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STATUS REPORT ON THE INTEGRATED EAGLE/BDS-D PROJECT

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ABSTRACT

This paper reports the status of the Integrated Eagle/BDS-D project which is investigating the interoperation of constructive combat models and virtual battlefield simulations within a distributed interactive simulation framework. The network architecture, network protocol, system architecture, and computer software are described. The processes of disaggregation, aggregation, and pseudo-disaggregation are described. Finally, an overview of the demonstration of this system at the AirNet training facility in Ft. Rucker Alabama is provided.

1 INTRODUCTION

"Constructive" battlefield simulations (models) typically control groups of entities (e.g. the tanks in a tank company) as aggregates rather than as sets of individual simulated entities. The position, movement, status, and composition of aggregate units are maintained for the unit as a whole and are the result of statistical analysis of the units' actions rather than the result of the actions of individual entities.

In contrast, "virtual" simulations typically represent each tank or vehicle as a distinct simulation entity and allow "Man in the Loop" interaction. The SIMNET networked training system is a prototypic distributed, virtual simulation operating in real-time. Manned simulators each represent a single vehicle. The human crews in their simulators interact in a common, simulated (virtual) battlefield through the exchange of information packets on the network that connects the simulators. Additional, unmanned entities in the virtual environment are generated and controlled by Computer Generated Force (or Semi-Automated Force) computer systems.

Interoperating constructive and virtual simulations provides benefits to two simulation communities. The analytic community can obtain detailed entity level information from virtual simulations and use that information to ground constructive models on vehicle level performance. The training community benefits by being able to conduct small unit virtual exercises within the context of a larger (brigade/ division/corps), dynamic battle. Constructive models are also used in training higher level commanders and their staffs. This training can also be enriched through the interoperation of constructive and virtual simulations by supplementing aggregate statistical interaction with entity interactions.

The interoperation of time-stepped, aggregate (constructive) simulations with real-time, entity level (virtual) simulations poses several technical challenges. Among those are space and time correlation, communication of information between simulations, and interaction between entities and aggregates. The Integrated Eagle/BDS-D project's goal has been to demonstrate the feasibility of the interoperability of constructive and virtual simulations through the integration of a constructive model (Eagle) and SIMNET.

A network architecture, network protocol, system architecture, and computer software have been developed to support constructive/virtual interoperation.

This work has been reported previously in (Karr, 1994b); duplicate text and background material are repeated here for clarity and completeness.

2 BACKGROUND

Computer based battlefield simulations and models can be divided into two broad classes, "aggregate" and "entity level", based on the granularity of the entities modeled. "Aggregate" simulations control units (e.g. the tanks in a tank company) as an aggregate rather than simulating each individual entity within the unit. The position, movement, status, and composition of aggregate units are maintained for the unit as a whole and are the result of statistical analysis of the units' actions rather than the result of the actions of the individual entities. In contrast, "entity level" simulations represent each vehicle as a distinct simulation entity. The position, movement, status, and composition of units in entity level simulations is inferred from the individual entities. Computer-supported wargames and distributed interactive simulations are typically aggregate and entity level simulations respectively (Mastaglio, 1991).

Simulations and models can also be classified on the basis of their time scales. Real-time simulations operate with events occurring at the same rate as the corresponding real-world events. Non-real-time simulations operate faster or slower than real-time.

Throughout this paper, "constructive" will apply to non-real-time, aggregate simulations and "virtual" to real-time, entity level simulations.

The differences in entity granularity and time scales among simulations create difficulties in simulation interoperability. For example, in the battlefield environment, it is difficult for entities in virtual simulations to detect and react to aggregate units. Similarly, units in constructive simulations typically do not detect and attack individual entities. The problems associated with differing time scales are obvious; simulations need to be operating at the same time scale for their interactions to make sense.

This paper discusses the Integrated Eagle/BDS-D project which began as a proof of concept demonstration of the interoperability of a constructive simulation (the Eagle combat model) and a virtual simulation (the Institute for Simulation and Training's Computer Generated Forces (CGF) Testbed operating in SIMNET). The project has been extended to study additional issues in interoperating constructive and virtual simulations. Three organizations are involved in this project: U.S. Army TRADOC Analysis Center (TRAC), Institute for Simulation and Training (IST), and Los Alamos National Labs (LANL). TRAC is responsible for the Eagle simulation, IST is responsible for the IST CGF Testbed, and LANL is developing the Simulation Integration Unit (SIU). Earlier work on this project has been reported in (Karr 1992a, 1993, 1994b, and 1994c).

2.1 Overview of Eagle

The Eagle system is a corps/division level constructive combat model that simulates ground combat at the company and battalion level. That is, the smallest units (maneuver units) in Eagle are the company and battalion. Eagle is a combat analysis tool used for combat development studies. It is used in analyzing the effects of weapons systems, command and control, military doctrine, and organization on force effectiveness. Eagle is implemented in LISP on Symbolics and Sun workstations and runs faster than real-time. It is described in (TRAC1-7, 1993).

2.2 Overview of SIMNET(BDS-D)/DIS

The U.S. Army/DARPA SIMNET(BDS-D) is a well-known distributed, interactive, virtual simulation system used to train tank and vehicle crews in cooperative team tactics. In SIMNET, individual vehicle simulators are connected via a computer network, permitting them to coexist in a common, shared simulation environment and to interact (e.g. engage in combat) through the exchange of information packets on the network. SIMNET simulators usually each represent a single tank or vehicle. The documentation of SIMNET is extensive; (Thorpe,1987) and (Pope,1991) are good examples.

The Distributed Interactive Simulation (DIS) protocol is intended to replace the SIMNET protocol. The development of the DIS protocol is a cooperative effort involving the Department of Defense, industry, and academia and is being done through a series of workshops coordinated by the IST. The latest version of the DIS protocol is documented in (IST-CR-93-15, 1993).

In a virtual exercise, the opponent for the trainees can be provided in different ways. One technique is to provide a computer based simulation that generates and controls one or more simulation entities (e.g. tanks and infantry). Such a computer generated opposing force is usually referred to as a Computer Generated Force (CGF) or Semi-Automated Force (SAFOR).

2.3 Overview of IST CGF Testbed

IST has been conducting research in the area of CGF systems and has developed a SIMNET and DIS compatible CGF Testbed that connects to a SIMNET or DIS network and provides a mechanism for testing CGF control algorithms. The IST CGF Testbed is described in (Smith, 1992) and (Karr, 1992b). A single Testbed system consists of a pair of IBM PC-compatible computers: the Operator Interface (OI) is the human operator console and the Simulator controls the behaviors of the simulated entities requested by the human operator. OIs and Simulators communicate with one another using non-SIMNET/DIS protocol data units (PDUs) and with the other simulators using SIMNET/DIS PDUs.

3 INTEROPERATION OF SIMULATIONS

Test scenarios have been devised (see figure 1) to demonstrate the interoperability of Eagle and IST CGF systems. Typically, an Eagle exercise consists of two brigade size forces with company and battalion maneuver units. Initially, no entities are controlled by the IST CGF system. The Eagle exercise occurs in a large area (100s km by 100s km) called the "Eagle area/world". The IST CGF system operates with a representation of an area of terrain called the "virtual area/world". The virtual area is within the Eagle area.

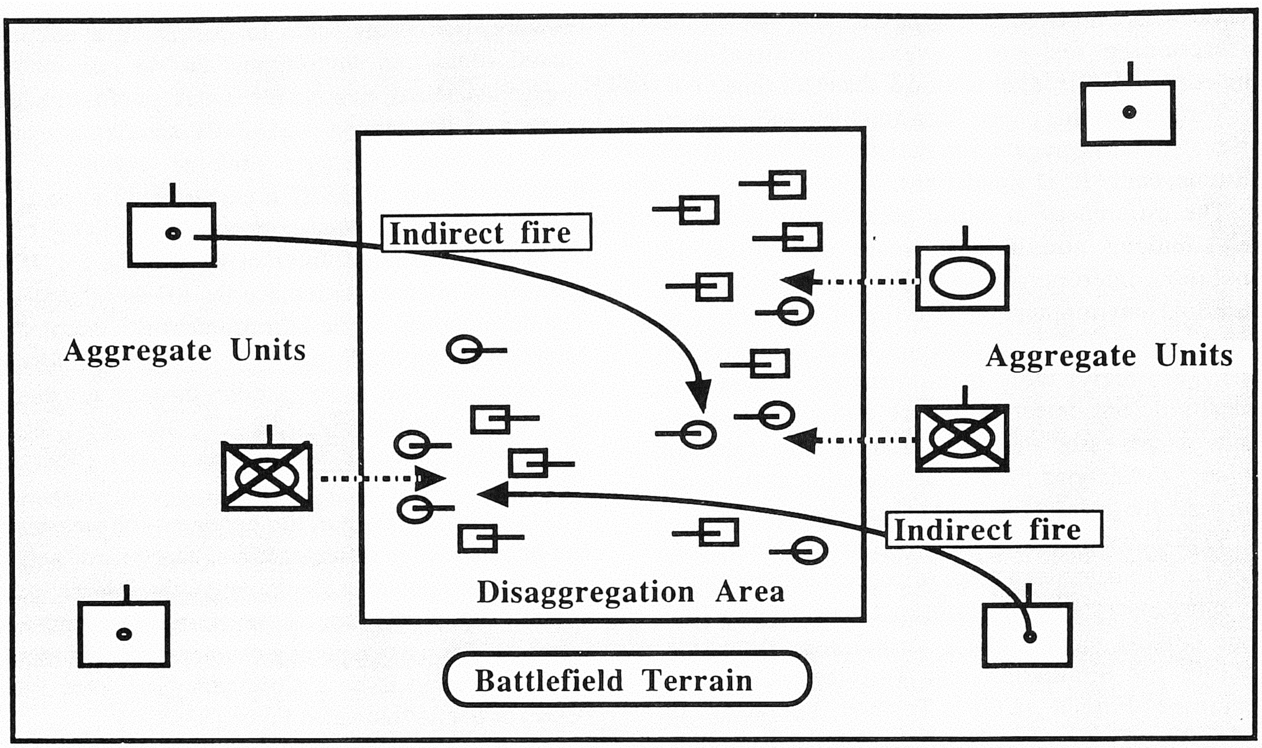


Figure 1. **Typical Scenario**

The Eagle model preregisters both the virtual area and one or more "disaggregation areas" within the virtual area.

When an Eagle unit enters a disaggregation area, the unit is "disaggregated" into its component entities. The component entities are instantiated as manned simulators and as virtual entities under control of IST CGF systems and the Eagle unit becomes a "shadow" or "ghost" unit (maintained but not controlled by Eagle). Combat occurs in the virtual world between virtual entities and in the aggregate world between aggregate units with indirect fire from either world crossing the constructive/virtual interface into the other world. When a disaggregated unit moves outside its disaggregation area, the unit is "reaggregated"; i.e. the virtual entities are removed and Eagle assumes complete control of the unit.

3.1 Responsibilities

During the course of the scenario, the components of the system have distinct responsibilities. The Eagle model simulates the constructive world, determines when units are to be disaggregated and reaggregated, sends/receives information to/ from the virtual world, and, while any unit is disaggregated, shifts to real-time execution.

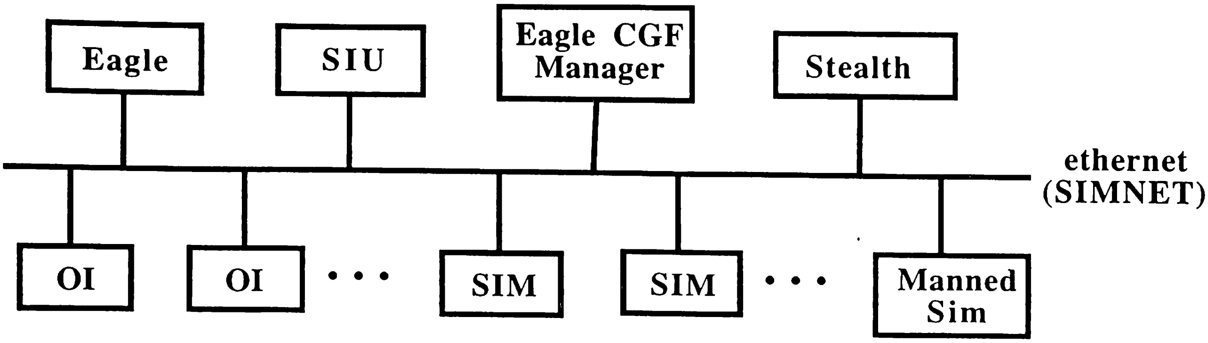
The IST CGF systems are responsible for responding to disaggregation/reaggregation requests, for simulating individual entities within the virtual world, and for sending/ receiving information to/from the constructive world.

The CGF operator is responsible for initiating, monitoring, and controlling simulated entities' behavior in the virtual world, for following the orders of the Eagle model, and for informing the Eagle model of his/her unit's progress in the battle.

The SIU coordinates the communication between Eagle and the CGF systems and maintains summaries of the disaggregated units' location and composition.

3.2 Network Configuration

Figure 2 shows the network configuration. The Eagle model, SIU, Eagle CGF Manager, CGF Operator Interfaces (OIs), CGF Simulators, Stealth, and Manned Simulators are all nodes on the network. All communication between Eagle and the CGF systems is mediated by the SIU. Eagle and the SIU communicate with via Remote Procedure Calls (RPCs). The SIU and the CGF nodes communicate with using an interoperability protocol (described below). Because the SIU translates, stores and forwards information between Eagle and the virtual world, this paper will discuss primarily the SIU and CGF protocol with the understanding that the information is then relayed



Eagle	- TRAC Eagle Simulation
SIU	- Simulation Integration Unit
Eagle CGF Manager	- IST CGF Testbed Manager
Stealth	- Stealth display device
OI	- IST CGF Testbed Operator Interface
SIM	- IST CGF Testbed Simulator
Manned Sim	- Manned Simulator

Figure 2. Network Configuration

between the SIU and Eagle via RPCs.

The SIU, OIs, and Simulators also receive virtual world PDUs from all nodes on the network. The OIs and Simulators process virtual world PDUs as a normal part of their operation. The SIU obtains and consolidates information about virtual entities from virtual world PDUs.

3.3 Interoperability Protocol

The SIU and the IST CGF Testbed communicate via ethernet using a set of PDUs called the Interoperability Protocol (IOP). SIMNET and IOP PDUs are distinguished by the arbitrarily chosen value in the type field in the association protocol layer of the SIMNET protocol. The IOP is described in detail in (Karr, 1994a). The IOP is being implemented within the DIS protocol's Set Data PDU.

The currently active IOP PDUs are:

- Status Request
- Unit Detail
- Change Unit Status
- Disaggregation Response
- Operation Order
- Frag. Order
- Operator Intent
- Call for Fire Request
- Eagle Indirect Fire
- Indirect Fire Volley.

3.3.1 Status Requests

The SIU and IST CGF Testbed use Status Request PDUs at system start up to identify one another's network addresses so that subsequent PDUs are sent point-to-point rather than broadcast.

3.3.2 Unit Detail

The Eagle model sends descriptions of aggregate units to the SIU which are forwarded to the virtual world in Unit Detail PDUs (UDPDU). Within each UDPDU is a field for the unit status (disaggregated, aggregate(pseudo-diaggregated), aggregate(icon), or invisible). Each UDPDU is directed to the Unit Appearance Manager (see below) which manages how the unit appears in the virtual environment. For example, when an aggregate unit's status changes to "disaggregated", the disaggregation process is initiated.

Two mechanisms have been developed to allow aggregate units to appear in the virtual environment. The Testbed stores the information in each UDPDU and produces SIMNET Vehicle Appearance PDUs (VAPDUs) at regular intervals for the aggregate units. Two "types" of VAPDUs are produced depending on the level of detail needed. The lowest level of detail, "icon unit appearance", produces one VAPDU for each unit. This VAPDU describes the unit as a SIMNET echelon and allows nodes on the net to display an icon for the aggregate unit. This approach minimizes network traffic but allows nodes in the virtual world to know about the aggregate units being simulated by Eagle. (Entity State and Aggregate Descriptor PDUs are used in DIS.)

A more detailed level of unit appearance is available to display the individual vehicles of aggregate units in the virtual world. In this approach, called "pseudo-disaggregation" (Root, 1993), VAPDUs for each of the vehicles within the unit are produced at regular intervals (every 5-10 seconds). The locations of these "pseudo-vehicles" are based on formations which are determined by the operational activity of the unit. Nodes on the network see a formation of vehicles moving across the terrain. Because these pseudo-vehicles are not being simulated as entities within the virtual world, they can not fire weapons, sight other entities, or receive fire. Pseudo-disaggregation provides a mechanism for putting "many" entities in the virtual world to create a realistic picture for sensor systems.

3.3.3 Change Unit Status

Whenever the status of a unit changes a Change Unit Status message is sent to the SIU. This message acts as a "warning" to the SIU that Disaggregation Responses (see below) will soon be arriving. This is a new message (not described in earlier reports) and was unnecessary when only the Eagle model initiated disaggregation/aggregation. CGF operator initiated disaggregation/aggregation were added for the Airnet Installation (see below). The operator at a CGF OI can now initiate disaggregation/aggregation by "clicking" on units/vehicles visible on the plan view display. This message informs the SIU (which informs the Eagle model) that a unit has changed its state.

3.3.4 Disaggregation Responses

A Disaggregation Response communicates to the SIU the virtual world vehicle identifiers for all the entities created by the disaggregation process. The SIU uses the vehicle identifiers to track the entities within a unit to maintain an accurate picture of the unit's location and composition (e.g. destroyed vehicles reduce a unit's composition). The SIU also uses the vehicle identifiers to track the sightings between vehicles of opposing forces; these vehicle sightings are used by Eagle to determine, at the aggregate level, when disaggregated units have "seen" one another.

3.3.5 Operation and Frag Orders

Operation orders generated by Eagle to control the behavior of Eagle units are sent (as text strings) along with Disaggregation Requests. An order is routed to the OI(s) controlling the entities in the unit for the operator to review and act upon. Frag order PDUs carry updates to previously issued operation orders.

3.3.6 Operator Intent

An operator communicates changes in his/her intent (e.g. Changing Phase or Task) to Eagle by sending Operator Intent PDUs to Eagle. Eagle updates its internal plans based on the intent messages.

3.3.7 Call for Fire and Eagle Indirect Fire

Call for Fire Request PDUs carry operator generated requests for indirect fire to Eagle. Included in the Call for Fire Request are the fields which specify the desired effect of the fire, the target type and echelon, and the type of cover and vegetation at the target.

The Eagle Indirect Fire PDU describes a single volley of indirect fire generated by an Eagle unit. The Testbed converts each Eagle Indirect Fire PDU into virtual Indirect Fire PDUs which cause visible detonations in the virtual world and damage to vehicles and infantry fireteams in their vicinity.

3.3.8 Indirect Fire Volley

Disaggregated artillery batteries may fire at aggregate units (unit icons or pseudo-vehicles). These indirect fires occur within the virtual world via the virtual world protocol and are communicated to the SIU via the IOP Indirect Fire Volley PDU. This PDU details the munition and locations of the detonations in a platoon-sized volley. Each timestep, the Eagle model incorporates the previous timestep's indirect fires into its damage assessment.

3.4 Testbed Communication Structure

Several constraints guided the design of the Testbed interface to the SIU:

1. Several OIs and Simulators might be needed to control the entities in a unit.
2. The disaggregation process should dynamically allocate OIs and Simulators in based on unit size.
3. Because the Testbed is undergoing constant modification, the interface must remain stable when viewed from the SIU.
4. The command and communication structure within the Testbed should follow the military tructure.

There are three types of entities within the Testbed: actors, static managers, and dynamic managers. Actors are simulated vehicles or infantry. Static managers are the always present internal objects within the Testbed that implement the simulation functionality. Dynamic managers are simulation management objects that are created as they are needed.

To satisfy the design constraints, a dynamic manager called the Eagle CGF Manager was created as the single point of contact between the SIU and all active Testbed nodes. This is accomplished by allowing only the Eagle CGF Manager to send and respond to a Status Request PDU. The Eagle CGF

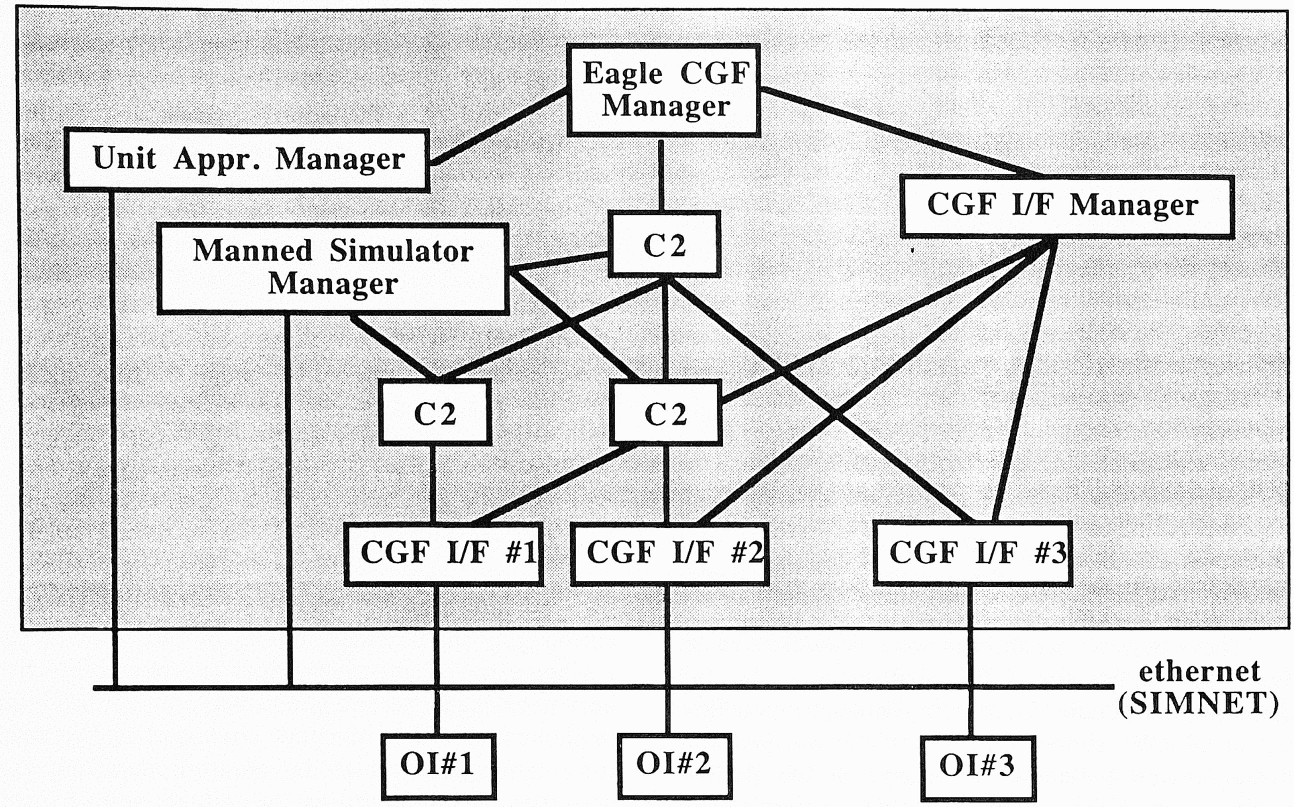


Figure 3. Testbed Communication Structure

Manager receives IOP PDUs from the SIU and passes each to the correct Testbed node and entity within that node. Similarly, all messages from Testbed entities to the SIU are transmitted through the Eagle CGF Manager.

When the Eagle CGF Manager receives a disaggregation request from the Unit Appearance Manager, it creates a "Command and Control" (C2) entity for that unit and forwards the disaggregation request to it. The C2 entities are dynamic managers and correspond to unit HQs or commanders. When a C2 entity receives a disaggregation request, it instantiates the vehicles at its level (e.g. command vehicles), creates C2 entities for its subunits, and sends subunit disaggregation requests to each of its subunit C2 entities.

The process of disaggregation descends through the command structure to the lowest subunit level which instantiates its vehicles and terminates the disaggregation process. This process is supported by "composition" and "formation" files which detail the composition of each unit in terms of subunits and vehicles and the locations of the subunits and vehicles relative to the higher unit's location.

Supporting the Eagle CGF Manager are four other types of dynamic managers: several CGF Interfaces, an CGF Interface Manager, a Unit Appearance Manager, and a Manned Simulator Manager. CGF Interfaces are dynamic managers through which the C2 entities communicate to the OIs controlling the individual vehicles. There is one CGF Interface for each available OI. The CGF Interface Manager is responsible for keeping track of the load on individual OIs and for allocating CGF Interfaces to C2 entities. Unit Detail PDUs are routed to the Unit Appearance Manager which initiates the disaggregation and aggregation processes and produces the PDUs to display aggregate units (and their vehicles) in the virtual world (Root, 1994). Finally, the Manned Simulator Manager keeps track of the available manned simulators, allocates them to C2 entities during disaggregation, and activates each manned simulator when it is allocated. See figure 3 for a diagrammatic representation of the communication pathways among the dynamic managers.

4 AIRNET INSTALLATION

To date, this project has been focused on solving constructive-to-virtual interface problems. Following a February, 1994 demonstration for DUSA Walt Hollis, the project shifted part of its efforts to preparing for fielded use in training and analysis. The first stage of this preparation is installation of the system at Fort Rucker's Airnet facility.

Both the Eagle model and the IST CGF Testbed were modified to include more realistic models for air units. In the IST CGF Testbed, these models include the capability for CGF helicopters to follow a manned rotary wing aircraft (RWA) simulator and fire when the manned RWA simulator fires.

In addition, manned RWA simulators have been connected to the Eagle/BDS-D structure so that disaggregations can instantiate manned RWA simulators as elements of a unit.

These new air capabilities were demonstrated on July 18, 1994 for GEN Robinson. In the demonstration, a trained U.S. Army helicopter crew flew a manned RWA simulator (this simulator was part of a disaggregated helicopter company) in the BDS-D environment. During their flight they encountered an Eagle controlled OPFOR unit. As the RWA simulator approached this unit, the state of this unit was changed to "pseudo-disaggregated". The crew reported sighting the pseudo-disaggregated tank company and then flew on to their final objective: another tank company.

As the RWA simulator approached their final objective, the Eagle unit was disaggregated. The crew then determined an engagement location for their Apache and for two CGF controlled Apaches and radioed that location to the CGF operator. When the CGF Apaches were in position, the manned RWA simulator opened fire on the tank company which caused the CGF Apaches to acquire and attack targets. Together, the manned RWA simulator and the CGF Apaches destroyed the tank company. While the Apaches returned to their base of operations, the destroyed OPFOR unit was aggregated behind them.

This demonstration provided a visualization of how the Eagle/BDS-D system could be used in air scenarios, both in analysis and training. We plan to continue work towards using Eagle/BDS-D in actual analysis and training scenarios.

5 PRELIMINARY RESULTS

Preliminary demonstrations of all components of this project have been successful.

During a typical scenario, Eagle aggregate units have moved into disaggregation areas and been disaggregated into a combination of virtual vehicles under control of IST Testbed systems and manned simulators (M1 tanks and Apache RWA). Combat occurs in the constructive and virtual worlds. During combat, constructive world indirect fire in response to Call for Fire Requests appears in the virtual world and damages virtual vehicles. Virtual world indirect fire is communicated to Eagle where damage is assessed. Operation Orders, Frag Orders, and Operator Intent messages are sent between Eagle and the human CGF operator. Constructive units appear in the virtual world as unit icons or "pseudo-vehicles". Finally, units are reaggregated in response to reaggregation requests.

6 CONCLUSIONS

The preliminary results of this project are encouraging and provide solutions in four areas. First, a scheme for constructive/virtual interoperability has been developed. Second, a network protocol has been implemented which transfers command and control information as well as information detailing the activities of the entities on either side of the constructive/ virtual boundary. Third, issues of temporal and spatial correlation have been addressed and limited solutions provided. Fourth, mechanisms for interaction (specifically combat) across the constructive/virtual boundary have been implemented.

This project demonstrates the feasibility of integrating the operation of constructive and virtual simulations.

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AUTHOR'S BIOGRAPHIES

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