

An Ontology Based Information Exchange Management System Enabling Secure Coalition Interoperability

Russell Leighton, Joshua Undesser

CDM Technologies, Inc., San Luis Obispo, California

E-mail: rleight@cdmtech.com, jundesse@cdmtech.com

Abstract

Military and humanitarian missions increasingly involve not only the participation of one nation but of forces allied in a coalition. Real-time information exchange is indisputably a critical aspect required for the success of these missions. The requirement for interoperability between deployed information management systems is not restricted to overcoming the low level obstacles in data exchange resulting from diverse information systems. The rising challenge is the selection and control of the content shared with coalition partners. Which coalition partner needs to be included in operational information? How is it assured that in a changing situation all affected partners are alerted? Currently, this management of information exchange is accomplished by Information Management Officers (IMO), who manually sift through all incoming operational data and piece by piece discern what information needs to be shared and with whom. The information base, however, has increased over time to the point that the IMO is being overloaded.

The Coalition Secure Management and Operations System (COSMOS) Advanced Concept Technology Demonstration (ACTD) was designed to help assist in the process of managing coalition information exchange and interoperability. Through the use of an ontology driven architecture, COSMOS is able to represent operational data with meaningful relationships and thus allows intelligent, autonomous software agents to reason about the needs of information exchange and assist the IMO in the decision making process. This information sharing is accomplished through the use of role-based Information Exchange Requirements (IER) which are individually assigned by the IMO and are specific to the roles played by each coalition member within the context of the overall mission. Agents, intelligent expert system software modules, are utilized to assist in the process of managing IER assignment and the assessment of information against the criteria which formalize the IER definition. It is through this process that information ex-

change is targeted to the coalition force components that have a specific requirement for information pertaining to their assigned roles.

Acknowledgment

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1. Overview

1.1. Background

The Coalition Secure Management and Operations System (COSMOS) Advanced Concept Technology Demonstration (ACTD) provides a venue to show how Command and Control (C2) information can be shared within a coalition C2 environment while retaining security of data exchange as dictated by individual member-nation doctrine. Secure information exchange is demonstrated through employment of formal rule declaration as defined by specific Tactics, Techniques, and Procedures (TTP) governing the dissemination of relevant information “to the right place at the right time” based on assigned operational roles and tasking [1].

The management of information exchange is naturally complex although employment of computer software tools can be effectively applied to aid in the processes governing the controlled exchange of information. The human factor plays an important role; fully automated information sharing is neither practical nor desirable. Thus, the COSMOS ACTD seeks to demonstrate capabilities that assist (but do not replace) the Information Management Officer (IMO) in

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managing C2 information exchange across coalition boundaries.

Employment of computer software tools, within the domain of controlled C2 information exchange, requires machine-level understanding of the information exchange process. This includes detailed understanding of the structure of the C2 information domain as well as the procedures utilized in managing the process. The structural representation of information can be readily defined in terms of an information model that captures detailed characteristics as well as explicit relationships inherent between information entities. In development for over twenty years through the Multilateral Interoperability Programme (MIP), a standard data model in the form of the Command and Control Information Exchange Data Model (C2IEDM) exists and has been accepted within a multi-national consortium within the NATO community [2]. This data model offers the means for representing information in a highly structured form that lends itself well as the basis for software-based analysis. The COSMOS ACTD has chosen the C2IEDM as the basis for development and demonstration of capabilities employed to aid in the management of the information exchange process. Along with the C2IEDM, MIP has defined a specific Data Exchange Mechanism (DEM), within a formal specification, that may be utilized in the exchange of data. By utilizing C2IEDM and the DEM, COSMOS has demonstrated controlled, secure information exchange within a data exchange environment which is currently established and deployed in the coalition C2 enterprise.

1.2. Shortfall Addressed

The MIP DEM specification describes the protocols and processes necessary for managing the exchange of C2 data as defined by the C2IEDM. The specification also describes a fairly general data filter mechanism. This mechanism may be used to limit the exchange of data to only that which satisfies explicit filter criteria. However, the specification defines these filters based on low-level data constraints which do not easily translate to Information Exchange Requirements (IER). Therefore, an additional capability is required to translate or interpret high-level IERs into these low-level data filters. Additionally, the DEM provides the facility for utilizing Operational Information Groups (OIGs) as the basis for a contractual agreement for the exchange of information between coalition C2 system nodes. Information included in specific OIGs can be targeted for exchange with other MIP-compliant C2 nodes based on negotiated contracts tied to these OIGs. Other than implied high-level information categories, these OIGs do not employ specific rules governing constraint of information content. The combination of low-level data filters and use of OIGs provides

the basis for specific control of information exchange. The addition of higher-level tools, such as those proposed by the COSMOS Information Management Officer's (IMO) Toolkit, would provide the required interfacing elements to allow effective use of the MIP DEM in the control of information exchange based on criteria intuitive to the function of the IMO (e.g., definition of IERs as applied to operational roles and tasking).

1.3. Functional Requirements

The COSMOS Information Management Tool (IMT) requirements are centered around the overarching requirement for managing the information exchange process. These requirements include creation, management, monitoring, and controlling information sharing agreements. These requirements, in turn, suggest a set of capabilities that augment (but do not necessarily replace) the information exchange management processes. For instance, the use of role assignment to operational units to provide a link to information requirements provides the facility for creating and managing sharing agreements. The IMT interface would provide the required interface allowing for Information Management Officer (IMO) interaction with role definition in terms of information exchange requirements. Additionally, this tool is required to archive this information for later retrieval and use during operations. The management of sharing agreements during planning, training, and operational use is facilitated through the use of the IMT and the pre-defined sharing agreements in the form of the operational role and associated information exchange requirements. Additionally, the IMT is required to provide reporting facilities to give access and control over the information exchange process through a view into the data exchange filters and contracts established as a result of operational role assignment. A key requirement for the COSMOS IMT is to provide direct IMO interaction in the exchange process through monitoring and controlling sharing agreements. In other words, even though the IMT facilitates the information exchange process through automated exchange control, the tool is not a "black box" and must include the user (in this case, the IMO) in the decision making process.

1.4. Enabling Capabilities

A principal enabling technology for providing collaborative decision support is the employment of a high-level information representation and the implicit framework required to support management and interaction with the Ontology. Services developed to support specialized information domains provide required capabilities in the form of

discrete software modules. These capabilities include support for agent/user interaction through object-oriented interfaces reflecting the information structure as defined by the Ontology. Common services are available to support asynchronous access, persistent storage, information mapping, and knowledge inference (such as might be required by software agents).

Additionally, a distributed information management framework provides flexibility in system deployment through run-time configuration without requiring software modification. Some level of platform independence is also inherent in such a framework - in other words, the ability to deploy across a distributed network is facilitated by platform-independent capabilities. A distributed information management framework also enables development of discrete software modules in the form of services and applications. Although not necessarily inherent, a highly desirable feature of a truly distributed information management infrastructure is the notion of location transparency which simply provides for information access without requiring any knowledge of the underlying information management functionality. In other words, information can be accessed by services and applications without any concern or knowledge about where the information is physically managed.

1.5. Ontology-Based Solution with Agents

The principal objective of COSMOS is to provide US and coalition forces with a secure and reliable capability for sharing the right information at the right time with the right forces. The solution that COSMOS provides is built on the internationally recognized C2IEDM data structure. It extends this data model with an ontology that provides the necessary context for software agents to automatically reason about battlespace events and assist the Information Management Officer (IMO) with the expeditious policy-driven exchange of information in a cross-domain environment.

The ontology approach is the enabler of all COSMOS capabilities and is therefore the essential core component of the distributed, service-oriented COSMOS architecture. Without the ontology component the cross-domain security capabilities of COSMOS could not be exercised by the IMO at the level of data granularity that is required for the effective exchange of data. More specifically, without an object-oriented internal ontology representation the COSMOS software would not be able to anticipate that a given force or unit will immediately or in the near future require the exchange of certain information to effectively perform its mission or, for example, to prevent a potential fratricide situation. Without such ontology/agent-based capabilities it

would all be left to the human operator (i.e., the IMO) who is likely to be overwhelmed by data and may not recognize this particular data exchange requirement until it becomes a crisis.

From a slightly more technical point of view:

- A key aspect that COSMOS provides over and above MIP is the concept of controlled-managed information exchange.
- Inherent in the control of information exchange is knowledge of both the natural structure of the information being exchanged as well as the logic and concepts that comprise the process used to manage information exchange.
- The ontology approach provides a mechanism for formally defining an information structure (e.g., an object model) that includes the complex relationships that are part of information that describes real world knowledge (i.e., the context within which data changes can be interpreted and analyzed).
- Information that describes knowledge within the Command and Control (C2) domain is formally defined by the C2IEDM data model, which is part of the MIP specification. C2IEDM can be represented using an ontological approach and the latter is in fact provided in this underlying data structure as part of the MIP specification. However, MIP does not provide a detailed model that defines the elements and concepts that are required to explicitly control the information exchange. MIP does provide a Data Exchange Mechanism (DEM) that loosely defines a protocol for establishing contracts (i.e., agreements to exchange data) based on Operational Information Groups (OIG). OIGs, within the MIP specification, are not constrained in a way that allows for explicit control of the information contained within them and hence has no formal mechanism for controlling information exchange.
- Without ontologies, it would be necessary to employ software tools that encapsulate the logic required to assess the C2 state and implicitly constrain information containment in specialized OIGs. Traditional approaches would hard code this logic into the software tools with internal information constructs (also hard coded) employed to simplify the coding logic. The ontology approach provides a formal means of describing these traditionally embedded constructs in a form that is directly presentable in terms that make sense to the user. Additionally, logic captured in this form can be readily used by software agents as a basis for their automated reasoning capabilities.

- The use of ontologies and software agents provides a formalized definition of the information and logic used to manage the information exchange process. Because of this formal definition it is possible to utilize tools and generic infrastructures to build and manage a system that implements the capabilities required to support the information exchange management process. Additionally, this approach provides a basis for evolving a system and its capabilities as new requirements arise without incurring significant development costs. Capabilities may be added by simply extending the ontology and adding agent logic (as additional agent modules) with minor user interface development.
- With the ontology approach, separate ontologies may be employed to address problem domains requiring specialized services. This offers significant flexibility in the deployment and operation of the system. For example, a separate security domain may be developed in the form of an ontology and agents utilizing the tools for constructing the requisite information infrastructure. Also, security management and monitoring functions require specialized operating environments that allow access to sensitive areas of the information management environment and as such require deployment within a secure network environment. By utilizing discrete ontologies and agents within a framework supporting distribution of the constructed services, it is possible to meet the requirement for supporting both the management of the information exchange and the information security. That is not to say that this would not be possible utilizing other approaches, however, the use of ontologies and agents does provide the means for more easily extending and maintaining these capabilities (i.e., it is simply just good software engineering and design practice).

2. Architecture

2.1. System Architecture

Figure 1 shows the overall system architecture for the COSMOS IMT. In this architecture, the Ontology domains represent the common knowledge infrastructure over which all clients within the IMT operate. It is important to note that user interfaces, agents, and the interoperability bridge all communicate through this common knowledge infrastructure. The components that make up the IMT architecture will be presented in more detail.

2.2. Physical Architecture

Figure 2 shows the physical components and interfaces that comprise the COSMOS IMT. Each of the domains, which were highlighted in the system architecture (Figure 1), are shown in more detail to illustrate that each domain has its own set of services that manage its content. The black arrows indicate dependencies which all eventually lead back to the Ontology domain models. In other words, the infrastructure built to manage the knowledge bases are all driven by the respective Ontology domain models. Additionally, note that client applications - especially the user interface, agents, and interoperability bridge - all operate through the object management layer which, in turn, provides access to all knowledge domains present in the system. Also recognize that in this framework all clients that interact with the knowledge base do so through a common interface and that all the details contained in the management of the information are hidden from these clients. They simply interact with objects as defined by the respective Ontology domain model. Another important aspect of this architecture is the services that provide the underlying infrastructure. In particular, the subscription service provides for an asynchronous query-like mechanism that allows clients to register for interests based on query criteria with notification upon satisfaction of those interests. Interests are registered in terms of the domain model and are, therefore, also tied to the natural information structure defined by the Ontology.

2.3. Components

Information Services

The Ontology infrastructure provides the common information conduit through which all components interact. The information structure presented by the Ontology reflects the structure defined by the individual domain models in which each model is a partitioning of the overall Ontology into logical information category groupings.

Interoperability Bridge

The IMT Bridge uses an Interoperability Bridge Framework as a solution to transfer information between a MIP-compliant system and the COSMOS IMT application. The Interoperability Bridge Framework provides a generic framework for seamless interaction and/or integration of multiple heterogeneous systems. Systems can register services with the Interoperability Bridge, publish local system requests and responses, and receive remote requests and responses without knowing intimate details about the remote system.

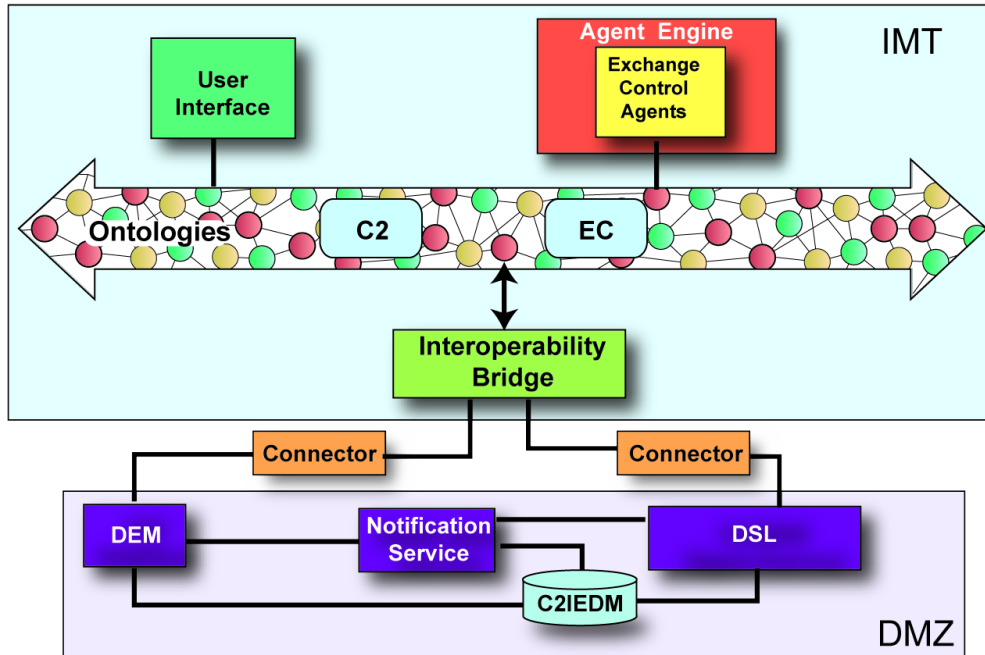


Figure 1. System Architecture

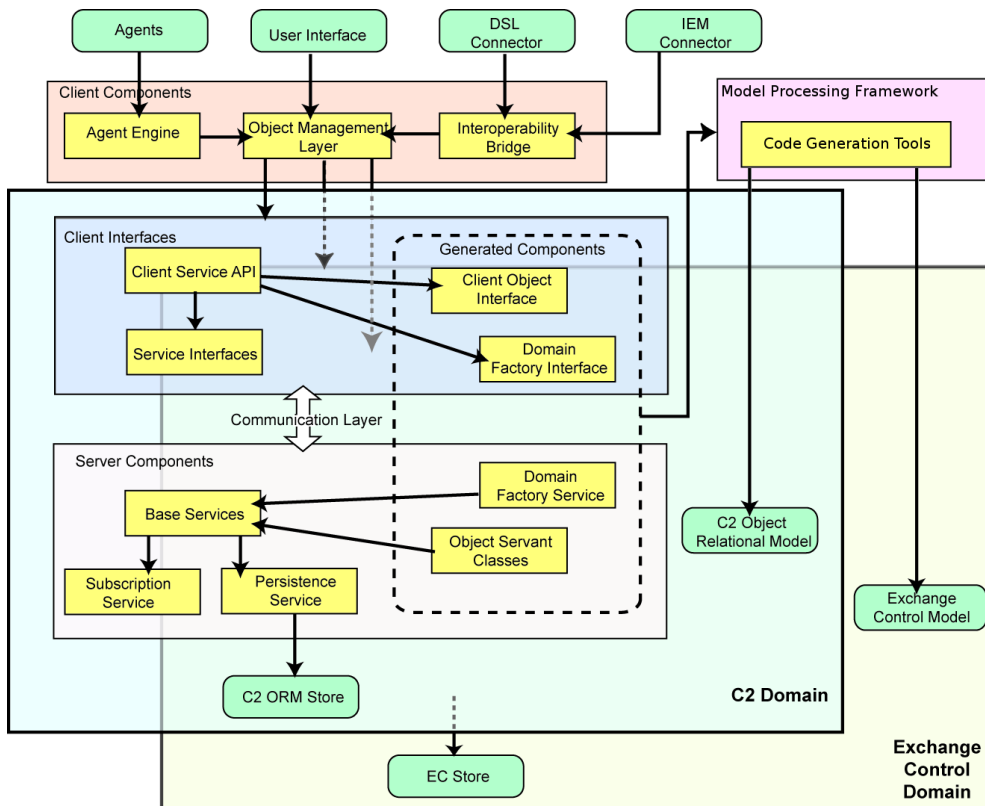


Figure 2. Physical Architecture

XML is sent (either by notifications or request mechanisms) from each application in its native format and translated by the bridge based on remote requests. Remote requests are brokered by the bridge to a remote system that can service that request. Information published to the bridge is in the XML format of the native system, usually in the format of the local application's specific domain (such as the C2 domain). Translators can be configured to transform the XML messages from a given remote system to native system format. While the framework supports multiple translation formats, the main translation format of the bridge is XSLT (Extensible Stylesheet Language Transformation). XSLT provides an XML-centric means to translate XML between multiple schemas.

Agent Engine

The Agent Engine is an autonomous software client that interacts, independently of other clients, with the COSMOS system. The word *autonomous* is used purposely, as no direct human interaction with the Agent Engine occurs. Once launched, the Agent Engine monitors the system, through the use of subscriptions, for specific patterns and classes of objects. When these patterns are met, action is taken, most often in the form of alerts or observations. These alerts or observations are then posted to the COSMOS system where the GUI client component picks them up and displays them for the Information Management Officer (IMO). This logic, or pattern matching, is carried out through the use of agents. An agent is considered to be a very specific goal orientated software module. Currently, the COSMOS Agent Engine is loaded with three (3) agents: The Unit Capability (UC) Agent, the Information Exchange Requirements (IER) Agent, and the Exchange Control (EC) Agent. The UC Agent is responsible for monitoring Unit Weapon Capabilities and alerting the IMO when these capabilities change. The IER Agent watches for new Tasks to be created and alerts the IMO that he may need to create IERs to share information with coalition partners. The last agent, the EC Agent, is responsible for information sharing to coalition forces, based on the IERs that the IMO creates. Currently the IMO is being overburdened and bombarded with too much information. These agents work independently of each other and are designed to assist the IMO by reducing and streamlining the workload.

User Interface

The COSMOS IMT User Interface constitutes a central component of the COSMOS Information Management Tool (IMT), a suite of applications which together provide the capability for managing the process of information exchange across Command and Control (C2) system boundaries.

COSMOS IMT information exchange management capabilities include the creation, management, monitoring, and control of information-sharing agreements. Specifically, the use of role or task assignment to operational units provides a link to information requirements, the basis for creating and managing sharing agreements.

The IMT user interface allows for Information Management Officer (IMO) interaction with role- and task-based information sharing agreements that are defined in terms of Information Exchange Requirements (IER).

2.4. Interfaces

Data Service Layer (DSL) Interface

The DSL C2IEDM Object Service interface provides a view into the command and control (C2) domain whose content is managed through the MIP and a C2IEDM-compliant database. This interface provides a read-only view providing only a subset of the total command and control picture as required for managing the information exchange process. Based on the requirements of the IMO and the IMT agents, interest subscriptions are established on the C2 domain and are reflected through the interoperability bridge and its connector to the DSL C2IEDM Object Service interface. Only the information that satisfies those interest criteria will be reflected back through the interface and in the C2 Ontology domain within the IMT.

Data Exchange Mechanism (DEM) Interface

The DEM interface provides access to information exchange management contracts and COSMOS Information Group (CIG) assignments. The Extensible Markup Language (XML) is used as the protocol language for information interchange through the interoperability bridge connector. Through the DEM interface, CIG assignments are affected by IMT interactions (whether through IMO or agent initiation). Information defined within the Exchange Control domain within the IMT will map to the management information used within the DEM. In other words, when either the IMO (through the user interface) or agents affect information in the Exchange Control domain, that information, in turn, will map directly to the DEM through the interoperability bridge and this DEM interface.

3. Design/Implementation

3.1. Command and Control (C2) Domain Model

Figure 3 shows a very small subset of the complete C2 Ontology domain, and only serves to illustrate the model representation as presented in the form of the Unified Modeling Language (UML). As published by the MIP, the C2IEDM is formally specified in terms of an Entity Relationship model which, in turn, may be used to directly construct a database schema suitable for managing data constrained to the structure of the C2IEDM. However, to effectively utilize information reflecting this structure, within the IMT architecture, it was necessary to provide a model in terms of UML. From the UML model, the C2 domain services may then be generated utilizing model processing code generation tools.

3.2. Exchange Control Domain Model

The exchange control domain, a portion of which is shown in Figure 4, defines objects that are used to affect the process of information exchange. Key concepts, defined within the exchange control domain, include the notion of a collaborator as an initiator and performer of actions, where actions are initiated/performed events that have time and duration. Kinds of collaborators include agents and C2 objects. In this domain model C2 objects shadow object items in the C2 domain and serve to specifically represent those entities that can play roles in actions - for example, military units. The notion of a node is also represented as a collaborator so that systems themselves can be represented as participating in actions (e.g., data exchange contracts). Kinds of actions include contract and information exchange actions. Additionally, information groups are represented as groups constrained by information exchange requirements. Information groups in the exchange control domain also shadow information groups defined in the C2 domain - for example operational information groups (OIG). Representation for constraints is included to provide definition of action triggers. Providing such action trigger definitions implies that if a constraint is matched then the associated action will be triggered. Area constraints are specifically represented as constraints tied to geophysical areas. Criteria are defined as a kind of constraint that groups other constraints using a logical operator. Criteria may be used to build reasonably complex constraints. For example, an area constraint may be defined and associated to an information exchange action with the implied exchange triggered if the area constraint condition is satisfied. It should be noted that

this complex behavior (action triggering) is only implied by the model definition of criteria - it is through employment of agents (software modules providing information inference) that this behavior is actually implemented. In fact it is the logic embedded in the Exchange Control agent (introduced previously) that provides the assessment function to determine the triggering of an information exchange action based on criteria satisfaction.

The combined Ontology diagram, shown in Figure 5, illustrates the connection between the Exchange Control and C2 domains. Specifically, through a one-way associations, the exchange control C2Item class shadows the C2IEDM ObjectItem class and the InformationGroup class shadows the C2IEDM OperationalInformationGroup. Since these are one-way relationships, only the exchange control domain requires knowledge of the C2 domain. There is no requirement for C2 domain entities to refer back to or have any knowledge of exchange control entities.

Information entities defined within the Exchange Control domain have been described as “shadowing” elements defined within the C2 domain. Specifically, elements in the Exchange Control domain are defined to reflect information contained in the C2 domain in a form that is more readily assessed for the purpose of managing information exchange. These elements are simply facades [3, 4] whose features are derived from information gathered from C2 domain elements. A simple example is shown in figure 4. The C2Item location features (latitude, longitude) are derived from the associated C2 Object Item Location (shown in figure 5) which, if defined specifically as an Absolute Point (a kind of Location defined in C2IEDM), contains features defining the absolute latitude and longitude coordinates of the associated Object Item. This derived location simply reflects the values defined in the referenced C2 domain entity. It is through use of these uni-directional associations and derived features that enables effective extension of the C2 domain without directly affecting its structure.

3.3. Agents

The Agent Engine is a Java-based client that connects to the COSMOS IMT system. Its main purpose is to aid the IMO by assisting in the management of the information exchange process (through the use of agents). The Agent Engine is responsible for managing the agents and directing information to and from them at the appropriate time.

Abstractly, an agent, as represented within the Agent Engine, is a software module dedicated to perform a specific task or series of tasks. The agent looks at the attributes of objects, either in one object or many objects, and if certain

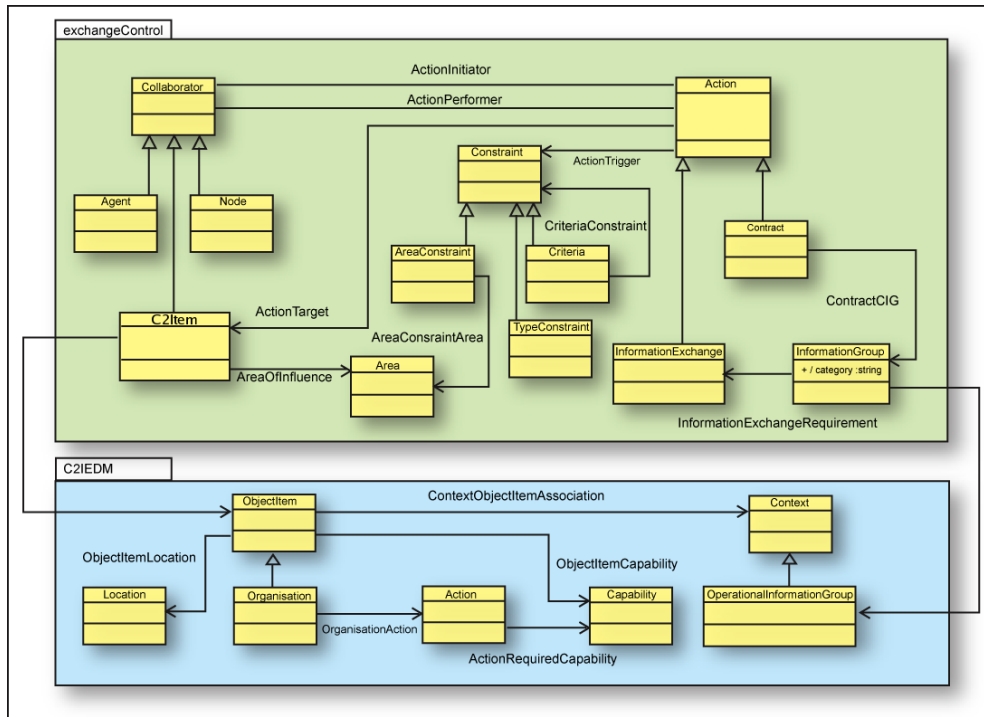


Figure 5. Combined Ontology

patterns or conditions are met, the agent executes the task or set of tasks.

Specifically, an agent within the COSMOS IMT is represented as an object within the Exchange Control Object Model. When the agent is loaded into the Agent Engine, an instance of the Agent class is created and posted to the COSMOS IMT system for other clients to utilize. As with the Agent Engine, all current agents are written in Java and utilize the Java Bean pattern to receive creation, modification, and deletion events on objects. These events are facilitated through the use of subscriptions. The Agent Engine can set up specific event listeners so that it receives only the information that its agents need.

For the COSMOS IMT, we have 3 primary agents: the Exchange Control Agent, the Information Exchange Requirements Agent, and the Unit Capability Agent. Each agent operates independently and toward a unique objective. In the following sub-sections, each agent is further defined and exemplified.

Unit Capability Agent

The Unit Capability Agent is responsible for monitoring all Units and their weapons. When the agent detects that a Unit is given a Weapon with a Fire Capability, it will create a circular Area of Influence (AOI) around the Unit equal to the

maximum firing range of that weapon. As the Unit receives and removes weapons from its arsenal, the agent will always keep track of the farthest reaching weapon, and its AOI will always reflect this farthest reaching weapon. The agent will also keep track of the weapon's operational quantity so that if it has fired all of its rounds, is damaged, etc., the agent will remove the weapon and utilize the next farthest reaching operational weapon as the AOI and its radius will be adjusted as appropriate. If there are no other operational weapons that have a maximum firing range, then the AOI is removed for that Unit as it no longer has an Area of Influence.

Information Exchange Requirements Agent

The Information Exchange Requirements (IER) Agent is responsible for alerting the IMO that a new Task has entered the system. Tasks and their requirements are the heart of the COSMOS system. It is through unit task assignment, and the details that define these tasks, that information requirements may be inferred, thereby, suggesting information be shared between coalition nodes to facilitate successful operational task completion. The IER Agent prompts the IMO to create Information Exchange Requirements for Tasks tied to specific coalition partners.

Exchange Control Agent

The Exchange Control Agent is responsible for deciding and automating the addition and subtraction of information from Information Groups, ultimately determining what is shared out to other COSMOS nodes that have contracts to receive information within the Information Groups. This agent capitalizes on the work done by the Information Exchange Requirements (IER) Agent and IMO. The Exchange Control Agent monitors all Object Items (Tracks, Platforms, Control Features, etc.) and checks to see if any of them meet the criteria created by the IMO through the IER Agent. If a piece of information meets the criteria put forth on an IER, then the Exchange Control Agent will add this piece of information to the coalition partner-specific information group on which the IER was defined. Once this piece of information is added to the group, the Exchange Control Agent continues to monitor it for updates. If, at any time, the piece of information changes to the extent that it no longer satisfies all the criteria defined on the group, then the Exchange Control Agent will remove it from the group and post a new observation for the IMO.

4. Conclusion

The COSMOS IMO Tool provides a framework designed to assist the IMO in the process of managing the controlled exchange of C2 information in the coalition interoperability operational environment. The framework utilizes architectural (e.g., Service-Oriented, Model-Driven) elements that enable development of domain specific services through employment of model processing tools and basic information management infrastructure. The interface presented through the framework provides an object-oriented view of the underlying information structure allowing software modules to be developed accessing information based on its natural structure without requiring knowledge of the information management functions. The IMO Tool system suite includes agents (software modules) whose logic is developed based purely on the process of managing information exchange captured from subject-area experts. Additionally, these services and software modules are decoupled processes that may be deployed across a heterogeneous network of computers. It is through the combination of these technologies that the system comprising the COSMOS IMO Tool is able to provide the required functional elements for secure information exchange in the coalition C2 network environment and enable future extension.

References

- [1] *Coalition Secure Management And Operation System (COSMOS) Advanced Concept Technology Demonstration (ACTD) Pub 8181, Data-Model-Based Information Sharing*
- [2] *The C2 Information Exchange Data Model, Edition 6.15e*, 2 December 2005
- [3] M. Fowler, *Analysis Patterns / Reusable Object Models*, Addison-Wesley, Reading, MA, December 1998, pp. 247.
- [4] E. Gamma, R. Helm, R. Johnson, and J Vlissides, *Design Patterns / Elements of Reusable Object-Oriented Software*, Addison-Wesley, Reading, MA, September 1998, pp. 185-193.

A. Glossary

Agent A software entity capturing domain logic/expertise (behavior and semantics). Provides feedback in response to satisfaction of logical conditions to enable collaborative decision support.

Contract An agreement between two nodes, established during the planning stage, to share information contained in specific CIGs. A single contract only defines information sharing in one direction (from the provider to the requester).

Command And Control (C2) The exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of a mission. Command and Control functions are performed through an arrangement of personnel, equipment, communication, facilities, and procedures employed by a commander in planning directing, coordinating, and controlling forces and operations in the accomplishment of the mission.

C2 Information Exchange Data Model (C2IEDM) MIP prescribed data model structured to support exchange of C2 information between MIP compliant systems.

Data Exchange Mechanism (DEM) MIP specification describing the protocols and processes necessary for managing the exchange of C2 data as defined by the C2IEDM.

Information Exchange Requirement (IER) The basic definition of a specific kind of information required to perform a particular activity or function. The requirement specification may be associated with one or more conditions that, when satisfied, trigger an appropriate information exchange action.

Information Management Officer (IMO) The user of the IMT. Node - A national entity capable of sharing operational information with, and receiving shared operational information from, other nodes.

Ontology A High-level information representation that defines structural hierarchy, characteristics, and relationships (i.e. object model) as well as inherent behavior and semantics (i.e. logic).

Operational Information Group (OIG) A coarse grained information group, defined as one of seven static OIG types directly defined in the C2IEDM.

Role Activity or function assumed by an operational unit. May be used to establish an entity fulfilling a particular role with its basic set of information requirements.

Unit Military organization that can assume roles and possess capabilities and assigned actions.

B. Author Biographies

Russell Leighton

Educational Background

M.S., Engineering Mechanics, The University of Texas at Austin, 1993

B.S., Aeronautical Engineering, 1984

Professional Background

CDM Technologies, Inc., San Luis Obispo, CA
May 1997 – Present

Mr. Leighton is the lead for a technical development team focused on providing support for a number of projects targeting development of knowledge management and decision support capabilities in the area of military command and control. Mr. Leighton is currently serving in the capacity of lead software engineer responsible for development of the Coalition Secure Operations and Management System (COSMOS) Information Management Tool (IMT).

Air Force Rocket Propulsion Laboratory / Phillips Laboratory, Edwards AFB, CA
June 1981 – May 1997

Mr. Leighton's work responsibilities included structural analysis of the propellant, case and bond systems for various solid propellant rocket motors. Additionally, Mr. Leighton was responsible for in-house and management of contractor development of software supporting solid rocket structural analysis.

Joshua Undesser

Educational Background

B.S., Electrical Engineering, Iowa State University , Ames, 2000

Professional Background

CDM Technologies Inc, San Luis Obispo, CA
July 2000 - Present

Mr. Undesser is a Software Engineer whose main focus has been in the design and development of autonomous agent-based decision-support systems. Two more notable projects that he has been involved in are IMMACCS (Integrated Marine Multi-Agent Command and Control System), which helps Marine commanders make time-critical decisions, and COSMOS (Coalition Secure Management and Operations System) which helps facilitate intelligent information sharing between coalition partners.

Ontology Based Information Exchange Management System for Secure Coalition Interoperability

21 May 2008

**AFCEA-GMU “Critical Issues in C4I”
Interoperability: Interoperating Collaborative Applications**

**Russell Leighton
Joshua Undesser
CDM Technologies, Inc.**

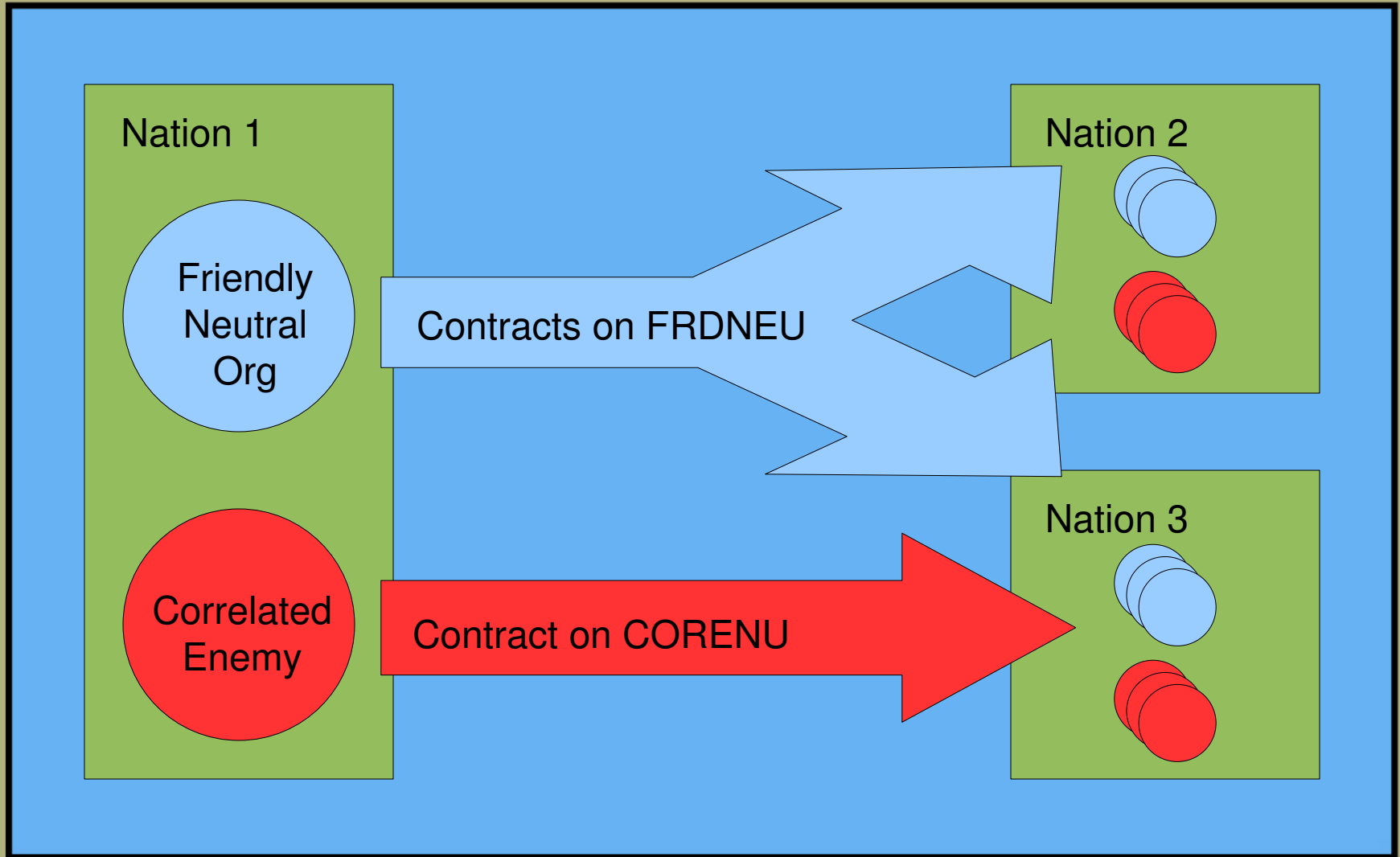
Background

- **Coalition Secure Management and Operations System (COSMOS)**
 - Multilateral Interoperability Programme (MIP)
 - Command and Control Information Exchange Data Model (C2IEDM)
 - Data Exchange Mechanism (DEM)
 - Constrained Information Exchange Based on Role
 - Information Exchange Requirements (IER)
 - Constraint Model for Concise IER Definition and Assessment

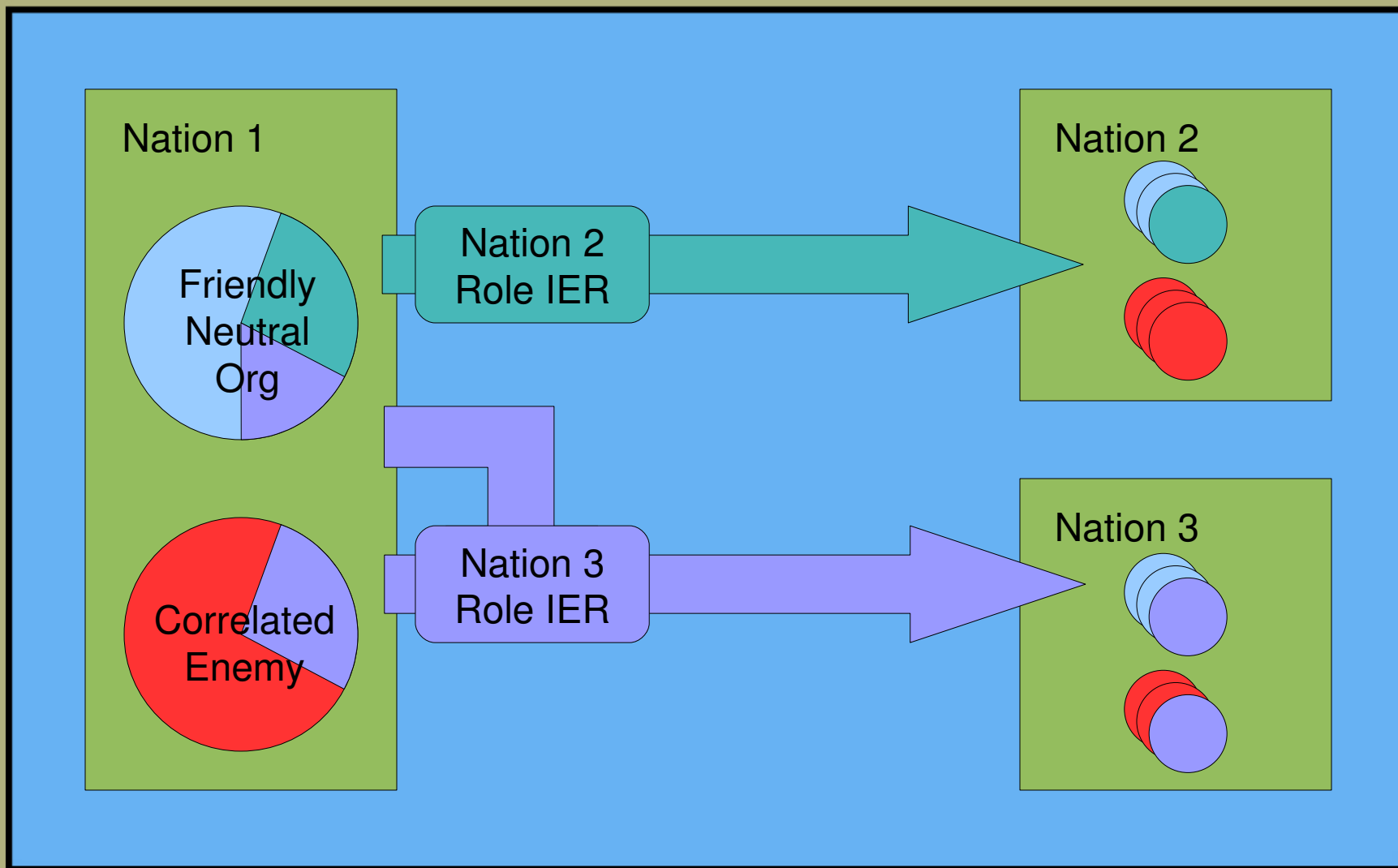
Background

- **COSMOS Primary Objectives**
 - To provide an acceptable level of security to the MIP data exchange environment
 - To reduce the volume of data that currently flows through MIP nodes
 - To allow Information Management Officers to tailor the data exchange at a finer level of granularity
 - To explore the potential capabilities and limitations of agent technology at higher levels of security control

MIP Exchange



COSMOS Exchange



Enabling Technologies

- **Knowledge Management Framework**
 - Service Oriented Architecture
 - Collaborative decision-support (agents and users)
 - High-level information representation (ontology)
 - Common services (distributable software modules/reuse)
- **Distributed Information Management**
 - Modular service and de-coupled applications allow flexibility in system deployment (platform independence)
 - Information location transparency
- **System Interoperability**
 - Access any information domain using structured data format
 - Information mapping to alternative views

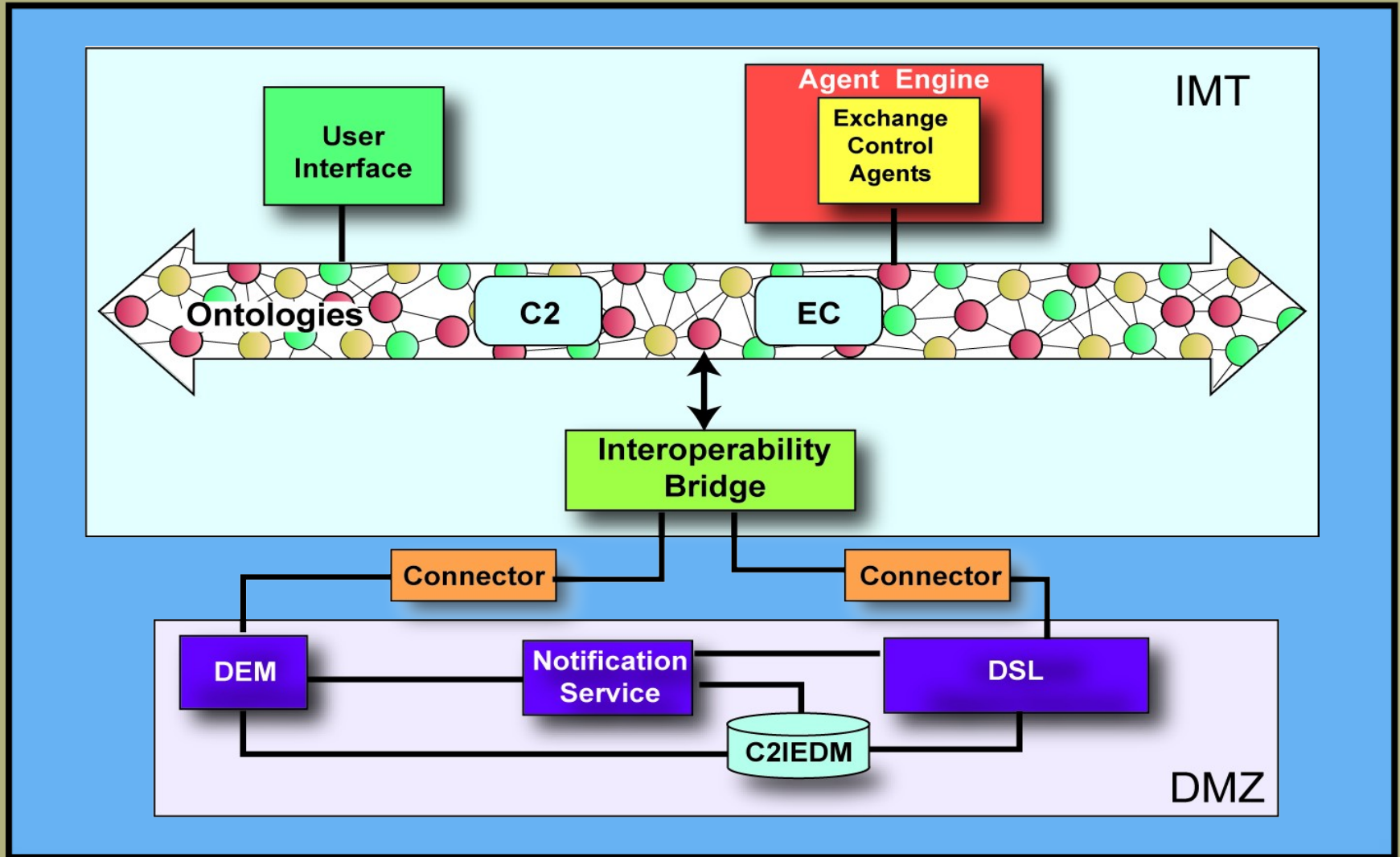
Foundational Concepts

- **Ontology** – High level information representation defining structural hierarchy, characteristics, and relationships (object model) as well as inherent behavior and semantics (logic).
- **Agent** – Software entity capturing domain logic/expertise (behavior and semantics). Provides feedback in response to satisfaction of logical conditions enabling collaborative decision support.
- **Information Exchange Requirement (IER)** – Basic definition of a specific kind of information required to perform a particular activity or function. The requirement specification may be associated with one or more conditions that when satisfied trigger an appropriate information exchange action.
- **Role** – Activity or function assumed by an operational unit. May be used to establish an entity fulfilling a particular role with its basic set of information requirements.

Key Processes

- **Define Role/Task Information Requirements**
 - Select IER criteria based on pre-defined/similar roles or tasks
 - Define/modify IER criteria composed of information value constraints (patterns)
- **Assess Information Exchange Requirements**
 - Evaluate national C2 information against coalition exchange requirements
 - Recommend exchange of information satisfying IER criteria through inclusion in relevant Information Group
- **Monitor Information Exchange**
 - Provide reports on node/contract/group activity
 - Validate incoming information against exchange requirements

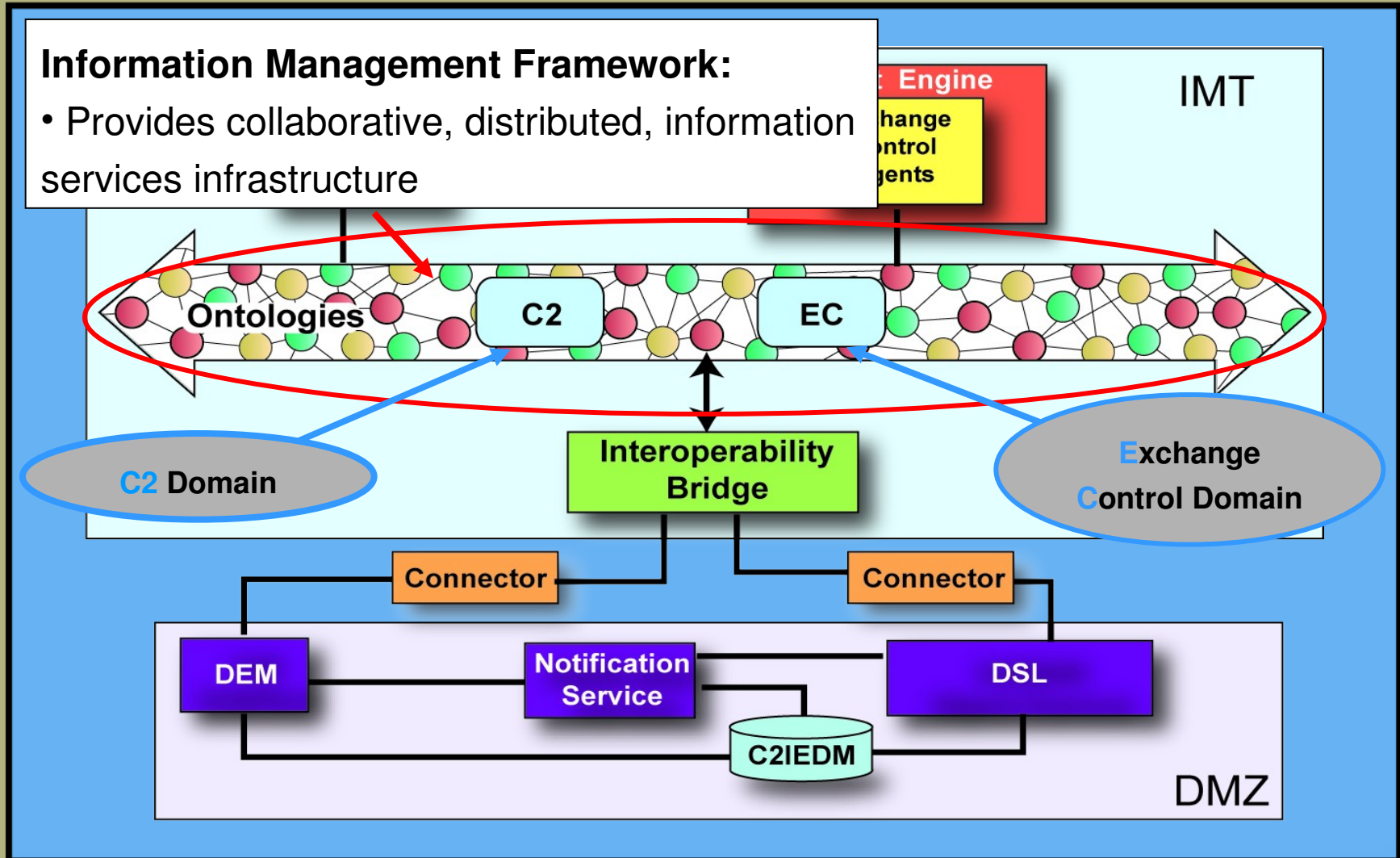
System Architecture



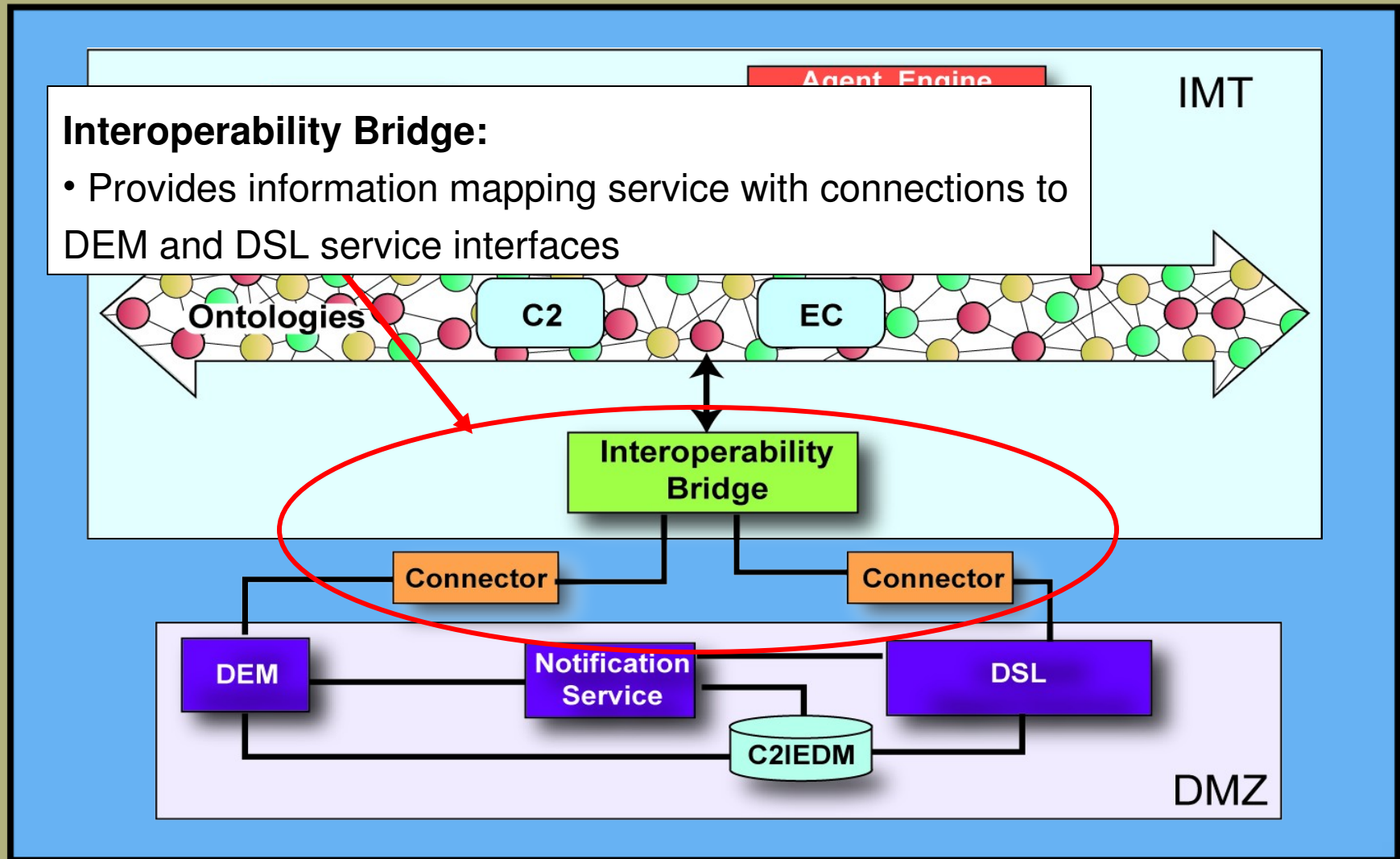
System Architecture

Information Management Framework:

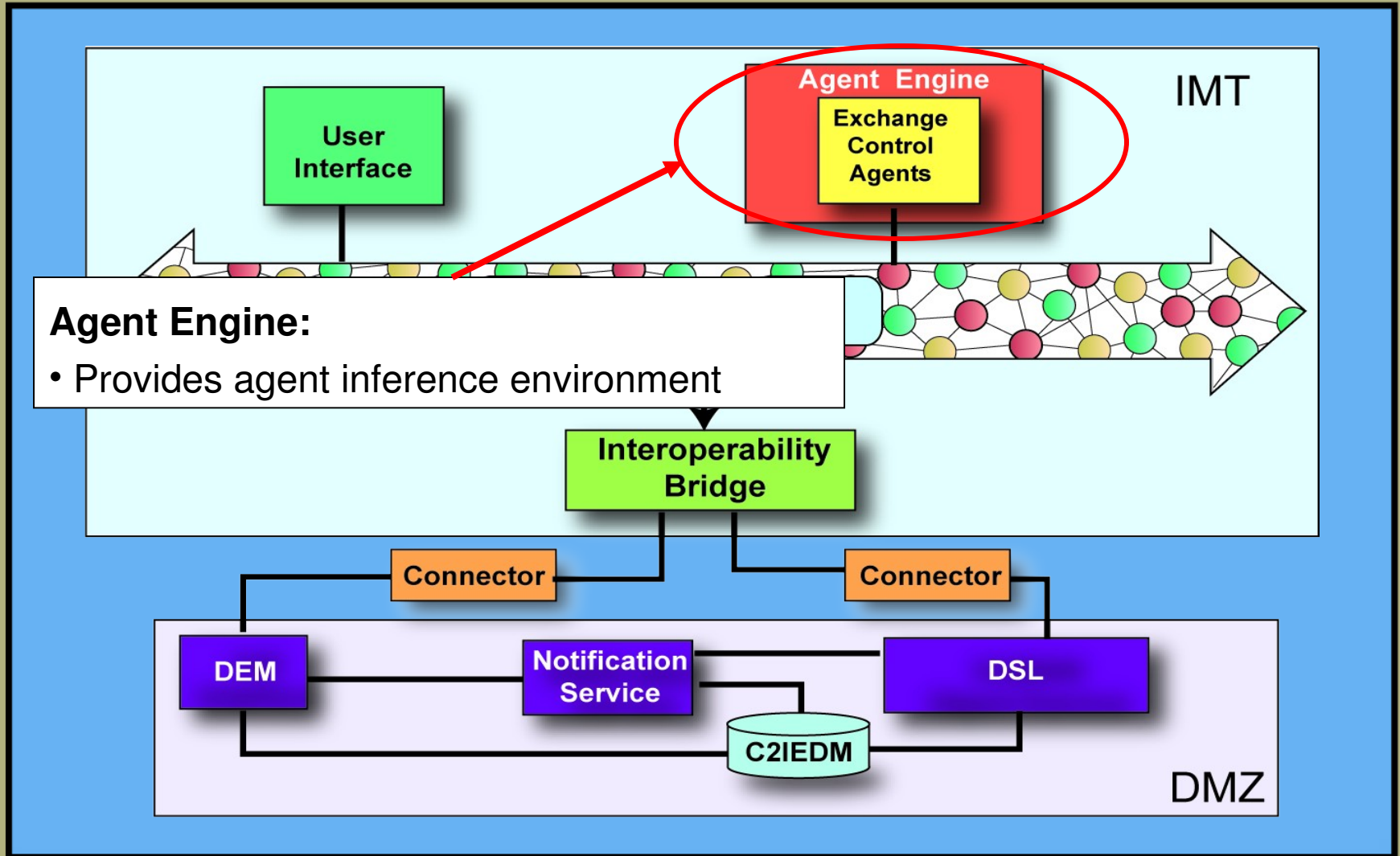
- Provides collaborative, distributed, information services infrastructure



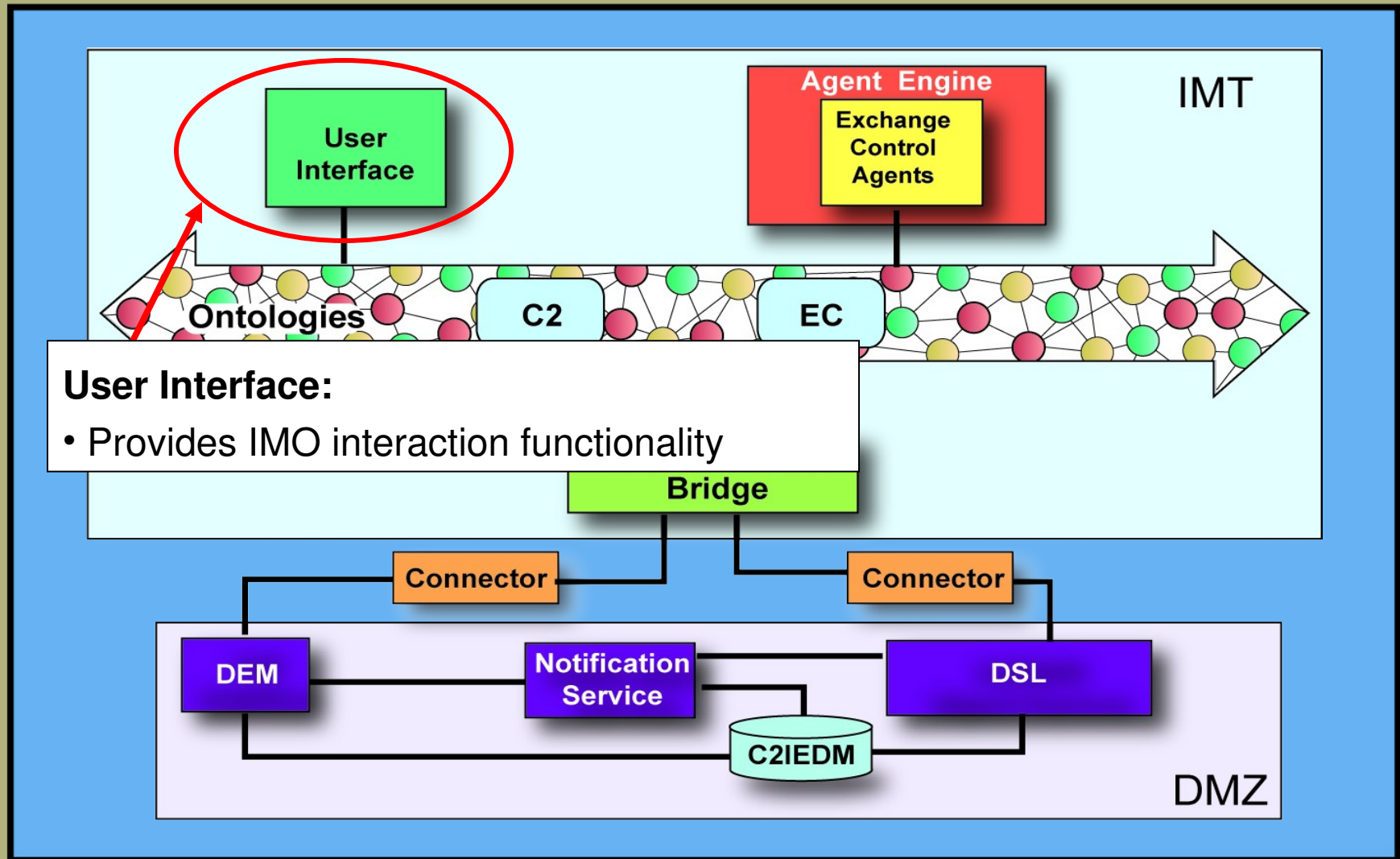
System Architecture



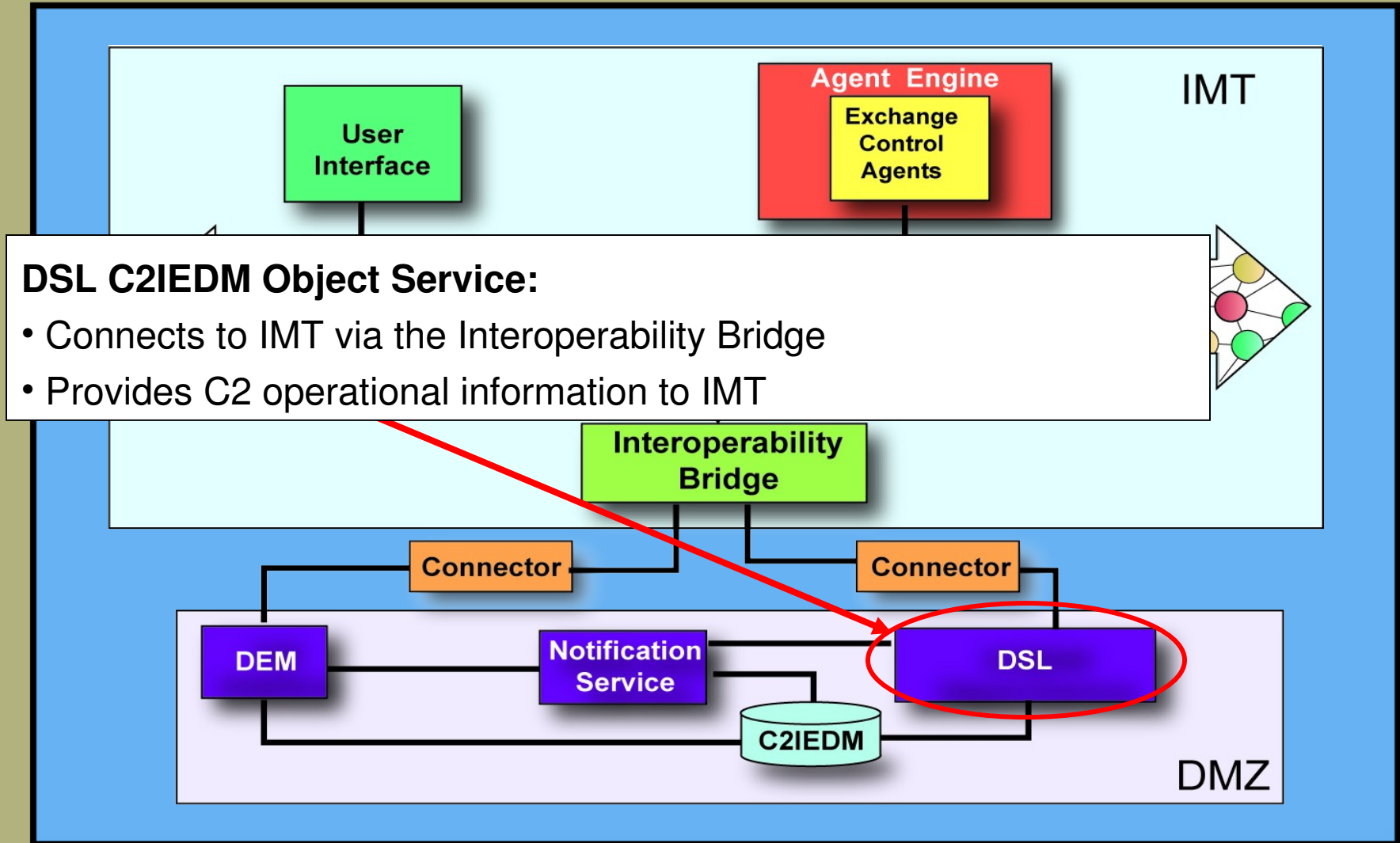
System Architecture



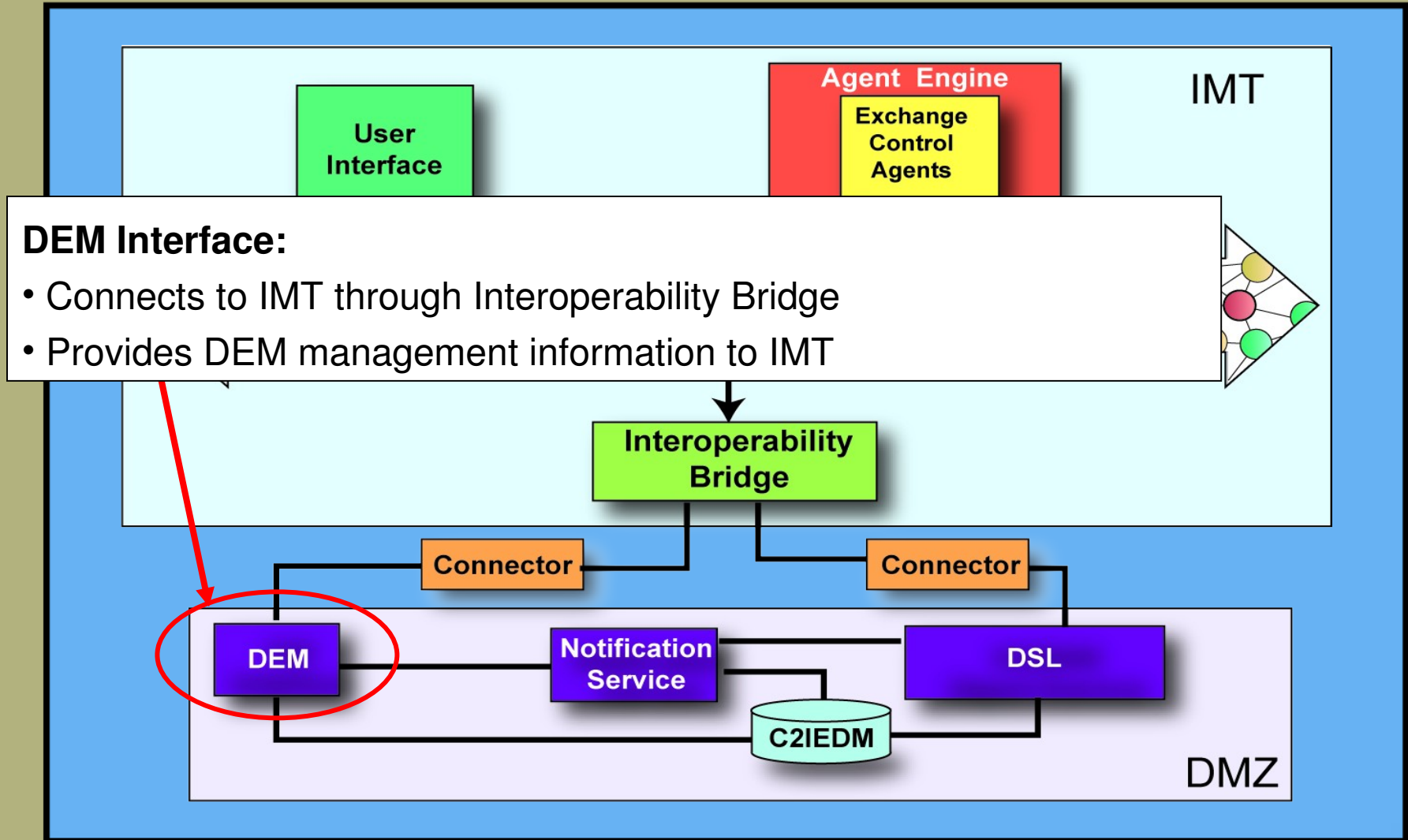
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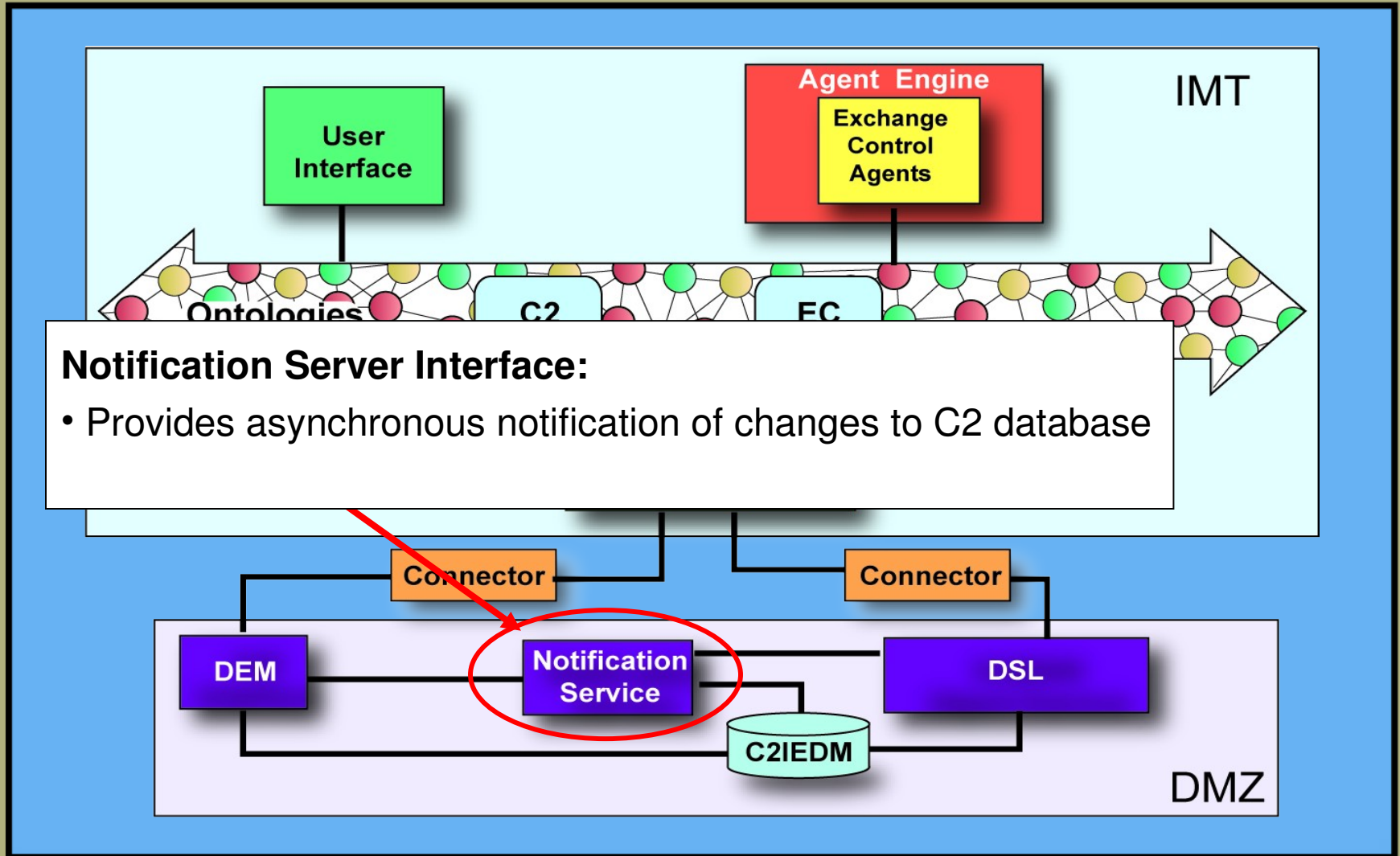
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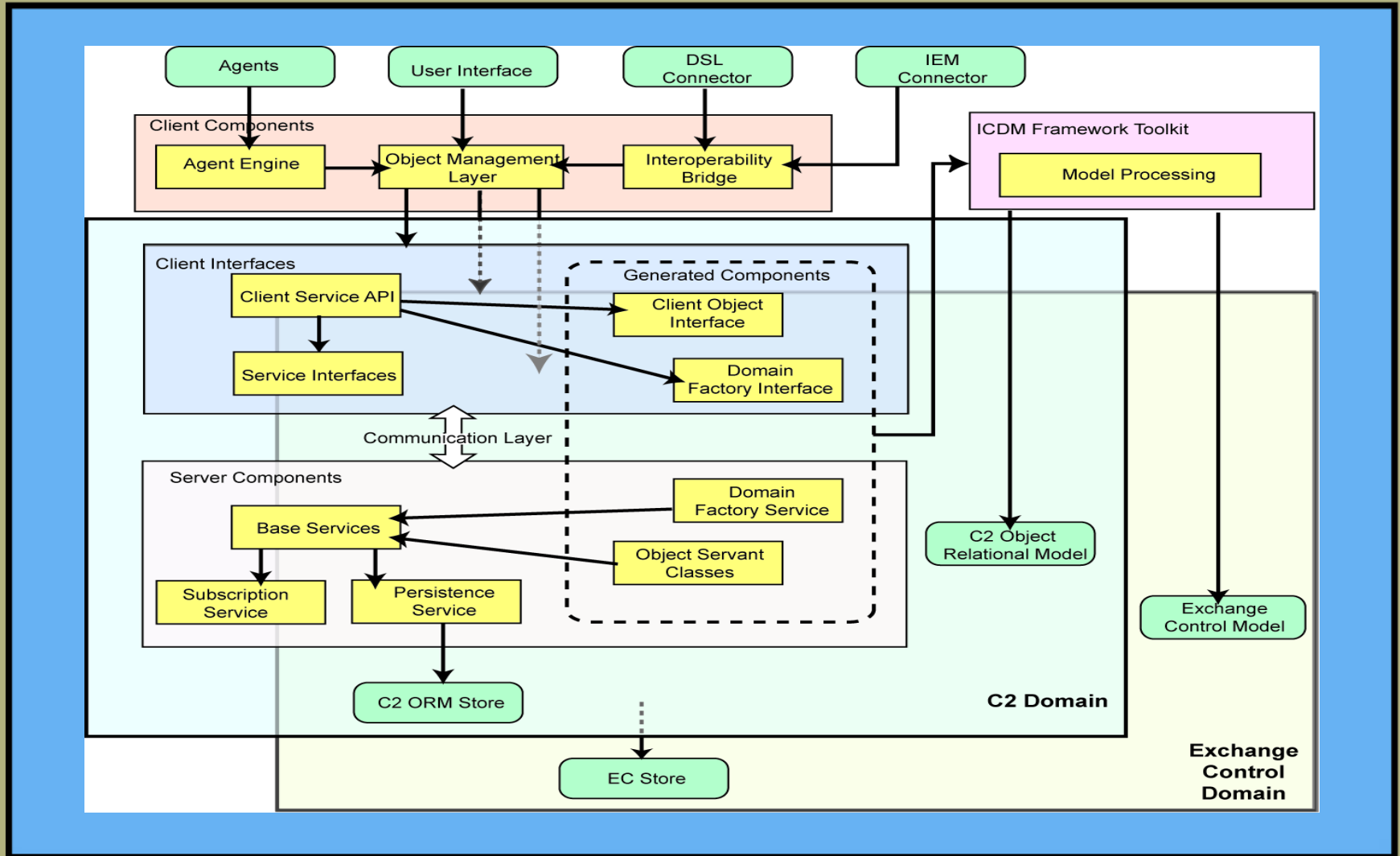
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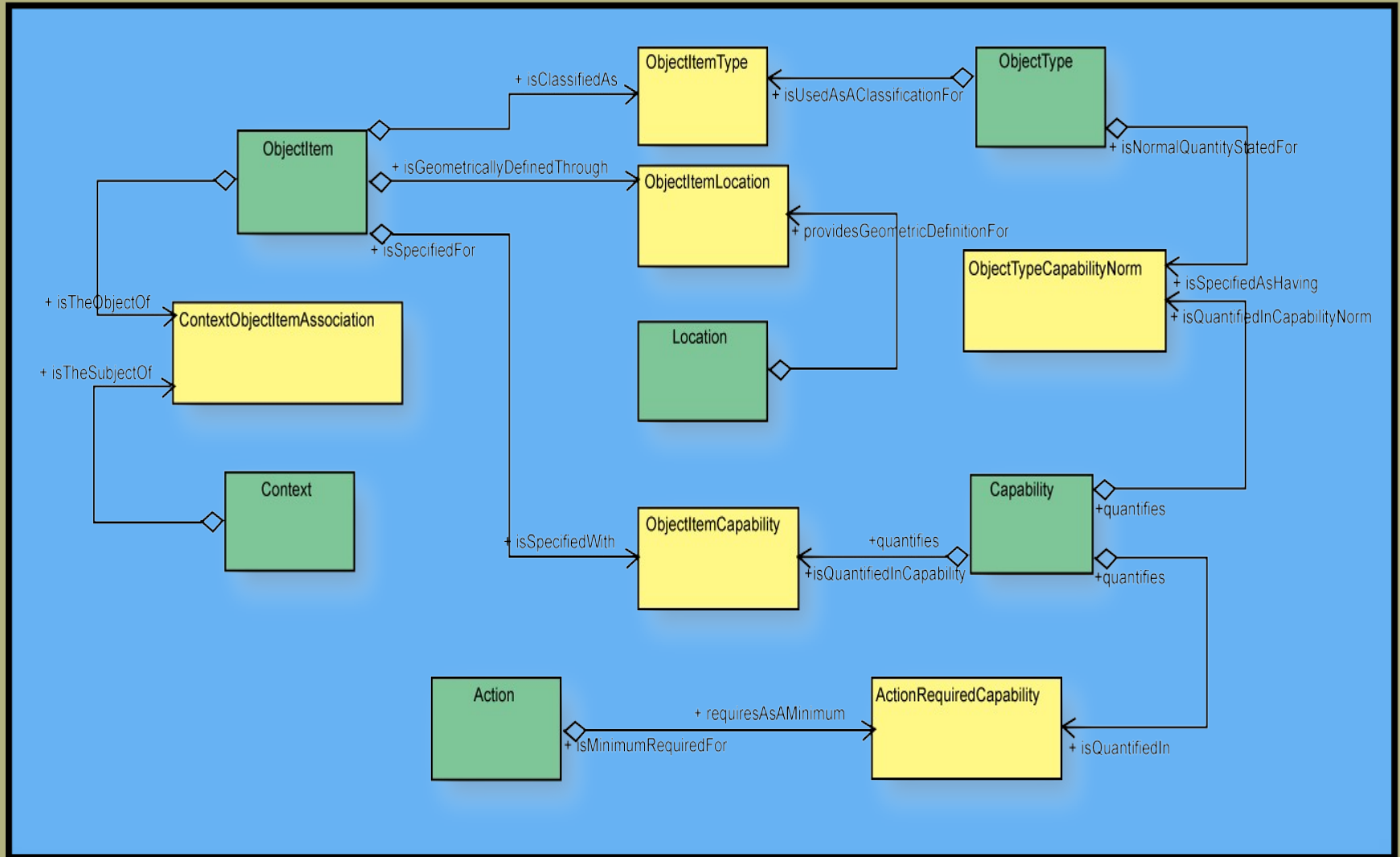
System Architecture



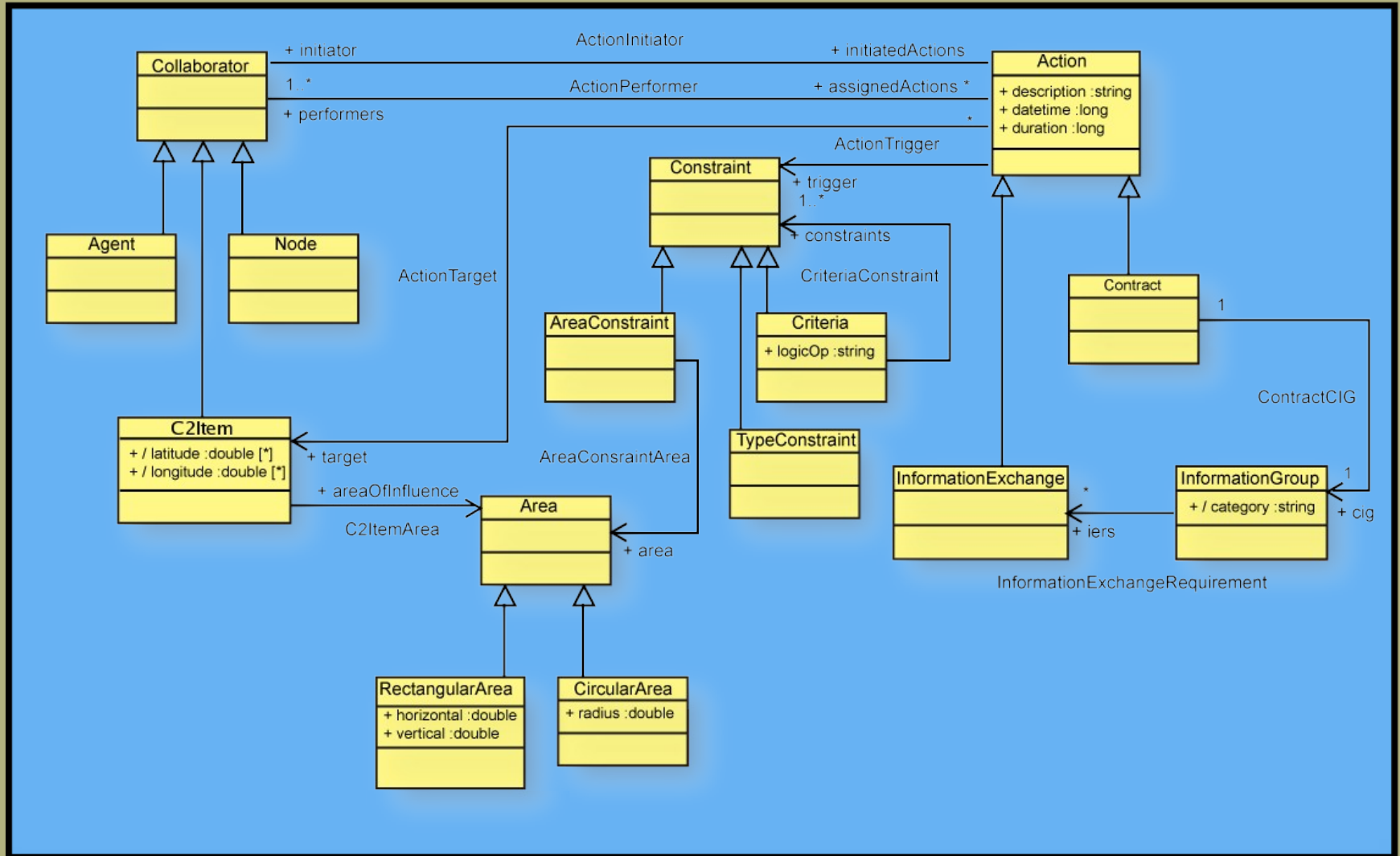
Physical Architecture



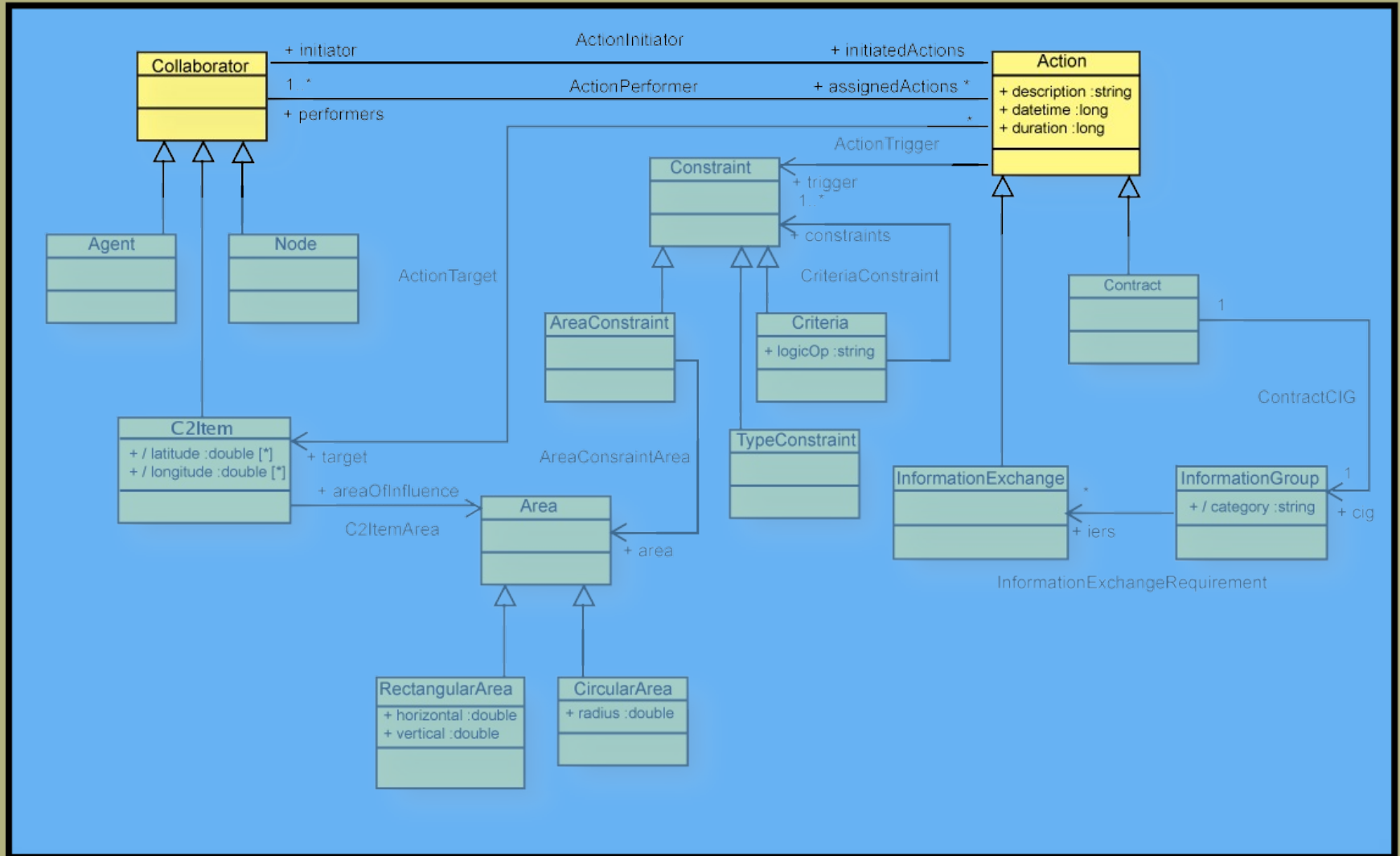
C2 Domain



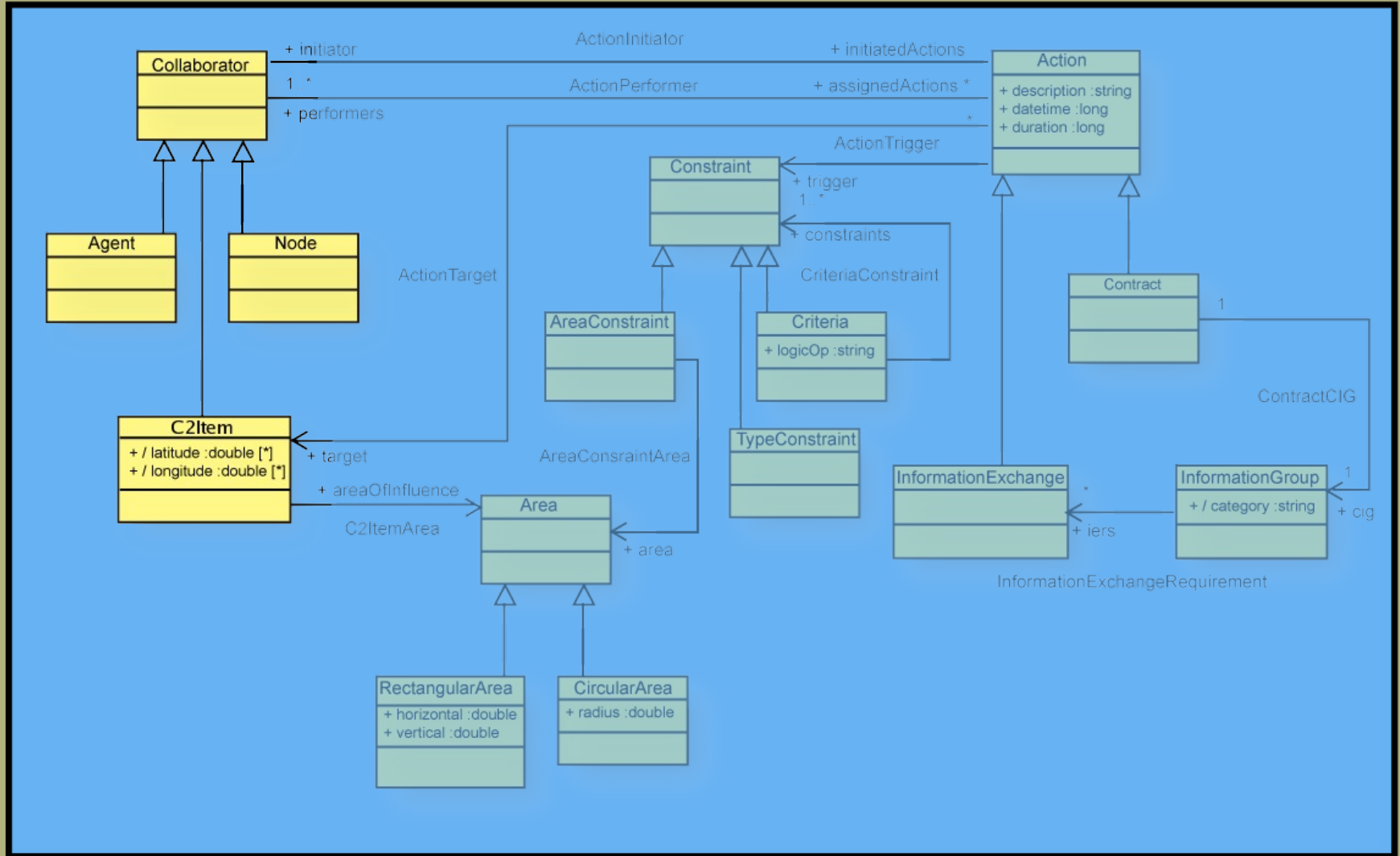
Exchange Control Domain

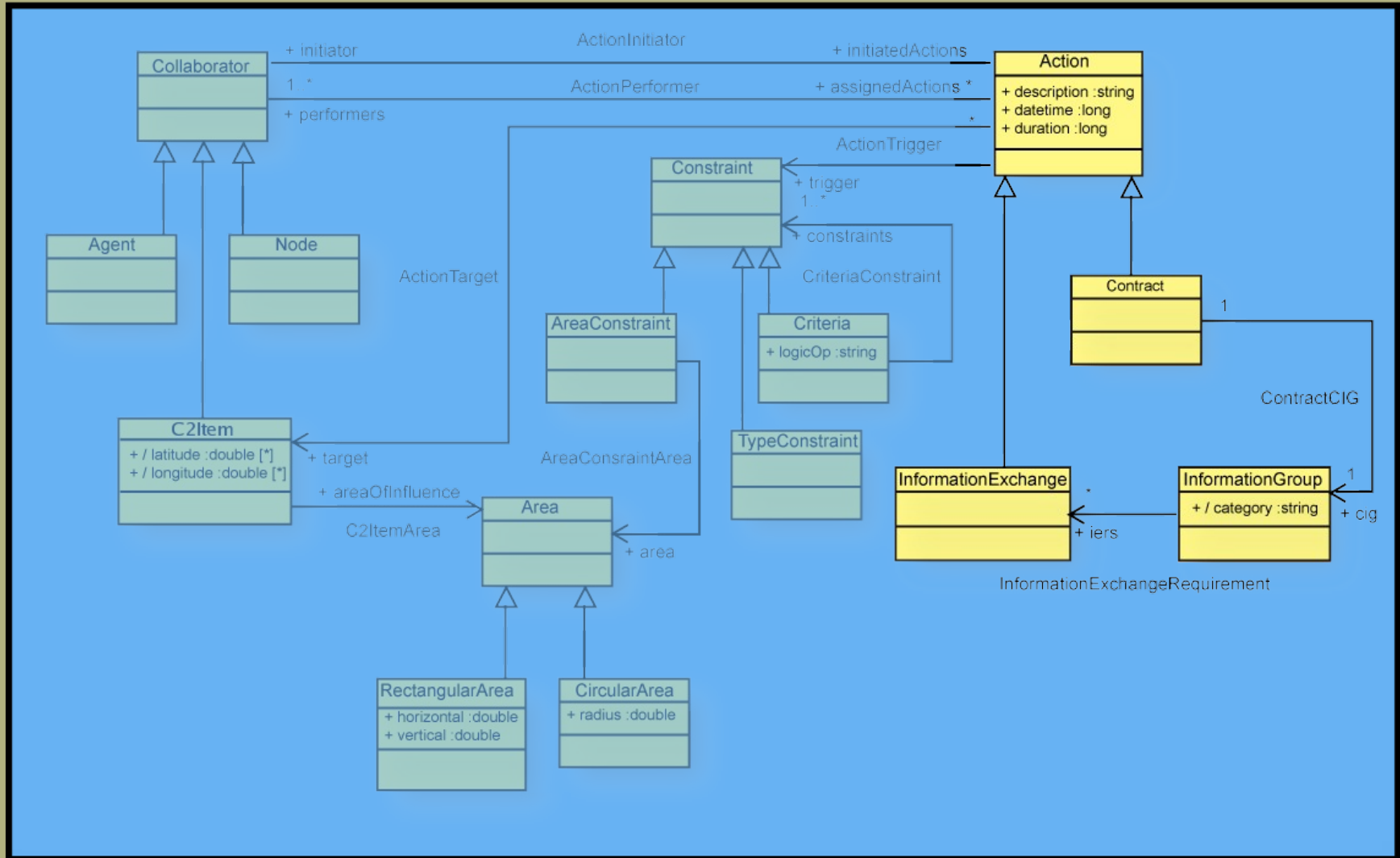


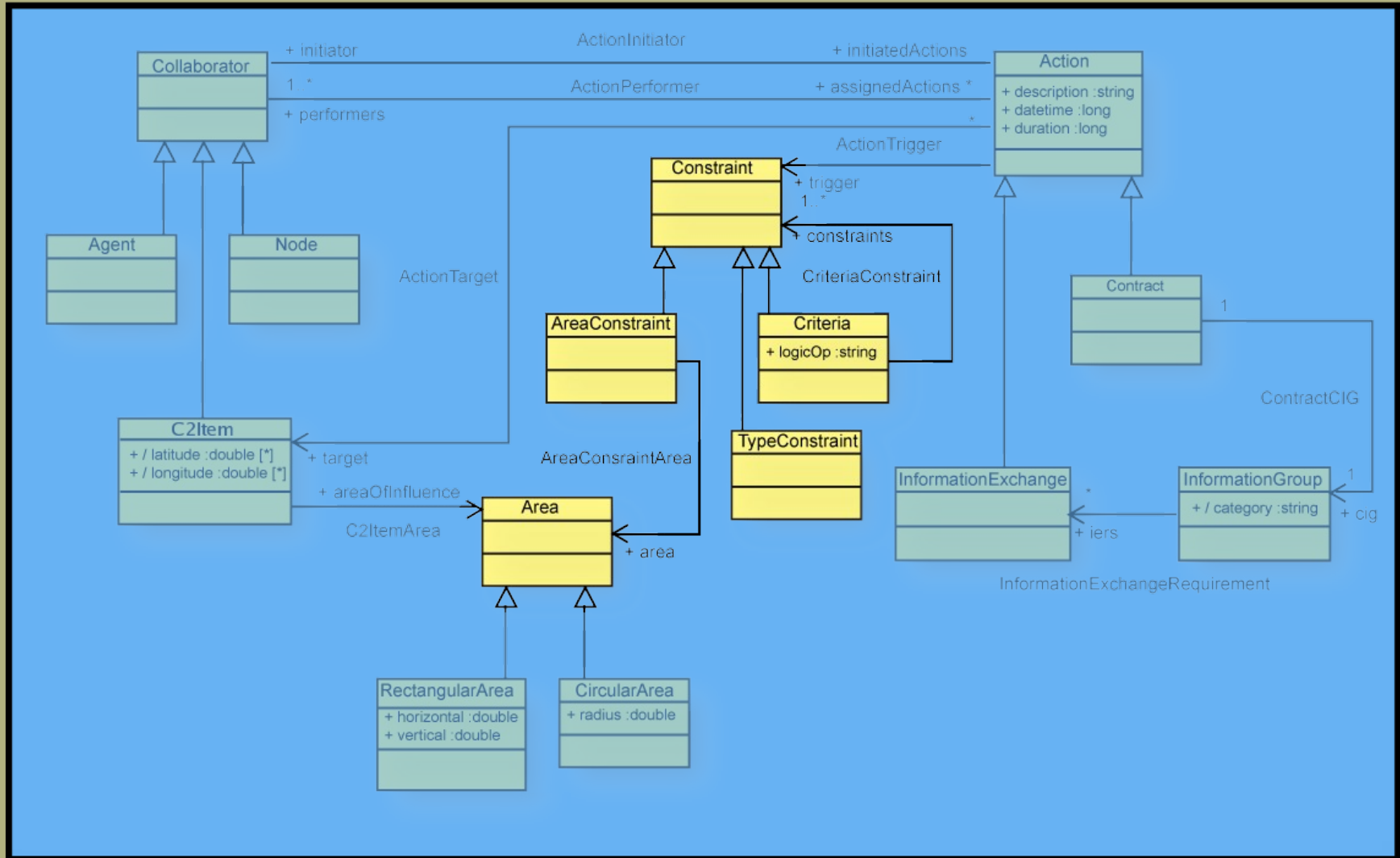
Exchange Control Domain

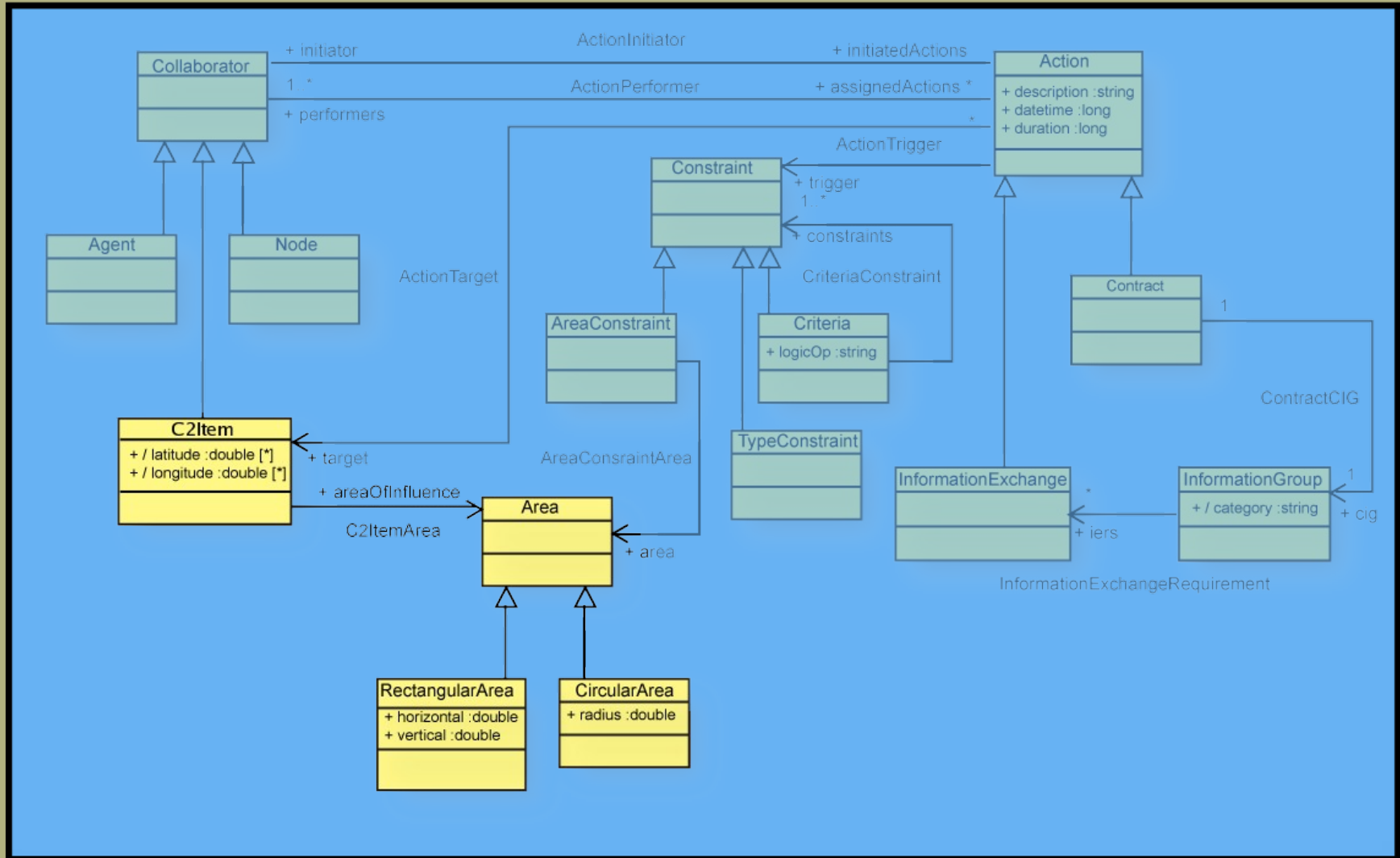


Exchange Control Domain

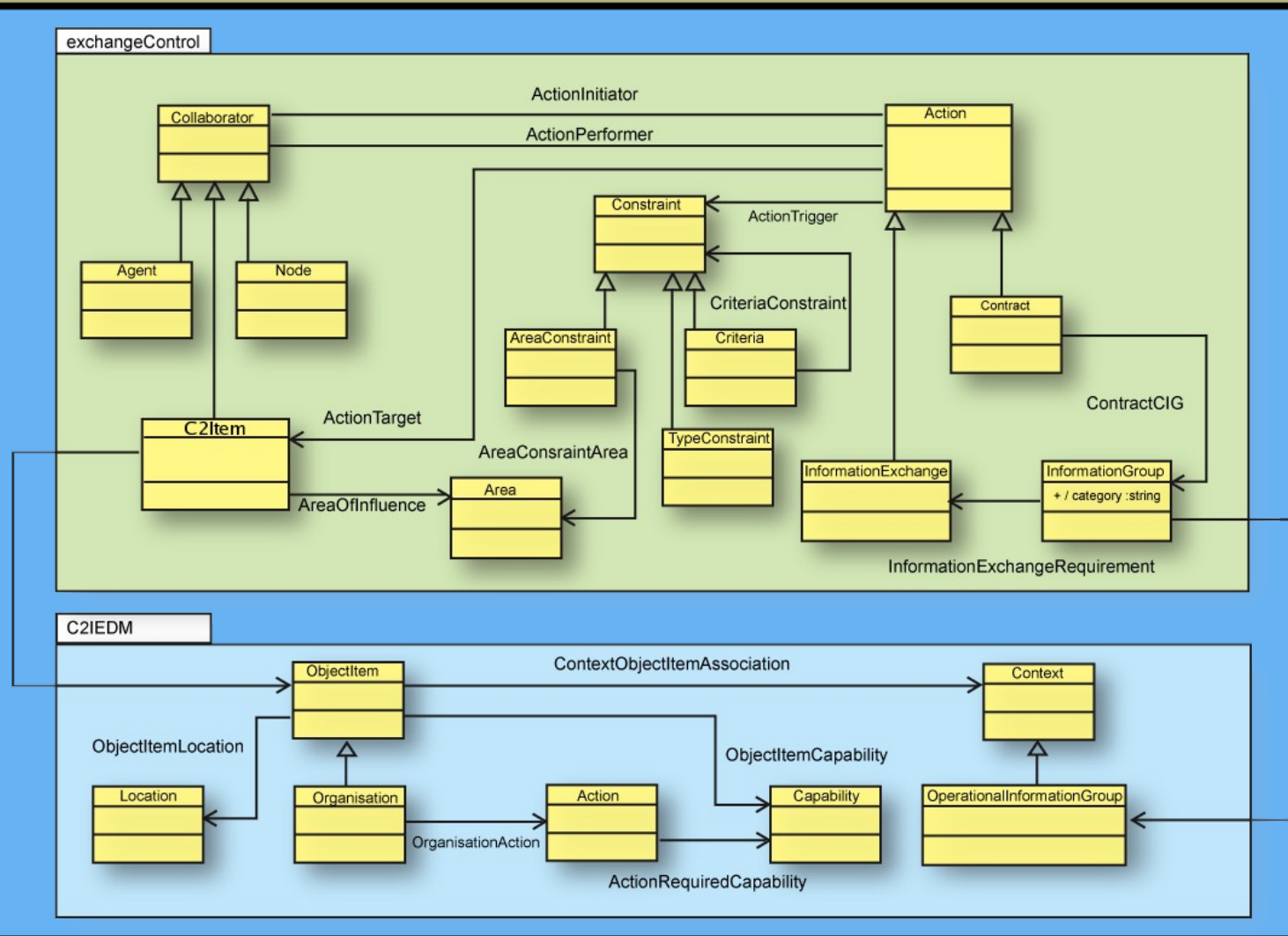








Combined Domains



Derived Features



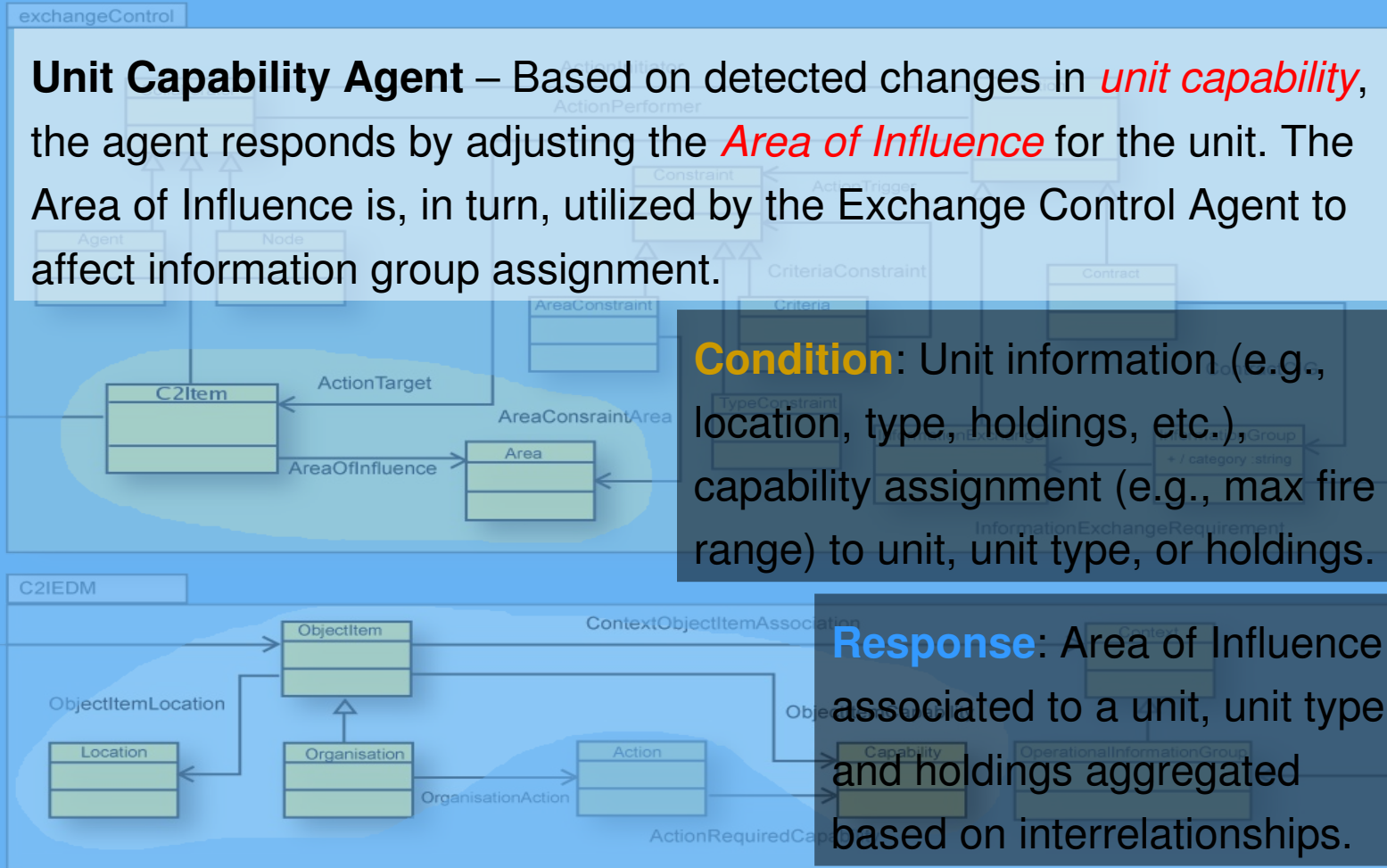
- `referenceId` -> `refObjectItem.referenceId`
- `location` -> `getLocation(refObjectItem...LongitudeCoordinate, refObjectItem...LatitudeCoordinate)`
- `country` -> `getCountry(refObjectItem...GeopoliticalCode)`
- `affiliation` -> `getAffiliation(refObjectItem...HostilityStatusCode)`
- `symbol` -> `getSymbolCode(self.affiliation, self.country)`

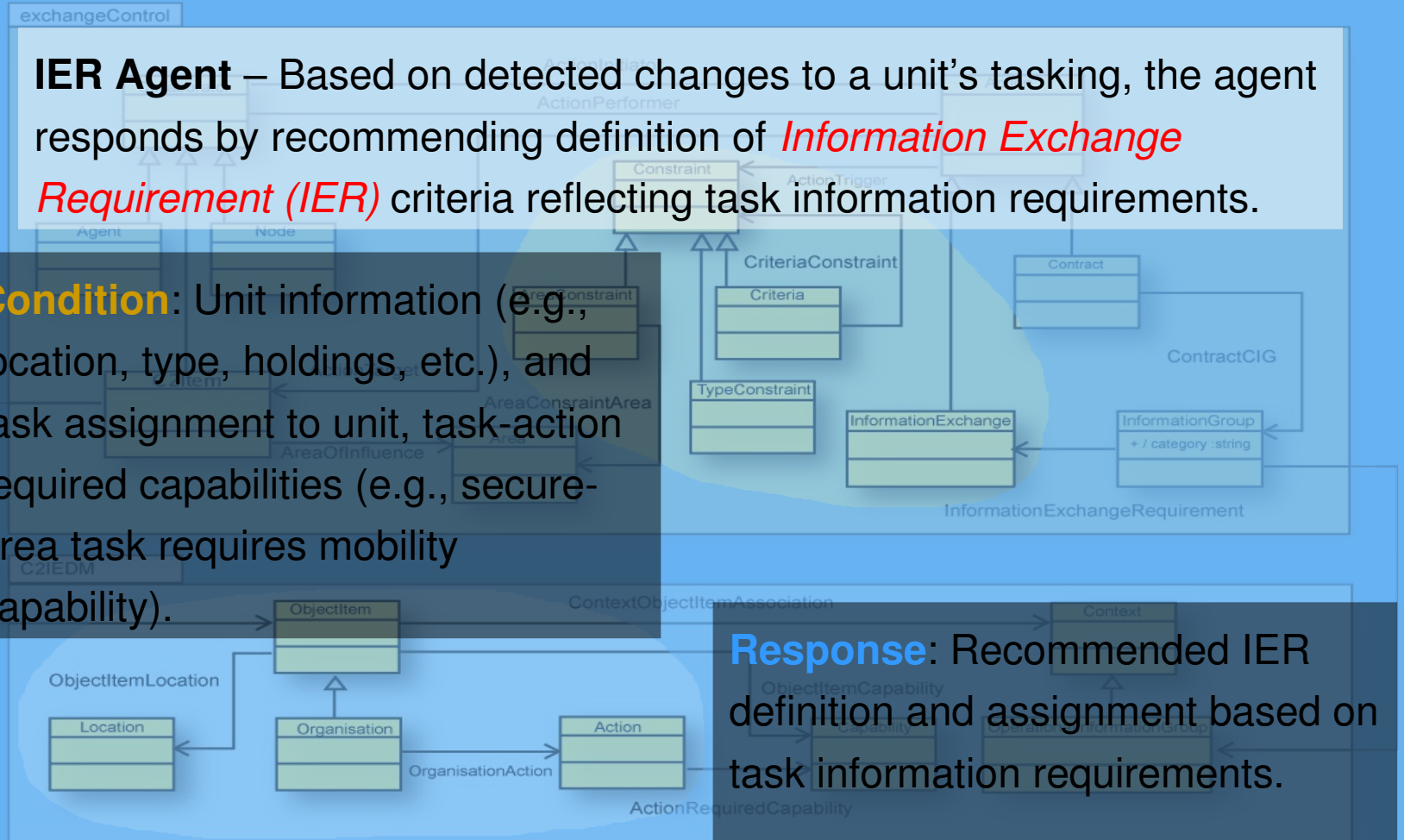
Agents

Unit Capability Agent – Based on detected changes in *unit capability*, the agent responds by adjusting the *Area of Influence* for the unit. The Area of Influence is, in turn, utilized by the Exchange Control Agent to affect information group assignment.

Condition: Unit information (e.g., location, type, holdings, etc.), capability assignment (e.g., max fire range) to unit, unit type, or holdings.

Response: Area of Influence associated to a unit, unit type, and holdings aggregated based on interrelationships.



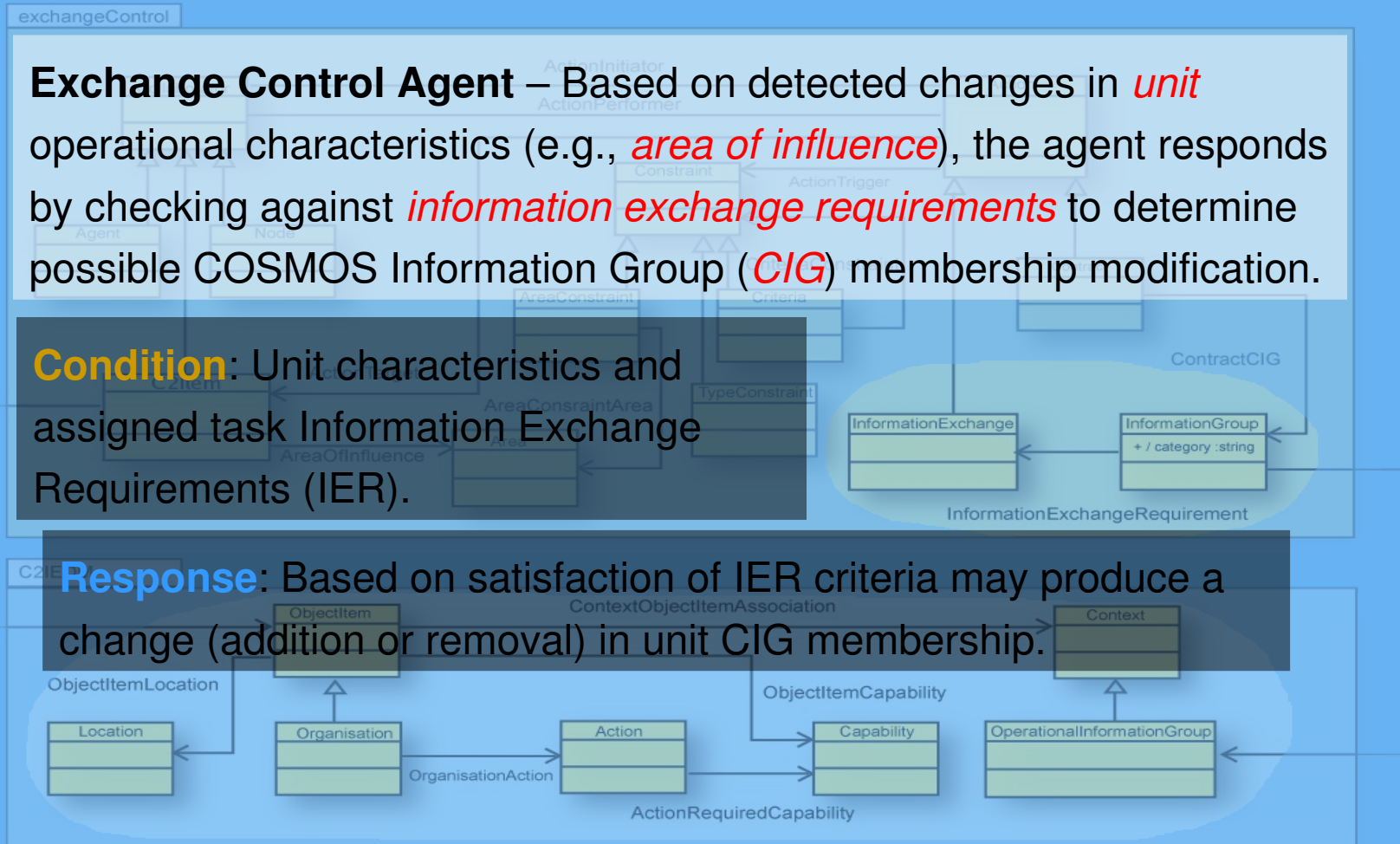


Agents

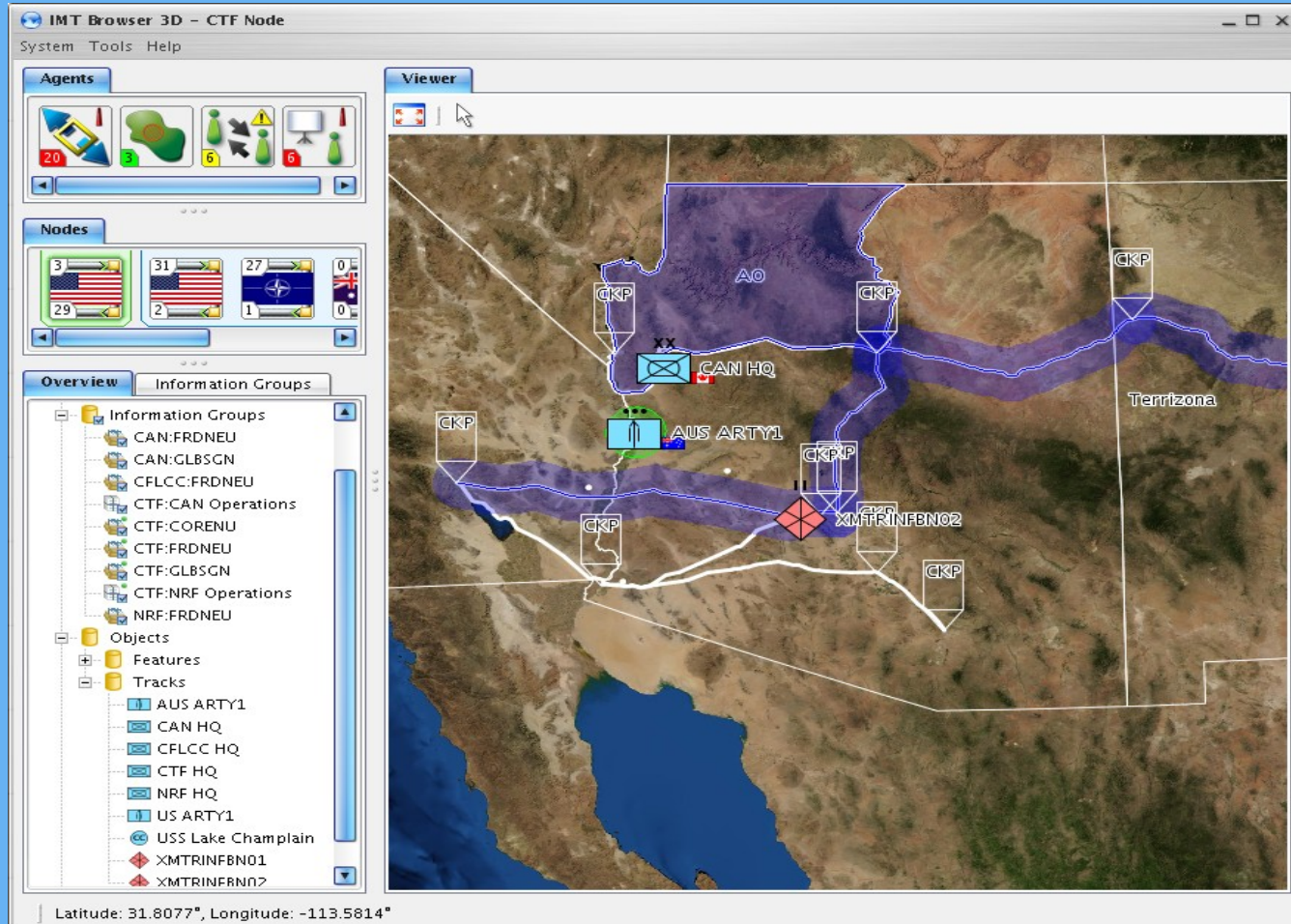
Exchange Control Agent – Based on detected changes in *unit* operational characteristics (e.g., *area of influence*), the agent responds by checking against *information exchange requirements* to determine possible COSMOS Information Group (*CIG*) membership modification.

Condition: Unit characteristics and assigned task Information Exchange Requirements (IER).

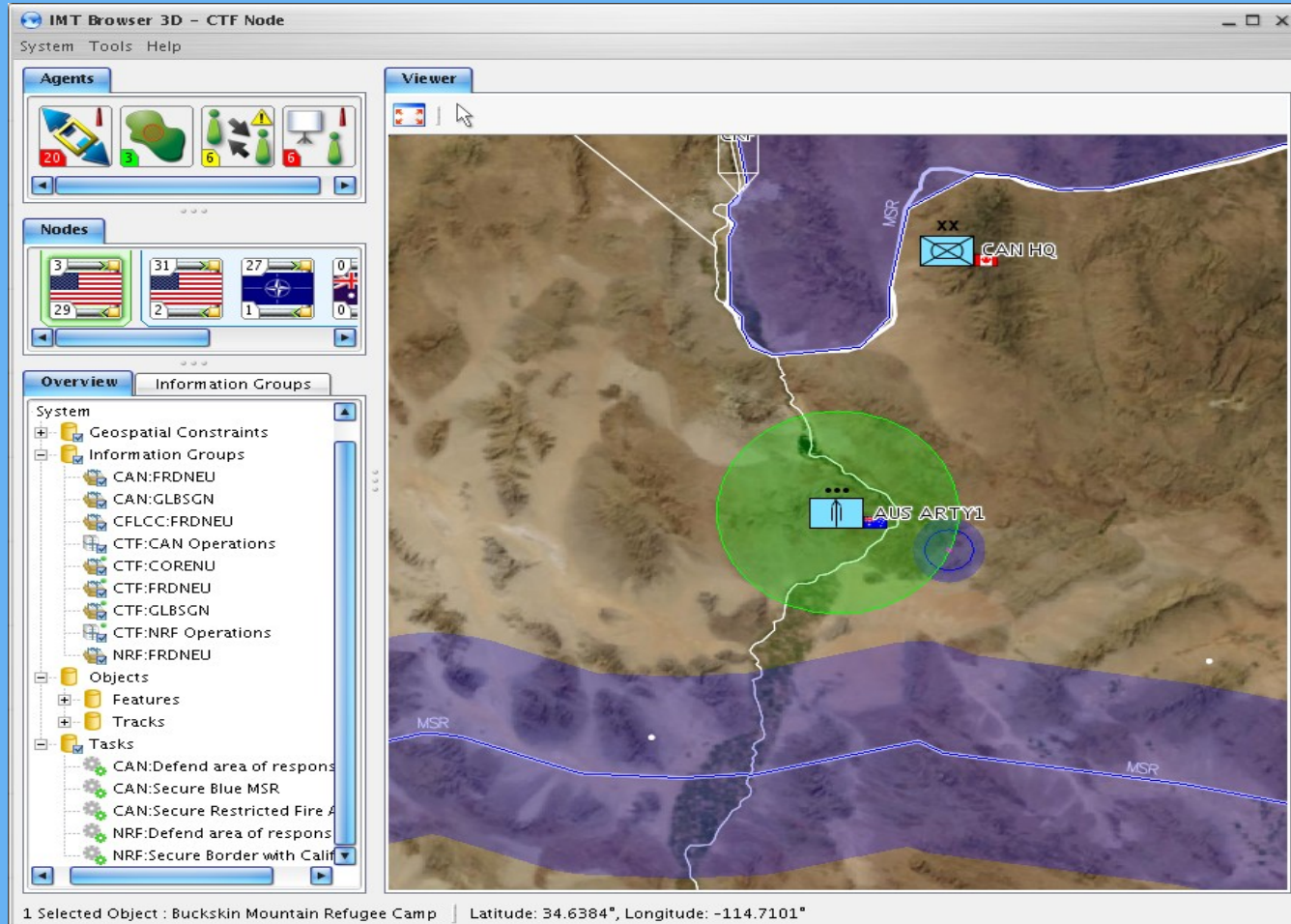
Response: Based on satisfaction of IER criteria may produce a change (addition or removal) in unit CIG membership.



IMO Tool



IMO Tool



Conclusion

- **Knowledge Representation**
 - Standard C2 Information Exchange Model
 - Exchange Control Model Incorporating Specialized Information Perspective and Information Exchange Constraint
- **Ontology Driven Framework**
 - Generated Information Management Framework
 - Collaborative Agents and User Interface
- **Service Oriented Architecture**
 - Information Management Services (Persistence, Subscription, Life-Cycle Management)
 - Distributed Software Modules