



Defence Research and  
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# Visual Analytics and Collaborative Technologies for the Maritime Domain

*Opportunities for Application and Proposed Design Concepts*

Valérie Lavigne  
Denis Gouin  
*DRDC Valcartier*

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*Salience Analytics Inc*

**Defence Research and Development Canada – Valcartier**

Technical Report

DRDC Valcartier TR 2012-424

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**Canada**



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## **IMPORTANT INFORMATIVE STATEMENTS**

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## **Abstract**

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This report describes the research done from April 2009 to December 2011 within the 11jm (previously 11hm) Applied Research Project (ARP) titled “Maritime Domain Analysis through Collaboration and Interactive Visualization,” regarding the application of visual analytics and collaborative technologies to the maritime domain. We first reviewed the challenges related to maritime operations. Then, we introduced the basic concepts underlying visual analytics and collaborative technologies. The core of the report presents the results from the exploration activities that led to the identification of maritime contexts where these technologies could be of use, the design of visual analytics and collaborative application mock-ups, and the exploration of collaborative technologies hardware and software in our laboratory. Finally, the report discusses the way ahead for the prototype.

## **Résumé**

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Ce rapport décrit le travail d’exploration réalisé entre avril 2009 et décembre 2011 dans le cadre du Projet de recherche appliquée (PRA) 11jm (auparavant 11hm) intitulé “Maritime Domain Analysis through Collaboration and Interactive Visualization”, qui porte sur l’application des technologies d’analytique visuelle et collaborative au domaine maritime. Nous revoyons d’abord les défis en lien avec les opérations maritimes. Ensuite, les concepts de base de l’analytique visuelle et des technologies de collaboration sont introduits. Le cœur du rapport présente les résultats des activités d’exploration qui ont conduit à l’identification des contextes maritimes dans lesquels ces technologies pourraient s’appliquer, la conception de maquettes d’applications d’analytique visuelle et de collaboration et l’exploration de matériel et de logiciel collaboratifs dans notre laboratoire. Pour terminer, nous discutons de la voie à suivre pour le développement du prototype.

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## Executive summary

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### Visual Analytics and Collaborative Technologies for the Maritime Domain: Opportunities for Application and Proposed Design Concepts

**Valérie Lavigne; Denis Gouin; Michael Davenport; DRDC Valcartier TR 2012-424; Defence R&D Canada – Valcartier; December 2012.**

**Introduction or background:** This report describes the explorative work performed from April 2009 to December 2011 within the 11jm (previously 11hm) Applied Research Project (ARP) (Maritime Domain Analysis through Collaboration and Interactive Visualization), regarding the application of visual analytics and collaborative technologies to the maritime domain. We first review the challenges related to maritime operations. Then, we introduce the basic concepts underlying visual analytics and collaboration technologies. The core of the report presents the results from the exploration activities that led to the identification of maritime contexts where these technologies could be of use, the design of visual analytics and collaborative application mock-ups, and the exploration of collaborative technologies hardware and software in our laboratory. Finally, the report discusses the way ahead for the prototype development.

**Results:** We identified a subset of maritime applications and tasks where the use of visual analytics has a high improvement potential. These are: the visualization of normal maritime behaviour, the detection of anomalies, and the collaborative analysis of a Vessel of Interest (VOI).

Promising collaborative technologies for application to maritime situation awareness and analysis were assessed in the lab. More specifically, we experimented with two different multi-touch tables, a large display wall, a gesture interaction device, and a rapid portal designing software. Maritime applications and mock-ups were built to showcase the capabilities of these new technologies for their use in a maritime surveillance context. We implemented a multi-touch version of Google Earth that can be used on a multi-touch table as well as with the wall display using gestures captured by a Microsoft Kinect sensor. A maritime situation awareness portal including various analysis tools mock-ups was developed using the SitScape software, and displayed on the knowledge wall. A simple application was also developed to display vessel information windows with various orientations.

**Significance:** The VA solutions we propose will offer cognitively rich visual representations that will lead to a more efficient exploration and analysis of the current maritime situation. These tools will also support communication of analysis results and teamwork collaboration. With our apps-based design approach, we propose new innovative visual analytics capabilities and apply existing visual analytics concepts to a real world problem.

**Future plans:** The next step consists of implementing the proof-of-concept Maritime Visual Analytics Prototype (MVAP). As the project resources are limited, a subset of the proposed ideas was selected for implementation into the prototype, based on the feedback from the operational community and the novelty and broad applicability aspects of the concepts. The workspace

concept was adopted along with the following app concepts: Vessel Summary Cards; Vessel Timeline; Time Slider on Ship Tracks; Dust, Magnets and Scatterplots; Thematic Views; Close-Encounter Pop-Up; Route Ribbons; and Word Clouds. User validation and evaluation activities will be conducted. They will provide an opportunity to integrate user suggestions and preferences.

It is believed that the advanced interface and interaction devices explored in the Ilab (Intelligence laboratory) will be helpful for collaborative analysis and for sharing situation awareness among a team of analysts. Many possible ways to enable collaborative teamwork were explored and the insight gained will be relevant to the next steps of the project. Future exploration could include multimodal interaction using tablets, smart phone devices, and speech interaction. We also intend to leverage the LiveSpaces technology for experimenting with the MVAP in a remote synchronous collaboration context.



# Sommaire

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## Visual Analytics and Collaborative Technologies for the Maritime Domain : Opportunities for Application and Proposed Design Concepts

**Valérie Lavigne; Denis Gouin; Michael Davenport ; DRDC Valcartier TR 2012-424 ; R & D pour la défense Canada – Valcartier ; décembre 2012.**

**Introduction ou contexte :** Ce rapport décrit le travail d’exploration réalisé entre avril 2009 et décembre 2011 dans le cadre du projet de recherche appliquée 11jm (auparavant 1hm) intitulé “Maritime Domain Analysis through Collaboration and Interactive Visualization”, qui porte sur l’application des technologies d’analytique visuelle et collaborative au domaine maritime. Nous abordons d’abord les défis en lien avec les opérations maritimes. Ensuite, les concepts de base de l’analytique visuelle et des technologies de collaboration sont introduits. Le cœur du rapport présente les résultats des activités d’exploration qui ont conduit à l’identification des contextes maritimes dans lesquels ces technologies pourraient s’appliquer, la conception de maquettes d’applications d’analytique visuelle et de collaboration et l’exploration de matériel et de logiciel collaboratifs dans notre laboratoire. Pour terminer, nous discutons de la voie à suivre pour le développement du prototype.

**Résultats :** Nous avons identifié un sous-ensemble d’applications et de tâches maritimes pour lesquelles l’utilisation de l’analytique visuelle offre un potentiel élevé d’amélioration: la visualisation du comportement maritime normal, la détection d’anomalies et l’analyse collaborative d’un navire d’intérêt.

Des technologies de collaboration prometteuses pour la connaissance situationnelle maritime et l’analyse de la situation ont été évaluées dans le laboratoire du renseignement. Plus spécifiquement, nous avons expérimenté avec deux tables multi-tactiles différentes, un mur d’affichage, un dispositif d’interaction gestuelle et un logiciel de conception rapide de portail d’information. Des maquettes d’applications maritimes ont été développées afin de montrer les capacités de ces nouvelles technologies dans un contexte de surveillance maritime. Nous avons implémenté une version multi-tactile de Google Earth qui peut être utilisée aussi bien sur une table multi-tactile qu’avec le mur d’affichage à l’aide de gestes captés par un capteur Kinect de Microsoft. Un portail de connaissance situationnelle maritime incluant des maquettes variées d’outils d’analyse a été développé à l’aide du logiciel SitScape et affiché sur le mur de connaissance. Une application simple a également été développée afin de montrer de l’information reliée aux navires selon différentes orientations.

**Importance :** Les solutions d’analytique visuelle que nous proposons offriront des représentations visuelles cognitivement riches qui mèneront à une exploration et une analyse plus efficace de la situation maritime actuelle. Ces outils supporteront également la communication des résultats d’analyse et le travail d’équipe collaboratif. Avec notre approche de conception basée sur les « apps », nous proposons des capacités innovatrices d’analytique visuelle et nous appliquons des concepts d’analytique visuelle existants à des problèmes réels.

**Perspectives :** La prochaine étape consiste dans le développement du prototype de preuve de concept d'analytique visuelle maritime. Comme les ressources du projet sont limitées, un sous-ensemble des idées proposées a été sélectionné pour être implémenté dans le prototype, en se basant sur la rétroaction de la part de la communauté opérationnelle, la nouveauté ainsi que l'étendue de l'applicabilité des concepts. Le concept d'environnement de travail a été adopté ainsi que les concepts d'apps suivants : Vessel Summary Cards, Vessel Timeline, Time Slider on Ship Tracks, Dust, Magnets and Scatterplots, Thematic Views, Close-Encounter Pop-Up, Route Ribbons, et Word Clouds. Des activités de validation et d'évaluation avec les usagers seront réalisées. Elles nous offriront l'opportunité d'intégrer les suggestions et préférences des usagers.

Nous croyons que les interfaces et interactions avancées qui ont été explorées dans le laboratoire seront utiles pour l'analyse collaborative et le partage de la connaissance de la situation à l'intérieur d'une équipe d'analystes. Plus moyens de permettre le travail d'équipe collaboratif ont été explorés et la connaissance acquise sera pertinente pour les prochaines étapes du projet. Les explorations futures pourraient inclure des téléphones intelligents et des tablettes ainsi que des interactions vocales. Nous avons également l'intention d'utiliser la technologie LiveSpaces pour expérimenter avec le prototype d'analytique visuelle maritime dans un contexte de collaboration synchrone à distance.

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# 1 Introduction

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The Applied Research Project (ARP) 11jm is lead by DRDC Valcartier and is titled “Maritime Domain Analysis through Collaboration and Interactive Visualization”. It started in April 2009 and will end in March 2014. This project aims at exploring and demonstrating how Visual analytics (VA) and collaborative technologies can:

- help Canadian Forces (CF) rapidly grasp and identify the key information elements and thus gain insight into the information / situation;
- improve the visualization of the Recognized Maritime Picture (RMP);
- help better comprehend a situation and how it could develop;
- allow to identify what is not known (data gaps and uncertainty);
- support detection, alerting, and visualization of anomalies;
- enable collaborative team work.

This report describes the explorative work performed within the 11jm (previously 11hm) project regarding the application of visual analytics and collaborative technologies to the maritime domain from April 2009 to December 2011. We first review the challenges related to maritime operations. Then, we introduce the basic concepts underlying visual analytics and collaborative technologies. The core of the report presents the results from the exploration activities that led to the identification of maritime contexts where these technologies could be of use, the design of visual analytics and collaborative application mock-ups and the exploration of collaborative technologies hardware and software in our laboratory. Finally, the way ahead for the prototype development is discussed.

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## **2 Maritime Domain Awareness and Analysis**

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### **2.1 Maritime Domain Awareness Definition**

“Maritime Domain Awareness (MDA) is the effective understanding of everything on, under, related to, adjacent to or bordering a sea, ocean or other navigable waterway, including all maritime-related activities, infrastructure, people, cargo, and vessels and other conveyances that could impact the security, safety, economy, or environment.” [1]

Maritime domain operators/analysts around the world typically have a mandate to be aware of all that is happening in maritime approaches. This mandate is based on the need to protect from attack, defend sovereignty, detect illegal activities, and support search and rescue activities.

In this report, we also use the term “maritime domain analysis”, which adds a situation analysis and sense making dimension that goes beyond simple awareness of what is going on.

### **2.2 Challenges at the RJOCs**

In Canada, the Canadian Forces Regional Joint Operational Centers (RJOCs) in Esquimalt and Halifax maintain a 24/7 watch over Canada’s three oceans. The production and exploitation of the RMP is an essential part of their work. Watch personnel continually interpret the maritime situation with reference to space and time. They need to:

- rapidly process a variety of sources of information in order to develop shared situational awareness (understand how a situation has developed and is expected to develop);
- rapidly develop shared understandings of the operational environment;
- and work in a collaborative setting (JIMP – Joint, Inter-agency, Multi-lateral, Public).

This is a challenging task because of the large number of vessel contacts and heterogeneous information sources that must be monitored, leading to a significant information overload [2]. Operators and analysts maintain 24/7 watch over the oceans in support of the mandate. They do so by extracting and analyzing situational facts from a variety of sensor data streams and analysis tools. The main challenges facing them are not a lack of data – in some ways they are drowning in data – but rather:

- the data has often been degraded by ambiguities and data entry errors, requiring operators to spend large amounts of time cleaning up the data to reveal the underlying situational facts;
- the data has too often been delivered to the operators as individual dots on screens, each from a different moment in time, rather than being first resolved into tracks;
- a huge fraction of the information presented to the operators is mundane, from platforms going about normal, legitimate activities, and no attempt is made to draw attention to the non-mundane.

## 2.3 Challenges at the MSOCs

The RJOCs are members of a larger entity known as Marine Security Operations Centers (MSOCs), which are comprised of:

- Department of National Defence (DND),
- Royal Canadian Mounted Police,
- Canada Border Services Agency,
- Canadian Coast Guard,
- Department of Fisheries and Oceans,
- Transport Canada.

The MSOCs have been established in order to contribute to the Government of Canada's National Security Policy core national security interests along with achieving the Government's plan to strengthen transportation security in general and marine security in particular. The Marine Security Operations Centres core functions are:

- “to manage the collection of all marine information and intelligence, surveillance, and reconnaissance data subject to all Government of Canada, Agency and Departmental legislation, policies, regulations, guidelines and standards governing the acquisition, distribution, exchange, integration, retrieval and storage of all information and data between all participating agencies and departments;
- to analyse and archive marine information and intelligence, surveillance, and reconnaissance data;
- to generate marine information and intelligence, surveillance, and reconnaissance products including the RMP;
- to exchange marine intelligence, information and data with other appropriate agencies and senior decision makers;
- to provide marine intelligence, information and data inputs to the Government of Canada Agency and Departmental Command Structures; and
- to bring to bear all civilian and military resources necessary to respond to a marine security threat within the framework of the national emergency response structure.” [3]

Fortunately, VAhas emerged as a new and multidisciplinary field that can help turn the information overload faced by the RJOCs and the MSOCs into an opportunity.



## 3 Visual Analytics

### 3.1 Introduction

It is anticipated that visual analytics has the potential to significantly improve the RMP by offering cognitively rich representations, information filtering and clutter reduction capabilities, multimodal interactions and teamwork collaborative capabilities, in order to provide better insight into information and increased situation awareness.

This section provides a short introduction to visual analytics, and contains information from [4]. A comprehensive review of VA concepts and techniques along with an assessment of how this emerging research field could hold solutions to defence and security challenges related to emergency management, military intelligence, counterterrorism, maritime domain awareness, cyber security, public health monitoring, and law enforcement, is provided in [5].

Thomas and Cook define VA as “the science of analytical reasoning facilitated by interactive visual interfaces” [6]. The goal of VA is to facilitate high-quality human judgement with a limited investment of the analyst’s time. According to [6], people use VA tools and techniques to:

- “synthesize information and derive insight from massive, dynamic, ambiguous and often conflicting data;
- detect the expected and discover the unexpected;
- provide timely, defensible, and understandable assessments;
- communicate assessment effectively for action.”

VA can help analyze entity behaviour, known patterns, and the links between them. Visual Analytics is often used in conjunction with other methods, as shown in Figure 1:

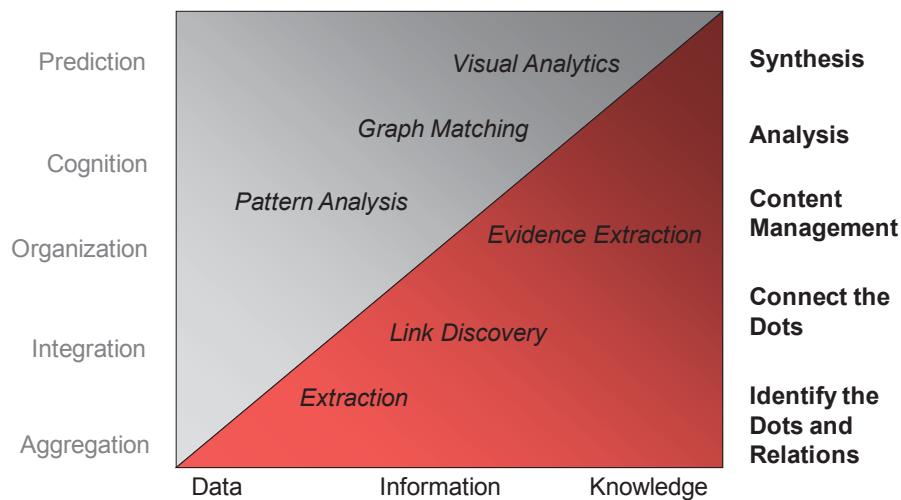
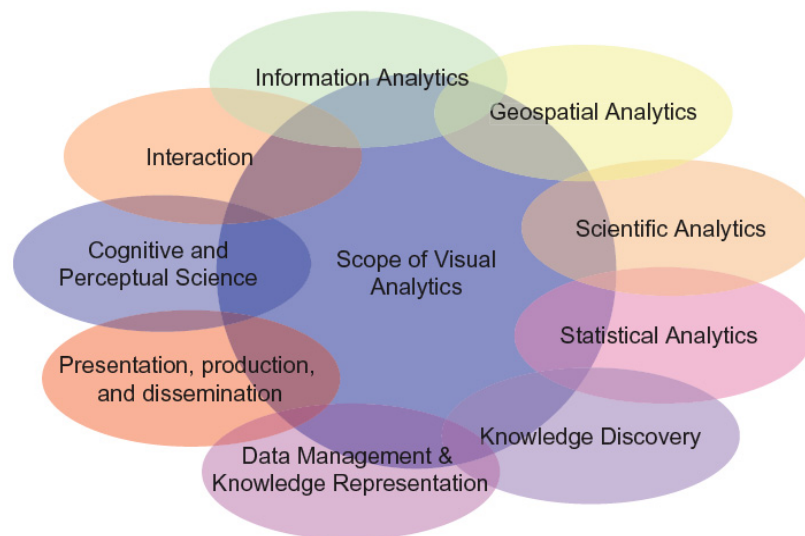


Figure 1: Analytical Reasoning & Visual Analytics [7].

Visual analytics is a multidisciplinary field that includes the following focus areas:

- “analytical reasoning techniques that let users obtain deep insights that directly support assessment, planning, and decision making;
- visual representations and interaction techniques that exploit the human eye’s broad bandwidth pathway into the mind to let users see, explore, and understand large amounts of information simultaneously;
- data representations and transformations that convert all types of conflicting and dynamic data in ways that support visualization and analysis;
- techniques to support production, presentation, and dissemination of analytical results to communicate information in the appropriate context to a variety of audiences”.[6]

The challenge of making visual analysis effective calls for advancement in a variety of research fields where much valuable prior work has been done. Figure 2 shows a non-exhaustive list of scientific disciplines that are relevant to VA [8]. Visualization, interaction science and analytical reasoning are three research domains that bring highly important scientific concepts to VA and these are described in the following sections.



*Figure 2: Visual analytics as a highly interdisciplinary field of research [8].*

## 3.2 Visualization

Humans discovered a long time ago that they could enhance their cognitive abilities by using external representation aids [9]. The use of visualization to present information is not a new phenomenon. It has been used in maps, scientific drawings and data plots for over a thousand years. For example, Figure 3 shows Minard’s map of Napoleon’s invasion of Russia. This flow map was published in 1869 on the subject of Napoleon’s disastrous Russian campaign of 1812.

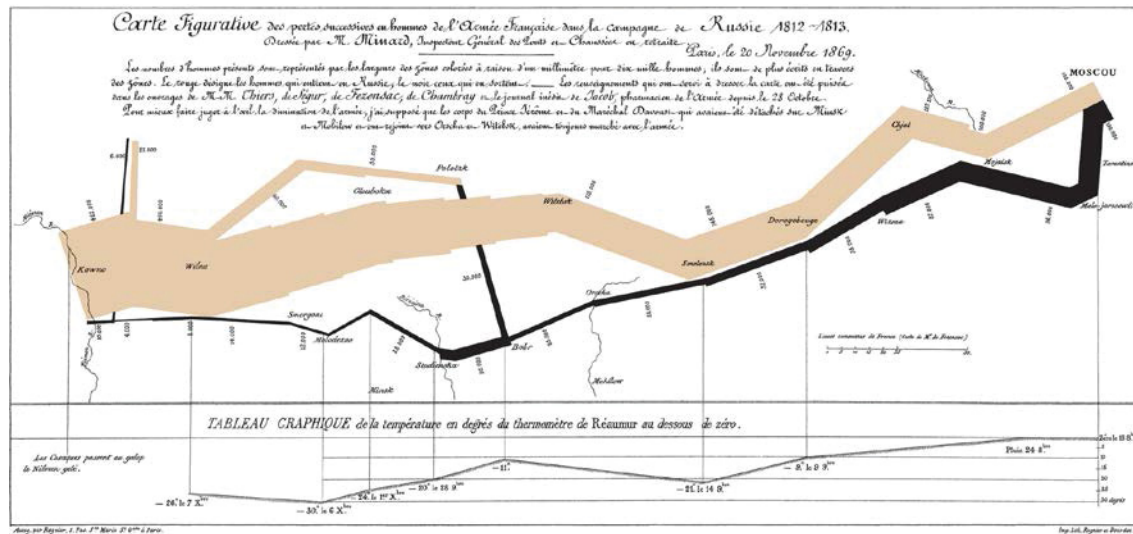


Figure 3: Representation of Napoleon's invasion of Russia [10].

The graph displays several variables in a single two-dimensional image [10]:

- the army's location and direction, showing where units split off and rejoined,
- the declining size of the army (note e.g. the crossing of the Berezina river on the retreat),
- and the low temperatures during the retreat.

The intent of visualization is not merely to display information using pictures. The visual representation should be designed in a meaningful way in order to provide insight to the user. The optimal choice is highly dependent on the data involved and the task to be performed.

Information can be presented visually using points, lines, shapes, colors, intensity, textures, motion, etc. To select effective visual cues for data representation, we can use results obtained from the study of human perception. Preattentive features form a set of visual properties that are detected very rapidly and accurately by the low-level visual system. These properties were initially called preattentive since their detection seems to precede focused attention. This process is effortless, meaning that it does not demand attentional resources for a human. In each case presented in Figure 4, a unique visual property in the target allows it to “pop out” of the display. Examples of tasks that can be performed using preattentive features are: target detection, boundary detection, region tacking; and counting and estimation [10]. In Figure 5, the use of semantic depth of field makes some chess pieces more salient to guide user's attention [11].

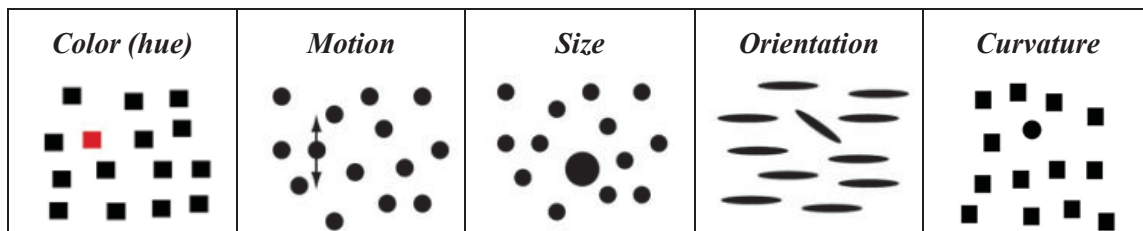
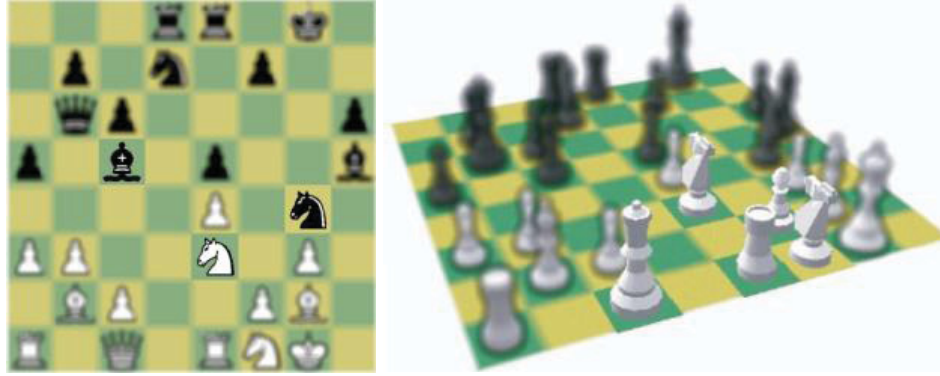


Figure 4: Examples of preattentive visual features (adapted from [10]).



*Figure 5: Semantic depth of field relies on preattentive features to offer a focus + context view. Focusing effects can highlight information [11].*

Color in information presentation is mostly used to distinguish one element from another [12]. Contrasting colors are different and draws attention, while analogous colors are similar and groups elements (see Figure 6). As [13] puts it: “avoiding catastrophe becomes the first principle in bringing color to information: Above all, do no harm.” Chosen poorly, colors can obscure the meaning of information.



*Figure 6: Contrast and analogy [12].*

The Gestalt laws of organization describe how people perceive visual components as organized patterns or wholes, instead of many different parts [14][15]. According to this theory, there are six main factors that determine how we group things according to visual perception: closure, similarity, proximity, symmetry, continuity and common fate.

Inattentional blindness, also known as perceptual blindness, refers to the inability to perceive features in a visual scene when the observer is not expecting them. Salient features within the visual field will not be observed if not processed by attention because the amount of information processed at any particular time is limited. In an experiment, 50% of subjects that were asked to watch a short video in which two groups of people pass a basket ball around and asked to count the number of passes failed to notice that a woman wearing a gorilla suit had walked through the scene [16].

### 3.3 Interaction

Interaction enables the user to explore the data, try out hypotheses, drill into data, gain insight, and collect knowledge. Human computer interaction has been an active research field for many years and is the study of interaction between people and computers. Visualization is considered interactive if control of some aspect of the information presented is available through a human input and the changes made by the user are incorporated in a timely manner.

Three categories of responsiveness (0.1s, 1s, and 10s) have been suggested to give an order of magnitude of the required response time for interactivity [17][18]. 0.1s is the upper limit for the system response to feel instantaneous. After more than 1s, the user's flow of thought is interrupted and the user loses the feeling of operating directly on the data. For delays longer than 10s, users will want to perform other tasks while waiting for the computer calculation to complete.

The famous visual information seeking mantra for designing advanced graphical user interfaces “overview first, zoom/filter, details on demand” comes from the interaction taxonomy from [19]. More recently, [20] proposed seven general categories of interaction techniques in information visualization:

- *Select*: mark something as interesting;
- *Explore*: show me something else;
- *Reconfigure*: show me a different arrangement;
- *Encode*: show me a different representation;
- *Abstract/Elaborate*: show me more or less detail;
- *Filter*: show me something conditionally;
- *Connect*: show me related items.

These categories are organized around the user's intent while interacting with the system rather than the low-level interaction techniques provided by the system. They also point out that “for different representation techniques, different interaction techniques are used to perform a similar task or achieve a similar goal”. [20]

### 3.4 Analytical Reasoning

Visual analytics is intended to be an active, engaging exploratory process of discovery. This human-information discourse is between the analyst and his data. It supports three goals: assessment (understand current situation and explain past events), forecasting (estimate future capabilities, threats, vulnerabilities and opportunities) and planning (develop options, create possible scenarios, and prepare reactions to potential events). Analysts apply reasoning techniques in order to achieve these goals. Visual analytics is meant to facilitate high quality analysis with a limited quantity of user's time. Six basic ways were identified in how information visualization can expand human cognition [9].

- *Increased resources*: high-bandwidth hierarchical interaction, parallel conceptual processing, offload of work from cognitive to perceptual system, expanded working memory and expanded storage of information.
- *Reduced search*: locality of processing, high data density and spatially-indexed addressing.
- *Enhanced recognition of patterns*: recognition instead of recall, abstraction and aggregation, visual schemata for organization, and enhanced patterns and trends.
- *Perceptual inference*: visual representations make some problems obvious, and complex specialized, graphical computations can be enabled.
- *Perceptual monitoring*: visualizations can allow monitoring of a large number of potential events.
- *Manipulation medium*: visualizations can allow exploration of a space of parameter values and amplify user operations.


## 4 Collaborative Technologies

### 4.1 Collaborative Working Concepts

In order to maintain general maritime domain awareness, government agencies and other organizations need to cooperate and coordinate. However, when threats are identified, collaboration is necessary. This is particularly the case when multiple agencies, for example within the MSOC, must share and process information about a Vessel of Interest (VOI) and monitor closely its activities.

Winer and Ray [21] provide the following characteristics for Cooperation, Coordination and Collaboration:

*Table 1: Key characteristics of Cooperation, Coordination and Collaboration [21].*

Cooperation	Coordination	Collaboration
Lower intensity  Higher intensity		
Shorter-term, informal relationships	Longer-term effort around a project or task	More durable and pervasive relationships
Shared information only	Some planning and division of roles	New structure with commitment to common goals
Separate goals, resources and structures	Some shared resources, rewards, and risks	All partners contribute resources and shared rewards and leadership

Collaboration can take place along two intertwined dimensions: whether collaboration is co-located or geographically distributed, and whether individuals collaborate synchronously (same time) or asynchronously, as represented in the Computer Supported Cooperative Work (CSCW) Matrix in Figure 7. As shown in that figure, a number of software and hardware solutions are available to provide collaboration. They go far beyond the rather simple technical aspect of connectivity and involve cultural, procedural, technological and organizational challenges.

Asynchronous collaboration allows participants to interact with its peers at different time through use of enabling technologies such as email, blogs, newsgroups, and large public displays. Synchronous collaboration, on the other hand, focuses on real-time collaboration. Team members communicate and share ideas concurrently. Both formal and ad hoc collaboration sessions can be held through virtual meetings, video conferencing, and non-technical means such as whiteboards.



Synchronicity of collaboration is not sufficient to provide alone a distinctive characteristic to define collaboration and provide a measure of its intensity. For example, under high collaboration intensity, asynchronous means are still heavily used and in addition are able to provide the necessary eventual audit traceability on the decisions that are made by the group in a near real-time manner [22].

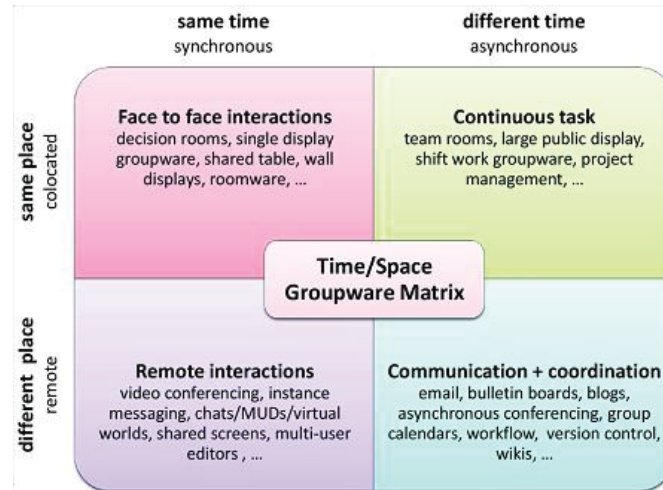


Figure 7: CSCW matrix [23].

In addition to the Time and Space dimension of collaboration, Bureau and Holmes [22] have identified two other important dimensions to collaborative working: the nature of collaboration and the maturity levels of collaboration. They produced the following taxonomy of collaborative working based on three pillars: Time and space collaboration; Nature of collaboration; and Maturity levels of collaboration.

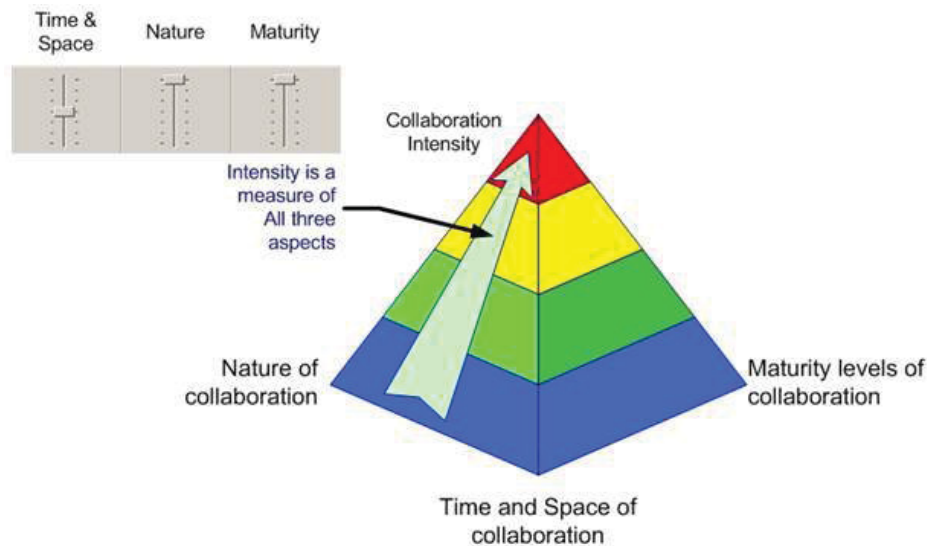


Figure 8: A three pillar taxonomy of collaborative working [22].



“Not all collaborations are alike as the very nature of human interactions taking place has a deep influence on the collaboration itself. The nature of collaboration focuses on interdependence relationships between participants. Collaboration implies at least a bidirectional relationship between peers” [22]. Three major factors have deep influence over the interdependence relationship between participants:

- The symmetry of knowledge relationship is referring to the essence of the share itself and the status between the participants. It is related to the knowledge transfer that takes place during the collaboration;
- The functional relationship is referring to the hierarchical relationship inside a structure that could impede or ease the collaboration process. This is more obvious in a military command structure where a commander’s presence or management style directly affect the collaboration process;
- The number of participants is playing a significant role in collaboration by the richness it brings in the collaboration process when little or no subordination is seen inside a group.

In terms of the nature of the collaboration, it is also necessary to distinguish the different backgrounds and roles of the collaborators, and the social/behavioural human dynamics that are established inside any given collaboration process. The following are four typical roles [22]:

- Leader/Follower. This posture is the weakest form of collaboration, in which a leader simply tells a follower to perform a task where the leader knows how to do it but does not want to spend the time on it. Little or no knowledge is transferred between the two collaborators.
- Mentor/Apprentice. This posture is distinguished by the symmetry of knowledge and status between collaborators and also by the significant knowledge transfers that occur during collaboration. The mentor shares with his apprentice the same knowledge baseline, so it cannot be taken as asymmetry of knowledge.
- Similar Peers. This is similar to a mentor/apprentice nature of collaboration. Similar-peer is characterized by the symmetry of knowledge, interests, and status between collaborators. It is also characterised by a higher number of collaborators involved in a collaborative session than the leader/follower or mentor/apprentice types. Exchanges are now both multilateral and more dynamic (even highly interactive). This signifies the emergence of collective knowledge and collective thinking concepts.
- Different Peers. This posture in collaboration reintroduces the notion of “asymmetry of knowledge” between participants. This asymmetry of knowledge should be seen as complementary skills, viewpoints and expertise that constitute a unique collective knowledge only possible through collaboration.

The more people have been collaborating in the past, the easier it is for them to continue collaborating. Their maturity level in terms of collaboration is based on five enabling conditions or success factors [22]:

- Shared objectives/end-state among participants and sense of urgency;
- Formal communication processes (protocols);
- Commitment and sense of belonging;

- Open communication, interoperability among participants, mutual trust and respect; and
- Complementary, diverse skills and knowledge, intellectual agility and autonomy of thinking.

As part of the 11jm project, various collaboration concepts and solutions have been considered and explored.

## 4.2 Multi-Agency Common Space

There are two important impediments to collaboration within multi-agency settings, such as the MSOC. First, each organization uses different applications. Second, there are jurisdiction constraints in sharing information. Fortunately, there are a number of software architectures and collaborative environments that can help support collaborative working.

It is proposed to setup a collaborative space (see Figure 9), which all agencies would be connected to in order to share information. The agencies networks would be connected to this collaborative space through a data diode and/or a fire wall, allowing them to move and share the required information, for example about a VOI. This shared area will be exploited by the collaboration infrastructure and applications.

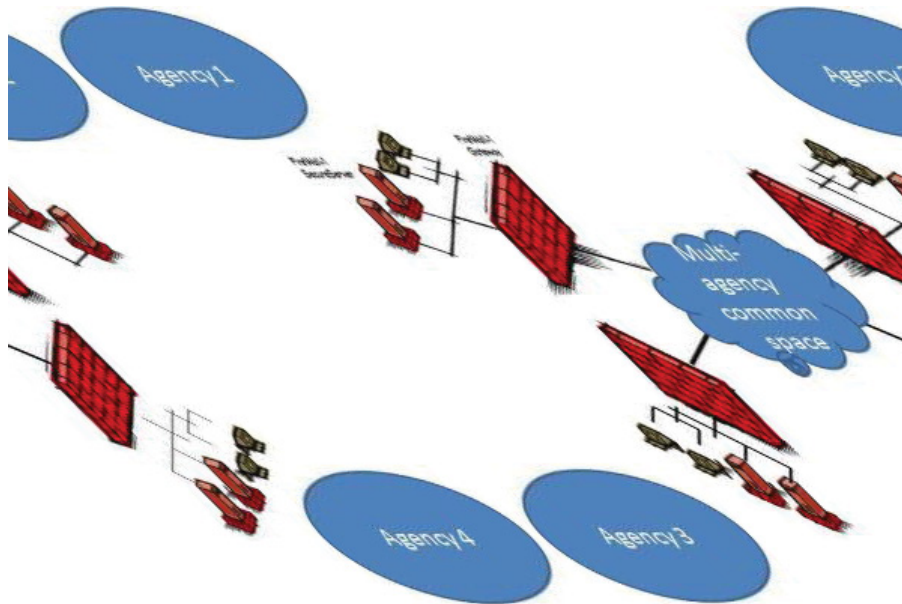


Figure 9: Schema of a multi-agency common space.

## 4.3 Common Operational Pictures and User-Defined Operational Pictures

The capacity to share information and build shared situation awareness within a team is seen as a critical element of optimal team functioning. This is often supported by a capability known as the Common Operating Picture (COP). The US Doctrine Dictionary defines the COP as “a single identical display of relevant information shared by more than one command. A common operational picture facilitates collaborative planning and assists all echelons to achieve shared

situational awareness” [24]. Another definition, espoused by DRDC Valcartier, is “the integrated capability to receive, correlate and display heterogeneous sources of information in order to provide a consistent view of the battlespace” [25]. This definition focuses on the integration capability versus the end product. Moreover, the end product is not simply a picture but an understanding of a common view.

The use of a COP in operational environments raised some problems and challenges to meet today’s and tomorrow’s needs. Some of the key issues with the COP are that:

- a user gets what somebody else decided he needs;
- the common view does not meet all user needs;
- much manual information management is needed.

All of this motivated the consideration for user-defined operating pictures (UDOP), that “are based on a common view but tailored to individual needs (content and depiction); allow users to pull the information they want or specify it and have it pushed to them; define the resultant picture as a sharable artefact; and enable creation of composite, shareable, customized information products” [26]. In accordance with User Defined Operational Picture concepts, team members can assemble the operational picture using a variety of apps, running on many portlets, on multiple displays, and if necessary in different locations.

Information portals have provided an efficient solution to implement COPs and UDOPs, enabling organizations to access, share and manage information and knowledge pertinent to the organizations.

“Seen from a technical point of view, portals are frameworks, which integrate various tools and applications together in a common framework” [27]. All information can be cross-linked and stored once; updates can be assured and the intellectual capital of the organization protected. This type of portal can offer a complete environment for everyone in the organization to do his or her job, completely and seamlessly integrated with the desktop.

The overall benefits are [27]:

- A single point of sharing and communication in the organization;
- Elimination of duplicate information;
- Reduction in information overload;
- Improved communication with all partners and customers;
- Access to a consistent set of applications with support and backups;
- International and multi-site collaboration without difficulties of shared drives and similar issues;
- Simple cross-functional cross-organization communication;
- Creating norms of information sharing and knowledge creation for the organization; and
- Communicating new reward systems, which emphasize knowledge sharing.

DRDC, as part of the COP 21 Technology Demonstration Program, has developed a vision for a contextual user-centric, mission-oriented Knowledge Portal, where each individual could access the right information from any sources in context of the tasks to be performed, and at the same time, support collaboration [27].

In short, the envisioned portal had the following requirements:

- Provide basic document management and information exchange/distribution services;
- Allow a federated access to multiple types of information from any media and from varying levels of abstraction;
- Allow arbitrary navigation and semantic connections to any sources and products;
- Take into account user individual interests and group constraints within a dynamic and evolving task context;
- Allow synchronous and asynchronous collaboration within groups of users; and
- Include a variety of services, such as personalization, contextual search, task-oriented, work-specific toolset, dashboard, multiple operations monitoring, briefing production and configuration.

Figure 10 shows an example of the COP 21 Knowledge Portal, where information is presented using multiple portlets [28]. Moreover, users can segment the information according to mission or theme portfolios. The portfolio manager displays the various pieces of information as a tree view, as illustrated in Figure 11, where a portfolio has been setup to assemble information about terrorist threats. Authenticated users may select a working portfolio, expand or collapse folders within that portfolio and select entries to display from portfolios/folders into the portal portlets.



*Figure 10: Example of the COP 21 Knowledge Portal.*

Portfolios can be shared amongst users and, as portfolios point to information, there is no duplication of information or version control issues. As new information is added or updated in a portfolio, the information becomes available to all users registered to that portfolio. Users are automatically notified of the new information through an event notification tool and are made aware of the portfolio entries that have changed since the last time of consultation.



Figure 11: Portfolio Navigator showing portfolio folders and entries.

## 4.4 Collaborative Environment Components

### 4.4.1 Knowledge Walls

Perhaps the simplest model of collaboration is through the use of a large group display, also called a knowledge wall. Control of the displayed information related to various tasks can be shared among an assembled team of analysts, each of whom can view contributions from the others in real time. Knowledge walls are already common in operation centers.

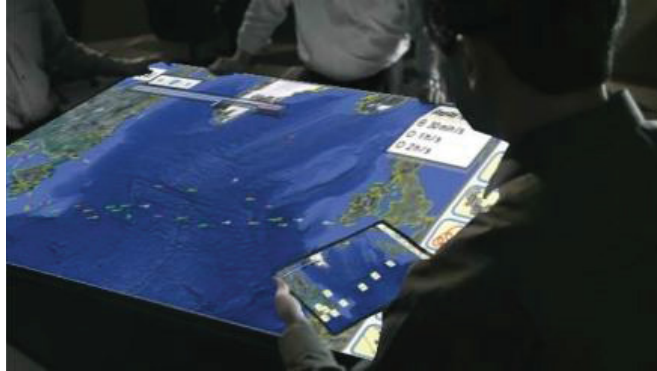
### 4.4.2 Multi-Touch Tables

In addition to the use of knowledge walls, a collaborative environment can include multi-touch tables. “The use of a multi-touch table environment has much potential for use with visual analytics. The most exciting prospect is the ability for multiple analysts to simultaneously explore the same data/information space” [30]. A unique advantage of multi-touch tables is that at all times, all collaborators have equal opportunity to participate in the analysis: control is neither centralized nor passed from person to person. Users can gather around the display surface; eye-to-eye interaction is provided; information is at the users’ fingertips; multi-touch interaction can improve user efficiency for several tasks; and globally, this can lead to improved shared awareness.

Various techniques are available to track which individual makes each gesture so that roles, responsibilities and privileges specific to individuals can be supported. Techniques include instrumenting the users [31], using pens [32], smart phones [33], tracking users’ locations around the tabletop [34], orientation of fingers [35] or hand contour [33].

### 4.4.3 Workstation and Tablet Computers

Finally, the collaborative environment can include workstations and tablet computers. A common collaboration pattern is to assign sub-tasks to individuals who work separately and then bring the results back to the collaboration space. Tablets hold particular appeal because they can “move with the group”. Figure 12 shows an individual attending a collaborative meeting with his tablet. Based in concepts illustrated in [36], he would be able to push information from his tablet to the multi-touch table or inversely.



*Figure 12: Combining personal device and multi-touch table interaction (adapted from [36]).*

## 4.5 Smart Room Environments

A smart room or intelligent environment is a “space in which computation is seamlessly used to enhance ordinary activity” [37], or a space “that is able to acquire and apply knowledge about the environment and its inhabitants in order to improve their experience in that environment” [38]. “The generic goal of such environments is to support group interactions at real time and in an intelligent way” [39]. In other words, smart room environments are physical spaces that are instrumented with various networked sensors and devices and support ubiquitous computing permitting to sense, interpret and react to human activity in order to enable better collaboration, increased productivity, creative thinking and decision making. Collaboration can take place within and across meeting rooms.

Closely related is a new science and technology area called “Ambient Intelligence” that applies to the instrumentation and support of smart room environments. Ambient intelligence is defined as “a digital environment that proactively, but sensibly, supports people in their daily lives” [40]. Ambient Intelligence “emphasizes or mainly deals with user-friendliness, more efficient services support, user empowerment, and support for human interactions. It builds on three recent key technologies: Ubiquitous Computing, Ubiquitous Communication and Intelligent User Interfaces” [41].

Additionally, in order to develop awareness of what is taking place in a smart room environment, there is a need to identify the people in the room or suite of rooms, determining their location and tracking their activities. This can be achieved using techniques ranging from badges, Radio-Frequency Identification tags, id-sensors (biometry) and computer vision. “Tag-based methodologies tend to be obtrusive, requiring the individual to continuously wear them, however

small the tag maybe. Some of the biometric techniques, such as fingerprint and iris scans, require a ‘pause-and-declare’ interaction with the human. They are less natural than face, voice, height, and gait, which are less obtrusive and hence are better candidates for use in smart environments” [42]. Audio/video recognition systems (using sensors such as the MS Kinect) could be used to track what activity or task a user is conducting, such as talking to another person or writing on a white board. Multiple techniques can be used which would then require a multimodal fusion system.



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## 5 Opportunities for Maritime Domain Analysis

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### 5.1 Methodology

Task analysis activities were conducted to identify the opportunities and potential requirements for the application of VA in the RJOCs. Our methodology included the review of previous knowledge elicitation studies from related DRDC research projects [43][44]. Then, we organized site visits at the RJOCs in Halifax and Esquimalt, where we were also able to observe duty personnel directly in their work environment. The domain knowledge was gathered through a mix of interviews, observations, and group discussions, and then documented in a report [45].

### 5.2 Opportunities Identified

The latest requirement elicitation activities conducted at the RJOCs identified nine opportunities for applying VA to MDA, along with the information that needs to be represented, limitations of the current approaches/technologies, resulting cognitive overload, applicable visual analytics technologies, and potential features required. For a detailed analysis of each opportunity, refer to [45].

#### 1. Collaborative Visual Analytics of a Vessel of Interest

When a decision is made to designate a ship as a VOI, a number of people at the RJOC work together to collect, interpret, and co-present as much information as possible about the vessel. VOI information is a mixture of geospatial and temporal shapes, commercial facts, photographs, schedules, etc. A collaborative visual analytics of a VOI solution would provide a collaborative multi-dimensional fusion space in which all the different information about a single track could be co-visualized and linked, and all collaborators would see their work and others' work rendered in meaningful ways, during the research process.

#### 2. Visualizing Normal Maritime Behaviour

When asked to describe their deficiencies, a large number of the personnel's suggestions related to understanding what is normal in each domain of interest, and communicating that knowledge to new analysts. A VA solution to visualizing normal maritime behaviour would begin with data mining of the RJOC archives and data warehouses, and would overlay specialized visualization and model-building capabilities. Analysts would be able to efficiently explore the domain and access a wide variety of statistics and patterns not normally visible to watch keepers.

#### 3. Wide Area Surveillance

Wide area surveillance is aimed at understanding everything that has happened, is happening, and is likely to happen, in a wide Region of Interest (ROI). A visual analytics for wide area surveillance solution would provide a multi-dimensional portrayal of the ROI and associated spaces (e.g. corporate relationships) that could be used to gain a more intuitive awareness of events and conditions in the whole ROI.

#### **4. Analysing Sensor Data Streams**

The RJOCs need to know about the integrity of its information sources and data streams. A data stream viewer VA capability would provide a visual space in which the massive streams of surveillance data can be visualized, monitored, and their statistics analyzed. Analysts would be able to visualize sensor status, sensor coverage patterns, data-link status, traffic patterns as a function of time, and data quality. This would support the detection of anomalies in the data traffic and investigation of the causes.

#### **5. Analysing Intellipedia Connections**

Interest was expressed in deploying a Canadian version of the US intelligence wiki “Intellipedia” [46]. There have been many initiatives to automatically visualize wikis, in part because wikis are very rich in inter-connections. This raises the possibility of deploying a VA capability to explore the wiki and identify higher-level patterns in the information.

#### **6. Analysis of Surveillance Coverage**

RJOC operators currently have no direct way of knowing whether surveillance aircraft have visited a region in an Area of Responsibility (AOR). A surveillance coverage analytics application would allow an operator to visualize the complex overlaps between surveillance swaths and vessel motion to determine the extent and the shape of any gaps in surveillance coverage.

#### **7. Visual Analytics for Knowledge Indexing**

Personnel described a need for help in learning about available knowledge assets when first assigned, maintaining telephone lists on many different systems, and knowing who to call when an unexpected crisis occurs. A VA solution would crawl databases and web sites to develop clusters of information using categories such as people, organizations, procedures, and information resources. It would then use visualization techniques to present them. Such a tool could be used for example to build a knowledge base of contact information of people and organization with different expertises, both in the CF and in other government departments, related to the operation in place. These requirements bring to mind the Knowledge Mapper or “KMapper” tool being developed by DRDC Valcartier [47]. The KMapper comes close to qualifying as a visual analytics tool – it has sophisticated interactive graphics – but it lacks any real support for analytical activity.

#### **8. Analysis of Intelligence Reports and Media Feeds**

Intelligence analysts at the RJOCs scan a variety of publications in search of information that may help the Navy better achieve its mandate, and all-news video stations are normally shown in the main operations room. RJOC analysts also author a number of intelligence reports for consumption by Canadian and Allied operational staff. Many of the intelligence publications are classified as Secret or higher. There are well-established VA tools for extracting intelligence information from large text repositories. Tools for analysing video feeds are more recent but they are emerging. This kind of tools might prove useful in

searching for patterns in an intelligence report, a video stream, or perhaps in other text repositories at the RJOCs.

## **9. Visualization of a Special Event**

Large events such as the 2010 Winter Olympics in Vancouver require a massive mobilization of security forces, including excellent collaboration between various security agencies. The Canadian Forces set up a separate task force (Joint Task Force Games) to coordinate their contribution to the 2010 Winter Olympics, which is indicative of the scale of their operation. VA solutions could help support a future special event of similar magnitude, such as G8 world leaders meetings. This potential situation points back to many of the challenges of the previous eight opportunities.

## **5.3 Selected Opportunities**

The scope of 11hm ARP does not allow addressing all of these potential applications of visual analytics and collaborative technologies. Rather, the 11jm project subsequent activities were focused on:

- Collaborative VA of a Vessel of Interest (CVAV), corresponding to Opportunity #1, and
- VA-based Anomaly Detection (VADA), which is a mix of Opportunity #2 Visualizing Normal Maritime Behaviour and Opportunity #3 Wide Area Surveillance, with an added focus on identifying maritime anomalies in the RMP.

We believe that these applications have the highest potential to gain improvement from VA solutions. However, the other opportunities were all documented and could be the basis for future research projects.

## **5.4 Collaborative Analysis of a VOI**

The RJOCs and MSOC agencies do not have enough manpower to fully analyze and interpret every vessel in Canada's area of responsibility so they use triage to identify VOIs that are worthy of special attention. The identification and tracking of VOIs is a key activity of the RJOCs and of the MSOCs. A VOI is designated by DND, a MSOC partner or an international partner such as the US Department of Defense. Once a VOI has been declared, multiple agencies and individuals collaborate to collect, interpret, and disseminate as much information as possible about the vessel.

Detailed analysis of a VOI is necessary to understand the intentions of the ship and whether it may represent a threat. To this end, the information that needs to be visualized is a mixture of ship tracks, photographs, schedules, self-reported information, commercial facts, and intelligence information.

However, as indicated in [48], analysis of a new VOI with current methods is manpower-intensive and can take days. This means a dramatic limitation on the number of ship tracks and volume of related data that can be collected and analyzed, relative to the tens of thousands of

ships that operate daily in the maritime domain. The current tools are limited in their ability to exploit new technologies (e.g. incorporation of metadata, use of advanced ship-tracking technologies) and to incorporate information into a comprehensive picture.

Underlying purposes for VOI analysis include:

- *Assert Sovereignty*: let the world know that Canada is aware of a VOI's behaviour, because a country that is not aware of activities in its oceans has a weaker claim on sovereignty over those oceans.
- *Anticipate Problems*: understand how a VOI might become a threat, or might be the subject of a threat.
- *Prevent Problems*: provide information to the VOI or to enforcement agencies to forestall future problems with that ship.
- *Detect Problems*: develop an understanding of what is usual, intended, and specifically planned for this ship so that deviations can be detected.
- *Respond Better to Problems*: in the event of a problem, provide CF commanders with better operational options by giving them more detailed, more timely, and more accurate information.

## 5.5 VA-based Detection of Anomalies

“In maritime surveillance, there are many vessels at sea at every point in time, and the vast majority of them pose no threat to security. Sifting through all of the benign activity to find unusual activities is a difficult problem. The problem is made even more difficult by the fact that the available data about vessel activities is both incomplete and inconsistent. In order to manage this uncertainty, automated anomaly detection software can be very useful in the early detection of threats to security” [49].

Maritime domain operators/analysts have a mandate to be aware of all that is happening within their areas of responsibility. This mandate derives from the needs to defend sovereignty, protect infrastructures, counter terrorism, detect illegal activities, etc., and it has become more challenging in the past decade, as commercial shipping turned into a potential threat. In particular, a huge portion of the data and information made available to the operators/analysts is mundane, from maritime platforms going about normal, legitimate activities, and it is very challenging for them to detect and identify the non-mundane [50].

NATO countries have been exploring fusion-based and rule-based approaches to anomaly detection. Moreover, DRDC has conducted significant R&D work in exploring rule-based systems for maritime anomaly detection. Comprehensive knowledge acquisition sessions in anomaly detection were conducted with subject matter experts and an ontology of anomalies was produced [50].

Examples of maritime anomalies are the following:

- Failure to reach a reported estimated time of arrival at a specified point
- Loss of reporting
- Movement that suggests activity of concern, such as very close proximity to other vessels in open waters
- Significant variance in voyage/route compared to historical trace of other recent voyages
- Unexpected or illogical course and speed changes
- Ships going where there is no port
- Divergence of AIS (Automatic Identification System) and radar

Although fusion-based and rule-based approaches to anomaly detection are very promising, it is felt that the use of VA could complement these approaches. Some typical questions an intelligence analyst may ask that could involve VA at one point are the following:

- Where is this ship? Where is it going? What is the best way to track it (sensor-wise)?
- Does this crew operate where it is supposed to?
- Is this ship following a normal route, taking into account the weather?

In a maritime domain awareness context, analysts also want to understand what is normal so that they can rapidly detect what is abnormal. In particular, watch officers and analysts need to know what the normal routes for different categories of ships are. They also want to know what the “pattern of life” in an area is.

Currently, the available knowledge about maritime behaviours, trends and patterns is largely built up from individual analyst’s experience and mentoring from more experienced analysts. Various elements of information are of interest to help understand normal maritime behaviour such as historical commercial routes and fishing areas. Analysts must also understand how external factors, such as seasonal activities, meteorological conditions and economic influences affect the maritime activities or sensor performance.

There exist techniques and strategies to model normal maritime behavior. “In a marine environment, there are nearly an infinite number of routes vessels can follow. However, to make a first order approximation of the majority of traffic, a logical approach is to define a few major traffic routes for an AOI (Area of Interest). Although not all traffic will follow these routes directly, they do capture the majority of transiting vessels and the typical time required to transit through an area” [51]. Moreover:

- commercial shipping transits along great circle routes to reduce time and distance between ports;
- because of natural choke-points, many routes are often funnelled together to reduce the number of routes to major ports;

- the best way to outline the major routes is to observe a map of RMP traffic over a significant period of time and highlight the routes with the most density. Ideally, the period of time should be long enough to collect data, but short enough to observe seasonal traffic variances.

One approach often considered is automatic anomaly detection. To this end, a DRDC project [52], has successfully explored the use of rule-based and description logic expert systems and identified a taxonomy of anomalies of interest (Figure 13). It describes 28 anomalies that would be of interest to the RJOCs, though many of them were not normally detectable using the information routinely available at the RJOCs at the time this study was done. Validation of alerts still needs to be done by human analysts. There are some anomalies however, either difficult to describe in a formal language or simply unexpected, that the automated rules will miss.

In contrast, VA detection of anomalies takes full advantage of the human ability to explore, create hypotheses and analyze what is going on. The computational strength of the machine is exploited in another way through the use of clever visualization, automatic clustering, and interactive analytical algorithms.

Even though we will leverage automated reasoning for anomaly detection from previous activities [52], our intent is to focus on innovative visual apps that help the operator detect unexpected anomalies by exploring the maritime situation.

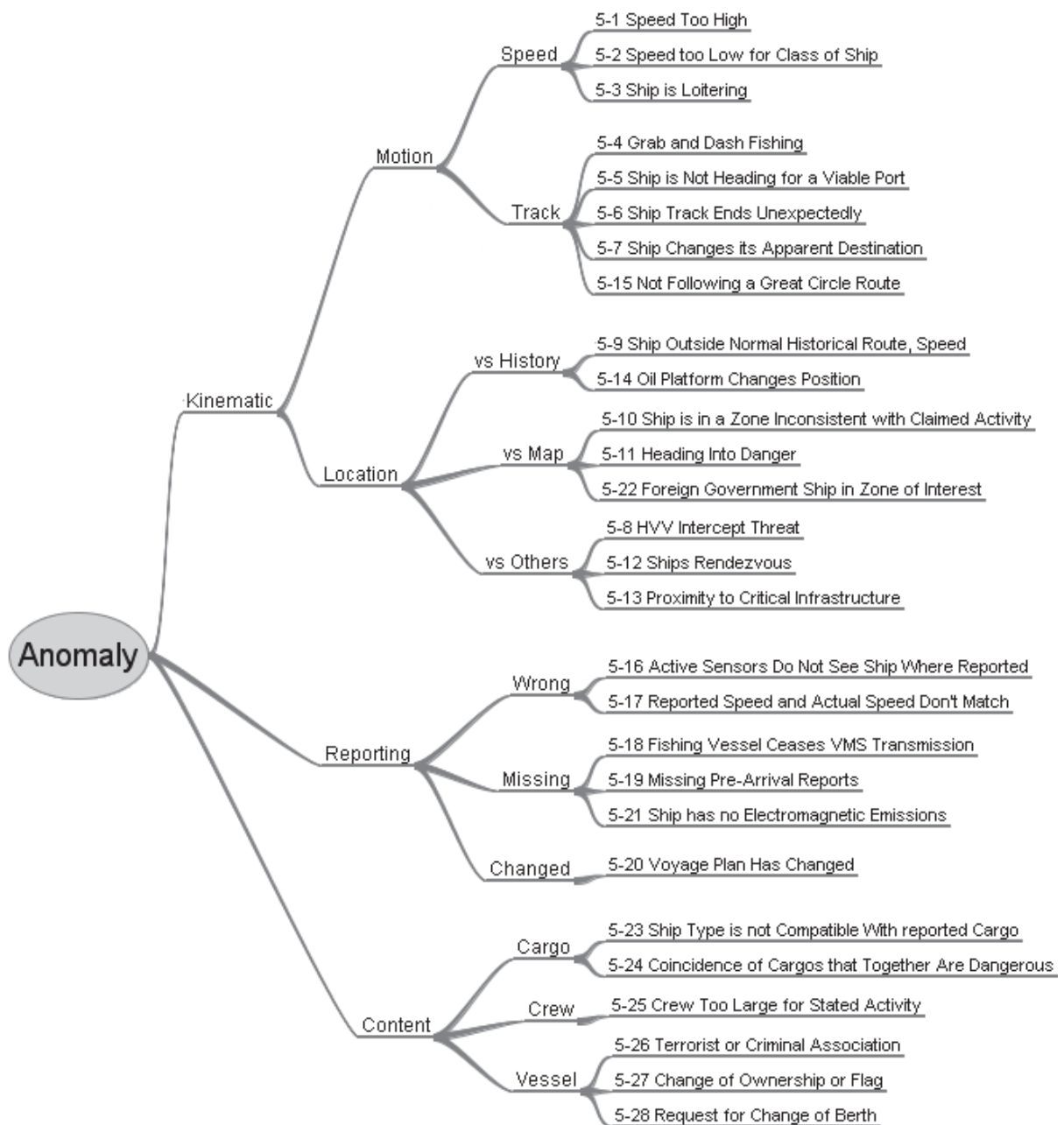


Figure 13: Anomalies of Interest as Identified by RJOC Experts. This taxonomy (from [53]) was first developed at a two-day workshop with subject-matter experts from RJOC(A) [44].

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## 6 Related Work

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### 6.1 Visual Analysis of Trajectories

Extensive work on the visual analysis of movement data led to the definition of aggregation methods suitable for movement data and to VA ways to visualize and explore the statistical patterns from trajectories [54]. Interactive Kohonen maps were also used for trajectories aggregation [55].

Clustering of trajectories helps analyze large group behaviours, but it does not easily allow visual identification of anomalous tracks. To this end, [56] produced ship density landscapes in which ships that are off historic routes and regular traffic lanes visually stand out. Vessel movement patterns can also be characterized using hybrid fractal/velocity signatures [57]. As analysts learn to visually interpret these signatures, they can recognize anomalous activities. Innovative tools for geotemporal visualization of trajectories exist [58].

### 6.2 Maritime Anomaly Detection

With some exceptions (e.g. [56] and [57]), published work regarding visual detection of anomalies is mostly concerned with network security [59]. The geo-temporal characteristics of vessel trajectory data are very different from computer intrusions, so new strategies are required. Vessel track analysis, for example, is multidimensional and can be affected by factors such as: time of the day/week/year, seasons, meteorological conditions, economic trends, and special events.

When considering maritime anomaly detection specifically, we rapidly find that research has largely focused on developing automated system that suggests potential anomalies to an operator for further investigation. Many of these maritime anomaly detection systems rely on models of normal/abnormal vessel kinetic behaviour to detect anomalies.

Self organizing maps were used and user can be involved in the anomaly detection process using interactive visualizations [59]. Reference [60] uses a Gaussian mixture model for maritime anomaly detection while [61] uses a Bayesian network. Spline-based trajectory clustering techniques were proposed by [62] to represent normal vessel behaviour for coastal surveillance. The use of a neurobiologically inspired algorithm for probabilistic associative learning of vessel motion was suggested by [63].

Rule-based expert systems rely on artificial intelligence rules derived from human expert knowledge acquisition activities. Such a system was built at DRDC [52], which we will use as an input in our prototype. This approach was also employed by [64].

### 6.3 Maritime Situation Analysis

Although the geospatial trajectory of a vessel is its most salient signature, maritime situation assessment requires the analysis of more varied data such as port visit history, owner relationships

and suspected criminal activities. The advantages of visualization for data mining applications are outlined by [65] and a number of examples are provided. The tight link between VA and data mining is also discussed by [66].

Visual exploration strategies can be used to extract patterns from past behaviour in a dynamic geo-spatial area of interest. For example, in Figure 14, the study of Somali pirate attacks shows that the attack pattern changed in response to the creation of the Maritime Security Patrol Area.

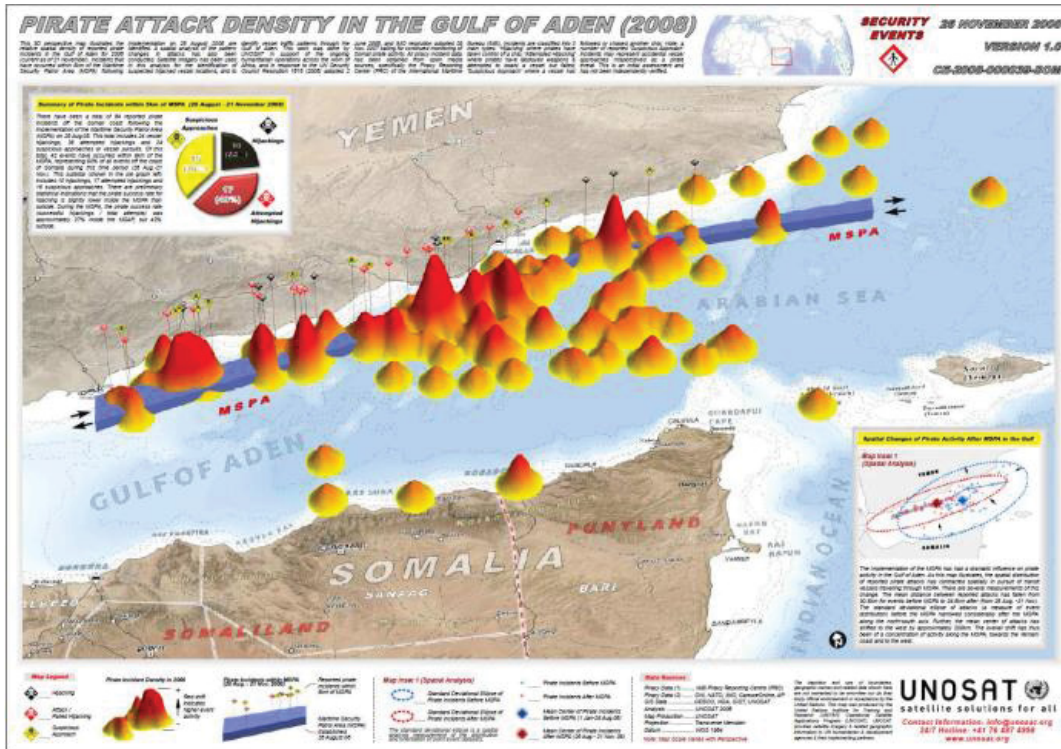


Figure 14: Visualization of pirate attacks evolution over time in the Gulf of Aden [67].

VA techniques have not been used in focused analysis of specific entities in the maritime domain. General trends were often identified but the visual analysis of individuals has received much less attention.

## 6.4 Design Considerations for Asynchronous Collaboration

“There is evidence that, due in part to a greater division of labor, asynchronous decision making can result in higher-quality outcomes, broader discussions, more complete reports, and longer solutions than face-to-face collaboration” [68]. Heer and Agrawala [69] have compiled design considerations for asynchronous collaboration in visual analysis environments, highlighting issues of work parallelization, communication, and social organization:

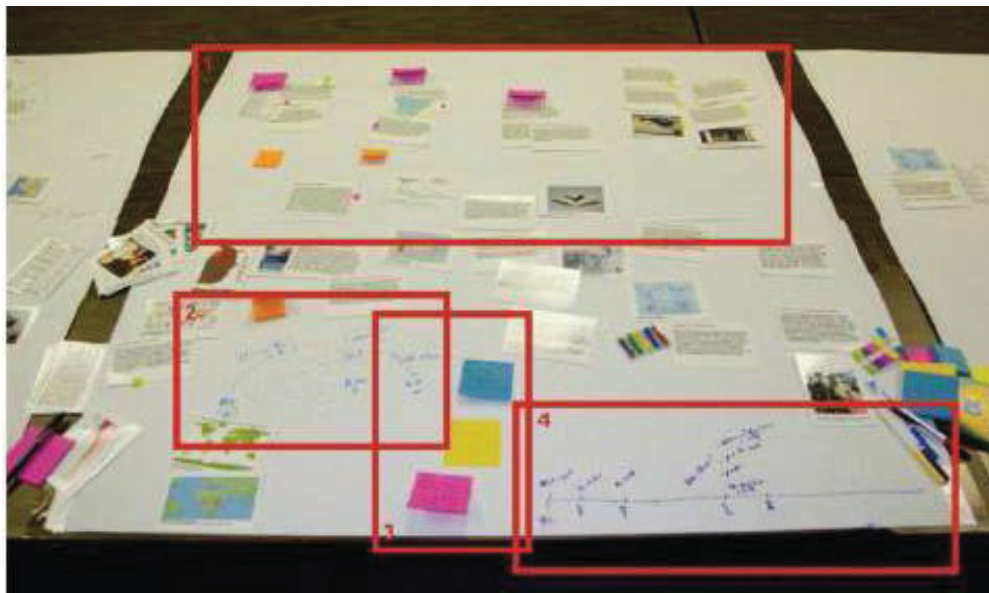
- Division and allocation of work. This involves the segmentation of effort into proper units of work, the allocation of individuals to tasks in a manner that best matches their skills and disposition, and the meaningful aggregation of the results.

- Common ground and awareness. Participants must be able to see the same visual environment in order to ground each others' actions and comments, bookmarking or sharing specific states of the visualization. They also require awareness of the timing and content of past actions.
- Reference and deixis. When collaborating around visual media, participants often need to refer to specific objects, groups, or regions visible on a display. References may be *general* ('northwest'), *definite* (named entities), *detailed* (described by attributes, such as the 'blue ball'), or *deictic* (pointing to an object and saying 'that one'; drawing a circle around a cluster of Items; or brushing / selecting a range of values in a chart).
- Incentives and engagement. There are incentives that could increase the level of contribution of participants in collaboration: Social psychological (e.g. as increased status / social visibility), hedonic (well-being or engagement experienced intrinsically in the work), monetary (material compensation). Design strategies would include providing personal relevance of the interface and data, and providing visibility of the contributions.
- Identity, trust, and reputation. Aspects of identity, reputation, and trust all influence the way people interact with each other. In collaborations where participants are not familiar with one another, mechanisms for self-presentation need to be included in the system design. Means of gauging a user's past actions or contributions are needed to aid awareness and to facilitate reputation formation.
- Group dynamics. Group management mechanisms can support the coordination of a work group on a specific task within a larger collaborative environment, providing notification and awareness features at the group level. Groups also provide a means of filtering contributions, improving tractability and reducing information overload for participants who may not be interested in the contributions of strangers. Increased group diversity can lead to greater coverage of information and improved decision making. However, diversity can also lead to increased discord and longer decision times.
- Consensus and decision making. From a design perspective, collaborators need communication mechanisms that allow points of dissent to be labelled and addressed, creating focal points for further discussion and negotiation. Formalizing contributions (observations, questions, and hypotheses) in structured argumentation systems could help structure discussion and voting. Users need feedback loops to gauge mutual understanding and mechanisms for distribution of information across group members. Narrative presentation of analysis "stories" is a natural and often effective way to communicate analytic findings and a potential catalyst for additional analysis.

## 6.5 Tabletop Experiment on Collaborative Visual Analytics

Over the last several years, interesting work has been conducted to support collaborative visual analytics. Robinson [70] reports on a tabletop experiment dealing with the collaborative synthesis of visual analytics results. Their experiment results indicate that groups use a number of different approaches to collaborative synthesis, and that they employ a variety of organizational metaphors to structure their information. The paper provides a set of general design guidelines for collaborative synthesis support tools:

- Supporting collaborative synthesis require flexible tools that begin by helping users establish common ground, letting them walking others through their prior work, narrating how they have structured their information, and helping them quickly identify which pieces they have in common.
- Collaborative synthesis tools need to support a wide range of organizational types (e.g. timeline, network, category groups) and allow for open forms of annotation and tagging. Figure 15 shows four metaphors that were used to develop a collaborative workspace: Along the top of the workspace hypothesis groups were created to indicate relevant times, places and other attributes. At bottom left, a social network was drawn to determine which people were related to each other in some way. At bottom center, the set of final hypotheses were summarized onto separate post-it notes and ranked. At bottom right, the participants drew a graphical timeline and plotted key events along it to try and discern the validity of a particular hypothesis.



*Figure 15: Collaborative workspace showing the use of multiple organizational methods [70].*

- Collaborative visual analytics tools should allow users to change their analysis strategy at will, and a flexible range of workflow processes must be supported. Some users will begin with an emphasis on previously developed hypotheses, others might focus attention on which information overlaps and which does not, and finally some may begin by reframing all of the information by some measure such as time, source, or certainty.
- The tools must support collaborative role assignment. In complex collaborative settings, analysts from different backgrounds will seek to adopt roles that suit their specific skills and expertise. Synthesis support tools need to provide users with the ability to customize interfaces accordingly.

Collaborative Sense-MakingOculus has developed a multi-user, collaborative visual analytics tool known as nSpace to collect, organize, and add meaning to analysis artifacts [71]. It is composed of Trist, an information triage component and a visual Sandbox. “TRIST uses multiple linked



views to support rapid and efficient scanning of thousands of information objects in one display. TRIST provides query planning, information comparison, source monitoring, trend analysis and includes multiple linked dimensions for information characterization and correlation. Analysts work with TRIST to triage their massive data and to extract information into the Sandbox. The nSpace Sandbox is a flexible and expressive thinking environment for evidence marshalling, sense-making and assessment. Key capabilities for the Sandbox include “put-this-there” cognition, node and link diagramming, assertions with evidence, automatic source attribution, source assessment, collaboration and scalability mechanisms to support larger analysis tasks.” [71]. In [72], they describe a use case where nSpace capabilities are applied in the context of the Visual Analytics Science and Technology (VAST) Challenge which is part of the annual IEEE VisWeek Conference.

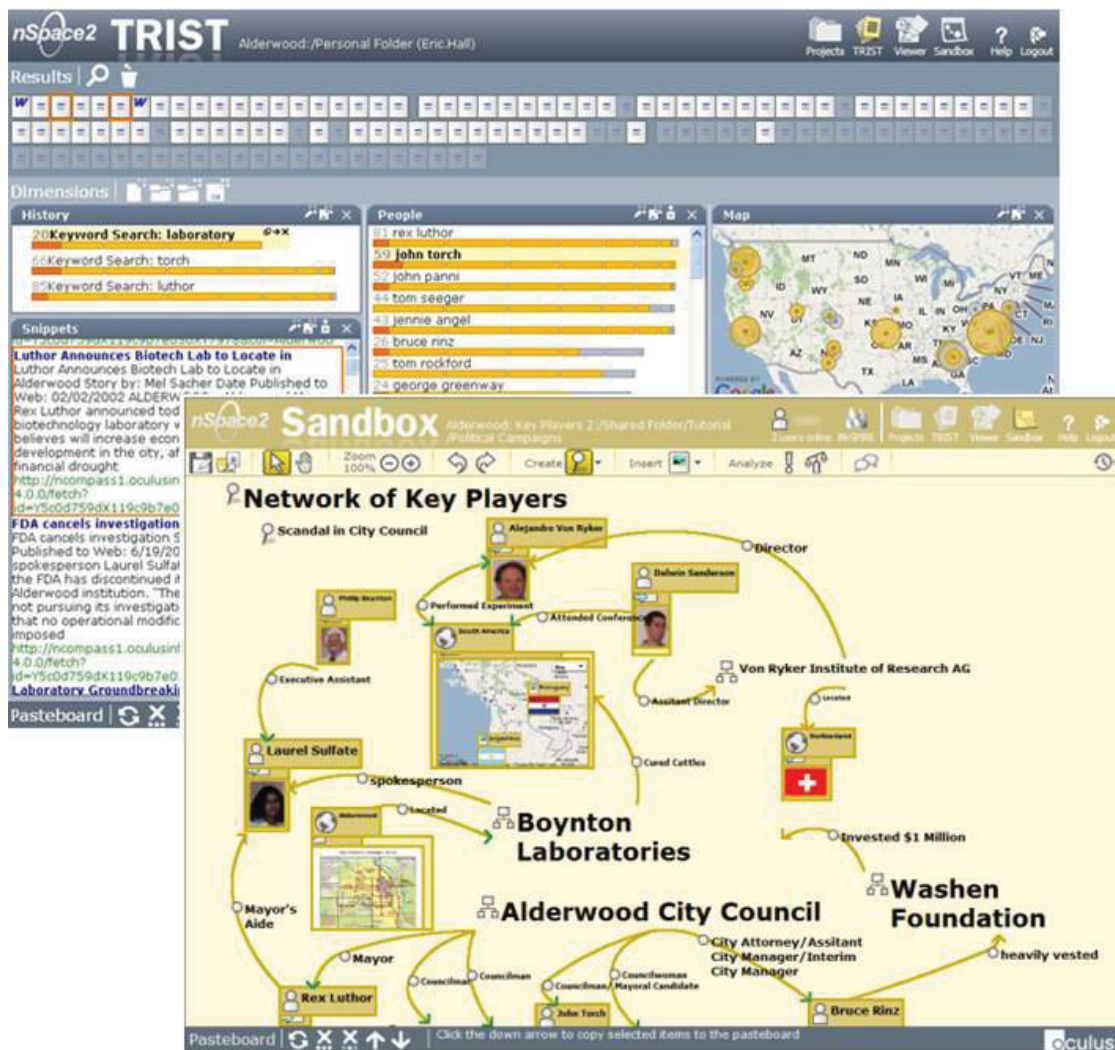


Figure 16: nSpace2 a visual analytics evidence marshalling and sense-making [71].

## 6.6 Interactive Tabletop Computing Platforms to Support Collaborative Planning and Decision-Making in the Military

Scott et al. [31] have investigated the potential for interactive tabletop computing platforms to support collaborative planning and decision-making in the military command and control domain. Inspired by the chart and plot tables historically used in the naval domain, they have developed a prototype based on a pen-based tabletop computing environment to showcase the manner in which relevant maritime data can be accessed and shared in a collaborative environment. To guide the development of their prototype, several design requirements were developed, based on the nature of the naval task environment and tabletop literature. Key aspects of these design requirements included:

- Provide access to dynamically updated, map-based data sources.
- Provide support to a team standing around the table for interacting with the system simultaneously.
- Support operators standing at any position around the table (omnidirectional / 360-degree interface).
- Enable work to be done on a horizontal surface orientation (table format).
- Support the notion of operator roles and corresponding security privileges (e.g. hide low-level operator-specific functions from other members, as well as restrict command-level decisions from those not authorized to enter them).
- Enable fine-grained input control (e.g. detailed, accurate annotation of interface content and media, and fine control for handwriting in the digital environment).
- Enable input logging on a per-user basis.

Figure 17 shows the prototype application running on a 3x4 foot, dual-projected display tabletop hardware setup equipped with multiple Anoto digital pens. Gallium Visual System's InterMAPhics6 geospatial visualization engine is used to render the operational picture.



*Figure 17: Maritime application running on a pen-based, collaborative tabletop system [31].*

The prototype provides a 360-degree collaborative interface. “In order to accommodate multiple users who may be interacting with the interface from different sides of the table, the interface content is provided in individual windows, which can easily be moved or rotated with a simple touch and drag gesture anywhere on the window border. The map content windows can also be resized to accommodate personal or shared use of the geospatial data. Thus, the layout of interface content can be easily adjusted to accommodate a wide variety of individual and shared content use, anywhere on the table. The software also enables simultaneous user interaction; thus, users are free to work in parallel, for instance an operator could be checking on a particular piece of information in a separate content window while others at the table discuss tactical strategy over a shared map.”[31]

Figure 18a illustrates three users simultaneously interacting with the multi-touch surface. Figure 18b shows how system-level menus are oriented towards each user, based on which side of the table this user stands. Similarly, as shown in Figure 19, pop-up menus are automatically rotated toward the table edge associated with the activating pen. Finally, different system options are displayed in the pop-up menus available in the interface, based on the user’s authority level (Figure 20).

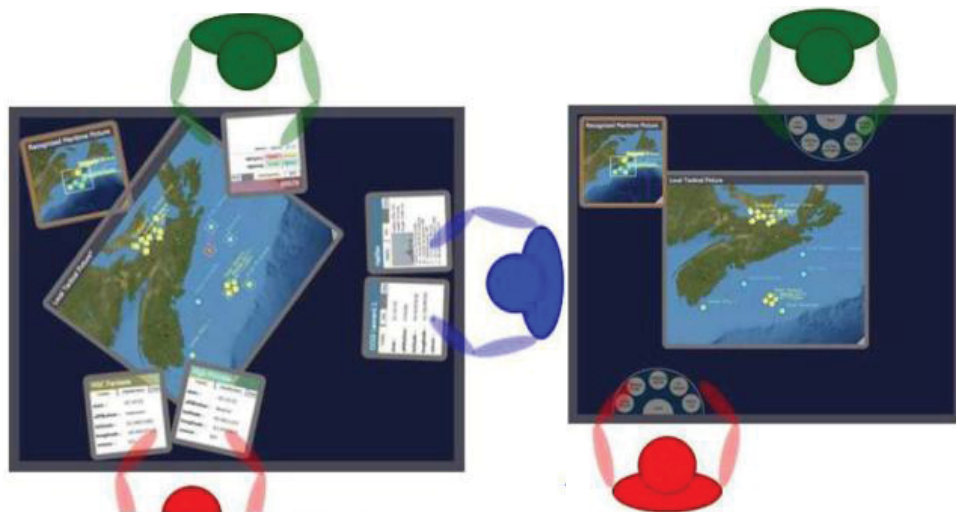


Figure 18: (a) Multi-user interface and (b) oriented system-level menus [31].

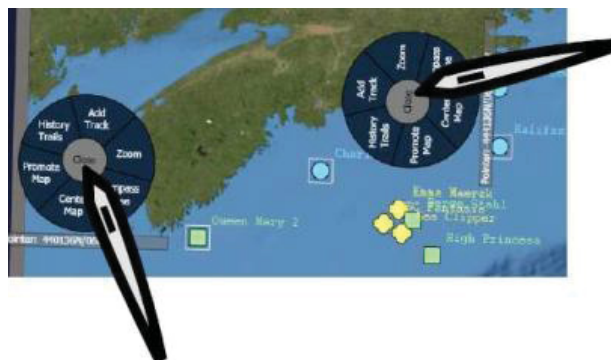


Figure 19: Orientation of the system-level menus toward each user [31].

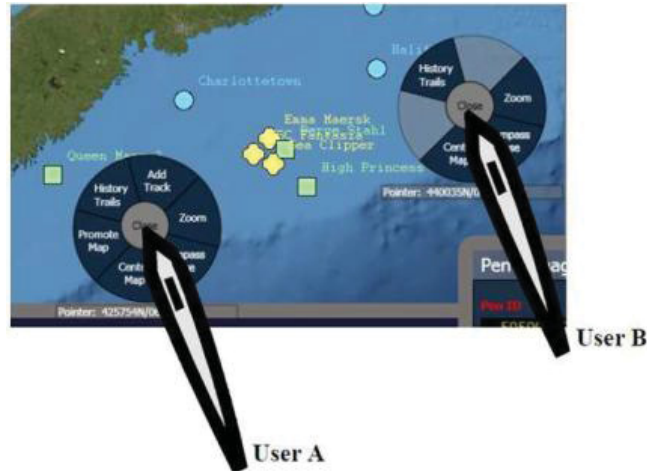


Figure 20: Interface tailoring for users with different security levels [31].

## 6.7 Collaborative Smartroom Environments

A smart room environment to consider for the collaboration infrastructure is the use of Livespaces, an integrated collaborative workspace developed by the Defence Science and Technology Organization, in Australia, to support advanced meeting spaces and distributed multi-site collaboration [75]. As illustrated in Figure 21, it consists of purpose-built furniture, power and networking infrastructure, and a variety of devices including lights, projectors, video matrices, computers, interactive surfaces, and videoconferencing hardware. Users experience features such as voice-, touch-panel and desktop-controlled room automation, desktop sharing, shared interaction with public displays, information sharing, scripted audio-video briefings, meeting transcription, and location-based services. Software developers benefit from ready-made infrastructure for collaborative applications and scalable distribution across wide-area networks. The LiveSpaces software has been contributed to the open source community [76].

Rather than developing collaboration services in each application, the collaboration services are provided by the Livespaces framework. One of the services allows any user to easily take control of an application running on a shared space, just by moving the mouse cursor to the top of his personal workstation, which then moves the cursor onto the shared screens. Any device such as large displays, a knowledge wall and multi-touch tables can easily integrated into the Livespaces framework.



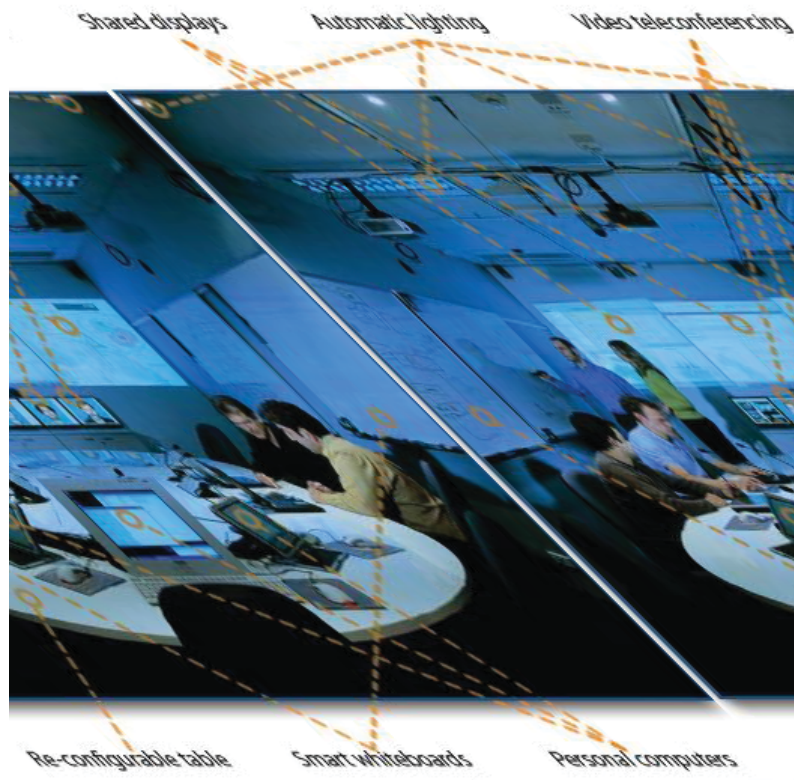


Figure 21: DSTO's Smart Room Environment, based on LiveSpaces [75].

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## 7 Design of Maritime Visual Analytics Applications

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### 7.1 Design Strategy

The design activities were performed with the intent of identifying how VA and collaborative technologies could enhance maritime analysis, more specifically in the context of the two main opportunities that were selected (see Section 5.3):

- Collaborative VA of a Vessel of Interest (CVAV)
- VA-based Anomaly Detection (VADA)

The related subtopic of visualizing data extracted through automated reasoning and stored in our Situational Fact Database (FSDB) was also explored. Not surprisingly, there is a lot of overlap between these topics and a lot of the explored concepts apply to more than one opportunity.

We followed a breath-first exploration strategy in our design activities in order to explore a broad solution space. The design activities resulted in a mixture of original innovative concepts and existing VA and collaboration concepts that are not presently applied to MDA. The contribution of this work is twofold:

- Existing theoretical and applied VA approaches have been extended and assembled into a suite that is optimized for this application.
- New VA innovative concepts have been developed in response to specific maritime domain requirements.

### 7.2 Apps Design Approach

Because of their 24/7 operational context, the RJOCs have for many years upgraded their information technology through a series of incremental improvements, rather than through system replacement cycles. Accordingly, the envisioned Maritime Visual Analytics Prototype (MVAP) [73][74] will consist of a set of services and widgets that could be added incrementally to a Service Oriented Architecture (SOA) similar to the possible future architecture to be used at the RJOCs. The design activities [77] thus focused on a set of compact software applications, commonly called “apps”, with the following characteristics:

- *Transient*: each app can pop up when needed and then be hidden away under an icon when not needed.
- *Self-contained*: apps can be added as a service without requiring changes to the operating system or to other applications.
- *Single-purpose*: users experience each app as doing one specific job.

These apps are all brought together into a common analytical workspace.

## 7.3 Desktop and App Icon Collection

There needs to be a common operational context in which all the apps operate. An application workspace would allow easy movement between different interconnected views of the domain by letting users select, customize, and arrange the views that contribute to their current task, effectively providing a UDOP [78]. In this shared workspace (a mock-up is provided in Figure 22), commonly-used arrangements could be saved and deployed. Automatically configured layouts based on the user role could also be provided. Portal views may be stacked on a single screen, distributed across multiple screens, or distributed between devices such as a laptop, a wall display or a tablet (Figure 23). Views generated externally, such as a video feed of the harbour, could also be inserted into the collaborative workspace.



Figure 22: Mock-up of an application workspace.



*Figure 23: The application workspace could be used with multiple devices.*

## 7.4 Analysis Sets

We propose an analysis workflow based on analysis sets supported by a suite of VA tools that help the operator narrow his analysis from the set of all vessels to smaller and more focused sets of interesting vessels. Practically, this means that we begin our process with an analysis set containing all the vessels. In order to bring that large set down to a manageable size, a wide range of tools are available. The first obvious way to filter the data is by focusing the analysis on a selected area of interest during a specific time interval (such as the last 24 hours). The tools proposed offer a visual analytics approach to create smaller subsets containing vessels, although other means could be employed to filter and refine the sets. The end results of the process are small sets of vessels that are identified as worthy of detailed analysis and possibly declared VOIs.

## 7.5 App Concepts

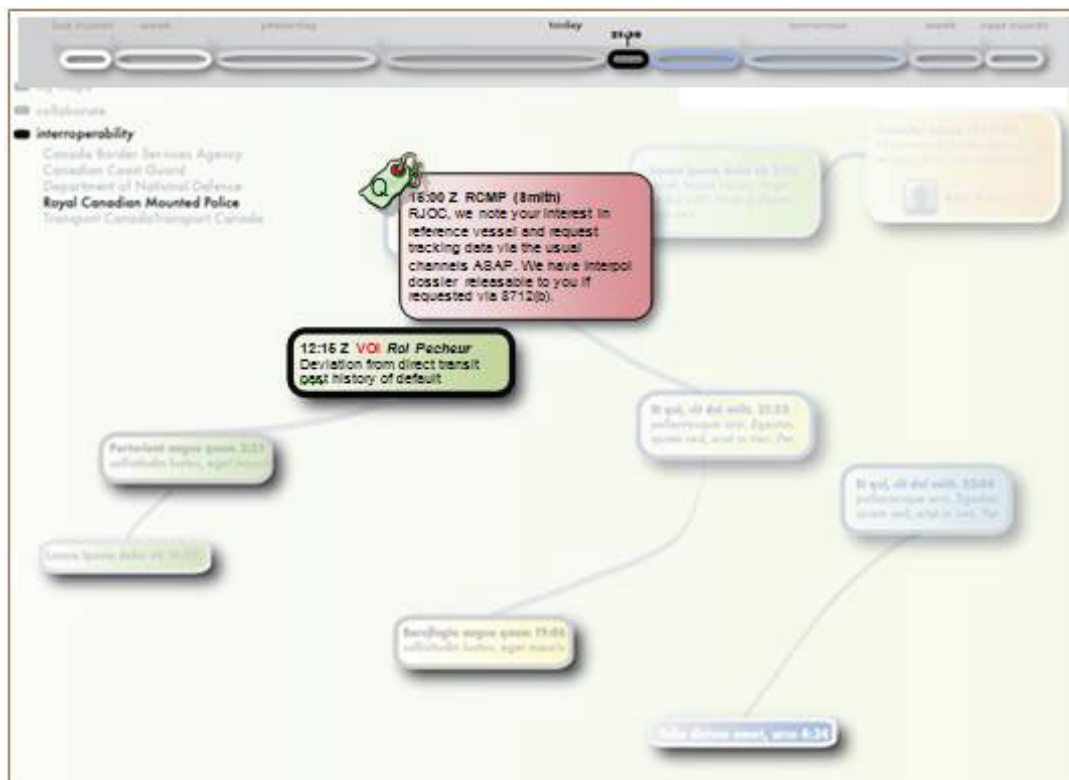
The design activities lead to 23 app concepts that were fully documented. For each app concept, [77] describes the concept, the sources of information, the visualization and collaboration techniques involved, as well as the key analytic activities. Mock-up images of each concept are also provided. Not reinventing the wheel, for a few of them, we simply identified existing commercial applications. Potential maritime scenarios were also created to showcase the use of these apps and are available in [79]. This section gives a one page introduction to each app including mock-up images.

### 7.5.1 Mind Map with Templates and Timelines

The Mind Map with a timeline allows users to organize their ideas and capture the decision making process. Commercial VA solutions such as GeoTime [58] have demonstrated the value of a tool in which observations can be collected, hypotheses tested, and a story constructed to interpret the evidence. As with other such tools, users can drag and drop into the Mind Map new evidence or snapshots of the current maritime picture.

When reviewing the evidence, analysts can choose to display the nodes and links on a timeline to provide the temporal context (past and future elements are faded). Expected or planned events (e.g. the departure of a ship) can also be placed in the future of the Mind Map App. Explicitly showing temporal evolution could lead to better insight into the reasons for past decisions and a clearer understanding of the thought process that led to conclusions. However, Mind Map data will need to be collected using a mechanism that requires so little time and energy that operators do not perceive it as an added drain on their time.

The Mind Map App could provide workflow services. Templates for analysis could be provided in the form of a complex but content-free mind map which acts like a form that needs to be filled out (e.g. a VOI analysis template) or a security checklist (e.g. for anomaly detection). Each empty mind map element can also provide a link to the app that can be used to complete that work item.



*Figure 24: The Mind Map with a timeline allows users to organize their ideas and capture the decision making process. A slider allows moving in time to see the temporal evolution of the data. Mind maps can be interconnected, aware of each other and contain collaboration tags.*



## 7.5.2 Link Analysis for Maritime Information

The Maritime Link Analysis App reveals patterns in relationships between objects, events, organizations, people, and abstract concepts. It can also provide mechanisms for characterizing those patterns, communicating the evidence behind them, and representing their meaning.

The key analytical activities are:

- Visualize connections between individuals in the various classes,
- Identify relationships that are of interest,
- Drill down in the data to find more interesting patterns,
- Interpret what each means or highlight questions that it raises,
- Extract evidence to build a “Story”,
- Export the Story to another tool such as the Mind Map App.

The needed visualization and analysis capabilities are very similar to capabilities in existing tools such as CoALA [80], nSpace [72] and Jigsaw [81]. We therefore expect that this capability could be implemented as an extension of one of those tools.

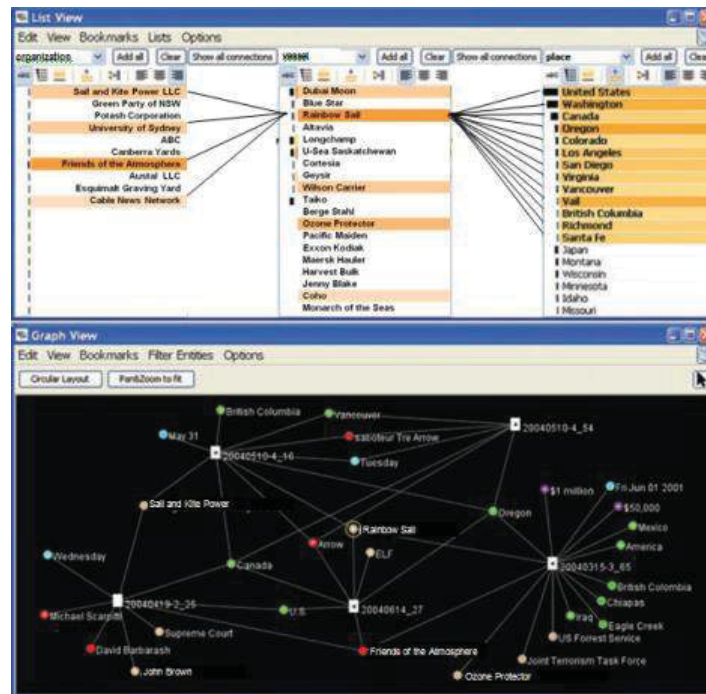


Figure 25: List and graph views examples of link analysis exploration of a VOI (modified from Jigsaw [81]). In the center panel of the list view (top), the analyst can display “vessels,” highlight one and find other ships (highlighted) that related to it. Similarly, selecting the “organization” and “place” classes show related organizations and geographical links. The graph view reveals another connection between the organizations.

### 7.5.3 Tag Browsing

The Tag Browser App displays tags in a tableau format for rapid browsing, similar to iPhoto [82]. This app provides a stand-alone way to browse all Tags of all classes as a single collection. Tags are small pieces of meta-information that are attached to data elements and remain invisible unless specifically visualized. Tags can be generated in two ways:

- *Manual Tagging*: users can add tags to text, image, or model data stored by any of the apps. Tags can be text or links, and are often anchored at a specific location in the data that is stored. Support for manual tagging is provided by each host app in accordance with its unique context, but all apps should use the same icon to initiate tagging.
- *Automated Tagging*: certain events, such as the non-detection of a vessel in a location where it was expected or the detection of an anomaly by an automated reasoner will insert tags automatically.

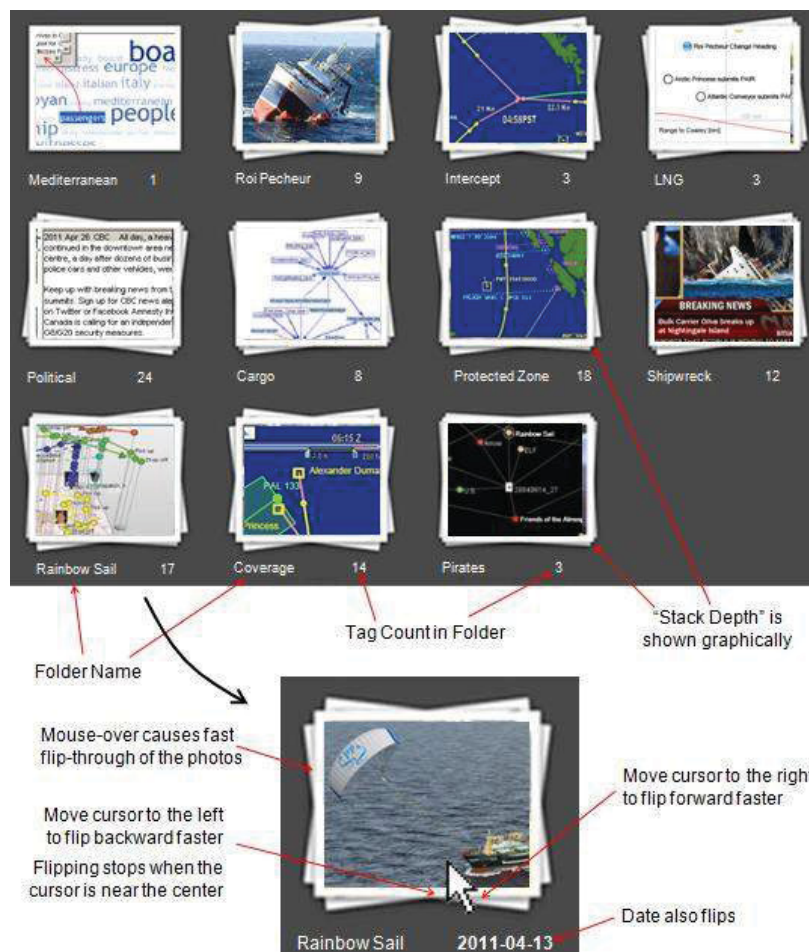


Figure 26: The Tag Browser is based on iPhoto's "wall" interface [82]. Tag vignettes are stored in folders and each folder is displayed as a stack of vignette snapshots. Mousing over a stack causes it to start flipping through its contents.



## 7.5.4 Vessel Summary Cards

The Vessel Summary Cards App creates and presents small-format “hockey card” summaries to aid in browsing through long lists of vessels. These visual cards show all the key characteristics of a vessel at a glance and analysts can rapidly flip through a virtual deck of summary cards using a card browser tool. Information is formatted so that the analyst can look for normally present or absent elements rather than having to read each card. This engages the human image-recognition capability to support more rapid browsing than simply scanning a spreadsheet-like list of database elements.

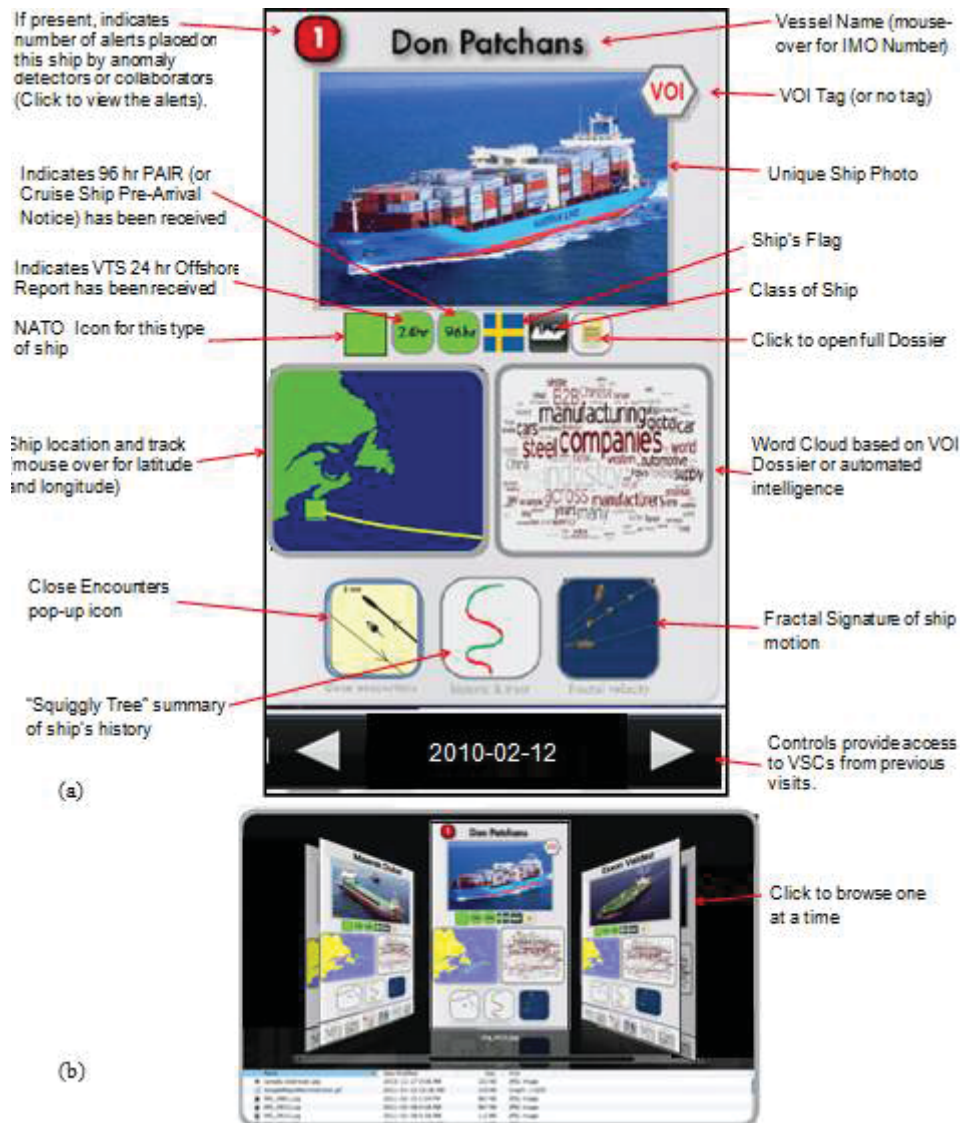


Figure 27: (a) Vessel Summary Card (b) Card browser mock-up similar to iTunes.

### 7.5.5 Vessel Timeline

The Vessel Timelines App portrays events on a timeline so that temporal patterns and temporal anomalies can be detected and analyzed. These timelines can be composed of vessel contacts (position, AIS message) and relevant events such as port departure, estimated arrival and 24hr call-in message. Two timeline alignments are valuable:

- Timelines concerning multiple vessels
- Multiple timelines concerning one vessel.

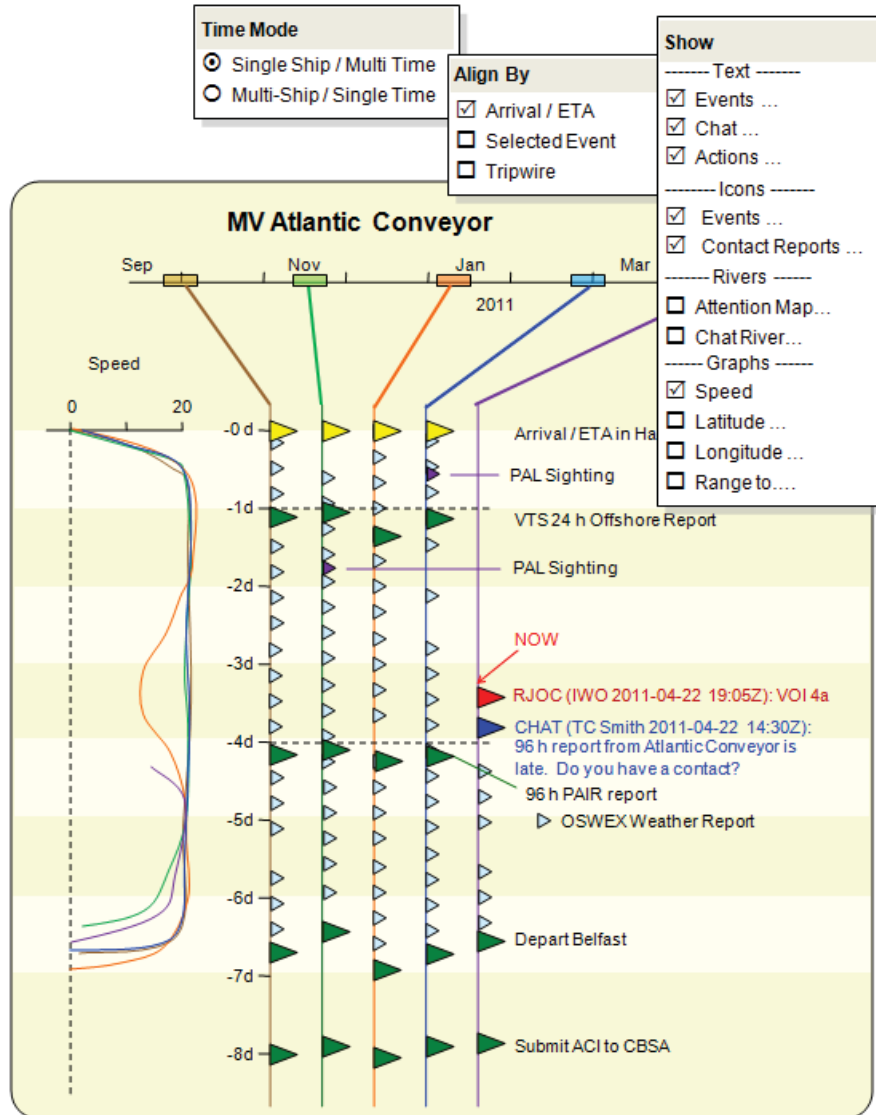


Figure 28: In this Vessel Timelines App mock-up, multiple timelines related to a single vessel are displayed vertically. It allows comparing the current voyage of the Atlantic Conveyor container ship to previous voyages. Based on previous history, a 96h report should be in by now. The graph on the left shows that the speed of the ship went down earlier for the current voyage.

### 7.5.6 New and Chat River

The News and Chat River App visualizes which news and chat topics are currently attracting the most attention. This facilitates collaboration by revealing patterns in group activities, and draw analysts' attention to newsworthy topics.

The RJOCs frequently monitor current affairs by displaying a TV news channel in the ops room, with closed captioning but no sound. A number of text analysis tools are available for recognizing topics of interest in textual data streams. These could be used to extract topical themes from the closed captions and thus provide a visualization of the news feed with overview and drill-down support. The same app could also be used to monitor Chat text on the military networks.

The key analytical activities are:

- Rapid assessment of the relevance of many hours of television and internet news, together with the current trends (e.g. whether a news story is growing or fading).
- Ability to filter out irrelevant feeds and drill-down on topics of interest.
- This will help prepare intelligence staff to brief senior officers.

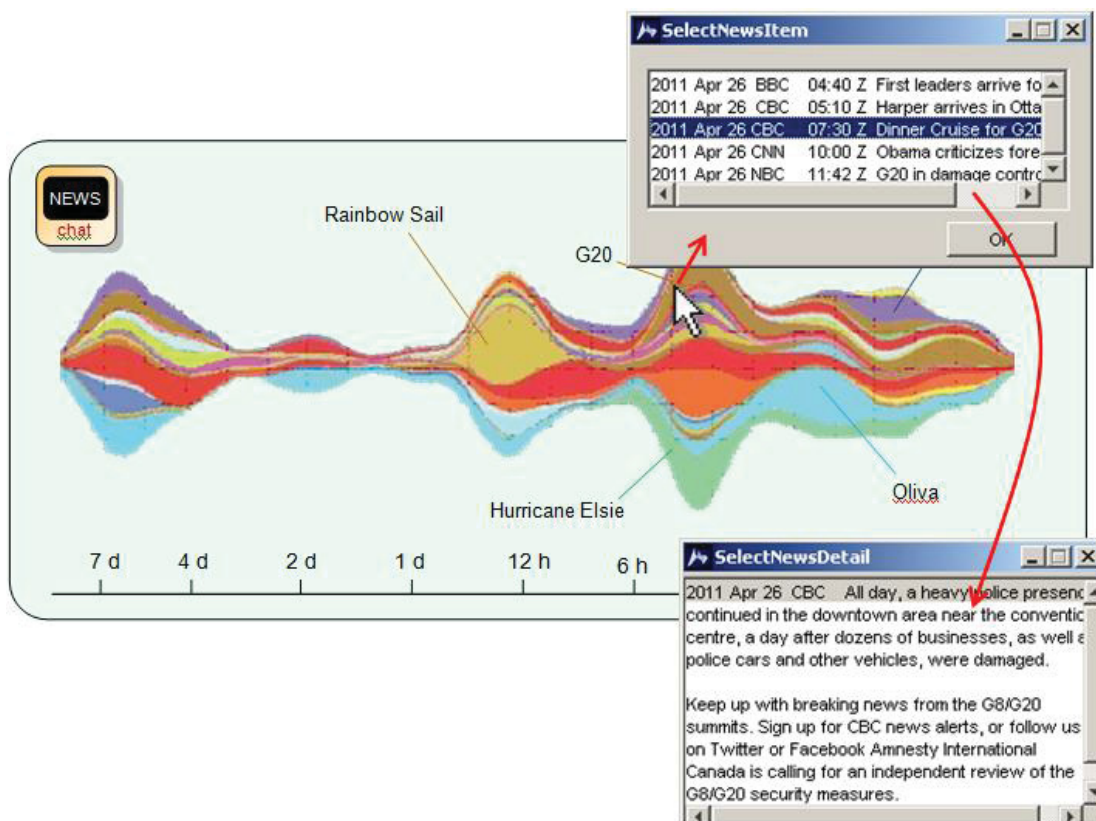


Figure 29: The News and Chat River App features a ThemeRiver<sup>TM</sup> display to provide a longer-term view of which topics are drawing the most attention. Clicking on a portion of the river reveals a list of news and chat items from that time period. Clicking on any of these brings up the full text.

### 7.5.7 Time Slider on Ship Tracks

The Time Slider on Ship Tracks App provides a 2.5 dimensional view of the maritime domain using an interactive chart. Spatial information can be explored using standard zoom and pan controls. Temporal information can be explored using a smooth time-slider with adjustable time window and a kinematic interpolation and extrapolation service. This time slider will allow the user to select a time interval to filter the information displayed. Interpolation is required to estimate past positions and future positions are determined using current kinetic information, published schedules and great circle routes where applicable.



Figure 30: (a) In Time Slider on Ship Tracks, the tracks' length is determined by the split time-slider. Contact reports are shown as very small circles, and tracks are red if inserted after the latest contact. As the analyst slides back in time, the tracks smoothly shift backwards. (b) Three vessel tracks at the current time plus the green observation swath of a maritime patrol aircraft. (c) When sliding into the future, the tracks turn pink to indicate a projection. Transport ships heading at a constant speed toward a declared destination have their tracks projected forward. The fishing boat has no clear destination, so a circle indicates the probable limits to her range of motion. A ferry is scheduled to leave, so its track is also shown in pink.

## 7.5.8 Visualize Time as Z Axis

The Visualizing Time in the Z-Axis App provides a 3 dimensional view of the maritime domain in which the vertical axis represents time. Spatial and temporal information can be explored by panning and zooming in the 3D space.

The key analytical activities are:

- Form a mental model (and export to a 3D model if required) of the locations, speeds, and interactions of all vessels in an AOI.
- Identify anomalies such as a rendezvous or change in speed.
- Understand the probable future time-evolution of all the vessels.

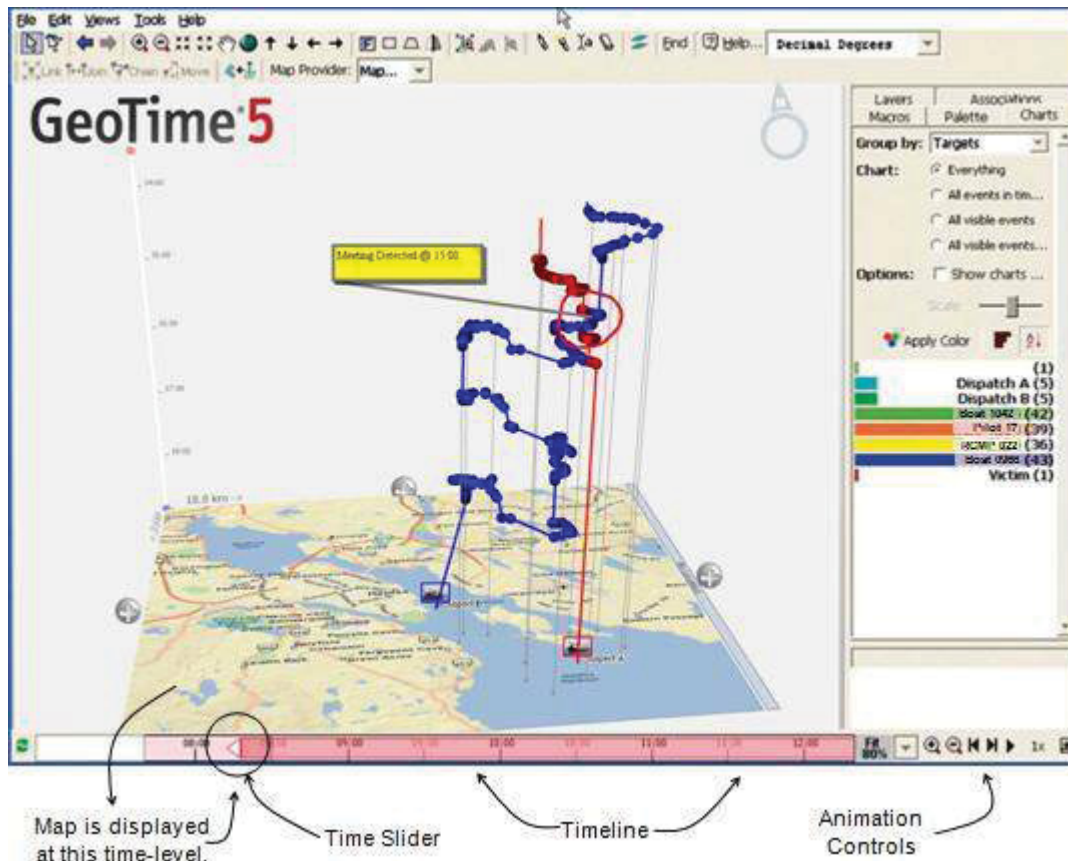


Figure 31: Visualizing Time as the Z Axis using GeoTime [83]. The vertical slopes of the coloured “world lines” represent the inverse of speed, and vertical lines represent stationary objects.



## 7.5.9 Attention Maps

The Attention Map App displays a ThemeRiver™ [84] showing RJOC team the analysis efforts spent on a variety of topics as a function of time with tag icons that provide links to analysis results in the mind map. To collaborate effectively, an analyst needs to know what his collaborators are doing. The Attention Map App provides this in two ways:

- **Collaboration Overview:** the main Attention Map plots analysis activity from all collaborators, as a function of time.
- **Collaboration Details on Demand:** links are provided to more detailed descriptions of the analysis that was done.

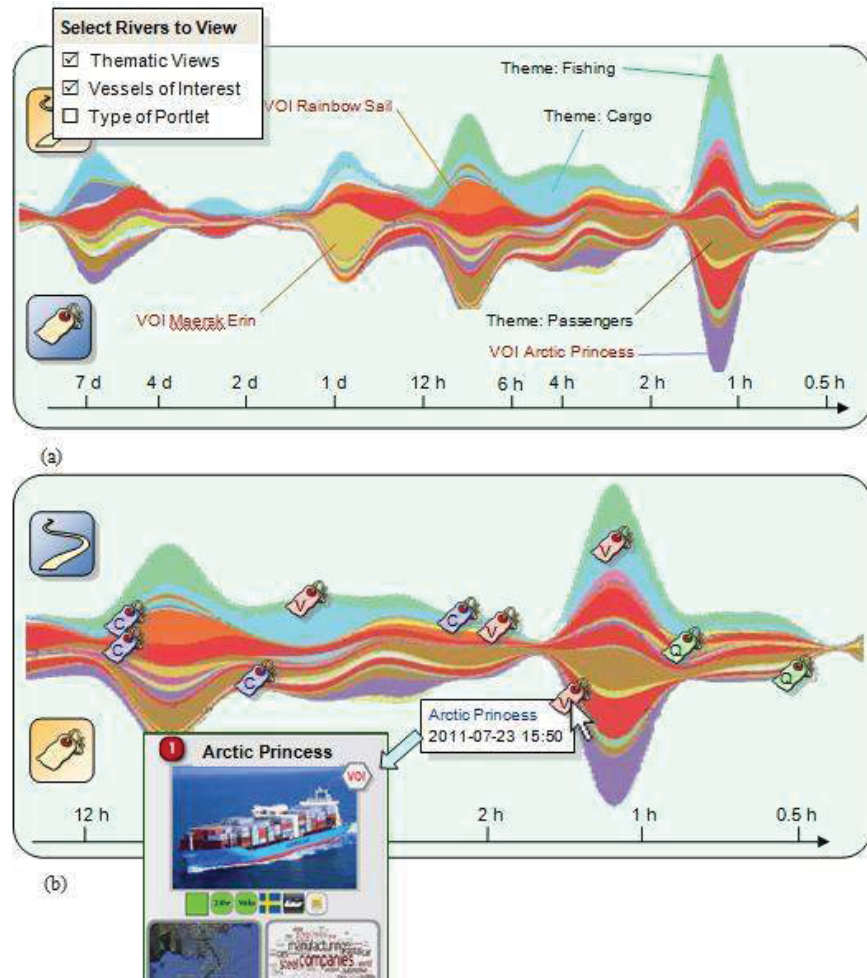


Figure 32: The attention map uses a ThemeRiver™ [84] visualization to show the number of collaborators tracking various topics. In (a) the display shows time spent in specific Thematic Views (e.g. Fishing, Cargo, and Passenger Ships) and on specific VOIs. Users can zoom on the time as sketched in (b). The tag button pops up tag markers that represent comments, questions, and VOIs, marked as C, Q, and V respectively. Mousing over a tag reveals a brief explanation and clicking brings up the full description.

### 7.5.10 Predictive Rendezvous

The Predictive Rendezvous App is an interactive “what if” tool to visualize how two or more ships might be heading toward a rendezvous, and how assets might be able to respond.

The co-location of two ships at sea may be an interception or a rendezvous, and may be for legitimate or illegitimate reasons such as the following:

- Legitimate Interception: Law enforcement activity.
- Illegitimate Interception: Piracy or harassment.
- Legitimate Rendezvous: A pilot boat meeting a client, fishing boats collaborating, or a supply ship servicing an oil rig.
- Illegitimate Rendezvous: Illicit transfer of cargo or passengers.

In Figure 33, the analyst suspects two ships of planning to intercept and harass an oil tanker. The time slider at the top left is adjusted to explore a potential intercept time and the app shows:

- Where the tanker would be at the specified time,
- How close the two attacking ships could be at that time, if travelling at top speed, and
- When an aircraft would have to leave the nearest airbase, to arrive on-scene at that time.

A key element of this App is the real-time re-mapping of the scenario as the time slider is adjusted. This provides a dynamic visual component that summarizes a complex what-if decision space. The coloured time slider also indicates the interval in which the vessel trajectories intercept.



Figure 33: Predictive rendezvous analysis.

### 7.5.11 Dust, Magnets and Scatter Plots

The Dust, Magnets, and Scatter Plot App uses scatter plots to visualize how properties of the maritime domain are correlated, uncorrelated, or anti-correlated. It could be used to examine whether ships tend to go slower in the winter, or if ship traffic tends to be heavier at certain times of day. It was inspired from the Dust & Magnets concept [85], which was designed to explore a multi-dimensional space of attributes.

The canvas space is filled with dots representing individual vessels, called the dust. Labelled magnets corresponding to vessel properties can be inserted into the canvas and clicking them will make the dust move according to the vessels' property values. An unlimited number of magnets can be used together, making this tool well suited to explore multiple dimensions at once.

We augmented the concept with scatter plot capabilities and the possibility to constrain the dust movement to vertical or horizontal bands (or both). Associating a vessel characteristic to the X or Y axis will prevent the dust points from leaving the bands in which they belong. This can enable greater insight about trends across the different categories represented by the bands. If no magnet is added to the canvas, the app can be used as a scatter plot tool.

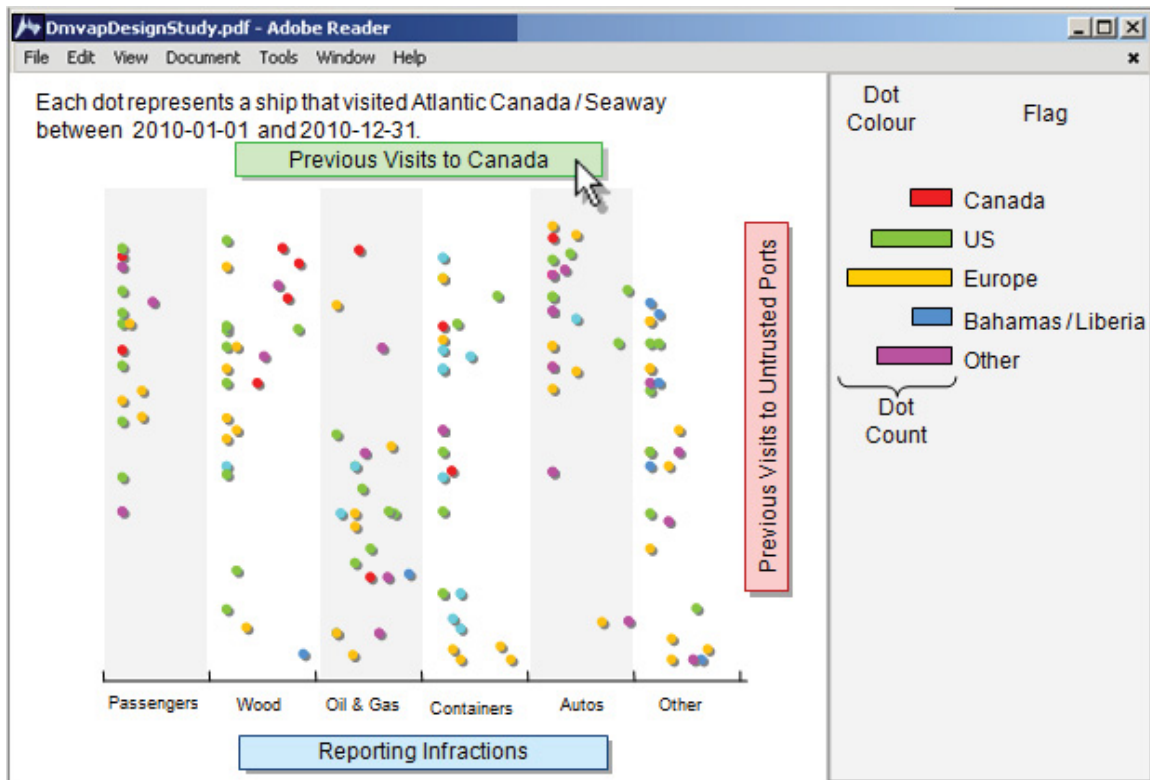


Figure 34: Example with one labelled axis and magnets. In this sketch the analyst is looking for patterns that influence trust in a vessel. The x-axis divides the dots by cargo class. Every time the “Previous Visits to Canada” magnet is clicked, dots travel upward in proportion to the number of times they have visited Canada. The red magnet draws dots to the side (within each band) if ships are regular visitors to foreign ports that do not have a trusted status.



### 7.5.12 Shipping Density Landscape

The Shipping Density Landscape App provides a visual summary of frequently-travelled routes used by shipping. Analysts can use it to understand the normal routes used by various classes of ships, and to extract Analysis Sets of vessels. This app is based on work by Willems [86][87].

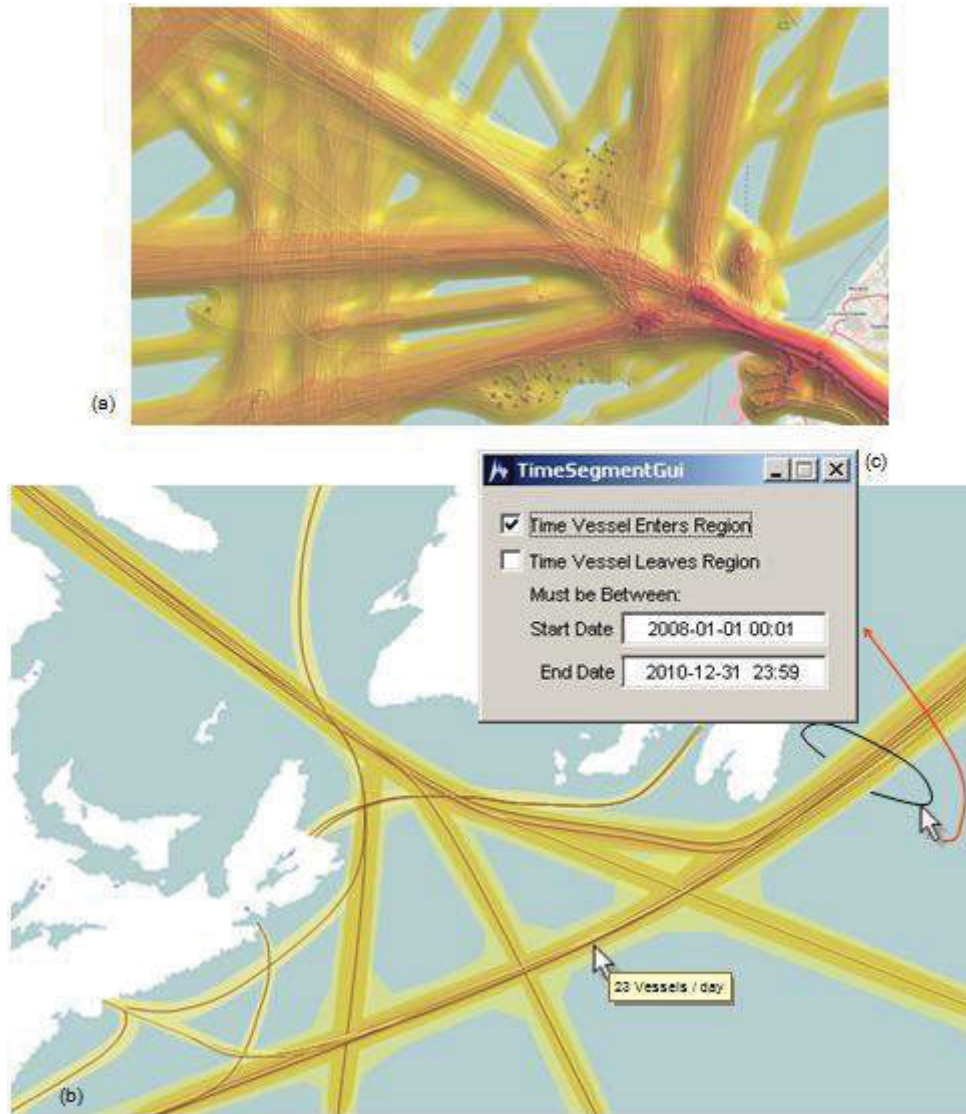


Figure 35: The Shipping density Landscape App shows the average of thousands of tracks as a coloured wash ranging from yellow (a few tracks) to red (many tracks) as in (a) from [87]. Individual recent tracks show up as raised ridges. Figure (b) sketches how this style could be applied to the Canadian AOR. Analysts can circle a route and specify a time range as shown in (c) to extract a set of vessels to the analysis set.

### 7.5.13 Periodic Bubbles

The Periodic Bubbles App reveals periodicities in ship tracks and thus helps to understand what is normal.

The key analytical activities are:

- Adjust the left half of the time slider to vary the period that is being investigated. Bubbles will grow and shrink in real time.
- Slide the right half of the time slider to vary the time-sample locations. The large bubbles will then trace out the route followed periodically by the ship.
- Point to a bubble for a tool-tip showing the identity of the ship.

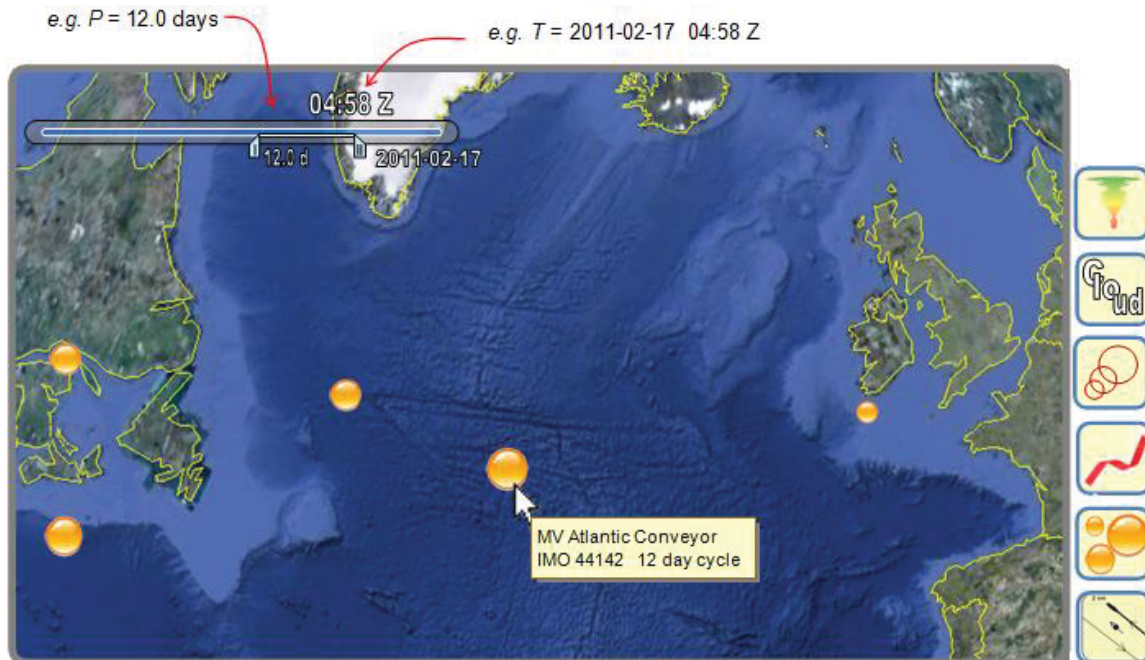


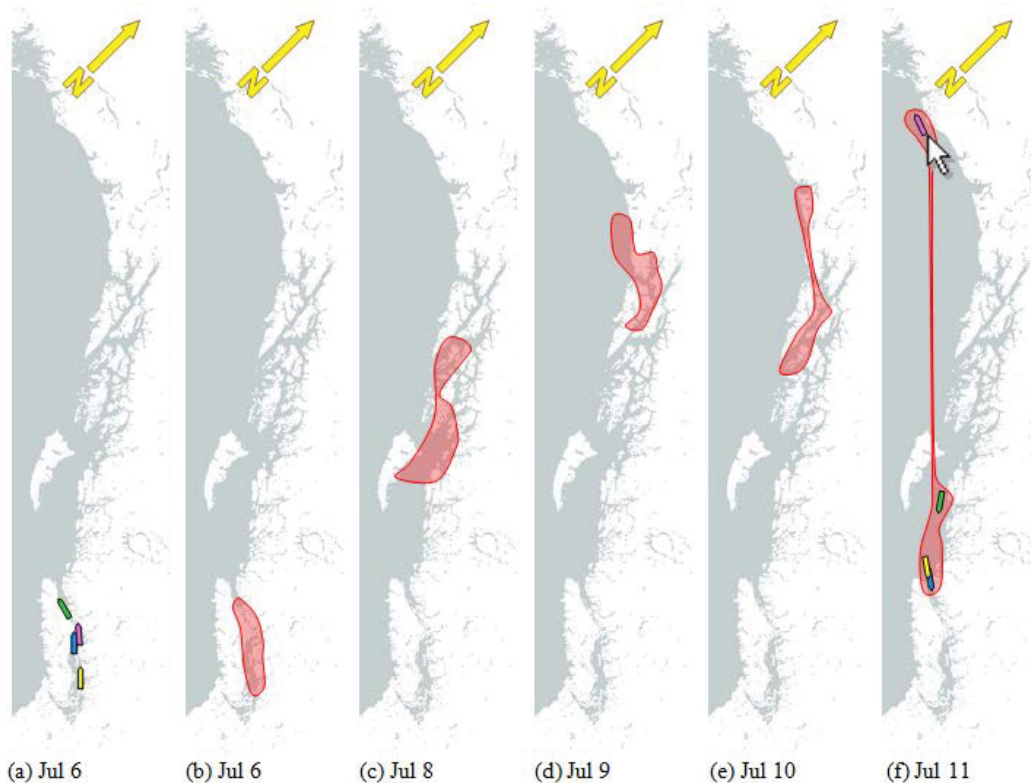
Figure 36: In this Periodic Bubbles App mock-up, the locations of ships were found at 04:58 on the following days: 2011-02-05, 2011-01-21, and 2011-01-09 and compared to the location of the same ship on 2011-02-17. If 0, 1, 2, or more than 2 of the locations match, then no bubble, a small, a medium, or a large bubble respectively, is inserted at each ship location. The user could click on the largest bubble to learn that MV Atlantic Conveyor, out of Halifax, operates on a 12-day schedule.

### 7.5.14 Bubble Sets for Fleets

The Bubble Sets for Fleets App displays groups of related ships within a “bubble” so that the analyst can think of the group as one entity and thus achieve a simpler mental model of the maritime domain.

Exploration of the dataset is critical to support the analytical process and develop insight. The number of tracks that can be displayed in the RMP is overwhelming. Just as contact data have been resolved into tracks, tracks should be clustered into groups in order to reduce visual clutter. The whole maritime dataset can then be explored one set at the time, while maintaining the possibility to drill down and look at individual vessels at anytime. Groups of tracks can be created using automatic or manual selection.

Because vessel icons are set by a military standard, we need an alternative to color coding to show set membership. Bubble sets [88] can group many entities visually into a single blob without affecting their spatial organization. Considering the shape of these blobs can even allow additional analysis capabilities. Any ship that is far away from the other members of the group will become salient as the blob shape stretches in its direction. This shape could become a feature that can be easily recognized for known fleets and any change would hence be easily noticed.



*Figure 37: In this mock-up, a bubble set is used to represent a cadre of Alaska cruise ships heading up for a 1 week cruise to Glacier Bay. At the midpoint (d-e) one ship breaks away as it is instead on a two-week cruise via Anchorage. The operator could click on the break-away ship (f) and remove it from the bubble set.*



### 7.5.15 Squiggly Tree for Ship Reliability

The Squiggly Tree for Ship Reliability App uses a simple visual convention to show the reliability of all ships in the analysis set. This app addresses the same topic as the Good and Bad Rivers App in Section 7.5.20, but it looks at all ships at once, and has a new focus on whether ships are getting better or getting worse. This app is based on the *Notabilia* visualization [89] which provides an interactive squiggly tree analysis of which Wikipedia article are voted in and which are voted out.

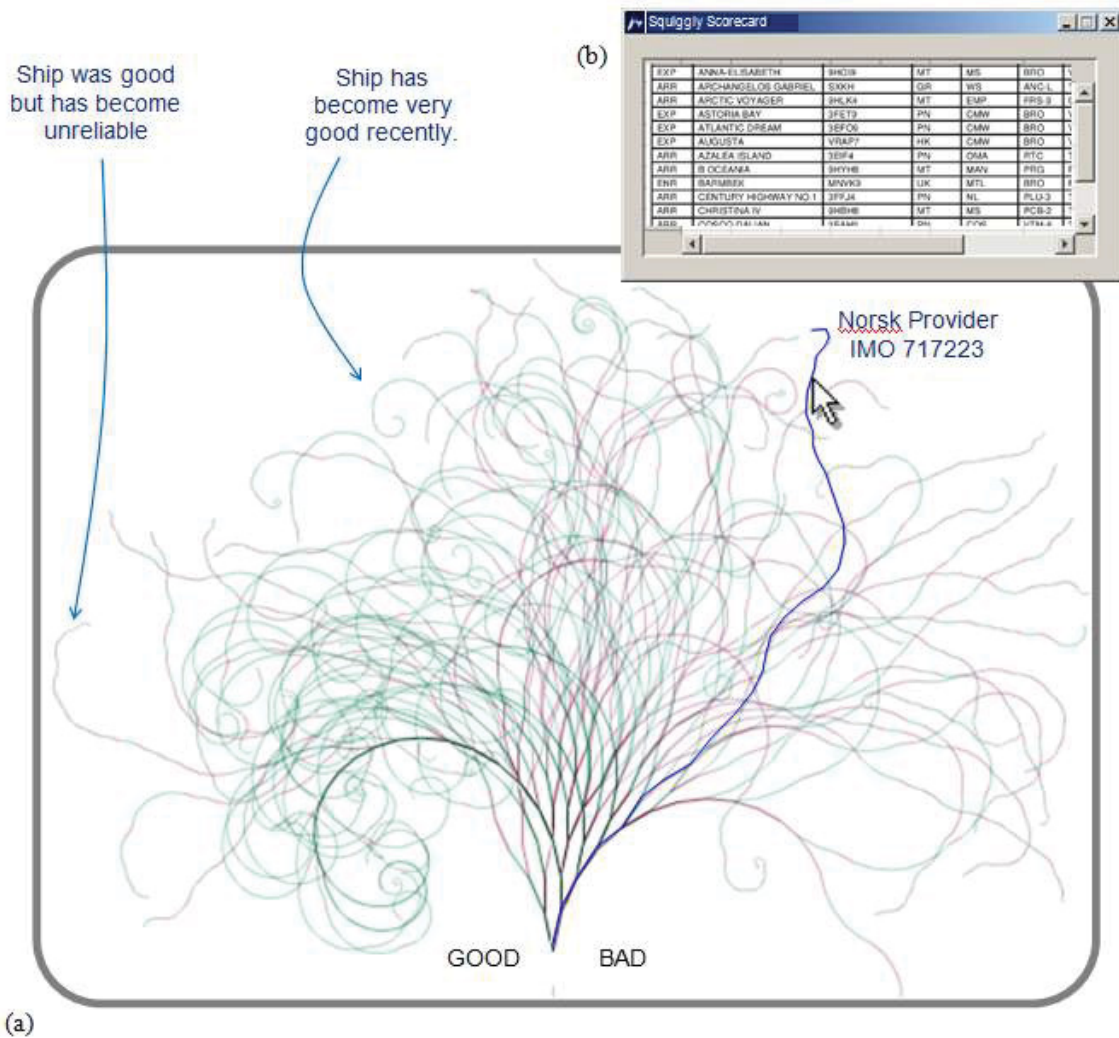


Figure 38: Each ship is represented by one stalk in the Squiggly Tree Apps showing the trees for a hundred ships. Each piece of evidence in favour of the ship causes the stalk to bend to the left, and each piece of negative evidence causes a bend to the right. The oldest evidence is at the bottom (by the “roots”) and the newest evidence creates the growing tip of each stalk. Mousing over a stalk highlights the whole stalk and flashes up the name of the ship, as shown. Double-clicking brings up a scrollable score card for that ship.

### 7.5.16 Thematic Views

The Thematic Views App provides a set of pre-defined or user-specified “thematic views” of the maritime domain that facilitate rapid shifts from one detection or analysis task to the next. In order to reduce information overload, we need to allow users to focus on the specific subsets of information required for their current task. In the Thematic Views App, visual layers separate the information elements into various themes such as commercial transportation, Vessels of Interest (VOIs) surveillance, sensor coverage analysis, or alerts from automatic anomaly detection systems. The possibility to hide or show individual layers of information allows the user to view only the relevant information needed for a particular task.

Various combinations of visualizations can be proposed and [77] provides the description of many example thematic views. We could create generic layouts for tasks or topics that are common and recurrent, as well as allowing users to create their own custom visual layouts employing the tools that suit their needs.

An example of this would be to display together fishing vessels, regulatory fishing zones, meteorological data and some annotations from a previous normal behaviour analysis (Figure 39). A visualization of tracks on the map along with the boundaries of a region of interest allows direct assessment of their relative position. This could be useful, for instance, to see if fishing ships are actually fishing.

Although only a map display is shown here, the concept extends to the entire analysis workspace and would be applied to the selection and configuration of the other apps.



Figure 39: Thematic view map mock-up related to fishing activities [73].

### 7.5.17 Close-Encounters Pop-Up

The Close-Encounter Pop-Up App gives a very concise visual summary of whether a ship has come close to another ship during a specified time period. If we consider the situation where an analyst wants to check if a rendezvous has taken place, the operator would need to use a time slider and replay the scene or turn on the time labels for each contact and mentally compare them.

The proposed encounter icons give a temporal overview for the narrow vicinity of a specific vessel. The icon is centered on the frame of reference of the current ship. A simple way to picture this concept is to imagine the icon moving along the ship track while other vessels leave a trace in it as they cross it. This pictogram tells the operator instantaneously if any other vessel has been in proximity to this ship anywhere during its complete journey.

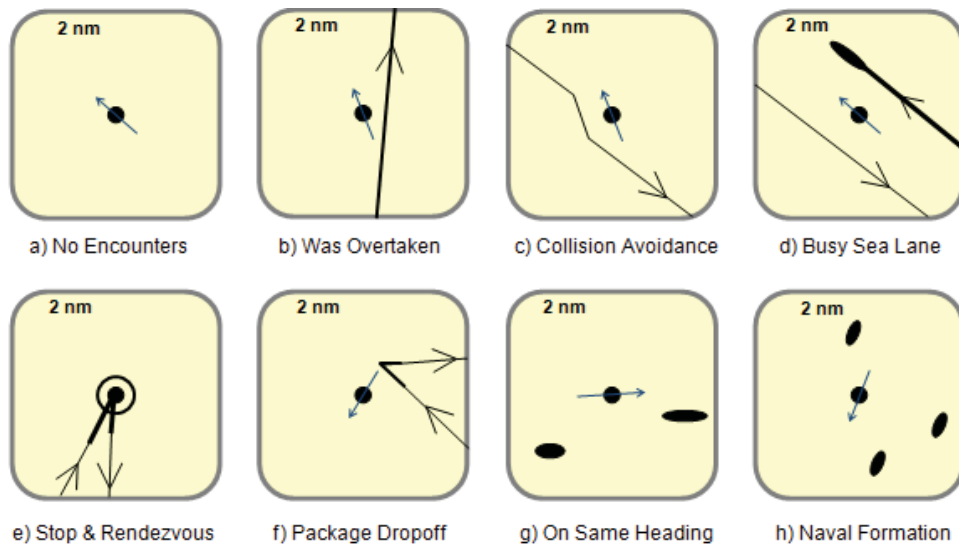


Figure 40: Examples of close-encounter pop-up icons.

The close-encounters icons can pop-up when we do a mouse-over on the tracks and instantly reveal if meetings may have happened. It can also be included in a vessel summary card. For wide-area surveillance, a single button will create pop-ups for all tracks of interest, so that a quick check can be done for all tracks. This icon can also be inserted in the Vessel Summary Cards.

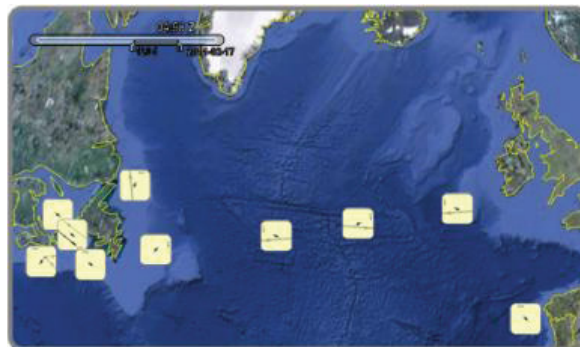


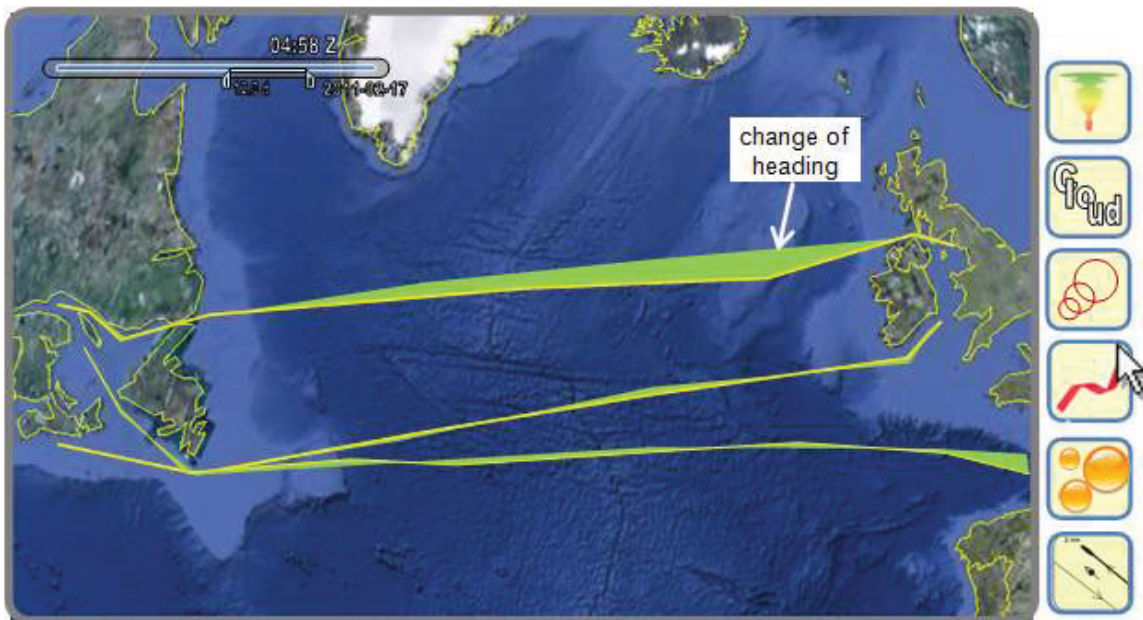
Figure 41: Close encounter pop-up icons on the map.

### 7.5.18 Route Ribbons

The Route Ribbons App quickly shows which transport ships are deviating from the most direct route to their destination. Transcontinental ships follow predictable routes, and any deviation from those routes is noteworthy. Many types of vessels also communicate their schedules publicly (ex: ferries). The route ribbons visually represent deviation from travel plans. The current track is displayed as a line. The space between this line and the expected route is filled with color, creating the “ribbon”. The ribbon gets larger as the vessel deviates from its normal route, thus increasing saliency as the behaviour becomes anomalous. An analyst can pop-up a temporary route ribbons overlay to get an instant visual indication of how well transcontinental ships are staying on great circle routes. The ribbons also show if vessels seems to not be heading to their stated destination.

Less direct routes may be followed for reasons such as:

- Ships carrying illegal migrants have been observed to follow less direct routes either to avoid observation or because they lacked the navigation software.
- Ships may also change their destination due to new instructions from their clients. The spot price of petroleum will vary from port to port, for example, as the result of the arrival or non-arrival of a tanker or Liquefied Natural Gas (LNG) carrier.
- Ships may divert to avoid weather or ice.



*Figure 42: Route Ribbons are displayed on the map and show deviation from the most direct route to the vessel's destination. The larger the deviation, the more visually salient the ribbon becomes.*



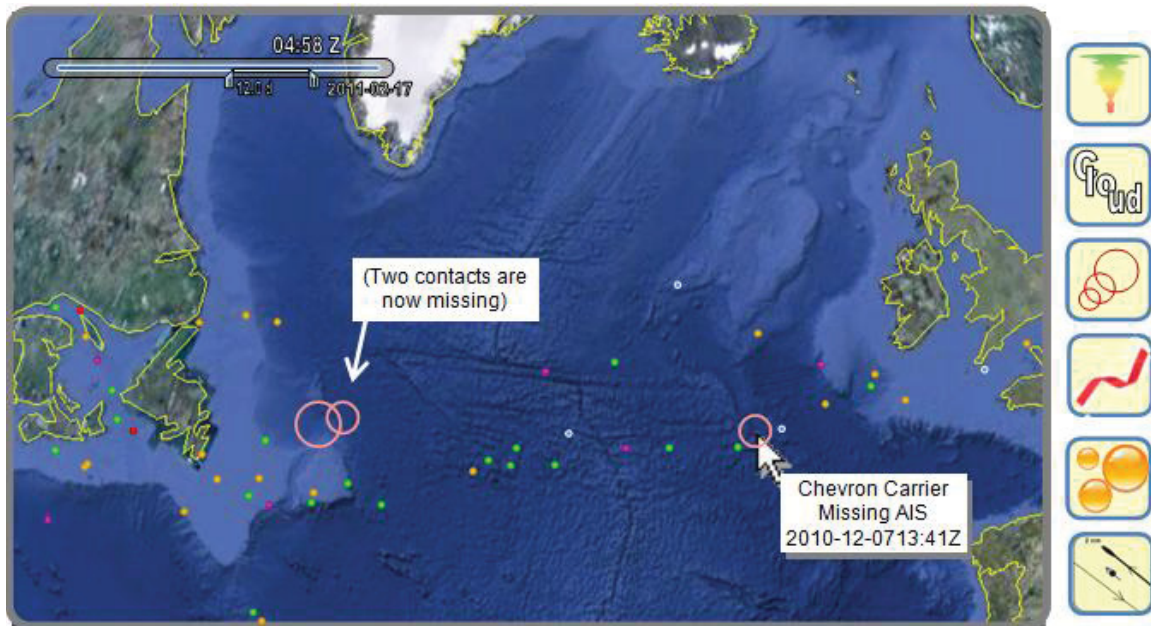
### 7.5.19 Missing-Contact Circles

The Missing-Contact Circles App draws attention to tracks that should have shown up on a sensor but did not. Currently, if a track that is not a VOI ends unexpectedly, that is if the vessel is not seen or tracking signals not received when they should be, the RJOCs will probably not notice. The Missing-Contact Circles App addresses this by popping up marker circles wherever a contact is missing.

The visualization is applied differently to different classes of ships as follows:

- Circles pop up when the Missing-Contact Circles icon is clicked, and go away when the icon is released. Some mechanism should be available for keeping the circles on when required (example double-click).
- For ships following a predictable route (e.g. a container ship heading to a known harbour) the circles are centered at the place where a contact was expected.
- For ships with an unpredictable route (e.g. fishing boats) the circles are centered at the last observation.

The size of the circle increases with the amount of time since the last contact.



*Figure 43: The Missing Contact Circles exist for only as long as the app's icon is pressed. This pop-up would frequently be used with the Time Slider on Ship Tracks App.*

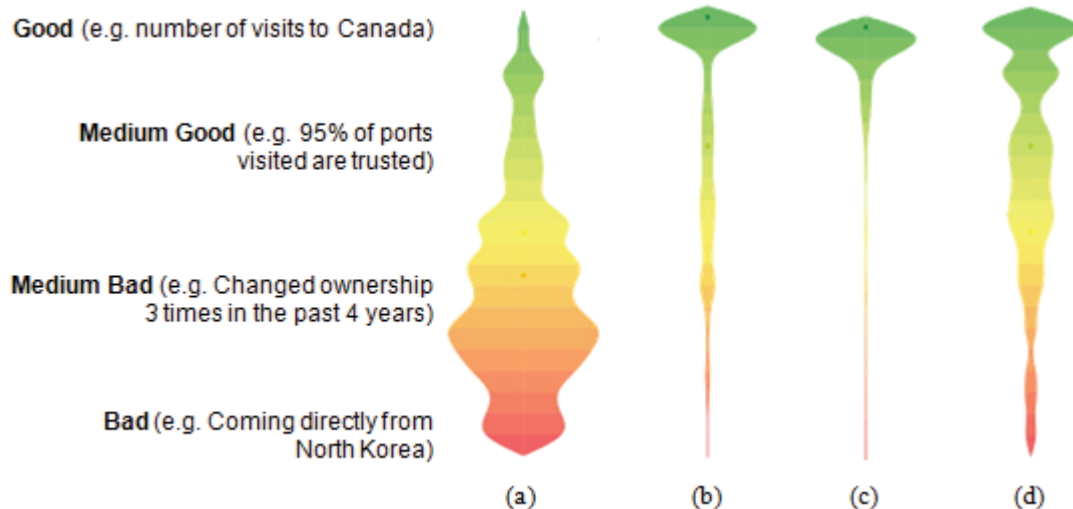


### 7.5.20 Good and Bad Rivers

The Good and Bad Rivers App provides a “visual signature” of regulatory compliance of a ship and thus helps scan large numbers of ships for anomalies.

RJOC analysts trust some ships more than others, based on their past history and familiarity. Previous studies refer to a notional “Warm and Fuzzy List.” To be on that list, a ship must satisfy the following (fuzzy) criteria (from Tables 4-11 and 4-12 of [53]):

- Travelling on a route it often travels.
- Came from a trusted port.
- Has no past of security infractions.
- Has no past of reporting infractions.
- Based in Canada.
- Has a trusted Flag.
- No recent request for a change of berth.
- No recent change of Flag.
- No recent change of ownership.
- No recent visit to a port with poor security.
- No recent large change of crew.



*Figure 44: Good and Bad Rivers Visualization: The colour indicates the goodness of a statistic and the width shows how many times a ship was given a statistic with that goodness. Thus (a) has a bad track record in many different ways, (b) is mostly good with a few minor concerns, (c) is pure as the driven snow, and (d) is somewhere between bad and good.*

### 7.5.21 Word Clouds

The Word Clouds App presents textual information in a spatial context to provide more in-depth situation awareness. Word Clouds (also known as “Tag Clouds”) are effective in visual analytics contexts because viewers “scan” them rather than “read” them [90], so the words become part of the visualization. The display of word clouds is also proposed for the Vessel Summary Cards to show vessels’ characteristics.



(a)



(b)

Figure 45: (a) Words can be displayed above vessels to describe cargo, port of origin, destination, flag, shipping line. (b) The user could also select a single topic such as cargo or cycle through all topics by clicking on the icon.

## 7.5.22 Facts on the Map

The Facts on the Map App displays a graph model of situational facts in concert with a geo-temporal map of the domain so that facts can be understood in geographic context, and facts related to geographic entities can be visualized. It jointly browses facts in their graphical and geospatial contexts. It thus provides a visual tool for exploring and understanding the Situational Facts Knowledge Base (SFKB).

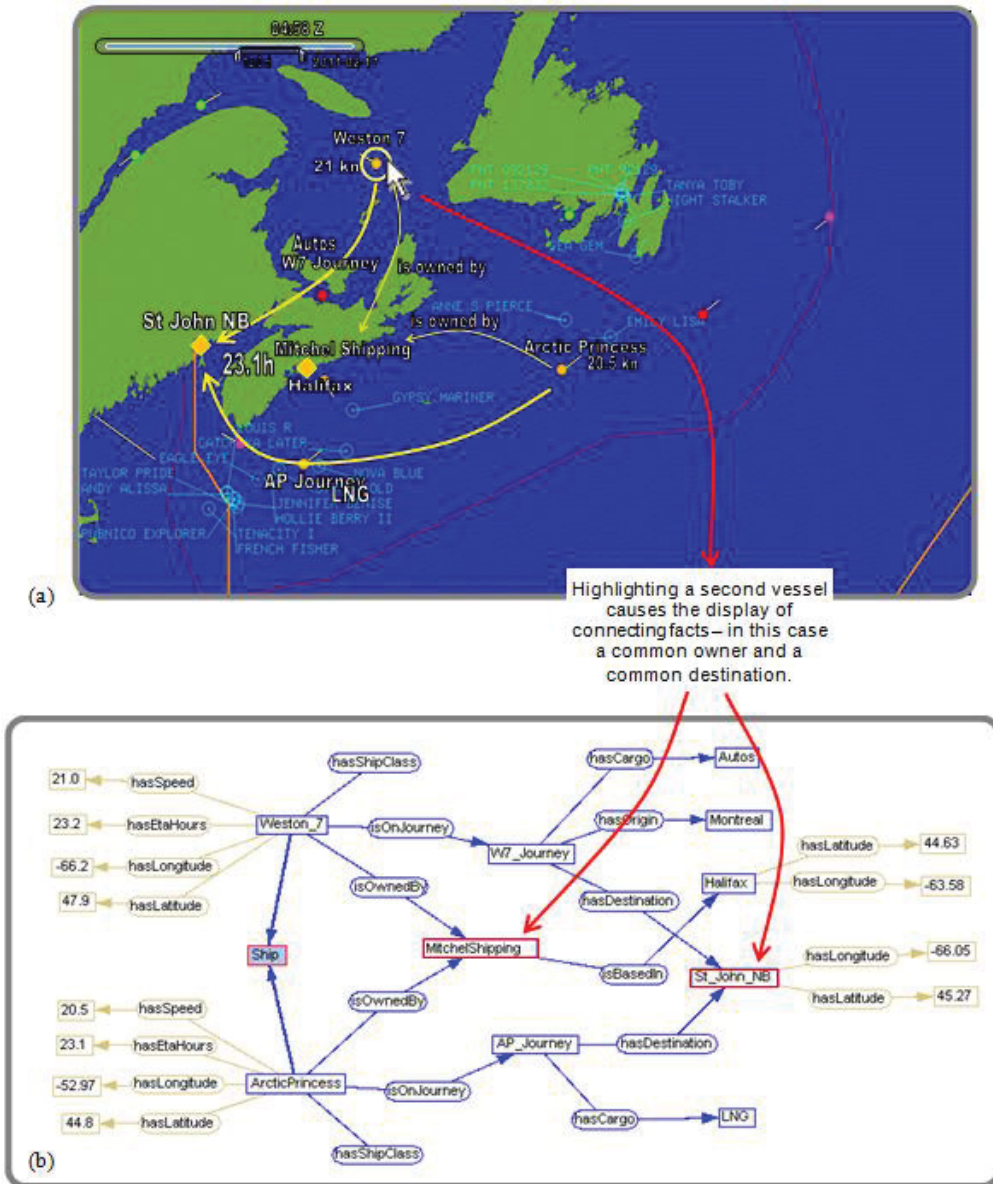


Figure 46: Facts on the Map highlights facts that connect individuals. Two vessels are selected on the map (a). The SFKB portlet (b) automatically finds facts that link both vessels, for example, that they both have the same owner and heading. These connecting facts are then displayed in word clouds on the map.



### 7.5.23 Visual Rationale

The Visual Rationale App shows the logic behind a fact generated by the automated reasoners.

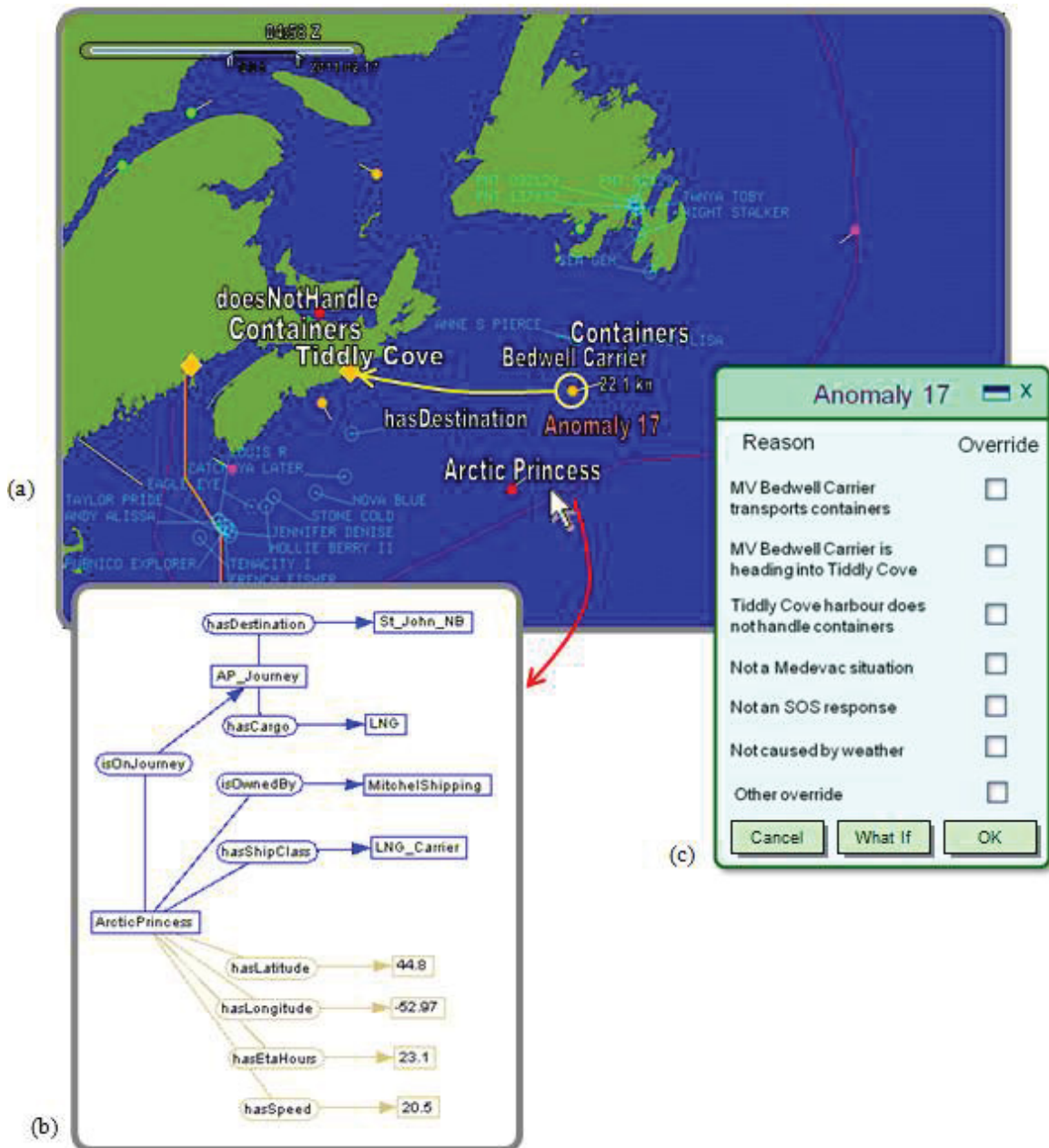


Figure 47: When automated reasoners detect an anomaly or a threat, the Visual Rationale App provides a visualization of the anomalous situation (a), an opportunity to drill-down for more information (b), a mechanism for investigating the cause of the anomaly, and an opportunity to override the anomaly condition (c). Window (c) is from [91].

## **7.6 Presentation to Domain Experts and Operational Community**

Scenarios, use cases and candidate apps were presented to domain experts at three workshops, totalling 5 days. Their comments influenced the proposed design of the apps. At the final workshop, domain experts from the Atlantic and Pacific operational community were gathered in Esquimalt and were briefed on most of the above apps in their final form.

Discussion during the presentation was animated and comments revealed a lot of interest in improving the present situations. Not surprisingly, opinions on how useful the innovations will be were very dependent on what portion of the RJOC or MSOC organization the respondent worked in. A summary of the expert response to the briefing is provided in [77]. Two common themes stand out:

- Many ideas are more applicable to MSOC than RJOCs.
- The information required for some apps may not be available.

## **7.7 Selected Concepts for the Maritime Visual Analytics Prototype**

The resources within the 11jm project do not allow us to pursue the development of all the imagined concepts into the Maritime Visual Analytics Prototype (MVAP). A subset of the proposed concepts was selected for the prototype development phase. The criteria for selecting those concepts were:

- Novelty of the proposed idea
- Potential for operational use
- Broad applicability

The workspace and analysis sets concepts were adopted along with a preliminary list of selected apps to populate it. Here are the app concepts that were selected as priorities for partial or full implementation in subsequent MVAP development activities:

- Vessel Summary Cards
- Vessel Timeline
- Time Slider on Ship Tracks
- Dust, Magnets and Scatter Plots
- Thematic Views
- Close-Encounter Pop-Up
- Route Ribbons
- Word Clouds

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## 8 Exploration of Collaborative Technologies

### 8.1 Collaborative Environment and Infrastructure

Our proposed approach to support collaborative analysis considers both the collaborative applications concepts presented in Section 7.5 and a collaboration infrastructure. An Intelligence laboratory (Ilab) has been stood up at DRDC Valcartier to conduct exploration. This physical collaborative environment is composed of individual workstations, multi-touch tables, large group displays, and network infrastructures with collaboration services such as conferencing. The multi-touch table will be used as a shared workspace where information from different departments can be brought together to discuss a situation, such as a VOI. We expect this advanced collaborative environment to improve the collaboration of co-located and virtual teams. We favour use a web based approach for the apps, leading to easier multi-device use.

Some exploration of collaborative technologies has already taken place within the lab. More specifically, we developed a multi-touch enabled version of Google Earth for use with maritime data on a multi-touch table and a share situation awareness portal mock-up to provide a knowledge wall capability.

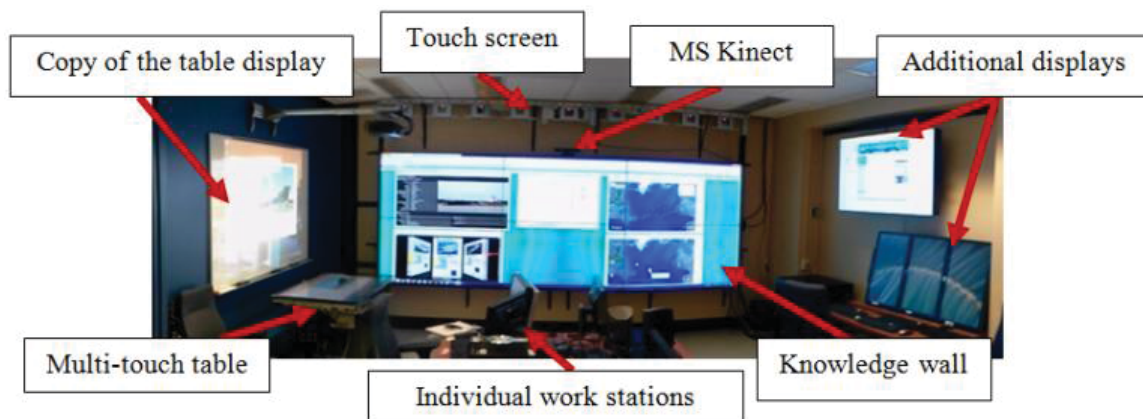


Figure 48: A picture of the large display and its immediate surroundings in the ILAB [92].

### 8.2 Shared Maritime Collaborative Portal

Within the maritime command centres (RJOCs and MSOC), knowledge walls could be used to display information that is of interest to many users, collectively, for example information concerning a VOI. “The purpose of the knowledge wall is to foster shared situation awareness, permit continuous updating of the military situation and enhance the senior staff’s ability to interact with supporting information systems. Moreover, an advantage of knowledge walls is to present on the same wall a lot of aggregated situation awareness information coming from various sources. Different screens can be used to monitor different parts of an operation. This helps commanders to obtain a global vision of the situation” [93].



The Knowledge Wall would support the concept of portfolios [27] where all information related to a single VOI would be regrouped. Control of the various portlets can be shared among an assembled team of analysts using keyboards and mice, each of whom can view contributions from the others in real time.

The Knowledge Wall could be largely based on SitScape Web-based, UDOP software. SitScape [94] is a software application that allows users to easily aggregate and visualize disparate applications and information sources into a collaborative UDOP, running onto a web browser for live monitoring, situational awareness, information sharing, and visual contextual collaboration. Various applications can easily be dragged and dropped onto the browser, and its different tabs, while maintaining a live feed connexion.

SitScape makes it possible to embed various elements in a web page, such as: desktop applications, PDF documents, PowerPoint presentations, web pages or parts of them, etc. This can be easily configured using the “Add Content” function which guides us in the process of adding almost anything (shown in Figure 49). SitScape allows sharing views with other users. It is even possible to annotate a view to facilitate the collaboration. It also includes many functions to help the users manage their content and provides many ways to display it.



*Figure 49: Sitscape's "Add Content" popup.*

In order to explore SitScape's capabilities, we developed a small portal [92] with various tabs (Figure 50) related to maritime situation awareness and analysis topics such as surveillance, VOI analysis, search and rescue operations and anomaly detection (more apps on Figure 51). The UDOP can be customized into a number of tab folders and it is accessed through a simple browser. Adding content to the SitScape portal was quite simple and really fast. This tool has good potential for rapid portal creation, although it may not support all types of applications and displaying applications running on a remote computer can lag noticeably.

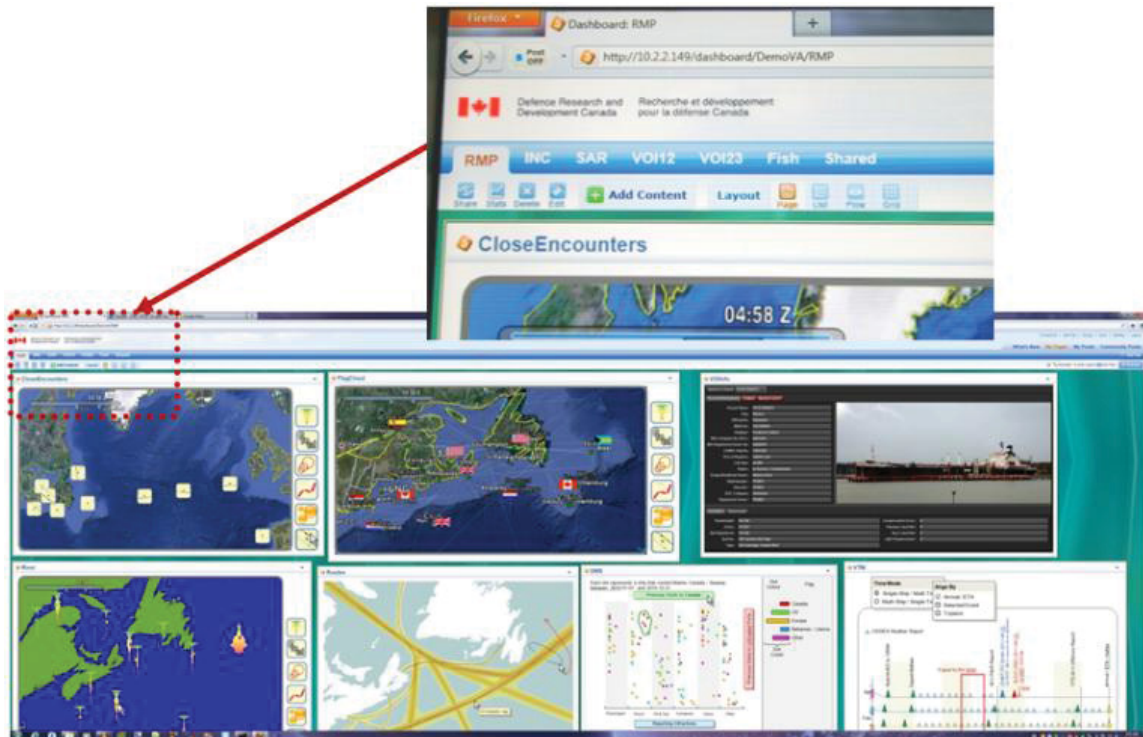


Figure 50: Maritime portal mock-up built with SitScape with multiple tabs involving many maritime application mock-ups [92].

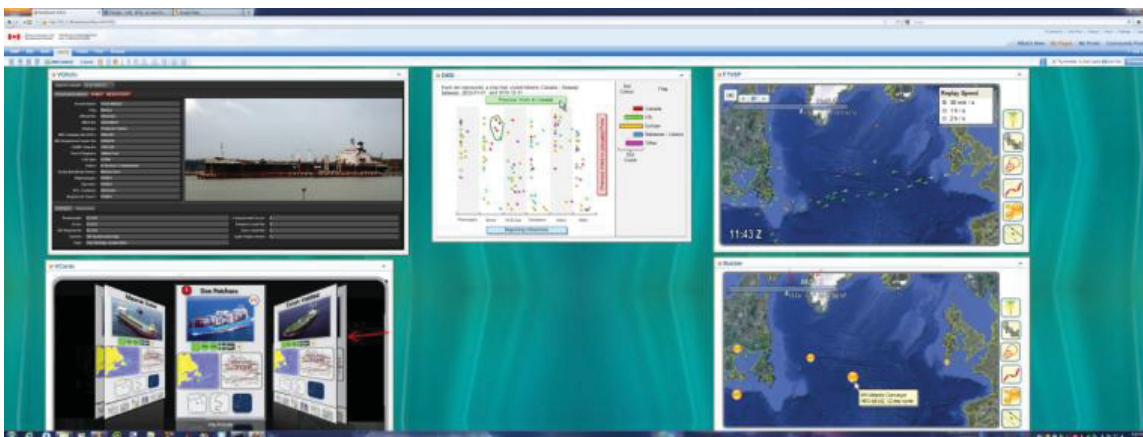


Figure 51: Another tab of the maritime portal mock-up involving more maritime application mock-ups [92].

Figure 52 shows a maritime portal mock-up displayed on our knowledge wall using SitScape [92]. This infrastructure has been built using a 3 x 2 configuration of 60 Inch LCD panels. It provides a seamless display of 1366 x 768 pixels. The total size of the configuration is 13' x 5'. A touch screen and MS Kinect interactions are enabled. In this mock-up, in accordance with UDOP concepts, team members can assemble the operational picture using a variety of apps, running on many portlets, on multiple displays, and if necessary in different locations.



Figure 52: Mock-up of a maritime portal on a large display with SitScape [92].

### 8.3 Multi-Touch Google Earth and Vessel Information

In the context of maritime operations, the map is key and would constitute the main element of information displayed on the tabletop surface. This has a close reminiscence with the former naval operation centers that used to lay out charts on tables [31]. The main map can be zoomed and panned using simple gesture interaction but not rotated. Other smaller portlets can be rotated for users along the different edges of the table.

Some applications, such as Google Earth, could benefit greatly from being multi-touch capable. Fortunately, in this case, Google provides access to some basic functions through programming. It was therefore attempted to add a multi-touch functionality to Google Earth [92], as illustrated in Figure 53. This small prototype allows visualization of vessel tracks as well as information retrieved from Lloyd's website along with vessel pictures from the ShipSpotting website, which are displayed as small vessel cards (Figure 54). This prototype also supports queries to find specific vessels. Working on a surface device may require displaying windows along different orientations as in Figure 55, which is also supported.



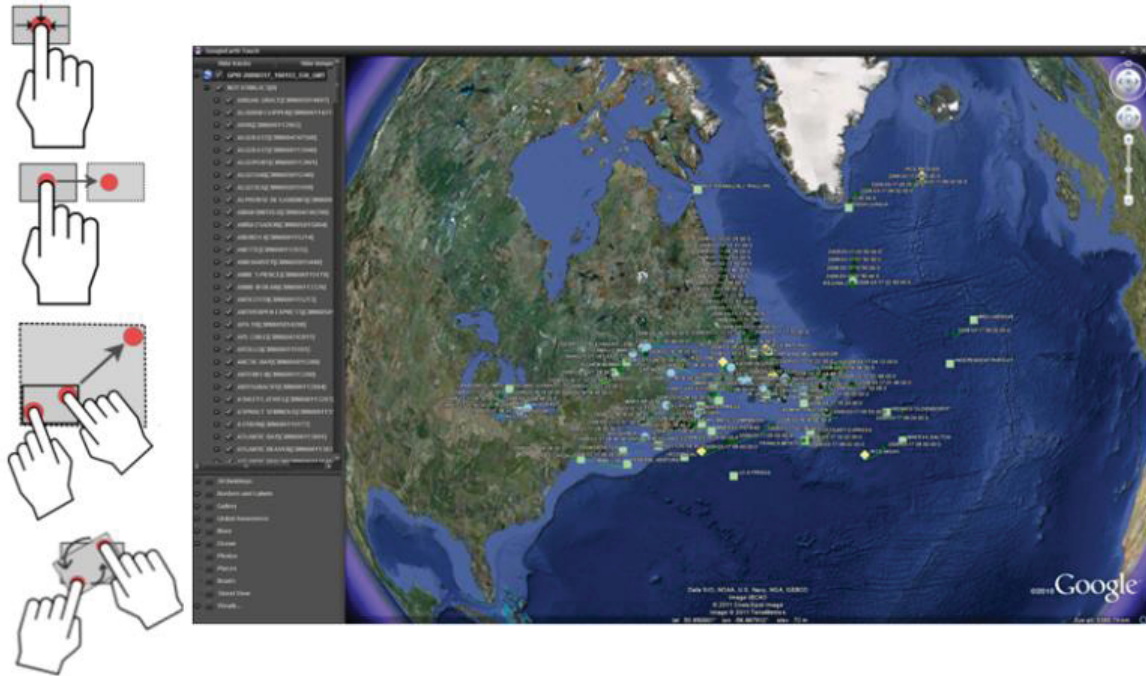


Figure 53: Multi-touch Google Earth application and supported gestures for manipulating the map and the vessel tracks [92].

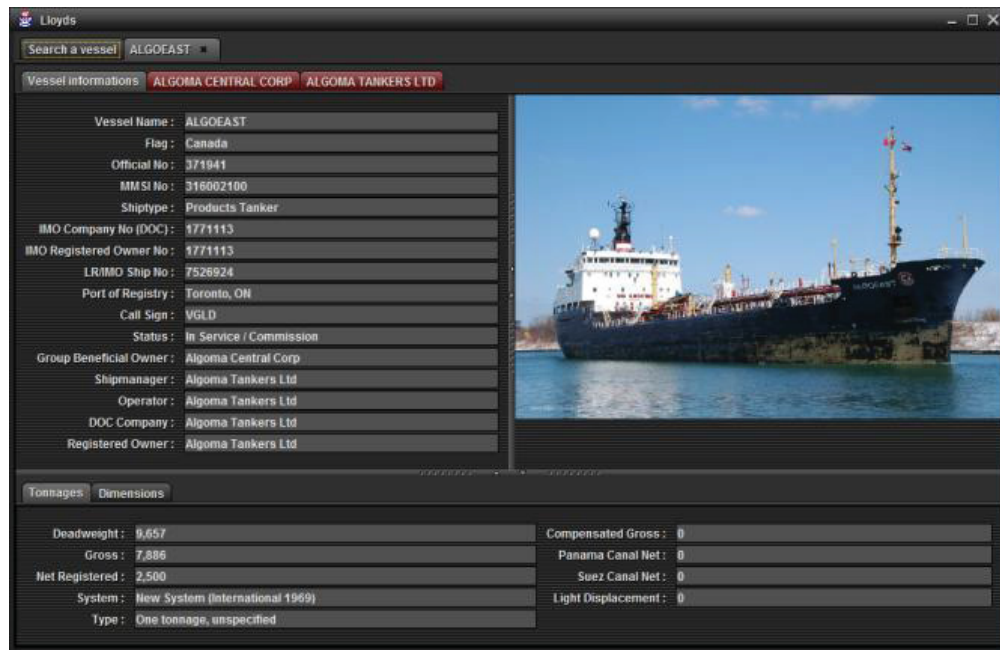


Figure 54: A vessel card in our prototype, showing retrieved information about a vessel and a photo [92].

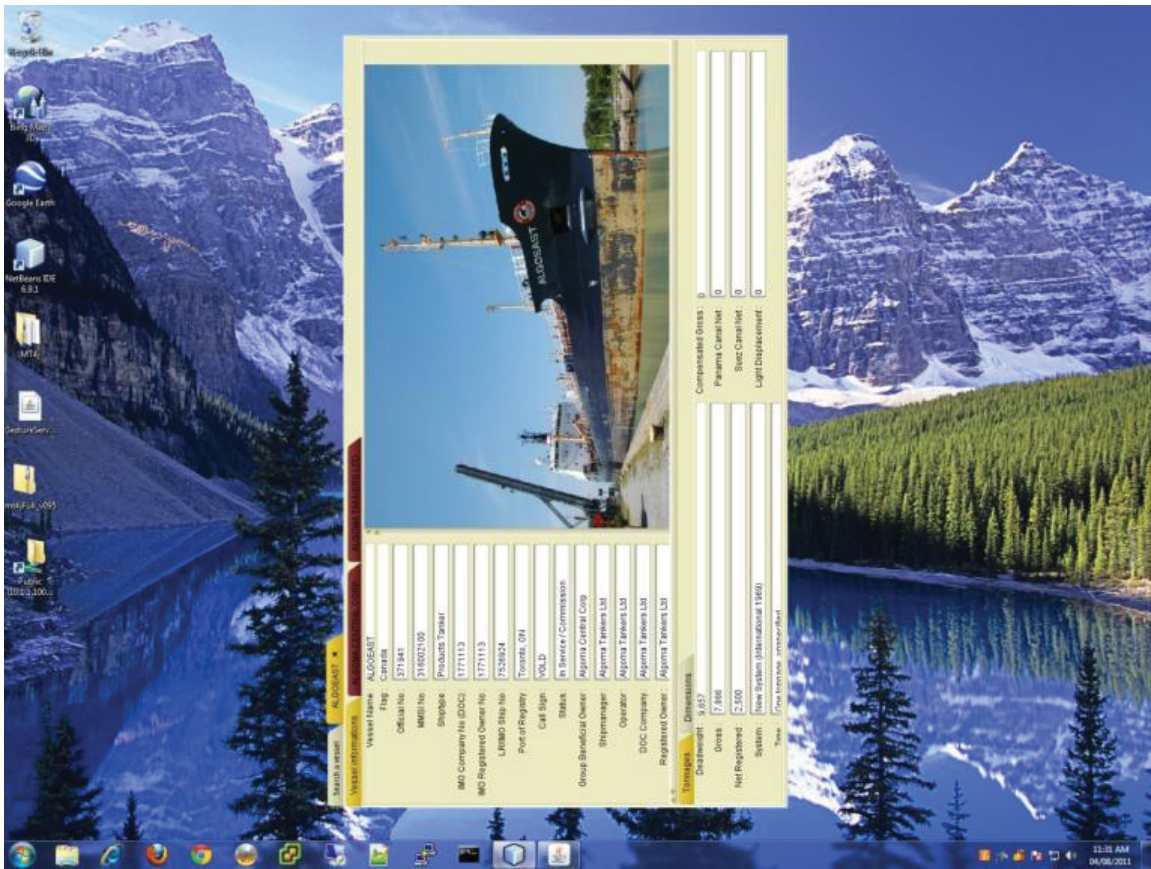


Figure 55: Displaying windows along different orientation for visualizing vessel information on the multi-touch table [92].

The knowledge wall of the Ilab can be controlled by standard keyboards and mice, as well as with a touch screen device that was installed on it. However, as the display is indeed quite large, users may want to interact with it from a few steps away in order to have a full view of the information presented. In that case, gesture interaction may prove handy. Using the MS Kinect device, we were able to interact with our multi-touch version of Google Earth on the large display through hand gestures in front of the knowledge wall [92].

All available gestures can theoretically be done. However, because the gestures are done with hands in the air, some are hard to do, like a click. A “touch” is detected when a hand is at a certain distance of the body. This means that to do a click, it is necessary to cross this invisible line and comeback rapidly and while doing this the cursor needs to stay at the same place which is not easy because even a little movement can change its position. Rotate and zoom gestures, on the other hand, are quite easy to perform. This experience with the Kinect shows that it is possible to create a functional interface with this technology but, it will require a little more effort (especially related to gesture definitions) to make it usable in everyday life situations.

## 9 Conclusion

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### 9.1 Results so far

In this report, we identified a subset of maritime applications and tasks where the use of VA has a high improvement potential, which are: the visualization of normal maritime behaviour, the detection of anomalies and the collaborative analysis of a VOI.

The VA solutions we propose will offer cognitively rich visual representations that will lead to a more efficient exploration and analysis of the current maritime situation. These tools will also support communication of analysis results and teamwork collaboration. With our apps-based design approach, we propose new innovative VA capabilities and apply existing VA concepts to a real world problem.

As the project resources are limited, a subset of the proposed ideas was selected for implementation into the Maritime Visual Analytics Prototype (MVAP), based on the feedback from the operational community and the novelty and broad applicability aspects of the concepts. The workspace concept was adopted along with the following app concepts: Vessel Summary Cards, Vessel Timeline, Time Slider on Ship Tracks, Dust, Magnets and Scatterplots, Thematic Views, Close-Encounter Pop-Up, Route Ribbons, and Word Clouds.

Promising collaborative technologies for application to maritime situation awareness and analysis were assessed in the lab. More specifically, we experimented with multi-touch table technology, a large display wall, a gesture interaction device and a rapid portal designing software. Maritime applications and mock-ups were built to showcase the capabilities of these new technologies for their use in a maritime surveillance context. We implemented a multi-touch version of Google Earth that can be used on a multi-touch table as well as with the wall display using gestures captured by a Microsoft Kinect sensor. A maritime situation awareness portal including various analysis tools mock-ups was developed using the SitScape software and displayed on the knowledge wall. A simple application was also developed to display vessel information windows with various orientations.

### 9.2 Ongoing Work in 11jm

Our ongoing work aims to demonstrate the use and expected benefits from the proposed visual analytics and collaboration concepts. Although all the proposed apps are tailored to address specific cognitive overloads that have been identified by RJOC personnel, the operational value of each app cannot be assessed until the prototype has been built and controlled evaluations done.

The next step consists in implementing the proof-of-concept Maritime Visual Analytics Prototype (MVAP). User validation and evaluation activities will be conducted. They will provide an opportunity to integrate user suggestions and preferences. Advancement regarding the MVAP will be described and discussed further in a separate report.

It is believed that the advanced interface and interaction devices explored in the lab will be helpful for collaborative analysis and for sharing situation awareness among a team of analysts.

Many possible ways to enable collaborative teamwork were explored and the insight gained will be relevant to next steps of the project. Future exploration could include tablet and smart phone devices as well a speech interaction. We also intend to leverage the LiveSpaces technology for experimenting with the MVAP in a remote synchronous collaboration context.



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## List of symbols/abbreviations/acronyms/initialisms

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AOR	Area of Responsibility
ARP	Applied Research Project
CF	Canadian Forces
COP	Common Operational Picture
CSCW	Computer Supported Cooperative Work
CVAV	Collaborative Visual Analytics of a VOI
DND	Department of National Defence
DRDC	Defence Research & Development Canada
JIMP	Joint, Inter-agency, Multi-lateral, Public
LNG	Liquefied Natural Gas
MDA	Maritime Domain Awareness
MSOC	Marine Security Operations Center
R&D	Research & Development
RJOC	Regional Joint Operational Center
RMP	Recognized Maritime Picture
ROI	Region of Interest
SFKB	Situational Facts Knowledge Base
SOA	Service Oriented Architecture
UDOP	User-Defined Operating Picture
VA	Visual Analytics
VADA	VA-based Detection of Anomalies
VAST	Visual Analytics Science and Technology
VOI	Vessel of Interest

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This report describes the research done from April 2009 to December 2011 within the 11jm (previously 11hm) Applied Research Project (ARP) titled “Maritime Domain Analysis through Collaboration and Interactive Visualization,” regarding the application of visual analytics and collaborative technologies to the maritime domain. We first reviewed the challenges related to maritime operations. Then, we introduced the basic concepts underlying visual analytics and collaborative technologies. The core of the report presents the results from the exploration activities that led to the identification of maritime contexts where these technologies could be of use, the design of visual analytics and collaborative application mock-ups, and the exploration of collaborative technologies hardware and software in our laboratory. Finally, the report discusses the way ahead for the prototype.

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Ce rapport décrit le travail d’exploration réalisé entre avril 2009 et décembre 2011 dans le cadre du Projet de recherche appliquée (PRA) 11jm (auparavant 11hm) intitulé “Maritime Domain Analysis through Collaboration and Interactive Visualization”, qui porte sur l’application des technologies d’analytique visuelle et collaborative au domaine maritime. Nous revoyons d’abord les défis en lien avec les opérations maritimes. Ensuite, les concepts de base de l’analytique visuelle et des technologies de collaboration sont introduits. Le cœur du rapport présente les résultats des activités d’exploration qui ont conduit à l’identification des contextes maritimes dans lesquels ces technologies pourraient s’appliquer, la conception de maquettes d’applications d’analytique visuelle et de collaboration et l’exploration de matériel et de logiciel collaboratifs dans notre laboratoire. Pour terminer, nous discutons de la voie à suivre pour le développement du prototype.

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visual analytics; collaboration; maritime domain awareness; recognized maritime picture; intelligence analysis; anomaly detection; vessel of interest; situation awareness; visualization; collaborative technologies; knowledge wall; multi-touch interaction; prototype development or identifiers



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