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INSTITUTE FOR SIMULATION AND TRAINING

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January 15-17, 1990

Summary Report

The Second Conference on Standards for the Interoperability of Defense Simulations

Volume II: Attendees List and Viewgraphs

Editors:
Karen Danisas
Bob Glasgow
Brian Goldiez
Bruce McDonald
Chris Pinon

This report is informational and does not express the opinions of PM TRADE or DARPA

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This report presents a summary of the activities of the Second Conference of Standards for the Interoperability of Defense Simulations sponsored by the Defense Advanced Research Projects Agency (DARPA) and the program Manager for Training Devices (PM TRADE). The workshop was hosted by the Institute for Simulation and Training/University of Central Florida (IST/UCF) on 15-17 January, 1990.

This volume of the report contains an attendees list, a copy of the view graphs used during presentations and a copy of all documents that were submitted at the conference for the attendee information.

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CONTENTS

SUMMARY REPORT

The Second Conference on Standards
for the Interoperability of Defense Simulations

January 15-17, 1990 Orlando, FL

INTRODUCTION

This report presents a summary of the activities of the Second Conference on Standards for the Interoperability of Defense Simulations sponsored by the Defense Advanced Research Projects Agency (DARPA) and the Program Manager for Training Devices (PM TRADE). The workshop was hosted by the Institute for Simulation and Training / University of Central Florida (IST/UCF) on 15-17 January 1990, in Kissimmee, Florida.

This is the second workshop concerning the development of technical standards for networking defense simulations. These standards are intended to meet the needs of large scale simulated engagements systems which are being used increasingly to support system acquisition, test and evaluation, tactical warfare simulation and training in DoD. The primary goals of this workshop were to provide a forum and discuss issues prior to the development of a Protocol Data Unit level standard, to capture networking requirements and needs, and to exchange ideas and keep interested parties informed on networking technology issues.

The three day workshop focused on two major topic areas: Communication Protocols and Terrain Databases. The Communication Protocols was headed up by Dr. Ron Hofer, Chief, Engineering, PM TRADE. This group was mainly concerned with what goes over the wire. The following subgroups dealt with those issues:

* Interface
* Time/Mission Critical
* Security
* Long Haul/Wide Band
* Non visual

The Terrain Databases Working Group was headed up by George Lukes, Director of the Center for Autonomous Technologies, U. S. Army Engineer Topographic Laboratory. This group was mainly concerned with how the terrain data is interpreted. The following subgroups dealt with those issues:

* Correlation
* Dynamic Terrain
* Unmanned Forces
* Interim Terrain Database

In response to comments made at this workshop, a new subgroup is being formed to address Human Performance Measures. This subgroup will address requirements for recording and assessing student performance in the simulators on the network. As part of this effort, issues concerning instructor interfaces for controlling exercises and evaluating student performance will be addressed. User inputs about needed capability for networked simulators will be solicited. Mr. Bruce McDonald, Institute for Simulation and Training, will chair this subgroup, and any comments and suggestions should be directed to him.

This report has been separated into three volumes. Volume I contains summaries of all presenters' speeches. Volume II contains an attendees list, a copy of the view graphs used during presentations, and a copy of all documents that were submitted at the conference for the attendee information. Volume III contains a copy of all position papers received by IST/UCF by 15 February, 1990.

APPENDIX A

Attendees List

NATIONAL SECURITY INDUSTRIAL ASSOCIATION
EVENTS REGISTRATION ROSTER
January 15-17, 1990

Attendee Name	Company Name
Craig S. Anken	Rome Air Development Center
Dr. Richard Astro	UCF
Norman C. Baillargeon	American Systems Corp
Gary E. Baker	Naval Space & Warfare Sys. Cmd.
Wolfgang Beisenherz	Ministry of Defense
Charles J. Benton	Technology Systems, Inc.
Barbara J. Birks	McDonnel Aircraft
Dr. Barry Boehm	DARPA
Larry R. Bouterie	Digital Equipment Corp
Arnold Bramson	General Electric Co.
J. Joseph Brann	IBM Corp., SID
Klaus Brueckner	Schleifring
Perry L. Buchanan	Digital Equipment Corp.
Jerry D. Burchfiel	BBN Systems & Technologies
J. Cadiz	University of Central Florida
Douglas R. Caldwell	U.S. Army - ETL
John Callaway	R & D Associaties
J. Phil Carley	Concurrent Computer Corp
James R. Cooley	AAI Corporation
Lloyd N. Cosby	Insitutute for Defense Analyses
Allan Cox	British Embassy
Dick Cranston	American Systems Corp.
Claude H. Crassous	THOMSON CSF Simulators Div.
Steven E. Cunningham	Technology Systems, Inc.
Dean Curtiss	Bendix Test Systems Division
Karen Danisas	University of Central Florida
Philip E. Danley	Grumman Aerospace Corp.
Dr. James W. Dilie	McDonnell Douglas Corp.
Drake Dingeman	Systran Corp.
Edmund J. Doughty	Harris Corp.

Colin Dutton	Army School Training Support
James Evans	USAF
Grayden Figart	SYSCON Corp
Dexter Fletcher	Institute for Defense Analysis
Mark A. Flood	U.S. Army Corps. of Engineers
Robert E. Fraser, III	Perceptronics
Mark D. Frost	Booz, Allen & Hamilton Inc.
Richard P. Gagan	Raytheon Co.
David N. Garnett	ETA Technologies
G. George	CAE - Link Flight
B. Glaskow	University of Central Florida
Brian F. Goldiez	University of Central Florida
Patrice Gosselin	CAE Electonics LTD
Kurt Graffunder	Hughes Simulation Systems
Bruce E. Green	Nat'l Sec Industrial Assoc.
Michael R. Gregary	Tracor Flight Sip. Inc.
Bernard E. Griffiths	Air Force
Raymond A. Haeme	Booz, Allen & Hamilton Inc.
Joseph P. Haller, Jr.	Grumman Corp
Christine Hanson	ASD/YWB
William T. Harris	Naval Training Systems Center
Michael Hayes	Perceptronics, Inc.
Dr. Ronald C. Hofer	Naval Training Systems Center
Eric Hoierman	Hughes Simulation Systems, Inc.
Sam R. Hellingsworth	Hughes Simulation Systems, Inc.
Udo Hollaender	Wegmann Co.
Michael D. Johnson	Digital Equipment Corp.
Randy L. Johnson	Naval Surface Warfare Center
Michael S. Kamrowski	Air Force Human Resources Lab.
Larry P. Keller	ARINC Research Corporation
Dr. Ron Kerber	McDonnell Douglas Corp.
R. Klasky	University of Central Florida
LTCOL Robert L. Kloecker	Army Joint Warfare Center
Samuel N. Knight	CAE-Link Corporation
Lee Kollmorgen	SIMNET
Ronald W. Krisak	ODASD/RA(R&T)

Jerrold E. Kronenfeld	Analytic Sciences Corp.
Georges Lavault	THOMSON CSF
Curtis G. Lawson	GTE Gov't Systems
Heinz-Bernd Lotz	BUNDESAMT FUR WEHRTECHNIK
George E. Lukes	U.S. Army Engr. Topographic Lab
Warren R. MacDiarmid	Science Applications, Inc.
Daryl R. Mair	Digital Equipment Corp.
Farid Mamaghan	BBN Systems & Tech. Corp. ASD
George L. May, III	Defense Mapping Agency
David R. McKeeby	Analysis & Technology, Inc.
Larry L. Mengel	USAARMC
Duncan C. Miller	BBN Systems & Technologies
John Miller	Sanders/Lockhead Co.
Richard Moon	Evans & Sutherland Computer Co.
H. Richard Moore	E-Systems Garland Div.
Phil Morris	BBN Systems & Tec. Corp. ASD
Franklin I. Moses	US Army Research Institute
Dr. J. Michael Moshell	University of Central Florida
Kevin B. Muhm	USAETL - GL-TA
Eugene P. Naccarato	Planning Research Corporation
Thomas M. Nelson	McDonnell Douglas Electr. Co.
Phil Ness	Boeing Co.
Raye Norvelle	U.S. Army Engr. Topographic Lab
James F. O'Bryon	ODISDA(A)
Alan B. Oatman	BBN
LTC Stephen S. Overstreet	USA Proj Mgr for Trng Devices
Juan A. Perez	U.S. Army - ETL
Daina Pettit	Evans & Sutherland Computer Co.
Pascal Peyronnet	THOMSON CSF - Simulators Div.
C. Pinon	University of Central Florida
Arthur Pope	BBN Systems & Tech. Corp.
Leland B. Ransom, III	Integration & Human Resources
Dennis W. Rebertus	CTA Incorporated
A. Hugh Rodgers	McDonnell Douglas Corp.
Lee Rogers	OSD
Alfredo A. Romagosa	Harris Computer Sys. Div.

Hugh C. Romine	CAE - Link Corporation
Robin M. Rouleau	AAI Corporation
William J. Rowan	Naval Training Systems Center
Paul E. Rubin	Computer Sciences Corp.
L. Michael Sabo	SSDS, Inc.
Arun Sankar	Hughes Aircraft Co.
Steven R. Sarner	ASD/YWB
Richard L. Schaffer	BBN Systems & Tech. Corp.
William H. Schelker	ASK/DPCTT
Marc Schlackman	GTE Gov't Systems
Bill W. Scott	E-Systems, Inc.
Steve S. Seidensticker	Logicon,Inc. Tac./Trgn.Sys.
Steven L. Shaffer	SSDS, Inc.
LTC James E. Shiflett (USA)	DARPA/ISTO
Jerome Shimp	Honeywell, Inc
Calvin S. Shoemaker	Flashpoint Computer Corp.
Stephen Smyth	BBN Advanced Simulation
Karl A. Spuhl	McDonnell Douglas Corp.
Steven D. Swaine	McDonnell Douglas Aircraft
Larry Stevens	AAI Corporation
Robert Stevens	ETA Technologies
J. Thompson	Univeristy of Central Florifa
Robert N. Thompson	ARINC Research Corporation
Kevin W. Tinsley	E-Systems, Inc.
Tom Underdown	Digital Equipment Corp.
Lawrence J. Van Sickle	McDonnell Douglas Corp
Rolland M. Waters	BBN Systems & Tech. Corp.
James W. Watson	Sparta, Inc.
Barry W. Webb	Lockheed Aeronautical Systems
Lawrence A. Welsch	NIST
G. Pete Wever	BBN Systems & Tech. Corp. ASD
Ronald L. Williams	ConCurrent Computer Corp.
Ronald Wimberley	Martin Marietta Simul. Sys.
LTC Albert Wimmeim	PM Trade
David C. Wood	The Mitre Corp.
Christopher E. Wright	GE/Simulation & Control Sys. Dept

Dr. Michael J. Zyda	Naval Postgraduate School
Colin G. Agostinl	Tracor Inc.
Robert Alger	Ford Aerospace
Carl Arizpe	Digital Equipment Co.
Gary Arrasmith	Hughes Aircraft Co.
John Bearfoot	MOD UK Army - Army Trng 4
Steven Blumenthal	BBN Sys. & Tech Corp.
Frank Calzaretta	BBN Sys & Tech Corp
Timothy B. Cunningham	Concurrent Computer Corp.
Tony Dalsasso	U.S. Air Force
James Dike	Harris/GSSD
John Doner	Harris Corp.
Dan Eliason	BBN
Ron Ewart	U.S. Air Force
Andrew Fyke	Hughes Aircraft
Tom Gehl	IBN
Stewart R. Gibb	Naval Air Sys. Command
James H. Hammond	Naval Oceanographic & Atmospheric Research Lab.
Ronald Hendricks	CAE-Link
James Hines	PRC
Johann Hinrichs	Competence Center Information
Clifford Holland	NOARL
Douglas I. Holmes	Lockhead Aeronautical Sys. Co.
Wendy Hudson	Concurrent Computer Co.
John Hukill	Martin Marietta Corp.
All Kerecman	USACECOM
John P. Killackey	Hughes Simulation Sys., Inc.
David Lawson	McDonnell Douglas Helicopter Co.
Michael Lombardi	USADECOM
Bryan Lowe	McDonnell Douglas Electronic
Frederick Mangol	Information Spectrum Inc.
Francis X. Maginnis	The Mitre Corp.
Dennis McBride	ISTO DARPA
Bruce McDonald	IST

William Murphy	Digital Equipment Corp.
Nicholas Palmiotto	BDM International. Inc.
James Panagos	Bolt Beranek & Newman
Dave Pfahler	Hughes Aircraft Co.
Lawrence Redmond	GTE Gov't Sys. Comm. Sys.
Paula Ridolfi	USAF ASD/YWB
Ronald G. Rhoades	BDM Int'l. Inc.
Warren E. Richeson	McDonnel Douglas
Bruce Robinson	Rh & Co./Ford Aerospace
John Ross	SSC Ltd.
Mel Sar	Harris Corp.
Randy Saunders	Hughes Simulation Sys., Inc.
Ludger Schumann	Competence Center Information
Steven Schwalan	CAE - Link
John Shockley	SRI Intl'l
Roger Sirfit	Autometric, Inc.
Rosaland Spina	General Dynamics Land Sys.
Thomas Stanzione	BBN
Terry Snyder	Grumman Simulation/Trainer Products
Richard Soeldner	Naval Training Sys. Ctr.
Jeffrey Stewart	Software Engineering Institute
Barry Tahlor	Concurrent Computer Corp.
Donald Tedder	Simulatin Animation Svcs. of Fl. Inc.
David Teichman	ECC Int'l
Gary Teper	Information Spectrum, Inc.
Ron Toupal	Merit Technology
David Tseng	Hughes Research Labs.
Darrell Turner	Martin Marietta, Info & Comm. Sys.
Richard Weatherly	Mitre
John Wang	Naval Underwater Sys. Ctr.
Haward Wichansky	USA CECOM
Pat Widder	McDonnell Douglas Helicopter
Patrick Yearick	CAE - Link Flt. Simulation
John Zammit	Digital Equip. Corp.
Gerald Zubak	Hughes Aricraft Co.

Richard Bouchard	Lockhead/Sanders
Jean Pierre Faye	Thompson CSF
Umberto Fontanella	Agusta SPA Divisione Sistemi
James A. Kane	Bolt Beranek & Newman
C. Lavault	Thompson - CSE
Matt Narotam	Burtek
Raye Norvelle	U.S. Army Engr. Topographic Laboratories
Barbara Osbon	General Dynamics Land Sys.
Dennis Pierce	ECC Int'l Corp.
Gerd - D. Rehberg	Wegmann & Co. GMBH
Robert Richbourg	U.S. Military Academy
Glenn Weissinger	General Dynamics
Phillip Yoo	Digital Equipment Corp.

APPENDIX B

View Graphs of Main Speakers

STANDARD PROCESS TOPICS

- Purpose/Scope
- Activities since last meeting
- Activities for this meeting
- Future activities

GOAL

DEVELOP STANDARDS

FOR THE

INTEROPERABILITY

OF SIMULATIONS

PURPOSE OF MEETINGS

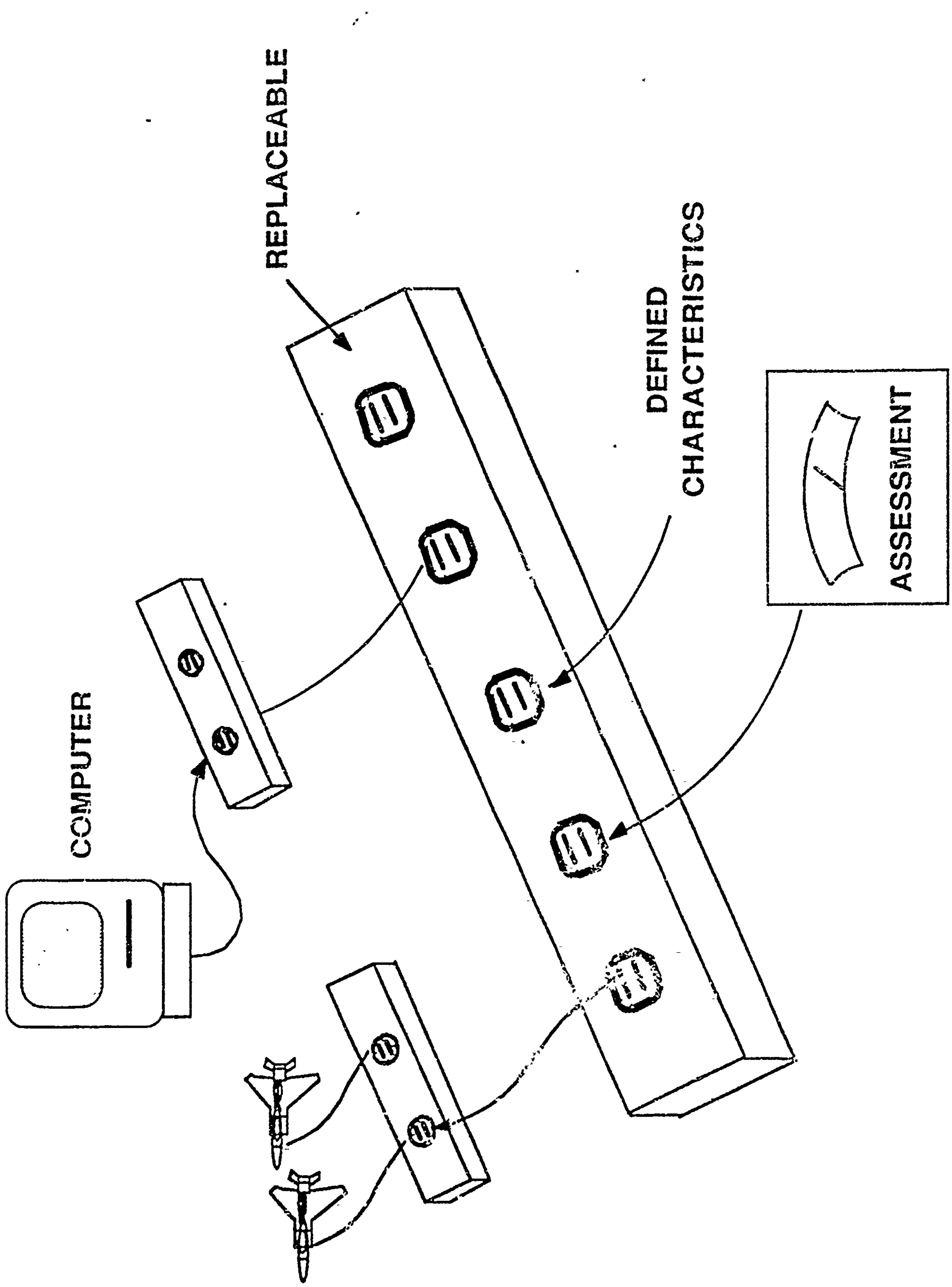
- Provide forum and discuss issues prior to generation of a standard
- Keep interested parties informed of status
- Pool knowledge and ideas to maximize expertise

SCOPE

Standardize

- Interfaces
- Transmission media
- Performance assessment methods

Consistent with current private sector and defense initiatives



REPLACEABLE
DEFINED CHARACTERISTICS
ASSESSMENT
COMPUTER

PROCESS

- Use SIMNET initially as a performance baseline
  - Decompose into major components
    Protocol Data Units (PDU's)
    Protocol (ETHERNET)
    Vehicle/Node Performance

- Assess private sector and defense needs
  - Testimonials
  - Interviews
  - Requirements statements

- Determine needs fulfilled by existing technology
  - Approval via consensus
  - Approval via verification

- Write an integration standard which considers:
  - Existing STNDS (e.g. MIL-STD-1815, FIPS)
  - Current technical initiatives (e.g. MODSIM, P2851, OSI)

- Address technology gaps

ACTIVITIES SINCE LAST MEETING

- Minutes published
- Steering committee formed/meetings held
- BBS established (407) 658-5077/8
- Subgroups formed/issues categorized
- Framework of standards process developed
- PDU's evaluated
- IST preliminary assessment of critical needs complete

STEERING COMMITTEE MEMBERS

- ARMY (PM TRADE)
- AIR FORCE (SIMSPO)
- NAVY (NTSC)
- DARPA
- IDA
- IST (CHAIR)
- MCDONNELL DOUGLAS
- BBN
- IBM
- EVANS & SUTHERLAND
- CAE LINK

STEERING COMMITTEE PURPOSE

- Direct action to proper groups
- Facilitate workshops
- Assess overall standards process/progress
- Insure interested parties have a voice

GROUPS/SUBGROUPS

- Communication protocols (R. Hofer) - What goes over the wire
  - Interfacing methods
  - Time/mission critical data
  - Security
  - Long haul/wide band methods
  - Non-visual needs

Army Topographic Lab

- Terrain databases (G. Lukes) - How data is interpreted
  - Correlation
  - Dynamic Terrain
  - Unmanned Forces
  - Interim terrain database

FRAMEWORK FOR DEVELOPING A STANDARD

- IST's role (Mr. Goldiez)
- DOD (Mr. Rogers)
- NIST (Dr. Welsch)

IST's ROLE

- OSI hierarchy is the model

- IST writes application layer standard
  - Workshop input 15 Feb 90
  - Draft complete 30 May 90
  - Staffed through JTCG as MIL-STD
  - NIST Identifies and coordinates private sector developments
  - DOD standard (Goal) 12/90
  - ARMY serves as custodian
  - Commercialization efforts continue
  - Other opportunities evaluated

DOD/OSI LAYERS

OSI	DOD
Application	Process
Presentation	Process
Session	Process
Transport	Host-to Host TCP
Network	Internet IP
Data Link	Network Access
Physical	Network Access

REF: STALLINGS

Books by Stallings are good for Networking.

Figure 1.8 A comparison of the OSI and the DOD communications architecture

IST ASSESSMENT OF DOD/INDUSTRY NEEDS (QUALITATIVE)

- Multi-level interoperability
- Clearly defined interfacing methods
- Clearly defined performance parameters/tools
- Open architecture
- Expandable system performance

iST ASSESSMENT OF CRITICAL SUBSYSTEM ISSUES

- Protocol data unit (PDU) definition

- Interface with or use of other standards
  - MIL-standards
  - ISO
  - FIPS (GOSIP)
  - Other pending/DE-FACTO standard

- Definition & matching of timing requirements and network performance with respect to
  - Long haul
  - Guaranteed delivery

- Correlation assessment methods

- Ability to scale-up/down

- Baseline terrain definition/conversion process

- Other issue from 8/89

Mr. Rogers

Dr. Welsch

NIST

PDU DISCUSSION

MR GLASGOW

ACTIVITIES FOR THIS MEETING

- Revalidate issues from August 89 as relevant
- Identify new issues
- Categorization/disposition of issues
- Discuss new position papers
- Begin to capture full requirements

DOD/INDUSTRY ISSUES
COMMUNICATIONS PROTOCOLS

ISSUES	FULFILLED BY: EXIST TECH	CONSENSUS	RESEARCH
• Architecture Which Supports Simulators of Different Fidelity			
• Method To Interface With Existing Simulators			
• Ability To Scale-Up Or Scale-Down			
• Methods Which Support Time Critical Applications			
• Approach For Voice And Data Communications			
• Incorporation Of Environmental Effects			
• Security Method			
• Publish Info On Connecting Dissimilar Simulators			
• Increase Size Of The Game Board			
• Machine Dependency Issues - External Vs. Internal Representation			
• Appropriateness And Use of ADA PDL			
• Method For Interfacing With The Live Exercise Environment			
• Standard Protocols Approach For Wide Area Communications (Long Haul)			
• Determine And List Events Requiring Guaranteed Delivery			

DOD/INDUSTRY ISSUES
COMMUNICATIONS PROTOCOLS

ISSUES	FULFILLED BY		
	EXIST TECH	CONSENSUS	RESEARCH
• Non-Visual Issues & Approach For Consideration			
• Liaison NSA Secure Data Network System (SDNS)			
• Identification Of Time Critical Events Which Make Tighter Update Periods Necessary (Adaptive Thresholds)			
• Absolute Clock Time Format And Definitions			
• Representation Of Location (Lat/Long)			
• Prioritize What Needs To Be Standardized & When			
• Incorporation Protocol Stack Architecture For Protocols			
• Incorporation Protocol Stds For Net & Transport For Multi-Cast			
• Incorporation of GOSIP			

DOD/INDUSTRY ISSUES TERRAIN DATABASES

ISSUES	FULFILLED BY EXIST CONSENSUS RESEARCH TECH
• Coordination Method (Organization) With DMA	
• Interim Terrain Data Assessment/ITD	
• Project 2851 ECP Assessment	
• Geodetic Frame Of Reference	
• Develorment Of Correlation Parameters And Metrics	
• Dynamic Terrain Feasibility/Methodology	
• Increase Size Of Game Board	
• Spherical Earth Model (Lat/Long)	
• Definition Of Solid Modeling Technique	
• Definiton Of Texture Representation	
• Distribution Format	
• Database Repository Organization	

INTEROPERABILITY EXPERIENCE

1. ORGANIZATIONS INVOLVED

2. GOALS

3. NETWORKING CONFIGURATION/DESCRIPTION

4. CONFIGURATION OF EACH NODE
   (e.g. update rate, synchronous transmission, H/W configuration, Visual/Sensor Simulation, Terrain Database Source, etc.

5. PERFORMANCE PARAMETERS MEASURED
   (To include Method and Scope of Measurement).

6. QUALITATIVE RESULTS

FUTURE ACTIVITIES

- Capture the requirement
- Assess on-going initiatives
- Assessment tools developed
- Standards opportunities evaluated
  - P2851
  - GOSIP
  - ITD/TTD
  - MODSIM
  - POSIX
  - ETC.
- Private sector coordination

THE IMPORTANCE OF SIMULATION INTEROPERABILITY STANDARDS

BARRY BOEHM
DARPA/ISTO
16 JANUARY 1990

BB/rc(1/11/90)-1

THREE AREAS OF IMPORTANCE:

- SOFTWARE ECONOMICS
- WEAPON SYSTEM CONCEPT VALIDATION
- FOUNDATIONS FOR THE FUTURE

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THE BIG-TICKET ITEM:

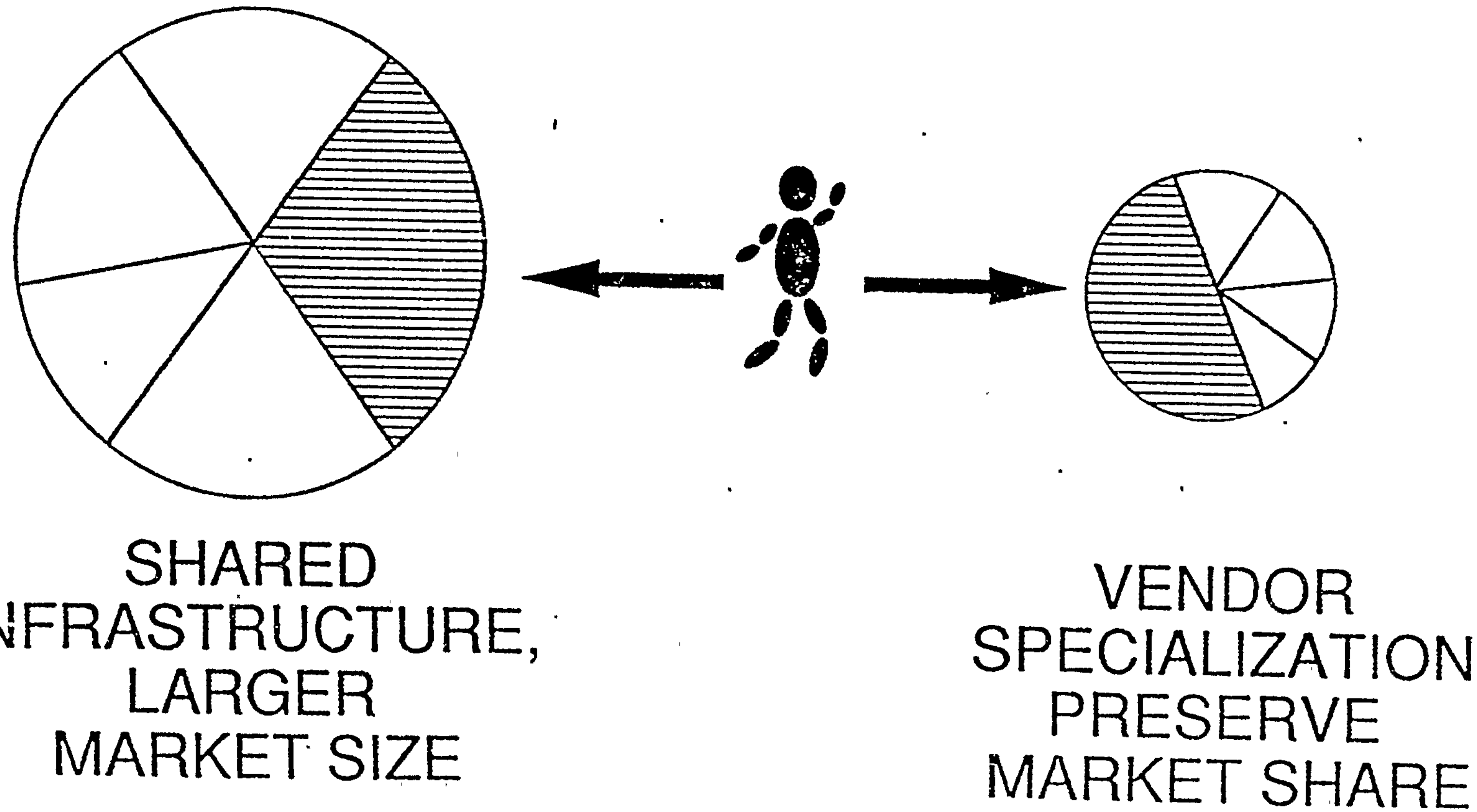
WRITE LESS CODE

- REUSABLE COMPONENTS
- VERY HIGH LEVEL LANGUAGES

BOTH DEPEND CRITICALLY ON GOOD INTERFACE STANDARDS

BB/rc(1/11/90)-3

MARKETING FORCES SHAPING SOFTWARE FUTURE



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STAGES OF GROWTH IN THE COMPUTER INDUSTRY

Stage	Shared Infrastructure	Value-Added Issues
I (1950)	None	shared utilities media standards
II (1960)	shared utilities media standards algorithms	MOL/HOL mixed peripherals (I/O stds.)
III (1970)	HOL's vendor utilities I/O standards plus previous base	software unbundling stable O/S interface
IV (1980)	vendor-line OS, utilties plug-compatible mainframes commercial S/W packages basic S/W environments plus previous base	portable OS, environment, networking standards
V (1990)	Ada portable OS, utilities portable environments networking standards some mainframe standards -Nebula. 1750	application standards mainframe standards
VI (2000)	Knowledge-based application standards, program generators, component libraries for some areas	application standards for more complex knowledge domains

BB/rc(1/11/90)-5

THREE AREAS OF IMPORTANCE:

- SOFTWARE ECONOMICS
- WEAPON SYSTEM CONCEPT VALIDATION
- FOUNDATIONS FOR THE FUTURE

BB/rc(1/11/90)-6

WEAPON SYSTEM CONCEPT VALIDATION

- SINCE STANDARD INTERFACES PERMIT SIMULATED INSERTION OF YET-UNBUILT WEAPONS SYSTEMS CAPABILITIES,

"FLY BEFORE YOU BUY"

BECOMES

"FLY BEFORE YOU BUILD"

BB/rc(1/11/90)-7

DARPA IS PRACTICING WHAT IT PREACHES

- MANAGEMENT DIRECTION TO USE SIMNET BEFORE DEVELOPING NEW DARPA PROTOTYPE SYSTEMS
  - DOD ROBOTICS MASTER PLAN
  - LASER SYSTEMS
  - SMART MINES
  - COMBAT VEHICLE COMMAND & CONTROL

BB/rc(1/11/90)-8

THREE AREAS OF IMPORTANCE:

- SOFTWARE ECONOMICS
- WEAPON SYSTEM CONCEPT VALIDATION
- FOUNDATIONS FOR THE FUTURE

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THE FUTURE:
ADVANCED BATTLE SIMULATION

- STANDARD INTERFACES ALLOW INTEROPERABILITY OF
  - REAL EQUIPMENT
  - SIMULATORS
  - SIMULATIONS
    - SOFTWARE MODEL RESULTS
    - SEMIAUTOMATED FORCES

BB/rc(1/11/90)-10

Enabling Technologies

- SIMNET object-oriented data structures
- SIMNET base of object and network interface conventions
- Next level of parallel computing beyond butterfly, MIPS, Touchstone, etc.
- Wideband networking (TWBNET)
- Basic SAFOR behavioral representation techniques (some risk here, but that's why DARPA role is necessary

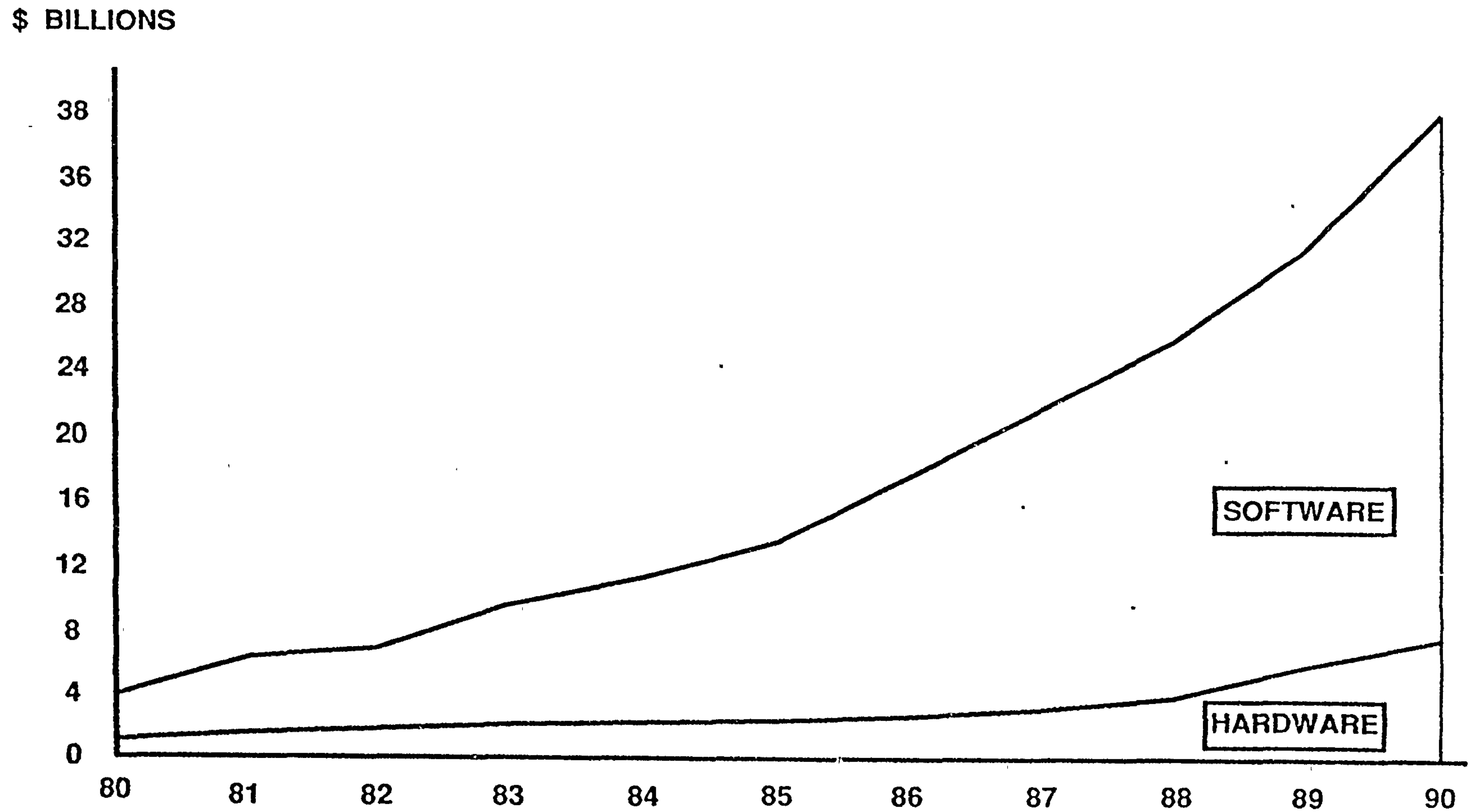
BB/rc(1/11/90)-11

A NOTE OF APPRECIATION

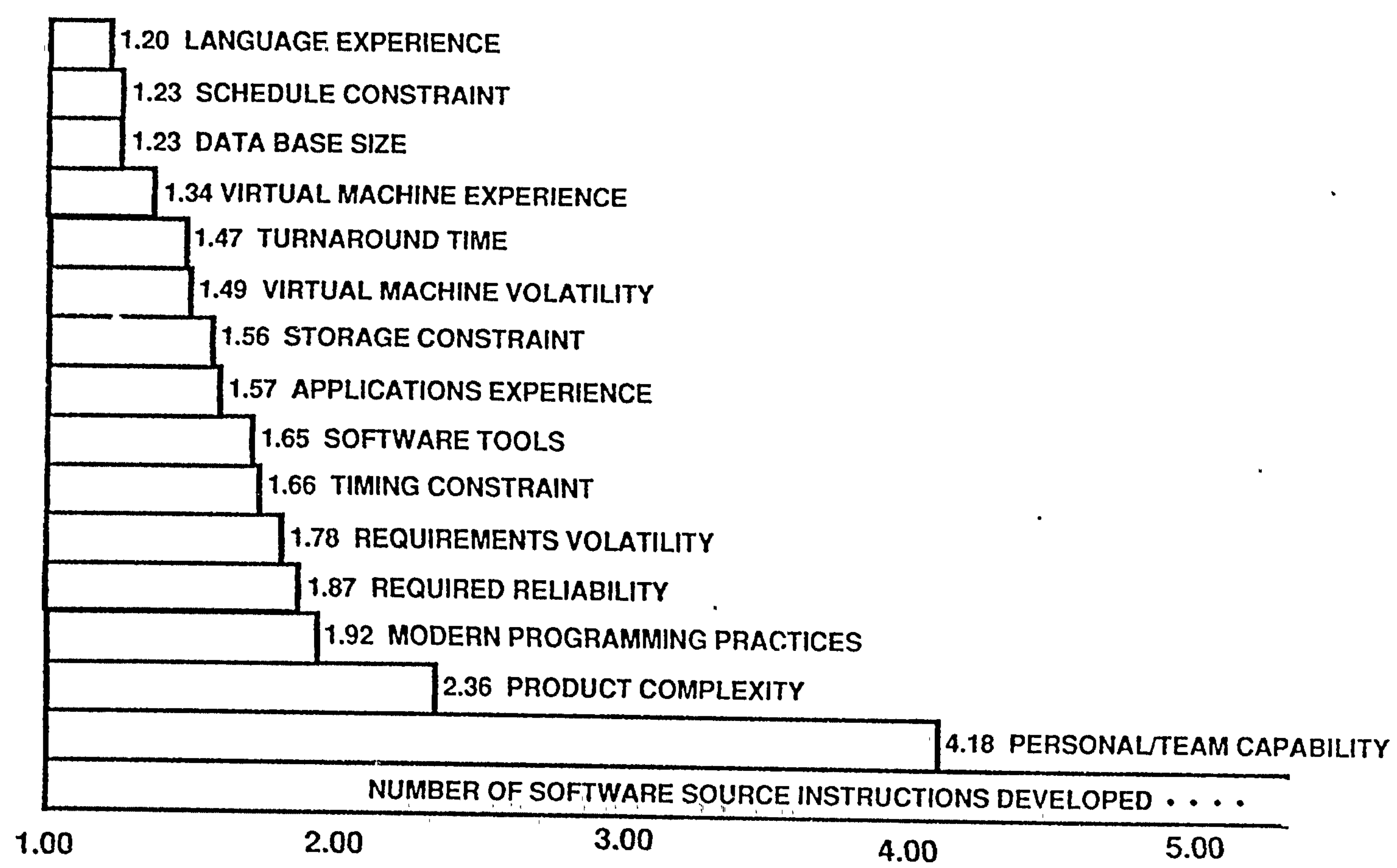
- STANDARDS HAVE HUGE LEVERAGE: BOTH WAYS
  - GOOD STANDARDS: RAPID PROGRESS, EXPANDED HORIZONS
  - BAD STANDARDS: SLOW PROGRESS, LIMITED VISION
- THEREFORE, STANDARDS DEVELOPMENT IS HARD, EXACTING WORK
  - NOT ALWAYS APPRECIATED
  - APPRECIATED HERE VERY MUCH
- SPECIAL THANKS TO:
  - ARMY, NAVY, MARINE CORPS & AIR FORCE REPRESENTATIVES
  - OSD & NIST STANDARDS OFFICES
  - IST, UNIVERSITY OF CENTRAL FLORIDA

BB/rc(1/11/90)-12

DOD EMBEDDED COMPUTER MARKET
SOFTWARE / HARDWARE



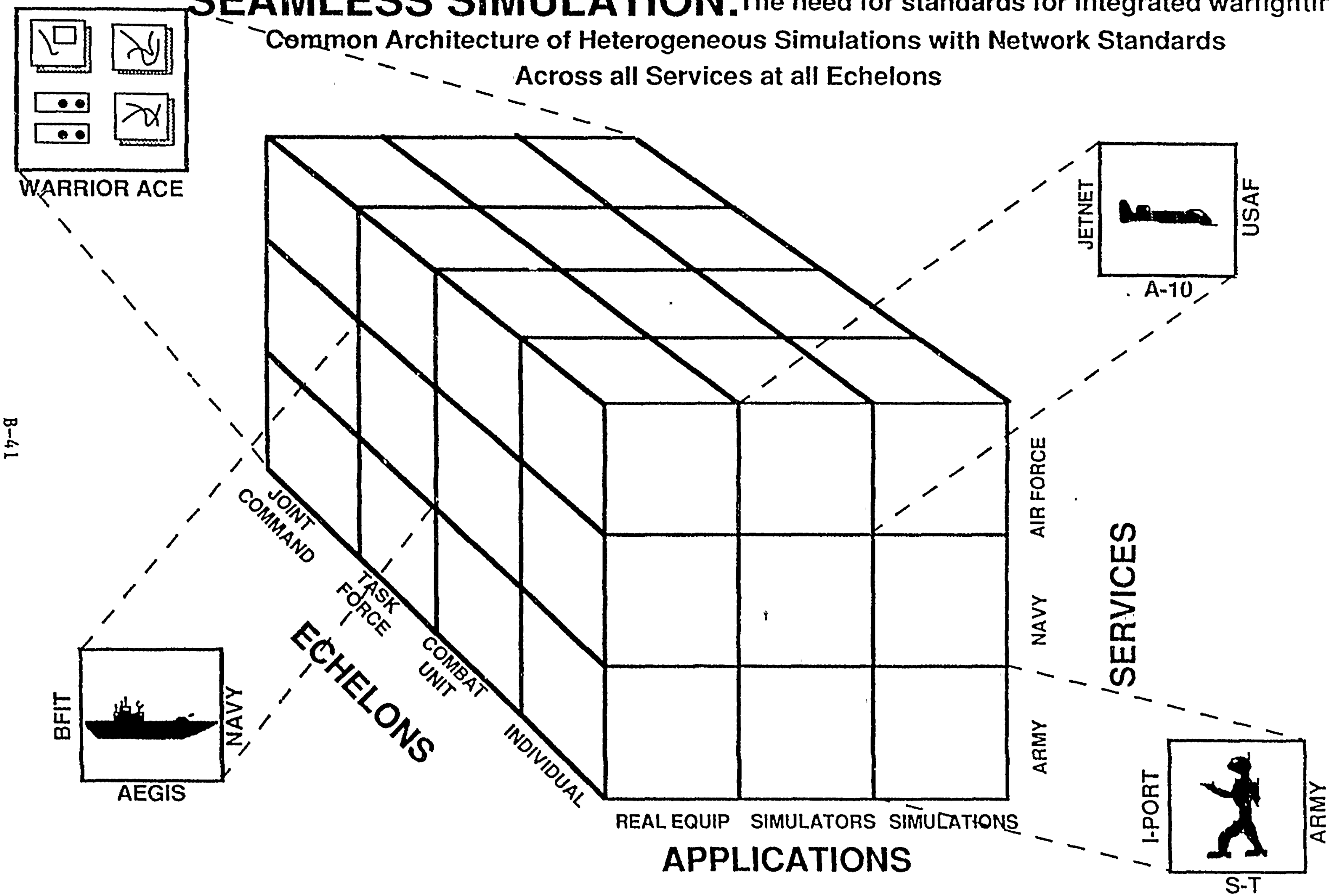
COCOMO SOFTWARE LIFE-CYCLE PRODUCTIVITY RANGES, 1985



SEAMLESS SIMULATION: The need for standards for integrated warfighting

Common Architecture of Heterogeneous Simulations with Network Standards

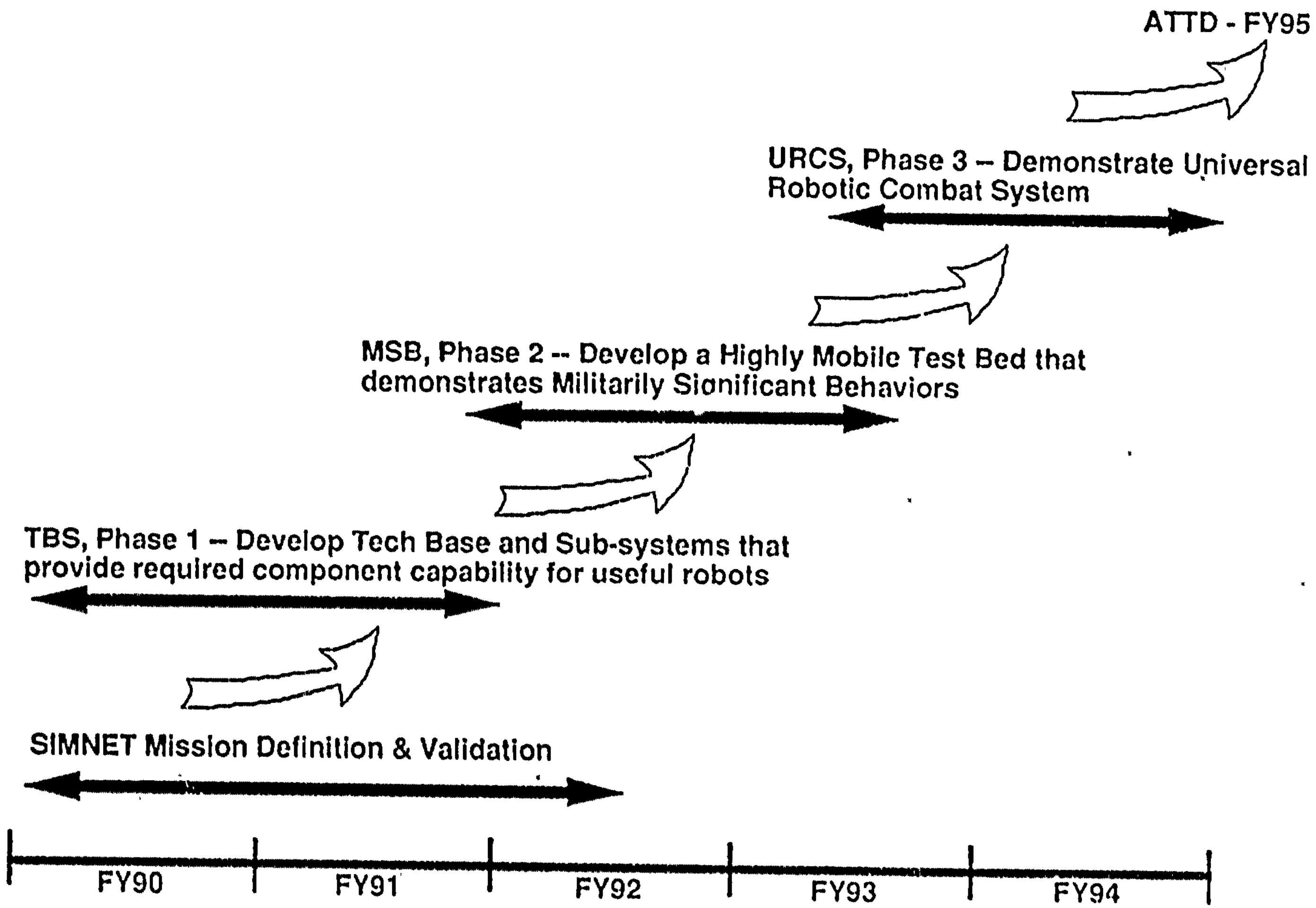
Across all Services at all Echelons



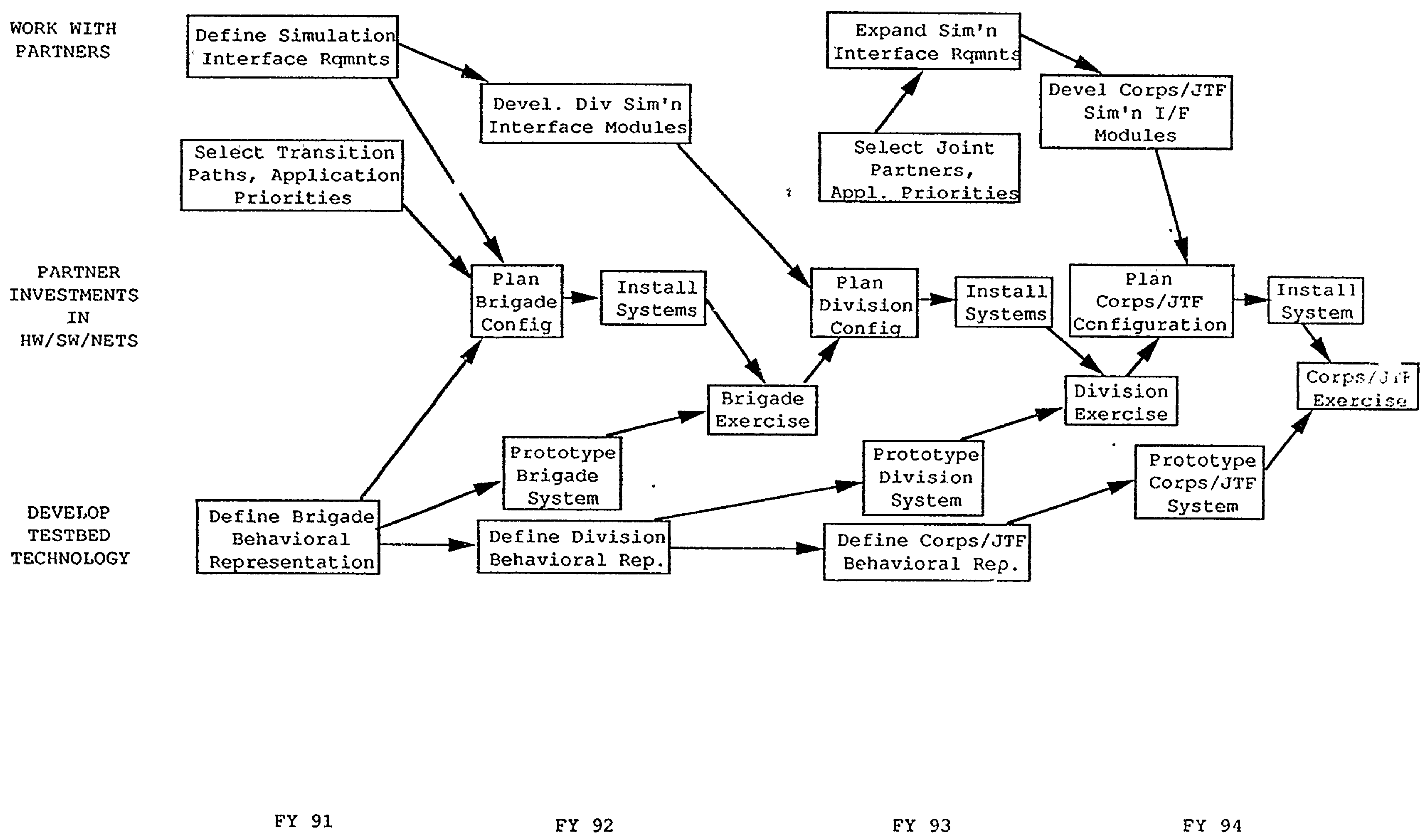
DoD ROBOTICS

Tech Base Plan

TB/RT: A 3-phase, 5-year program leading to Advanced Technology Transition Demonstration of a coordinated, multi-vehicle Robotic Combat Unit performing attack, defend, delay, reconnaissance and security missions.



ADANCED BATTLE SIMULATION APPROACH

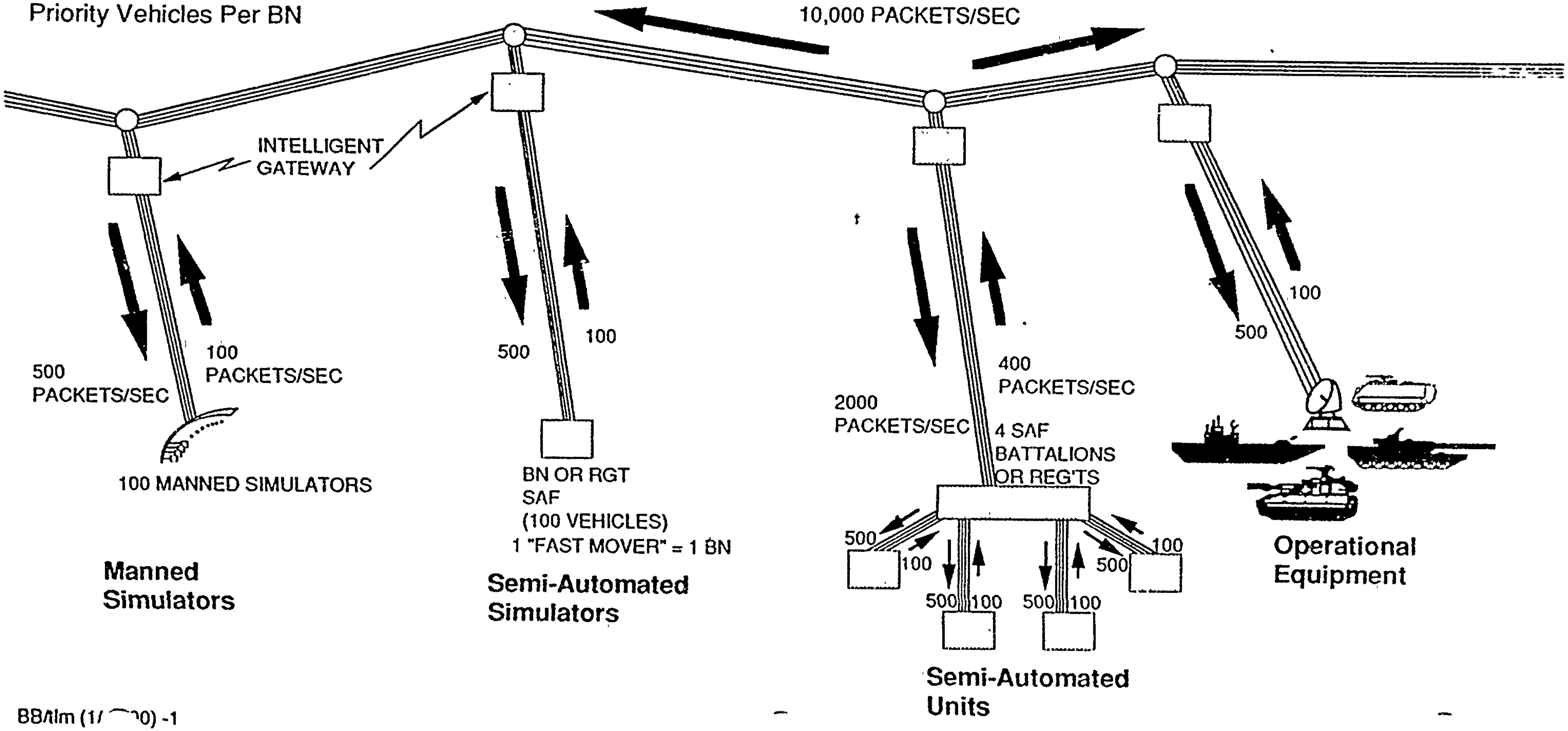


INTELLIGENT NETWORK FOR 10,000 VEHICLE EXERCISE

Intelligent Gateway
Tracks Local Vehicles
Prioritized Remote Vehicles
According to
- Type of Remote Vehicle
- Type of Local Vehicle
- Geographic Proximity

Sends 500 Highest
Priority Vehicles Per BN

Wideband Net
(Automatically Reoptimizes
In Response to Varying Loads of
Vehicle Traffic, Radio Traffic, E Mail,
Teleconferences, Etc.)



BB/tlm (1/ ‾‾0) -1

MR. JAMES O'BRYON

DIRECTOR

LIVE FIRE TESTING

DEFENSE RESEARCH & ENGINEERING

OFFICE OF THE SECRETARY OF DEFENSE

SIMULATION IN WEAPONS DESIGN: A NEED FOR DEFENSE-WIDE SIMULATION STANDARDS

SECOND WORKSHOP ON STANDARDS

FOR

INTEROPERABILITY OF DEFENSE SIMULATIONS

KEYNOTE SPEAKER

HYATT CONFERENCE CENTER

ORLANDO, FLORIDA

16 JANUARY 1990

DEFINITION

SIMULATION - A METHOD FOR IMPLEMENTING A MODEL. IT IS THE PROCESS OF CONDUCTING EXPERIMENTS WITH A MODEL FOR THE PURPOSE OF UNDERSTANDING THE BEHAVIOR OF THE SYSTEM MODELED UNDER SELECTED CONDITIONS OR OF EVALUATING VARIOUS STRATEGIES FOR THE OPERATION OF THE SYSTEM WITHIN THE LIMITS IMPOSED BY DEVELOPMENTAL OR OPERATIONAL CRITERIA. SIMULATION MAY INCLUDE THE USE OF ANALOG OR DIGITAL DEVICES, LABORATORY MODELS, OR "TESTBED" SITES. SIMULATIONS ARE USUALLY PROGRAMMED FOR SOLUTION ON A COMPUTER; HOWEVER, IN THE BROADEST SENSE MILITARY EXERCISES AND WARGAMES ARE ALSO SIMULATIONS.

DOD 5000.3-M-1

Chart 1

Simulation Progress

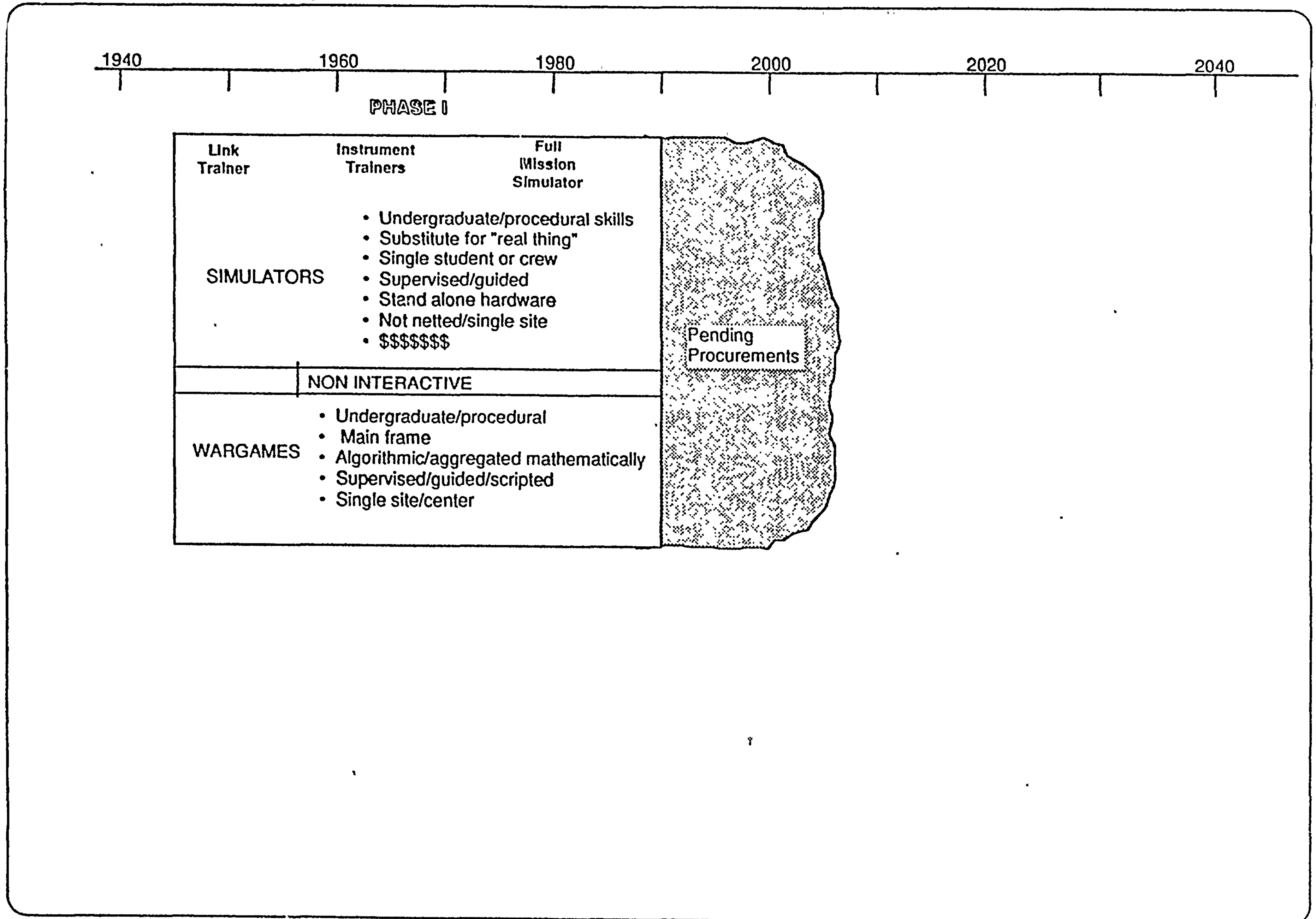


Chart 2A

Simulation Progress

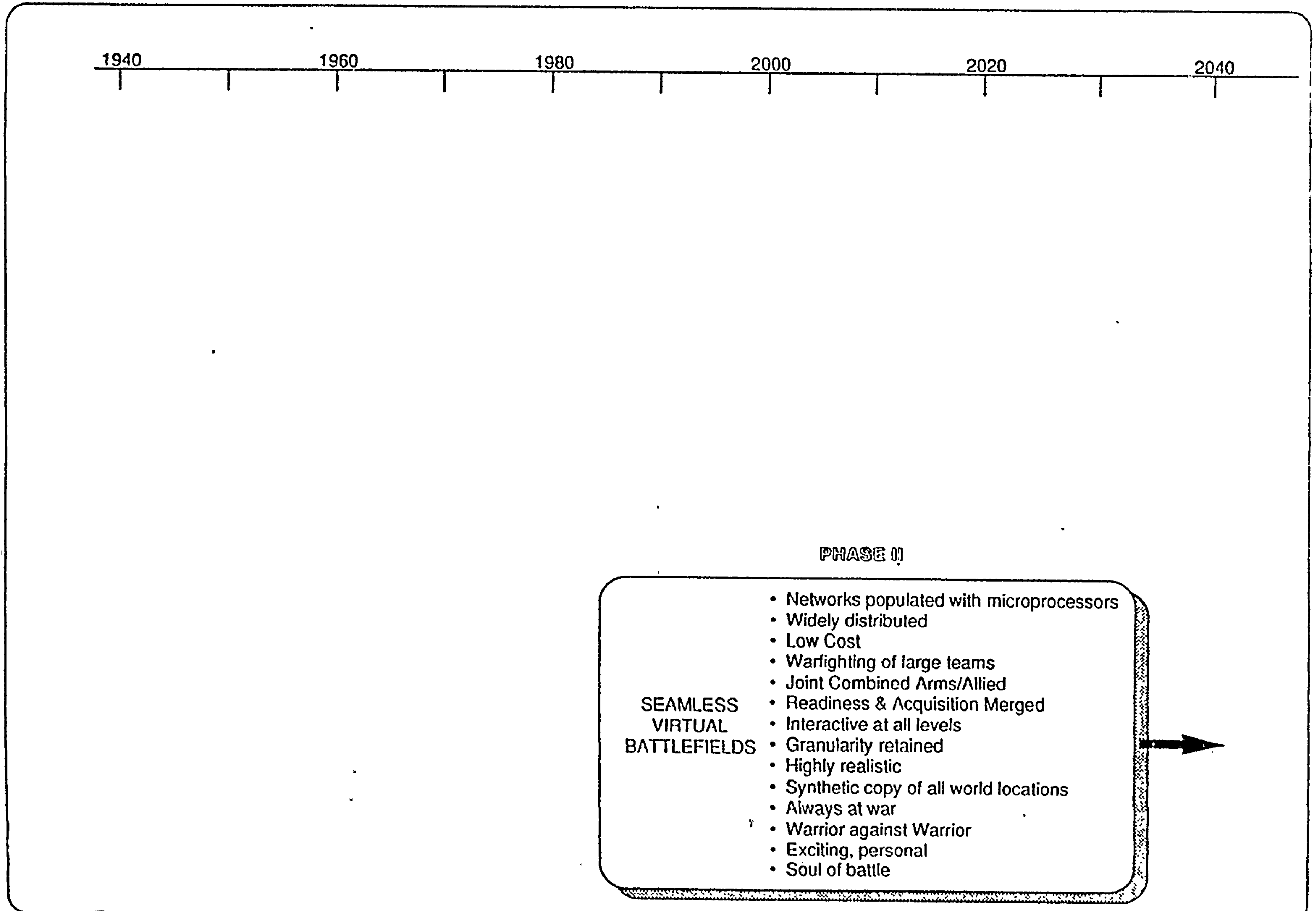


Chart 2B

Simulation Progress

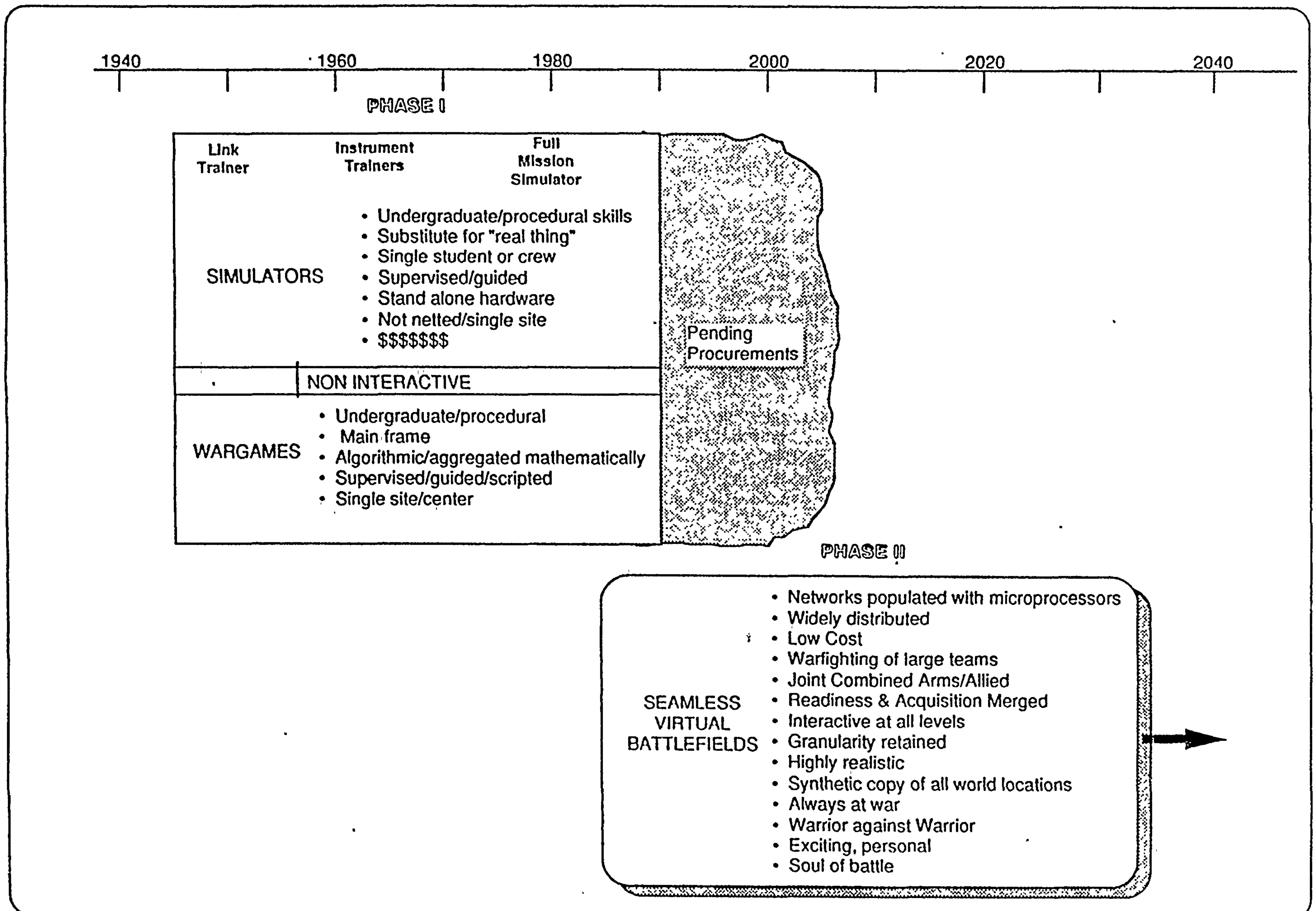


Chart 2C

SUMMER STUDY TASK FORCE

"EXAMINE THE CONTRIBUTIONS OF MODELING AND SIMULATION TO DEFENSE TEST AND EVALUATION SO AS TO IMPROVE THE ACQUISITION PROCESS."

Chart 3

WHY DO WE NEED IT

- SIMULATED EXERCISES ARE CLEARLY CHEAPER
- WE CAN DO TASKS THAT ARE TOO DANGEROUS FOR FIELD
- WE CAN COLLECT AND ANALYZE MORE DATA FASTER
- ROC'S CONTAIN SOME GUESSED-AT REQUIREMENTS
- PROTOTYPING IS SLOW AND TYPICALLY TOO LATE
- TACTICS AND DOCTRINE ARE NOT ALWAYS AVAILABLE FOR NEW SYSTEMS
- PEOPLE DEVELOPMENTS ENTER THE PROCESS LATE
- ADDRESSES NEED TO ASSESS JOINT EXERCISE
- TEST PLANNING IS AN IMPRECISE ART
- TESTER'S BATTLEFIELD IS INCOMPLETE (NIGHT, ADVERSE WEATHER, FOG-OF-WAR, FULL-UP JOINT WAR)
- HUMAN ELEMENT IS OFTEN MISSING OR MISPLAYED IN ANALYSIS

Chart 4

GRESHAM'S LAW

"THE QUANTIFIABLE TENDS TO OBSCURE THE SIGNIFICANT"

Chart 5

CONTRIBUTIONS OF COMMON SEAMLESS SIMULATION TO TESTING

- REFINE CONCEPTUAL SYSTEMS PRIOR TO BUILDING
- PRETEST A FIELD TEST
- SUPPLEMENT FIELD TEST
- TEST CLASSIFIED PROGRAMS WITHOUT FIELD EXPOSURE
- PRETRAIN TEST UNIT PERSONNEL
- EXAMINE HUMAN ENGINEERING ISSUES
- ENHANCE ANALYTICAL MODELS
- FILL-IN THE FIELD TEST GAPS
- CUT COSTS IN HARDWRE RECONFIGURATION

Chart 6

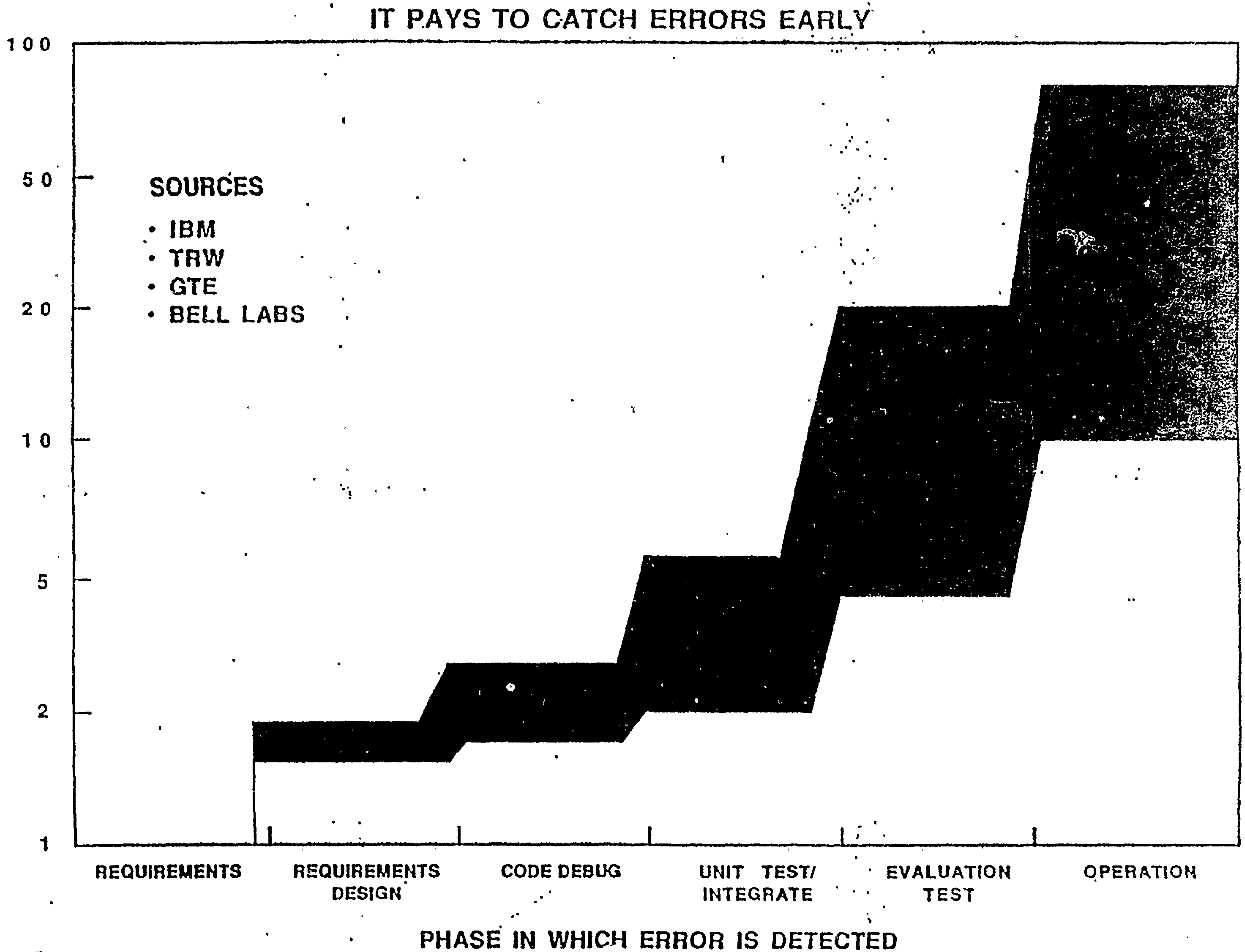


Chart 7

227187

CONTRIBUTION OF COMMON SEAMLESS SIMULATION TO EVALUATION

- EVALUATE HUMAN-MACHINE INTERFACE ISSUES
- EVALUATE ALTERNATIVE TACTICS AND DOCTRINE
- EVALUATE EFFECTS OF ORGANIZATION ALTERNATIVES
- EVALUATE TEST PLANS
- EVALUATE SYSTEM PERFORMANCE ALTERNATIVES
- EVALUATE SOME SYNERGISTIC EFFECTS

Chart 8

THE PAYOFF

- INSIGHTS AT THE FRONT-END OF REQUIREMENTS
- POTENTIAL DOLLAR/TIME SAVINGS IN PROTOTYPING
- POTENTIAL TIME AND EFFORT SAVINGS IN O&O DEVELOPMENT
- POTENTIAL SAVINGS IN COSTLY OPERATIONAL TESTING OF SYSTEMS
- POTENTIAL TO INSURE INTEGRATION OF SYSTEMS INTO THE JOINT/ALLIED WARFIGHTING TEAMS

Chart 9

POTENTIAL SOURCES OF PROBLEMS IN EFFECTING CHANGE

- IMPATIENCE
- RESISTANCE
- PAROCHIALISM
- SUPERFICIALITY

John Betti, USD(A)

Chart 10

SIMULATION AS A STRATEGIC U. S. TECHNOLOGY

THE KEY TO DEFENSE PREPAREDNESS 1995-2020

LTC (P) James E. Shiflett, U. S. Army

Defense Advanced Research Projects Agency

Washington, D.C.

(202) 694-4002

DARPA SIMULATION PROGRAM STATUS

OUTLINE

SIMNET TRANSITION

- SITE SCHEDULE (Chart)
  - ECP/ECO MODS
    - SAF 3.X
      - VERSION 6.0 S/W

AIRNET

- RUCKER, 31 JAN 90
  - 8 GENERIC HELO & 2 CAS

SIMNET-D

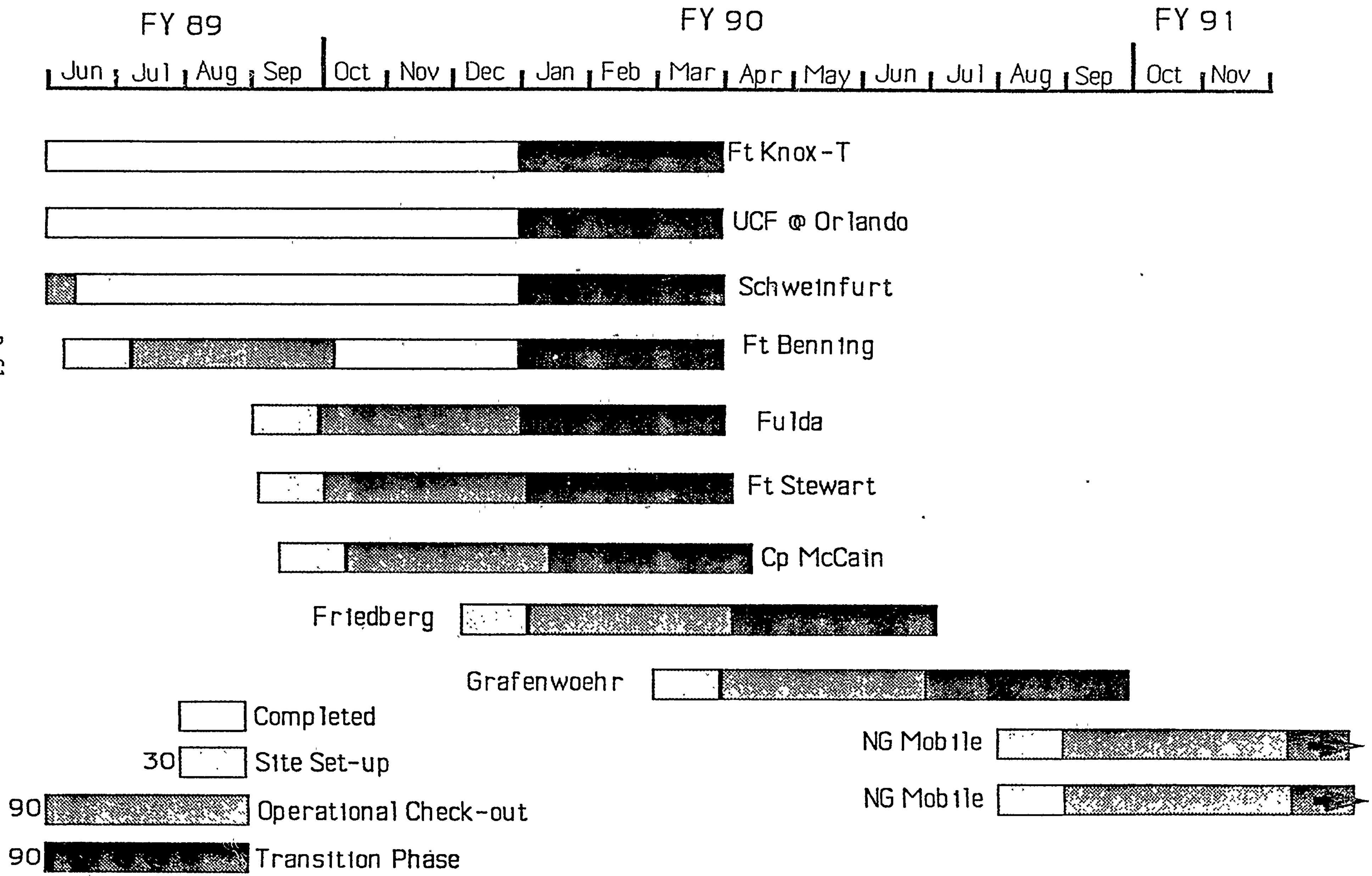
- FAADS (Chart)
  - BFIT (Chart)
    - ACMENET (Chart)
      - CVCC (Chart)

CONTRACTS

- CLS-PM TRADE
  - CCTT-PM TRADE
    - ADST-DARPA/PM TRADE

As of 16 Oct 89

SIMNET Sites Transition to ARMY



SIMNET-D: FAADS Exercises

Sponsor: Army Air Defense Artillery School, Fort Bliss, TX

Period: 1988-1989

Purpose: Evaluate effectiveness of SIMNET for simulation of Air Defense system; prepare soldiers for initial operational test and evaluation (IOTE) exercises to ensure success in actual field tests.

Major Developments and Accomplishments

- Development of Air Defense simulators for combined arms exercises
- Simulation of radar and electro-optical systems
- First use of SIMNET by defense contractor to support system development and test

SIMNET-D: Battle Force In-port Trainer (BFIT)

Sponsor: Navy Ocean Systems Command, San Diego, CA

Period: 1989-1990 (ongoing)

Purpose: Incorporate Navys BFIT training system in SIMNET warfighting environment using SIMNET protocols, and conduct joint Army/Navy exercise involving naval support of Army operation.

Major Development and Accomplishments

- First extension of SIMNET to sea-land battle
- First incorporation of existing Navy simulator into SIMNET via SIMNET protocol
- First use of actual Navy ship (LHD-1 WASP)

SIMNET-D: Aircrew Combat Mission Enhancement Network (ACMENET)

Sponsor: USAF Human Resource Laboratory; Williams AFB, AZ

Period: 1989 (and beyond)

Purpose: Construct network of multiple, geographically dispersed, dissimilar aircrew simulators; use SIMNET protocols as basis for the network to ensure interoperability with SIMNET

Major Developments and Accomplishments

- First Air Force sponsored SIMNET application
- First incorporation of non-SIMNET simulators into a SIMNET network environment
- Introduction of higher speed, multiple subsystem air vehicles

DOCUMENTATION

DOD	NGSBs
SPECS	STDs
STDS	
HANDBOOKS	

ORDER OF PREFERENCE

MIL-STD-970/DODD 4120.2

1. NGS

   INTERNATIONAL

   U.S.

2. FED SPECS/STDS

3. MIL SPECS/STDS

PREPARING ACTIVITY

PM TRADE (   )

- OBTAIN PROJECT NO.
- AUTHORIZE COORDINATION
- APPROVE DOCUMENT(S)
- MAINTAIN DOCUMENT(S)
- CANCEL DOCUMENT(S)

FLOW OF DSP

1. COORDINATE MIL-STDs/MIL-HDBKs
2. RESOLVE COMMENTS
3. APPROVE DOCUMENT(S)
4. SUBMIT TO ISO THROUGH ANSI FOR CONVERSION TO ISO STANDARD(S)
5. REPRESENT U.S. IN TAG W/ISO
6. PARTICIPATE IN DEVELOPMENT AND APPROVAL OF ISO STANDARD(S)
7. ADOPT ISO STANDARDS THROUGH ANSI CONCURRENT WITH APPROVAL BY ISO AND CANCEL MIL-STD(S)

TRUSTED SIMNET

Presented by
Lt Col Steve Sarner
ASD/YWB
(513)255-7177

PROBLEMS

- SIMNET moving from lab to field
- Many anticipated SIMNET devices will be classified
  - Classified equipment
  - Classified performance
- OPSEC considerations
  - Commander's tendencies
  - Aggregation

AREAS OF CONCERN

- OPSEC
- COMSEC
- TEMPEST
- COMPUSEC
-
-
-
-

POLICY

- Designated Approving Authority (DAA) accredits systems
  -- Identified in PMD, usually field commander
- Commander of classifying agency releases data
- You must convince both they can trust your system
  -- Approval based on evaluation
    --- IAW DoD 5200.28-Std, Dec85

DETERMINATION OF LEVEL OF TRUST

Risk = (Max data sensitivity) - (Min user clearance)

Risk = (Secret) - (Uncleared)

Risk = (3) - (0)

B3 Level of Security is Required

Source: CSC-STD-003-85

Changing Patterns of Technology and the Defense Industry

By
Ron Kerber

GP01-0065-1-D

Changing Defense Environment

- INF/CFE
- Soviet Changes
- Eastern Europe
- U.S. DoD Budget
- NATO Nations Budget Priorities

(Caution: Rapid Change Is Difficult)

GP01-0065-2-D

Future NATO Role

- Already a Success
- Stabilizing Influence
- Synergistic With World Stability
  - Mobile
  - Flexible
  - C^3I

GP01-0065-3-D

Implications for U.S. Defense

- Fewer More Effective Weapons
- Strong C^3I
- High Mobility
- Training
- Simulation

GP01-0065-4-D

Economic Cooperation of Nations

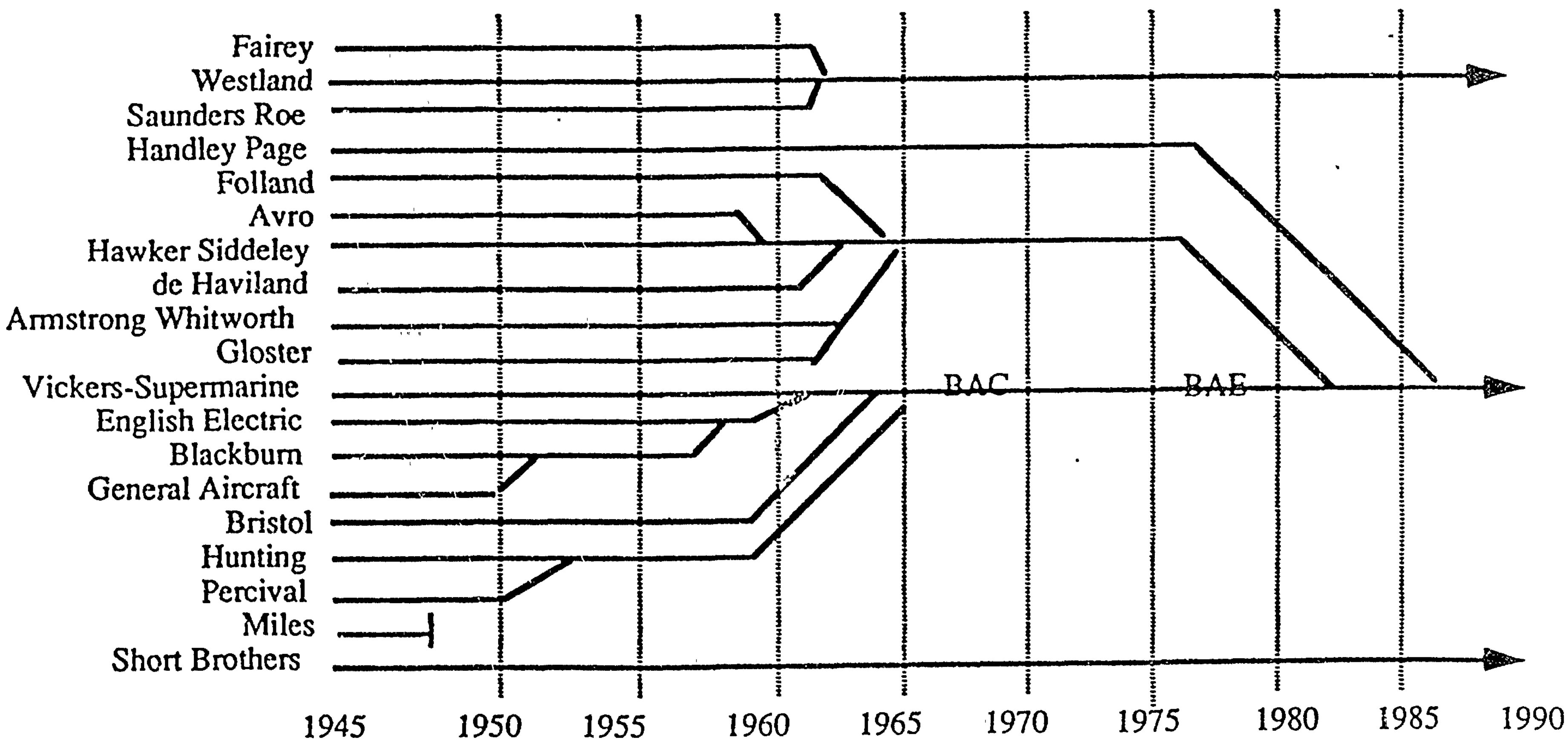
- IEPG
- EC (EC92)
- AIRBUS
- EFA
- Arianespace
- HERMES
- Space Station

GP01-0065-5-D

International Industry Consolidation

GP01-0065-6-D

EVOLUTION OF U.K. AIRCRAFT MAKERS



MDC International

England	AV-8B, T-45
France	Missiles
Germany	Space Station, Training
Japan	Space Station, F-15
Korea	Helicopter, F/A-18
Israel	Helicopter, Missiles
Italy	Space Station, MD-80
Spain	F/A-18, MD-80, Training
Switzerland	F/A-18

GP01-0065-7-D

Technology Factors

- Commercial/Dual Use Domination
  - VHSIC
  - Software
  - Manufacturing Technology
  - Composites
  - Man/Machine Interface
  - Communication

- Defense Specific Applications
  - Stealth
  - Chemical Defense
  - Combat Simulation

GP01-0065-8-D

Implications for Industry

- Be Willing to Change
- Be Flexible

GP01-0065-9-D

Implications for Government

- Reasonable International Policies
- Maintain Technology Position
- Maintain Industrial Base

GP01-0055-10-D

Need for Training and Simulation

- Fewer Exercises
- Difficulties in Training in Europe

GP01-0065-11-D

Effective Training & Simulation Implies Standards

- Interoperability of Models
- Re-Use
- Modular Design
- Validation

GP01-0065-12-D

Summary

- Must Maintain Strong National Defense
- Simulation & Training Are Key
- Strong Technology Base
- Strong Industrial Base
- Must Be Economically Competitive

GP01-0065-13-D

APPENDIX C

View Graphs and Documents for the
Network Communications
Working Group Breakout Sessions

SIMNET
as a
General Simulation Interface

The MITRE Corporation

16 January 1990

MITRE

Background and Structure

- Sponsor is interested in a general simulation interface
  - Promote software reuse
  - Increase functionality
- Forming a cohesive joint simulation from existing systems is a complex problem
  - Simulation communities have divergent goals
  - Existing interfaces are *ad hoc*
- Propose framework for discussing simulations and interfaces
- Attempt to reconcile various interface requirements using the SIMNET design

MITRE

Dimensions of the Simulation Interface Problem

- Three classes of issues
  - Data Semantics
  - Time Management
  - System Architecture
- Usually applied in a layered approach
- Subtleties of Time and Data Semantics often ignored

MITRE

Data Semantics

- Study of simulated entities
  - Meaning
  - Composition
  - Representation
- Concerned only with entities that are externally perceivable and/or controllable by simulation users
- Expressed as a collection of attributes
- Relies on some context
- Aggregation/Disaggregation most common problem

MITRE

Time Management

- Scheme by which simulated time is advanced
- Usually a primitive part of the simulation execution model
  - Time Stepped
  - Event Driven
  - Continuous Realtime
- Critical to proper simulation state access

MITRE

System Architecture

- Organization of data and computation
  - Sources and sinks of information
  - Process model
  - Hardware configuration
  - Database organization and disposition
- Often taken as the entire interface problem

MITRE

Brief SIMNET Description

- Entities have public and private attributes
  - Private used by entity owner, stored uniquely
  - Public used globally, stored redundantly
- Each public attribute has a dead reckoning algorithm
  - Predicts attribute value changes
  - Reduces number of update messages
  - Globally understood
- Public attributes are always temporally correct and consistent
- Time management scheme: Continuous-realtime

MITRE

Interface Design Issues
Data Semantics

- New simulations might extend the context of entire confederation
  - New entity types
  - Associated dead reckoning algorithms
- Not all simulations use the same aggregation level
  - JESS, GRWSIMS: military organizational units
  - RAPIDSIM: tons of cargo
  - Current SIMNET: combat vehicles
- Need an aggregation transformer
  - Listen to message traffic and synthesize updates for missing levels
  - Could be impossible (equivalent to predicting human behavior)

MITRE

Interface Design Issues
Data Semantics
(concluded)

- Fundamentally different terrain assumptions
  - SIMNET: continuous
  - Hex based games: discrete
  - Continuous allow infinite number of locations (real number coordinates)
  - Discrete limited to fixed number of named locations
- Dead reckoning algorithms would be host specific
  - Continuous simulations use different map systems
  - Discrete simulations use different quantization schemes

MITRE

Interface Design Issues
Time Management

- All simulations in confederation must be paced by real time
  - Many current simulations rely on changing the simulation rate to meet player needs (including making it negative)
- SIMNET public attribute distribution mechanism cannot be support by time-stepped simulations
  - Delay between the decision to change a public attribute and the broadcast of updates is not allowed
- No delay permitted in processing update messages

MITRE

Interface Design Issues

System Architecture

- To support high level games, scalability must be addressed
  - ACE-89 exercise supported more than 30 000 combat units
- Linear growth in communication requirements only possible with a broadcast media
- Computation requirements may depend more on the confederation size than on the local requirements
- Some localization mechanism is needed
  - Partition entities by geography and/or ownership
  - Need an update message gateway

MITRE

Next Steps

- Characterize some representative existing systems
  - GRWSIMS: large, centralized, time-stepped
  - JESS: medium size, distributed database, incremental updates, event-driven
- Use understanding to postulate a strawman interface design based on SIMNET philosophy
- Describe areas where additional research is needed

MITRE

SUB GROUP ISSUES
INTER-SIMULATOR INTERFACING METHODS

- ARCHITECTURE WHICH SUPPORTS SIMULATORS OF DIFFERENT FIDELITY
- METHOD TO INTERFACE WITH EXISTING SIMULATORS
- ABILITY TO SCALE UP OR SCALE DOWN
- METHOD FOR INTERFACING WITH THE LIVE EXERCISE ENVIRONMENT
- REPRESENTATION OF LOCATION (LAT/LONG)

6

Long Haul Sub-Group

NINE ISSUES FOR FURTHER DISCUSSION

* Security

* Definition of present protocol and mapping to ISO profile.

* Time stamping and latency

* Recommend ISO profile for SIMNET spec., evolution to FDDI/ISDN/etc.

* Additional service requirements driven by joint service doctrinal guidance

* NIST, ITS/NTIA, university contributions to the evolution

* Consideration of NATO

* C & I testing, and V &V of simulators

* Use of other network assets

* Database to house information and CM

INTRODUCTION

Real Net was developed in the ALV program to provide real-time autonomous vehicle control, sensor data processing, and artificial intelligence programs with a high bandwidth, low latency inter-process communications capability based on a message passing paradigm.

The ALV utilizes a real-time distributed processing architecture featuring Symbolics, WARP, SUN, VICOM and Intel processors. Blending this mixture of heterogeneous processors into a real-time vehicle control system presents a unique set of networking/communications requirements including:

- Fixed Time, Low Latency Data Transfer
- High Bandwidth
- Heterogeneous Processor Integration
- Local and Distributed Processors and Processes
- Flexible Process Allocation and Migration
- Low Cost Integration of New Machines
- Point to Point & Selective Broadcast of Messages
- Simple Multi-Lingual Application Interface (LISP, PASCAL, 'C', PLM-86)
- Commercial Protocol Compatibility
- Flexible Transmission Media Alternatives (Twin Axial Cable, Fiber Optic Cable, T1, 56 KBPS serial, Ethernet, etc.)

These requirements are equally germane for a variety of applications including computer vision, robotics, real-time simulation, etc. Real Net is currently being used on both the DARPA/MMC ALV program and the DARPA/MMC SMART Weapons program.

Real Net

George P. Celvi and Thomas J. Mowbray
Martin Marietta
(303) 977-0830

ABSTRACT

Real Net provides the software tools necessary to construct a distributed processing environment which acts as a single "Virtual Machine" for a real-time system. The first implementation of Real Net is operational aboard the Autonomous Land Vehicle and within its Laboratory. Real Net employs an 80 megabit/sec token ring local area network as the foundation for integrating Vicom Digital Image Processors, SUN-3/X80 workstations, Intel 80X86 processors, and Symbolics Lisp Machines into a single asynchronous real-time network.

Real Net enables application processes, currently C/UNIX, PLM-86/IRMX, Lisp, and Pascal/Versados to exchange memory objects with other application processes located anywhere on the distributed local ring network, or on any gateway accessible network. Memory to memory transfers are implemented across the LAN to implement three address methodologies:

- Point to Point (process A to process B)
- Group (process A to processes B, C, D, X. Z, etc.)
- Broadcast (process A to every other process)

Communications processes may reside within the same processor (intra-process communications) or on any network accessible host processor (inter-processor communications). A single object exchange request may be targeted for any collection of distributed processes which reside on the originator's host, or on any collection of network accessible hosts. The routing of data and delivery occur in a transparent manner with respect to the sending process.

Internet Protocol (IP) datagram services are provided to allow network to network data routing and internet addressing. This facility provides for fragmentation and reassembly of data streams to/from data packets. Adherence to IP packet format, addressing, and protocol ensures compatibility with commercial gateways and communications devices.

DETAILED DESCRIPTION

Real Net is a set of communications software developed for a variety of processing architectures. It is intended to implement a "Virtual Machine" processing architecture using a collection of non-homogeneous processors. Real Net's "Virtual Machine" configuration is file driven and is established at LAN (Local Area Net) start-up. Once established it may be selectively modified Real-Time (milliseconds).

A complete software specification including module narratives, data dictionary, and module pseudo code and logic charts are available through the Autonomous Land Vehicle (ALV) project. This description is a summarized extract from the documentation.

VIRTUAL MACHINE CONCEPT

Under the "Virtual Machine" concept, a real-time run cycle may be construed as a multi-player game. The players of the game are software processes or tasks, which may reside anywhere on the playing field. The playing field is an abstraction, which may be construed as the total collection of host processors. All players may be executing on the same processor, or be distributed across a collection of processors located on the same network or on adjacent networks inter-connected by IP gateway devices. The playing field is variable in nature and may be redefined at any time. An initial "game" configuration is established at start-up but may be modified real-time to add/delete players, or expand/shrink the field of play by re-allocating players to different processors.

As with any game, certain rules govern the interaction of players on the field of play. These rules exist under the "Virtual Machine" concept, and are manifested in the definition of interfaces between players (processes). The interfaces between processes are delineated in terms of data items (item ID#, type, source player, destination players) stored in an Interface Control Document (ICD) file. This file defines the data objects which may originate or terminate at any process. Processes are mapped onto physical hardware units within the "Virtual Machine" via a Player Host File (player and IP/hardware addresses). When processes wish to exchange data items across networks, packets are automatically routed through IP gateway devices across network boundaries. Paths inter-connecting networks are stored in the Gateway Routing Table (IP to IP address routes).

Under the rules of play, any process may originate a data item for transfer with no knowledge of the actual destination. Real Net will automatically route the data to the proper destination(s) whether within the same machine, on the same network, or across networks in response to a single application transfer request. Data will automatically be formatted for receipt at the target node(s), (resolving byte swap/word swap contingencies) with non-redundant delivery to one or more processes at each node, as defined in the configuration files.

This provides a robust framework for integrating processes into a real-time "Virtual Machine" environment. Watch dog timers, network management, data recording, and other real-time functions may be added or deleted as necessary by expanding the game to include new processes. Since the "Virtual Machine" may be expanded or contracted in real-time, redundant/exception processes may exist in a dormant state and become active as needed in response to conditions detected by watch dog timers, network management, or data recording functions.

The actual transfer of objects between processes appears as continuous DMA operations across the LAN, with a consistent process interface methodology implemented in the applications' language, and resident within the host processor's operating system framework (non-operating system implementations are also supported).

MEMORY RESOURCES

Real Net uses a shared memory pool for exchanging data to/from application processes, and for buffering input/output LAN traffic. The resource pool is used for allocation of storage for several critical data structures. These structures and their functions are as follows:

- Input Transaction Assignment Queue -- records arrival of data from LAN and coordinates delivery to target players.
- Output Transaction Assignment Queue -- records requests for transfer of data items and coordinates prioritized IP datagram service. Contains pointer to copy of data item awaiting transfer.
- Routing Table -- stores required IP and hardware addresses for each item output by the individual node (synthesis of ICD, Player/Host and Gateway Files).
- Input Network Status Log -- contains counters which keep track of inbound LAN traffic and item deliveries (displayed at end of run).
- Output Network Status Log -- contains counters which record outbound LAN traffic and packet refusals/failure (displayed at end of run).
- Input/Output Buffers -- storage areas for data items awaiting delivery to players.
- Pointer Reference Table -- points to Real Net data structures (for reference by multiple software layers).

SUPPORTED DATA CLASSES

Two classes of data items are supported under Real Net:

- Refresh data items
- Multiple occurrence data items

Refresh data items are overwritten whenever a packet arrives from the LAN containing data for that item ID#. Buffering and handshaking prevents inadvertent overwriting of a refresh data item input buffer, while data is being delivered to a target player. On output, any pending transfer for a refresh data item is overwritten by a new transfer request. The new data (for the Old item) retains its place in the prioritized Output Network Assignment

Queue. The output item overwritten is recorded in the Output Network Status Log for display upon completion of the real-time run cycle. The number of output buffers allocated for a refresh item is two. The number of input buffers allocated for a refresh data item is the number of target processes within the local host (for the item) plus one.

Multiple occurrence data items are allocated a set of revolving buffers. The number of buffers is determined by the configuration manager and stored in the ICD file. Multiple occurrence data item input buffers are recycled following delivery of the item to all target processes within the local host. If all input buffers are full when a new packet containing the data item arrives then the oldest non-busy buffer is recycled, and the over-write recorded in the Input Network Status Log.

On output attempts, successive entries are made in the Output Transaction Assignment Queue for multiple occurrence data items. However, when all available output buffers are full, failure status will be returned to the application process, and the failure is recorded in the Output Network Status Log for subsequent display.

Any data type may be defined within a data class. Examples of valid data items include:

- ASCII data
- Bytes
- Words
- Long words
- Reals
- Arrays
- Records
- Complex data structures

No size limitation is imposed on data items. A special class of data type, Files, are implemented using file buffers to prevent memory overflows. All other data objects for transfer must be sized so as to fit in available memory.

SOFTWARE

Real Net provides a consistent application interface for inter-processor (across the LAN) and inter-process (local host) communications. The software architecture is comprised of three real-time layers:

- Application Interface (IF)
- Data Transport Executive
- LAN IF

A fourth major software component, which is not directly involved in the real-time transfer of data, is initialization. Real Net's processing architecture and a functional summary of the major software components are summarized in Figure 1.

INITIALIZATION

The initialization software provides three functional capabilities:

- Configuration Manager
- LAN Start-up
- Run-time Initialization (functioning as Initialization Master of Initialization Slave)

Four disk files control the configuration of the "Virtual Machine" for a real-time run:

- Interface Control Document File -- defines, for each data item,
  - item specifics such as size, item priority, etc.
  - Player (process) sending item
- Player/Host File -- defines which machine, (via IP address) in the network each player resides
- Gateway File -- defines all gateway addresses and routing information allowing any network ring to access any other ring.
- Destination Player File -- defines Player(s) receiving each data item.

These files are maintained by an operator using the Configuration Manager Software on a SUN-3 workstation. (see Figures 2 and 3). The operator then loads one each of these files into a shared memory region using the LAN Start-up software (start up mode). The Run-time Initialization sends to all other nodes in the network, node-specific subsets of the four configuration files.

The Run-time Initialization software (slave mode) following reception of the node-specific subset configuration file performs the following:

- builds the local routing table
- allocates storage for and initializes locally required input/output buffers
- allocates storage for and initializes the input/output transaction assignment queues
- allocates storage for and initializes the network traffic status logs (input and output)
- sets up pointer reference table pointers for use by Application IF and Data Transport Executive software in accessing all buffers and queues

- Verifies communications with target nodes in routing table via Comm Check messages
- Sets the node Real Net mode to real time run mode

The Initialization software (functioning as initialization master) after broadcasting the configuration file subsets to all initialization slaves, also performs the above steps. Successful master/slave initialization is verified through the exchange of a test pattern packet, using the Application Interface Send and Receive calls.

When the network is to be re-configured, (Run-time initialization mode) the operator simply loads a new set of configuration files using the LAN Start-up software. The new configuration is compared to the current configuration and all affected nodes are sent an initialization request. The interrupt handlers on the affected nodes (run-time) change the mode back to Run-Time Initialization and invoke the Run-time Initialization software, (functioning again as initialization slaves). Applications attempting data transmission/reception on the affected nodes receive wait status until re-initialization is complete. Upon reception of the new mode-specific configuration files at the attached nodes new data structures are created input/output buffers are flushed, and initialization processing is verified. The mode is then reset to run mode.

APPLICATION IF

Real Net provides three function calls (accessed as library routines, etc.) which are implemented in C, Pascal, PLM-86, and Lisp. These function calls are:

- Send (data pointer, item#, status pointer, byte count)
- Receive (data pointer, item#, byte count, player identifier, status pointer)
- Status (entry#, item#, query type, input/output, player identifier)

SEND

Send enables an application to request transfer of a data item to another process or group of processes. The destination is not known to the sending process. Parameters furnished with the send call define the transfer request to be implemented. The send call verifies the destination host address of the target process(Es) from the routing table. If any target process is resident within the sender's local machine, then Send calls Inter-Memory Transfer to copy the data into an appropriate shared memory input buffer for delivery to the target process(Es).

If any target process is located on an external host machine, then the transfer request is recorded in the Output Transaction Assignment Queue for implementation by the Data Transport Executive. The configuration files contain priority indicators for both item priority and player priority. A cumulative priority is assigned to each pending transaction in the output Transaction Assignment Queue. This cumulative priority determines the relative sequence of transfer assignments which the Data Transport Executive will enforce.

A send call returns the Output Transaction Assignment Queue entry number when successful. When unsuccessful a negative number is returned indicating the nature of the failure: (i.e., item not found in routing table, output buffers all full, etc.)

RECEIVE

A Receive call forces delivery of an input buffer item to a requesting process, when the item in question has not been previously delivered to the requesting player. Delivery masks are used to orchestrate non-redundant delivery of data to individual players. Mask values for each receiving player are computed at Run Time Initialization. Upon transfer of a data item and storage in an input buffer for delivery to target players, the delivery mask is copied into the Input Transaction Assignment Queue record, pointing at the input buffer. Upon request for the item by a player, the Input Transaction Assignment Queue record delivery mask is compared with the player's delivery mask. If the item has not been previously delivered to the requesting player, then the data is delivered and the Input Transaction Assignment Queue record's delivery mask is decremented by the player's mask. This prevents redundant delivery of data to the same player.

When no data is pending delivery for a player and item ID#, combination, a failure status is returned. Otherwise, successful status is returned and the byte count field is set to the size of the data object in bytes, and a local copy of the data buffer is provided to the requesting player.

When no data is pending delivery for a player and item ID# combination, a failure status is returned. Otherwise, successful status is returned and the byte count field is set to the size of the data object in bytes, and a local copy of the data buffer is provided to the requesting player.

STATUS

The application process may request status on pending item deliveries, or on requested transfer requests. Status requests are made for either input or output queue status as distinct calls.

When input status is requested for an item number, the call will return as the status value the number of input buffers pending delivery for the player/item ID #, combination. Zero is returned when no items are pending delivery. The application may subsequently request receipt of data items until the indicated amount of deliveries have been made.

Output status may be requested in two ways: by item ID# or by entry number (as returned in the send call). If output status is requested by item ID# the n the status field is set to the number of transactions in the Output Transaction Assignment Queue (priority sequenced) and implement all pending transfer requests. When implemented as a server process, the DTE continuously scans the Output Transaction Assignment Queue and processes transfer requests as they are recorded by other processes. The DTE server checks for higher priority transfer requests after every packet is originated. Higher priority packet requests are therefore interleaved with lower priority transfer requests. Within a priority level (0-2 for items, 0-2 for players, cumulative 0-4) transfer requests are processed on a FIFO bases. The DTE software is implemented on a separate SBC for Intel Multibus applications, similar implementations could be made available for other shared bus implementations (VME, VERSABUS, etc.).

The DTE provides the following processing functions for each requested output transaction:

- Prioritized servicing of transfer requests from multiple processes
- Protocol enforcement for Pronet, IP, and application protocols including: check sum generation, packet structure definition and header construction
- Control of gather DMA operations to assemble output packets in the LAN hardware IF board set transmit buffer
- Control of packet transfer via LAN IF library calls
- Display of network status log data (input and output) at the completion of a real-time run cycle

Run Time Initialization Processing:

The DTE suspends scanning of the Output Transaction Assignment Queue during Run Time Initialization, and resume active processing when the nodes Real Net mode is reset to real time run mode.

LAN IF

The LAN IF routines provide an interface library to invoke LAN hardware IF functions from high level application languages. Specific functions enabled include:

Hardware Checkout:

- analog and digital loop back testing
- In/Out DMA: Routines for using the on board programmable DMA controller for moving data to and from the Pronet 80 boards buffers.
- Packet Origination: Routines for introduction of a packet stored in the Pronet 80 boards transmit buffer onto the LAN for delivery at another node, output traffic is recorded in the Output Network Status Log.
- Packet Status: Routines for verifying acceptance or refusal of an originated packet by a target node.
- Interrupt Handler: Inbound packets are copied from the LAN and pre-scanned by the interrupt handler as to contents. For data item 0 (administrative packets

containing commands) appropriate responses are generated and transmitted to the Configuration Manager.

For real-time data transfers the address of an available input buffer for the item is determined, and the data contents of the packet are copied into the data buffer using the in DMA routine. The receipt is recorded in the Input Transaction Assignment Queue for delivery to the target player, counters in the Input Network Status Log are updated. When the packet received is inappropriate (not item 0 and not an item targeted for this node) the data portion is copied into a "junk" buffer.

Run Time Initialization Processing:

The interrupt handler is always active and provides routines for handling data item 0 packets. These routines enable down load and storage of the configuration files, as well as responses to Comm Check messages and other required handshake acknowledgements. When real-time data items are received during Run Time Initialization they are copied into the "junk" buffer.

HARDWARE

The hardware requirements to implement a Real Net system are flexible, and allow for mixed media LANs with disparate bandwidth communications links. Minimal hardware requirements include: (non-real time LANS (i.e., Ethernet) can also be integrated into a Real Net system assuming non-deterministic timing attributes can be tolerated).

(1) A non-contentious/deterministic serial/parallel bus system between nodes of the Real Net where:

a) distance between nodes can be > 50 ft.
b) # nodes can be > 25
c) data rate can be > 10 megabytes/second

(2) The ability to I/F to multiple local bus types, i.e.,

a) UNIBUS/QBUS
b) VME bus
c) Multi bus
d) Versabus, etc.

(3) The local bus interfaces have the ability to do DMA in/out of the local bus memory, and that control of the DMA is available directly by Real Net software drivers, i.e., there are not multiple layers of software between the Real Net software and the actual data movement hardware.

(4) All I/O operations to the local bus/Real Net bus have the ability to be interrupt driven.

The current implementation of Real Net uses Proteon Inc. Pronet 80 hardware. This hardware provides interface board, sets for VME Bus, Q Bus, Unibus, PC, Bus Multibus, and with appropriate adapter boards, virtually all commercial bus architectures. The LAN itself is a fault tolerant 80 megabit token ring.

Transmission media operations include: (slower data rates may be required for some media, but software is not impacted)

- Fiber Optic
- IBM Twinax
- Microwave
- Coaxial Cable RF (T1 and 56 KBPS serial interfaces)

Each host interface board set provides access to the LAN for packet origination and reception. An on-board programmable DMA controller chip provides the means for performing scatter/gather operations. Gather operations are used to strip header data from inbound packets, and copy data segments into appropriate input buffers for subsequent delivery.

Commercial gateways provide IP routing services between Pronet token ring networks and other commercial IP Networks.

SIMNET LONG HAUL NETWORK (LHN) OVERVIEW

Combat units at geographically dispersed SIMNET sites can participate in real-time large scale tactical exercises when their respective local area networks (LANs) are connected by a long haul network (LHN). LHN links can be land lines or satellite hook-ups. Each LAN has a small gateway computer that communicates with all the other gateways on the LHN. The LHN links and the gateways connect the LANs in a manner that is transparent to the combat vehicle simulators, thus making the simulation a single network which requires no change to the SIMNET Protocol.

Distributed Simulation Requirements for the LHN

The basic LHN requirements are the same as those for the LAN – high bandwidth, Protocol Data Unit (PDU) multicasting, negligible delay and variability of delay – but the increased data traffic over the greater distances of the LHN creates some special considerations:

- Bandwidth costs over long distances are expensive.
- While the LAN uses commercial off-the-shelf components, the LHN is largely a custom-designed network. Modifying existing networks proved extremely expensive, either in development or fielding costs.
- LHN voice communication is handled as digitized voice packets through the gateways in place of the simple radio network used with the LAN.
- Land lines are an inherently point-to-point broadcast medium. While the LAN supports direct multicasting between simulators, the LHN must rely on each gateway to make sure that all other gateways get all the network information needed by all the LANs.
- To handle the increased data traffic from so many simulators broadcasting over greater distances, the LHN uses data compression algorithms that maximize efficiency of channel usage and cut down on delay time.

SIMNET LHN Configuration

On a typical LHN, a local gateway computer communicates through dedicated data lines to all of the remote gateway computers. These, in turn, redistribute the information to the internal LANs via the SIMNET Protocol.

The SIMNET LHN currently uses the BBN Butterfly™ parallel processor as its gateway computer. The Butterfly provides maximum compatability and code sharing of digital interface signalling code, and its parallel nature allows easy upgrade if gateway or network requirements increase. Current Butterfly gateway capacity is 500 vehicles and nine land phone lines.

Butterfly is a trademark of Bolt Beranek and Newman Inc.

The current LHN land link is an AT&T single dial–up 56 kilobits/sec phone line supporting 100 vehicles each way. This is cost effective since the long distance portion of the link is engaged only when a connection is made, much like a telephone. Vehicle capacity increases as more lines are added. Higher bandwidth lines are also available, such as T1 lines operating at 1.544 megabits/sec.

Land lines are proven to be reliable and maintainable, and they do not suffer from satellite transmission delay. The advent of fiber optics means land lines will become cheaper and more secure. As land lines become even more efficient, transmission capacity will increase.

For remote sites, mobile sites, or in situations where the cost of land lines is prohibitive, the SIMNET LHN can use high bandwidth dedicated satellite channels.

Conclusion

Regardless of the distance between them, combat units are now undergoing real–time combined arms tactical training on the same simulated battlefield. The SIMNET LHN has advanced in broadcast routing, in reduction of bandwidth requirements by data compression, and in reducing delay through the simulation network. These advances mean that widely dispersed LANs of combat vehicle simulators now operate as if they were a single network. This total training approach does away with the expense of moving large numbers of men and equipment, yet provides practice in the warfighting skills that up until now could only be acheived through actual battle.

TERRESTRIAL WIDEBAND NETWORK (TWBnet) OVERVIEW

The Terrestrial Wideband Network (TWBnet) is a Defense Advanced Research Projects Agency (DARPA) – sponsored program that provides cost–effective high bandwidth packet switching betwee *various sites throughout the continental United States. The TWBnet also prc ides multicasting service (delivering the same message to multiple receivers), which makes it appropriate for Distributed Simulation applications such as SIMNET. As a result, the TWBnet will be the long haul network for the March 1990 WAREX exercise, an advanced SIMNET exercise involving 800 simulated combat vehicles communicating in real time.*

TWBnet History

The Terrestrial Wideband Network evolved out of the Wideband Network, which started in the late 1970's as a high–speed, satellite–based packet switch network. The Wideband Network was the first high–bandwidth network to provide time–division multiple–access (TDMA) service to multiple senders and receivers. The broadcast nature of the satellite links was used to provide multicasting service.

The Wideband Network went through several evolutionary changes – new and faster parallel processing hardware for the packet switches, new protocols to provide faster, more reliable and efficient communications, and network management systems to provide a more robust network. Many research applications took advantage of the services provided by the Wideband Network, particularly those needing multicasting or time–sensitive high bandwidth delivery: packet speech, video and multi–media conferencing, and work with new algorithms for file transfer and interactive computer sessions.

After more than a decade of service, the Wideband Network was transitioned to use dedicated terrestrial T1 lines in the Spring of 1989, and became the Terrestrial Wideband Network.

How does the TWBnet work?

The TWBnet uses a backbone of Wideband Packet Switches (WPS) connected by 1.5 megabits/sec. T1 terrestrial lines. Each WPS has one or several gateways connected to it, with the gateways located with the WPS or by other terrestrial lines. The gateways are connected both to hosts and local area networks.

The WPS are currently Butterfly™ parallel processors, and take traffic from their gateways and place it on the T1 backbone. Time on the backbone is divided into frames, much like a train is divided into boxcars. Each frame, or box car, is dedicated to one WPS according to the competing needs of all of the WPS. A sophisticated algorithm for frame reservations prevents the collision of frames. Since the T1 lines are full duplex, one set of frames runs one way through the backbone and another independent set runs the other way. In this way, all information sent by one WPS gets to all others without having store–and–forward delays.

Butterfly is a trademark of Bolt Beranek and Newman Inc.

Requests for bandwidth are done with the Stream Transport (ST) protocol. The ST protocol provides the concept of a virtual multicast circuit, allowing the WPS to reserve frames in advance for the data. Therefore, with ST there is no delay while waiting for the frame reservation process.

Network monitoring takes place both over the TWBnet and through the Internet, with the Network Operations Center (NOC) located in Cambridge, MA.

How is SIMNET using the TWBnet for WAREX 3/90?

WAREX 3/90 is a multiple–site advanced distributed simulation exercise. Up to 800 vehicles (manned simulators and human controlled, computer–generated opposing forces) will participate at four sites in the continental United States. Up to 12 radio voice channels will be provided over the network between the sites. The total traffic for voice and simulation data is expected to be near 1 megabit/sec.

Each SIMNET site participating in WAREX 3/90 is being provided with an ST gateway which will provide service directly to the SIMNET Ethernet™. The ST gateway will also provide standard DoD Internet Protocol service (which allows Telnet, FTP, etc.) to each site. The ST gateway will be reading the SIMNET Protocol packets from the local Ethernets™, adding an appropriate ST header, and handing them to the WPS for transmission over the TWBnet.

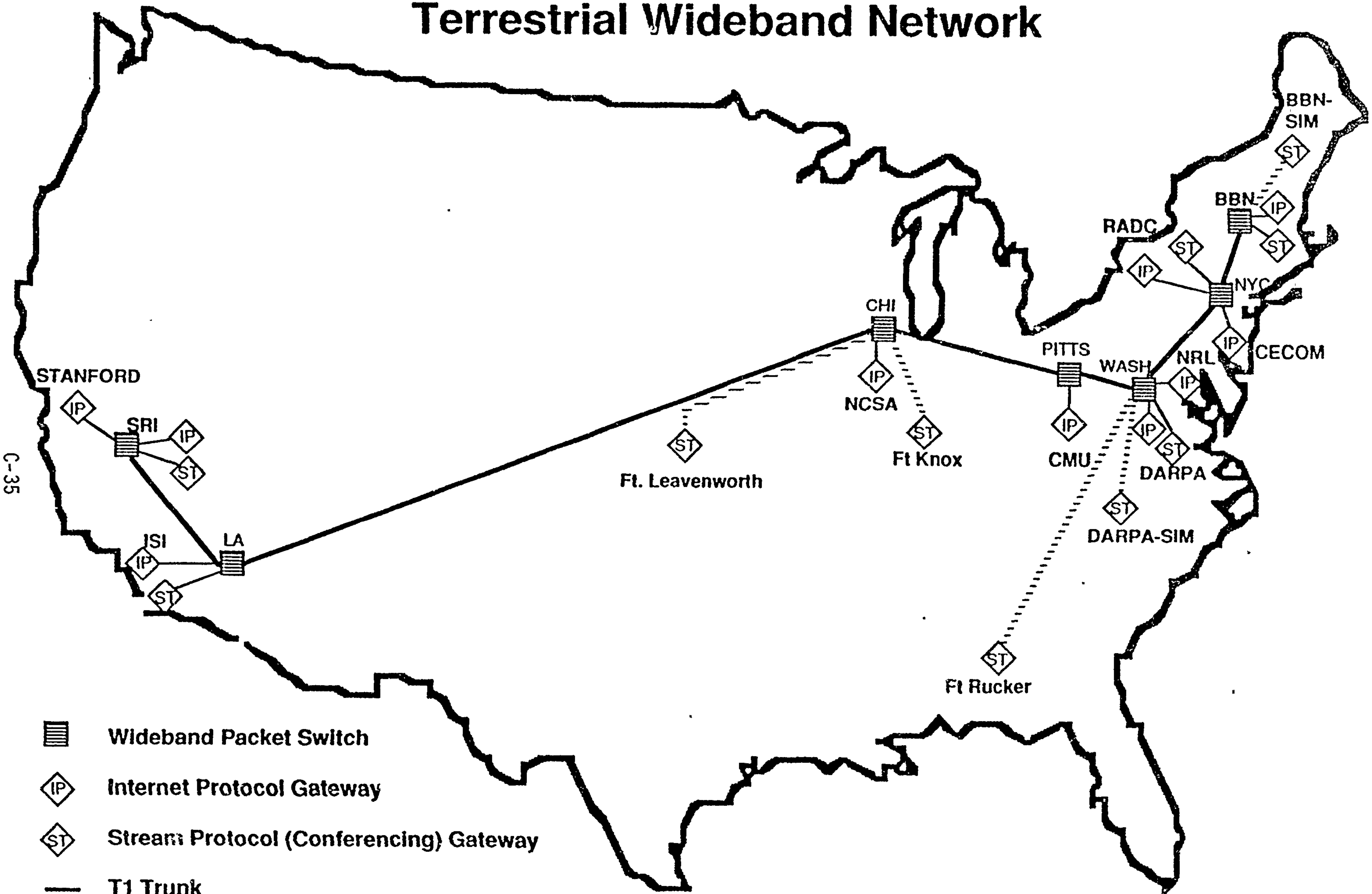
The sites participating in WAREX 3/90 are Ft. Leavenworth, KS, Ft. Knox, KY, Ft. Rucker, AL, and SIMNET–Washington. Developers will be observing from Cambridge, MA. Most of the traffic will be coming from the three Forts, with all traffic being carried to all sites.

Conclusion

The Terrestrial Wideband Network is an effective multiple–user carrier. By providing high–bandwidth, low–delay service to many users, it lowers the cost to each user. The effectiveness of its use for a demanding application will be shown by WAREX 3/90, a SIMNET exercise with many vehicles operating in real time.

Ethernet is a trademark of the Xerox Corporation.

Terrestrial Wideband Network



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APPENDIX D

View Graphs and Documents for the
Terrain Databases
Working Group Breakout Sessions

Terrain Database Working Group

Second Workshop on Standards for the Interoperability of Defense Simulations

15-16 January 1990

Hyatt Orlando Hotel

George E. Lukes

U. S. Army Engineer Topographic Laboratories

Fort Belvoir, Virginia

Diverse Terrain Database Applications

- Visual Out-the-Window Displays
- Radar Displays
- Infrared Displays
- Plan View Displays
- Hardcopy Maps
- Planning for Semi-Automated Ground & Air Vehicles
- Calculations
  - Ballistics
  - Intervisibility, coverage diagrams
  - Route selection, spatial reasoning
- Other

Open Issues

- Geodetic Frame-of-Reference
- Correlation parameters and metrics
- Extensions to Project 2851
- Interim Terrain Database (ITD) Assessment
  (content, currency, metric accuracy, etc.)
- Dynamic Terrain
- Coordination within DMA Standards Activities

Interim Terrain Database

New DMA Interim Terrain Data (ITD) is the only near-term source of standard digital terrain data to support ground forces:

- Digitized 1:50,000 Tactical Terrain Analysis Database
- Digitized 1:250,000 Planning Terrain Analysis Database
- 1,200 Sheets of Germany & Korea by 1994
- To support operational systems (DTSS, ASAS)
- Initial datasets available to DoD contractors under:
  - relevant on-going contracts
  - Army R&D Unfunded Study Program
- Fact sheets distributed

Project 2851

Project 2851 represents emerging specification and production system to produce DoD Standard Simulator Databases:

- IOC 1991 in St. Louis facility
- Focused on visual and sensor simulators
- Draft Specification for Generic Transform Database (GTDB)
- New provisions for XDFAD Output
- New provisions for grid and TIN terrain repesentations
- Simulation networking requirement not originally envisioned
- Unmanned systems not currently scoped
- Ready to consider additional requirements

SIMNET Database Interchange Specification

Under the SIMNET Program, BBN is developing a SIMNET Database Interchange Specification (SDIS) as an exchange format for SIMNET databases

- Documented in BBN Report 7108
- Based on ASN.1 (ISO 8824 & 8825)
- Hand-crafted "Bald Hills" dataset illustrates concept
- Initial dataset distributed to 10 sites
- SIMNET Hunter-Liggett dataset (8 km x 8 km) to follow

Terrain Database Working Group Agenda

Tuesday -- 15 January 1990

1:30 pm - 3:00 pm **Terrain Database Working Session**

- Interim Terrain Database (ITD) Update
  Juan Perez, ETL Digital Concepts & Analysis Center

- Project 2851 Update
  Tony DalSasso, ASD/YWB, Wright Patterson AFB

- SIMNET Database Interchange Specification (SDIS) Update
  Pete Wever, BBN Systems and Technology Corp.

Terrain Database Working Group Agenda

Tuesday -- 15 January 1990

3:30 pm - 5:00 pm **Subgroup Overviews and Testimonials:**

- Correlation -- Duncan Miller, BBN
- Dynamic Terrain -- Richard Moon, E&S
- Geodetic Frame of Reference -- Jerry Burchfiel, BBN
- Unmanned Forces -- Dexter Fletcher, IDA

7:00 pm **Subgroup Working Sessions**

SECOND WORKSHOP ON STANDARDS FOR THE INTEROPERABILITY OF DEFENSE SIMULATIONS

TERRAIN DATABASE WORKING GROUP

These notes augment the summary briefing charts presented in the final session of the Workshop on 17 January 1990 and address the specific issues identified in the opening session.

1. COORDINATION WITH DMA

Continuing coordination with the Defense Mapping Agency (DMA) on specific product requirements is being handled by DOD Service Labs/Staff and/or Joint Offices. Area coverage requirements will be handled primarily through Unified and Specified (U&S) Commands.

Terrain database issues in simulation networking require continuing coordination between P2851, PM-TRADE, ETL, TRADOC TSM and DARPA.

2. INTERIM TERRAIN DATA ASSESSMENT/ITD

ETL is working with PM-TRADE to investigate ITD related issues in conjunction with P2851 and SIMNET. Coordination among PM-TRADE, ETL, DARPA, P2851 will be necessary for ITD assessment, with additional support from BBN, IST, and PRC.

3. PROJECT 2851 ECP ASSESSMENT/ITD

See ITD assessment/ITD (Item #2 above).

4. GEODETIC FRAME OF REFERENCE

The Working Group recommended adoption of the DMA World Geodetic System (WGS 84).

5. DEVELOPMENT OF CORRELATION PARAMETERS AND METRICS

See Subgroup Chairman Duncan Miller's viewgraphs.

6. DYNAMIC TERRAIN FEASIBILITY/METHODOLOGY

See Subgroup Chairman Richard Moon's viewgraphs.

7. INCREASE SIZE OF GAME BOARD

The Working Group recommended use geocentric Cartesian coordinates in network protocol to support potentially global "gaming boards". Standard conversion routines for soldier-machine interfaces to-and-from geographic coordinates and MGRS are needed with test data sets for validation testing.

8. SPHERICAL EARTH MODEL (Lat/Long)

The Working Group recommended adoption of geographic coordinates (latitude/longitude/altitude) for standard Navy and Air Force soldier-machine interfaces and MGRS (UTM and UPS) for standard Army soldier-machine interfaces.

Coordinate systems transformation need to preserve relevant tactical effects of curved earth (finite distance to horizon) in computer image generation.

9. DEFINITION OF SOLID MODELING TECHNIQUE
Working Group anticipates use of Project 2851 (P2851) solid modeling techniques and libraries. P2851 has adopted a constructive solid geometry (CSG) approach to build Standard Simulator Data Base (SSDB) models. SSDB CSG models are transformed into polygonal models based upon target IG's performance capabilities and distributed in GTDB format.of this software is ongoing; anticipate completion in early February 1990. A limited number of transformed models will be included within GTDB data sets to be distributed beginning in April 1990.

10. DEFINITION OF TEXTURE REPRESENTATION

Project 2851 presently does not include a representation of texture maps. Proposed engineering change (ECP) currently in evaluation would add geospecific (photo) and generic texture map representations. Proposed capabilities are to be fully integrated within the Project 2851 system in mid-1992. Distribution of sample GTDB's with texture maps would be scheduled for early 1992.

11. DISTRIBUTION FORMAT

Working Group recommended adoption of the Project 2851 GTDB as the future distribution format. Specification is available now. Two types of GTDB are supported: (1) gridded-terrain/vector culture; and (2) polygonal-terrain/vector or polygon culture. Gridded GTDB's are critical to support many existing CIG architectures as well as semi-automated forces (SAF) and hard-copy/soft-copy cartographic displays. Polygonal GTDB's are designed to maximize correlation between a family of existing and anticipated heterogeneous CIG architectures. Sample GTDBs to be produced beginning in April and distributed to ISWG.

12. DATABASE REPOSITORY ORGANIZATION

The Working Group recommended adoption of the proposed Project 2851 repository at DMA Aerospace Center, St. Louis, MO. Initial operational capability (IOC) is scheduled for May 1991. The proposed P2851 facility is to be administered by DMA, managed by a tri-service liaison board, and contractor-operated.

13. SEMI-AUTOMATED FORCES (Unmanned Vehicles)

See Sub-Group Chairman Dexter Flecher's viewgraphs.

23 January 1990

George E. Lukes, Chairman
Terrain Database Working Group

COORDINATE SYSTEM CONVERSIONS

APPROXIMATE METHOD

U. S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
FORT BELVOIR, VIRGINIA

ISSUE:

HOW TO TRANSFORM GROUND COORDINATES FROM ONE SYSTEM TO ANOTHER IN A SIMPLE, SPEEDY AND ACCURATE MANNER.

WHY?

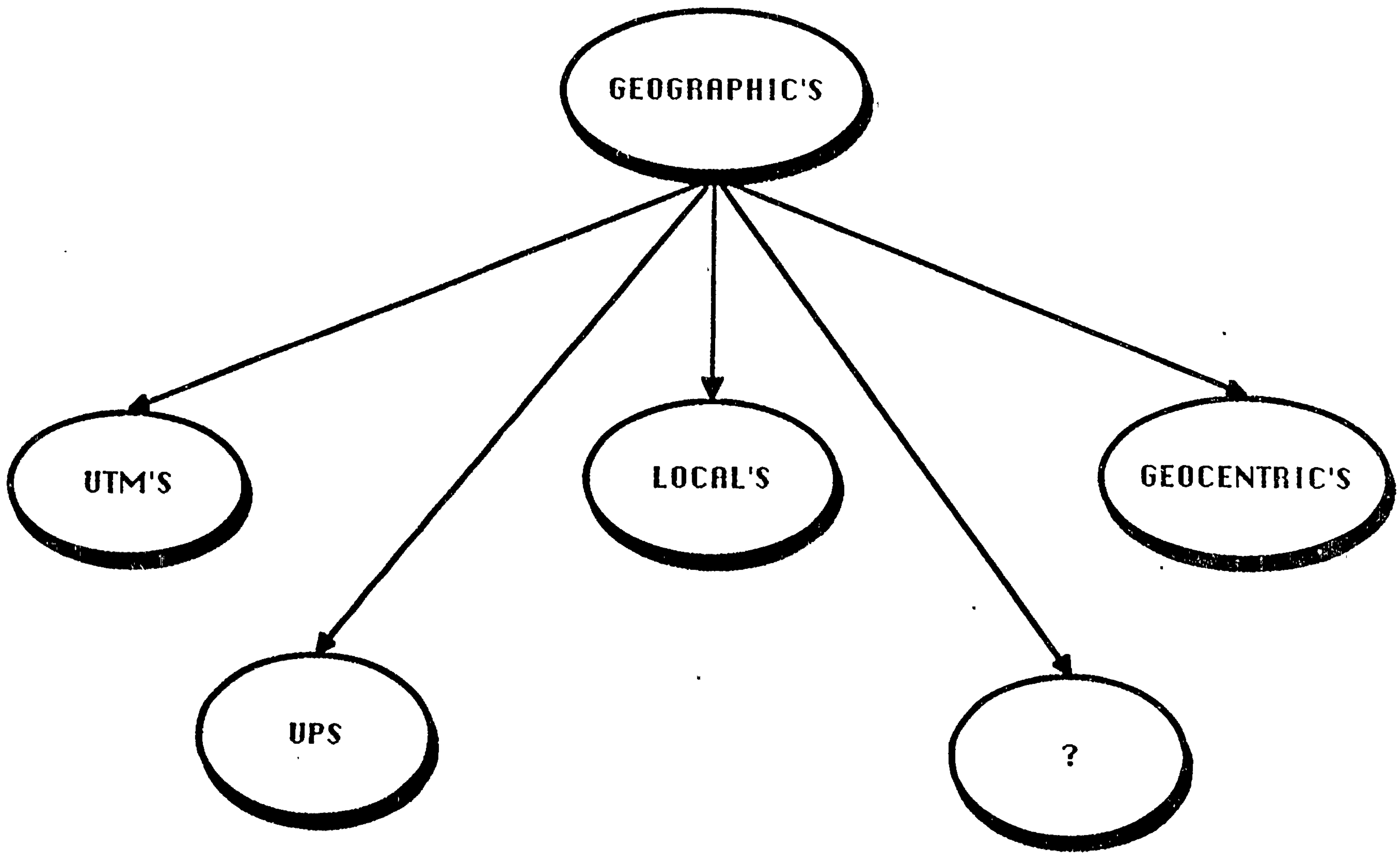
VARIOUS SIMULATORS MAY HAVE INTERNAL, USER-DESIGNED COORDINATE SYSTEMS. CONVERSION OF OUTPUT COORDINATES TO A GLOBAL SYSTEM IS REQUIRED FOR INTERFACE TO OTHER USERS.

CANDIDATE METHODS:

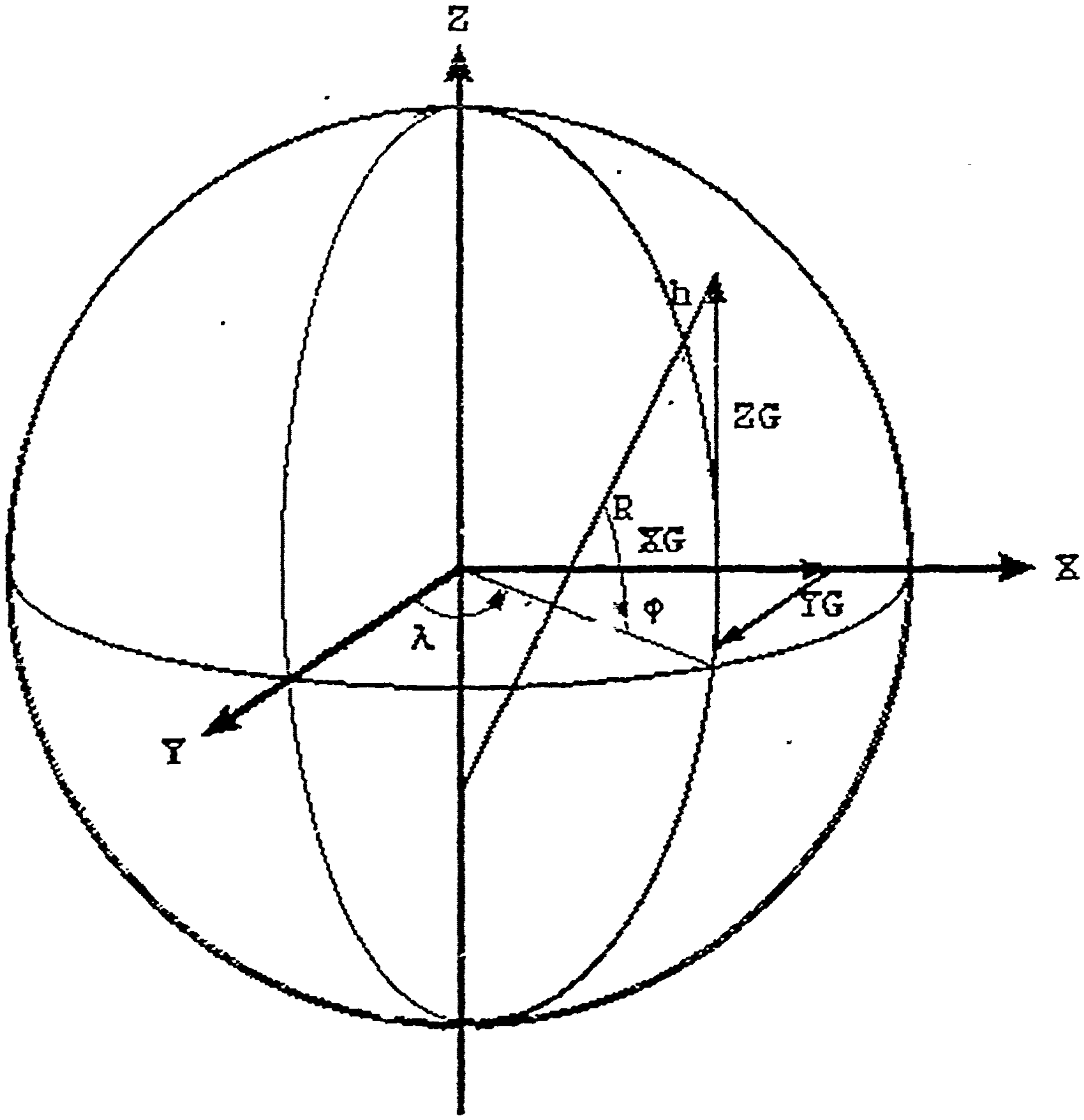
RIGOROUS COMPUTATIONS

APPROXIMATE POLYNOMIAL TRANSFORMATIONS

BASIS FOR COORDINATE TRANSFORMATIONS



GEOCENTRIC COORDINATES

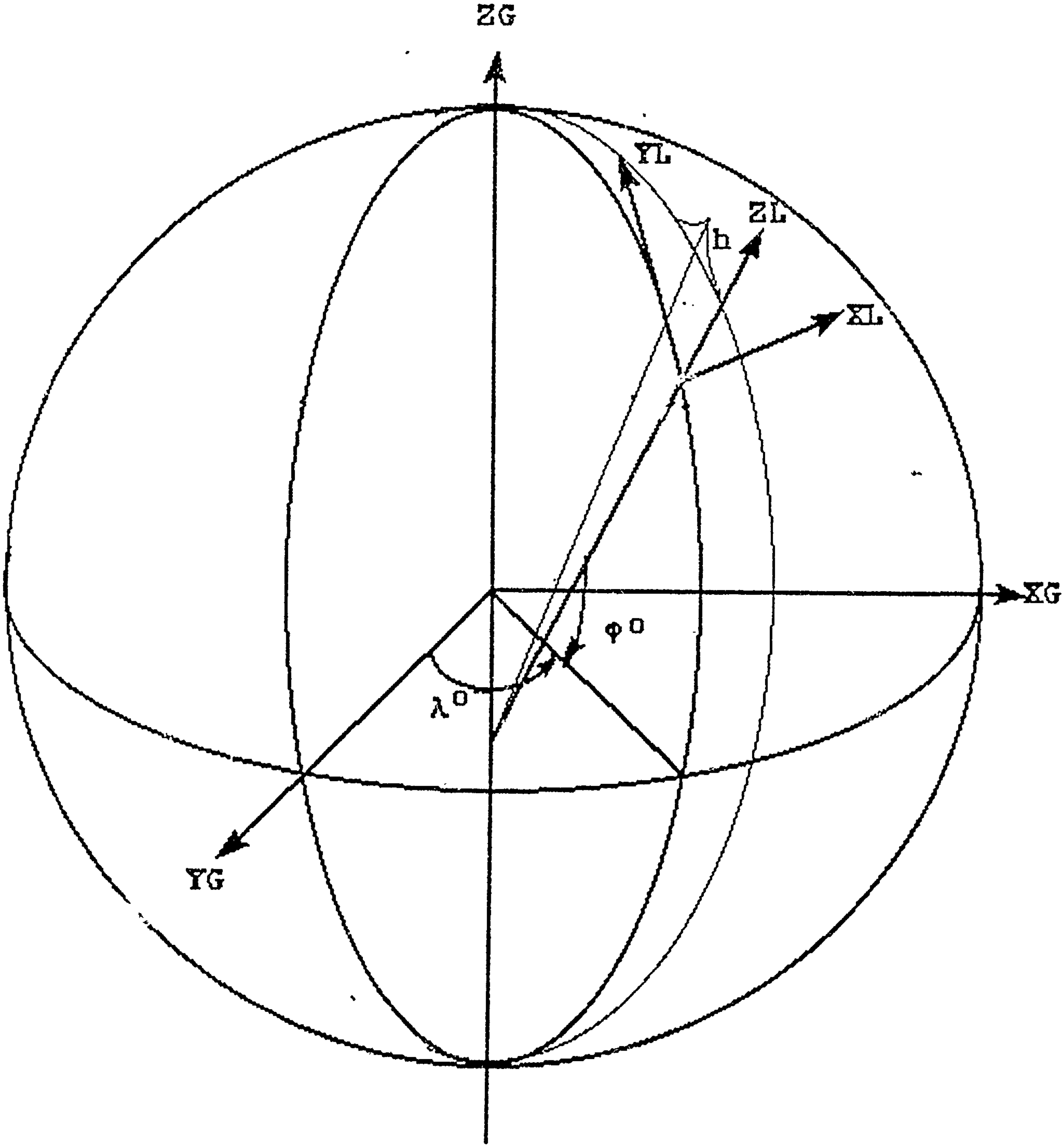


$$XG = (R + h) * \cos\varphi * \sin\lambda$$

$$YG = (R + h) * \cos\varphi * \cos\lambda$$

$$ZG = (R (1 - e^2) + h) * \sin\varphi$$

LOCAL RECTANGULAR COORDINATES
(CARTESIAN)



UNIVERSAL TRANSVERSE MERCATOR (UTM)

$$\text{EASTING} = .9996 * R * X + 500000.$$

$$X = d\lambda * \cos\varphi + d\lambda^3 * \cos^3\varphi * (1 - t^2 + n^2)/6$$

$$+ d\lambda^5 \cos^5\varphi (5 - 18t^2 + t^4 + 14n^2 - 58t^2 n^2)/120$$

$$+ d\lambda^7 * \cos^7\varphi * (\ldots\ldots\ldots\ldots)$$

$$\text{NORTHING} = .9996 * (S + R * Y)$$

$$Y = d\lambda^2 * \sin\varphi * \cos\varphi/2$$

$$+ d\lambda^4 * \sin\varphi * \cos^3\varphi (5 - t^2 + 9n^2 + 4n^4)/24$$

$$+ d\lambda^6 * \sin\varphi * \cos^5\varphi * (61 - 58t^2 + t^4 \ldots)$$

$$S = a(1-e^2)*(A*\varphi-B*SIN2\varphi/2+C*SIN4\varphi/4-D*SIN6\varphi/6)$$

$$\begin{aligned}
A &= 1 + 3e^2/4 + 45*e^4/64 + 350*e^6/512 \\
B &= 3e^2/4 + 15*e^4/16 + 525*e^6/512 \\
C &= 15*e^4/64 + 105*e^6/256 \\
D &= 35*e^6/512
\end{aligned}$$

$$R = a/SQRT(1 - e^2*SIN^2(\varphi))$$

a ...... Semi Major Axis of Spheroid
R ...... Radius of Earth in Prime Vertical
e ...... Eccentricity of Spheroid
φ ...... Latitude of point
$d\lambda$ ...... Longitude of pt from Central Meridian

$$\begin{aligned}
t &= TAN\varphi \\
e'^2 &= e^2/(1-e^2) \\
n^2 &= e'^2*COS^2\varphi
\end{aligned}$$

TRANSFORMATION POLYNOMIALS

<u>6-TERMS</u>

$$XC = a_0 + a_1*XM + a_2*YM + a_3*XM^2 + a_4*YM^2 + a_5*XM*YM$$

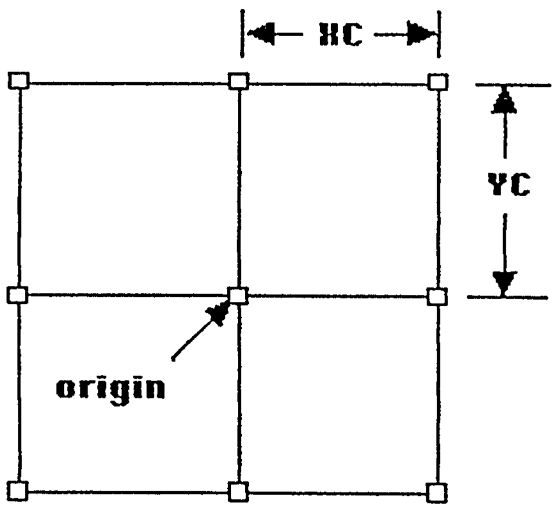
$$YC = b_0 + b_1*XM + b_2*YM + b_3*XM^2 + b_4*YM^2 + b_5*XM*YM$$

<u>9-TERMS</u>

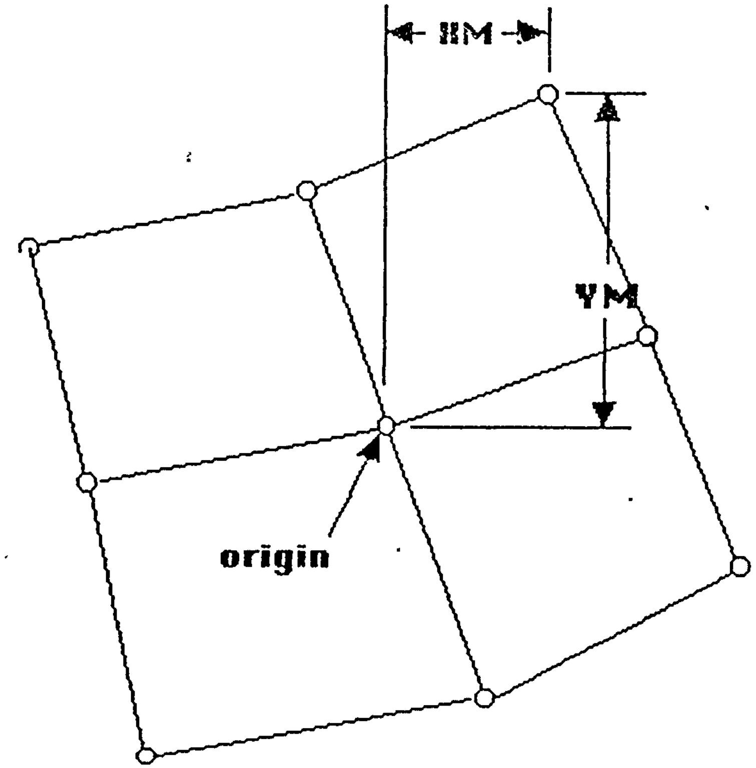
$$XC = a_0 + a_1*XM + a_2*YM + a_3*XM^2 + a_4*YM^2 + a_5*XM*YM$$
$$a_6*XM*YM^2 + a_7*YM*XM^2 + a_8*XM^2*YM^2$$

$$YC = b_0 + b_1*XM + b_2*YM + b_3*XM^2 + b_4*YM^2 + b_5*XM*YM$$
$$b_6*XM*YM^2 + b_7*YM*XM^2 + b_8*XM^2*YM^2$$

GEOGRAPIC VS UTM GRIDS



GEOGRAPHIC'S



UTM'S

ACCURACY TESTS

AREA OF COVERAGE

	15 min (27x22 km)		30 min (55x44 km)		45 min (82x67 km)		60 min (110x89 km)	
	max error (meters) in East and North							
	e	n	e	n	e	n	e	n
6-TERM	.014	.006	.119	.049	.375	.166	.889	.395
9-TERM	.001	.000	.007	.001	.025	.004	.059	.010

TIMING TESTS

(1 MILLION PTS)

	SG-4D/80GT	VAX 780
6-TERM	13 secs	141 secs
9-TERM	18 secs	218 secs
RIGOROUS	90 secs	1461 secs

INTERIM TERRAIN DATA (ITD) FACT SHEET

BACKGROUND

The Army, through the Engineer Topographic Laboratories (USAETL), Digital Concepts and Analysis Center (DCAC), is committed to ensuring that Army's near-term requirements for a tactical-level digital terrain analysis product are fulfilled by an acceptable means. During 1988, both USAETL and the Office of the Deputy Chief of Staff for Intelligence (ODCSINT), represented Army in discussions with the Defense Mapping Agency (DMA) to provide an interim terrain data (ITD) product to adequately and expediently service Army's near-term requirements. Subsequently, DMA committed to producing a volume of ITD to support the operational requirement of the Army's Digital Topographic Support System (DTSS). DMA delivered, to Army, draft Interim Terrain Data Prototype Product Specifications in Sep 88, and a prototype data set in Dec 88. The Army evaluated their suggested approach in terms of the data sets' user-friendliness, and ease of production, and recommended changes, some of which have already been implemented by DMA

DISCUSSION

During Oct 88, DCAC conducted an in-depth evaluation of the draft ITD product specifications with technical support provided by in-house personnel and DCAC's engineering support services contractor, with comments furnished to DMA in a technical report. As stated in the draft ITD prototype product specifications, DMA proposes building ITD data sets initially through software conversion of existing Terrain Analysis Production System (TAPS) data, then by digitizing hardcopy (analog) tactical/planning terrain analysis data bases (T/PTADB's) and finally by new product generation via the DMA Mk.85 Feature Extraction System (FE/S) using data collection software designed for terrain analysis. In December 1988 DMA delivered the first ITD prototype data set to the Army. DMA produced the prototype through a conversion of the six (6) 15' x 15' cells of DTD generated from the [now defunct] TAPS. The TAPS software conversion process included both data exchange format and coding scheme changes.

The majority of the ITD data sets will be produced from existing analog products and will consist of 6 (six) segregated files that represent the T/PTADB terrain feature data themes of surface configuration (slope), surface drainage, surface materials (soils), vegetation, transportation and obstacles. For all ITD data sets, terrain elevation data is provided as DMA Digital Terrain Elevation Data DTED Level 1 (three arc-second data). The ITD product data exchange format is DMA's Standard Linear Format (SLF) and the feature/attribute coding scheme is the DMA Feature File (DMAFF).

The current DMA production schedule for ITD calls for the production of 20 cells in FY89. These 20 cells include 4 cells Fort Hood, Texas (U), 1 cell Middle East (C), 1 cell Korea (C), and 14 cells Europe/Germany (C). DMA began producing these data in Jun 89. The Middle East cell will be a digitized PTADB (1:250,000); the other 19 cells will be digitized TTADBs. Based on the current schedule, ITD production for the outyears will likely be 150 cells (FY90), 180 cells (FY91), 252 cells (FY92), 300 cells (FY93), and 300 cells (FY94). Testing and evaluation of DMA's ITD production system commenced in Apr 89 with the generation of an initial (test) data cell over Germany.

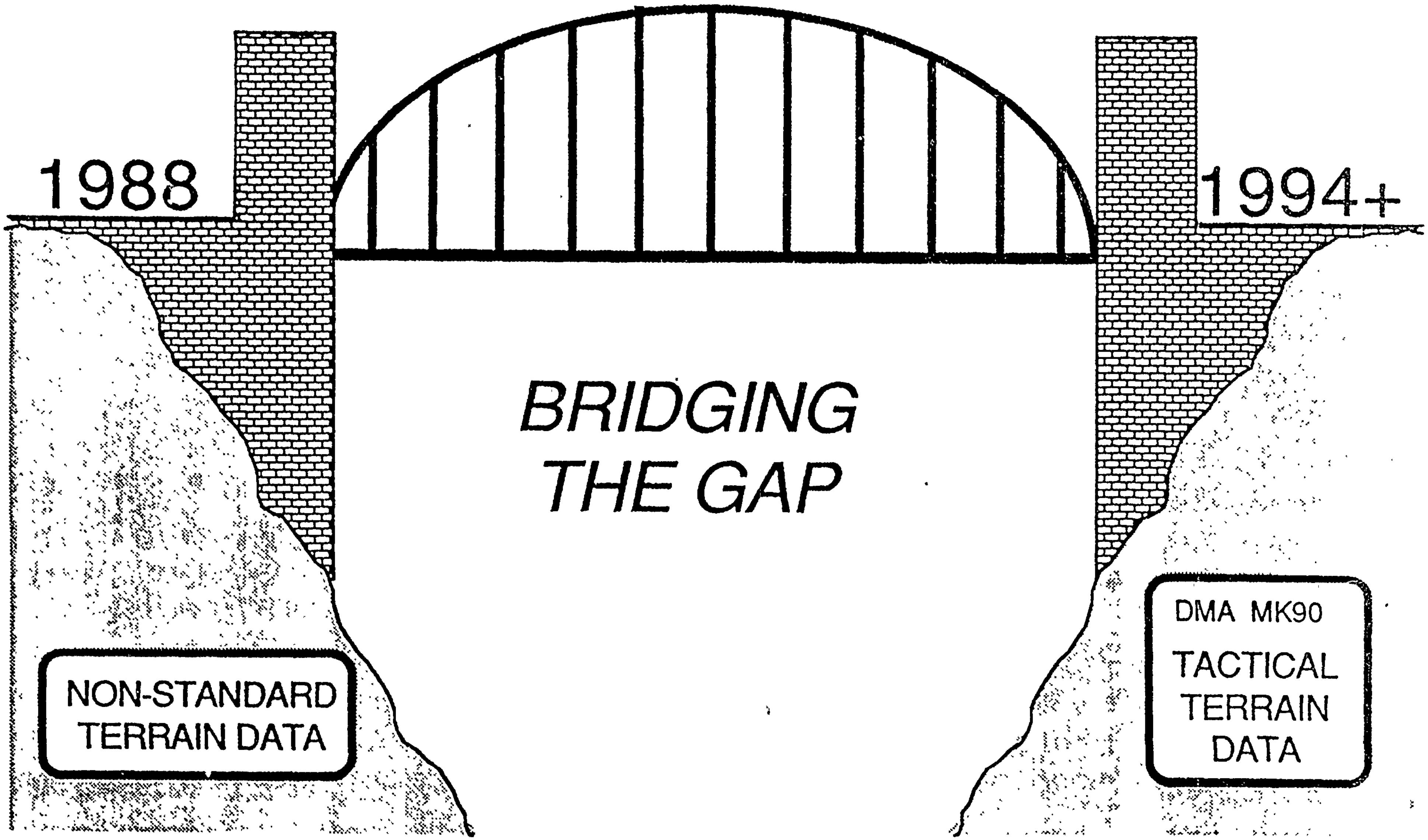
DCAC is currently investigating other ITD and ITD-related issues including Army co-producibility of ITD, data structure, format and coding scheme conversions, and quality control software development. DCAC conducted a technical evaluation of the completed ITD prototype data set. Participants in the evaluation process were the DTSS contractor and ETL Geographic Systems Laboratory personnel that are supporting the DTSS program. DCAC and GSL personnel will continue to monitor the ITD production program, DCAC also plans to evaluate a production-quality ITD cell in the near future.

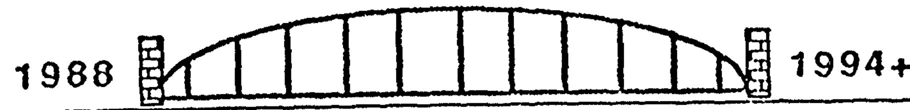
The points of contact for ITD within the Army are as follows:

ODCSINT: MAJ Kurt Hovanec, commercial 202-695-5509, AUTOVON 225-5509
USAETL: Mr. Francis Capece, commercial 202-355-2804, AUTOVON 345-2804

Date of last revision: 15 August 1989

INTERIM TERRAIN DATA





ITD - BRIDGING THE GAP

INTERIM TERRAIN DATA (ITD)

A TACTICAL-LEVEL DIGITAL PRODUCT THAT
WILL SUPPORT ARMY'S NEAR-TERM (1988-1994+)
TACTICAL AND ANALYSIS COMMUNITY REQUIREMENTS
FOR DIGITAL TERRAIN DATA SETS

1988 1994+

ITD - BRIDGING THE GAP

INTERIM TERRAIN DATA (ITD)

OBJECTIVES:

- SUPPORT FIELDING OF DTSS AND OTHER TACTICAL SYSTEMS
- LIMIT NEAR-TERM PROLIFERATION OF NONSTANDARD DIGITAL TERRAIN DATA PRODUCTS

1988 1994+

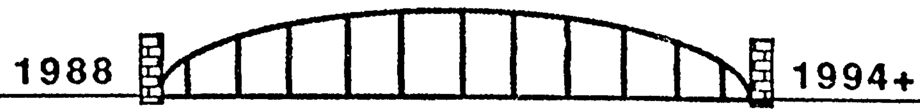
ITD - BRIDGING THE GAP

INTERIM TERRAIN DATA (ITD)

<u>CONTENT</u>

SURFACE CONFIGURATION (SLOPE)	OBSTACLES
SURFACE MATERIALS (SOILS)	VEGETATION
SURFACE DRAINAGE	TRANSPORTATION

DIGITAL TERRAIN ELEVATION DATA (DTED LEVEL 1) WILL BE PROVIDED



ITD - BRIDGING THE GAP

INTERIM TERRAIN DATA (ITD)

<u>DATA STRUCTURE:</u> VECTOR

<u>EXCHANGE FORMAT:</u> 2-D STANDARD LINEAR FORMAT (SLF)
[2ND ED, APR 86]

<u>CODING SCHEMA;</u> DMA FEATURE FILE (DMAFF)
[2ND ED, FEB 85 DRAFT]

APPLICATIONS

ITD WILL BE THE PRIMARY TACTICAL- LEVEL DTD INPUT TO THE DIGITAL TOPOGRAPHIC SUPPORT SYSTEM (DTSS) IN THE NEAR-TERM

DTSS MISSION : PROVIDE AUTOMATED TERRAIN ANALYSIS SUPPORT TO THE ARMY ENGINEER TOPOGRAPHIC UNITS

DTSS APPLICATIONS:

- MASKED AREA PLOTS
- 3D PERSPECTIVE VIEWS
- BRIDGE/ROUTE CLASSIFICATION
- POTENTIAL AVENUES OF APPROACH
- LINE OF SIGHT PROFILES
- DROP/LANDING ZONES
- CROSS-COUNTRY MOVEMENT
- POTENTIAL RIVER-CROSSING SITES

ADDITIONAL APPLICATIONS

MAP BACKGROUND DISPLAY

AIR ROUTE PREDICTION/CORRELATION

GROUND ROUTE SELECTION/NAVIGATION

SENSOR MANAGEMENT/CORRELATION

MISSION PLANNING

LOGISTICS/INVENTORY MANAGEMENT

TRAINING

TERRAIN/THREAT ANALYSIS

ITD Potential as a Digital Terrain Data Base to Support Ground Forces Simulation

- Determine Applicability as Source to P2851/RRDB DBs
- Study Implementation on Army Training Simulators

BBN Systems and Technologies Corporation

A Subsidiary of Bolt Beranek and Newman Inc.

Report No. 7140

TERRAIN REASONING IN THE SIMNET SEMI-AUTOMATED FORCES SYSTEM

Thomas Stanzione

October 1989

Presented at the Geo'89 Symposium on Geographical Information Systems for Command and Control, SHAPE Technical Centre, The Hague. The Netherlands, October 1989.

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Prepared by:

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1. Abstract

Terrain reasoning is an important component of military mission planning, and must be present in any combat simulation in order to provide realistic training. The Semi-Automated Forces (SAF) system, which is a part of the DARPA SIMNET program, is a realtime, large scale, high resolution, man in the loop combat simulation system, which provides continuous simulation at all levels, from individual vehicles to large (regimental) units. The SAF system contains a terrain reasoning component, which provides realism to the SAF vehicles and assists the SAF unit commander with mission planning. This system works at all levels of the simulation, from the individual vehicle level to the highest echelon level, and incorporates multiple terrain reasoning applications. At the vehicle level, the terrain reasoning system performs local area reasoning, which includes finding defensive positions and avoiding obstacles, such as water, buildings, and other vehicles. At the higher echelon levels, this system performs reasoning with map-like objects, such as roads, avenues of approach, and rivers, to support operations like route planning and coordinated bridge crossings. For most missions, this system provides seamless performance at all levels of the simulation. For example, avenues of approach and unit boundaries are utilized to generate routes for a unit and its sub-units, then individual vehicles perform the local area reasoning as they follow those routes. The system interacts with battlefield environment models, including intelligence, electronic counter measures (ECM) and meteorological models, in order to provide realistic mission planning. For example, routes generated from just the terrain may be modified based on intelligence data, such as known enemy locations, or meteorological data, such as poor mobility due to weather conditions.

A powerful terrain representation has been developed to support the terrain reasoning component of SAF. This representation is an object-oriented, quadtree based approach, which allows data objects to be stored in different ways at different levels of abstraction. This allows reasoning to be performed quickly over large areas of the terrain and then focused in on smaller areas for more exact reasoning. For example, roads can be stored very accurately at the lowest level of the tree, so that individual vehicles can follow them and not run off of them. At a higher level, a road network which approximates each road as a straight line segment between intersections can be stored, which can be used to quickly find shortest routes over large distances. The terrain representation also supports dynamic terrain, so that the exact state of the simulated battlefield can be represented. Dynamic terrain allows simulation objects to effect the terrain, such as destroy bridges or generate minefields. This representation provides for realtime modification so that these dynamic terrain effects are incorporated into the terrain reasoning process.

An important component of the terrain reasoning system is the unit commander operating the workstation. A powerful soldier-machine interface allows the results of the terrain reasoning process to be monitored and modified by the commander at any time. The terrain reasoning system is not dependant on the commander, but he provides a supervisory component to it. He may provide additional collateral information to the planning process, such as suspected enemy positions, in order to regenerate a set of routes, or he may modify the results of the planning process, such as moving waypoints along a generated route. He may enter battlefield control measures, such as phase lines and unit boundaries, which are also utilized by the terrain reasoning process, so that routes stay within designated sectors and allow the units to reach a particular location at a particular time. He may perform these modifications at any time, so that a mission can be redirected based on modified terrain reasoning results. The terrain representation in this system allows the terrain to be displayed and updated rapidly, so the commander can view a map of the terrain along with the battlefield control measures. The quadtree approach allows rapid retrieval of user selected areas of the terrain, so the commander can magnify or scan to a section of the map quickly.

2. Introduction

The SIMNET program, an advanced technology project sponsored by the Defense Advanced Research Projects Agency (DARPA) in close cooperation with the Army, contains a Semi-Automated Forces (SAF) system, which utilizes a terrain reasoning subsystem. SIMNET [11, 12] utilizes a large scale network of low-cost, full-crew tank and aircraft simulators, which allow the Army to conduct platoon-, company-, and battalion-level exercises incorporating all of the tactical, logistic, administrative, and communication elements that are critical to actual field operations. The SAF system [2, 3] allows exercises at the regiment and above levels to be run without requiring large numbers of fully crewed simulators. SAF allows a complete battalion to be controlled from a single workstation and is fully integrated into SIMNET, so that, at any level, fully crewed simulators can take the place of a SAF vehicle. This system operates within the SIMNET environment, where it must exhibit realistic behavior in order to engage in combat with manned simulators, and it must fight to win in that environment.

In order for any combat simulation to be effective, the simulation system must be able to reason about terrain, explain that reasoning to the user, and rapidly display the terrain through a powerful user interface. At the heart of any combat simulation is a requirement for intelligent reasoning over terrain for mission planning. This ranges from micro-terrain navigation and route planning for individual vehicles (such as SIMNET semi-automated vehicles or autonomous land vehicle simulations) to mission planning for large units. The terrain reasoning process must take place at various levels within the simulation, as shown in Figure 1. At the highest level, human level reasoning using map objects, such as roads and avenues of approach must take place. At an intermediate level, automated terrain reasoning, using similar map objects, must be performed. At the lowest level, vehicle level reasoning of local terrain, such as soil type covered or terrain slope, must take place.

When real world terrain reasoning occurs, many terrain factors are taken into account. Networks of road and water systems are used to find the best routes between locations. Cross country mobility factors based on attributes such as slope, soil type and weather are used in planning unit movements. Visibility factors such as hill tops and tree cover, and vulnerability factors, such as bridges and canyons, all play a part in reasonable terrain reasoning. This paper describes some of the research into data representation and reasoning techniques performed at BBN, along with their testing and use in the SIMNET environment, in order to provide a real-world solution to semi-automated terrain reasoning.

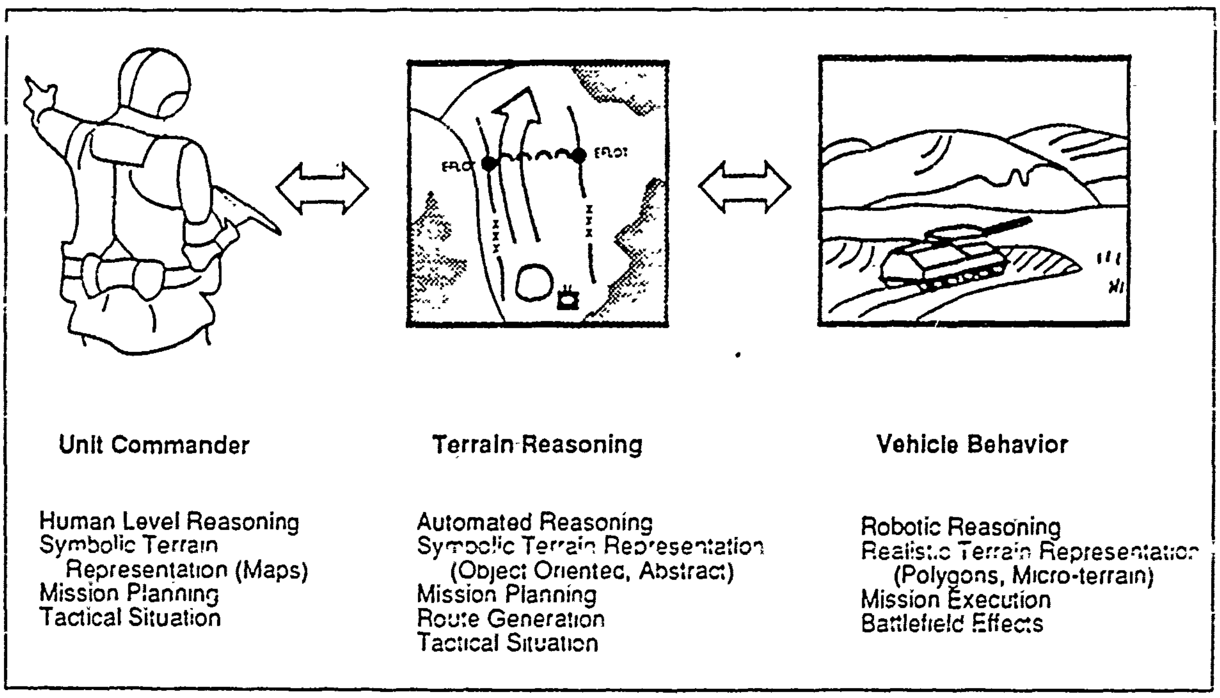

Figure 1
Terrain reasoning within a combat simulation is performed at various levels.

3. Terrain Representation

3.1. Requirements

Military terrain reasoning for mission planning is generally performed using maps of the battle area. Terrain features are represented as abstract objects with specific attribute information displayed along with feature locations. Spatial relationships of these objects are interpreted by the user based on these locations. For automated terrain reasoning, the terrain features used have to be represented similarly. Therefore, the terrain representation is a large factor in the ability to reason about the terrain. The representation should have the following characteristics:

- Be object oriented, to allow various classes of terrain objects and their relationships to be stored.
- Support rapid search techniques to allow high level reasoning to be performed in a reasonable time.
- Be easily expandable, so that new static object types can be added to it and also to allow dynamic terrain to be added and deleted during runtime.
- Provide connectivity information along with supporting static information, to assist the reasoning process. For example, distances along road segments within a road network can be added when the road network is generated, so that this information will not have to be calculated at runtime.
- Support logical operations on area objects since many different area objects can overlap. For example, one of the reasoning processes might be to determine the intersection of a mobility corridor and a minefield in order to find a safe passage to an objective.
- Handle different objects in different ways in order to be most efficient. For example, linear objects should be stored in some type of networks so that their connectivity is represented, whereas area objects should be represented in such a way that their geometry is preserved.
- Allow the terrain objects to be displayed efficiently and quickly, since most military applications of terrain reasoning require the results to be displayed over a representation of the underlaying terrain. The terrain should retain its object oriented structure when displayed, so that the user can interact with it.
- Be as compact as possible. This will provide more rapid searching during terrain reasoning, limit the amount of data necessary in computer memory when drawing and during searches, as well as limit the amount of computer storage that is necessary to store the terrain.
- Be organized spatially so that specific regions of the terrain can be displayed quickly, without having to search the whole terrain database to find all the objects to draw.
- Store different representations of the same objects in different ways, so that more fidelity is displayed when it is necessary. For example, when a large scale is being displayed, roads can be represented by the network information only, but as the scale of the display is made smaller, the road width and road type information could also be displayed.
- Efficiently store three dimensional data and be able to display this elevation information in a useful manner, such as contour lines and elevation slices. This is necessary to provide as much information to the user so that he may verify the results of the automated planning or do his own planning if the automated planning breaks down.

The object oriented terrain used by the SAF system has other requirements imposed on it because it is used in conjunction with the SIMNET Computer Image Generator (CIG) runtime databases. The CIG's are used within the manned simulators to provide a visual scene of the battlefield to the soldiers taking part in the battle. The SAF vehicles are also seen by these soldiers on the battlefield through the CIG's, so the placement of the SAF vehicles on the terrain is critical for a realistic simulation. The SAF terrain must correspond exactly to the SIMNET terrain in specific areas, particularly bridges and water, since, for example, the SIMNET vehicles will bog down if driven into water. If a unit commander sends a SAF unit across a bridge, that bridge must be at the same location as the bridge in the SIMNET environment or the SAF vehicles will get stuck in water or appear to drive through the water. Trees and treelines are another feature that must be represented exactly, since they can be used for concealment. Other features like hills and mobility areas can be represented more abstractly, since these features are not used for vehicle level reasoning, so their exact locations are not as critical to the simulation.

The runtime terrain database used in the CIG is not suited for either reasoning or drawing. This database consists of a large number of polygons which are optimized to display quickly when used with the CIG hardware in the manned simulators. The terrain polygons, which have different elevations at each vertex, are used to display the underlying terrain. Terrain objects, which are made up of large numbers of individual polygons, are used to display the terrain specific objects on the underlying terrain. For example, roads are represented as a series of road polygons overlaid on the terrain polygons, as shown in Figure 2. The individual runtime objects are made up of a large number of polygons for two reasons. Firstly, the runtime database is broken up into load modules to limit the number of polygons that need to be handled at any one time by the CIG hardware. This forces objects to be broken up at these runtime module boundaries. Secondly, objects are broken up so that they lie flat on the underlying terrain polygons. This large number of object polygons make drawing of the terrain objects very slow. Also, reasoning on these objects is extremely difficult because there is no connection between the individual polygons of the same object.

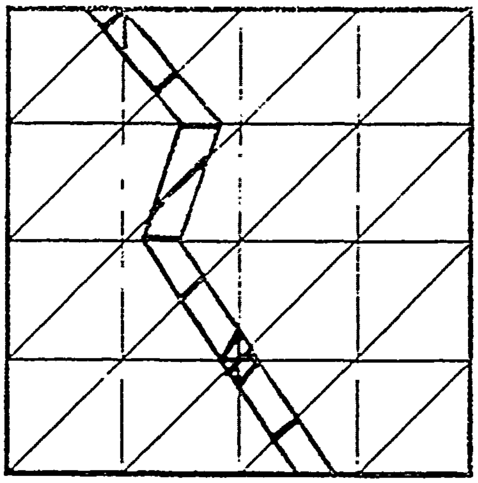

Figure 2
Feature polygons, such as this road, are overlayed onto underlaying terrain polygons.

3.2. Diversified Quadtree Representation

Various representation schemes and their organization were investigated in order to determine an optimal terrain representation for the SAF system in accordance with the above guidelines. Previous investigations of various hierarchical spatial data representations were reviewed and evaluated according to these guidelines. Quadtrees [10], which subdivide the terrain into areas containing a single feature, are useful for storage of area and point features. Techniques exist for efficient generation and searching of quadtrees. Multiple quadtrees can be used to store overlapping regions, and routines exist for performing Boolean operations on quadtree regions. Specialized quadtrees have been developed which provide efficient storage of other feature types. For example, PMR quadtrees [8] store linear features by subdividing the terrain into areas containing a set number of vector endpoints. All quadtrees, however, require a large amount of memory and are not always optimized for memory accesses. R-Trees [4] provide a representation for area features that is optimized for memory access, but is based on overlapping regions, so some loss of spatial relationship occurs. Octtrees [5] are useful for storage of three dimensional data, but require extremely large amounts of memory and are quite complex.

Topographic databases for geographic information systems are based on levels of organization for terrain features. One such database [6] utilizes a cartographic features level and a topological elements level to store feature attributes and locations, respectively, and a spatial clustering layer to store spatial relationships, by sorting the features according to size and location. A database based on planar subdivision [7] stores regions as polygons and linear features as edges. Weights are assigned to the polygon interiors and edges, and are used for terrain navigation. A hybrid data structure based on quadtrees [1] has been proposed which stores indices into feature data structures. Vector representations are used for linear features and quadtrees are used for area features. A pyramid, which is represented by a quadtree, is used to store the spatial relationships.

Two approaches were considered for the SAF terrain database, a unified data structure approach and a diversified data structure approach. The unified approach stores all of the terrain objects in the same data structure, which is then used for both reasoning and drawing. A quadtree structure was investigated, with the leaf nodes of the tree corresponding to individual terrain objects. In this approach, each quad is broken down into four new quads until each quad completely contains one terrain feature, as can be seen in Figure 3. This approach was tested with a portion of the Ft. Knox database and generated 83,402 four meter^2 quads within an 8 by 8 kilometer area. This approach worked well for certain reasoning operations, like identifying the types of terrain features crossed by a particular route. Using a Symbolics 3675[1], the system was able to identify all of the terrain features along a 8 kilometer route within 0.5 seconds. The main drawback with this approach was that it lacked the connection information needed for other reasoning operations, like road following. Also, it was moderately slow to draw the quadtree nodes, because the quads at the lowest level were small (4 meters^2) in order to provide smooth borders. It also required a large amount of memory to store this database, both on disk and during runtime.

[1]Symbolics 3675 Lisp Machine, 4MWords Memory, Floating Point Accelerator, 474 MByte Disk, 24 Bit Frame Buffer, Genera 7.2 Operating System.

A diversified quadtree representation, which is better suited for both reasoning and display, was also investigated for use within the SAF system. In this representation, each quad contains pointers into data structures holding the actual terrain features and each leaf node has a large fixed ground size, as shown in Figure 4. Each feature type is stored in a separate data structure which is optimized for that object type. Different data structures are used to index into the feature data structures, for determining the spatial relationships between features. For example, road segments are stored in an array, with each quad containing pointers into the road segment array. A road intersection array is also generated, with pointers into the road segment array. This array specifies where intersections are located and which road segments form them. With this approach, abstract data structures can be stored at higher levels of the quadtree. This allows representation of objects at different levels of fidelity, so that reasoning can be performed quickly over large areas of the terrain and then focused in on smaller areas for more exact reasoning. Also, large areas of the terrain can be displayed at a lower fidelity to speed up drawing time. The quadtree structure provides the data organization to limit the search space to only areas of interest. This is especially important when the reasoning is at the vehicle level, where each vehicle needs to know about the terrain immediately surrounding it. This representation allows for easy updating because only the indices of the objects are stored in the quadtree. When new features need to be added or existing features updated, only the indices in the quads need to be changed. Dynamic terrain can also be handled with this representation since the underlaying data structures, which normally are static structures, can also be dynamic and the quads can be updated in real time. This representation also handles the case of overloading within an area of the terrain. If the system performance is significantly degraded because of too many features within a quad, that quad can be broken down into four new quads, which can themselves be broken down if necessary, until each quad contains a more reasonable amount of data.

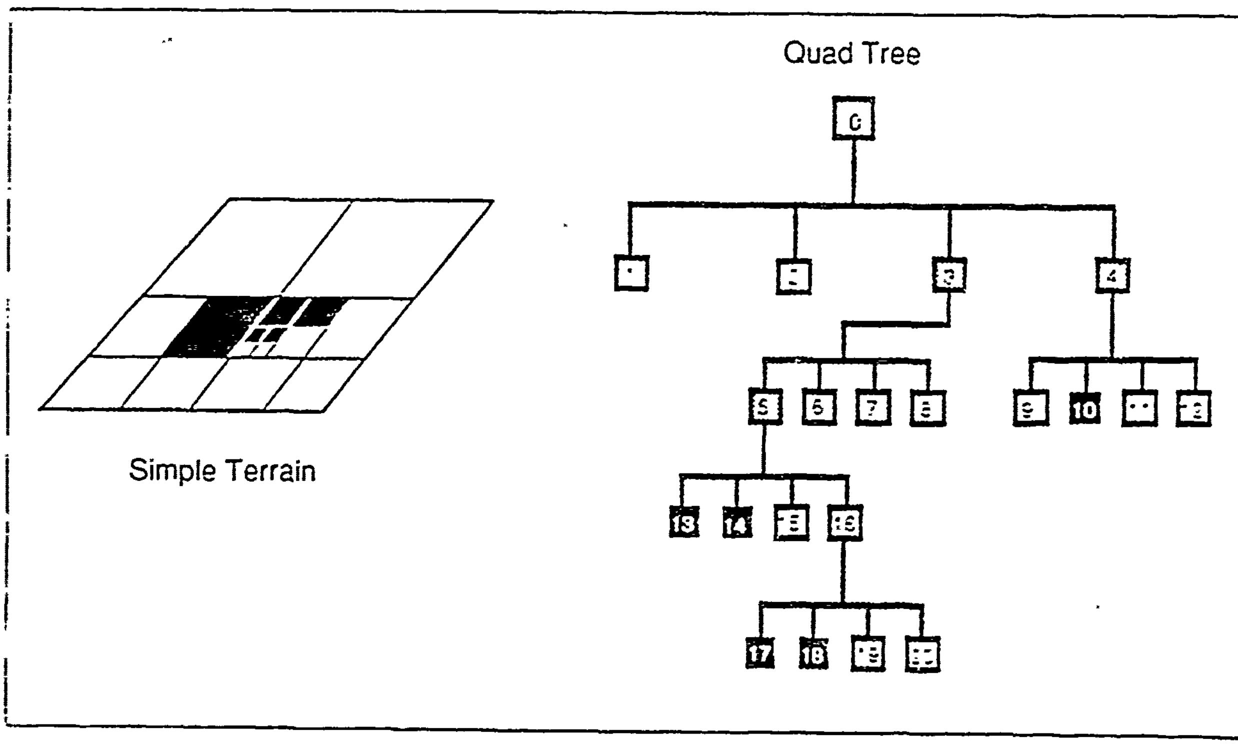

Figure 3
The classical quadtree approach divides the terrain until each quad node contains only a single feature.

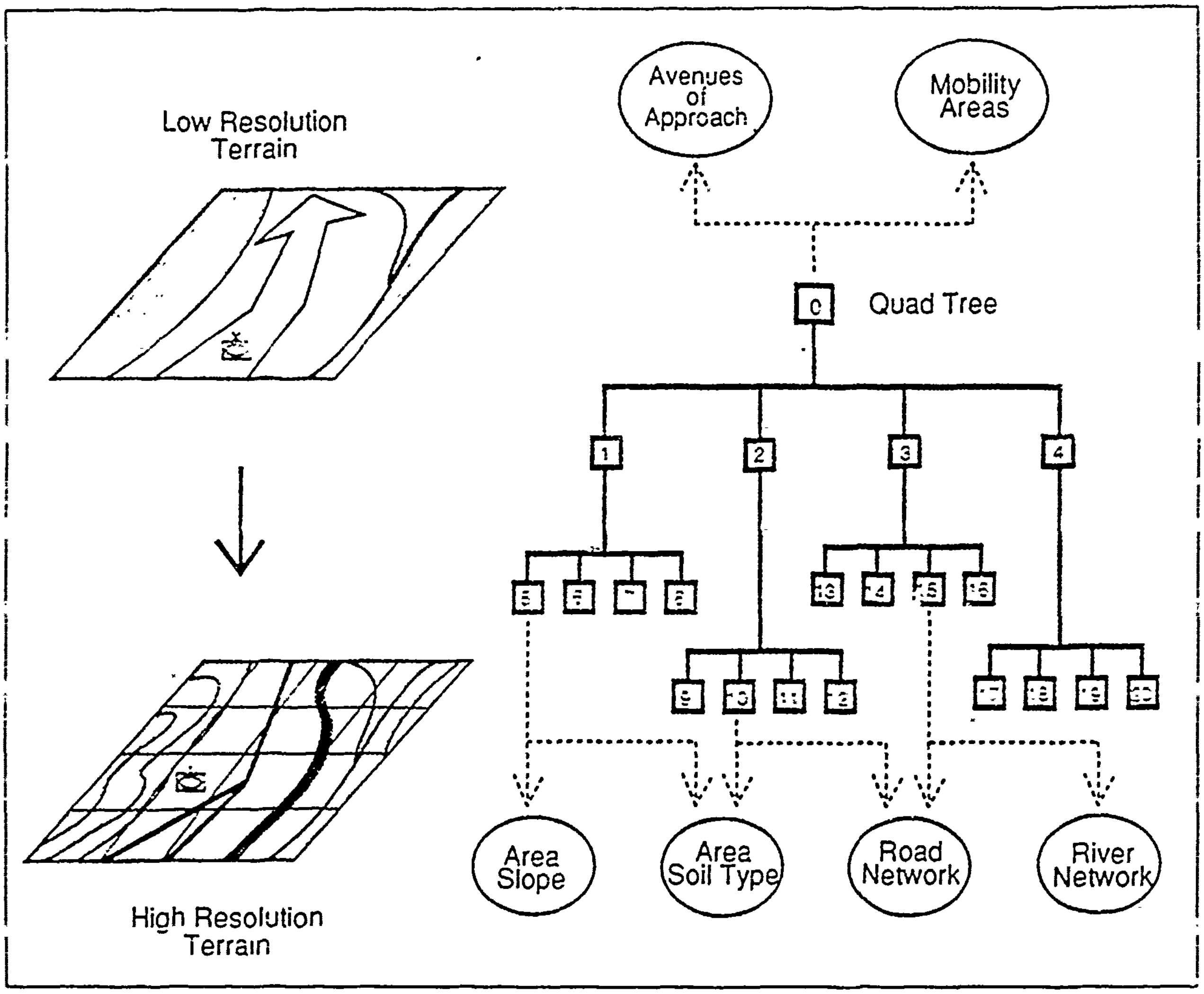

Figure 4
The diversified quadtree approach allows high level reasoning to be performed on low resolution representations of terrain features and high level reasoning to be performed on high resolution representations of the same features.

3.3. Performance Study

A study was conducted to determine how different parameters of the diversified quadtree affect its performance. The two factors investigated were the minimum size of the leaf nodes and the method of filling the quadtree. A test database of 50 by 50 kilometers^2 was used for this study. Two methods of filling the diversified quadtree were investigated. The first method, leaf filling, fills only the leaf nodes of the tree with indices into the feature arrays. If a feature is present in more than one quad, the index is duplicated in those quads. The second method, fully populated, allows any node of the quadtree to contain indices into the feature arrays. In this case, a feature is stored in the smallest quad that completely contains it, so there is no duplication of indices. The leaf filling method is better suited for databases which contain smaller features, since the duplication of indices of large features slows down drawing and searching. There is a trade-off, however, because in the fully populated method the data become less spatially organized. Features of any size that cross quad boundaries are moved to higher levels of the quadtree. This is particularly severe at the center of the database, because any feature that crosses the center lines will reside at the top of the tree. Therefore, when drawing or searching a single leaf quad, all the quads above it in the tree have to searched for features that may be in that quad. With the leaf filling method, all of the indices for that leaf quad reside within it so no other searching needs to be done.

The results of the diversified quadtree study are shown in Figures 5 through 8 The effects of quad node leaf size on the storage requirements for the quadtree structure is shown in Figure 5. The quadtree memory refers to the memory needed for the quadtree structure itself and the indices contained within the quad nodes, but not the structures storing the terrain features. A quadtree with very small leaf nodes requires a large amount of memory for this quadtree structure. A quadtree with large leaf nodes require less memory, but the data lose spatial organization. Figure 6 shows the effects of quad node leaf size on drawing time for a high and a low map scale, when drawn on a Symbolics 3675 At the low map scale (1:12,500), drawing time increases slightly with larger leaf nodes, since more objects are contained in each quad node as the minimum size increases. At the high map scale (1:100,000), drawing time is relatively constant for the fully populated quadtree, but decreases rapidly as the minimum size increases for the leaf filled quadtree. The number of duplicate indices increases as the minimum leaf node size decreases, so objects are drawn many more times with smaller leaf nodes. There is no duplication of indices in the fully populated quadtree, so drawing time is constant The leaf filled quadtree draws faster at the low map scale due to its better spatial organization. Figure 7 shows the number of duplicate indices in a leaf filled quadtree for various leaf node sizes. Most feature types show a large amount of duplication within smaller leaf nodes. Roads do not show much duplication because the road segments tend to be less than 1250 meters long so that they do not cross many quad boundaries. Finally, Figure 8 shows the drawing speed at all of the map scales for the two types of quadtrees, using a leaf node size of 2500 meters^2. The drawing routine uses the quadtree search routines, so drawing time can be used as a measure of searching efficiency. The fully populated quadtree draws faster at higher scales, because of the duplication of indices, but the leaf method draws faster at lower scales because of its better spatial organization. At the 1:200,000 map scale, the quadtree is not used for drawing, since all of the features are drawn, so both methods exhibit similar drawing times. A quad node leaf size of 2500 meters^2 was eventually chosen for the SAF database because the data still retain sufficient spatial organization with adequate memory usage. A fully populated quadtree was also chosen, due to the many large area objects in the database and the faster drawing time at the higher scales, which take the longest to draw.

3.4. Quadtree Search Algorithms

Figure 9 shows the three types of quadtree search algorithms developed for use with the fully populated quadtree. The first technique shown finds all of the quad nodes that descend to a particular leaf node. This routine is used to find all of the features at a particular location on the database. Starting at the top of the tree, this routine traverses the appropriate child nodes until it reaches the leaf node, keeping track of all of the nodes traversed. In this way, all nodes that do not have that leaf node as a descendant and all siblings of that leaf node are eliminated from the search space. The second technique finds all of the quad nodes that descend to more than one quad leaf node. This routine is used for finding all of the features that may be passed through by a linear or area object. Starting at the top of the quadtree, each node is tested to see if it passes through the area of interest, which is usually the bounding rectangle of the linear or area object. If a quad node is totally outside of the test area, it is eliminated from the search space and its descendants are not tested. If a node is partially or completely within the test area, it is retained and its descendants are tested. The third technique is similar to the first, but is used to find features that are close to a particular location on the ground. This routine is used to find features that may be in neighboring quad nodes of a particular point. This routine creates a rectangular test area around a location by adding and subtracting half a leaf node width and height to the location. The second search algorithm is then used to find all of the quad nodes that contribute to

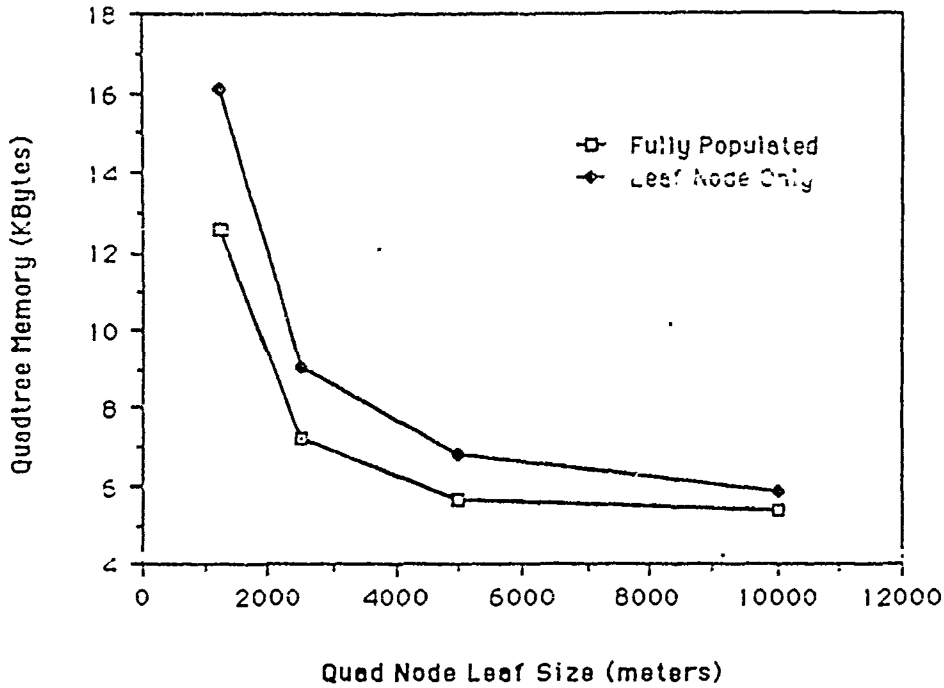

Figure 5
Smaller quadtree leaf nodes generate larger quadtrees but provide more spatial organization than quadtrees with larger leaf nodes.

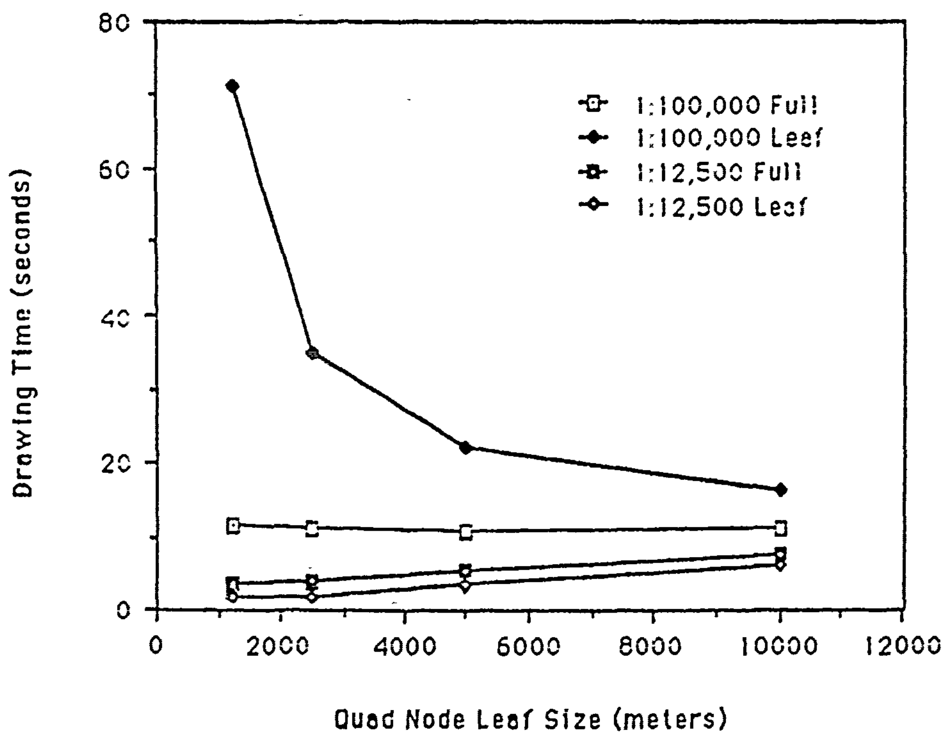

Figure 6
Leaf node size has a greater effect on drawing speed with leaf filled quadtrees, due to the duplication of indices.

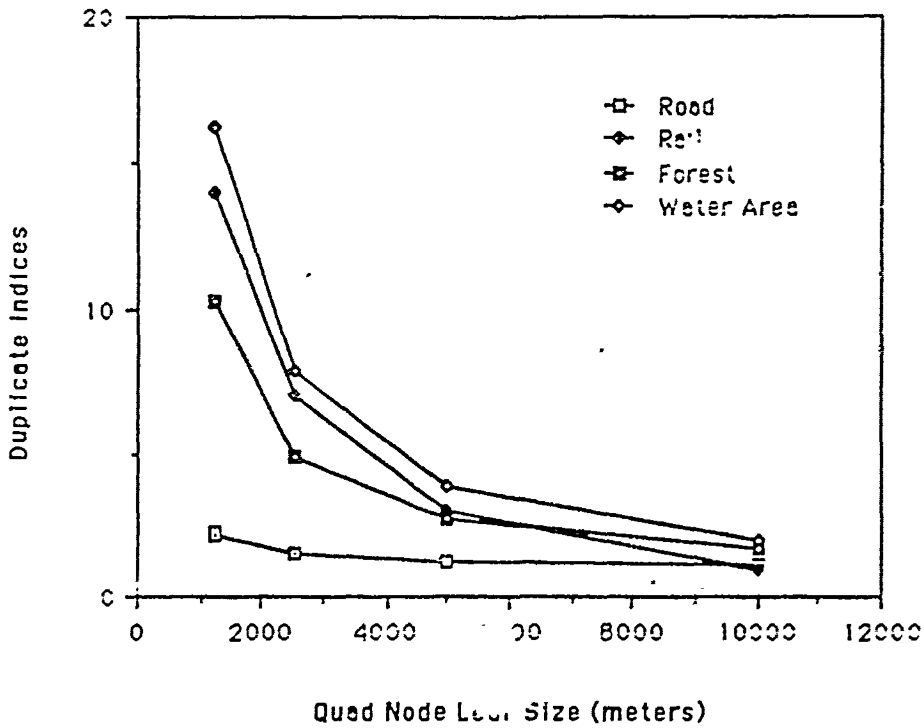

Figure 7
Leaf filled quadtrees contain many duplicate indices at small leaf node sizes.

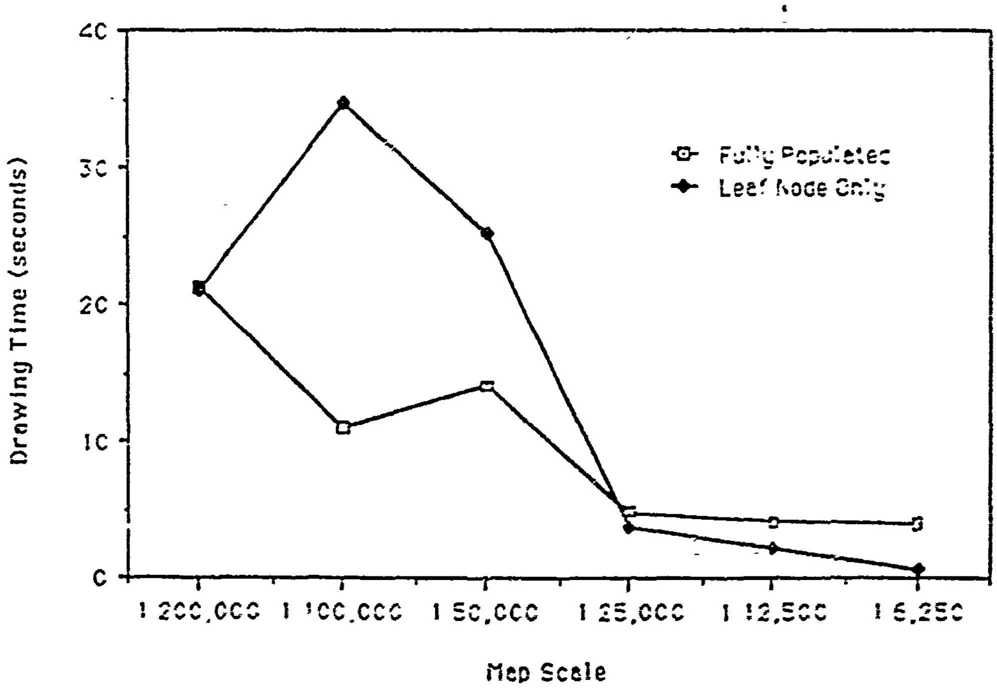

Figure 8
Fully populated quadtrees provide faster drawing at higher map scales, but slower drawing at smaller map scales.

that test area. If the location is close to the center of a leaf quad node, the test area will be completely within that leaf node, so only quad nodes that descend to that leaf will be retained in the search space. If, however, the location is near the edge of a leaf node, the test area will extend into one or more neighbor leaf nodes, so quad nodes that descend to any of those leafs will be retained in the search space.

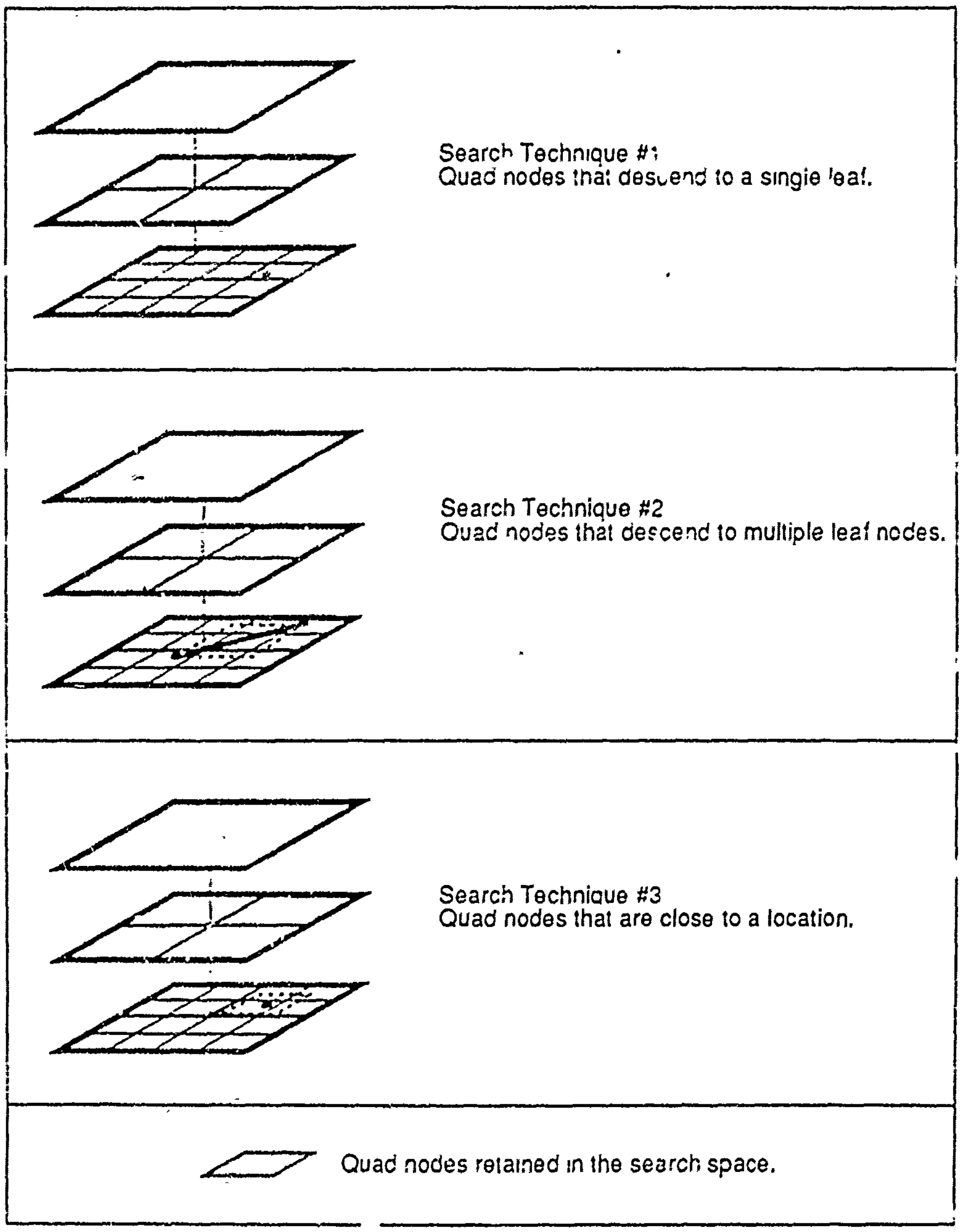

Figure 9
Three quadtree search techniques are used with the SAF terrain database.

3.5. SAF Terrain Database

Two databases, whose characteristics are shown in Figure 10, have been generated for use within the SAF system Both of these databases are based on quad leaf node sizes of 2500 meter^2. In order to evenly divide the whole area down to this size, both quadtrees are based on an overall size of 80 kilometer^2. The memory size shown is the amount of disk storage for the quadtree and all of the feature objects. The contour lines make up a significant portion of each database, especially Ft. Hunter-Liggett because of the mountainous terrain in that area. This representation is essentially two dimensional, where elevation data are stored as contour lines and area features. Octrees could have been used to store the elevation data, but the memory requirements and complexity precluded their use in the current system. Elevation data necessary for actual vehicle placement on the ground are obtained from the runtime CIG terrain polygons, so that vehicles will appear correctly in the manned simulators. Octrees may be used to store this elevation data in future versions of the system.

There are five classes of terrain objects in the SAF terrain database. These are networks, area features, linear features, point features, and dynamic terrain. In the present system there are networks of roads, rivers, and railroads, and area features of water, forest, and soil type. The linear features consist of treelines and contour lines, and the point features are individual trees and buildings. Dynamic terrain consists of battlefield control measures, such as phase lines and objectives, and minefields.

SAF Terrain Databases		
	Ft. Knox	Ft. Hunter-Liggett
Area of Terrain	75 x 50 km^2	50 x 50 km^2
Number of Quads	1365*	1365*
Leaf Node Size	2500 meters^2	2500 meters^2
Memory Size	1.6 MBytes	2.1 MBytes
Minimum Elevation	115 meters	0 meters
Maximum Elevation	300 meters	1780 meters
Contour Line Interval	5 meters	10 meters
Contour Memory Size	1.2 MBytes	1.8 MBytes

* - Number of quads based on 80 x 80 kilometer^2 area

Figure 10
Characteristics of the SAF Terrain Databases

The networks are represented as arrays of segment objects and arrays of intersection objects, as shown in Figure 11. The segment objects are the segments of each feature that run between the intersections. Each segment object contains a list of points specifying the midline endpoints of each leg within that segment along with the width of that segment and the total distance along that segment. The intersection objects contain the location of the intersection along with a list of the segment identifiers which connect at that intersection and the identifier of the intersection at the opposite end of each of those segments. In the SAF system, an intersection occurs where two or more network segments come together or a single segment ends. and the identifiers are simply the indices into the segment and intersection arrays. Each feature is represented as a separate network instead of a single network of all linear features. This speeds searching since each network can be searched independently, and allows each network to be displayed separately.

Bridges are handled as a special case of roads and are stored within the road network. Each side of a bridge is considered an intersection, so each bridge is a separate road segment object. These objects have all of the same information as normal road objects, but are identified as a bridge segment. This allows more precise road following routines to be run when a vehicle is crossing a bridge, as well as allowing bridges to be identified as targets.

The river network consists of an array of water segments, similar to the road segment array, where each segment is broken up where more than two rivers meet, where a river segment meets another network segment. or where the width of the river segment changes. The river segment width information is stored along with the midline points. The width information is stored as a list of three values which consist of the widths at each end and at the center. These widths are used in the drawing routine to taper the segments when they are drawn. Also, each water segment is labeled as being fordable or unfordable water. The rail network is very similar to the road network. Multiple tracks are treated as single segments with additional width.

Area features within SAF consist of forests, areas of similar soil type, and bodies of water not represented in the river network, such as oceans, lakes and reservoirs. These features are represented as objects consisting of boundary segments and triangles, as can be seen in Figure 12. The boundary segments are a list of all connected boundary points for each area feature. This list is used during terrain reasoning. The triangles are the minimum number of three sided polygons necessary for drawing the complete area. These are used by the drawing routine to draw these object quickly and used by the terrain reasoning routines for rapid screening. Finally, the area objects contain attribute information pertinent to that area object type. For instance, forest objects contain attributes about the general type of trees in that forest, as well as pointers into the tree and treeline representations for those objects that are within the forest.

Linear features are represented as arrays of linear objects, where each object consists of a point list and associated attributes, such as heights of treelines and elevation of contour lines. The contour lines are generated from the initial database elevation points, usually DMA DTED data. They are broken up at quad node boundaries, since, otherwise, they tend to cover a large portion of the database. Point features are represented as arrays of point objects, where each point has a location and other attributes based on the object type, such as type of building or height of a tree. Locations can either consist of a single point, such as the location of a tree, or a list of four points to specify a rectangular object, such as a building.

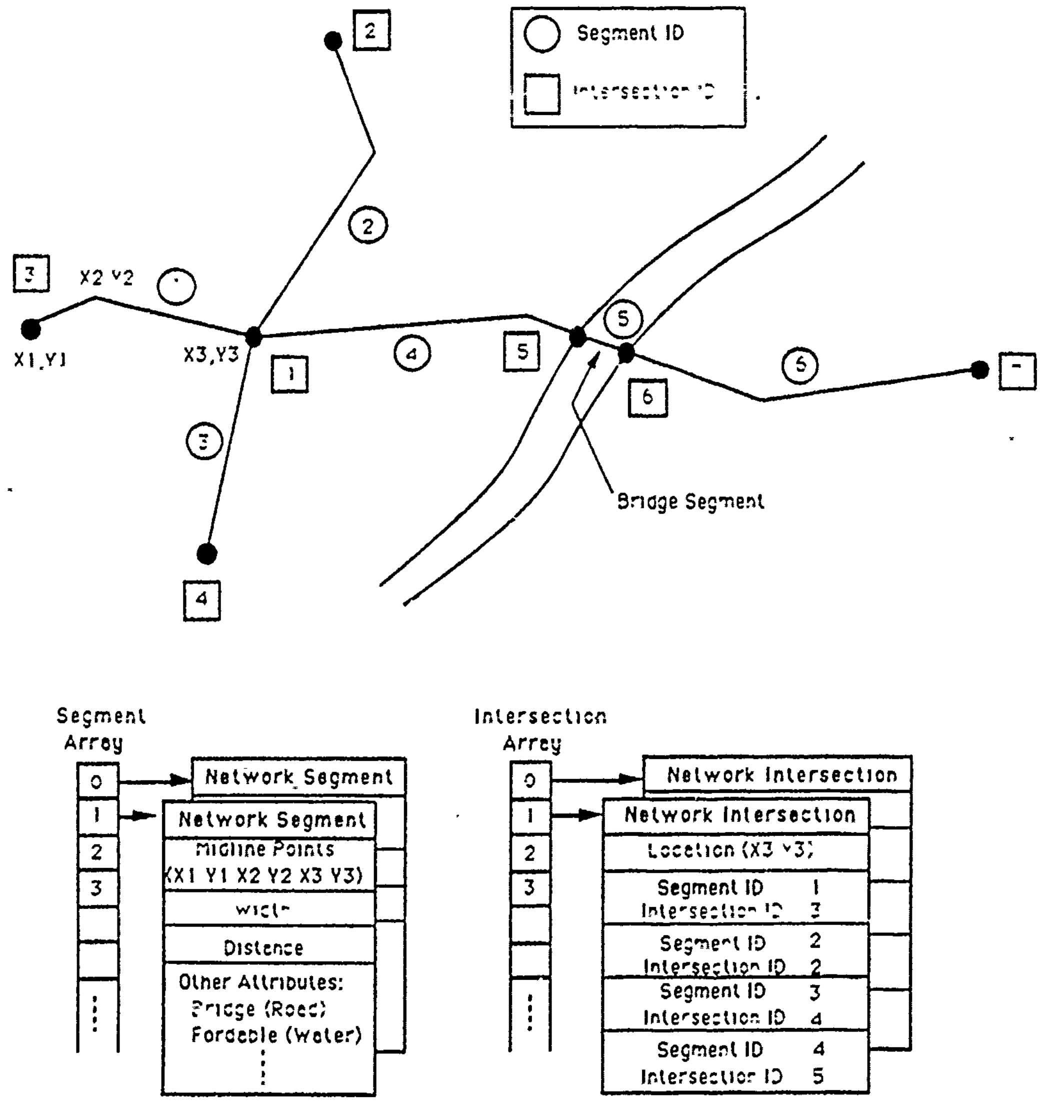

Figure 11
Network data structures consist of network segment arrays and network intersection arrays.

Dynamic features consist of objects entered at the workstation which can be removed or edited. These objects can be battlefield control measures and minefields. In future versions of SIMNET, there will be much more dynamic terrain, such as blown up bridges and tank traps. The current SAF terrain representation will easily accept these new features, since each feature is stored in a separate array. This array can be dynamically edited, and the resulting index changes made to the quadtree in realtime.

Battlefield control measures consist of avenues of approach, objectives, phase lines, axes of advance, unit boundaries, forward lines of troops (FLOT, EFLOT), lines of departure and lines of contact. The dynamic area features, such as avenues of approach, are represented similarly to static area features, and the dynamic linear features, such as phase lines and unit boundaries are represented similarly to static linear features. All of these features are editable, can be incorporated into missions, and used by the mission planning routines. Battlefield control measures can be saved into overlay files and reused at a later date or shared between workstations during an exercise.

Minefields are represented as linear objects with variable widths, minefield density and mine sensitivity. These objects are also editable, but delays have been built into the system to take into account the time it takes to clear or modify a minefield in the real world. Minefields can be saved in overlay files, but they do not create the minefield when loaded back in. This prevents many copies of the same minefield being created in the SIMNET environment when overlay files are shared among different workstations. It does allow other workstations to display the locations of previously created minefields, however.

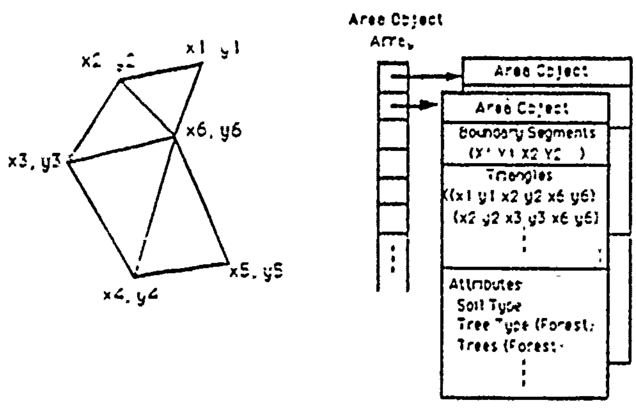

Figure 12
Area objects contain boundary segments, triangles, and attribute information.

4. Terrain Presentation

The SAF terrain database is an integral part of the mission planning process. The user is also an integral part of this process and therefore must be able to interact with the terrain database. The terrain must be displayed quickly and in a form that the user is familiar with. The SAF system presents the terrain in the same form as a military map, since that is what a unit commander uses during mission planning. Along with the terrain features, which are displayed in color, UTM grid lines and a legend are displayed. Routines are provided to change the scale of the map display and change the location within the terrain that is being displayed.

The diversified quadtree representation used in the terrain reasoning system is used to display the terrain. This representation is organized spatially, which allows it to be displayed quickly, while still retaining the object oriented structures. This is important because the user is interacting with the terrain features on the display, such as selecting roads and bridges, and the selection of the terrain objects must be performed in realtime. If a separate representation was used for display, a conversion routine would be needed between the two representations. Two representations would also necessitate larger storage requirements as well as contribute more complexity to the system. With the single representation, the same routines that are optimized for searching during terrain reasoning are used during display, which also allows the terrain to display faster and with less complexity.

During a typical use, the map display is redrawn quite frequently, so much work went into drawing the terrain as quickly as possible. One effective technique was to incorporate a very efficient clipping algorithm into the system [9]. Even though the data are stored spatially in the quadtree, if part of a quad is being displayed, many features and portions of features must be clipped by the drawing software. For example, with the Symbolics drawing routines, when the data are clipped before calling the drawing routine, using this efficient clipping algorithm, drawing is improved by up to a factor of 10, especially at lower map scales. This clipping algorithm is also used during some terrain reasoning operations to limit the number of objects searched. For example, the bounding rectangle of a water segment is used as a preliminary test to see if a route passes through that water segment.

The quadtree structure provides other advantages for faster drawing. Some features are stored with different representations at different levels of the quadtree. For example, individual trees and treelines are stored at the bottom of the tree, but are aggregated into forest area objects at higher levels of the tree. At higher map scales these forest objects are drawn, and at lower scales the trees and treelines are drawn. The area feature representation also contains a list of pre-computed triangles generated from the boundary polygon. Routines that draw polygons with arbitrary numbers of sides first break up the polygons into triangles, and then draw these triangles. By pre-computing the triangles, the Symbolics drawing routines are 2 to 4 times faster, depending on the complexity of the polygon. Network segments and linear objects are drawn as single pixel width lines at higher map scales, but with their true widths at lower scales. Some linear features, like treelines, are drawn as a straight line connecting the two endpoints at higher map scales, but as a line connecting all the points at lower scales. Other linear features, such as contour lines, are simply not drawn at the higher map scales. For instance, the contour line interval ranges from 40 meters at the highest scale (1:200,000) to 5 or 10 meters at the lower scales (1:6,250 and below). Contour lines are also broken up at quad boundaries to limit the amount of clipping that needs to be done at lower scales.

The map is displayed on an 8 bits per pixel Symbolics color screen. The color map space is divided into 3 planes to limit the amount of redrawing that has to be done. The terrain plane, which is 3 bits deep, is used to display most of the terrain features. The commander can select which features to display at any time, so this plane is redrawn only when one or more features are added or deleted from the display. The vehicle plane, which is 4 bits deep, is used to display the locations of vehicles on the battlefield. This plane also contains the legend, so that it can be displayed or removed quickly without redrawing the terrain features. Similarly, a one bit overlay plane is used to display the battlefield control objects, grid lines, and contour lines, so that these can also be displayed or removed from the screen quickly.

5. Terrain Reasoning

A terrain reasoning system for military mission planning should have the following characteristics:

- Support mission planning and execution based on user-supplied criteria, such as maximize cover or time.
- Built in such a way as to generate mobility corridors for large units as well as specific routes for individual vehicles.
- Look at terrain features such as elevation, slopes, soil types, trees, and penetration points, and have the ability for collateral and intelligence data to be incorporated into the planning process, such as weather, situation and contact reports.
- Address the area of obstacle avoidance. Most previous systems have looked at areas of trafficability, but not specific points within these areas. An obstacle avoidance component is necessary in the planning system, such that obstacle crossing and penetration points should be identified and routes adjusted automatically to use them. For example, if two areas of high trafficability are separated by a river, the system should not discount their connectivity. Instead, it should look for crossing points over that river, either with bridges or fording points.
- Take into account military doctrine. For example, for a river crossing, whether a single bridge can be used or, if available in an area, multiple bridges should be used. Also, it should determine the tactics that should be used for that river crossing, based on collateral information.

The terrain reasoning system currently in the SAF system supports multi-level reasoning. At the vehicle level, local area reasoning is being performed, using terrain objects in the diversified quadtree and runtime terrain polygons. The vehicles perform obstacle avoidance on each other and objects on the terrain, such as buildings. Vehicles look ahead to their next route waypoint and when a possible collision is detected, the bounding volume of the obstacle is used to alter the route of that vehicle, as shown in Figure 13. The new route is then checked for other obstacles, which, if present, are avoided similarly. The terrain immediately surrounding the vehicles is examined before obstacle avoidance is performed. For example, if the obstacle occurs on a bridge, such as a damaged vehicle blocking the bridge, the moving vehicle will try to go around the damaged one, as long as the new route does not go off the bridge into the water. If this is not possible, the moving vehicle will look for an alternate route over the water. This is done by searching for other bridges or fording points within the local area and generating new routes to the other side of the original bridge. If an alternate route, which does not go through water, can not be generated, the unit commander is prompted for a new route.

Vehicle level reasoning also takes place when vehicles are attacking and defending. Intervisibility calculations are performed which take into account the terrain elevation and terrain objects. An attacking vehicle can only target enemy vehicles that he can see. Defending vehicle can use the terrain to conceal themselves, by either hiding behind hills, treelines, or buildings. The intervisibility routines are probabilistic, so objects like treelines do not completely conceal a vehicle, but severely reduce the probability of detection. The unit commander can position the vehicles in his unit to be just out of detection range from a specific point on the terrain He first commands these vehicle to move close to these concealed positions and selects the point to be concealed from. The intervisibility routines then determine the exact locations for all of the vehicles and they move to them.

At higher echelon levels, the terrain reasoning system assists the unit commanders with route generation during mission planning, using the terrain data within the diversified quadtree. At all levels, mission routes are generated based, to a large extent, on the terrain. The unit commanders select the area within which the routes are to be generated by creating unit boundaries on the terrain. Routes for all vehicles and subordinate units within that unit are then generated within those unit boundaries, such that untrafficable terrain is avoided and water is crossed at bridges or fording points. The generated routes are presented to the unit commander so that he may modify them to be better suited for the mission. If a complete route cannot be generated the commander is presented with a partial route, which he can then modify to completion. Whenever the unit commander is entering routes manually or modifying a route, the terrain reasoning system checks to see if that route, or any subordinate routes that will be generated from that route, cross water without the aid of a bridge or fording point. If any route does, the commander is notified so that he can modify that route to avoid the water.

One of the modifications the unit commander can make is to specify all or part of a route to be a road march. The commander selects a point for his vehicles to get on a road by choosing a road segment from the map. He then selects either an intermediate road point or a point for his vehicles to get off the road by choosing another road segment. The terrain reasoning system then determines the best road route between the two road points, as demonstrated in Figure 14. This route is usually the shortest distance road route between the two points, but depends on the type of mission it is to be used for. If the objective of the mission is maximum speed, such as an attack mission, the road segment types are weighted so that paved roads have an advantage over dirt roads. If the mission objective is stealth, such as a scout mission, dirt roads are weighed to be more advantageous. Bridges also are weighted so that routes that do not have to cross them take precedence. Any number of consecutive road points can be entered to fine tune the road route. Any number of road routes can be incorporated into a mission route. The road route finder returns a list of road segments in the correct order that connect the two road points. If the points do not connect or if the number of alternative paths gets very large, the road finder connects the two points with a cross country route and warns the commander that a suitable road route could not be found. The commander can either accept that route segment or undo that point and put in intermediate points to generate a suitable road route.

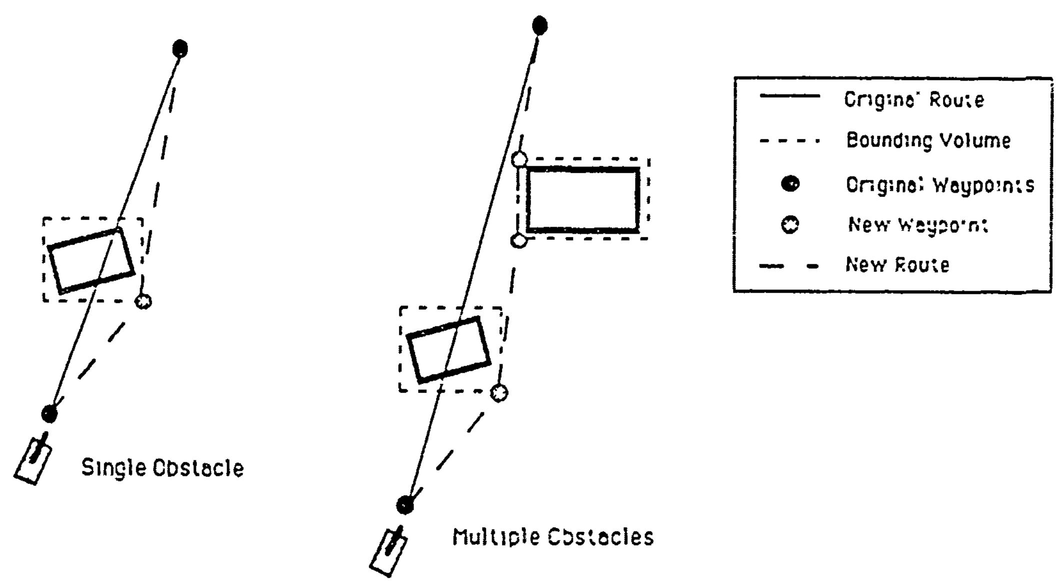

Figure 13
The bounding volumes of obstacles are used to generate routes around them.

As part of the route planning process, the commander can explicitly specify a bridge to cross along a route. The system determines the direction to cross the bridge based on the previous points in the route. The tactical situation and collateral information are used to determine how that bridge is crossed. For example, if a company is to cross a bridge and they are on a road march and there are no reports of enemy vehicles in the area, the company crossing the bridge will stay in column formation as they cross it. If, on the other hand, they were not on a road march, can see enemy vehicles, or have reports of enemy vehicles in the are... they will deploy into a defensive posture before crossing the bridge and cross it one platoon at a time. When all of the platoons and company command vehicles have crossed the bridge, they get back into formation and continue the mission.

An A* search algorithm [13] is used with the road intersection and road segment arrays to find the road routes. This algorithm uses the straight line distance between intermediate points on the route and the destination point as an estimate of the remaining route distance to the destination. This estimate is always an underestimate of the remaining distance, so that this procedure will always produce optimal routes. Because the estimate is an underestimate, however, more routes have to be searched to find the optimal route than if the estimate was closer to the true distance between the points. This requires longer time to find the optimal

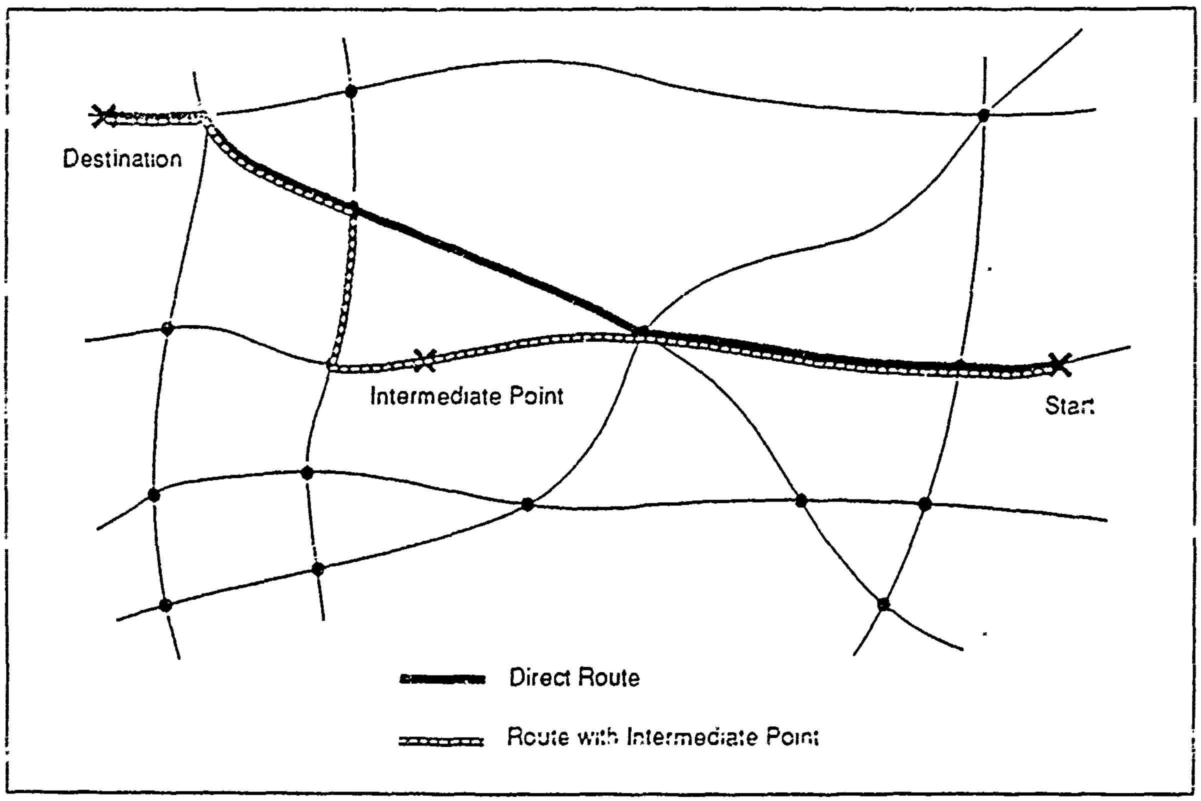

Figure 14
An A* algorithm is used along with the road network to find road routes between points.

route, but in these databases most of the road segments are fairly straight between the intersections, so that the estimates are close to the actual distances. The times required for these searches are quite small, so that, for example, a road route on the order of 50 kilometers can be generated in less than one minute. The A* algorithm is also non-opportunistic, such that if the situation changes during the generation of a route, this algorithm can not use those changes for that route. In the current system, however, most route generation takes place at mission planning time. If the situation changes during mission execution, the A* algorithm can be rerun to generate new local routes for those sub-units affected by the change in situation. This is illustrated in Figure 15. During the execution of the mission, one of the bridges along Company A's route is destroyed, so the A* algorithm is rerun for Company A to generate a new route across the river. The network representation within SAF is not specific to the A* algorithm, so that other search algorithms can be tested in this system.

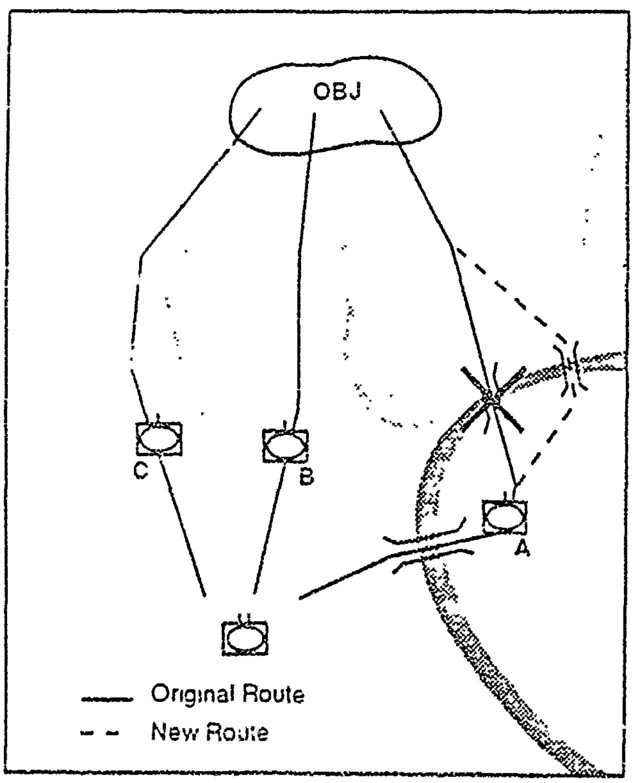

Figure 15
When a bridge is destroyed during mission execution, a new partial route is generated for Company A.

6. Extensions

There are a number of extensions planned for the SAF terrain reasoning system. One area of research is to expand the realtime capabilities of the system, in order to obtain more realistic vehicle behavior, especially during combat. For example, moving vehicles will make better use of terrain for cover and concealment during combat. Another area of research is to increase the mission planning capabilities. As more collateral information is added to SIMNET, it will be added to the SAF mission planning process. ECM models, such as radar and communications jamming, are currently under development for inclusion into SIMNET. These effects will have to be taken into account for SAF missions, so that vehicles avoid areas of intensive jamming, for example. Weather effects will also have to be taken into account. Finally, the automation of all of the terrain reasoning operations normally performed by unit staff personnel, such as avenue of approach generation, is planned for the SAF system. This will remove more of the mission planning burden from the unit commanders, allowing them to concentrate on the tactical aspects of the missions.

7. Conclusion

The current SAF system contains a powerful terrain representation that provides the terrain reasoning system rapid access to the terrain features in a realtime, large scale, hierarchical, high resolution combat simulation. The terrain reasoning system provides man in the loop route planning functionality and in future systems will provide more intelligent mission planning and execution capabilities. SIMNET provides an ideal testbed for terrain reasoning research. The state of the terrain can be modeled at many levels of fidelity, and the vehicles can be provided with various levels of autonomous behavior. Terrain reasoning systems developed in this simulated battlefield environment can be easily extended into the real world combat environment, since SIMNET simulates such a large portion of the battlefield systems and models and this terrain reasoning system utilizes most of them.

8. Acknowledgments

The author would like to thank Stephen Downes-Martin for his support and ideas during the design of this system and his review and comments of this paper. I would also like to thank everyone on the SAF development team for their support during the development of this system, especially Joshua Smith for the obstacle avoidance code and Tom Mitchell for the user interface.

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Appendix E

The SIMNET Tutorial

Tutorial on the SIMNET Network and Protocols

Presented January 15, 1990

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Protocol Tutorial

- Overview
- Everything the simulated world includes
- Goals of the SIMNET protocols
- Architecture of the distributed simulation
- Protocols
- Layering of protocols
- Distributed simulation concepts
- Communicating vehicle appearance
- Effect of dead reckoning on network traffic
- Data communication requirements
- Network performance
- Association protocol
- Simulation protocol
- Data collection protocol
- Data representation
- Object type numbering scheme
- Elements of communication compatibility
- Future work

Overview

- "The SIMNET Network and Protocols", dated 31 July 1989
- "Summary of SIMNET Protocol Changes, August 1989 - January 1990"
- requirements: the simulated world
- architecture: networks, layered protocols
- communicating vehicle appearance information
- supporting networks
- survey of protocol interactions
- representation of information
- communicaton compatibility
- future work

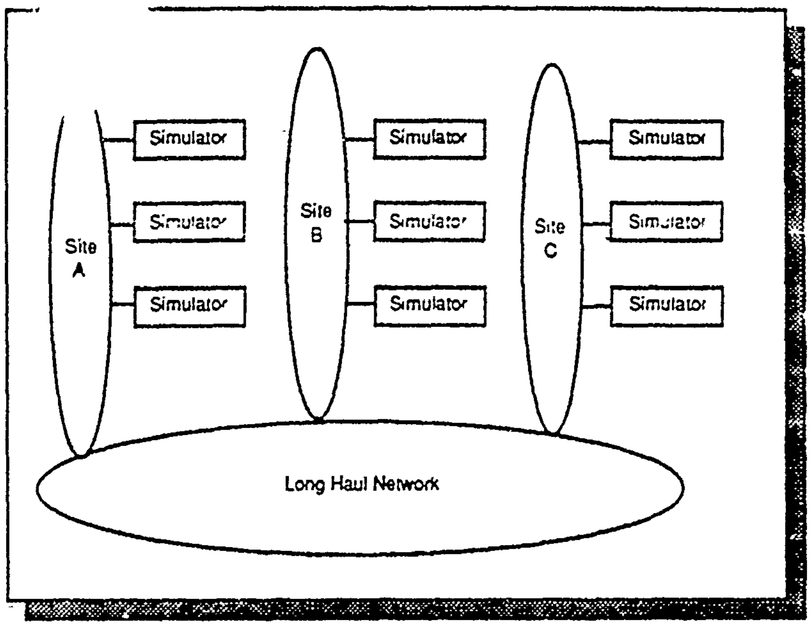
Ev ng the simulated world includes

- a of terrain
  - y tens or hundreds of kilometers on a side
  - populated with features: hills, rivers, roads, trees, buildings...
  - static — not changing in the course of a simulation
- a particular date and time
- vehicles that move dynamically and engage in combat
- supplies of munitions, such as fuel and ammunition
- the transfer of munitions from one vehicle to another
- weapons fire and its effects upon vehicles
- damage to vehicles and vehicle breakdowns
- repairs performed by one vehicle on another
- radar emissions and detection by radar

Goals of the SIMNET prot)'s

- a real–time network of hundreds of simui
- ensure a consistent view of the simulatec d
- be parsimonious and efficient
- allow efficient distribution of computation tasks
- be robust (not error-sensitive; self-correcting, if possible)
- easily accommodate new kinds of vehicles, weapons, phenomena...
- make available information useful for analysis

Arc ure of the distributed simulation



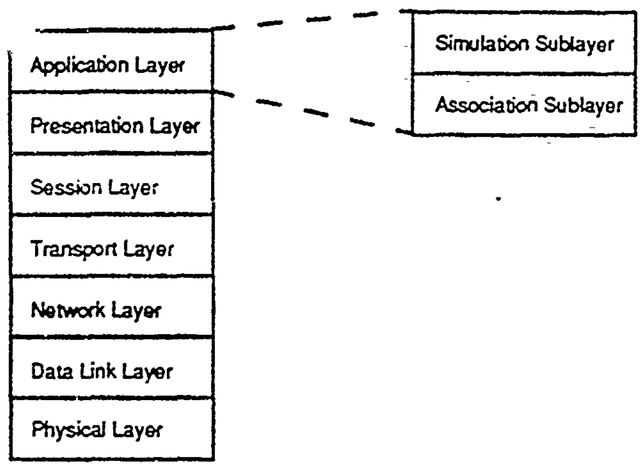
- a simulator might:
  - simulate a single vehicle (e.g., a flight simulator)
  - simulate a group of vehicles (e.g., Semi–Automated Forces)
  - play a role in initializing other simulators (e.g., MCC system)
  - give a window into the simulated world (e.g., Plan-View Display)
  - make an historical record (e.g., Data Logger)

Protocols

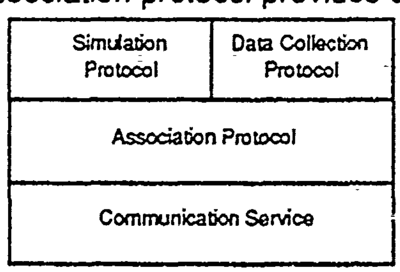
- three simulator–to–simulator protocols are defined:
  - a *simulation protocol* for representing the simulated world
  - a *data collection protocol*, to support analysis
  - an *association protocol*, to convey the other two

Layering of protocols

- : s are defined within the framework of the OSI
  e model



- the association protocol provides common services



Distributed simulation con ͻ.s

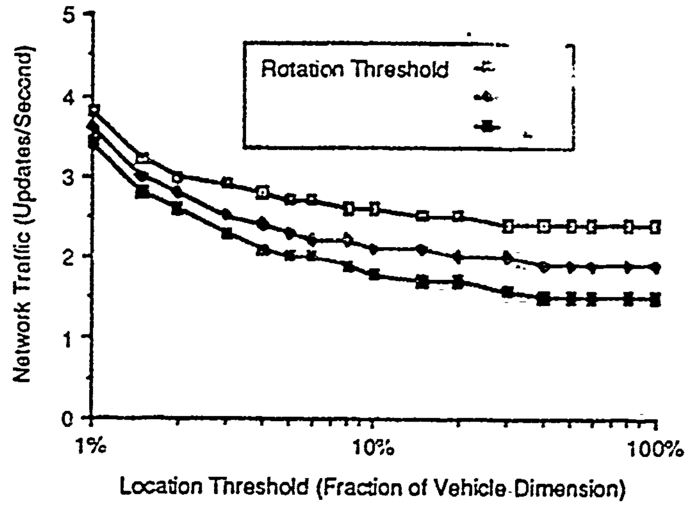
- an exercise is a joint activity of simulators
- it has a simulated world, some participating ͻ.ılators, and an exercise identifier
- there can be many concurrent but independent exercises
- a simulated world is populated by vehicles
- each vehicle has these static attributes:
  - which side it is fighting on
  - what organizational unit it is allocated to
  - what type of vehicle it is
  - a unique vehicle identifier
- each vehicle has a dynamic appearance described by:
  - where it is, and how it is oriented
  - a marking or label (e.g., "Titanic" or "PltLdr/3/C")
  - variations on its basic appearance: flames, smoke, dust cloud...
- each vehicle has internal state represented by:
  - operational status of various subsystems
  - quantities of various munitions on board
- each vehicle's appearance is periodically reported with a state update message

C ·· ıunicating vehicle appearance

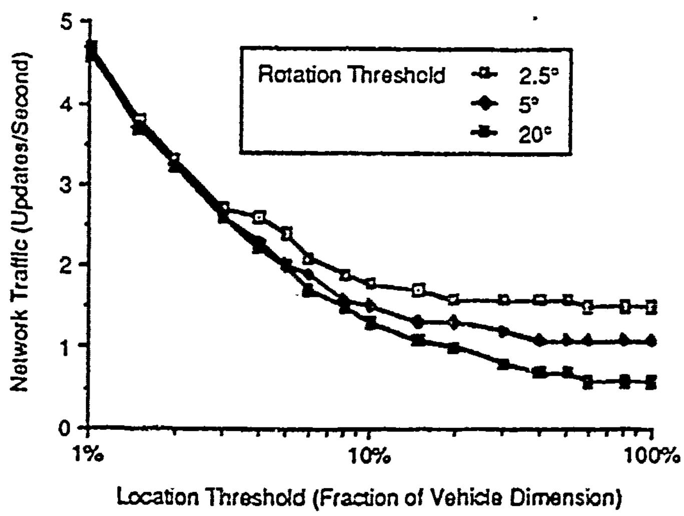
- de oning reduces the need for communication ba
- va .d reckoning approaches are possible:
  - no use of dead reckoning
  - location updated using velocity
  - velocity updated using linear acceleration
  - rotation updated using rate of rotation
  - velocity updated using rotation
- vehicles are classified, partially according to dead reckoning method
  - *static class* — those that remain stationary
  - *simple class* — location updated using velocity
  - *tank class* — like simple, but has a turret
- discrepancy thresholds determine when state updates are issued
  - any discrete change in appearance (e.g., catching fire)
  - translation by 10% of vehicle's dimension
  - rotation about any axis by 3 degrees
  - movement of turret or gun barrel by 3 degrees

Effect of dead reckoning on netwc raffic

- dead–reckoning a tank using velocity on..



- dead–reckoning an aircraft using velocity, linear acceleration, and rate of rotation:



[illegible] communication requirements

- SIM[illegible] protocols are application layer protocols
- SIM[illegible] protocols are supported by network layer service
- network must support broadcasting or multicasting of datagrams
- datagrams range up to 256 bytes; most are 128 bytes
- guaranteed delivery not required; occasional failures tolerated
- a level of performance determined by the "size" of the simulation
- various network technologies may be used
- network may be a combination of local-area and long-haul networks
- Ethernet has been used successfully as a LAN

Network performance

- most network traffic is due to vehicle state .a'.s
- network traffic depends on:
  - number of vehicles participating
  - types of vehicles (ground vs. air vehicles)
  - how vehicles are behaving (stationary. cruising, jinking...)
- ground vehicles (tanks) produce an average of one update per second
- close–support air vehicles produce an average of six per second
- each update is communicated as a 128–byte datagram
- each update must be communicated to all simulators in "real time"
- network delay, and delay variance, can be detrimental
- how much delay is acceptable depends on application:
  - relatively slow–moving ground vehicles can tolerate 300 ms
  - high–speed aircraft flying in formation cannot

Association protocol

- st[illegible]d composite of certain transport, session, and ap[illegible] layer services
- eliminates need for separate transport and session layer protocols
- supports two modes of communication:
  - datagram service provides best-effort delivery
  - transaction service pairs request and response, provides retransmission
- clients are addressed by site number, simulation number
- clients belong to multicast groups

Simulation protocol

- activation of vehicles
- deactivation of vehicles
- vehicle state update
- weapons fire
- collision between vehicles
- transfer of munitions between vehicles
- repairs by one vehicle to another

Data collection protocol

- status reporting
- event reporting

Data representation

- formal notation: *data representation notation*
  - provides a concise, unambiguous description of data element encoding
  - e.g.,

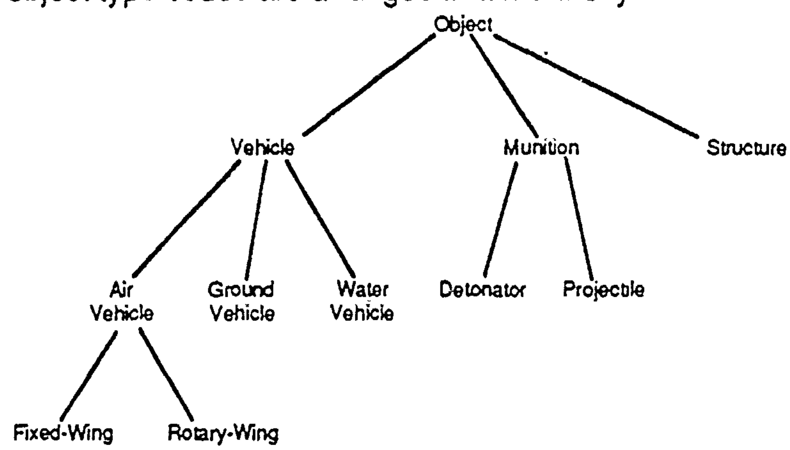
```
type ObjectType UnsignedInteger (32)

type MunitionQuantity sequence {
    munition  ObjectType,
    quantity  Float (32)
}
```

- aim is to minimize protocol's dependence on machine architecture and language
- restrictions on data element alignment and size are enforced
  - e.g., a floating point number occupies 32 or 64 bits
  - e.g., a 32-bit quantity is aligned on a multiple of 32-bits

Ͻbject type numbering scheme

- ·ːs include vehides, ammunition, quantities of fuel, ɔarts...
- a ᴊᴅject's type must be represented for communication (e.g., M1A1 tank, 155 mm HE shell)
- object type codes are arranged in a hierarchy



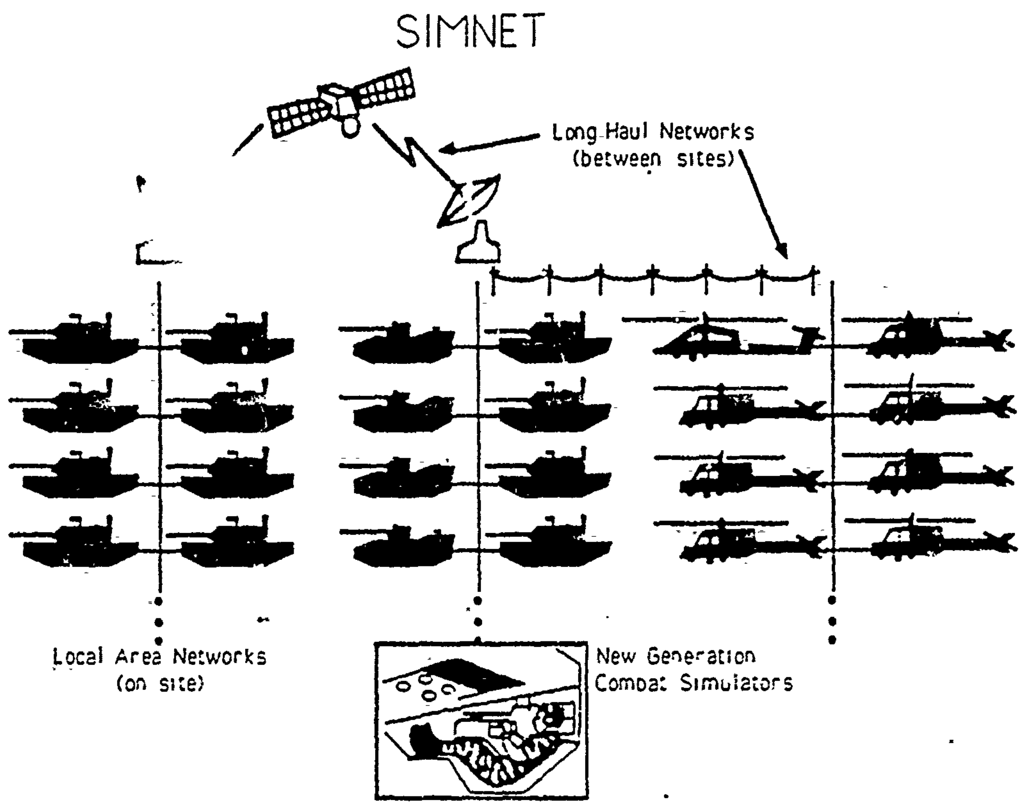
- this scheme, once defined, remains valid as new objects types are added
- software can understand something about an object based on where its type code places it in the hierarchy
- this allows new types of objects to be introduced without disrupting existing software

Elements of communication compatibility

- scope of simulation
  - what phenomena are part of the simulated world
- architecture
  - what things are computed where
  - the use of dead reckoning
- messages and their contents
  - what PDUs are used
  - what information each PDU contains
- message encoding
  - how information is represented as bits
  - e.g., the use of ANSI/IEEE standard floating point format
- underlying network services
  - choice of networks for various parts of the internet
  - e.g., use of Ethernet or FDDI
- ongoing internet administration
  - the assignment of site and simulator addresses
  - coordination of exercise identifiers
  - registration of simulator type codes
  - extensions — e.g., to object type numbering scheme

Future work

- ·sions for additional types of vehicles and simulators
- ʳeckoning algorithms
    - using higher–order derivatives of location and rotation
    - blending in new appearance information
- missiles
    - transfer of missile simulation from firing simulator
    - homing on continuously designated targets
- dynamically changing terrain
- atmospheric effects, such as smoke and clouds



SIMNET OVERVIEW

SIMulator NETwork (SIMNET) is a U.S. Army/Defense Advanced Research Projects Agency (DARPA) – sponsored program that provides realistic combined arms battlefield training for combat vehicle crews. SIMNET is a significant new approach to training both large and small combat units. Hundreds of low–cost, full–crew ground vehicle and aircraft simulators at widely dispersed sites are linked by a common real–time data communications network. Crews of these simulators can see and interact with each other against accurately scaled opponents on the same realistic battlefield.

SIMNET Benefits

SIMNET allows fully–manned platoon–, company–, and battalion–size units to conduct force–on–force engagements against opposing units of similar composition without incurring the costs of transporting large numbers of personnel and equipment. These engagements include the complete range of command and control and combat service support elements essential to actual military operations.

SIMNET is a test bed for future full combined arms joint tactical training projects such as the U.S. Army's proposed Close Combat Tactical Trainer (CCTT). SIMNET is expandable, and greater numbers of simulators can share the network to increase the scope of the exercise.

SIMNET is a "simulate before you build" development model for new weapons systems and combat tactics. New ideas can be tested and evaluated in the SIMNET world safer and at less cost than in the field.

What is SIMNET?

Manned simulators representing the main current combat vehicles:

- M1 Abrams main battle tank
- M2/M3 Bradley infantry fighting vehicle
- Generic attack helicopters
- Generic fixed– wing close air support aircraft
- Generic air defense artillery

Automated combat support and combat service support vehicles:

- Artillery (self–propelled howitzers and mortars)
- Fuel and ammunition resupply vehicles
- Maintenance/repair vehicles

Combat unit personnel control these vehicles from the consoles of the SIMNET Management, Command, and Control (MCC) system. There are also consoles for exercise start–up and close air support missions.

Semi–Automated Forces (armor, mechanized infantry, air defense vehicles, helicopters, fixed–wing aircraft) controlled by a human commander. These forces provide an opponent as realistic as the manned simulators. The computer processes detailed simulations for each vehicle, providing route–following, obstacle avoidance, formation–keeping, target acquisition, etc. The commander monitors the force's behavior on a Plan View Display, and can intervene at any time to redirect the activities of a company, platoon, or even a single vehicle.

Data collection and analysis systems which store the state update messages broadcast from all vehicles during the exercise. As soon as the exercise is completed, these messages can be replayed onto the network and the entire exercise can be repeated and observed from above (on a Plan View Display) or from the participant's level (from the vantage of a 'Stealth' vehicle which can assume the role of any other combat vehicle). In addition, a powerful set of data extraction and statistical analysis and plotting tools can measure and report on individual vehicle or combat unit performance within minutes.

How Does SIMNET Work?

SIMNET is a Distributed Simulation. No central computer directs the activities of the various simulation elements. Instead, each simulator has its own microcomputer(s) which talks to each of the other simulation elements. As the network expands, each new simulator brings with it the computer resources necessary to support its computational requirements. Adding new simulators does not require that the existing ones be modified.

Each manned simulator typically consists of a host computer, a computer image generation (CIG) color visual system, and user interface controls. The simulators at a given site are conr ted by an Ether-net™ local area net- (LAN) and com-municate via the SI T Protocol. Each simulator trans specially for-matted information called Proto-col Data Units (PD that vehi-cle's location, move d appearance in relation to other si vehicles, and receives similar data from them. Sites are connected to each other by long haul network (LHN) links over land lines or by satellite. Each LAN has a small gateway computer which efficiently inter-faces with the LHN.

Ethernet interfaces are inexpensive, avail-able from multiple vendors for practically all computer makes, and they support multicasting (the simultaneous broadcast of data to multiple simulators on the net-work) with automatic error detection. Ethernet can efficiently handle the simu-lation traffic of up to 1000 vehicles on a single network. Furthermore, LHN links are easily installed.

Conclusion

SIMNET is currently operational at train-ing sites in the United States and Europe. Simulators can now be linked on a world-wide network to support large-scale train-ing exercises and the development of new doctrine, tactics, and weapons systems. Pre-combat simulation training means a higher probability of success in actual battle. The variability of the SIMNET battlefield means that victory goes to the side that is able to plan and execute its combined arms operations better than its opponent. SIMNET meets the combined arms training objectives realistically and cost-effectively.

Ethernet is a trademark of the Xerox Corporation.

APPENDIX F

View Graphs of Concluding Remarks

SECOND WORKSHOP ON STANDARDS FOR THE
INTEROPERABILITY OF DEFENSE SIMULATIONS

TERRAIN DATABASE WORKING GROUP

These notes augment the summary briefing charts presented in the final session of the Workshop on 17 January 1990 and address the specific issues identified in the opening session.

1. COORDINATION WITH DMA

Continuing coordination with the Defense Mapping Agency (DMA) on specific product requirements is being handled by DOD Service Labs/Staff and/or Joint Offices. Area coverage requirements will be handled primarily through Unified and Specified (U&S) Commands. Terrain database issues in simulation networking require continuing coordination between P2851, PM-TRADE, ETL, TRADOC TSM and DARPA.

2. INTERIM TERRAIN DATA ASSESSMENT/ITD

ETL is working with PM-TRADE to investigate ITD related issues in conjunction with P2851 and SIMNET. Coordination among PM-TRADE, ETL, DARPA, P2851 will be necessary for ITD assessment, with additional support from BBN, IST, and PRC.

3. PROJECT 2851 ECP ASSESSMENT/ITD
See ITD assessment/ITD (Item #2 above).

4. GEODETIC FRAME OF REFERENCE

The Working Group recommended adoption of the DMA World Geodetic System (WGS 84).

5. DEVELOPMENT OF CORRELATION PARAMETERS AND METRICS
See Subgroup Chairman Duncan Miller's viewgraphs.

6. DYNAMIC TERRAIN FEASIBILITY/METHODOLOGY

See Subgroup Chairman Richard Moon's viewgraphs.

7. INCREASE SIZE OF GAME BOARD

The Working Group recommended use geocentric Cartesian coordinates in network protocol to support potentially global "gaming boards". Standard conversion routines for soldier-machine interfaces to-and-from geographic coordinates and MGRS are needed with test data sets for validation testing.

8. SPHERICAL EARTH MODEL (Lat/Long)

The Working Group recommended adoption of geographic coordinates (latitude/longitude/altitude) for standard Navy and Air Force soldier-machine interfaces and MGRS (UTM and UPS) for standard Army soldier-machine interfaces. Coordinate systems transformation need to preserve relevant tactical effects of curved earth (finite distance to horizon) in computer image generation.

9. DEFINITION OF SOLID MODELING TECHNIQUE

Working Group anticipates use of Project 2851 (P2851) solid modeling techniques and libraries. P2851 has adopted a constructive solid geometry (CSG) approach to build Standard Simulator Data Base (SSDB) models. SSDB CSG models are transformed into polygonal models based upon target IG's performance capabilities and distributed in GTDB format.of this software is on-going; anticipate completion in early February 1990. A limited number of transformed models will be included within GTDB data sets to be distributed beginning in April 1990.

10. DEFINITION OF TEXTURE REPRESENTATION

Project 2851 presently does not include a representation of texture maps. Proposed engineering change (ECP) currently in evaluation would add geospecific (photo) and generic texture map representations. Proposed capabilities are to be fully integrated within the Project 2851 system in mid-1992. Distribution of sample GTDB's with texture maps would be scheduled for early 1992.

11. DISTRIBUTION FORMAT

Working Group recommended adoption of the Project 2851 GTDB as the future distribution format. Specification is available now. Two types of GTDB are supported: (1) gridded-terrain/vector culture; and (2) polygonal-terrain/vector or polygon culture. Gridded GTDB's are critical to support many existing CIG architectures as well as semi-automated forces (SAF) and hard-copy/soft-copy cartographic displays. Polygonal GTDB's are designed to maximize correlation between a family of existing and anticipated heterogeneous CIG architectures. Sample GTDBs to be produced beginning in April and distributed to ISWG.

12. DATABASE REPOSITORY ORGANIZATION

The Working Group recommended adoption of the proposed Project 2851 repository at DMA Aerospace Center, St. Louis, MO. Initial operational capability (IOC) is scheduled for May 1991. The proposed P2851 facility is to be administered by DMA, managed by a tri-service liaison board, and contractor-operated.

13. SEMI-AUTOMATED FORCES (Unmanned Vehicles)

See Sub-Group Chairman Dexter Flecher's viewgraphs.

23 January 1990
George E. Lukes, Chairman
Terrain Database Working Group