Performance Evaluation of LS-DYNA3D on NEC SX-4 Series

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Introduction

Enormous amounts of computer resources are required to perform large deformation analyses for automobile crashworthiness. Finite element models used to assess vehicle crashworthiness often have more than 90,000 elements and would require more than 20 hours of simulation time on fast vector computers such as the NEC SX-3 and Cray C90 [1].

The explicit finite element program LS-DYNA3D is widely recognized to be the premier software for crashworthiness analysis. LS-DYNA3D offers extensive capabilities in crash-, impact-, dummy-, airbag-, and metalforming analysis. The range of features and capabilities of LS-DYNA3D are constantly expanding and improving due to the demands from industry. LS-DYNA3D has wide number of elements and options available to enable simulation models to include almost all details of the real structure (e.g., steering wheel construction, rubber wheels and wheel suspension, motor suspension and even the jack and spare wheel for rear crash).

In order to satisfy demands from industry for cost effective computer hardware to perform computational simulations for structural deformations and fluid flow analysis, NEC has recently introduced the SX-4 series of scalable parallel vector supercomputer. The SX-4 performance ranges from the single processor SX-4/Ce 1 GigaFLOPS entry model to the 512 processor SX-4/512M16 - a TeraFLOPS system with a total main memory capacity of 128 Gigabytes. The SX-4 series in shared memory mode supports up to 32 processors with peak performance of 64 GigaFLOPS and main memory of up to 8 Gigabytes. The SX-4 series utilizes high speed, low-power CMOS technology to provide leading performance and a fully air-cooled system which uses fraction of power required by previous generation Bi-Polar implementations. CMOS technology makes the SX-4 series highly affordable with price-performance and maintenance costs comparable to high end workstations. SX-4 operating system is SUPER-UX, which is a robust implementation based on System V UNIX with 4.3 BSD extensions. The SX-4 supports three levels of processing - vector processing, shared memory parallel vector processing, and distributed memory parallel vector processing. SX-4 includes FORTRAN77/SX, FORTRAN90/SX, C/SX, HPF/SX and MPI/SX to support various programming models. The purpose of this paper is to explore the performance of the SX-4 when running crashworthiness problems using LS-DYNA3D with respect to other types of computing hardware.

Two types of crashworthiness problems are considered in this paper: First, vehicle-to-vehicle collisions and second, single-vehicle roadside hardware collisions. Vehicle-to-vehicle collisions represent approximately 70 percent of all highway accidents and roadside hardware collisions represents about 10 of all motor accidents in the Unites States [2] [3]. Accidents involving new and emerging types of vehicle like wedge-shape vehicles, minivans, cab forward designs, sport utility vehicles, and pickup trucks are of immense interest to both vehicle and highway designers. Non-linear finite element analysis is one tool that is being applied the problem of building better vehicles and roadways [2]. This paper considers two particular simulations a (1) vehicle-to-vehicle collision and (2) a vehicle colliding with a typical guardrail. Specifically, this paper compares the performance of identical dataset run on NEC SX-4, NEC SX-3R, NEC SX-3, Cray C90 and SGI Power Challenge computers.

Table 1
Analysis Case Parameters

Case	Description	Termination Time (Bench/Animation)	Initial Velocity	Animation Timestep
Vehicle-vehicle	Identical mid-size vehicles in an offset frontal collision	10 ms/100ms	55 kph	5 ms
Guardrail-vehicle	Small passenger collision with a steel-post W-beam guardrail	235 ms/235 ms	100 kph	11.75 ms

Table 2
Model Sizes

Case	Number of Materials	Nodes	Beam Elements	4-Node Shell Elements	8-Node Solid Elements
Vehicle-vehicle	248	53952	284	56742	0
Guardrail-vehicle	28	8669	105	6910	809

Vehicle-Vehicle Benchmark Case

The vehicle-vehicle benchmark case is a simulation of a collision between two Ford Taurus automobiles, modeled using 124 material types, 26,976 nodes, 142 beam elements, and 3,455 4-node shell elements, per car. The model of the Ford Taurus was first developed by Varadappa *et al* in a study for the National Highway Traffic Safety Administration (NHTSA) [4]. Subsequently this model was modified by other NHTSA researchers and is being used to simulate an offset frontal collision between two identical vehicles with each car moving toward the other with an initial velocity of 55 kph [5]. The vehicles strike each other overlapping by 50 percent on the driver side of each vehicle. An automatic single surface (type 13) sliding interface at the front of each car is used to model contact between the vehicles. The primary structural components (hood, fenders, bumper, etc.) of the cars were modeled using the piecewise linear isotropic plasticity shell elements (type 24), while the steering and suspension components (steering column, front struts, suspension links, driveshaft, etc.) for each car were modeled using elastic beam elements (material type 1).

The same LS-DYNA3D input file was used for all the comparisons. Since the purpose of this study was to investigate computer hardware performance rather than simulating the physical events, only 10 msec of contact time were simulated. The simulation was allowed to run to 100 msec on the NEC SX-3 for the purpose of generating figures and ensuring that there were no unexpected computational problems.

Table 3
Vehicle-vehicle Benchmark Results

Machine	Memory (MB)	Processors Available	Processors Used	Runtime (CPU sec)	Cycles	Speed (cycles / sec)
SGI Power Challenge	128	1	1	17,216	11,123	0.646
CRAY C94/264	512	2	1	4,699	11,123	2.367
NEC SX-3/22	512	2	1	4,425	11,123	2.514
NEC SX-3/44R (dedicated)	4000	4	1	2,519	11,123	4.416
NEC SX-4 (dedicated)	8000	32	1	2,630	11,123	4.229

The results from each of the benchmark runs were output through the MPGS option of LS-DYNA3D and visualized using Ensight v5.5. The vehicle-vehicle dataset was rerun, increasing the simulation time by a factor of 10 so that the characteristics of the collision could be observed. The offset frontal impact (Figure 1 and 2) shows significant deformation to both vehicles but only in the designated "crumple zones" toward the front of the vehicle. Figure 2 shows the damage to one of the vehicles with the other vehicle removed for clarity. There is relatively little damage to the passenger side and the passenger compartment of the vehicle.

Guardrail-Vehicle Benchmark Case

The guardrail-vehicle benchmark case simulates the interaction of a small 820-kg vehicle striking a common guardrail system, the G4(1S). The vehicle model was developed by Ray and Cofie in a Federal Highway Administration (FHWA) study [6]. The model of the G4(1S) guardrail is being used by Ray to study performance problems with typical roadside hardware [2]. As shown in Table 2, the combined guardrail-vehicle model is constructed from 6910 4-node shell elements, 809 solid elements and 105 beam elements. The beam elements are used to model components like the axles, MacPhearson struts, tie-rods and steering linkages. The solid elements are used to model the engine block and the tires. The remaining components, representing the bulk of the model, are constructed using shell elements. A total of 28 materials are used, the majority using the kinematic/isotropic elastic-plastic material model (type 3). Contact is modeled using a single automatic contact interface (type 13). This vehicle and guardrail model represent a much coarser mesh than the vehicle-vehicle case since the desired output focuses more on the long-term kinematics of the vehicle rather than the precise failure mechanisms of vehicle components.

The same LS-DYNA3D input file was used for all the comparisons shown in Table 4. Since the total mesh was much smaller than the vehicle-vehicle case, the entire 235 msec impact was run on all the machines.

Table 4
Guardrail-vehicle Benchmark Results

Machine	Memory (MB)	Processors Available	Processors Used	Runtime (CPU sec)	Cycles	Speed (cycles / sec)
SGI Power Challenge	128	1	1	24,665	167,954	6.812
CRAY C94/264	512	2	1	8,110	167,719	20.681
NEC SX-3/22	512	2	1	5,352	167,711	31.336
NEC SX-3/44R (dedicated)	4000	4	1	3,048	167,747	55.035
NEC SX-4 (dedicated)	8000	32	1	3,506	167,742	47.844

The results from each of the benchmark runs were output through the MPGS option of LS-DYNA3D and visualized using Ensight v5.5. Plots from the guardrail-vehicle dataset (Figures 3 and 4) show that the most significant deformation to both the car and the guardrail occur about 106 msec after the initial impact.

Conclusions

Two significant classes of problems in crashworthiness analysis, namely, (1) vehicle-vehicle impact, (2) vehicle-guardrail impact were described and performance results were presented for high-end workstations (SGI Power Challenge L 90 MHz) and vector supercomputers (NEC SX-4, NEC SX-3 and Cray C90).

Table 5
Benchmark Performance Ratios

Machine	Vehicle-Vehicle Case	Vehicle-Guardrail Case
SGI Power Challenge	1	1
CRAY C94/264	3.66	3.04
NEC SX-3/22	3.89	4.61
NEC SX-3/44R	6.83	8.09
NEC SX-4	6.55	7.03

Table 5 highlights relative performance of various computing platforms. Please note that dedicated machine environments were used for NEC SX-3/44R and vehicle-vehicle benchmark case for SX-4. This is the first time LS-DYNA3D is being executed on SX-4 and absolutely no tuning of the code has been performed on SX-4. It is expected that SX-4 performance for LS-DYNA3D will improve significantly as further tuning is performed and evolution of compilers takes place.

Table 4 indicates that vector supercomputers provide significant performance enhancements over the high-end RISC workstations for crashworthiness analysis using LS-DYNA3D. Performance of SX-4 is roughly equivalent to SX-3R series with significant decrease in price due to CMOS technology. It is expected that SX-4 performance on LS-DYNA3D will improve as further tuning is performed. It appears that vector supercomputers provide outstanding performance in a single processor mode.

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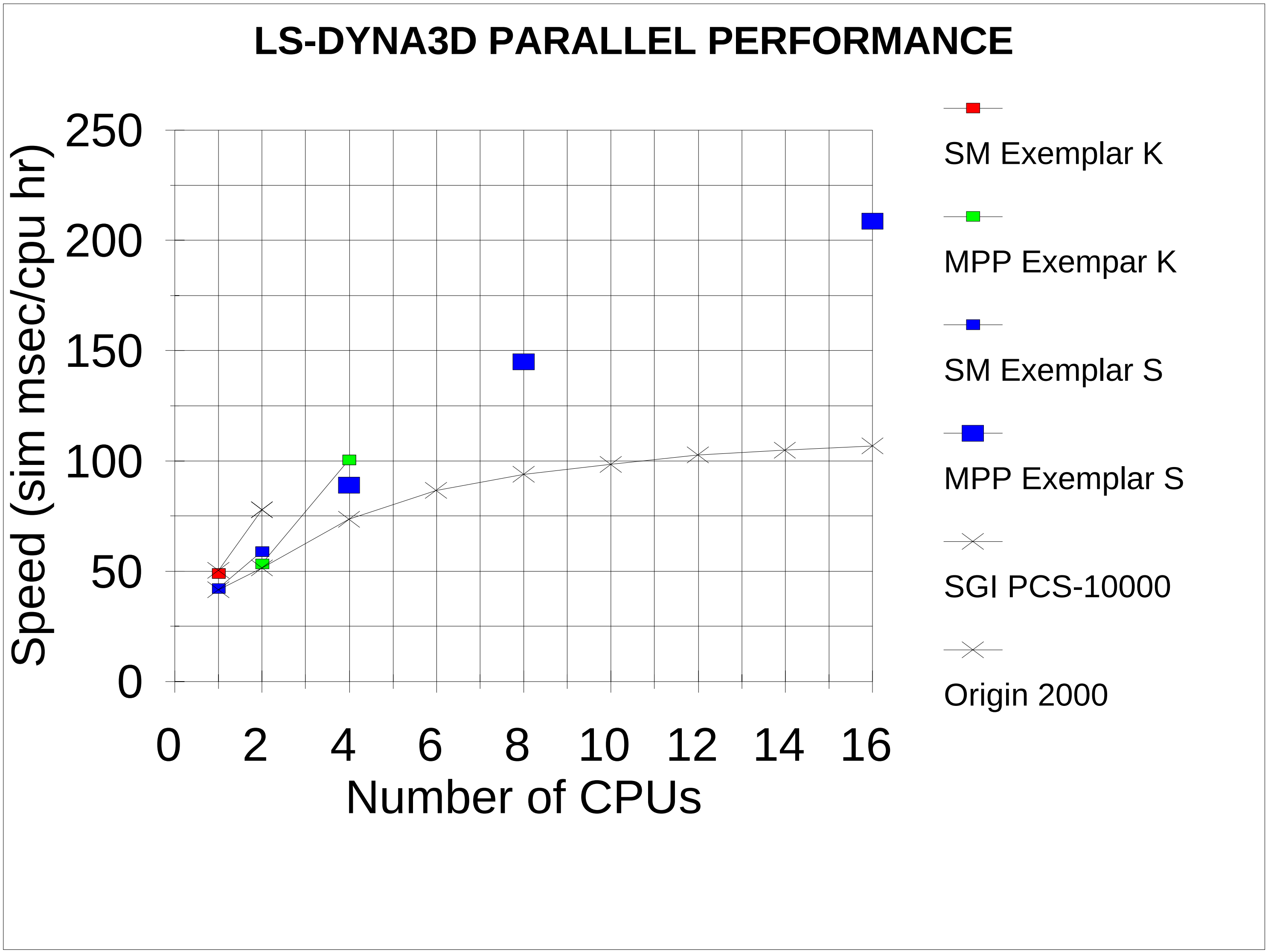
LS-DYNA3D PARALLEL PERFORMANCE
Speed (sim msec/cpu hr)
0
50
100
150
200
250
0
2
4
6
8
10
12
14
16
Number of CPUs
SM Exemplar K
MPP Exemplar K
SM Exemplar S
MPP Exemplar S
SGI PCS-10000
Origin 2000