

Collaborative Interactive Visualization – Exploratory Concept

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ABSTRACT

Dealing with an ever increasing amount of data is a challenge that military intelligence analysts or team of analysts face day to day. Increased individual and collective comprehension goes through collaboration between people. Better is the collaboration, better will be the comprehension. Nowadays, various technologies support and enhance collaboration by allowing people to connect and collaborate in settings as varied as across mobile devices, over networked computers, display walls, tabletop surfaces, to name just a few. A powerful collaboration system includes traditional and multi-modal visualization features to achieve effective human communication. Interactive visualization strengthens collaboration because this approach is conducive to incrementally building a mental assessment of the data meaning. The purpose of this paper is to present an overview of the envisioned collaboration architecture and the interactive visualization concepts underlying the *Sensemaking Support System* prototype developed to support analysts in the context of the *Joint Intelligence Collection and Analysis Capability* project at DRDC Valcartier. It presents the current version of the architecture, discusses future capabilities to help analyst(s) in the accomplishment of their tasks and finally recommends collaboration and visualization technologies allowing to go a step further both as individual and as a team.

Keywords: Collaboration, interaction, visualization, Intelligence, analyst, sensemaking

1. INTRODUCTION

Dealing with an ever increasing range of data of diverse types is a challenge that (military intelligence) analysts face day to day. Digital data is regularly accessed by these people in order to visualize, interpret and analyze information, to comprehend a complex situation either individually or as a team, to share results with other (team) members, to fuse information from different sources of data, or to support decisions and hypotheses. Increasing individual and collective comprehension goes through *collaboration* between (co-localized and/or geographically dispersed) people. We work under the hypothesis that better is the collaboration, better will be the comprehension.

Joint Intelligence Collection and Analysis Capability (JICAC), the R&D project in which the work presented in this paper is realized, has to develop and demonstrate an advanced prototype of an Intelligence production capability intended for all-source, multi-intelligence analytical teams in production environments of the future. This project is the first instantiation of the *Future Intelligence Analysis Capability (FIAC)* vision that aims at advancing the state-of-the-art of intelligence methods and resources in order to adapt to and anticipate the new challenges of the Canadian Armed Forces and other government agencies. As expressed in (Poussart, 2013), “FIAC addresses information services: (1) from a multi-intelligence and all-sources perspective, (2) over the full intelligence cycle, (3) but especially toward enhancing analysis capabilities. FIAC seeks, in particular, to exploit an optimized level of synergy between human cognition and machine intelligence, using advanced, collaborative interaction. A key paradigm is that all participants share a single, unified data/information space, irrespective of their actual physical location.” Figure 1 depicts the FIAC operating concept. The bottom pane shows the conceptual mapping of the analysis phases of the intelligence cycle, based on the framework introduced in (Pirolli and Card, 2005). The top frame provides an artist’s rendition of an analysts team using advanced visualization and interaction technologies, virtual reality, spatial computing, virtual assistants that are capable of operating at high cognitive levels, extensible work spaces, conferencing with remote facilities, etc. The side panes represent high performance computing resources for intelligent processing: on one side are those in direct, real time support for the on-going analysis work, on the other side are those involved in the optimized management of the resources (human and machine based), as well as essential infrastructure for communication, archiving, and resource allocations.

This paper presents the latest architecture version underlying the *Sensemaking Support System (S3)* prototype developed for the JICAC project. The S3 is a step towards the implementation of the FIAC concepts. It consists of various

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intelligence analysis web services build of top of big data technologies exploited through a single web application. The system has been developed following main design principles from the *Service Oriented Architecture - Reference Architecture*¹ (SOA-RA) technical standard produced by *The Open Group*. Following the architecture overview, the paper focusses on new capabilities of interest for the military intelligence analyst of the future and pursues with collaboration and visualization tools that analyst or an analysts team could use to exploit capabilities included in the S3.

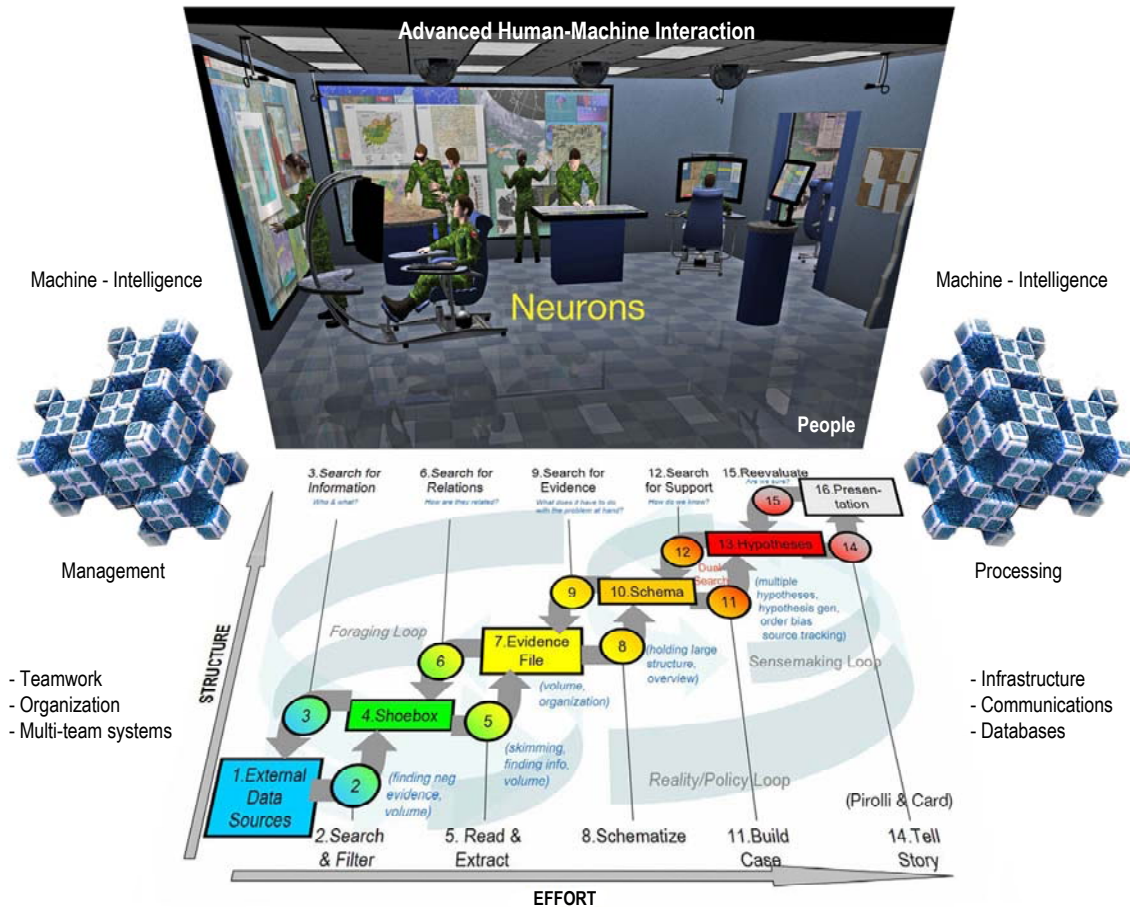


Figure 1. FIAC operating concept (Poussart, 2013)

2. COLLABORATIVE INTELLIGENCE PRODUCTION CAPABILITY

The proposed collaborative military intelligence production capability combines the current S3 prototype with a context management sub-system in order to provide adaptive collaboration features in support to the whole intelligence production workflow. The resulting context-aware system adapts its behavior and features dynamically according to various aspects of the context (e.g. current users, their roles, tasks, permissions and locations, limited nearby resources, missions objectives and so on) in order to optimize exploitation of the system while providing continual system feedback and a seamless user experience across the whole system.

From the point of view of the intelligence analyst, the proposed capability provides at the right time the relevant tools and just the appropriate information elements to support his/her current work and the next steps while avoiding cognitive overload. The analyst can request information and produce results while the system is responsible for delivering the appropriate notifications to concerned assets. On the other hand, the system has to balance resource allocation and data sharing in order to process and coordinate various requests from multiple collaborators while ensuring the convergence of the whole team towards a common objective.

¹ http://www.opengroup.org/soa/source-book/soa_refarch/

Figure 2 shows an overview of the envisioned architecture integrating the context-adaptive collaboration capability with current and future components of the S3 prototype such as the *Unified Data Space (UDS)*, various *Intelligence Production Services* and a “publish & subscribe” *Messaging Service*. The diagram also depicts basic data flows and interactions with the users.

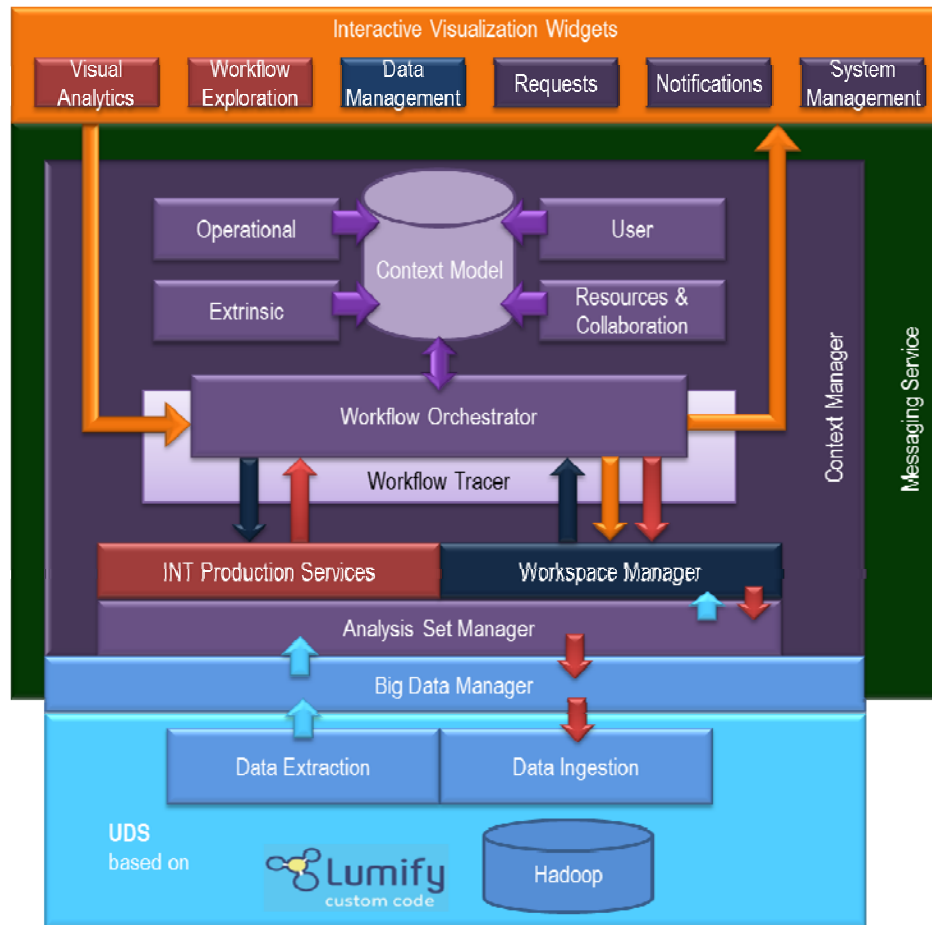


Figure 2. Architectural overview of the proposed collaborative intelligence production capability

S3 Components

The whole S3 prototype sits on the *UDS* where validated common knowledge is stored. Based on the Lumify software², this important component exploits big data technologies such as Hadoop³ and Storm⁴ to extract, ingest, process, filter and index large amounts of data according to requests and operations executed from the S3 interfaces.

Above this database resides the *Big Data Manager* responsible for transparent data transmission between the *UDS* and the rest of the S3 system.

Another core component is the *Messaging Service*, realizing some of the needed features in the integration layer defined in the SOA-RA. This component is also a prerequisite for most of the collaboration and interaction features mentioned further. It manages multiple independent pipelines for partitioned message exchanges across a shared network allowing multiple services, users and other system components to share data and send notifications between each other while maintaining privacy and partitioning between the various topics.

² <https://www.altamiracorp.com/blog/products/lumify>

³ <http://hadoop.apache.org/>

⁴ <http://hortonworks.com/hadoop/storm/>

Context Manager

The proposed *Context Manager* takes care of everything related to system usage and current status of the situation. It monitors current online users, available services and devices; it keeps sets of analysis data up-to-date; it manages data and notification exchanges between users and services; it responds and adapts to situation changes, to new requests and updated targeting priorities while providing a seamless user experience and proper feedback through *Interactive Visualization Widgets*.

To achieve all those features, the *Context Manager* relies on multiple sub-components, each responsible to store and react to specific aspects of the context:

- The *Context Model* is the actual placeholder for persisted contextual information. Context changes are transmitted between components of the system through the *Messaging Service*.
- The *Analysis Set Manager* is responsible to gather from the *UDS* and keep up-to-date a reference set of the necessary data that is required to fulfill the information needs for the different workspaces currently in use.
- The *Workspace Manager* holds multiple independent workspaces allowing users to manipulate datasets obtained through the *Analysis Set Manager* in a private or shared data space before publishing results. It also allows an analyst to work on multiple intelligence problems separately.
- The *Workflow Orchestrator* exploits contextual information to plan and coordinate the concurrent executions of various processing and collaboration tasks to fulfill requests and support the work of multiple users sharing limited resources.
- The *Workflow Tracer* keeps tracks of every step followed by the analyst and every action initiated by the *Workflow Orchestrator* during his/her work. A *Workflow Exploration* interface is used to keep the user aware of the current status of his/her work, to backtrack on previous actions, or simply for review.

The following section describes in more details the contextual information managed in the S3 system and the exploitation of the *Context Manager* to provide adaptive collaboration interfaces.

3. CONTEXT AWARENESS

Taking into account the usage context has considerable implications for the system. Context is by nature a concept that is not easily defined and context modeling can involve an almost infinite number of elements. One has to draw a line and decide what will be considered depending on the application. It can be constituted of a number of relevant pieces of information including static and dynamic elements that make up the analyst's working situation.

Consequently, only some aspects are to be considered in the *Context Manager*. Here is a non-exhaustive list of context properties divided into four main categories:

- *Operational context*: role, rank, current task, mission objectives, assigned information requests and tasks, focus of interest (geographical areas, topics, targets and so on);
- *User context*: properties and preferences of each single user, his/her personality, cognitive style, physical disabilities, spoken languages, cultural differences, level and field(s) of expertise and so on;
- *Resources and collaboration context*: information space, available services and computing power, display count and sizes, available interaction modes, taskable assets, human team members who can contribute and their areas of expertise; and
- *Extrinsic context*: connectivity, bandwidth, geographical location, time of the day, weather, working conditions, and other characteristics of the physical working environment (mostly elements that are partially or totally out-of-control for the users).

These context properties are stored in the *Context Model*. The *Workflow Orchestrator* exploits every possible pieces of contextual information to ensure an optimized execution of the workflow. The *Workspace Manager* component is mostly related to the user context since it keeps track of the data the user is working on.

For a visual interface to support the user in an optimal fashion, information presentation should adapt to the user's working context. This is the basis of intelligent adaptive interfaces. There are three aspects of the user experience that can be adapted:

- Information content: choose what is being presented to the user;
- Information presentation: adapt how the data is being presented; and
- Proposed actions: produce a set of proposed next steps for the task currently being performed.

Unless the use cases are well defined and mostly static, current and past contextual information must be considered by the system in order to propose appropriate next actions to users. By exploiting relevant aspects of the context such as user profiles, past actions, availability of resources and so on, the system learns from usage history to enhance its prediction and profiling capabilities in support to each individual user.

The next section covers more deeply the *Workflow Orchestrator* and *Workflow Tracer* concepts applied to track and exploit the analyst's actions while performing work in order to propose next steps and optimize his/her interactions with the other team members.

4. ANALYST'S WORKFLOW

In the context of military intelligence production, it is unfortunately common that military personnel are assigned tasks for which they could not get full training prior to the assignment or do not perform on a daily basis. There is an expectation that the interface should support the workflow of those users by assisting them in real-time during the ongoing process, and even suggesting a sequence of steps to be performed next. The tools designed for this purpose are the *Workflow Tracer* and the *Workflow Orchestrator* components which are part of the proposed *Context Manager* capability.

Workflow Tracer

For some well understood and routine processes the steps sequence can be predefined. However, there are a number of activities where the steps are not always identical and sequential. Intelligence analysis is one such process. Some sequences of actions can be performed in multiple orders while still producing similar results. Some steps could be redundant, recursive or conditional to some prerequisites. While performing an exploratory analysis, one could also wish to step back to a previous operation to try a different approach and compare the results obtained.

The *Workflow Tracer* records every step and constitutes an historic of previous actions. The user can navigate within the traced workflow through a *Workflow Exploration* interface and create branches for alternatives approaches. Intelligence analysts are often performing multiple tasks in parallel while they wait for new information to arrive or when a particular assignment sees their priority increased. In the *Workflow Tracer* and its associated exploration interface, this sequence of recorded tools interactions can be split intelligently along working lines that are associated with the different high level tasks that a user is performing in parallel, allowing him/her to alternate between them.

Recording every action that the user takes with the *Workflow Exploration* interface is the first step toward building a capability for analyzing these workflows in order to produce useful tasks recommendations. Keeping a history of interactions is also desirable because it supports audit and acts as a reminder to the user for what has been done in the past regarding a specific question or dataset.

Workflow Orchestrator

The *Workflow Orchestrator* exploits elements of the context to plan and coordinate the execution of multiple *Intelligence Production Services* in order to achieve the processing tasks defined by the analyst. This component has to handle many aspects of the context in order to maintain the proper execution of multiple workflows simultaneously with limited dynamic resources. Many factors and events can affect the workflow execution. Some are desired and voluntary, some are unpredictable. The impact and the response also vary depending on the situation. Results, notifications and information requests are displayed through the *Interactive Visualization Widgets*.

Within the *Workflow Orchestrator*, the user can select the next actions and tools that will be used on the data or as part of the analysis process. This selection can be made from a library of available processing steps. This can be very efficient for performing repetitive task. At any time, the user can aggregate a group of processing steps to form a higher

level processing box in the *Workflow Orchestrator*. This new box is then made available in the processing steps library. This allows an experimented analyst to create a plan that can later be followed by more junior personnel. After the higher level process is inserted into the analyst's work line, each of the steps can be followed in a continuous flow. The work line visualization then serves as reference tool, showing which step the user is now performing and what will be the next one.

The *Workflow Orchestrator* also goes one step further than the *Workflow Tracer* by exploiting recorded usage information to provide future actions planning and predictions capabilities. When planning the next step, available actions to be performed by the analyst could be recommended based on what the system learns from the users. Using pattern recognition on sequences of processing steps forming a work line in the *Workflow Tracer* could lead to the identification of groups of steps that are often performed together in a specific order. The work lines performed by other analysts can be added to the mix, where their actual contribution will be modulated by a similarity measure between the users and their context models.

This may be considered as a first step towards a future fully functional Intelligent Assistant / Virtual Analyst capability (Gouin, Lavigne and Bergeron-Guyard, 2012). As the system learns from user interactions, it could assemble lines of increasingly complex processing steps and have a number of these steps performed automatically.

The proposed steps may also involve actions assigned to other team members, thus supporting a collaborative analysis process. The *Workflow Orchestrator* then acts both as the tool for organizing work and monitoring its execution, allowing team members to be alerted when a co-worker has completed a needed task or when another person is waiting on them to perform an action. Boxes for disseminating results can also be included in the process planning so that this is performed automatically as soon as the results are available.

The next section covers collaboration and visualization tools that are of interest for analysts when working in collaboration with other analysts.

5. SUPPORTING COLLABORATION AND VISUALIZATION TOOLS

The most recent technologies allow people (e.g. military intelligence analysts) to collaborate with each other and to access, visualize, and share digitized data in various settings such as wireless hand-held mobile devices, over networked computers, through display walls, tabletop surfaces, to name just a few. This kind of collaboration is named technology-mediated collaboration. Chosen technologies must overcome time and space constraints when people having to collaborate on a common task cannot be gathered in the same room or cannot exchange information in real-time. Of course, technology must also facilitate collaboration between people localized in the same room at the same time.

In order to assist military intelligence analysts in their job as a team, technologies must allow every single user to work and perform individual tasks (e.g. annotation in the form of labeling or *tagging*, interactive visualization, notification, distributed visual analytics...) while contributing to the realization of greater objectives shared by the team. Figure 3 exposes a non-exhaustive summary of (combination of) technologies based on the time/space categorization matrix (Johansen, 1988) that considers work contexts along the space and time dimensions: whether collaboration between co-located or geographically distributed analysts and whether they collaborate at the same time (synchronous) or not (asynchronous). As expressed by (Rodden and Blair, 1991), in the day-to-day activity, a whole team can be either purely co-located, virtually co-located (different locations but connected via video and/or audio systems), locally remote (e.g. in the same building), worldwide remote (limited accessibility between team members) or simply a mix of the four ones. Furthermore, the time can be as well purely synchronous or asynchronous as a mix of the two ones.

Another aspect to keep in mind while doing collaborative work is the fact that tools used by a single user to do his/her job have usually not been designed and developed to be useful and usable for both individual and collaborative work (e.g. a shared touch-table). Consequently, when people have to collaborate together on such a tool, part of the work has to be realized in a sequential and iterative way by team members or the interface must be adapted in order to allow multiple collaborators to interact simultaneously. From time to time context-aware technologies can encompass this issue, especially for visualization and interactive technologies.

Virtual collaboration (Quarter 2 to 4, Figure 3), the opposite of *direct collaboration* (Quarter 1, Figure 3), is the method of collaboration between people not physically present in the same location. This fully technology-mediated collaboration "follows the same process as direct collaboration, but the parties involved in virtual collaboration do not physically interact and communicate exclusively through technological channels" (Peters and Manz, 2007). Dispersed

teams use virtual collaboration to simulate / to mimic the sharing of information present in face-to-face meetings, communicating virtually through visual, verbal, written, and digital means.

*Mobile collaboration*⁵ is a process of communication using electronic assets and accompanying software designed for use in remote locations. Recent technological advancements in *mobile collaboration* have extended the capabilities of *traditional videoconferencing* beyond the offices and meeting rooms for use with hand-held mobile devices, enabling collaboration independent of location (by exploiting wireless, cellular and broadband technologies) and permitting true mobile collaborative possibilities. Newest generations of hand-held electronic devices feature video, audio, and on-screen drawing in addition to capabilities to broadcast over (secure) networks, enabling multi-party conferencing in real time.

“Video conferencing has become an umbrella term to describe all types of video based communication (video chat between two or more people from laptops, a point to point call using sophisticated systems found in conference rooms, calls between two phones reminiscent of the original picture phone or multi-party calls similar to audio conferencing.”⁶ *Telepresence* refers to technologies which allow people to feel as if they were present, to give the appearance of being present, or to have an effect at a place other than their real location (e.g. telerobotics). A popular application is found in *telepresence videoconferencing*. Telepresence via video deploys greater technical sophistication and improved fidelity of both sight and sound than in traditional videoconferencing. *Holographic telepresence*⁷ is an evolving technology for full-motion, three-dimensional video conferencing. Holography⁸ is a technique which enables three-dimensional images (holograms) to be made.

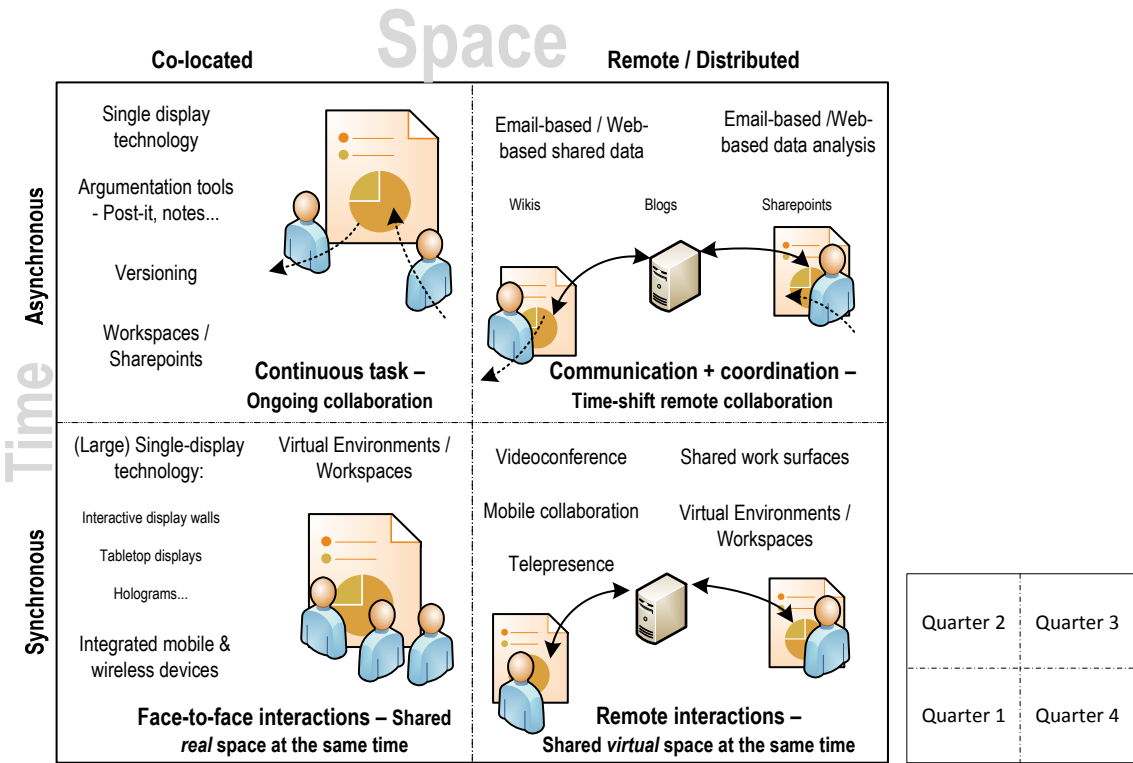


Figure 3. Collaborative visualization in terms of time and space aspects and types of technology involved

A powerful collaboration capability includes the visualization aspect which is a means to achieve effective human communication. Vision is the humans’ dominant sense. More than 50% of a human brain’s neurons are used to see

⁵ http://en.wikipedia.org/wiki/Mobile_collaboration
⁶ <http://bluejeans.com/blog/video-conferencing-vs-telepresence>
⁷ <http://whatis.techtarget.com/definition/holographic-telepresence>
⁸ <http://www.sciencedaily.com/releases/2015/02/150204090101.htm>

(including 3D and full color). Multi-dimensional visualization in an immersive display system (e.g. 3D image display wall, CAVE Automatic Virtual Environment – CAVE⁹, Head Mounted Display – HMD...) is also to be considered in our digitized world because these systems support, among other things, the ability to (1) simultaneously exhibit a large amount of data; (2) represent multidimensional dataset more efficiently compared to any other display devices; (3) explore data in a more intuitive way through interactions with visually rendered data; (4) analyze and interpret data faster; and (5) help escaping the conventional bias towards 2D computing by organizing content more effectively in 3D. Interactive visualization strengthens collaboration for the reason that this approach is conducive to incrementally building a mental assessment of the data meaning.

In order to take efficiently advantage of these visualization and collaboration technologies to enhance the intelligence analysis process and provide adaptive user interfaces, the *Context Manager* has to consider multiple aspects of the context. The *Workflow Orchestrator* should support each user during the execution of his/her work by suggesting the most appropriate (available) interaction devices and corresponding *Interactive Visualization Widgets* for his/her current task (e.g. interactive displays and tablets could be adequate devices for the *Workflow Exploration* widget; shared screens can be used to disseminate information and results to team members). The *Workflow Orchestrator* must also ensure that display and interactions devices are exploited efficiently by the whole team, especially when resources are limited (e.g. manage displayed data on shared display to provide relevant information for the whole team). Figure 4 gives examples of collaboration and visualization technologies of interest that were explored within DRDC research projects. The way they could be exploited with *Interactive Visualization Widgets* and other application tools to perform a number of collaborative military intelligence tasks is also discussed.

⁹ The CAVE (from *Mechdyne* – <http://www.mechdyne.com/>) at DRDC-Valcartier is a multiperson, four-sided (three walls – two are pivoting around an axe from 0 to 90° – and a floor), high-resolution 3D environment that is used for viewing and interacting with virtual content. To achieve realistic interactions with immersive displays the tracking system (IS-900 system from *Intersense* – <http://www.intersense.com>) has fast update rates, low latency and smooth tracking. Consequently, it provides smooth and precise position and orientation (6-DOF) of the user's head while not interfering with the user's immersive experience. The tracking system offers ergonomically designed devices: a head tracker attached to stereo glasses (CrystalEyes®3 from *StereoGraphics Corp.* – <http://www.reald.com>) and a tracked wand (from *InterSense*) which incorporates buttons and a joystick for interaction with the virtual content. Stereoscopic rendering based on stereo (active) glasses provides to the user the depth perception of virtual content.


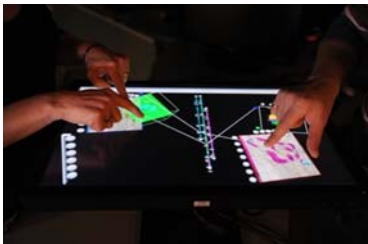



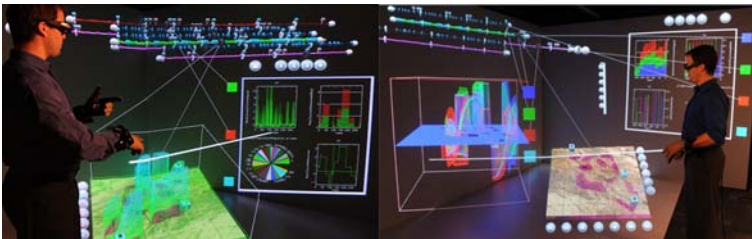
Direct Collaboration (co-located + synchronous)	
<p>Using an immersive display system – Collaborative data analysis and interactive data visualization.</p> 	<p>Using a tabletop display (e.g. <i>Interactive Visualization Widgets, Workflow Orchestrator, Workflow Tracer</i>).</p> 
<p>Direct Collaboration – People working collaboratively in the <i>same virtual environment</i>, one person working directly with the <i>immersive version</i> (left image) and the others co-located in the same space working with the <i>desktop version</i> (left image).</p>   <p>Remote Collaboration – Idem as previous one but additional team members work in remote (right image). No videoconferencing or telepresence, the <i>virtual environment</i> is the <i>shared space</i> and everyone does what he/she has to do to realize the shared goal.</p>	
<p>Direct Collaboration – Through an interactive large display wall (e.g. enhancing <i>Visual Analytics</i> widgets such as the <i>Graph Analyzer</i> widget designed for <i>Social Network Analysis</i> (Lavigne, Lecocq, Martineau and Mokhtari, 2014)).</p> <p>Remote Collaboration – A display wall could also be used when analysts are in remote locations (it becomes a shared surface between the dispersed collaborators).</p> <p>Continuous Task – A display wall could support ongoing work between co-located collaborators.</p>	
<p>Remote Collaboration – Same immersive virtual environment shared by two different locations. Analysts manipulate tools and data in order to augment their problem comprehension.</p>	

Figure 4. Examples of technologies of interest for collaborative military intelligence analysis

6. CONCLUSION

During the last few years, DRDC has investigated methods and techniques to help military intelligence analysts to do their job. Widget prototypes related to *Social Network Analysis* (through different use-cases), *Visual Analytics* (in the Maritime domain), *Case-Based Reasoning*, to name just these ones, have been developed and integrated in the current version of the S3 prototype. DRDC is currently investigating new capabilities and also the technological means through which they can be deployed to be of better interest.

The proposed collaborative military intelligence production capability is a context-aware system adapting its behavior and features dynamically according to various aspects of the context in order to optimize exploitation of the system by multiple analysts simultaneously while providing continual system feedback and a seamless user experience across the whole system. The *Context Manager* sub-system is responsible for context model persistence and has to manage

system's behaviors depending on the current situation. Context information stored in the model can be partitioned in four categories: (1) operational, (2) user, (3) resources and collaboration and (4) extrinsic contexts.

Contextual information can be exploited to adapt three aspects of the user interface: (1) content, (2) presentation and (3) proposed actions. Part of the *Context Manager*, the *Workflow Orchestrator* has to consider this contextual information in order to plan and coordinate the concurrent executions of various processing and collaboration tasks. The *Workflow Orchestrator* also extends the *Workflow Tracer*, keeping tracks of every step performed by the analyst, by exploiting usage history statistics to provide appropriate action recommendations.

A wide range of visualization and interaction technologies are available to implement a collaborative intelligence production capability. Depending on deployment setup, visualization and interaction needs, the chosen technologies can take many forms, from the traditional laptop computers to fully immersive 3D environments. Moreover, shared displays and devices with specific interaction features (e.g.: touch-wall, CAVE) could be unique or limited in the working environment and must be used efficiently by the team. Consequently, the *Context Manager* must not only consider visualization and interaction features of available devices but it must also take into considerations the availability and proper usage of those limited assets.



Figure 5. Implementation of part of the FIAC vision in a virtual immersive context

REFERENCES

- [1] Poussart, D., "Future Intelligence Analysis Capability – Towards a Cohesive R&D Program Definition", DRDC Valcartier Internal Report, (2013).
- [2] Pirolli, P., and Card, S., "The Sensemaking Process and Leverage Points for Analyst Technology as Identified Through Cognitive Task Analysis," Proc. IEEE Symposium Computational Intelligence Analysis, 1-6, 2005.
- [3] Gouin, D., Lavigne, V., and Bergeron-Guyard, A., "Human-Computer Interaction with an Intelligence Virtual Analyst," Proc. Knowledge Systems for Coalition Operations, Pensacola, FL, US, 1-5 (2012).
- [4] Johansen, R. "Groupware: Computer Support for Business Teams," Free Press, N.Y., 1988.
- [5] Rodden, T. and Blair, G., "CSCW and Distributed Systems: The Problem of Control," Proc. of the Second European Conference on Computer-Supported Cooperative Work, 49-64, 1991.
- [6] Peters, L. M., and Manz, C. C., "Identifying antecedents of virtual team collaboration," Team Performance Management 13.3/4: 117-129, 2007.
- [7] Lavigne, V., Lecocq, R., Martineau, É., Mokhtari, M., "Graph Analyzer Widget Closer to Agility through Sense-Making," Proc. International Command and Control Research and Technology Symposium, 2014.