This project has received funding from the COSME programme
of the European Union under grant agreement No
EASME/EMFF/2016/1.2.1.9/03/SI2.763845 - CISE DMS

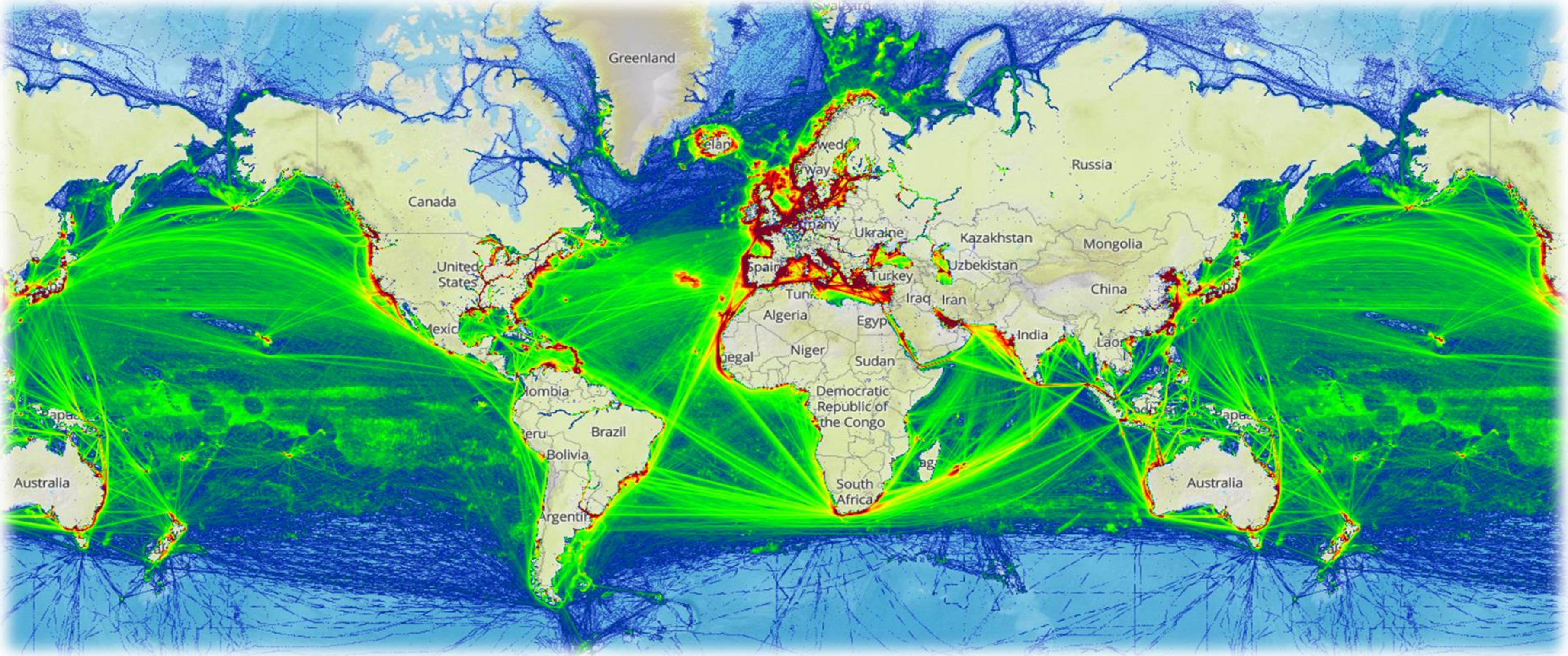
GRAPH-BASED ANALYSIS OF MARITIME PATTERNS OF LIFE

WISSAME LADDADA
CYRIL RAY

Arts et Metiers Institute of Technology
Ecole Navale
Naval Academy Research Institute (IRENav)

A WORLDWIDE COVERAGE OF NAVIGATION DATA…

… but partial (local) views depending on needs, access right, …



Maritime traffic (marinetraffic.com)

And a lot of research focusing on algorithms exploring positioning data (i.e. GPS positions of ships)

This project has received funding from the COSME programme
of the European Union under grant agreement No
EASME/EMFF/2016/1.2.1.9/03/SI2.763845 - CISE DMS

GRAPH-BASED ANALYSIS OF MARITIME PATTERNS OF LIFE

From Moving Objects to Pattern of Life

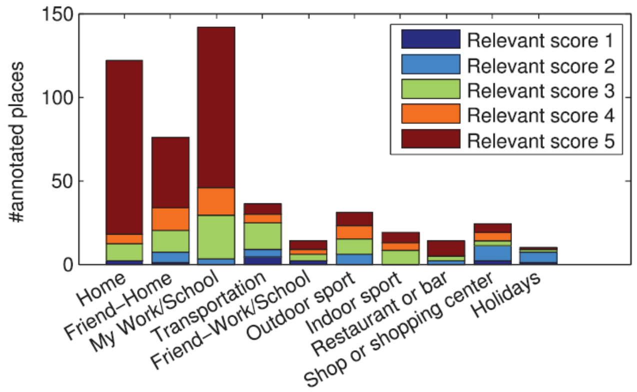
PATTERN OF LIFE

Pattern of life in urban domain

- “Instead of studying raw geographic coordinates, we are interested in understanding human mobility patterns based on sequences of place visits which encode, at a coarse resolution, most daily activities.”
- Also address the problem of automatic place labeling from mobility data

Do, Trinh Minh Tri, and Daniel Gatica-Perez. “The places of our lives: Visiting patterns and automatic labeling from longitudinal smartphone data.” IEEE Transactions on Mobile Computing 13.3 (2014): 638-648

Focused on annotated/semantic places, but also link, with a broader view to semantic trajectories



Pattern-of-life analysis

- “Is a method of surveillance specifically used for documenting or understanding a subject's (or many subjects') habits”
- “This information can then potentially be used to predict future actions by the subject(s) being observed”

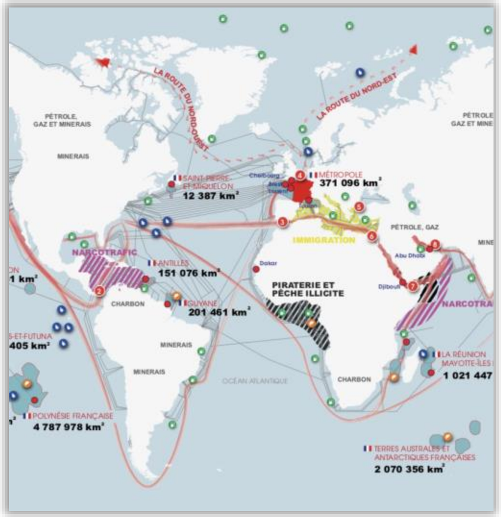
Wikipedia contributors. "Pattern-of-life analysis." Wikipedia, Feb. 2019, Accessed, June 2019.

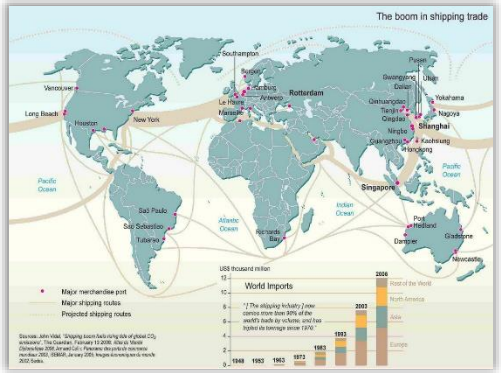
MARITIME PATTERN OF LIFE

Maritime Pattern of Life (PoL) aims at understanding and monitoring the behavioral patterns of a certain vessel to analyze and use for potentially predicting its future actions

In the maritime domain, PoL addresses the understanding of navigation data at an aggregated level (meso, macro)

- Represent the different ship life cycles and activity patterns with a certain level of abstraction
- Represents vessels' PoLs as node graphs instead of time series aligned with minutely geographic position coordinates
- Based on annotated places describing stationary areas, key points in maritime routes, areas of activity





FROM MOVING OBJECTS TO SEMANTICALLY ENRICHED SIMPLIFIED TRAJECTORIES USING GRAPH DATABASES

Can easily describe the semantics and properties of trajectories formed by connecting series of raw mobility data points

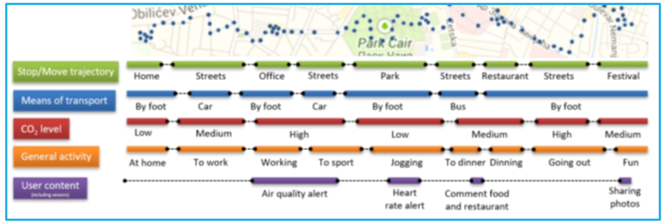
- Represent the temporal aspects
- Represent the spatial semantics of moving objects and associated spaces of mobility
- Represent the thematic semantics, that can belong to any theme depending on the application context

Can materialize complex relationships

- Represent temporal and topological spatial relations
- Link time, space, events, patterns and thematic information

Good level of flexibility and agility

- Integrate easily other themes (e.g. additional contextual information)
- Quite easy to design and maintain



S. Ilarri, D. Stojanovic and C. Ray, (2015). Semantic management of moving objects: A vision towards smart mobility. Expert Syst. Appl., 42 , 1418 – 1435.

FOUR MAIN STEPS

« offline »

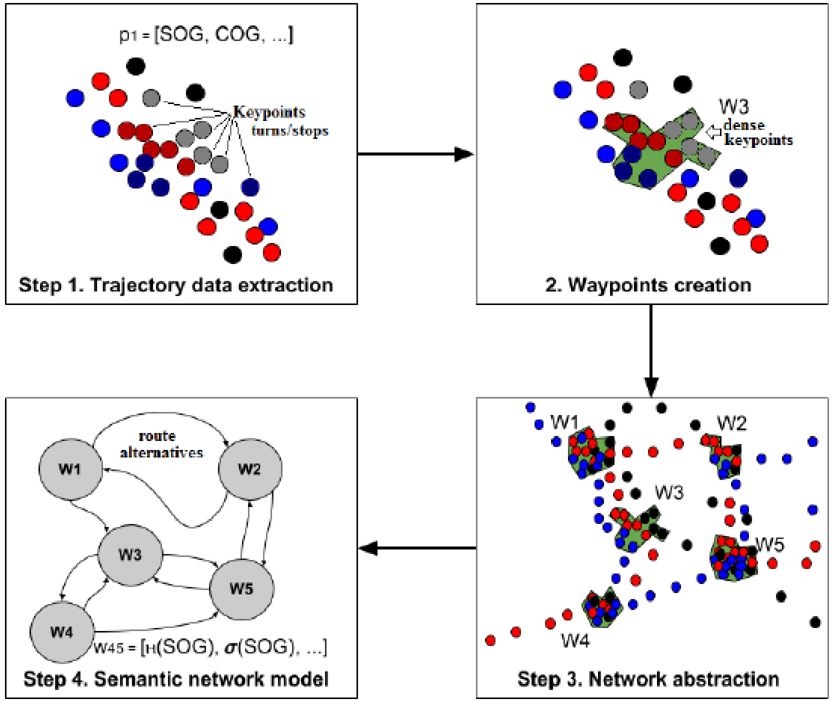
Automated nodes detection, graph construction based on historical data

Definition of node and edge types and semantics

Use graph analysis techniques to understand vessel behavior, detect anomalies (e.g. drug traffic behavior, etc.) through patterns

« online »

In real-time, based on an interactive application for visualizing the PoL of either all ships, or filtered ships by type, or by identifier, apply the needed analysis/prediction based on preferences



Iraklis Varlamis, Konstantinos Tserpes, Mohammad Etemad, Amilcar Soares Júnior and Stan Matwin. A network abstraction of multi-vessel trajectory data for detecting anomalies. BMDA 2019

This project has received funding from the COSME programme
of the European Union under grant agreement No
EASME/EMFF/2016/1.2.1.9/03/SI2.763845 - CISE DMS

GRAPH-BASED ANALYSIS OF MARITIME PATTERNS OF LIFE

Graph Modelling

ECOLE NAVALE

Arts Sciences et Technologies et Métiers

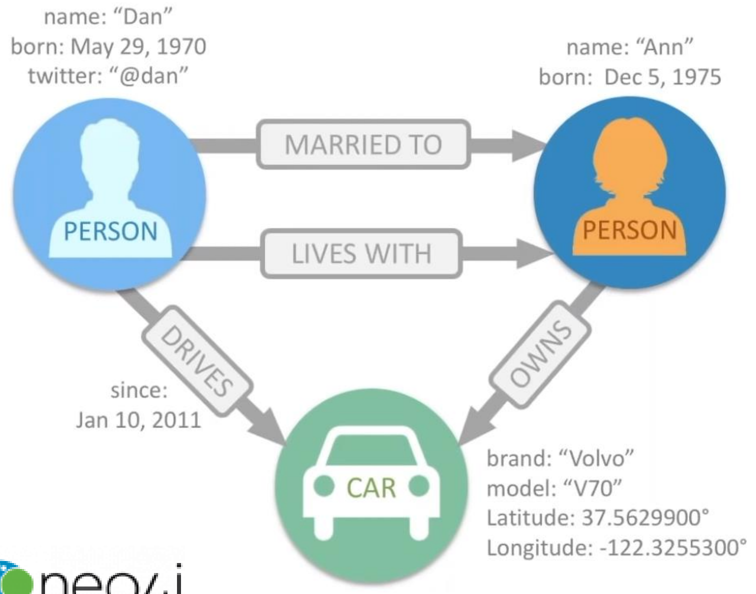
LABELLED PROPERTY GRAPH MODEL

There are three dominant graph data models: the property graph, Resource Description Framework (RDF) triples, and hypergraphs [Graph Databases, I. Robinson, J. Webber & E. Eifrem, O' Reilly, 2015]

Nodes:
- Can have labels to classify nodes
- Labels have native indexes

Relationships:
- Connect nodes by type and direction

Properties:
- Attributes of nodes and relationships
- Stored as Name/Value pairs
- Can have indexes and composite indexes
- Visibility security by user/role



neo4j

GRAPH MODELLING FOR MARITIME PoL

Each edge entity represents one segment

- A segment node is enriched by properties coming from attributes in the relational database
- Specifically, *id_segment*, *max_speed*, *min_speed* and *avg_speed*

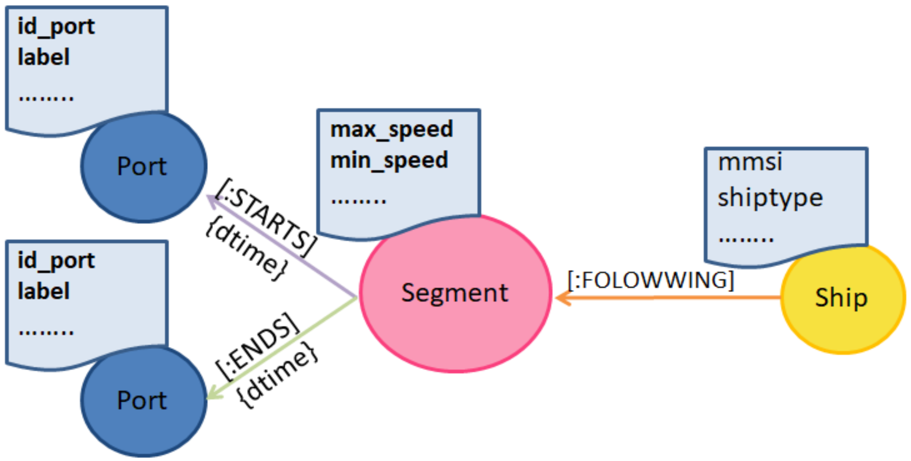
MMSI attribute remains as property for the Ship node

- Also including ship type
- And other "static" properties (name, draught…)

Port node represents known ports

- A port node is enriched by "static" properties coming from attributes in the relational database
- Attributes related to edges (*source_id* and *target_id*) are converted into STARTS and ENDS realtion with respectively the properties *source_time* and *target_time*

Relation between static_ships and edges_list table is expressed by the relation FOLLOWING between Ship and Segment nodes



The dataset produced 68,000 nodes and 90,000 relationships

This project has received funding from the COSME programme of the European Union under grant agreement No EASME/EMFF/2016/1.2.1.9/03/SI2.763845 - CISE DMS

GRAPH-BASED ANALYSIS OF MARITIME PATTERNS OF LIFE

Pattern of Life Analysis

ECOLE NAVALE

Arts et Métiers Sciences et Technologies

LIFE CYCLE ANALYSIS

- For a known ship
  - Extraction of historical life cycle
  - Identification of events (e.g. RDV) in life cycle
  - Detection of unusual life cycle
  - Prediction of the next segments and nodes
- For unknown ship, predict current life cycle (origin and destination) based on learnt patterns
- Detect user-demanded events or patterns (single and shared by multiple ships, passages trough wish nodes and links…)

Real-Time Analysis

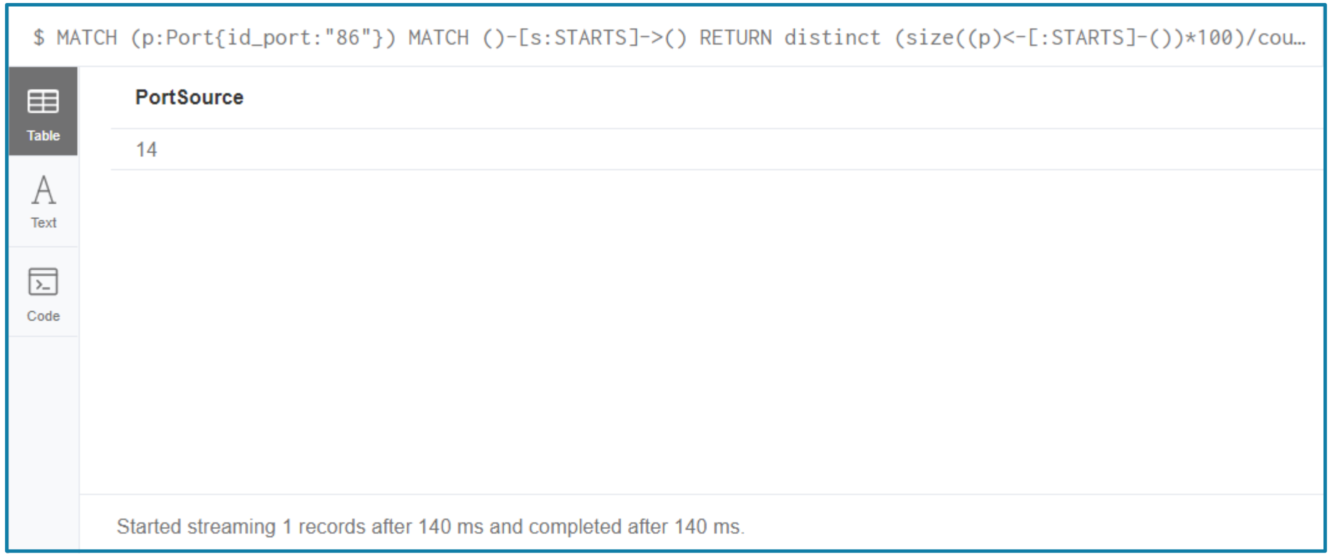
- Extract [learn] navigation patterns with respect to time, ship type, and activity type
- Use graph analysis with centrality measures and new operators to understand the network
- Spatial and spatio-temporal events and patterns in historical data

Offline Analysis

WISH NODES AND LINKS: OUTGOING AND INCOMING FLOW

Check the influence of ports in the network and their connectivity or adjacency

(examples of variation: per period of time, connectivity (i.e. number of destination from a node…)



Percentage of outgoings traffic flow from one specific port vs. overall outgoings flow

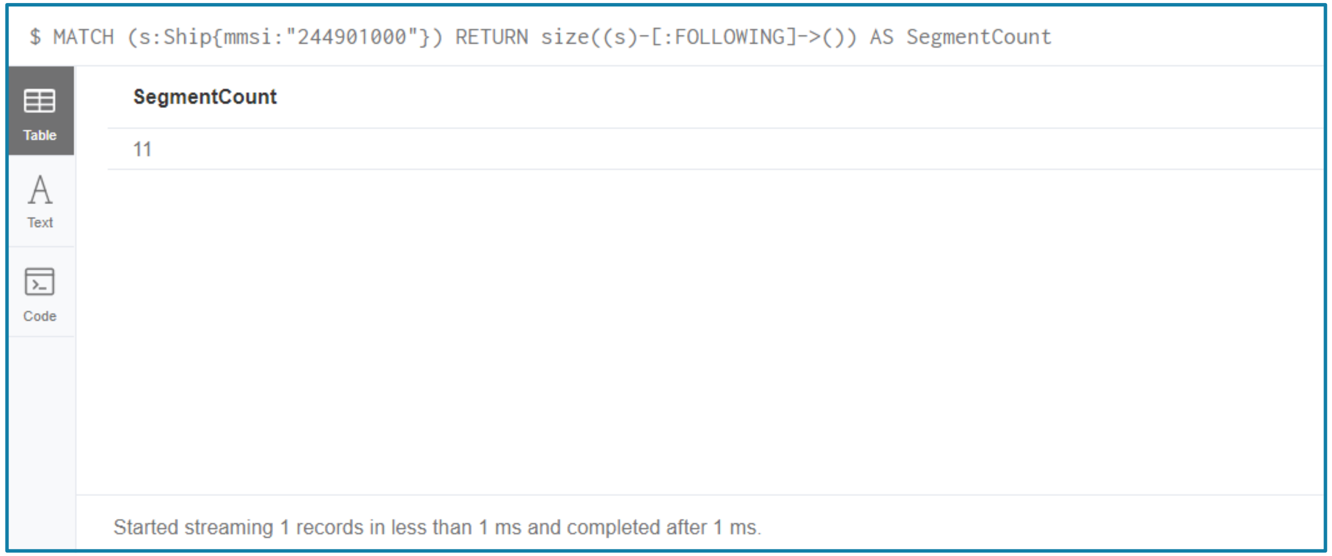
Query

```
MATCH (p:Port{id_port:"86"})
MATCH ()-[s:STARTS]->()
RETURN distinct (size((p)<-[:STARTS]-())*100)/count(s) AS PortSource
```

HISTORICAL LIFE CYCLE (1/2)

Frequency movements of an object between points of interest (vessel's trip analysis)

(example of variation: per period of time, involving a given port, usage of distinct keyword…)



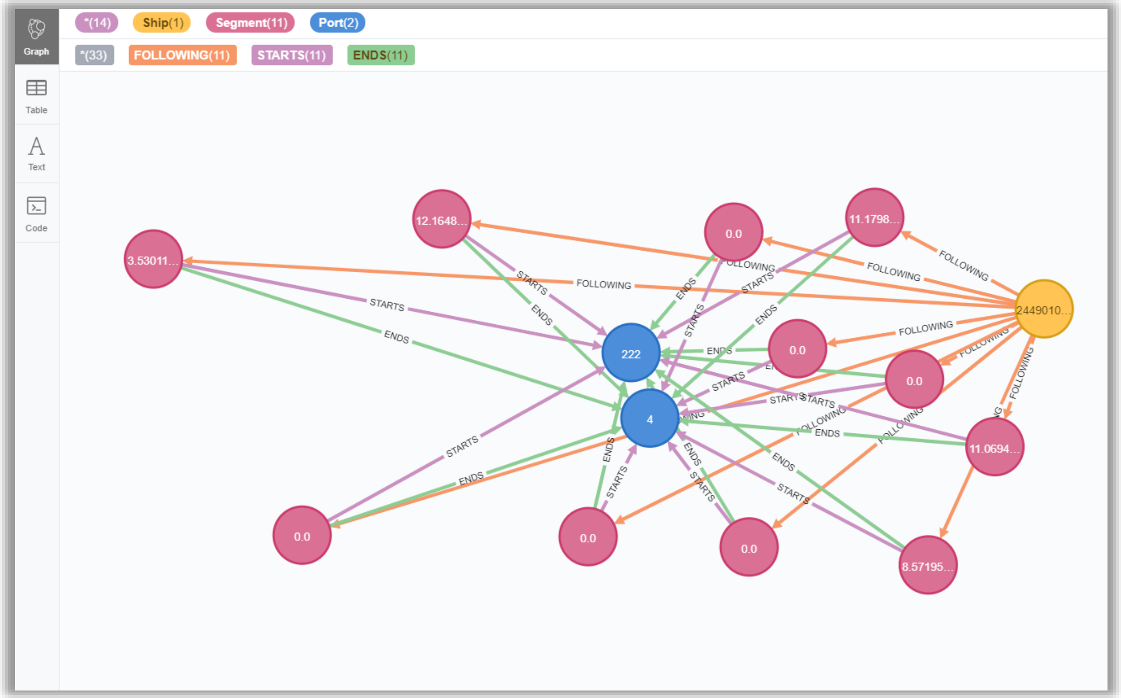
Segments followed by a given ship (SYDBORG, NL)

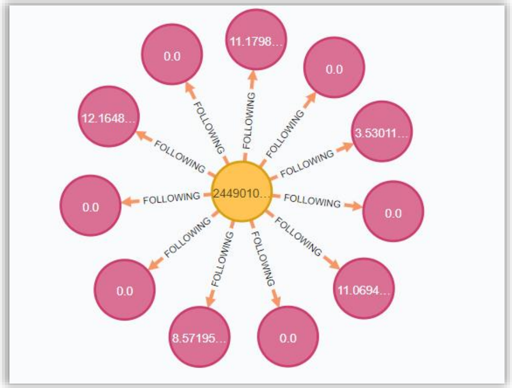
Query

```
MATCH (s:Ship{mmsi:"244901000"})
RETURN size((s)-[:FOLLOWING]->()) AS
SegmentCount
```

HISTORICAL LIFE CYCLE (2/2)

Frequency movements of an object between points of interest (vessel's trip analysis)





Segments followed by a given ship (SYDBORG, NL)

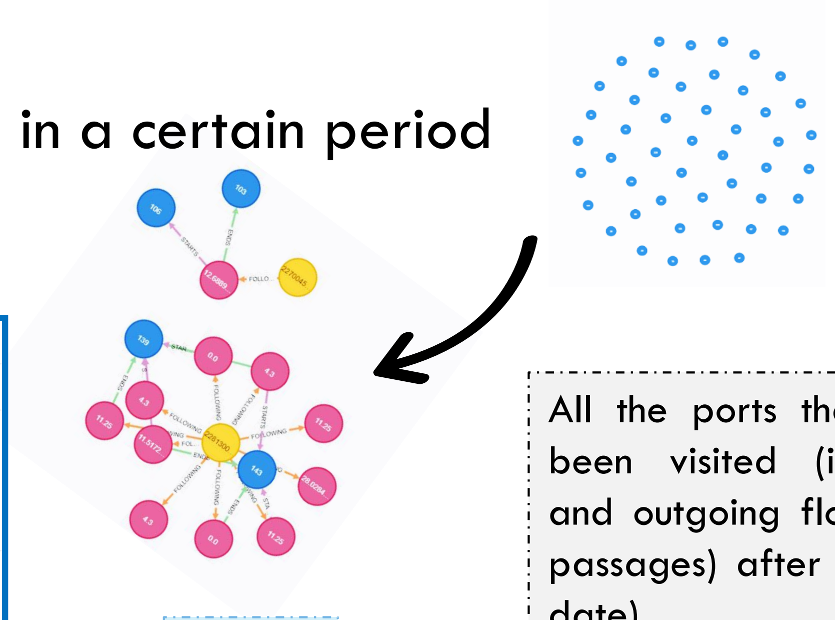
Query

```
MATCH (s:Ship{mmsi:"244901000"})-
[f:FOLLOWING]->(g:Segment)
RETURN s,g
```

Each link include max speed, min speed avg, transit time…

OUTGOING/INCOMING ANALYSIS WITH TIME CONSTRAINT

Informative knowledge about port's activity in a certain period



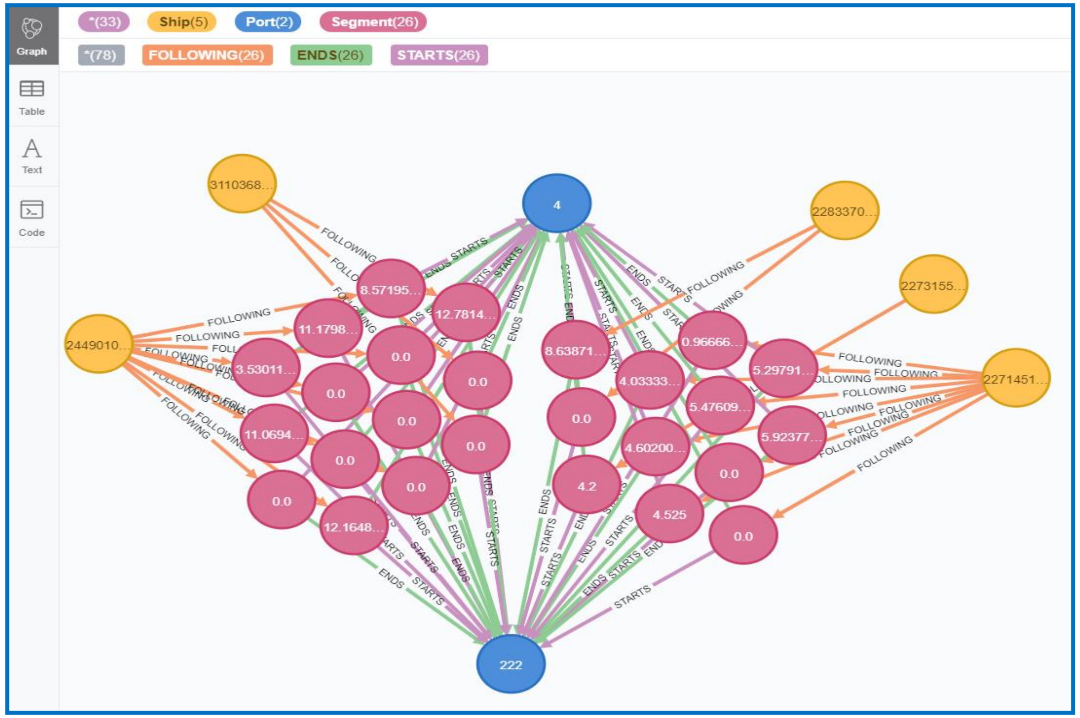
All the ports that have been visited (incoming and outgoing flows and passages) after a given date)

Query

MATCH (h:Ship)-[f:FOLLOWING]->
(s:Segment)-[e]-(p:Port) WHERE
e.dtime >datetime("2016-01-31")
RETURN distinct p,h LIMIT 10000

MEETING POINTS DETECTION USING TIME CONSTRAINT

Interactions between vessels and knowledge about vessels and time/places of rendez-vous



For a given ship, provides the list of visited ports and the list of other ships also there at the same time

Query

```
MATCH (h:Ship)-[f:FOLLOWING]->
(s:Segment)-[r]-(p:Port)<-[g]-(d:Segment)<--
(t:Ship{mmsi:"244901000"})
WHERE r.dtime=g.dtime
RETURN distinct h,p,r.dtime,g.dtime,d,s LIMIT 1000
```

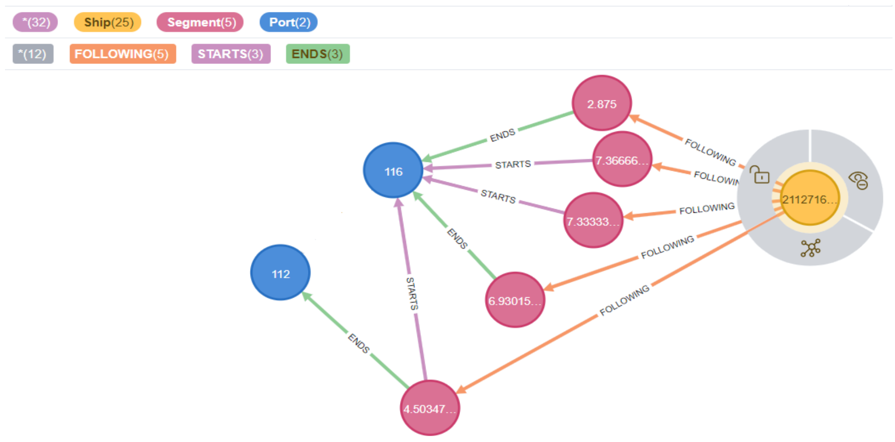
NEW EDGES AND TRAJECTORY PREDICTION PERSPECTIVES (1/2)

In order to predict the next segment of a vessel, we need to get the percentage of outgoing flow from one port to another vs. overall outgoing flows

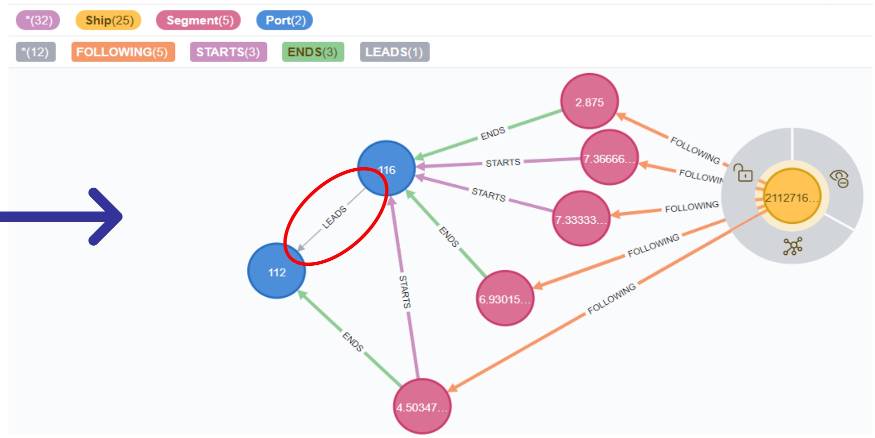
This entails the creation of new edges that define directly the connectivity between ports for each vessels

Upon relation between ports
- Seg1- STARTS → Port1
- Seg1- ENDS → Port2

Creation of new segments
- Port1- LEADS → Port2
- LEADS {MMSI,….}



Existing link between ports #116 and #112 for ship 211271630



Oriented relationship (LEADS) created from the port #116 to the port #112

NEW EDGES AND TRAJECTORY PREDICTION PERSPECTIVES (2/2)

Matching LEADS relationship for a ship or a ship type can extract the percentages relating to the destination ports

These results (from historical data) allow to predict what would be the next segments/destination for any ship or ship type

Query

```
MATCH (p:Port)-[l:LEADS{mmsi:"227569380"}] ->( p1:
Port)
WITH p,p1, count(l) as sizeL
MATCH (p)-[l1:LEADS{mmsi:"227569380"}] ->()
WITH p, sizeL , collect (p1) as ports, count (l1) as sizeL1
RETURN distinct p , head (ports).id_port, sizeL, sizeL1,
(sizeL * 100. 0 / sizeL1) as percentage
```

{ "id_port": "90" }	"86"	13	37	35.13513513513514
{ "id_port": "90" }	"91"	24	37	64.86486486486487

e.g. the ship with the MMSI "227569380" leaving the port (90) has 35.13% of its journeys towards port #86 against 64.86% in destination of port #91

CONCLUSION

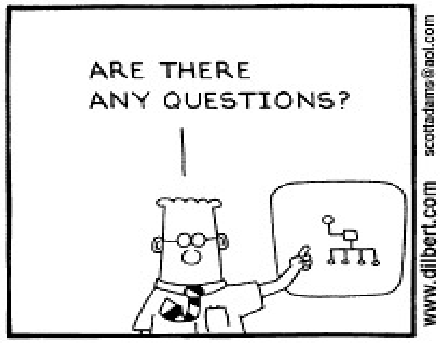
A PoL graph modeling for maritime traffic implemented into Neo4j graph database

Cypher query language to analyze ship's trip and activities using time constraint

Perspectives:

- Using graph algorithms as built-ins to enhance patterns analysis
  - Centrality algorithms (pagerank algorithm, betweenness centrality algorithm…)
  - Community detection algorithms (louvain algorithm, label propagation algorithm...)
- Extending the graph with more knowledge related to waypoints and ships
  - Enrich semantic interpretation
  - Extract paths and models for Decision tree learning

THANK YOU FOR YOUR ATTENTION !



GRAPH-BASED ANALYSIS OF MARITIME PATTERNS OF LIFE

WISSAME LADDADA
CYRIL RAY

Arts et Metiers Institute of Technology
Ecole Navale
Naval Academy Research Institute (IRENav)

This project has received funding from the COSME programme of the European Union under grant agreement No EASME/EMFF/2016/1.2.1.9/03/SI2.763845 - CISE DMS