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Multi-Reasoner Inference

Final Report

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Defence and Public Security
Contractor's Document Number: MRI-242-0449
Contract Project Manager: Gilles Clairoux, (514) 393-8822 x 318
PWGSC Contract Number: W7701-10-4064
CSA: Mr.Étienne Martineau, Defense Scientist, 418-844-4000 x 4501

Defence R&D Canada – Valcartier

Contract Report
DRDC Valcartier CR 2012-005
January 2012

Canada

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Abstract

To support its research activities in the intelligence domain, the Intelligence and Information (I&I) Section at DRDC Valcartier is developing the Intelligence Science & Technology Platform (ISTIP) as a major component of its R&D infrastructures. To improve the reasoning capabilities of the platform, the mandate of this contract is to produce a Multi-Reasoner Inference (MRI) capability based on the Multi-Intelligence Tool Suite (MITS) and the ISTIP software components previously developed by the I&I Section. Five main different services have been developed containing four individual reasoners and one multi-reasoner orchestrator. The reasoners that have been created are a Case-Based Reasoner (CBR), a Rule-Based Reasoner (RBR), a Descriptive-Logic Reasoner (DLR) and a KInematics and Geospatial Analysis Reasoner (KIGAR) which is based on the KIGAM module of the Inference of Situational Facts through Automated Reasoning (ISFAR) tool. Through the use of a common reasoning framework, these reasonners can now leverage their reasoning capabilities by sharing their strength to other reasonners and achieve an amazing synergy. This document is the final report of the MRI.

Résumé

Afin de supporter ces activités de recherche dans le domaine du renseignement, la Section du Renseignement et Information de RDDC Valcartier développe la Plate-forme de Science et Technologie du Renseignement (ISTIP) comme un composant majeur de ses infrastructures de R&D. Afin d'améliorer les aptitudes de raisonnement de la plate-forme, le mandat de ce contrat est de créer un outil d'inférence Multi-Raisonneur (MRI) basé sur la « Multi-Intelligence Tool Suite » (MITS) et sur les composants logiciels déjà implémentés par la section I&I. Cinq différents services ont été développés comprenant quatre raisonneurs individuels et un orchestrateur multi-raisonneur. Les raisonneurs qui ont été créés sont un raisonneur par cas (CBR), un raisonneur par règles (RBR), un raisonneur ontologique (DLR) et un raisonneur d'analyse cinématique et géo-spatiale (KIGAR) basé sur le module KIGAM de l'outil d'Inférence Automatisée de Faits Situationnels (ISFAR). Grâce à l'utilisation d'un cadre de raisonnement commun, ces raisonneurs peuvent désormais exploiter leurs capacités de raisonnement en partageant leurs forces à d'autres raisonneurs et parvenir à une synergie épatante. Ce document est le rapport final du MRI.

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Executive summary

Multi-Reasoner Inference: Final Report

Guillaume Morin-Brassard; DRDC Valcartier CR 2012-005; Defence R&D Canada – Valcartier; January 2012.

Introduction or background: As specified in the SOW, to support its research activities in the intelligence domain, the I&I Section at DRDC Valcartier is developing the Intelligence Science & Technology Integration Platform (ISTIP) as a major component of its R&D infrastructures. The ISTIP is a Service-Oriented Architecture (SOA) Platform for the iterative and incremental development and integration of the innovative, loosely coupled, reusable, composable and interoperable services required to perform tasks in computer-based intelligence support systems.

Two other major components of the R&D infrastructures of the I&I Section are the Multi-Intelligence Tools Suite (MITS) and the Multi-Intelligence Capability Test Bed (MICTB). The MITS is a federation of innovative, composable and interoperable intelligence related tools that exploit the ISTIP services into an overall, continuous process flow relevant to the intelligence community. The MICTB is an environment containing the hardware, instrumentation, simulators, software tools, datasets and other support elements needed to conduct testing and evaluation, in a laboratory environment, of multi-intelligence capabilities.

A number of services aligned with the development principles adopted for the ISTIP had already been implemented and were available on the ISTIP. Examples are:

- Inference of Situational Facts Through Automated Reasoning (ISFAR) – The ISFAR service was an environment facilitating the exploitation of the complementary strengths and expressiveness characteristics of different knowledge representation approaches (e.g., description logic, "if-then" rules, etc.) thereby enabling synergy between these approaches and the corresponding reasoning paradigms. In the ISFAR environment, automated reasoners built from complementary knowledge representations are coupled together by a "situational fact manager" and thus co-exploited. There were three reasoning components that had been developed to use domain knowledge to derive in an automated way relevant "new" facts about the situation from time-varying data and information.
- Semantic Annotation of Text Documents (SATD) – The SATD service uses application domain description resources (taxonomies, ontologies, etc.) to produce in an automated way semantic annotations of text documents presented (in different text format) to the service.
- Maritime Track Data Retrieving (MTDR) service is a structured source processing service enabling the ingestion into the MITS of structured maritime track data available in GPW-like format.

The MITS has been created in 2008 and it has since evolved in different directions, following research opportunities sponsored by different customers/partners. As a result, multiple "stovepipe" versions of the MITS have been produced with some overlapping functionalities, but

also with important differences in functionalities development philosophy/approach and enabling technologies. At the moment, there are essentially three concurrent versions of the MITS:

1. MITS Version 1.0 (or more simply MITS 1.0)

2. MITS Version 2.0 (or more simply MITS 2.0, also known as MITS – Land)

3. MITS – Maritime (or more simply MITS-M)

Some integration of software components coming from the existing prior versions of the MITS has been achieved recently, using the MITS 2.0 as the integration platform, thereby producing an enhanced version of the MITS 2.0 (a version referred to as “MITS 2.0-M” or “MITS-R&D”). For some aspects of the development activities of this contract, we had to use the version of the MITS 2.0 baseline as a starting point.

This document presents the Final Report for the Multi-Reasoner Inference system, according to the IEEE 12207. Its purpose is to:

- Enumerate the project objectives.
- Describe the achievements and realizations of the project.
- List the issues encountered during the project realization.
- Highlight the potential future work that can be done to improve the system.

Results:

Five main different services have been developed containing four individual reasoners and one multi-reasoner orchestrator. The reasoners that have been created are a Case-Based Reasoner (CBR), a Rule-Based Reasoner (RBR), a Descriptive-Logic Reasoner (DLR) and a KInematics and Geospatial Analysis Reasoner (KIGAR) which is based on the KIGAM module of the Inference of Situational Facts Through Automated Reasoning (ISFAR) tool. A common framework as also been developed to easily add a new reasoner and improve the reasoning capabilities of the platform.

Sommaire

Multi-Reasoner Inference: Final Report

Guillaume Morin-Brassard ; DRDC Valcartier CR 2012-005 ; R & D pour la défense Canada – Valcartier; janvier 2012.

Introduction ou contexte: Comme spécifié dans le SOW, afin de supporté ces activités de recherche dans le domaine du renseignement, la Section I&I du RDDC Valcartier développe la Plate-forme d'Intégration de Science & Technologie du Renseignement (ISTIP) comme composant majeur de son infrastucture de R&D. L'ISTIP est une plate-forme avec Architecture Orientée Service (SOA) pour le développement et l'intégration itérative et incrémentielle de services, composables, réutilisables, innovants, faiblement couplés et interopérables requis pour exécuter des tâches dans des systèmes de renseignement basé sur les ordinateurs.

Deux autres composants majeurs des infrastructures de R&D de la Section I&I sont le « Multi-Intelligence Tool Suite (MITS) » et le « Multi-Intelligence Capability Test Bed (MICTB) ». Le MITS est une fédération d'outils de renseignement innovants, composables et interopérables qui exploitent les services d'ISTIP dans un processus complet et continu favorable à la communauté du renseignement. Le MICTB est un environnement contenant le matériel, l'instrumentation, des simulateurs, des outils logiciels, bases de données et d'autres éléments de soutien nécessaires pour effectuer des tests et l'évaluation, dans un environnement de laboratoire de multi-intelligence. La figure 1 illustre les trois composantes mentionnées ci-dessus et leurs relations.

Un certain nombre de services alignés sur les principes de développement adopté pour l'ISTIP avait déjà été mis en œuvre et sont disponibles sur la plateforme ISTIP. Les exemples sont:

- Inférence de faits situationnels par le raisonnement automatisé (ISFAR) - Le service ISFAR est un environnement facilitant l'exploitation des atouts complémentaires et les caractéristiques d'expression de différentes approches de représentation des connaissances (par exemple, logiques de description, des règles «si-alors », etc), ce qui permet une synergie entre ces approches et les paradigmes de raisonnement correspondant. Dans l'environnement ISFAR, les raisonneurs automatisés construit à partir des représentations des connaissances complémentaires sont couplés entre eux par un « gestionnaire de faits situationnels » et donc co-exploités. Il y avait trois composantes de raisonnement qui avaient été développées pour utiliser les connaissances de domaine afin de déduire dans un système automatisé de manière pertinente de "nouveaux" faits concernant la situation où les données et informations varient dans le temps.
- Annotation Sémantique de Documents Texte (SATD) - Le service SATD utilise les la description des ressources du domaine d'application (taxonomies, ontologies, etc) afin de produire des annotations sémantique de façon automatisée pour les documents texte présenté (en différents formats texte) au service.
- Récupération de Données de Trajets Maritimes (MTDR) est un service de traitement de sources structurées permettant l'ingestion dans le MITS de données structurées de trajets maritimes disponibles, comme le format GPW.

Le MITS a été créée en 2008 et il a depuis évolué dans des directions différentes, suivant les possibilités de recherche parrainé par différents clients / partenaires. En conséquence, plusieurs versions isolées du MITS ont été produits avec des fonctionnalités qui se chevauchent, mais aussi avec des différences importantes dans le développement de fonctionnalités, dans leur approche philosophique et dans leur choix technologiques. Pour le moment, il y a essentiellement trois versions concurrentes du MITS:

1. MITS Version 1.0 (ou plus simplement MITS 1.0)
2. MITS, version 2.0 (ou plus simplement MITS 2.0, également connu sous le MITS-Land)
3. MITS-Maritime (ou plus simplement MITS -M)

Certains composants logiciels d'intégration provenant de la version précédente du MITS ont été réalisés récemment, utilisant le MITS 2.0 comme plate-forme d'intégration, produisant ainsi une version améliorée du MITS 2.0 (une version appelée « MITS 2.0 M » ou « MITS-R&D »). Pour certains aspects des activités de développement de ce contrat, nous avons dû utiliser la version de de base de MITS 2.0 comme point de départ.

Ce document présente le rapport final pour le système d'inférence Multi-Raisonneur, selon la norme IEEE 12207.

Son but est de:

- Énumérer les objectifs du projet.
- Décrire les réalisations du projet.
- Dresser la liste des problèmes rencontrés lors de la réalisation du projet.
- Souligner le travail futur qui peut être fait pour améliorer le système.

Résultats :

Cinq différents services ont été développés comprenant quatre raisonneurs individuels et un orchestrateur multi-raisonneur. Les raisonneurs qui ont été créés sont un raisonneur par cas (CBR), un raisonneur par règles (RBR), un raisonneur ontologique (DLR) et un raisonneur d'analyse cinématique et géo-spatiale (KIGAR) basé sur le module KIGAM de l'outil d'Inférence Automatisée de Faits Situationnels (ISFAR). Un cadre applicatif commun a aussi été créé afin d'ajouter facilement d'autres raisonneurs et améliorer les capacités de raisonnement de la plate-forme.

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1 Project's Objectives

As specified in the SOW, the aim of this work was to produce a Multi-Reasoner Inference (MRI) capability based on the Multi-Intelligence Tools Suite (MITS) and the Intelligence S&T Integration Platform (ISTIP) software components previously developed by the Intelligence and Information (I&I) Section at DRDC Valcartier as part of its software infrastructure supporting research and development.

This contract contained 5 major tasks which were:

- **Task 1 - Multi-Reasoner Inference (MRI) Capability**

  Design & develop a new Multi-Reasoner Inference (MRI) capability based on the Multi-Intelligence Tools Suite (MITS) and the Intelligence S&T Integration Platform (ISTIP). MRI functionality must be implemented as a service or a set of services on the ISTIP. Reuse where possible existing ISFAR service code.

  - Subtask 1.1 – Fact & Fact Container Data Model.
    - Must use the data model.
    - Up-date the model if necessary.
  - Subtask 1.2 – External Interface to the MRI Service.
    - Must specify the external interface to the MRI.
  - Subtask 1.3 – Internal Coordination and Fact Exchange Mechanism.
    - Must define and specify the principles of the internal coordination and the fact exchange mechanism between the individual reasoners of the MRI service.
  - Subtask 1.4 – Individual Reasoning Services.
    - Must design and develop a set of individual standalone reasoning services running on the ISTIP.
  - Subtask 1.5 – Multi-Reasoner Orchestration Functionality.
    - Must design and develop a multi-reasoner orchestration functionality to enable the integration and coordination of all of the individual reasoners described at subtask 1.3.

- **Task 2: Graphical User Interface (GUI) and Visualisation Capability**

  Must implement the necessary GUI and widgets on the MITS 2.0-M, and the required ISTIP visualization services, to support the exploitation of the new services resulting from the development activities specified for task 1.

  - Subtask 2.1 – Analysis of the Visualization Capability.
    - See list of potential functionalities.
    - Must conduct an analysis of the requirements.
    - Must analyse and document the constraints.
    - Must analyse and document the following aspects.
      - Reusability of visualization components.
      - Coordination between components.

                - Constraints arising from the use of open source visualization resources identified by the exploration of the followings:
                    - Execution timing and performance.
                    - Technological constraints.
        - Subtask 2.2 – Exploring Open Source Components for the visualization Service(s) & Widget(s).
        - Subtask 2.3 – Evaluation of the Efforts Required to implement Visualization and Interaction Functionalities.
            - Must evaluate the efforts required to implement the specific visualization and interaction functionalities and make priority recommendations for implementation.
        - Subtask 2.4 – Development of the Visualization Service(s) & Widget(s).
            - Must select the functionalities based on the contractor's evaluation of required effort and priority recommendations.
            - Must document the Software Interface Design Description (SIDD) of the visualization service(s) using IEEE-12207 SIDD standard.

Important Note that the initial requirements concerning the implementation of visualisation services for the MRI have been reduced at the kickoff meeting because there were not enough time available to develop all components. Fujitsu presented different options and DRDC representatives chose to concentrate the efforts on the reasoners and only implement a minimalist interface enabling the user to select a predefined reasoning context, custom facts and additional facts coming from fact containers. This user interface allows also to start, update and delete Multi-Reasoner inference processes and consult inference process results.

- **Task 3: Demonstration of the MRI Capability in the Maritime Domain**
    - Must develop a demonstration highlighting the powerful capabilities of the MRI services.
    - Must develop a credible situation analysis scenario in the maritime domain.
    - Must include elements of anomaly detection, vessels of interest and threat analysis in the Maritime domain.
    - Must produce a demonstration document.
    - Must execute the demonstration to the SA while highlighting the steps of the demonstration in this document.
    - MRI services must be demonstrated by feeding them with different datasets through the MICTB.
    - Must perform the necessary work on the MICTB to emulate data/information sources with a significant amount of data/information.
- **Task 4: Documentation**
    - Must produce the documentation for the MRI and the GUI and visualization capabilities.
    - Must produce all the necessary system and software documentation related to the development activities specified in the contract.

- Documentation must be harmonized with the existing documentation of the ISTIP, format IEEE 12207.

- **Task 5: Project Management**

  Provide project management services in an agile, light and efficient manner.

  - Subtask 5.1 – Kick-Off Meeting.
  - Subtask 5.2 – Progress Review, Validation, Working & Informal Meetings.
  - Subtask 5.3 – Final Presentation & Demonstration.
  - Subtask 5.4 – Final Meeting.
  - Subtask 5.5 – Final Report – Two weeks prior to final meeting, a draft version of the final report (electronic) must be provided to SA for review.

2 Achievements

Here is a list of the main achievements accomplished during this project.

2.1 Deliverables

The following table presents the project's deliverables, excluding the MRI source code.

Table 1 : Deliverables

Deliverable	Description
Project Management Plan	This management deliverable presents the project objectives, the structure of the team and the project's planning and the control mechanisms.
MRI Software Architecture Description document	This document presents the Software Architecture Description (SAD) for the Multi-Reasoner Inference service and related reasoners services.
MRI Software Interface Design Description (SIDD) document	This document identifies and describes interfaces to other systems, subsystems and applications of the MRI system.
SPFT2SF Converter Software Architecture document	This document presents the Software Architecture Description (SAD) for the Spatial Feature to Situation Facts Converter system.
SPFT2SF Converter Software Interface Design Description (SIDD) document	This document identifies and describes interfaces to other systems, subsystems and applications of the MRI system.
IDE Configuration Manual	This document contains information necessary to initially configure the Eclipse Integrated Development Environment (IDE) to be able to develop MRI/ISTIP components.
SPFTM & AFEXTD - Software Architecture Description document*	This document presents the Software Architecture Description (SAD) for the SPFTM and AFEXTD system.
Development Report ISTIP SPFTM and AFEXTD capability document*	This document contains one section for each of the services developed for the SPFTM and AFEXTD capabilities.
Development Report – Group A, Deliverable 3*	This document contains one section for each of the services developed for the SFM, SFKB, SOM, SMM capabilities.
Demonstration Scenario	Documents describing the demonstration scenario vignettes.

Vignettes	
Progress Reports	These management deliverables describe the project's progression.
Project Final Report	The current deliverable describes project's objectives, achievements, issues, future works and conclusion.
Demonstration presentation	A power point presentation containing a general overview of the MRI system and supporting the demonstration scenarios.
Project Final Presentation	A PowerPoint presentation describing the project's objectives, achievements and future works.

* Existing document that has been updated to include modifications required by this contract.

2.2 Realizations

The following section presents all the requirements accomplished during this project.

Task 1 - Multi-Reasoner Inference (MRI) Capability

- A common framework has been implemented to easily develop reasoners, which can work as standalone reasoners or be called from the MRI Orchestrator to achieve a Multi-Inference Reasoner capability.
- A Kinematic and Geographical Analysis Reasoner (KIGAR) has been implemented by extracting ISFAR analyses and wrapping them within a MRI framework compliant reasoner bean.
- A Rule-Based Reasoner (RBR) has been created by extracting the MITS rule-based inference engine from MITS and wrapping within a MRI framework compliant reasoner bean.
- A Case-Based Reasoner (CBR) has been created by wrapping up jColibri functionalities within an MRI framework compliant reasoner bean.
- A Descriptive-Logic Reasoner (DLR) has been created by wrapping up the Pellet reasoner functionalities within an MRI framework compliant reasoner bean.
- An MRI orchestrator reasoner bean has been developed to achieve a Multi-Reasoner Inference capability.
- A Spatial Feature to Situational Facts (SPFT2SF) converter service has been created to be able to easily convert any spatial features into situational facts through an SOA compliant web service.
- All service uses the already existing facts and spatial features data models. Moreover they all have external web service interfaces. Reasoners also have EJB local and remote proxy interfaces.
- All components come with their set of unit tests and functional tests. All pre-existing components that have been modified for the purpose of this project, have been

retested to make sure there was no regression and when required their tests have been adapted to fit the new modifications.

Task 2: Graphical User Interface (GUI) and Visualisation Capability

- A reasoning workspace has been created and added to the wasPrototype application.
- An inference process dashboard widget has been created to be able to start, update, delete and consult the MRI inference processes.
- A context creation/update widget has been created to be able to select parameters, knowhow and facts to be processed.
- A reasoning results viewer widget has been created to be able to consult MRI inferred facts.

Task 3: Demonstration of the MRI Capability in the Maritime Domain

- Four (4) realistic scenarios have been created to demonstrate the MRI capabilities in the maritime domain.
- Scenarios involving two or more reasoners at a time to demonstrate each reasoner capability and to show the power of the Multi-Reasoner capability.
- Some scenarios also demonstrate the Threat ontology capability.
- A presentation was also created to support the demonstration scenario and explain its content and context.
- Data and metadata was all fed through the MRI facts mechanism.

Task 4: Documentation

- Required documents have been produced and are delivered with this project. See the deliverables (Section 2.1) for an extensive list of the document produced in the scope of this project.

Task 5: Project Management

- The following project management steps have been performed:
  - Kick-Off Meeting
  - Different Progress Review, Validation, Working & Informal Meetings
  - Final Demonstration
  - Final Presentation and Meeting
  - Final Report

Extension: Threat Ontology

- Creation of a basic threat ontology defining the major concepts and rules of a threat-related ontology. It also defines how a threat can be inferred and how entities are linked together.
- Creation of a Maritime Threat ontology based on the threat-related ontology.
- Inclusion of this threat ontology in the final demonstration dataset.

3 Encountered Issues

3.1 Case-Based Reasoning

One of the Case-Based Reasoning steps is to convert a set of facts into different situations based on a template. In the case of the MRI-CBR, the templates are defined as a set of atom definition with a join constraint. The join constraint defines a set of arguments that must have the same value to be grouped as a single situation. A situation is created each time facts have the specified atom definition ids (null are accepted) and respect the join constraint. This is working properly but is pretty limitative since we only have a single join constraint and thus we can only compare a single argument value.

We first tried to implement a multi-join constraint mechanism to be able to create templates involving the comparison of many different parameters with many different values but our conclusions were that time necessary to implement such a solution would be way over the time available for this project. We then had to implement a simpler solution (single-join constraint). See future works for more details about the potential improvements that could be done concerning this issue.

3.2 Demonstration Data

The creation of the demonstration data supporting the scenario vignettes required a lot more time than what we previously planned. The factors influencing this were the following:

- Converting scenarios from a textual format to a realistic dataset where all track data and metadata, spatial features data and metadata, inference rules, ontologies and other required data must be realistic requires a lot of time to think about a way to connect all these data and generate all the required data (kml tracks + their metadata, inference know how and parameters for each reasoner, ontologies, additional facts containing demo-related metadata, etc.)
- KIGAR analyses were not always directly outputting required information. New analysis or workaround solutions had to be implemented to obtain the desired scenario results.
- Some bugs in the application have been discovered during the data set creation phase. These were minor and have been quickly fixed but required a bit of debugging time.

3.3 KIGAR SoapUI Tests

The conversion of existing ISFAR tests to KIGAR SoapUI functional tests took more time than what we expected. Considering the fact that it was only a test conversion, our time estimations were not that high. Thereby, considering that all spatial features existing in the ISFAR tests had to be converted to facts, and that all tracks and rules add to be ported from Java code to XML, this took more time than we expected. This has finally been done, but we first had to delay their creation to make sure we would not compromise other reasoners deliveries.

3.4 JBoss AS Authentication

See section 4.1.

4 Rectifications

This section lists the rectifications that should be applied to the MRI.

4.1 JBoss AS Authentication

At the beginning of the MRI project, all tests running on the secured "Test" environment were running properly but the more components we were deploying the more issues with authentication we had. In fact, JBoss Application Server 5.1 (JBossAS) has an issue concerning the propagation of authentication credentials when there are many beans involved, and this is even more frequent when using message driven beans with the @RunAs annotation (which we are using in the MRI, 1 per reasoner). This results in authentication exception being thrown to the client even if the client has the right credentials (SSO credentials) to access to the services.

This issue is documented in the JBoss AS bug tracker many times. Many issues have been closed stating that the JBoss AS versions prior to JBoss AS 7 are not supported anymore and will not be fixed. Therefore, it will be mandatory to migrate to JBoss AS 7.0 or later if we want to reactivate the single sign-on security on the "Test" environment. Since this requires migrating all enterprise applications using the JAAS security and running on JBoss AS 5.1, we did not do it in the scope of this project since it required a lot more time than what was planned, which has been approved by the client.

JBoss AS Bug Tracker Issues:

https://issues.jboss.org/browse/JBAS-7819
https://issues.jboss.org/browse/EJBTHREE-1945

At the moment the security has been completely deactivated on the "Test" environment to make sure applications run properly.

To reactivate it:

1. Sign-in on the continuous integration server with an account having admin rights: http://10.9.1.207:8080/
2. Click on the "Deploy to test" task
3. Click on the "Edit Configuration Settings" in the top right corner of the window
4. Click on the "Runner Ant" tab located on the right
5. In the "Additional Ant command line parameters" text box, replace this parameter:

   -Dapply-security=false

   By

   -Dapply-security=true
6. Click the "Save" button at the bottom of the screen
7. Run the task "Deploy to test"

5 Future Works

The following section presents future works that could be accomplished to improve the MRI capabilities.

5.1 Migration to JBoss AS 7

Due to the authentication issue documented in the Known Problems section, we strongly suggest to eventually do a migration from the JBoss AS 5.1 to the latest JBoss AS server (currently 7.0.2).

5.2 Improve Rule-Based Reasoning with Built-In functions

The actual Rule-Based Reasoner uses simple argument comparisons and does not permit complex validations of time range and geospatial calculations. To permit complex comparisons and improve its reasoning capabilities, built-in functions support could be added and custom built-in functions developed to support more precise and more complex rules using time, geographical data, etc.

The implementation of these built-in functions requires adding new argument types and developing specific code to support the different functions you want to support. For example, a built-in function could be developed to check if two geometries are near. Then a system argument or fact definition would be required. This definition would ask the user to specify two geometries he wants to compare or two geometries references and a proximity threshold. If the two geometries are respecting the proximity threshold, then the premise would be true. This has to be repeated for each type of built-in function you want to be able to perform.

Having such capabilities would really improve the rule-based engine and make it possible to interact more with time and geospatial based arguments.

5.3 Improve Case-Based Reasoning with multi-join constraints

At the moment, the Case-Based Reasoner uses a single join constraint which makes it possible to create a template by comparing only a single value for a single set of arguments. Based on our observations and lessons learned during the demonstration creation, we noted that there is a huge potential in case-based reasoning but there is one limitation with the currently implemented version of the CBR. To improve the CBR template creation possibilities, a multiple-join constraints mechanism could be developed. This way, it would be possible to create templates where facts could be joined based on different arguments and based on different values. This would greatly improve the CBR reasoning capabilities.

This is less trivial then it looks; it might require the use of an advanced algorithm to resolve the possible solutions like the “Rete” algorithm or an equivalent.

5.4 Improve KIGAR temporal support

Based on the demonstration we had to produce in the scope of this contract, we realized that many analyses of the KIGAR reasoner are centered on the last position of a track and does not permit the extraction of data contained in the middle of a track (in the past). This results in a system that is really good at analysing a snapshot in time but is hard to support when we analyse a situation progressing in time.

Another modification to the system could improve the temporal support. Since the actual KIGAR module is a ported version of the ISFAR system into the MRI system, the facts generated are almost the same that were generated by ISFAR which means that they contain minimal information like a Subject, a track unique identification number and the state that had been extracted by the analysis, like: "IsLoitering(Great Catch, 10001)". Some energy could be invested to improve the analysis results and add more metadata to the facts like:

- Contacts id or Contact geo-location that triggered that state
- Timestamp of the contact
- Any other useful metadata

5.5 Add or modify KIGAR analyses

There are KIGAR analyses that could be added (like the Stopped at Destination analysis that has been added for the purpose of the demonstration) or modified to extract geospatial related situations that are often a nice to know when analysing spatio-temporal features. Some of these additions or modifications could be:

- Modify the Is Loitering analysis to be able to know if a boat is loitering even if we don't know its destination or add a new analysis extracting that type of information (i.e. If the boat is going really slow and is not near any port (not docked)).
- Create a derived Course Proximity analysis where it is not only the smallest distance between two tracks but which also manage the time dimension and checks what was the smallest distance between the two tracks during their life period (i.e. if two boats are following each other and are following the same route, the course proximity result will be 0, but they might have never been nearer than a X kilometers).
- Create a derived Rendezvous analysis where instead of predicting if a rendezvous will occur it extracts rendezvous that already occurred.

5.6 Facts clean-up mechanism

Inference rules can sometime contain "NOT" operators which will infer new facts if one or more fact definition is "NOT" found. Since we are inferring facts in an open world, some facts that could prevent other facts to be inferred might not exists at a certain point but might exist at some later point. This can result in a situation where facts have been inferred at some moment but after the reception of new facts, these might not be true anymore. We must then not use the "NOT" operator or use a clean-up mechanism to remove/disable facts that are not true anymore.

5.7 Facts Merging

Facts are actually filtered based on their type and arguments values. If two arguments have the same type and arguments values, the latest is discarded so that there is no duplication of facts. This is good to reduce system load and to prevent exponential facts creation, on the other hand, this technique can sometimes drop useful metadata and facts justifications. For example, if 2 different reasoners infer the same fact in 2 different ways, the fact justifications will be different but their type and arguments can be the same. Then one of the 2 will be discarded and we will lose some metadata and justifications. A fact merging algorithm could be developed to prevent that metadata loss.

5.8 Split Reasoning Context

The reasoning context is actually contained in a single file. It contains the new facts, the inferred facts, the parameters, the know how, the error messages and the inference process status (NEW, RUNNING, ERROR, COMPLETED, etc.). It could be a good idea to split the content of the reasoning context in two different files, one containing the facts and a second part containing the process status and error messages. This would prevent the loading of the full context in memory each time we want to access the process status and error messages (like in the MRI visualisation service – inference process dashboard).

5.9 Threat Ontology

The last part of the contract involved the creation of a threat ontology. A lot of thinking has been done to create an ontology from which it would be possible, through the use of an owl reasoner, to deduce potential threats for a subject. This has been achieved through the use of SWRL rules enabling the deduction of new relations between subjects and their environment. During the creation process of this ontology, we realized that to be able to deduce such relations between subjects and their environment, the use of SWRL rules was necessary. The same kind of reasoning could also be achieved through the use of the rule-based reasoner and would probably be more user-friendly to maintain than SWRL rules. We are then not sure that a pure ontology based approach to deduce threats is the way to go. Ontologies are more suited for classification reasoning tasks than rule-based reasoning tasks. Taking the pure SWRL rules out of the ontology and use the full potential of the MRI could be a good alternative.

6 Conclusion

Before the MRI, there were different initiatives working on implementing different types of reasoning capabilities but each in a separate system, for example, rule-based reasoning in the MITS or kinematic and geospatial analysis reasoning in the ISFAR system. These isolated reasoning services were offering great reasoning capabilities but they all had their limitations.

The MRI project goal was to create a multi-reasoner inference capability based on the previously created MITS services and ISTIP platform services where the full potential of each reasoner could be leveraged by grouping the capabilities of many stand-alone reasoners together. The goal was not to merge those reasoners in a single reasoner but to orchestrate all those reasoners in a common workflow where reasoning inputs and outputs are automatically shared through the reasoner to achieve a productive synergy.

During the first sprint of the MRI project, good effort has been put on creating a multi-reasoner framework which makes it possible to easily integrate different reasoners together and leverage the reasoning capability of the ISTIP platform. Moreover, a reasoner orchestration service has been developed to easily manage the fact exchange mechanism between the reasoners. The ISTIP platform now has a tool enabling the integration of any new type of reasoning capability in a minimal amount time and money.

Based on our tests with the MRI and on the demonstration created for the MRI project, our conclusions are that the reasoning capabilities of the MRI are considerably better than the simple addition of each reasoner capability separately. The combined reasoning capabilities makes it possible to deduce a lot more complex things since there are things that a single reasoner could not deduce on itself before and required external output to be able to achieve the same results. For example, the MITS rule-based inference engine could not infer on advanced kinematic and geospatial data related facts, but now, in combination with the KIGAR reasoner, it is now possible to do rule-based inferring from kinematic and geospatial statements coming from the KIGAR.

Our conclusions on the MRI are that the reasoning capabilities are greatly improved, the interoperability of the reasoning capabilities through a common data model (the situational fact model) improves the interoperability of the services, the common reasoning framework improves the inclusions of any other reasoning capabilities really easily, and the base has been set for a great reasoning capability framework.

However, to be production ready, we suggest realising the steps stated in the section 5. Once these steps completed, the MRI will certainly be the cornerstone for the ISTIP platform reasoning capabilities.

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Glossary

CBR	Case-Based Reasoning
DLR	Descriptive Logic Reasoning
DND	Department of National Defence
DRDC	Defence R&D Canada
GUI	Graphical User Interface
I&I	Intelligence and Information
IDE	Integrated Development Environment
ISFAR	Inference of Situational Facts Through Automated Reasoning
ISTIP	Intelligence S&T Integration Platform
JAAS	Java Authentication and Authorization Service
KIGAR	Kinematics and Geospatial Analysis Reasoning
MDB	Message Driven Bean
MICTB	Multi-Intelligence Capability Testbed
MITS	Multi-Intelligence Tools Suite
MITS-M	Multi-Intelligence Tools Suite – Maritime
MRI	Multi-Reasoner Inference
MSA	Maritime Situational Awareness
RBR	Rule-Based Reasoning
R&D	Research and Development
SAD	Software Architecture Description
SIDD	Software Interface Design Description
SATD	Semantic Annotation of Text Documents
SPFT2SF	Spatial Feature to Situational Facts
SPFTM	Spatial Features Management
SOA	Service Oriented Architecture
SSO	Single Sign-On

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To support its research activities in the intelligence domain, the Intelligence and Information (I&I) Section at DRDC Valcartier is developing the Intelligence Science & Technology Platform (ISTIP) as a major component of its R&D infrastructures. To improve the reasoning capabilities of the platform, the mandate of this contract is to produce a Multi-Reasoner Inference (MRI) capability based on the Multi-Intelligence Tool Suite (MITS) and the ISTIP software components previously developed by the I&I Section. Five main different services have been developed containing four individual reasoners and one multi-reasoner orchestrator. The reasoners that have been created are a Case-Based Reasoner (CBR), a Rule-Based Reasoner (RBR), a Descriptive-Logic Reasoner (DLR) and a KInematics and Geospatial Analysis Reasoner (KIGAR) which is based on the KIGAM module of the Inference of Situational Facts through Automated Reasoning (ISFAR) tool. Through the use of a common reasoning framework, these reasonners can now leverage their reasoning capabilities by sharing their strength to other reasonners and achieve an amazing synergy. This document is the final report of the MRI.

Afin de supporter ces activités de recherche dans le domaine du renseignement, la Section du Renseignement et Information de RDDC Valcartier développe la Plate-forme de Science et Technologie du Renseignement (ISTIP) comme un composant majeur de ses infrastructures de R&D. Afin d’améliorer les aptitudes de raisonnement de la plate-forme, le mandat de ce contrat est de créer un outil d’inférence Multi-Raisonneur (MRI) basé sur la « Multi-Intelligence Tool Suite » (MITS) et sur les composants logiciels déjà implémentés par la section I&I. Cinq différents services ont été développés comprenant quatre raisonneurs individuels et un orchestrateur multi-raisonneur. Les raisonneurs qui ont été créés sont un raisonneur par cas (CBR), un raisonneur par règles (RBR), un raisonneur ontologique (DLR) et un raisonneur d’analyse cinématique et géo-spatiale (KIGAR) basé sur le module KIGAM de l’outil d’Inférence Automatisée de Faits Situationnels (ISFAR). Grâce à l'utilisation d'un cadre de raisonnement commun, ces raisonneurs peuvent désormais exploiter leurs capacités de raisonnement en partageant leurs forces à d'autres raisonneurs et parvenir à une synergie épatante. Ce document est le rapport final du MRI.

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