Parallel Discrete Event Simulation: A Pedestrian View

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Parallel Discrete Event Simulation

Parallel Discrete Event Simulation

PDES

Overview

Proof Types

1. Simulation Types
2. Vernacular
3. Tidbits

PDES Types

CONSERVATIVE
OPTIMISTIC

Sources

1. Academic papers
2. Books
3. Unpublished

Bryant: 1977

MIT/LCS/TR-188

SIMULATION OF PACKET COMMUNICATION ARCHITECTURE COMPUTER SYSTEMS

by

Randal Everitt Bryant

November, 1977

Bryant 1977

Bryant: 1977

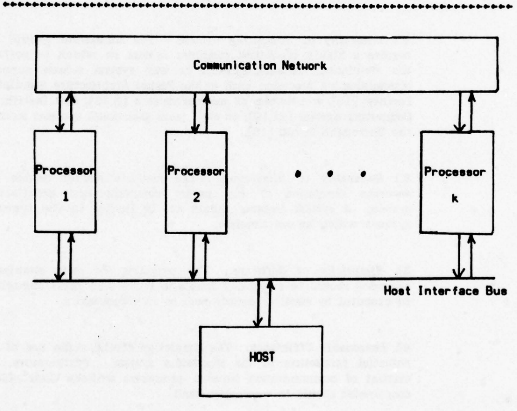


Figure 1.2 - Structure of Simulation Facility

Chandy & Misra: 1979

440 IEEE TRANSACTIONS ON SOFTWARE ENGINEERING, VOL. SE-5, NO. 5, SEPTEMBER 1979

Distributed Simulation: A Case Study in Design and Verification of Distributed Programs

K. MANI CHANDY AND JAYADEV MISRA, MEMBER, IEEE

Chandy and Misra 1979

Chandy & Misra: 1979

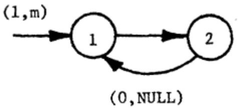


Fig. 2. A simulation that never terminates.

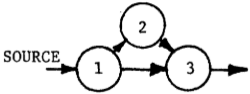


Fig. 3. An acyclic network that may deadlock.

Battlefield Simulations

1. Gilmer Jr 1988
2. **The performance of a distributed combat simulation with the time warp operating system** Wieland, Hawley, Feinberg, et al. 1989
3. **Implementing a distributed combat simulation on the time warp operating system** Wieland, Hawley, and Feinberg 1989

Hierarchical Decompositions

1. Gilmer Jr 1988
2. Ziegler, Hu, and Rosenblit 1989

Fujimoto: Parallel discrete event simulation

Fujimoto 1990

Fujimoto, Again: Parallel discrete event simulation

213

ORSA Journal on Computing
Vol. 5, No. 3, Summer 1993

0899-1499/93/0502-0213 $01.25

FEATURE ARTICLE

Parallel Discrete Event Simulation: Will the Field Survive?

RICHARD M. FUJIMOTO / *College of Computing, Georgia Institute of Technology, Atlanta, GA 30332-0280; Email: fujimoto@cc.gatech.edu*

(Received: September 1992; revised November 1992, March 1993; accepted: April 1993)

Fujimoto 1993

Kunz: Modeling and tools for network simulation

8. Parallel Discrete Event Simulation

Georg Kunz (RWTH Aachen University)

8.1 Introduction

Ever since discrete event simulation has been adopted by a large research community, simulation developers have attempted to draw benefits from executing a simulation on multiple processing units in parallel. Hence, a wide range of research has been conducted on Parallel Discrete Event Simulation (PDES). In this chapter we give an overview of the challenges and approaches of *parallel simulation*. Furthermore, we present a survey of the parallelization capabilities of the network simulators OMNeT++, ns-2, DSIM and JiST.

Kunz 2010

Stathopoulos: Personal Web Page

Parallel Discrete Event Simulation

PDES: the execution of a single DES program on a parallel computer

Why PDES?

large simulations consume enormous amounts of time on sequential machines

- engineering
- computer science
- economics
- military applications

Stathopoulos n.d.

Massively Parallel Discrete Event Simulation I

1. Towards parallelization of large-scale Ada simulations using time warp Carothers, Hybinette, and Fujimoto 1998 [1]
2. Optimistic parallel discrete event simulation based on multi-core platform and its performance analysis Su et al. 2009
3. Multithreading for optimizing pdes on multicore platforms Jagtap 2012

[1] THAAD Integrated System Effectiveness Simulation, (TISES) Horn et al. 1997

Massively Parallel Discrete Event Simulation II

4. **A fast implementation of parallel discrete-event simulation on gpgpu** Sang et al. 2013
5. **Parallel Discrete Event Simulation for Multi-Core System** Wang et al. 2014
6. **Optimization of parallel discrete event simulator for multi-core systems** Wang et al. 2014 ♦
7. **Parallel Discrete Event Simulation for Multi-Core System** Wang et al. 2014
8. **Experiences with implementing parallel discrete-event simulation on GPU** Sang et al. 2019
9. **An efficient multi-threaded memory allocator for PDES applications** Li et al. 2020

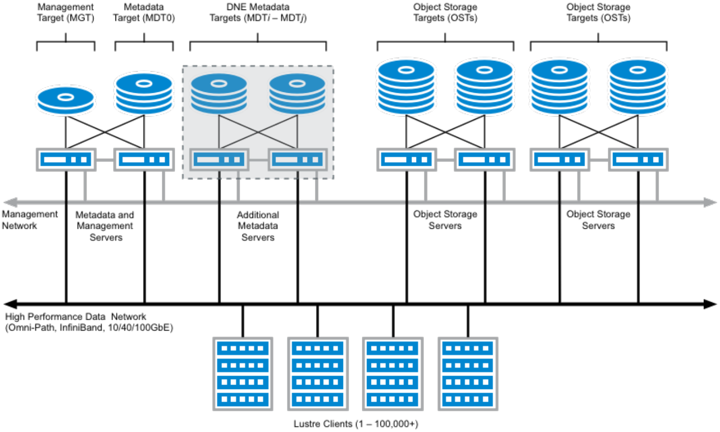
Parallelization Tools

1. File systems (Lustre)
2. Performance Analysis Tools (Vampir, Tau, NVIDIA)
3. Data formats (HDF)
4. Parallel databases

Lustre File System

Open-source, parallel file system

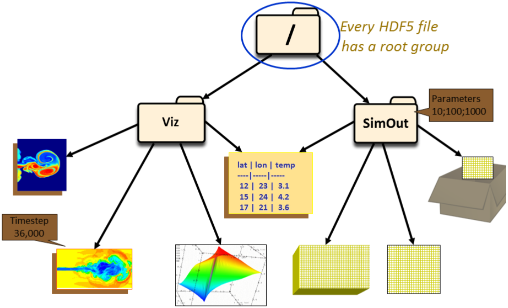
Lustre File System Wiki



Hierarchical Data Format (HDF)

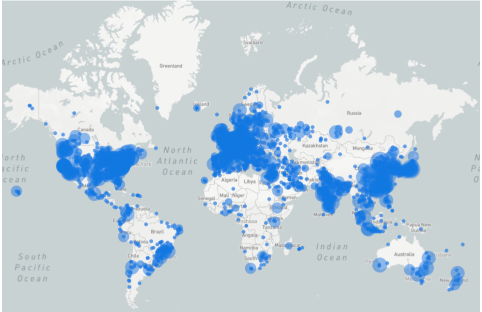
Set of file formats designed to store and organize large amounts of data

Hierarchical Data Format (HDF)



Sharing data

Hierarchical Data Format (HDF) Weekly Clinic



Tuesday, 11:20 Mountain

NVIDIA Performance Analysis Tools

NVIDIA Nsight Systems

NVIDIA® Nsight™ Systems is a system-wide performance analysis tool designed to visualize application's algorithm, help you select the largest opportunities to optimize, and tune to scale efficiently across any quantity of CPUs and GPUs in your computer; from laptops to DGX servers.

NVIDIA® Nsight™

The ultimate development platform for heterogeneous computing. Work with powerful debugging and profiling tools, optimize the performance of your CPU and GPU code. Find out about the Eclipse Edition and the graphics debugging enabled Visual Studio Edition.

NVIDIA Visual Profiler

This is a cross-platform performance profiling tool that delivers developers vital feedback for optimizing CUDA C/C++ applications. First introduced in 2008, Visual Profiler supports all CUDA capable NVIDIA GPUs shipped since 2006 on Linux, Mac OS X, and Windows.

TAU Performance System®

This is a profiling and tracing toolkit for performance analysis of hybrid parallel programs written in CUDA, and pyCUDA., and OpenACC.

VampirTrace

A performance monitor which comes with CUDA, and PyCUDA support to give detailed insight into the runtime behavior of accelerators. Enables extensive performance analysis and optimization of hybrid programs.

The PAPI CUDA Component

A hardware performance counter measurement technology for the NVIDIA CUDA platform which provides access to the hardware counters inside the GPU. Provides detailed performance counter information regarding the execution of GPU kernels.

The NVIDIA CUDA Profiling Tools Interface

(CUPTI) provides performance analysis tools with detailed information about GPU usage in a system. CUPTI is used by performance analysis tools such as the NVIDIA Visual Profiler, TAU and Vampir Trace.

NVIDIA Topology-Aware GPU Selection

(NVTAGS) is a toolset for HPC applications that enables faster solve times with high GPU communication-to-application run-time ratios. NVTAGS intelligently and automatically assigns GPUs to message passing interface (MPI) processes, thereby reducing overall GPU-to-GPU communication time.

Vampir

Display and analyze arbitrary program behavior
at any level of detail

TAU: Tuning and Analysis Utilities

Portable profiling and tracing toolkit for performance analysis of parallel programs written in Fortran, C, C++, UPC, Java, Python

TAU: Tuning and Analysis Utilities

1. Sameer S Shende and Allen D Malony. "The TAU parallel performance system". In: The International Journal of High Performance Computing Applications 20.2 (2006), pp. 287–311
2. Kathleen A Lindlan et al. "A tool framework for static and dynamic analysis of object-oriented software with templates". In: SC'00: Proceedings of the 2000 ACM/IEEE Conference on Supercomputing. IEEE. 2000, pp. 49–49

TAU: Tuning and Analysis Utilities

3. A Malony et al. “Performance technology for parallel and distributed component software”. In: Concurrency and Computation: Practice and Experience 17.2-4 (2005), pp. 117–141
4. David E Bernholdt et al. “A component architecture for high-performance scientific computing”. In: The International Journal of High Performance Computing Applications 20.2 (2006), pp. 163–202

Thrust

1. GitHub– Thrust: The C++ Parallel Algorithms Library
2. GitHub– About CUB
3. NVIDIA developer blog: Popular Open Source Thrust and CUB Libraries Updated
4. Introduction to CUDA Libraries : Thrust

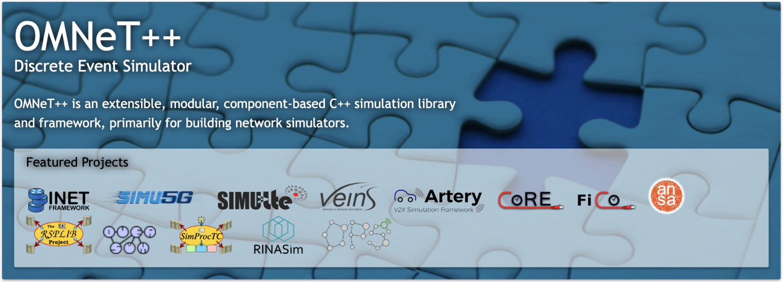
Proof Types

1. Naïve expansion
2. Dedicated Web Sites
3. Federation of American Scientists

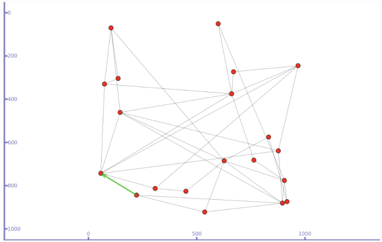
Network Parallel Discrete Event Simulations

1. OMNet
2. ns-3
3. DSIM
4. JiST

OMNET++


OMNeT++
Discrete Event Simulator
OMNeT++ is an extensible, modular, component-based C++ simulation library and framework, primarily for building network simulators.
Featured Projects
INET FRAMEWORK
SIMU5G
SIMUlte
veins
Artery
V2X Simulation Framework
CoRE
FiCo
an sa
The RSPLIB Project
SimProcTC
RINASim

ns-3



ns-3
Network Simulator

ns-3 is a discrete-event network simulator for Internet systems, targeted primarily for research and educational use. ns-3 is free, open-source software, licensed under the GNU GPLv2 license, and maintained by a worldwide community.

Download | Docs | App Store

DSIM

Open Simulation Solutions

for Research, Development and Training

D-SIM and D-WORLD are the perfect software solutions for Open Simulation in which you control all the simulators in one distributed virtual world

D-SIM

Your solution for rapid development in an open simulation framework.

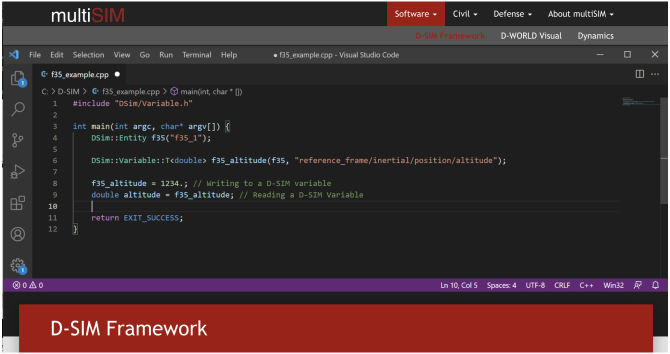
D-WORLD

Your virtual reality render engine for realistic simulations in one distributed world.

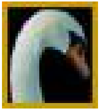
Dynamics

Your high-fidelity physics solution for aircraft and vehicle simulations.

DSIM


multiSIM
Software
Civil
Defense
About multiSIM
D-SIM Framework
D-WORLD Visual
Dynamics
File Edit Selection View Go Run Terminal Help
● f35_example.cpp - Visual Studio Code
f35_example.cpp
C: > D-SIM > f35_example.cpp > main(int, char * [])
#include "DSim/Variable.h"
int main(int argc, char* argv[]) {
DSim::Entity f35("f35_1");
DSim::Variable::T<double> f35_altitude(f35, "reference_frame/inertial/position/altitude");
f35_altitude = 1234.; // Writing to a D-SIM variable
double altitude = f35_altitude; // Reading a D-SIM Variable
return EXIT_SUCCESS;
}
Ln 10, Col 5 Spaces: 4 UTF-8 CRLF C++ Win32
D-SIM Framework

JiST



Java in Simulation Time

Scalable Wireless Ad hoc Network Simulator

JiST Swans Network Simulator

high-performance discrete event simulation engine
over a standard java virtual machine

The University of New Mexico

Bibliography I

[1] David E Bernholdt et al. "A component architecture for high-performance scientific computing". In: The International Journal of High Performance Computing Applications 20.2 (2006), pp. 163–202.

[2] R. E. Bryant. Simulation of packet communication architecture computer systems. Tech. rep. USA, 1977.

[3] Christopher D Carothers, Maria I Hybinette, and Richard M Fujimoto. "Towards Parallelization of Large-scale Ada Simulations Using Time Warp". In: Summer Computer Simulation Conference. Society for Computer Simulation, etc. 1998, pp. 600–605.

Bibliography II

[4] K. Mani Chandy and Jayadev Misra. "Distributed simulation: A case study in design and verification of distributed programs". In: IEEE Transactions on software engineering 5 (1979), pp. 440–452.

[5] Richard M Fujimoto. "Parallel discrete event simulation". In: Communications of the ACM 33.10 (1990), pp. 30–53.

[6] Richard M Fujimoto. "Parallel discrete event simulation: Will the field survive?" In: ORSA Journal on Computing 5.3 (1993), pp. 213–230.

Bibliography III

[7] John B Gilmer Jr. “An assessment of” Time Warp” parallel discrete event simulation algorithm performance.”. In: SCS Multiconference on Distributed Simulation. 1988, pp. 45–49.

[8] Dawn Horn et al. “THAAD integrated system effectiveness simulation (TISES)”. In: Modeling and Simulation Technologies Conference. 1997, p. 3522.

[9] Deepak A Jagtap. “Multithreading for optimizing PDES on multicore platforms”. MA thesis. State University of New York at Binghamton, 2012.

[10] Georg Kunz. “Parallel discrete event simulation”. In: Modeling and Tools for Network Simulation. Springer, 2010, pp. 121–131.

Bibliography IV

[11] Tianlin Li et al. "An efficient multi-threaded memory allocator for PDES applications". In: Simulation Modelling Practice and Theory 100 (2020), p. 102067. ISSN: 1569-190X. DOI: https://doi.org/10.1016/j.simpat.2020.102067. URL: https://www.sciencedirect.com/science/article/pii/S1569190X20300010.

[12] Kathleen A Lindlan et al. "A tool framework for static and dynamic analysis of object-oriented software with templates". In: SC'00: Proceedings of the 2000 ACM/IEEE Conference on Supercomputing. IEEE. 2000, pp. 49–49.

Bibliography V

[13] A Malony et al. "Performance technology for parallel and distributed component software". In: Concurrency and Computation: Practice and Experience 17.2-4 (2005), pp. 117–141.

[14] Janche Sang et al. "A fast implementation of parallel discrete-event simulation on GPGPU". In: Proceedings of the International Conference on Parallel and Distributed Processing Techniques and Applications (PDPTA). The Steering Committee of The World Congress in Computer Science, Computer . . . 2013, p. 501.

Bibliography VI

[15] Janche Sang et al. "Experiences with implementing parallel discrete-event simulation on GPU". In: The Journal of Supercomputing 75 (2019), pp. 4132–4149.

[16] Sameer S Shende and Allen D Malony. "The TAU parallel performance system". In: The International Journal of High Performance Computing Applications 20.2 (2006), pp. 287–311.

[17] Andreas Stathopoulos. Parallel discrete event simulation. URL: https://www.cs.wm.edu/~andreas/umsa/lectures/cs-sim-pdes.pdf.

Bibliography VII

[18] Nianle Su et al. "Optimistic Parallel Discrete Event Simulation Based on Multi-core Platform and its Performance Analysis". In: 2009 International Conference on Complex, Intelligent and Software Intensive Systems. Mar. 2009, pp. 675–680. DOI: 10.1109/CISIS.2009.59.

[19] Jingjing Wang et al. "Parallel Discrete Event Simulation for Multi-Core Systems: Analysis and Optimization". In: IEEE Transactions on Parallel and Distributed Systems 25.6 (2014), pp. 1574–1584. DOI: 10.1109/TPDS.2013.193.

Bibliography VIII

[20] Frederick Wieland, Lawrence Hawley, and Abe Feinberg. "Implementing a distributed combat simulation on the time warp operating system". In: Proceedings of the third conference on Hypercube concurrent computers and applications-Volume 2. 1989, pp. 1269–1276.

[21] Frederick Wieland, Lawrence Hawley, Abe Feinberg, et al. "The performance of a distributed combat simulation with the time warp operating system". In: Concurrency: Practice and Experience 1.1 (1989), pp. 35–50.

Bibliography IX

[22] B.P. Ziegler, J.H. Hu, and J.W. Rosenblit. "Hierarchical, modular modelling in DEVS-scheme". In: WSC '89: Proceedings of the 21st conference on Winter simulation. 1989, pp. 84–85. DOI: Pages84-89https://doi-org/10.1145/76738.76749.

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