High-Level Taxonomy of Geovisual Analytics Tasks for Maritime Surveillance

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Abstract. Maritime safety and security require a constant surveillance of the traffic at sea, and several human actors are in charge of this control. Potential risks alerts, suspicious vessels and description of the situation are managed by visual surveillance systems. But these systems do not provide real analysis tools for maritime traffic data. Geovisualization and visual analytics have shown to be very efficient to handle big sets of heterogeneous data, and to make knowledge discovery easier to users. But advanced visual analytics environment can appear to be too complex to be used, according to user's skills. Surveillance tasks need to be formalized for having proper analysis tools. In our research toward user's skill adapted geovisualization, we propose here a study of visual surveillance tasks in maritime surveillance in a high-level taxonomy. Spatialization of the data will be processed according to these tasks, for proposing adequate visualization methods.

Keywords: Visual analytics, geovisualization, maritime surveillance, risk management

1. Context & Objectives

Using the proper tools for leading visual analytics of massive data is a problem that has been raised by research for many years. In our research, we investigate the use of geovisual analytics for monitoring and analyzing traffic data in maritime domain.

Maritime traffic is the most important traffic for merchandise exchange, representing more than 90% of world's trade. Its importance makes it a very sensitive domain, which needs a permanent monitoring. Safety and security have to be monitored and analyzed to prevent accidents or illegal activities at sea, such as piracy, drug traffic or illegal immigration.

Large vessels are tracked with the use of AIS (Automated Identification System), which broadcast kinematic and static information about the vessels by radio waves. The location, speed, heading, type of ship and other useful information are monitored with the use of Maritime Surveillance Systems (MSS). MSSs generally consist in monitoring screens with tables of data and a near real-time cartography of the monitored area. The scale of this area goes from a port, to a wider area such as the Mediterranean coast.

Table 1 illustrates the type of data contained within an AIS message: as information is manually registered, some fields can be missing or unreliable (e.g. the destination field here). *Figure 1* gives an example of a visual system for vessels monitoring in a French MRCC (Maritime Rescue Coordination Center) of the Mediterranean Sea, CROSS-Med[1] in La Garde (France).

Field	Description	Value example
MMSI	Maritime Mobile Service Identity	236152040
IMO	International Maritime Organization identifier	927851
shipname	Name of ship	NIZZA LA BELLA
country	Country of immatriculation for ship	France
sestination	Destination of ship	HOME
shiptype	Type according to IMO	Fishing
shiplength	Length in meters	18
shipdraught	Draught / draft in meters	3
lon	Location of ship	13.9751316
lat	Location of ship	55.001736
sog	Speed in knots	3.4
rot	Rate of turn	0
heading	Direction of ship in degrees	125
navstatus	Description of navigation status	Engaged_in_Fishing
utctime	Date and time of data	2013-03-13 8:04:36.399

Table 1. Example of data within an AIS message

The major objective of these visual tools is to detect unusual or dangerous behavior at sea, that can be caused by human intentions (such as piracy), or uncontrolled events (material defects, meteorological context, etc.). Analysis of past events, that uses replay of the scene, is also a major task for mari-

[1] *Centre Régional Opérationnel de Surveillance et de Sauvetage en Méditerranée*

time surveillance: analysts would look for the reason of an accident, or they would extract a pattern in illegal activities for further monitoring.

However, various projects and studies showed that there is a need for improving the analysis of maritime data, for supporting analysts in their tasks (e.g., Morel et al. 2010, Riveiro & Falkman 2011, Vatin & Napoli 2013). The major issue in current research is to improve the modeling of risks at sea, using machine-learning techniques (data-mining), semi-automated techniques (Spatial OLAP) or human-centered approaches (visual analytics) (Bédard, Rivest, & Proulx 2007, Idiri & Napoli 2012, Chaze et al. 2012). Although automated methods showed promising results in discovering patterns in accidents and traffic data, users prefer relying on visual methods, for there is not “black box” effect in the data analysis (Morel et al. 2010). Moreover, visual methods in data analysis allow users to understand the patterns easier, and remember it efficiently (Guo et al. 2011).

Figure 1. Maritime surveillance system in a French MRCC (CROSS-Med)

2. Visual Support for Traffic Data Analysis

Geovisual analytics applied to mobile objects data have been well developed in the past few years. Traffic data are indeed widely used by the geovisualization community for testing new algorithms and new visual tools (e.g., Andrienko & Andrienko 2008, Andrienko & Andrienko 2011). In the field of maritime monitoring, the recent works of Riveiro (2011) and Willems

(2011) brought major improvements in visual analytics for anomaly detection at sea. Their researches were based on Gaussian mixture models and advances Kernel density estimation for visualizing the behavior of ships at the scale of the sea, and compare it to “normal” kinematic and behaviors. The work of Hurter et. al (2009) also brought substantial improvements in the interaction with trajectories data, applied to air traffic control.

But the diversity of these works makes it even harder to choose the proper visualization methods for studied data. Moreover, previous researches in the 90's and 2000's have developed languages and decision tools for proposing adapted visualization according to the type of data (Shneiderman 1996, Card & Mackinlay 1997). These studies showed that the process of visualization and the type of data to be analyzed have to be formalized, in order to be compared and used within an intelligent program: the most interesting models of the visualization process are the ones of Card & Mackinlay, then extended for dynamic data by Hurter & Conversy (2007), and the model of Chi (2000), for they describe the complete process of data modeling, filtering and visualizing.

In our research, visualization is defined as the spatial metaphor of heterogeneous data, such as described by Fabrikant & Skupin (2005): “*spatialization is defined as a data transformation method based on spatial metaphors, with the aim of generating a cognitively adequate graphic representation for data exploration and knowledge discovery in multi-dimensional databases*”. This definition also represents the very process of data visualization described by Chi, and can be used in a formal description and programming language. This way, both geographical and non-geographical data benefit of the research in visualization, and can be combined in interactive visual interfaces.

Figure 2 illustrates how Chi’s Data State Reference Model is used to describe the process of visualizing simple maritime geographical data, such as the location of vessels. Raw data (value) are the location of ships at the time of AIS emission ; analytical abstraction are pairs of decimal numbers for *(lon, lat)* ; visualization abstraction is the spatialization into points ; finally the view is the map, using specific symbology and interaction tools (such as pan, zoom, filter, etc.). The map in the figure represents the location of ships in the North Sea (north of the Netherlands) on 15 March 11:15.

Within an interactive map, or any other type of environment for visual analytics, the visualized information can be concrete geographical data (such as ship location and trajectory, meteorology), concrete non-geographical information (such as ship description) or abstract data (inferred information such as alerts, scenarios, data classification or data aggregation). Maritime surveillance requires the visualization of risk information, which Idiri &

Napoli (2012) define as the combination of a ship's behavior, a geographic area (dangerous or not) and situation (such as ship type, or visibility).

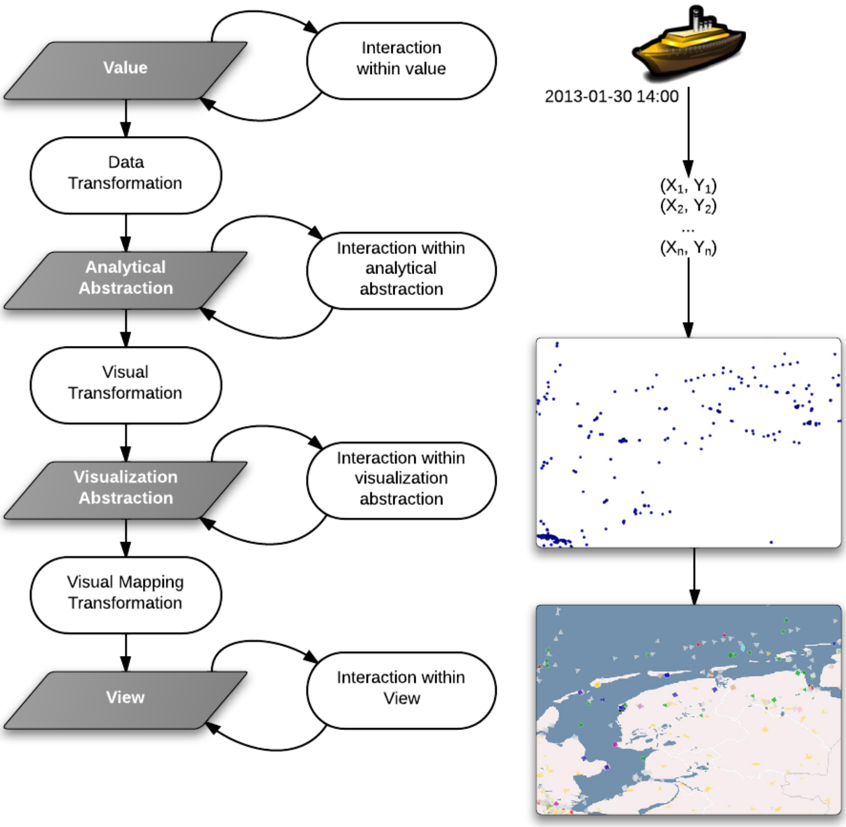

Figure 2. Data State Reference Model for visualization process taxonomy (based on Chi 2000), and the example of ship location mapping

In the next part, we go into details about the specificities of risk control and its application to maritime surveillance with visual platforms. We describe the main within risks management and present an example of geovisualization applied to a specific maritime event of interest.

3. Formalization of Methods for Visual Surveillance

3.1. High-Level of Visual Analytics Tasks

Risk management process can be divided into four major steps, according to the work Wybo (2012), which are illustrated in *Figure 3*. This process is the base for discovering knowledge in the monitored domain, and for using this new knowledge efficiently. In the rest of this paper, we will explain what the corresponding tasks in maritime visual surveillance are, and the way geovisual analytics are used for each of these steps. This description highlights major steps that formalize visual analytics tasks.

Figure 3. Risk management process (based on Wybo 2012)

Anticipation phase is the modeling of potential risks that are known and must be controlled and prevented. At step 2, vigilance means controlling the system of interest with a constant monitoring ; control is defined as the comparison between actual state of the system and intended (normal) state (Hollnagel & Woods 2005). Whenever unexpected events happen, an accurate analysis of the situation must be completed to take proper decisions (step 3), and to discover new rules for risk modeling (step 4). This general framework of risk management highlights the major concepts that can be completed with the use of (geo-) visual analytics: (1) characterization of risks and behaviors, (2) monitoring of the system of interest and (3) analysis of the events and data.

Based on this general framework, we propose a high-level taxonomy of tasks for visual surveillance, since this is a major step toward the use of cognitively plausible visualization (Fabrikant & Skupin 2005). To describe the tasks of traffic surveillance, they are divided into the three concepts that were described above. We apply these steps to maritime surveillance by the means of (geo-) visual analytics. First, the identification and description of risks and dangerous behaviors at sea: this is the baseline used for controlling risks and comparing monitored data to models of risky situations. Then, the monitoring tasks are the most common uses of maritime surveillance systems and anomalies detection (unusual behavior) in near real-time data. Finally, the analysis tasks: these are more advanced tasks that take into account historical data, in order to detect patterns and to understand the conditions of an event (such as collision, grounding). *Table 2* lists these high-level tasks and gives some examples for each concept.

Task	Description	Geovisual analytics examples
Identification	Modelling of behaviors or areas that present potential risks.	Mapping sensitive zones regarding piracy or meteorology. Visualizing dangerous profile of ships to look for.
Monitoring	Near real-time surveillance of the information, and decision-making.	Detecting fishing ship entering a restreint fishing area. Detect a stop at sea.
Analyzing	Manipulation of historical data to extract patterns and knowledge.	Comparing usual fishing behavior to a specific ship's behavior. Searching for crossing or close trajectories.

Table 2. High-level tasks for visualization in surveillance system

The low-level tasks are specifications of these high-level tasks: they would depend on the type of risk to monitor and the information to take into account. To go deeper into this taxonomy, the concepts to which the tasks are applied are classified within four major categories: objects, behaviors, events and context. Some examples in *Table 2* illustrate these categories. In the next part, we describe a specific event of fishing alert to illustrate the principle of interaction between objects, behaviors, events and context information, and we explain how visualization can be used.

3.2. Visual Detection of a Maritime Fishing Alert

These general tasks for visual surveillance need to be specified with low-level concepts. This way, the properly adapted geovisualization methods could be proposed. As our study aims at developing a methodology for proposing plausible visual methods, these specific concepts must concern visual tasks such as visual mining and communication. For this purpose, we use a bottom-up approach for risks detection and analysis: starting from well-known risks or forbidden ship behaviors, we describe the visual tasks that have to be performed.

Some examples of major issues that have to be recognized are: prohibited fishing, unusual trajectory, drug traffic or determined attack (such as piracy). To investigate the contribution of geovisual analytics, we will give more details about prohibited fishing events. Prohibited fishing can be caused by a fishing ship stopping in a restricted fishing area, two fishing ships having parallel trajectories (parallel fishing) or two fishing ships close to each other and stopping at sea. Vandecasteele & Napoli (2012) modeled these types of risks within an ontology, for automated alerts discovery. We use this model of risks for investigating the needs in visualization. *Figure 4* illustrates the ontological model for illegal fishing scenario, to be used in an automated process. Each of the concerned objects requires a corresponding visual modeling to be discovered by visualization instead of automation.

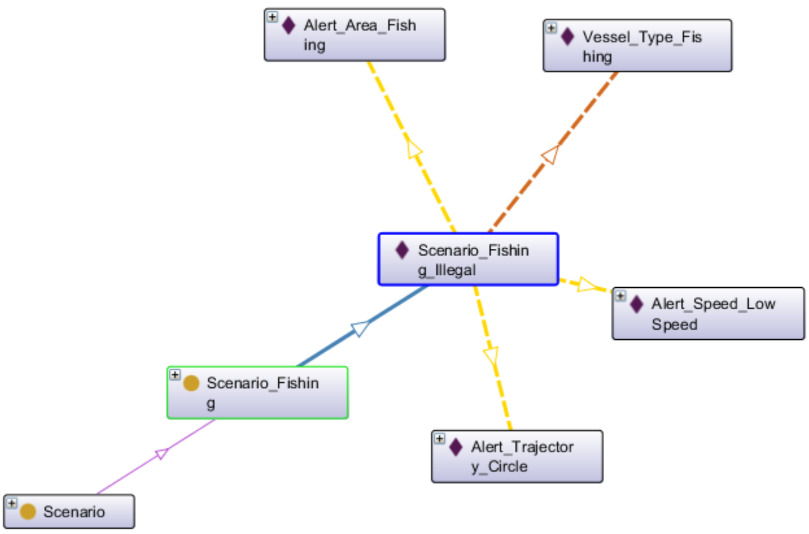

Figure 4. Model of illegal fishing scenario within an ontology (based on Vandecasteele & Napoli 2012)

Modeling these events with visual features can goes from simple geovisualization of geographic concrete features to more advanced geovisual analytics of geographical and abstraction space, spatialized within a visualization.

Figure 5 illustrates a simple illegal fishing scenario, but only some characteristics of previous model are visualized: the ship type is *Fishing* (colored legend) and it is situated inside an area of restricted fishing. As this visualization is a "snapshot" at a certain time, information about its kinematic are not displayed. Yet, information about low speed or the shape of its trajectory has to be visualized to get real knowledge on the situation. An accurate assessment of possible infraction cannot be made at this point. Automation can raise an alert from previous ontology, by processing information found within the database, but visualization has to be improved if used by human operators without artificial intelligence.

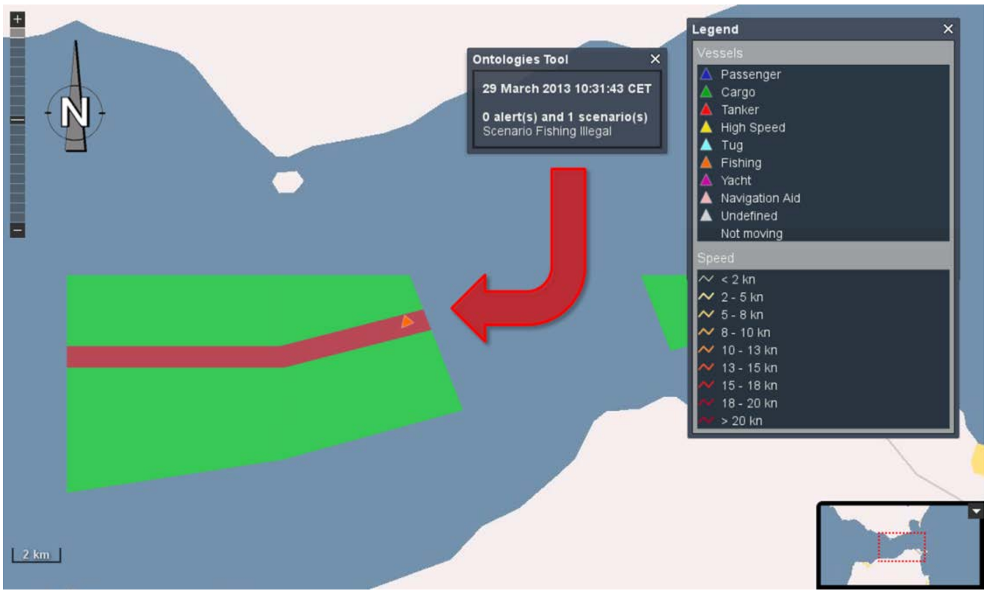

Figure 5. Fishing vessel (orange triangle) entering a limited fishing area, in the Strait of Gibraltar

To improve the visualization, *Figure 6* displays the past trajectory of the ship, with color code for its speed (in knots in the legend) and the current speed with a proportional line. These simple encodings of the information can help comparing actual situation to a potential illegal behavior, which was previously characterized (global body of knowledge). In this case, we can visually extrapolate the future trajectory of the ship, and understand there is no infraction yet, and there is little chance the ship will stop now.

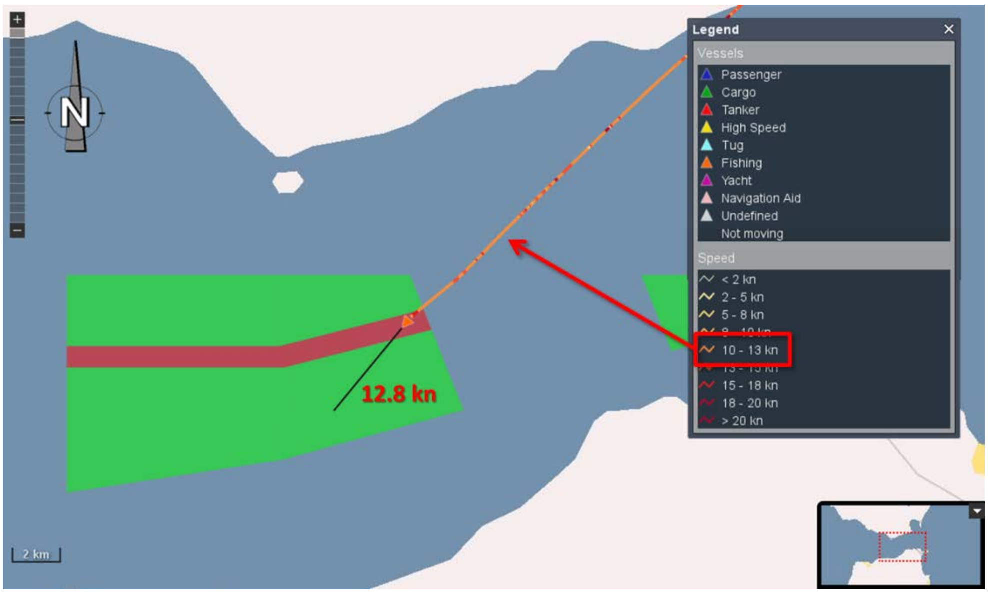

Figure 6. The same fishing ship with extra information on speed and trajectory

For the same type of scenario, a particular information about the kinematic of the ship is the stop event. Detecting a stop in this type of 2D representation of a trajectory is not possible, as a stop is not a line. Two means could be proposed for stop detection. First, using a 3D space-time cube allows to detect the speed of moving object by the slope of the line: weak slope means the object traveled a large distance during a few time (high speed), whereas strong slope means the object made short travel during a long time (low speed). But visualizing both dynamic of vessel in 3D and context information (map of restricted area) is quite complicated in 2D. Second solution is to visualize stop as a point, of which one attribute could be the duration of spot. This way, a new visual variable is used for visualizing this event: for instance, a circle with varying size or color.

Figure 7 illustrates a type of visualization of stops at sea, where size and color of circle stand for the duration of stop. In this representation of a specific part of a trajectory a large red circle stands for stop of more than 1h, completed by extra information on demand. This type of geovisualization, synchronized with a speed graph, is easier for searching long stops at specific areas as stops and areas limits are on the same plan. In this example, speed graph shows a long stop, but the map visualization explains this stop was in a port area.

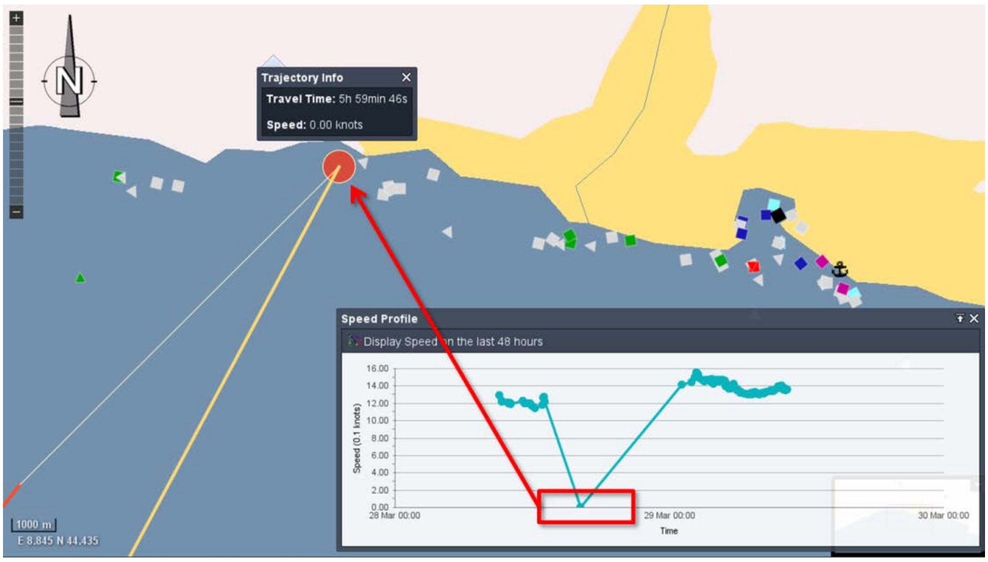

Figure 7. Trajectory, speed and stop information

From this example of a possible fishing alert, some categories of interest for visual analytics of risk at sea can be extracted. The ontology developed by Vandecasteele (2012) and the results from data-mining by Idiri & Napoli (2012) proved that risks can be described by the interaction between: geometrical data (monitored objects), context data, time data (interval of interest), kinematic data and attributes of objects. For visualization purpose, each of these information levels has to be taken into account in the geovisual analytics environment as we have seen in the example above. Within a human-machine environment, three major spaces for visualization require synchronization for their analysis: map space, attribute space and time space. In these spaces, the same information can be represented more than once in order to extract patterns, such as time and geographical context.

The development of low-level tasks must take into account the type of relevant information (time, space, attribute, etc.), the amount of data and their extent (in time or space).

Table 3 summarizes the information spaces and the process of visualization that was chosen for this geovisualization example. Chi's Data State Model for the visualization process has been used to describe various process for obtaining final geovisualization. Arrows (→) are used when data are already in a proper format for visualization.

		Within Value	Data Transformation	Within Analytical Abstraction	Visualization Transformation	Within Visualization Abstraction	Visual Mapping Transformation	Within View
Space	Context	Restricted area shape	→	→	Choose color code	→	Map area	Pan, zoom
	Object	Vessel position; Vessel trajectory	Extract coordinates and relative data	Dynamic filtering	Create 2D points and lines	Abstraction: points; lines	Map point & line features	Pan, zoom, details on demand
	Event	Stop	Extract position and stop duration	→	Create circle	Abstraction: colored circle, various size	Map point features	Pan, zoom, details on demand
Time	Kinematic	Vessel past speed	Extract past records	→	Create time series	Abstraction: time series of speed values	Map into line chart	Filter, zoom
		Vessel speed	Extract speed	→	Create vector	Abstraction: line	Map speed vector	-
Attribute		Vessel type	→	→	Choose color for type	Color	Use on location point	-

Table 3. Data State Model applied to restricted fishing example

4. Conclusion and Future Work

In this paper, we investigated the major role of visualization for traffic control, especially the maritime domain. We have seen there is a need for formalizing of the various visual tasks of control and the events that happen at sea, in order to propose the most adequate visual analytics tools. The information spaces of (1) space, (2) time and (3) attributes must be visualized and controlled by interactive tools for data exploration. Knowing the type of analysis to be lead and the behaviors and events to find will help in building proper visualization environment.

As discussed in the previous parts, visual analytics understanding and effective use strongly depends on user's skills. If the user does not understand a method of visualization, it won't be properly used, or even not used at all. That's why user's evaluation of geovisualization must be taken into account, to propose most usable geovisualizations. Future work will concern (1) the extension of low-level tasks and (2) evaluating the way user perceives easiness of use what the main features for understanding visualizations are (amount of data, animation, etc.). For this purpose, we will use evaluations indicators such as Perceived Usefulness and Perceived Ease of Use described by Davis (1993) in the Technology Acceptance Model.

References

Andrienko G, Andrienko N (2008) Spatio-temporal aggregation for visual analysis of movements. In Proc. of IEEE Symposium on Visual Analytics Science and Technology, 2008. VAST'08. 51–58.

Andrienko N, Andrienko G (2011) Spatial generalization and aggregation of massive movement data. IEEE Transactions on Visualization and Computer Graphics, 17 (2):205–219.

Bédard Y, Rivest S, Proulx MJ (2007) Spatial On-Line Analytical Processing (SOLAP): Concepts, architectures and solutions from a geomatics engineering perspective. In Data Warehouses and OLAP: Concepts, Architecture and Solutions, 298–319. Wrembel R. et C. Koncilia (Eds).

Card SK, Mackinlay J (1997) The structure of the information visualization design space. In Proc. of IEEE Symposium on Information Visualization, 92‑99. InfoVis '97. Washington, DC, USA: IEEE Computer Society.

Chaze X, Bouejla A, Napoli A, Guarnieri F (2012) Integration of a bayesian network for response planning in a maritime piracy risk management system. In Proc. of 7th International Conference on System Of Systems Engineering. SOSE 2012. Genoa, Italy.

Chi EH (2000) A taxonomy of visualization techniques using the data state reference model. In Proc. of the IEEE Symposium on Information Visualization 2000, 69–76. Salt Lake City, USA: IEEE Computer Society.

Davis FD (1993) User acceptance of information technology: system characteristics, user perceptions and behavioral impacts. International Journal of Man-Machine Studies 38(3):475‑487.

Fabrikant SI, Skupin A (2005) Cognitively Plausible Information Visualization. In Exploring Geovisualization, Elsevier Ltd., 667–690. Jason Dykes, Alan M. MacEachren, Meno-Jan Kraak.

Guo H, Wang Z, Yu B, Zhao H, Yuan X (2011) TripVista: Triple perspective visual trajectory analytics and its application on microscopic traffic data at a road intersection. In IEEE Pacific Visualization Symposium 2011, 163–170.

Hollnagel E, Woods DD (2005) Joint Cognitive Systems: Foundations of Cognitive Systems Engineering. CRC Press.

Hurter C, Conversy S (2007) Extension d'un modèle de visualisation pour la caractérisation d'interfaces graphiques dynamiques. In Proc. of the 19th International Conference of the Association Francophone d'Interaction Homme-Machine, 39–42.

Hurter C, Tissoires B, Conversy S (2009) FromDaDy: Spreading aircraft trajectories across views to support iterative queries. IEEE Transactions on Visualization and Computer Graphics, 15 (6):1017–1024.

Idiri B, Napoli A (2012) Découverte de règles d'association pour l'aide à la prévision des accidents maritimes. In Revue des Nouvelles Technologies de l'Information, 23:243–248. Bordeaux, France: Editions Hermann.

Morel M, Napoli A, George JP, Jangal F, Giraud MA, Botalla M (2010) Surveillance et contrôle des activités des navires en mer : ScanMaris. In Proc. of Workshop Interdisciplinaire sur la Sécurité Globale, Troyes, France.

Riveiro M (2011) Visual analytics for maritime anomaly detection. PhD Thesis, Örebro University, Sweden. 230 p.

Riveiro M, Falkman G (2011) The role of visualization and interaction in maritime anomaly detection. In Proc. of SPIE-IS&T Electronic Imaging, 7868:78680M. San Francisco, CA, USA: Chung Wong, P. (Eds).

Shneiderman B (1996) The Eyes Have It: A task by data type taxonomy for information visualizations. In Proc. of the IEEE Symposium on Visual Languages, 336–343. Boulder, USA: IEEE Computer Society.

Vandecasteele A (2012) Modélisation ontologique des connaissances expertes pour l'analyse de comportements à risque – Application à la surveillance maritime. PhD Thesis, MINES ParisTech – CRC, Sophia Antipolis, France. 212 p.

Vandecasteele A, Napoli A (2012) Spatial ontologies for detecting abnormal maritime behaviour. In Proc. of OCEANS 2012 MTS/IEEE Yeosu Conference, Yeosu, South Korea.

Vatin G, Napoli A (2013) Guiding the controller in geovisual analytics to improve maritime surveillance. In Proc. of GEOProcessing 2013: The Fifth International Conference on Advanced Geographic Information Systems, Applications, and Services, Nice, France.

Willems N (2011) Visualization of vessel traffic. PhD Thesis, Technische Universiteit Eindhoven, The Netherlands. 143 p.

Wybo JL (2012) Maîtrise des risques et prévention des crises. Lavoisier. Tec & Doc. Lavoisier.