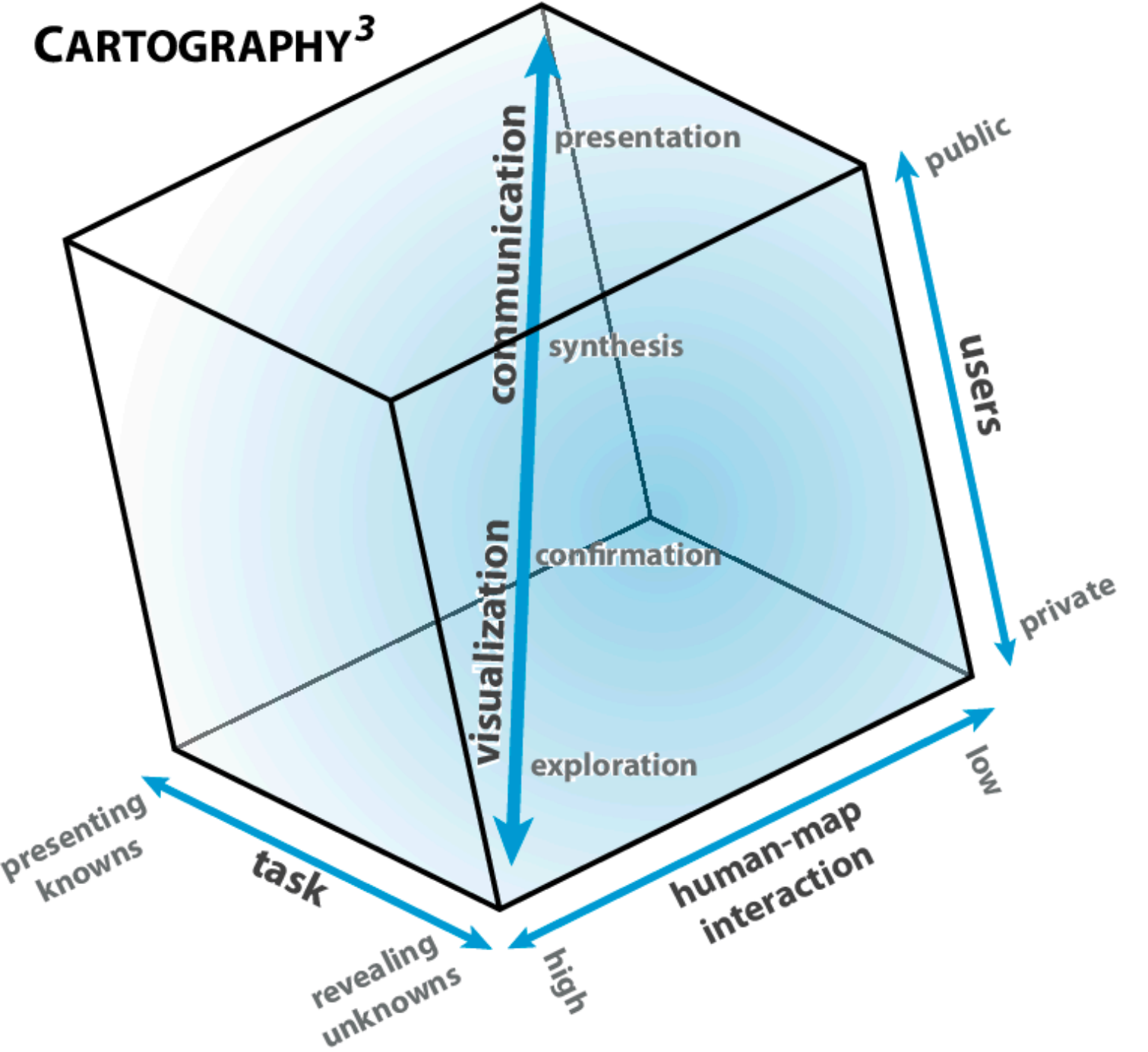
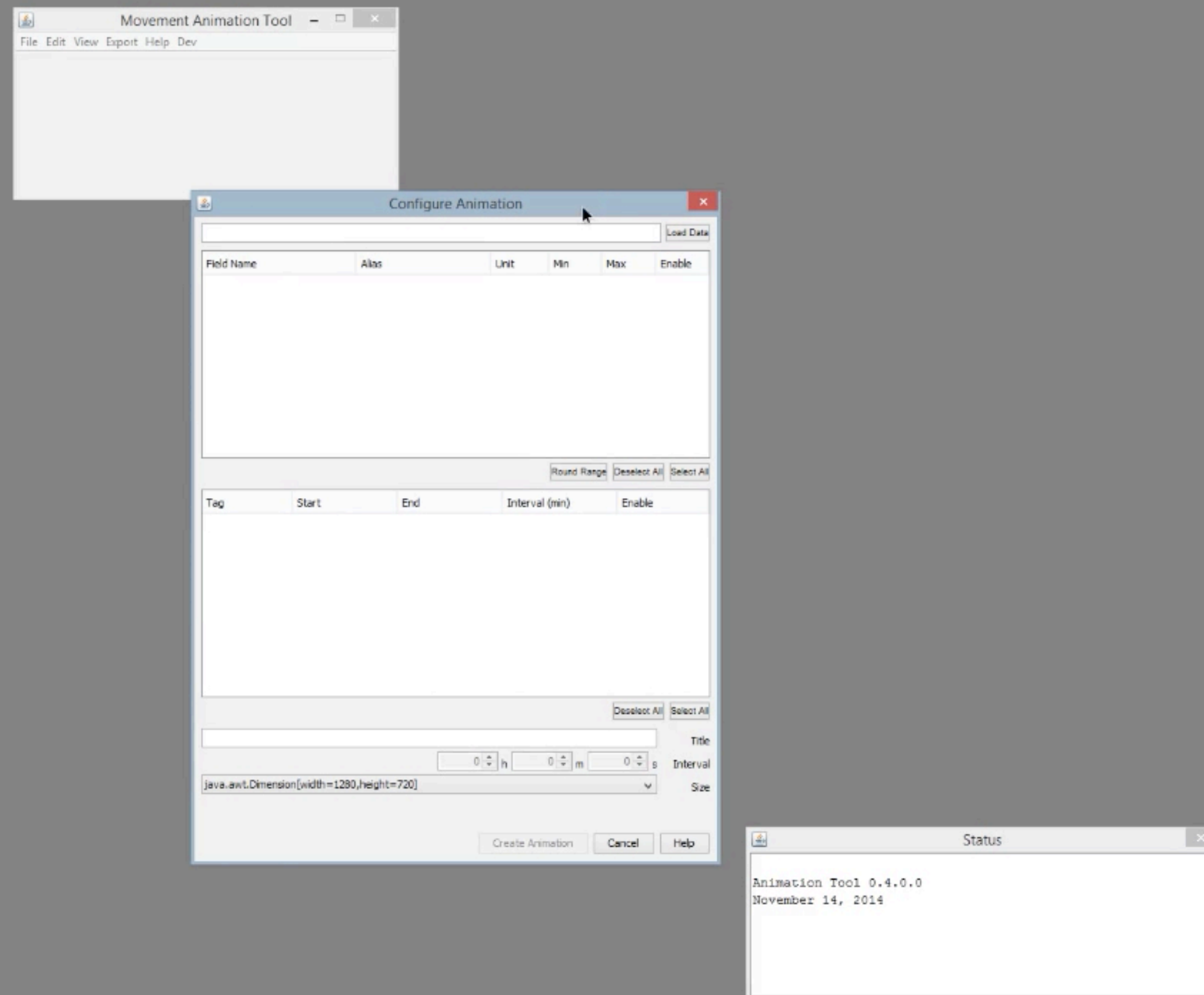


**Collaboration with Esri**  
*N. Shepard*

# Interaction Elements, Exploratory Tools, Flexibility

DYNAMOVIS

<http://geog.ucsb.edu/~dodge/dynamovis>



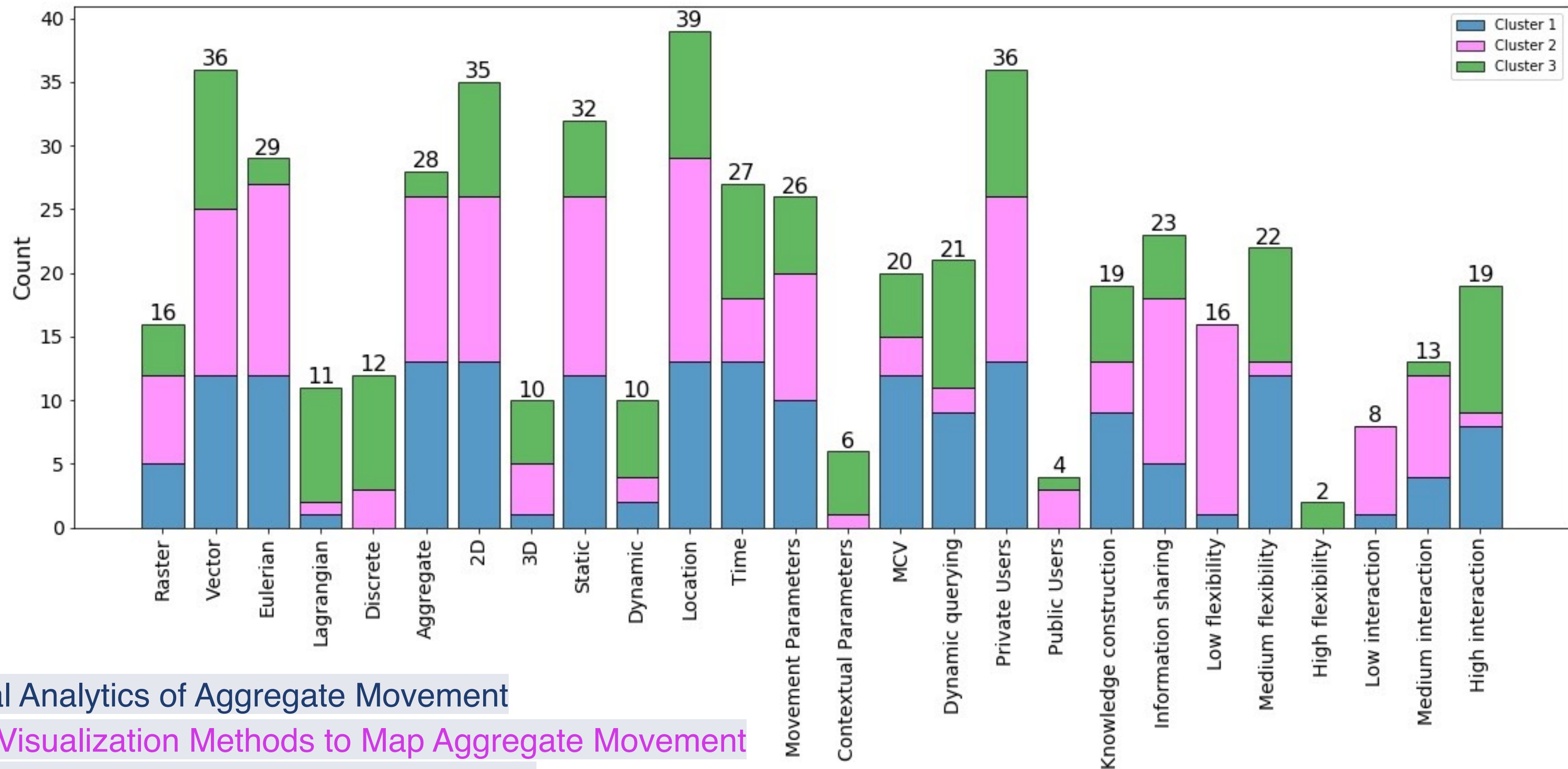
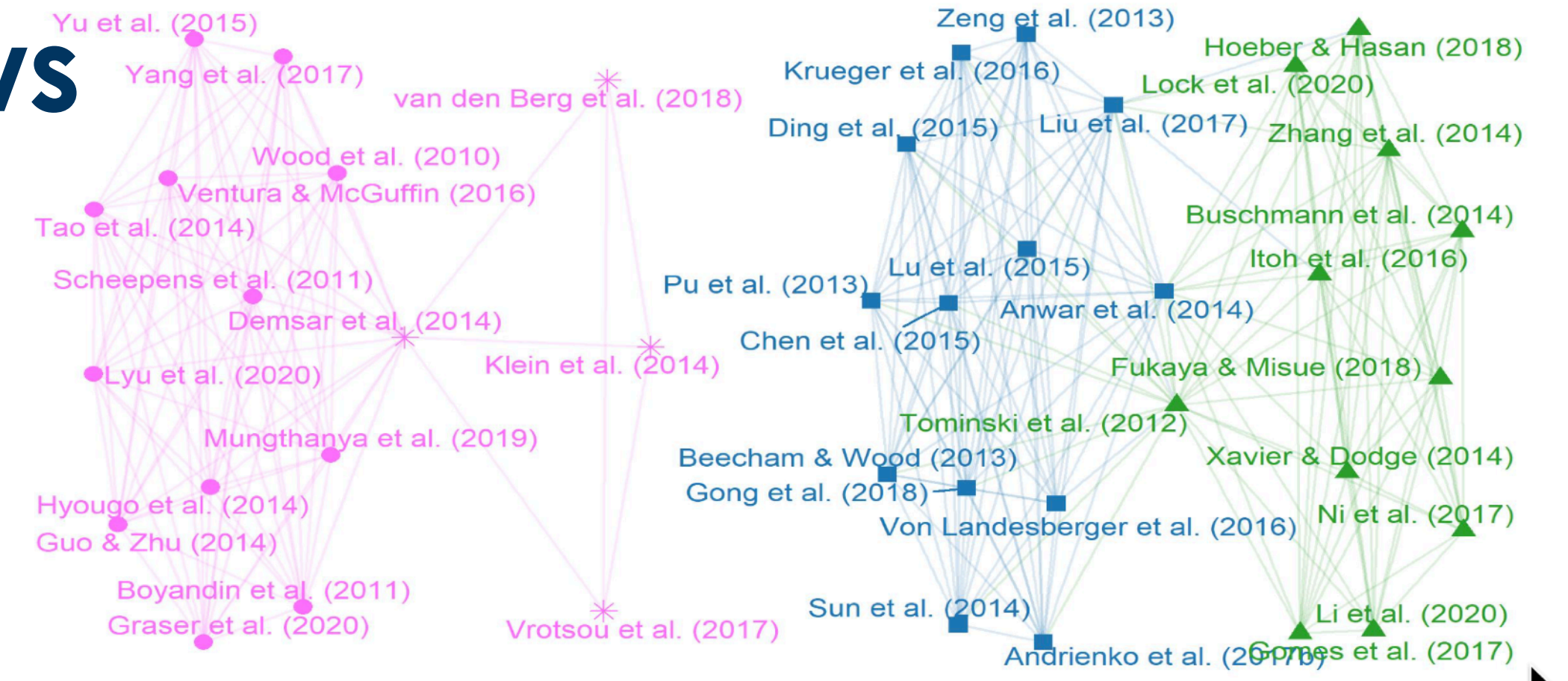
MacEachren et al., (2004), Roth (2013)

Developers (undergraduate students): Glen Xavier, Pinki Wong, Kate Carlson

# Visualization of Movement and Flows

## A decade in review (2010-2020)

Source: Dodge and Noi (in review) CaGIS



Cluster 1: Interactive Visual Analytics of Aggregate Movement

Cluster 2: Communicative Visualization Methods to Map Aggregate Movement

Cluster 3: Exploratory and Dynamic Visualization of Trajectories

# Summary and Future work

- Many interesting work on visualization of movement and flows
- Integration of movement and context parameters
- Interactive and flexible Visualizations for movement (discrete and aggregate forms)
- Usability studies and evaluation
- WhereNext? Evaluate the elements of the framework

THANK YOU!



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Many thanks to all collaborators and students who made this research possible, including Evgeny Noi (UCSB), UMN undergrads (Pinki Wong, Kate Carlson); Glenn Xavier (UCCS), Esri team: Nathan Shephard, John Grayson.

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