Virtual Management of Radiology Examinations in the Virtual Radiology Environment Using Common Object Request Broker Architecture Services

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In the Department of Defense (DoD), US Army Medical Command is now embarking on an extremely exciting new project—creating a virtual radiology environment (VRE) for the management of radiology examinations. The business of radiology in the military is therefore being reengineered on several fronts by the VRE Project. In the VRE Project, a set of intelligent agent algorithms determine where examinations are to routed for reading bases on a knowledge base of the entire VRE. The set of algorithms, called the Meta-Manager, is hierarchical and uses object-based communications between medical treatment facilities (MTFs) and medical centers that have digital imaging network picture archiving and communications systems (DIN-PACS) networks. The communications is based on use of common object request broker architecture (CORBA) objects and services to send patient demographics and examination images from DIN-PACS networks in the MTFs to the DIN-PACS networks at the medical centers for diagnosis. The Meta-Manager is also responsible for updating the diagnosis at the originating MTF. CORBA services are used to perform secure message communications between DIN-PACS nodes in the VRE network. The Meta-Manager has a fail-safe architecture that allows the master Meta-Manager function to float to regional Meta-Manager sites in case of server failure. A prototype of the CORBA-based Meta-Manager is being developed by the University of Arizona's Computer Engineering Research Laboratory using the unified modeling language (UML) as a design tool. The prototype will implement the main functions described in the Meta-Manager design specification. The results of this project are expected to reengineer the process of radiology in the military and have extensions to commercial radiology environments.

THE US ARMY Great Plains Medical Command (GPRMC), led by the Brooke Army Medical Center (BAMC) has embarked on a futuristic project that will revolutionize the practice of teleradiology in the Department of Defense (DoD).[1] The US Army virtual radiology environment (USAVRE) is a Continental United States (CONUS)-based network that connects all the Army's major medical centers and Regional Medical Commands (RMC). The purpose of the USAVRE is to improve the quality, access, and cost of radiology services in the Army via the use of state-of-the-art medical imaging, computer, and networking technologies. The VRE contains multimedia-viewing workstations for static and dynamic modality cases.[2] The storage and archiving systems are based on a distributed computing environment using common object request broker architecture (CORBA) middleware protocols. Collaborations between archive centers and viewing workstations are managed by CORBA functions and multimedia object streams. The candidates for the underlying telecommunications network include an asynchronous transfer mode (ATM)-based backbone network (CBI-Net) that connects to the RMC regional networks and PACS networks at medical centers and RMC clinics and a T1 router-based network (MEDNET).[3] The US Army Information Systems Engineering Command (USAISEC) at Ft Huachuca, AZ is responsible for the ATM CBI-Net backbone network to the RMC sites. The US Medical Command (TIMPO) office is responsible for the MEDNET network. The first phase of the VRE project is connection of 10 hospital sites to the BAMC in the GPRMC. The main components of the VRE Project include: (1) digital imaging network picture archiving and communications systems (DIN-PACS) networks, which are Army hospital sites; (2) a telecommunications network that connects the 10 medical treatment facility (MTF) hospitals to the BAMC; and (3) the Meta-Manager, which is an intelligent operations and management system for the VRE that controls the routing of cases between the hospitals.

In this presentation, we describe the use of CORBA services to connect the Meta-Manager to the DIN-PACS hospital networks over the telecommunications network. Figure 1 shows the protocol stack for the VRE network and the location of the CORBA middleware standard protocols.[4]

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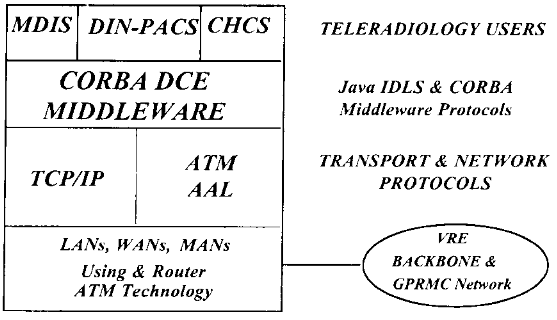

Fig 1. CORBA Protocols provide the integration of VRE components.

META-MANAGER FUNCTIONALITY

The Meta-Manager performs several functions that allow the intelligent and automatic case routing of patient cases in the VRE network. Patient cases include patient demographic information in DICOM formats, sets of images, and maybe prior examinations. The cases are acquired at MTF hospitals in the DIN-PACS networks in x-ray, computed tomography (CT), magnetic resonance imaging (MRI), and ultrasound modalities. The Meta-Manager is notified of new cases and determines at which hospital the cases should be read. The major functions and components of the Meta-Manager that involve the use of CORBA services are:

- Client Meta-Manager (CMM) interfaces to the DIN-PACS networks send and receives information on cases and case routing.
- Regional Meta-Manager (RMM) is responsible for routing cases within a RMC.
- Master Meta-Manager (MMM) is the operation control center for the VRE and can route cases between RMCs.
- The Client, Regional, and Master Meta-Manager provide failsafe and persistent operation so the VRE services are available 24 hours a day 7 days a week.
- Security services for VRE component access control, authentication, communications, and storage are provided by the Meta-Manager.
- Network and DIN-PACS node availability is monitored by the Meta-Manager via the use of CORBA operating system agents between the CMM, RMM, and MMM nodes.
- The MM graphics user interface (GUI) provides operator monitoring and intervention of the case routing and the overall operation of the VRE system.

The VRE is a large-scale distributed system.[5] The Army would like to take advantage of the size of the system to provide new levels of interaction between remote physicians, either DoD or commercial. At the same time, the new system must to adhere to the existing organizational structure for medical operations in the Army.[6] This introduces a three-level communications hierarchy into the VRE system. Figure 2 shows the Meta-Manager communications hierarchy between the major components.

Each level of the Meta-Manager hierarchy adheres to the following design rules:

1. Each Meta-Manager node is responsible for storing and tracking patient cases introduced from within their domain.
2. A new case is only be passed up the hierarchy tree if can not be adequately processed in the local domain.
3. In the absence of a higher controlling authority, the current domain must provide best-

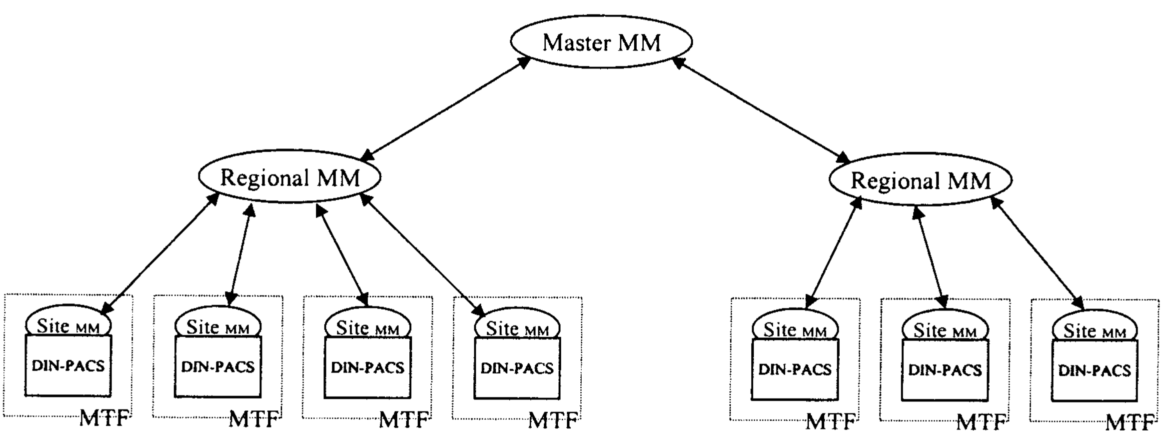

Fig 2. The Meta-Manager communications hierarchy has 3 levels.

effort Meta-Manager functionality. This means the Meta-Manager will do the best it can to provide normal VRE functionality given that it can not defer cases to a higher authority when it can not adequately processed the case in the local domain.

4. A Meta-Manager command center must have prior knowledge of all entities under its control. While this imposes a management burden on the administrators of the system it adds a level of security against false (spoofing) DIN-PACS sites gaining entry to the system.

OBJECT-ORIENTED DESIGN FOR THE VRE AND META-MANAGER

In this project, an object-oriented design (OOD) was developed for the Meta-Manager using the unified modeling language (UML) and a Rational Rose Toolkit for documentation and visual design. The OOD for the MM included the use of use-case diagram, state diagrams, case and object hierarchy diagrams, component, and time sequence diagrams. The ODD included the definition of MM actors, use cases, and functional relationships using these presentations. Figure 3 shows the VRE generic object classes in a high-level Object Model form. The interaction between the major VRE objects and functions is depicted in the diagram.

CORBA SERVICES IN THE VRE AND META-MANAGER

The Object Management Group (OMG) is an international standards body that has developed the specifications for the CORBA middleware standards. In the VRE project, we have adopted the use of CORBA object services in the development of a VRE prototype and pilot system in the GPRMC. CORBA services give the VRE several benefits including scalability, heterogeneity, interoperability, security, and fault tolerance through the use vendor develop CORBA products. After evaluation of vendor CORBA products we have settled on the VisiBroker for Java 3.4 object request broker (ORB) and related services. The VisiBroker and CORBA services we use in the development of the Meta-Manager are as follows:

- *Smart Binding*—VisiBroker enhances performance by choosing the optimum transport mechanism whenever a client binds to a server object. If the object is local to the client process, the client performs a local method call. If the object resides in a different process, the client uses the Internet Interoperability Protocol (IIOP). This feature is used to bind to CMM, RMM, and MMM object services.
- *Smart Agents*—Smart Agents are an Inprise proprietary feature and are an extension to the CORBA specification that makes it easy to obtain object references. A Smart Agent can automatically reconnect a client application to an appropriate object server if the server currently being used becomes unavailable due to a hardware or link failure. Smart Agents use VisiBroker's Object Activation Daemon (OAD) to launch instances of a server process on demand. This feature is used to provide MM object registration, persistent state, and fault tolerance for the MM clients and servers.
- *Object Activation Daemon (OAD)*—This feature automatically activates a server when a client requests a bind to the object. The object implementation is registered with the OAD. This feature is

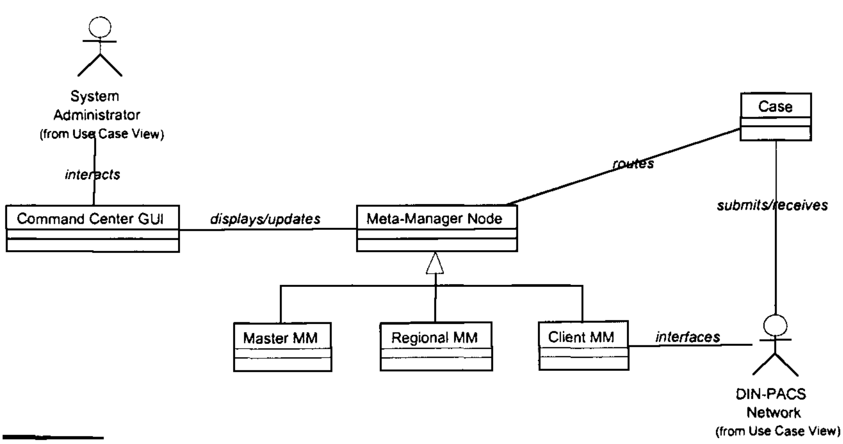

Fig 3. The VRE object model shows interaction between objects and functions.

used to start servers after a fault or power-out at MM server sites.

- *Enhanced Thread and Connection Management*—VisiBroker provides two thread policies to choose from: (1) thread pooling and (2) thread-per-session. With a given thread policy for an object server, VisiBroker automatically selects the most efficient way to manage connections between client applications and servers. The MM clients and servers use threads-per-session.
- *Location Service*—The Location Service is an Inprise proprietary feature and an extension to the CORBA specification that provides general-purpose facilities for locating object instances. Working with the Smart Agents on a network, the Location Service can see all the available instances of an object to which a client can bind. The main use of this feature is load balancing on servers. The MM GUI to get status of the MM objects uses this feature.
- *Smart Stubs*—A stub is a Java object in a client that represents a remote object and its methods. Stubs can be customized to intervene in every client invocation on a remote object to introduce "smart" handling of certain situations. This capability is useful for caching, load balancing, and logging. This feature will be used for logging MM events and communications.
- *Communication Event Handlers*—VisiBroker allows client applications and object implementations to define their own methods for handling ORB exception and recovery processing. The event-handling mechanism notifies clients and object implementations of system events and can be used to implement accounting, tracing, debugging, logging, security, and encryption facilities. The MM exceptions are handled with the event handlers.
- *Gatekeeper*—VisiBroker Gatekeeper runs on a web server and enables client programs to make calls to objects that do not reside on the web server and to receive callbacks. The Gatekeeper also handles communication through firewalls. Gatekeeper enables communications to a hospital with a firewall and allows authenticated browser access to the MM GUI.
- *Secure Sockets Layer (SSL)*—Clients and servers that use VisiBroker's SSL feature are assured of each other's identities and of the privacy and integrity of their communications. Until CORBA Security Services are mature, this is the security feature for MM client and server communications.

The VisiBroker services for CORBA will be implemented in a six-node Meta-Manager prototype. Figure 4 shows the current implementation of the Meta-Manager nodes in the prototype and locations of the MM nodes in the prototype. Eventually, the MM will be developed by industry to operate over the GPRMC and VRE's 10 nodes.

The MM prototype nodes will be located at the Computer Engineering Research Laboratory (CERL) at the University of Arizona, the Technology Integration Center at Ft Huachuca, AZ, and at the Radiology Department, BAMC, Ft Sam Houston, TX. Each location will have two NT workstation nodes with the VisiBroker ORB and Java implementation of the MM software system. The communications network for the MM prototype will be the internet, initially and then MEDNET.

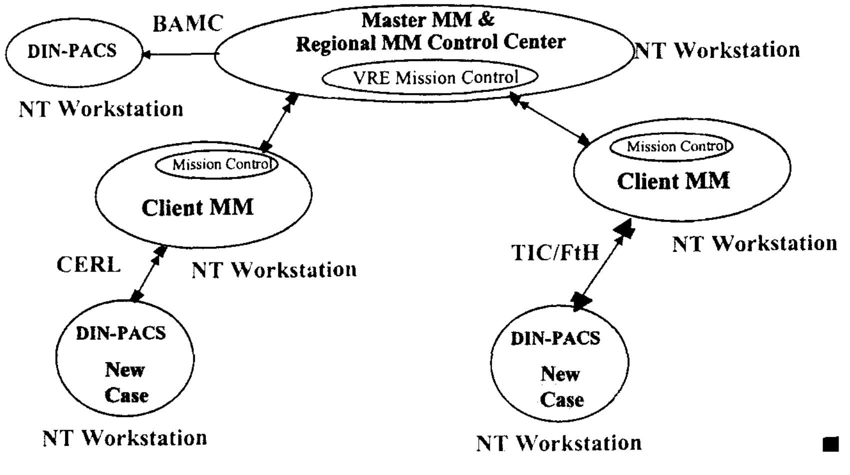

Fig 4. The MM prototype has 6 nodes to demonstrate its operation.

SUMMARY

The VRE Project is an ambitious venture by the GPRMC. The VRE Project demands the application of state-of-the-art object-oriented technology and networking hardware and protocols. In this presentation, the use of object-oriented UML and CORBA technology is described. In other presentations, on the VRE Project, the benefits and vision of the VRE technology are described for the application to commercial radiology.[1]

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