A CLIENT-SERVER APPROACH TO DCE INTER-OPERABILITY THE CRONUS/ISIS PROJECT (CRISIS)

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19950605 033

Rome Laboratory
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Distributed computing environments (DCEs) support several key attributes that are essential for the development and execution of Command and Control (C2) applications. These attributes include heterogeneity, resource availability, concurrent programming, fault tolerance, and resource management. Many DCEs claim to support all or some of these key attributes. In reality, however, no one DCE can easily and efficiently address all the needs of every application. The needs of large applications that encompass a diverse set of requirements, such as C2 applications, are especially difficult to satisfy with any one DCE. The reason for this is that many DCEs are designed using vastly different design methodologies that make them better suited for different types of problems. The Cronus/ISIS (CRISIS) project is an attempt to combine attributes from multiple DCEs to allow the application designer more freedom when designing complex applications. Specifically, the objective of the CRISIS project is to design and demonstrate the inter-operability of two structurally different DCEs. This was accomplished by building an application that spans two mature yet different DCEs (Cronus and Isis). The rationale for doing this was to utilize the strengths of each distributed computing environment, where a certain DCEs design methodology is better suited for that part of the application.
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1.0 Introduction

Distributed computing environments (DCEs) support several key attributes that are essential for the development and execution of Command and Control (C2) applications. These attributes include heterogeneity, resource availability, concurrent programming, fault tolerance, and resource management. Many DCEs claim to support all or some of these key attributes. In reality, however, no one DCE can easily and efficiently address all the needs of every application. The needs of large applications that encompass a diverse set of requirements, such as C2 applications, are especially difficult to satisfy with any one DCE. The reason for this is that many DCEs are designed using vastly different design methodologies that make them better suited for different types of problems.

The Cronus/Isis (CRISIS) project is an attempt to combine attributes from multiple DCEs to allow the application designer more freedom when designing complex applications. Specifically, the objective of the CRISIS project is to design and demonstrate the inter-operability of two structurally different DCEs. This was accomplished by building an application that spans two mature yet different DCEs (Cronus and Isis). The rationale for doing this was to utilize the strengths of each distributed computing environment, where a certain DCE's design methodology is better suited for that part of the application.

This paper is organized as follows: In section 2 a Cronus overview is presented. An overview of the Isis distributed computing environment is presented in section 3. Section 4 compares several mechanisms provided by Cronus and Isis. The CRISIS architecture and two examples are discussed in section 5. Section 6 summarizes the CRISIS work as well as how it benefits current and future technologies.

2.0 Cronus Overview

Cronus is a distributed computing environment that supports heterogeneous computer systems interconnected on a high-speed local area network (LAN) or wide area network (WAN) [Berets93]. Cronus was developed by BBN Systems and Technologies Incorporated to support distributed command and control applications, under the sponsorship of the U.S. Air Force (Rome Laboratory). The present version of Cronus provides support for such diverse systems as Sun workstations running Sun UNIX, DEC machines running VMS or ULTRIX, HP machines running HP-UX, and several parallel machine architectures. Cronus currently supports applications written in the following languages: C, C++, FORTRAN, and Common Lisp.

The Cronus distributed computing environment is based on the object model. An object consists of state information maintained in an object database and a collection of rules that govern how this state information may be examined or changed. Each rule represents an operation on the object. Objects and their associated operations are managed by object managers. Operations on objects are invoked by client programs or by other object managers.

Cronus object types define how the objects are to be used and implemented. Types are made up of operation code, operation interfaces, and data structures that specify the representation of the various objects. Types are also placed in a hierarchy structure that allows new types to be created as subtypes of existing ones.

Cronus consists of services, clients, and the Cronus kernel. Services (a service consists of one or more object managers) implement both system and application functions. Current system services provided by Cronus include an authentication service, a symbolic
naming service (global), a network configuration service, a directory service, and an object type definition service. Clients within Cronus are processes that use services. The Cronus kernel itself resides above the native operating system and is primarily responsible for transmitting synchronous or asynchronous operation invocations from clients to services. The Cronus kernel makes the network appear transparent. For example, a client on one host in a given Cronus configuration can invoke an operation on an object type whose manager resides on another host in the network (Figure 1).

![Figure 1. Cronus Communication.](image)

By using an object-oriented approach, Cronus is able to provide a variety of high level abstractions such as: (1) Management of replicated data (on disk); (2) Parallelism, by splitting a computation among several machines; (3) Monitoring and reporting the status of a computation; (4) Dynamic reconfiguration from failures; (5) Support for multi-domain applications; and (6) Support for multi-clustered networks.

### 3.0 Isis Overview

Isis is a distributed computing environment that provides high level tools which support the development of fast reliable distributed applications. Isis provides mechanisms that support heterogeneous computer systems interconnected on a high-speed local area network (LAN) or wide area network (WAN). Isis was sponsored in part by the Defense Advanced Research Projects Agency (DARPA) and developed at Cornell University, Ithaca, New York. It is currently available commercially through Isis Distributed Systems, Inc.

The Isis distributed computing environment is based on the concept of *process groups* [Birman91][Cooper92]. Process groups are a lightweight programming construct. A single process can belong to any number of groups and there is minimal overhead associated with joining and leaving groups. Groups have a hierarchical namespace, much like a file system namespace, and permit flexible, location transparent addressing. Process groups are also capable of spanning across multiple machines. Isis provides mechanisms for communicating atomically with a group, as one might do to inform its members of some event, or to issue them a request of some sort. Such a communication takes the form of a *multicast*, in which one or all the members of the group receive the message, and zero or more respond (depending on the needs of the particular application) [Birman89].

An important strength of the Isis environment lies in its support for implementing *virtual synchrony* [Birman87]. Virtual synchrony permits the programmer to design a distributed program for execution in a simplified environment, wherein all processes observe events simultaneously and therefore in the same order. Events such as communication with a group or detection of failures are atomic in a virtual synchronous setting: all group members receive a message (or observe failures) if any does [Birman89].

Using process groups and virtual synchrony, Isis is able to provide a variety of high level abstractions such as: (1) Management of replicated data (in memory or on disk); (2) Parallelism by splitting a computation among several machines; (3) Coordination of an external action; (4) Synchronization of concurrent actions (such as when several
processes share a resource that only one can use at a time); (5) Monitoring the status of a computation, process or computer, and triggering user-programmed defined actions should the status change; and (6) Dynamic reconfiguration from failures to include the integration of a recovered machine into the operational system, restarting of the services that should run at that location and the ability to bring the services up-to-date concerning the active state of the system [Birman89].

The Isis distributed computing environment currently supports applications written in C, C++, FORTRAN, ADA and Common Lisp. Isis runs on (and between) SUN, DEC, HP, GOULD, NEXT, and APOLLO equipment, and currently requires the UNIX or MACH operating system. However, ports to other operating systems such as AIX and VMS are being considered.

4.0 Cronus and Isis Mechanisms
Cronus and Isis provide support for several key distributed computing attributes. These attributes include distributed processing, fault tolerance, real time, limited adaptive resource management, heterogeneity (to include languages, operating systems and machine architectures) and support for multi-domained applications. In the paragraphs that follow each of these characteristics will be described further, and the extent to which Cronus or Isis provide inherent support for these capabilities will be compared.

4.1 Distributed Processing
Distributed processing may be defined as concurrent processes cooperating towards common goals where each process is likely to have incomplete and/or inconsistent global state information. Distributed processing provides many desirable attributes to include: Redundant Processing - several processes performing the same task perhaps on different data; Concurrent Processing - work is divided among several processes, each of which will contribute to the final result; Resource Sharing - sharing data, memory, CPUs, disks, and other physical devices for a common goal, or because a host is deficient in the resources it requires; Reliable Communication - reliable communication between processes whether they are on the same host or on different hosts connected by LANs and WANs; and Heterogeneity - the inter-operandability of languages, operating systems and machine architectures.

Cronus and Isis both support the attributes of distributed processing to some degree. However, different characteristics are evident due to the vastly different design methodologies of Cronus and Isis. For example, both systems provide reliable communications between processes but a characteristic of Isis is to also preserve message order. Therefore, if your application needs reliable ordered communications, Isis should be used because Cronus provides no inherent mechanisms to preserve order.

4.2 Fault Tolerance
Fault tolerance may be defined as the ability of a system or component to perform its function, despite the presence of hardware or software faults. Fault tolerant mechanisms must also be able to detect and/or recover from hardware and software faults. Faults fall into three classes hardware, software, and communication. Two examples of hardware faults are: (1) the complete loss of a host/service; and (2) degradation in the performance of a host/service due to overload conditions. Software faults include the following types of faults: (1) algorithmic faults; (2) software component faults (service loss); and (3) timing faults. Finally, two examples of communication faults are: (1) loss of connectivity (local area network or wide area network); and (2) overloaded or congested communications.

Cronus and Isis both provide and/or support a limited number of fault tolerant mechanisms. Replication - Replication is defined as multiple copies of a resource maintained on different hosts to improve availability or survivability; Triple Modular Redundancy (TMR) - TMR is defined as three processors running the same code on
the same data and voting on the result to mask out an error by any one processor; and
N-Version Programming - N-Version Programming is defined as N versions of a
program (using different algorithms) operating on the same data and voting on the
results. The only one of these fault tolerant mechanisms that is directly supported by
Cronus and Isis is replication. The other mechanisms, however, can be supported but
are more application specific.

Both Cronus and Isis directly support replication. The replication mechanisms
within Isis are more flexible and dynamic than those found within Cronus. For
example, Isis requires no pre-defined and pre-compiled read or write quorum as does
Cronus. However, Cronus replication mechanisms are better able to maintain
consistency during and after a network partition. This is because Cronus does have
pre-defined read and write quorums. If a distributed application becomes partitioned
due to a network failure, Cronus will allow the partition containing a majority of the
application copies (i.e., managers) to continue execution pending a recovery from
the network failure. Upon recovery of the network, Cronus provides guarantees to
insure all copies of the application are brought up to the current (consistent) state.
The choice to use Cronus or Isis once again depends on the needs of the particular
application.

4.3 Real Time
"Real time may be defined as a system or
mode of operation in which computation is
performed during the actual time that an
external process occurs, so that the
computation results can be used to control,
monitor or respond in a timely manner to the
external process” [IEEE90]. Using this
definition, a system with real time response
capability would be able to incorporate
scheduling and resource decisions based on
the current conditions of both system and
environment. At present, neither Cronus nor
Isis has the ability to comprehensively support such real time computations.
However, if only part of an application has a
real time requirement then an integration
similar to the CRISIS integration, but with
real time system support, would address this
issue. This shows the strength of the CRISIS
environment, i.e. an application programmer
is not stuck with any one technology but can
exploit different technologies to solve his
problems.

4.4 Resource Management
Adaptive resource management may be
defined as the ability of a system to change
its internal state to be consistent with its
external environment. Adaptive resource
management should allow for both the static
mapping of application components within
the system as well as the ability to
dynamically react to changes in the runtime
requirements that could not possibly be
anticipated. Therefore, a base for adaptive
resource management should be supported to
improve throughput and provide some level
of fault avoidance. This base should also
support both static and dynamic migration of
processes and data.

Adaptive resource management mechanisms
can be used to automatically adapt to
evolving resource availability. Therefore, in
the event of failures, the system may
automatically instantiate or migrate
application functionality within and among
the surviving system resources. Isis provides
some support for adaptive resource
management that includes "recycling" idle
workstations for remote use and managing a
pool of "compute servers". It can also
manage a reliable replicated service by
ensuring that some desired number of copies
of the service are always running, despite
machine failures. Cronus, on the other hand,
provides no such mechanisms [Isis92].

4.5 Multi-domained Support
Support for multi-domained applications is
also desirable. This would permit controlled
access to resources (e.g., computers and
data) in a flexible and efficient manner.
Cronus supports multi-domained
applications by a mechanism called clusters.
A cluster is a set of hosts grouped together
into a single administrative unit. Each
cluster is autonomous, and therefore
responsible for its own administration and
control. No host is permitted to be a member of more than one cluster. Clusters allow boundaries to be erected between organizations, but can selectively allow or deny foreign clusters access to services that they support. This feature allows an administrator to selectively choose the services that will be exported from one Cronus cluster to another, thereby limiting the remote computing/communications burden. Isis process groups, by default, provide a much less sophisticated mechanism (compared to Cronus) to support multi-domain applications. Process groups differ from clusters in that a member of one group can join any number of other groups. Process groups also have very little access control for joining a group, and once they become a member they can gain access to all the group services.

5.0 The CRISIS Architecture
The design goals of the CRISIS architecture are very straightforward. CRISIS must demonstrate the inter-operability of two structurally different DCEs (Cronus and Isis) in a form that is easy to use. In doing so, it must not inhibit the functionality of either DCE.

In order to accomplish this goal, CRISIS capitalized on the fact that both DCEs selected support the client-server model. In this model, clients make invocations to a population of servers which can be resident on several nodes in the system. The servers are passive entities waiting to service an invocation from a client. Therefore, by using this client-server model, an Isis client can be embedded inside a Cronus application to allow an Isis server to be called from Cronus. The reverse is also possible. A Cronus client can be embedded in an Isis application to allow a Cronus server to be called from Isis.

This is a fairly simple approach to the integration of two complex systems. However, this form of integration preserves the integrity of both DCEs and is fairly simple to use, thus meeting the design goals.

A description of the testbed and two examples follow to illustrate the use of such a system.

5.1 The Rome Laboratory Testbed
Rome Laboratory currently has an in-house distributed computer systems research, development and evaluation laboratory called the Distributed Systems Environment (DISE). Among the capabilities available within the DISE is the ability to demonstrate key distributed systems attributes utilizing various DCEs e.g. Cronus [Berets93], Isis [Birman91], and OSF/DCE [Johnson91].

The hardware configuration used consisted of three Sun workstations (SPARCstation 20's) connected on an ethernet LAN. The operating system used was Solaris 1 (BSD v4.1.3). The DCEs used were Cronus v3.0 and Isis v3.0.8.

5.2 The Inventory Example
To test out the feasibility of the CRISIS architecture, a simple Cronus manager called the inventory manager was used. The inventory manager is a sample manager distributed with the Cronus software. It simulates an inventory control system which provides operations to create items, add and subtract from the quantity of an item, and delete items.

5.2.1 An Isis Client within a Cronus Manager
The first case is to embed Isis client code inside of a Cronus manager. Below is the canonical representation of the Cronus inventory item type.

cantype ITEM
representation is Item: record
  Description: ASC
  annotate "A string that describes the item."
  Count: U16I
  annotate "The number of items in the inventory."
end ITEM
So, an inventory item is a record containing a description string (e.g. hammer) and an unsigned 16-bit integer representing the current quantity of the item in the inventory.

A typical operation on an inventory item is to add to the quantity of that item. This operation is defined in the inventory manager as a generic operation called "AddToItem". This operation is defined in the inventory manager's typedef file in the manner shown below:

```
generic operation AddToItem{
    Description: ASC;
    Add: U16l;
}
returns{
    Count: U16l;
    Description: ASC;
}
annotate "This operation adds new stock to an inventory item.";
```

In order to make these Isis calls from Cronus, several include files are required in the Cronus operations code, as below:

```
#include "isis.h"
#include "isis_errno.h"
```

These are the standard include files in Isis server code as well.

Below is a pseudocode version of the Cronus AddToItem operation with the embedded Isis client code. The actual code is provided in Appendix A.1.

```
AddToItem(...) begin
    retrieve item from Cronus object database;
    join Isis process group;
    call Isis task invAddToStock(item_name, count, addamt);
    leave Isis process group;
    update item count with result returned from Isis;
    store the updated object in the Cronus object database
end
```

Lastly, here is pseudocode for the Isis AddToStock task as defined in the Isis server code. The actual code appears in Appendix A.2.

```
AddToStock(message) begin
    get item_name, count, and addamt from message received
    from Cronus;
    add addamt to count;
    return a message to Cronus consisting of the item_name
    and the new count;
end
```

It should be readily apparent that the Isis AddToStock task simply adds an amount to a count and returns the new count and description. While this is a very trivial operation, it nevertheless demonstrates that a Cronus manager can issue a call to an Isis server and receive results back.

This example is executed by first starting the Cronus inventory manager and the Isis server. Using either a Cronus client or
TROPIC (TRansportable Operation Interface for Cronus), the AddToItem operation can be invoked. For example, entering "on {inv} AddToItem hammer 10" through tropic will invoke the Cronus AddToItem operation which in turn will call the Isis AddToStock task.

5.2.2 A Cronus Client within an Isis Server

Next comes the second case: embedding Cronus client code inside of an Isis server. Demonstrating this case was slightly more difficult because the Cronus inventory manager had to first be converted into Isis server code. After that was accomplished, the AddToStock task as defined in the Isis server code was modified to call a Cronus operation to perform the add. This is quite similar to what was done in the first case.

Below is pseudocode for the Isis AddToStock routine with the embedded Cronus client code. The actual code appears in Appendix A.3.

```
AddToStock(message)
begin
    get item from Isis store;
    invoke the Cronus operation AddToStock(item_name, count, addamt);
    update the inventory item in the Isis store with the new count;
end
```

In order for the Isis server to make Cronus calls, like the AddToStock call above, the following Cronus include files are required in the Isis server code file.

```
/* Cronus includes */
#include <stdio.h>
#include <cronus.h>
#include <equal.h>
#include <futures.h>
#include "inventory.h"
```

Pseudocode for the Cronus AddToStock operation which is called by the Isis task AddToStock follows below. The actual operation code appears in Appendix A.4.

```
AddToStock(...) 
begin
    add addamt to count;
    return new count and item_name to Isis;
end
```

Again, this Cronus operation merely adds a numeric quantity to an inventory item and returns the new quantity and description to Isis. Regardless of its simplicity, it demonstrates that not only can Cronus managers communicate with Isis servers, but Isis servers can talk to Cronus managers as well.

This example is executed by starting the Isis server and the Cronus manager. By issuing Isis calls of the form

```
c1cast(group_addr,ADD,"Rs5hd","hammer",25,1,
"%4d",answer);
```

the Isis AddToStock task is called which in turn calls the Cronus operation AddToStock to perform the add. The Cronus operation then returns the new quantity and description back to Isis.

Since communication is possible in both directions between Isis and Cronus, it seems likely that these two distinctly different DCEs can be used together to create a single distributed application. This distributed application could take advantage of the features unique to both Cronus and Isis, and thus enhance its capability.

5.3 The JDL Example

The inventory example above proved the inter-operability of Cronus and Isis for a simple example. To test this inter-operability on a more complicated example, the Target Filter (targfil) Manager component of the Joint Directors of Laboratories (JDL) experiment was selected.
The JDL experiment simulates a joint tracking and targeting system. Each service (Army, Navy, and Air Force) provides an application, which is integrated into the overall, distributed environment. Common software elements, user interfaces, data storage devices, and synchronization mechanisms are shared between the three services. The application is constructed of 10 components: synchronization (timing), target simulation, track simulation, track reporting, sensor simulations, target filtering, weather information, situation reporting, data management, and graphical interfaces (see Figure 2).

![Figure 2. JDL Diagram](image)

The Target Filter manager is a Cronus manager that receives target detections from sensor managers, filters out false detections and sends real detections to a Simulation Data Manager.

Originally, all of the JDL managers were written in Cronus. The goal was to implement the Filter Detections operation as an Isis server and have the JDL simulation run as before. That is, the modification to the simulation would be transparent to the user and both Cronus managers and Isis servers would be used in the simulation.

Appendix B.1 shows the modified Cronus Filter Detections routine. It is important to note that the Cronus Filter Detections routine is not entirely replaced by the Isis server code. The header of the operation is left intact, along with the three standard Cronus operation parameters: a pointer to an operation independent header, a pointer to the operation’s input arguments, and an output parameter for returning values. This was intentionally done to facilitate communication with the other Cronus managers in the simulation, most notably the Sensor Managers and SimData manager. If the entire Cronus Filter Detections routine was removed, the Sensor Manager code would have to be modified to be capable of calling the Isis Filter Detections task instead of the Cronus operation. The goal was to keep the modifications isolated to the Target Filter manager to minimize the impact on other JDL managers. Keeping a “stub” of the Cronus Filter Detections operation allows this to be done. The Sensor Managers communicate with the Cronus Filter Detections operation as before. The difference is that the “guts” of the Cronus Filter Detections operation have been removed and replaced with a call to the Isis Filter Detections task (see Figure 3).

```c
jdltfGetFilterDetections(r,input,output)
OperationParms *r;
reqjdltfGetFilterDetections *input;
repjdltfGetFilterDetections *output;
{
   Call to Isis Filter Detections Task
}
```

![Figure 3. Cronus Stub](image)

The first part of this Cronus operation converts the array of DETECTIONDATA into an array that can be handled by Isis. The reason for this is the nested structures within the DETECTIONDATA structure. There is no easy way in Isis to pass an array of structures with nested structures. The workaround was to “flatten” the DETECTIONDATA structure. That is, all of the nested structures are removed and each field is inserted in a new IDD (Isis Detection Data) structure. So, the first part of the code
copies the appropriate DETECTIONDATA information into the “flattened” IDD structure. An array of IDD structures can be passed to Isis with no problem at all. Once the array of IDD structures is passed to Isis, the Isis Filter Detections task converts it back into an array of DETECTIONDATA, filters out false target detections, and stores the results with the Cronus Simulation Data Manager.

The next section of the routine joins the Isis process group and issues the call to the Isis Filter Detections task shown below:

```c
nresp=ecast(group_addr,FILTER,”%B”&Id,input-dimensions:DETECTIONS,ALL,”%d”,&test);
```

Id is the flattened array of DETECTIONDATA, and input-dimensions:DETECTIONS is the number of detections in the current sensor sweep.

After this call, the rest of the routine simply leaves the Isis process group and frees memory allocations.

In summary, the Cronus Filter Detections routine converts the data into a form that can be used by Isis, joins the Isis process group, makes the call to Isis to perform the target filtering, and then leaves the Isis process group and frees memory. The Isis Filter Detections routine, which does the actual target filtering, is shown in Appendix B.2.

The first part of the Isis FilterDetections routine converts the flattened array of IDD type back into an array of DETECTIONDATA, array “list”. After this is done, the array of targets are filtered. New and/or modified targets are updated with the Cronus Simulation Data Manager. The actual update is performed by a call to the Cronus operation UpdateSimObject.

One important point needs to be made about the following line in the Isis server code:

```c
i = jdlobj_declare();
```

Without this declaration, the CanTypeToLen call fails, and thus the Isis Filter Detections task fails as well. The reason this call is needed is that a DETECTIONDATA object is a subtype of type JDLOBJ which in turn is a subtype of type OBJECT. In the inventory example, an INVENTORY object was a direct subtype of OBJECT. To quote from the Cronus 3.0 Programmer’s reference manual: “All cantypes defined by type object (obj), are already declared so there is no need to call obj_declare(). Whenever using routines that access any standard Cronus cantypes, the user must declare the cantypes first.” This is accomplished above by calling the jdlobj_declare routine.

So, in summary, Isis received the array of detections from Cronus, filtered out the false detections, and made the appropriate Cronus calls to store the real target information in a Cronus object database. The entire JDL demonstration runs as if never modified. So the Cronus/Isis integration is a success in this more complicated example as well.

The JDL example above shows the interoperability of Cronus and Isis. However, it does not show how the unique features of Cronus and Isis were combined to produce a greater capability than either DCE alone. To do this, the Isis Resource Manager is configured to keep a minimum number of copies of the Isis FilterDetections service running at all times. This is superior to the Cronus replication mechanism because Isis will automatically restart the FilterDetections service even after failures occur to maintain the desired number of copies. With Cronus, manual intervention is required to restart a failed service.

6.0 Summary
The CRISIS project focuses on one serious limitation of today’s distributed computing technologies. This limitation is that no one DCE can easily and efficiently address all the needs of every application. The reason for this is that many DCEs are based on vastly
different design methodologies that make them better suited for different types of problems. With the technology available today, why should application designers settle for one particular DCE that does not totally fulfill their needs? The CRISIS project addresses this problem by using the client-server model to integrate two different DCEs. This method was fairly simplistic and preserved the integrity of both DCEs.

What is the future of CRISIS? It is useful for legacy software. For example, a Cronus developer can use existing Isis services in the development of applications, thus saving time and money. Similarly, existing Cronus services can be used in the development of Isis applications.

An environment like CRISIS would also be useful as the micro-kernel architecture matures. As DCEs are layered on top of the micro-kernel, CRISIS-like solutions can act as the glue to integrate them and allow them to inter-operate. An application designer could then use several different DCEs to solve a problem and not make the compromises that are associated with choosing just one DCE.

The Object Management Group (OMG) is currently developing a Common Object Request Broker Architecture (CORBA) specification that is trying to address this inter-operability concept. Both Cronus and Isis are undergoing development to become CORBA compliant. Hopefully CORBA compliant DCEs will eventually support heterogeneous distributed computing environments. Until then, efforts like CRISIS demonstrate that this interoperability is attainable today without undue complexity.
References


Appendix A

Appendix A.1 (Cronus code with embedded Isis client code)

```c
invgenAddToItem(r, input, output)
    OperationParms *r;
    reginvgenAddToItem *input;
    repinvgenAddToItem *output;
{
    Item             *ip;
    register ObjectDescriptor *objdesc;
    int               i;

    /* for find item */
    Item        **ItemL;
    int         nItemL;
    UUID        *UIDL;
    int         nUIDL;

    /* for AddToStock */
    char        *desc;
    int         count;

    /* Isis Variables */
    address     *group_addr;
    groupview   *group_v;
    int         nresp;
    short       nmemb;

    /* invoke FindItem to get uid */
    i = InvokeinvgenFindItem(input->Description,
                               &ItemL, &nItemL, &UIDL, &nUIDL, NULL);

    if (i == ERROR)
        PSST(PSS студр, PS_X_BAD, PS_LOG_ALWAYS,
             "Can't Find Item:\n\t\n",
             ErrorMessage());

    /* Get the object from object database. */
    if ((objdesc = ReadObjectDescriptor(UIDL[0])) == NULL)
        PSST(PSS студр, PS_CAN_ABORT|PS_X_BAD,
             PS_LOG_ALWAYS,
             "AddToItem: Error reading object descriptor:\n\t\n",
             ErrorMessage());

    if ((ip = GetINVData(objdesc)) == NULL)
        PSST(PSS студр, PS_CAN_ABORT|PS_X_BAD,
             PS_LOG_ALWAYS,
             "AddToItem: Error getting object data:\n\t\n",
             ErrorMessage());

    /* CONNECT TO Isis */
    isis_remote_init((char *) 0,1602,1603,Isis_AUTOSTART);
```

isis_start_done();

group_addr = pg_lookup(INV_GROUP_NAME);

pg_client(group_addr, "");

/* GET THE CURRENT PROCESS GROUP VIEW */
group_v = pg_getview(group_addr);

/* FIND OUT HOW MANY MEMBERS ARE IN THE PROCESS GROUP */
nmemb = group_v->gv_nmemb;

/* BROADCAST THE COUNT FREQUENCIES REQUEST TO THE SERVERS */
printf(" Broadcasting to %d servers\n", nmemb);

/* CALL the Isis task invAddToStock */
nres = ccast(group_addr, ADD,"%s%d%d", ip->Description, ip->Count, input->Add, 1, "%s%d", desc,&count);
pg_leave(group_addr);

printf("desc = %s, count = %d, \n",desc,count);
ip->Count = count;

/* Provide output parameters for reply. */
output->Count = ip->Count;
output->Description = Talloc (strlen (ip->Description) + 1);
(void) strcpy (output->Description, ip->Description);
output->valid = TRUE;

/* Update the database. */
StoreINVData(objdesc, ip, TRUE);
WriteObjectDescriptor(objdesc);

FreeINVData(ip);
(void) FreeObjectDescriptor(objdesc);
}

Appendix A.2 (Isis AddToStock task)

invAddToStock (msg_ptr)
    message  *msg_ptr;
{
    char  item_name[25];
    int   count, addamt;

    msg_get(msg_ptr, "%s%d%d", item_name, &count,
            &addamt);
    if (addamt < 1)
        
        reply(msg_ptr, "%d", NOT_POSITIVE);
Appendix A.3 (Isis code with embedded Cronus client code)

```c
invAddToStock(msg_ptr)
    message *msg_ptr;
{
    char item_name[25];
    int addamt, itemindx;
    int i;
    int count;
    char *desc;

    msg_get(msg_ptr, "%s%d", item_name, &addamt);
    if (addamt < 1)
    {
        reply(msg_ptr, "%d", NOT_POSITIVE);
        return;
    }

    itemindx = finditem(item_name);
    if(itemindx >= 0)
    {
        /* update Count by invoking Cronus operation */
        i = InvoketagenAddToStock(item_name, inv_db[itemindx].Count, addamt, &count, &desc, NULL);

        if (i == ERROR)
            PSST(PS_STDERR | PS_X_BAD, PS_LOG_ALWAYS, "Error invoking AddToStock:\n\t%s\n", ErrorMessage());

        printf("CRONUS returns -> Description is %s, New Count is %d\n", desc, count);
        inv_db[itemindx].Count = count;
        reply(msg_ptr, "%d", inv_db[itemindx].Count);
    }
    else /* Return error */
        reply(msg_ptr, "%d", NO_ITEM);
}
```

Appendix A.4 (Cronus AddToStock Operation)

```c
atgenAddToStock(r, input, output)
    OperationParms *r;
    reqatgenAddToStock *input;
    repatgenAddToStock *output;
{
```
printf("Cronus operation AddToStock received Isis invocation\n");

/* Check to make sure positive number of items are being added. */
if (input->AddIt < 1)
{
    Nack(r, E_MUST_ADD_POSITIVE);
    return;
}

/* Update the object. */
input->OrigCount += input->AddIt;

/* Provide output parameters for reply. */
output->ReturnCount = input->OrigCount;
output->ReturnDesc = Talloc (strlen(input->OrigDesc) + 1);
(void) strcpy (output->ReturnDesc, input->OrigDesc);
output->valid = TRUE;
printf("Cronus operation AddToStock returning results to Isis\n");
}
Appendix B

Appendix B.1 (Cronus Filter Detections Operation with Embedded Isis client code)

```c
jdltfilgenFilterDetections(r, input, output)
  OperationParms *r;
  reqjdltfilgenFilterDetections *input;
  repjdltfilgenFilterDetections *output;
{
  /* Isis Variables */
  message  *msg_p;
  address   *group_addr;
  groupview *group_v;
  int       nresp;
  short     nmem;
  IDDTYPE   *Idd, *Idd_test;
  int       I, test;
  char      *temp;

  /* Notify the StatusDisplay Manager */
  DisplayStartOp( r->msgdes.source );

  /* “Flatten” the array of DETECTIONDATA */
  Idd = (IDDTYPE *) malloc(sizeof(IDDTYPE) *
                  input->dimensions.Detections);
  for (i = 0; i < input->dimensions.Detections; i++)
  {
    temp = UUIDtoString(input->Detections[i]->OriginUID, NULL);
    strncpy(Idd[i].OriginUID, temp);
    free(temp);
    strncpy(Idd[i].OriginName, input->Detections[i]->OriginName);
    temp = INTERVALtoString(input->Detections[i]->Time, NULL);
    strncpy(Idd[i].Time, temp);
    free(temp);
    Idd[i].snr = input->Detections[i]->snr;
    temp = UUIDtoString(input->Detections[i]->Target->TargetUID, NULL);
    strncpy(Idd[i].TargetUID, temp);
    free(temp);
    strncpy(Idd[i].TargetDescription, input->Detections[i]->Target->
                  TargetDescription);
    strncpy(Idd[i].TargetType, input->Detections[i]->Target->
                  TargetType);
    Idd[i].TargetNum = input->Detections[i]->Target->TargetNumber;
    strncpy(Idd[i].ThreatValue, input->Detections[i]->Target->
                  ThreatValue);
    Idd[i].Latitude = input->Detections[i]->Target->
                  TargetLocation.Latitude;
    Idd[i].Longitude = input->Detections[i]->Target->
                  TargetLocation.Longitude;
    Idd[i].Altitude = input->Detections[i]->Target->
                  TargetLocation.Altitude;
  }

  printf("Connecting to Isis\n");
  /* need to define a new format type in order to pass an array of
     records */
```
isis_define_type('x', sizeof(struct ISISDetectionData), idd_conv);

/* CONNECT TO Isis */
isis_remote_init((char *) 0,1602,1603,Isis_AUTOSTART);
isis_start_done();
group_addr = pg_lookup(TARGFIL_GROUP_NAME);
pg_client(group_addr, "");

/* GET THE CURRENT PROCESS GROUP VIEW */
group_v = pg_getview(group_addr);

/* FIND OUT HOW MANY MEMBERS ARE IN THE PROCESS GROUP */
nmemb = group_v->gv_nmemb;

/* BROADCAST THE COUNT FREQUENCIES REQUEST TO THE SERVERS */
printf(" Broadcasting to %d servers\n", nmemb);
nresp=cicast(group_addr,FILTER,"%X",Idd,input->dimensions.Detections,
             ALL,"%d",&test);

printf("Isis error number = %d \n",isis_errno);
printf("test = %d \n",test);
printf("NUMBER RESPONDING nresp = %d \n",nresp);

for (i = 0; i < input->dimensions.Detections; i++)
{
    free(Idd[i].OriginName);
    free(Idd[i].TargetDescription);
    free(Idd[i].TargetType);
    free(Idd[i].ThreatValue);
}
free((char*) Idd);
pg_leave(group_addr);
printf("Leaving Isis\n");

/* Notify the StatusDisplay Manager */
DisplayFinishedOp();
}

/* This function is called by isis_define_type inorder to pass an array of structures of type inv_element In a message */

idd_conv(Idd)
    struct ISISDetectionData *Idd;
    {
        msg_convertlong(&Idd->snr);
        msg_convertlong(&Idd->TargetNum);
        msg_convertlong(&Idd->Latitude);
        msg_convertlong(&Idd->Longitude);
        msg_convertlong(&Idd->Altitude);
    }
Appendix B.2 (Isis Filter Detections Routine)

IsisFilterDetections(msg_ptr)
message *msg_ptr;
{
    int    j, i, top, MapNum, ndx, new, nlist, MapFlag, ThisList,
    Updated;
    int   NumReal = 0, NumSemi = 0, NumFake = 0;
    int   *flag;
    UID   thisuid, *simuid, null_uid;
    BOOL  FOUND;
    LOC3D  pos; /* Lat, Long, Alt */
    char  *desc, *dtype, *threat;
    DETECTIONdata **list;
    octet  dd_canvalue;
    long   dd_canlen;
    SENSORdata **SensorStatsTemp;
    int    count;
    IDDTYPE *Idd;

    printf("*** Entered the Isis filter routine. ***\n");

    msg_get(msg_ptr, "%x", &Idd, &count);
    reply(msg_ptr, "%d", 5);

    list = (DETECTIONdata **) malloc(sizeof(DETECTIONdata *) * count);
    for (i = 0; i < count; i++)
    {
        list[i] = (DETECTIONdata *) malloc(sizeof(DETECTIONdata));
        STRINGtoUID(Idd[i].OriginUID, &list[i]->OriginUID);
        list[i]->OriginName = (char *) malloc(strlen(Idd[i].OriginName) +
        1);
        strcpy(list[i]->OriginName, Idd[i].OriginName);
        STRINGtoINTERVAL(Idd[i].Time, &list[i]->Time);
        list[i]->snr = Idd[i].snr;
        list[i]->Target = (TARGETdata *) malloc(sizeof(TARGETdata));
        STRINGtoUID(Idd[i].TargetUID, &list[i]->Target->TargetUID);
        list[i]->Target->TargetDescription = (char *)
        malloc(strlen(Idd[i].TargetDescription) + 1);
        strcpy(list[i]->Target
        ->TargetDescription, Idd[i].TargetDescription);
        list[i]->Target->TargetType = (char *)
        malloc(strlen(Idd[i].TargetType) + 1);
        strcpy(list[i]->Target->TargetType, Idd[i].TargetType);
        list[i]->Target->TargetNum = Idd[i].TargetNum;
        list[i]->Target->ThreatValue = (char *)
        malloc(strlen(Idd[i].ThreatValue) + 1);
        strcpy(list[i]->Target->ThreatValue, Idd[i].ThreatValue);
        list[i]->Target->TargetLocation.Latitude = Idd[i].Latitude;
        list[i]->Target->TargetLocation.Longitude = Idd[i].Longitude;
        list[i]->Target->TargetLocation.Alitude = Idd[i].Altitude;
    }

    msg_delete(msg_ptr);

    nlist = count;
    Report.TotalDetections += nlist;
    Report.OpsProcessed++;

    18
GetNullUID(&null_uid);

i = jobj Declare();

/* Check if detections are Real/Semi/Fake */
for (ndx = 0; ndx < nlist; ndx++)
{
    /* copy vital information used as the key parameters when calling
       the SimulationData manager. */
    CopyUID( & (list[ndx]->Target->TargetUID), &thisuid );
    CopyLOC3D( & (list[ndx]->Target->TargetLocation), &pos );
    threat = malloc( strlen(list[ndx]->Target->ThreatValue)+1 );
    strcpy( threat, list[ndx]->Target->ThreatValue );
    desc = malloc( strlen(list[ndx]->Target->TargetDescription)+1 );
    strcpy( desc, list[ndx]->Target->TargetDescription );
    dtype = malloc( strlen(list[ndx]->Target->TargetType)+1 );
    strcpy( dtype, list[ndx]->Target->TargetType );
    i = CanTypeToLen( DETECTIONDATA, list[ndx] );
    if( i == -1 )
        PSST(PS_LOG, PS_LOG_ALWAYS,
        "CanTypeToLen Error:\n\t\s\n",
        ErrorMessage());
    printf("Return value of CanTypeToLen call: \%\n", i);
    printf("threat = \%s, decs = \%s, dtype = \%s \n", threat, desc, dtype);

    /* check if real detection */
    if ( NOT IsNullUID( &thisuid ) )
    {
        printf( "PROCESSING Detection[\%d]\n", ndx );
        NumReal++;

        /* change coords to minutes */
        pos.Latitude = ((pos.Latitude / 10) / 60);
        pos.Longitude = ((pos.Longitude /10) / 60);

        printf( " Detection is REAL @ \
(\%ld,\%ld,\%ld)\n", pos.Latitude, pos.Longitude, pos.Elevation );

        /* check to see if detection has been seen before. if so,
           update it. if not, create/store new detection with
           simdata manager. */
        simuid = CheckStorageList( thisuid );
        if (simuid == NULL)
        {
            printf( " Detection is being STORED\n" );

            /* Send detection to simdata manager */
            simuid = &null uid;
            FOUND = StoreSimObject( simuid, &pos, AirForce,
            TargetData, threat, dtype,
            DETECTIONDATA, i, list[ndx] );

            /* if operation successfully completes, add the
               simdata object UID to the storage list and report
               to other targfil managers. */
            if (FOUND == OK)
            {
                printf( " STORING Detection\n" );
                AddToStore( thisuid, *simuid );
            }
        }
    }
printf( "Notifying other TargetFilters of Detection\n" );
IdentifyTarget( thisuid,*simuid );
}
else /* log reason why operation failed */
{
printf( "Unable to complete operation: SimulationData Manager\n" );
printf( "%s\n", ErrorMessage() );
}
else /* this detection needs updating */
{
printf( "UPDATING Detection\n" );
UpdateSimObject(
    simuid,&pos,NULL,NULL,NULL,NULL,
    DETECTIONDATA,i,list[ndx] );
}
else /* process the fake detection */
{
    NumFake++;
}
} /* iterate to next detection */
printf( "Finished DetectionSet: %d Detections\n\n",nlist );
Report.RealDetections += NumReal;
Report.SemiRealDetections += NumSemi;
Report.FakeDetections += NumFake;

printf("*** Exitd the Isis filter routine. ***\n");

return( OK );
}

/* init */
void
pg_init()
{
printf("in pg_init\n");
}

/* This function is called by isis_define_type inorder to pass an array of structures of type inv_element in a message */
idd_convert(Idd)
    Struct ISISDetectionData *Idd;
{
    msg_convertlong(&Idd->snr);
    msg_convertlong(&Idd->TargetNum);
    msg_convertlong(&Idd->Latitude);
    msg_convertlong(&Idd->Longitude);
    msg_convertlong(&Idd->Altitude);
}
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