A Short course of LS-DYNA/MPP®

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Introduction

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- What drives the MPP development?
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Development History

- Public domain DYNA3D, Dr. John O. Hallquist/Lawrence Livermore National Laboratory, 1976
  - Weapon simulations
- LSTC and LS-DYNA3D® founded by Dr. J. O. Hallquist in 1988
  - Recognized market for commercial applications
- In the 1990's …
  - LS-DYNA2D and LS-DYNA3D® combined (LS-DYNA)
  - Implicit capability (LS-NIKE3D) introduced to LS-DYNA®
  - Thermal capability (TOPAZ) introduced to LS-DYNA®
  - Introduced MPP capability
  - Eulerian/ALE element formulations and Euler/Lagrange coupling introduced
  - LS-POST, LS-OPT® introduced

Development History

- Since 2000,
  - Expanded MPP capability
  - Meshless methods introduced
  - LS-POST expanded to include preprocessing (LS-PrePost®)
- Worldwide distribution: US, UK, Nordic countries, France, Germany, Italy, Netherlands, Japan, Korea, China,Taiwan, India, Brazil; also through ANSYS and MSC.
- 60+ full-time employees + numerous consultants
- Products:
  - LS-DYNA®
  - LS-PrePost®
  - LS-OPT®
  - FE Models: Dummies, barriers, head forms
  - USA (Underwater Shock Analysis)

Development History

- Automotive
  - Crash and safety
  - Durability
  - NVH
- Aerospace
  - Bird strike
  - Containment
  - Crash
- Manufacturing
  - Stamping
  - Forging
- Structural
  - Earthquake safety
  - Concrete structures
- Electronics
  - Drop analysis
  - Package design
  - Thermal
- Defense
  - Weapon design
  - Blast response
  - Penetration
  - Underwater shock analysis
- Also, applications in biomedical, sports, consumer products, etc.

Development History

- Combine the multi-physics capabilities
  - Explicit/Implicit solver
  - ALE, SPH, EFG
  - Heat Transfer
  - Airbag particle method
  - Acoustics (USA)
  - Interfaces for users, i.e., elements, materials, loads
  - Electromagnetic (version 981)
  - Incompressible fluids (version 981)
  - CESE compressible fluid solver (version 981)
- into one scalable code for solving highly nonlinear transient problems to enable the solution of coupled multi-physics and multi-stage problems.

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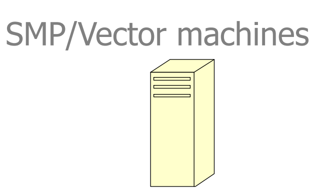
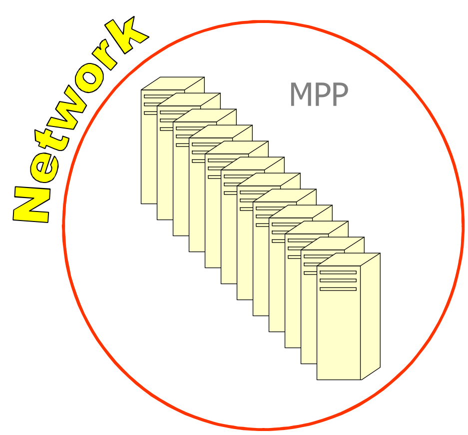
Development History

MPP is a special version of LS-DYNA®, that is developed to run on a number of computers connected in a network. For large models this it is necessary to have large computer resources to finish a simulation in an acceptable time.





SMP can run multiple CPU's but they are placed in the same computer

Development History

- SMP (Shared Memory Parallel)
  - Start and base from serial code
  - Using OpenMP directives to split the tasks
  - Only run on SMP (single image) computers
  - Scalable up to ~8 CPUs

- MPP (Message Passing Parallel)
  - Using the domain decomposition method
  - Using MPI for communications between sub-domains
  - Work on both SMP machines and clusters
  - Scalable >> 8 CPUS
  - Dramatically reduced elapsed time and the simulation cost

Development History

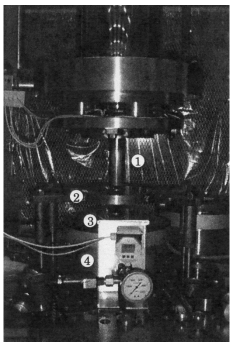
Many of the features were implemented as customers required it. This means that features were not implemented in option blocks.

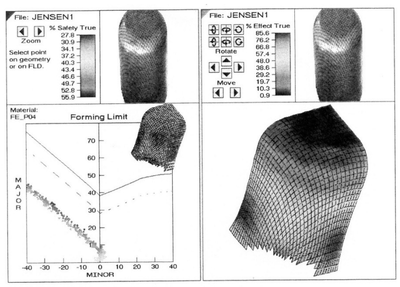
- MPP-DYNA was initiated in 1993 (version 930)
- Nearly fully supported contact algorithms (1996)
- P-file, composition and analyze in one run (1996)
- CONSTRAINED_options (1996)
- Limited ALE capabilities (1998)
- SPH (2002)
- EFG (971)
- Thermal (971)
- Constantly development, recently some feature first in MPP, before they appears in MPP!

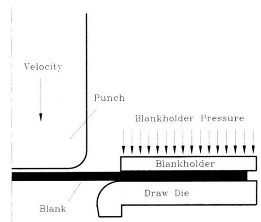
What Drives the MPP Development?

Scaling Example for SMP

Set-up

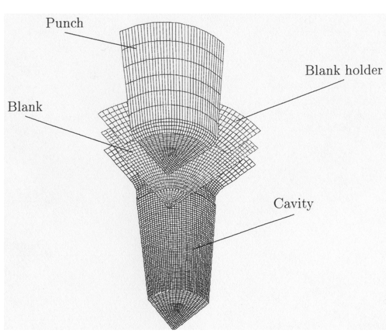


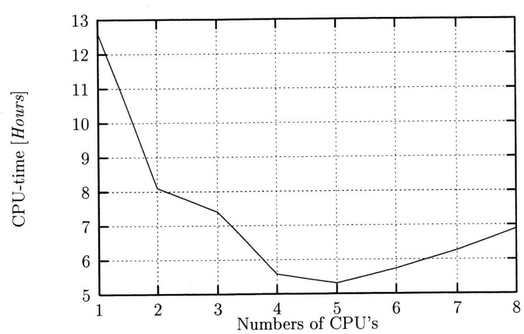




What Drives the MPP Development?

Scaling Example for SMP





What Drives the MPP Development?

- Changing of regulations
- Increasing of material cost
- Reduce design and test schedule
- Changing of computing environment

What Drives the MPP Development?

Changing of regulations

- Safety tests of frontal, offset, side, etc are required to market cars in most countries and new regulations are added constantly
- More complicated analysis need to be done which involved multi-physics
- Product cycle reduced from several years to ~18 months
- Turn around time over night

Changing of modeling

- Smaller and smaller element size
- More expansive element formulation
- Non-local failure (reduce analysis noise)
- Complicated spotweld capabilities (cluster of solids)
- More sophisticated material models

➡ *Longer simulation time*

Changing of modeling to Include Multi-Physics and Multi-Stages

- Multi-physics: ALE + FSI - airbag, fuel tank
- Multi-physics: EM + metal forming
- Fine meshed barrier
- Bio-dummy
- Crash model with stamped parts

➡ *Much longer simulation time*

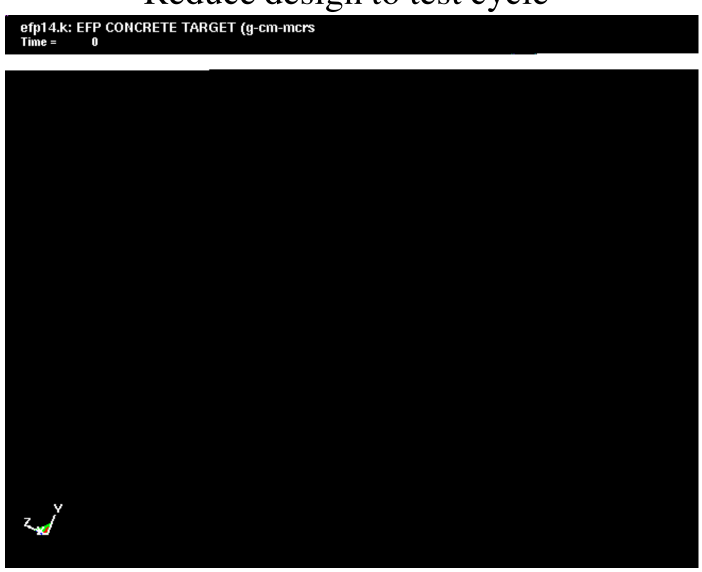
What Drives the MPP Development?

Cost reduction

- Produce more durable end products
- Save raw material in production line
  - few grams per product but save millions dollars in production
- Product cycle reduced from 1 year to 3 months
- Turn around time in few hours

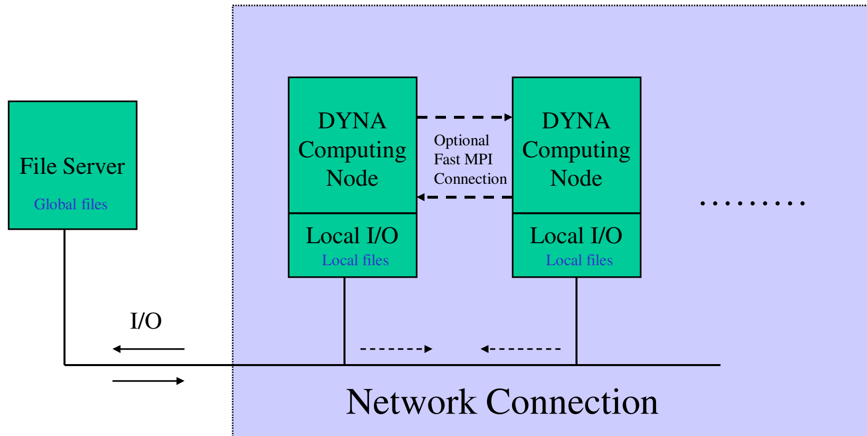
What Drives the MPP Development?

Reduce design to test cycle



What Drives the MPP Development?

Changing of computing environment



Changing of computing environment

Before 1997

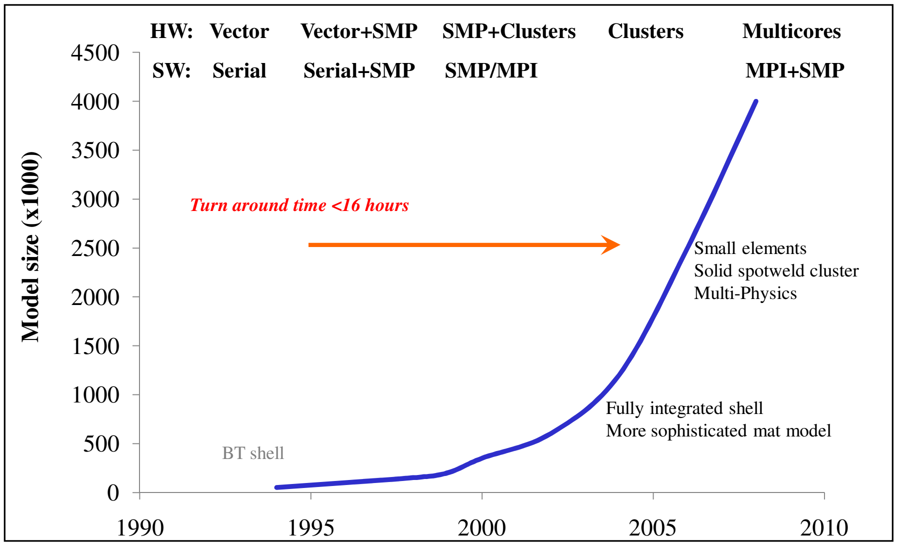
- ~ 64 CPUs SMP/Vector computers
- >$100/CPU minute

Now and future

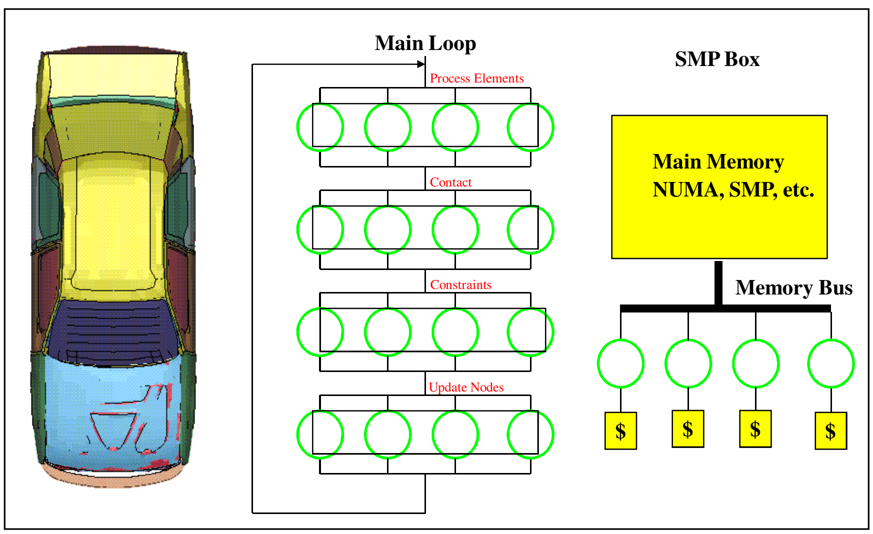
- > 2000 CPUs clusters and growing
- no longer a consideration

What Drives the MPP Development?

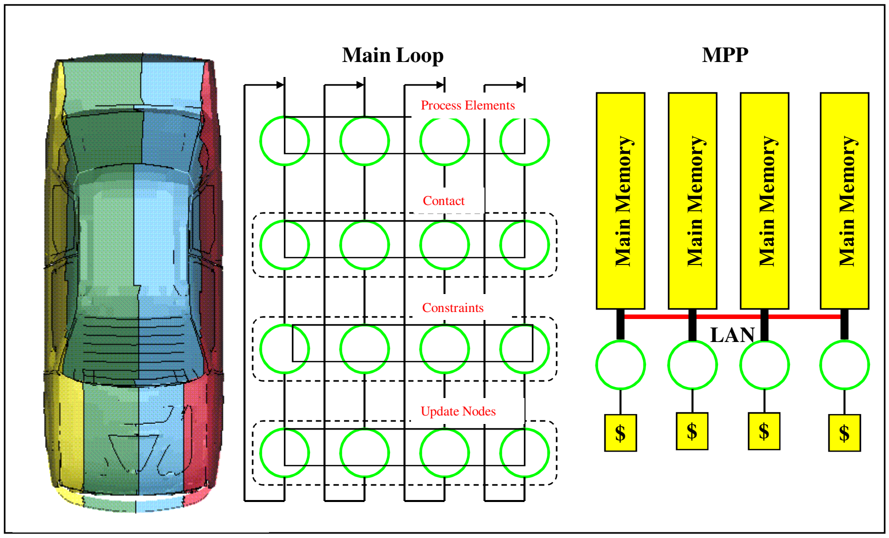
Computer and computing technology



Implementation of SMP Parallelism



Implementation of MPP Parallelism



Implementation of SMP and MPP

- SMP
  - Long history of production use
  - Stability
  - Rich features and many advanced new features
  - Easier for most of developers
- MPP
  - New algorithms
  - Parallelism requires new algorithms and new coding
  - Some features unsupported
  - Better speedup

Implementation of SMP and MPP

Some of the Different implementations

- *AIRBAG_
- *ALE_
- *BOUNDARY_
- *COMPONENT_
- *CONTACT (major – will discussin "Contact" Section)
- *CONSTRAINED_
- *DAMPING_
- *DATABASE_
- ....

But *ELEMENT_ and *MAT_ are the same !!

Implementation in Production

Basic customer requirements

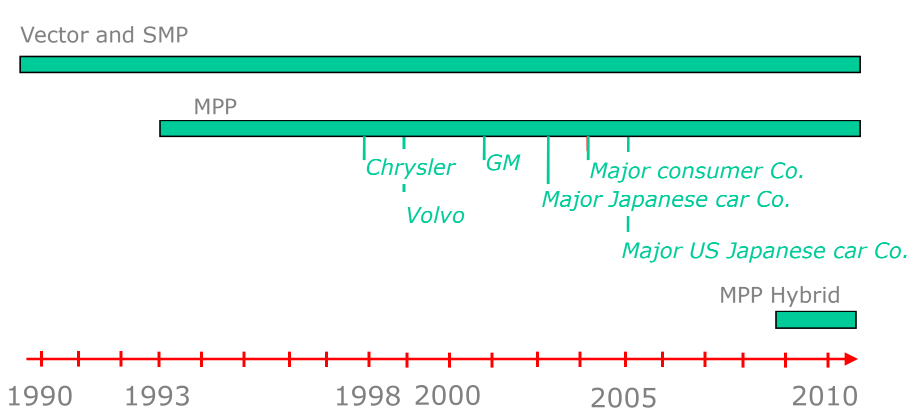
- Repeatability: Same decomposition = same answer
- Consistency between SMP and MPP
- Serial/SMP input = MPP input for zero conversion effort
- Decomposition+Solution in single run
- Single source for MPP and SMP for easier tacking bugs
- Supports all features/options in production models

Implementation in Production

- MPP project starts from 1993
- Chrysler 1998
  - Phase I (Q3/98) – 30 6-month old models
    - Check for missing features
    - SMP/MPP performance, results comparison
    - Open 2 12-processor queue
  - Phase II (Q1/99) – 20 production models
    - SMP/MPP performance, results comparison
    - Open 8 12-processor queues
  - Phase III (Q2/99) - 5 models for QA
    - SMP/MPP performance, results comparison
    - Madymo coupling
    - Open 16 12-processor queues + Open several 24-processor queues for high priority jobs

Fully production in 1999 and most jobs finished overnight

Implementation in Production



Implementation in Production

Impact of Computing Environment

- ~ 64 CPUs SMP/Vector DYNA Nodes at 1996
  → 800 CPUs clusters and growing
- >$100/minute at 1996 → less $1/minute
- 3 days/job (100K elements) → overnight turn around time (1 million elements+more)
- 2009: 3 million elements – overnight!

Numerical Variations

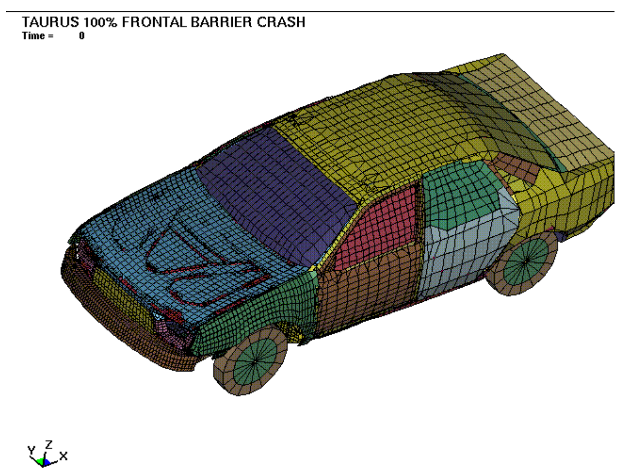
Example: Taurus to Rigid Pole

Frontal impact:

No. of materials: ~130

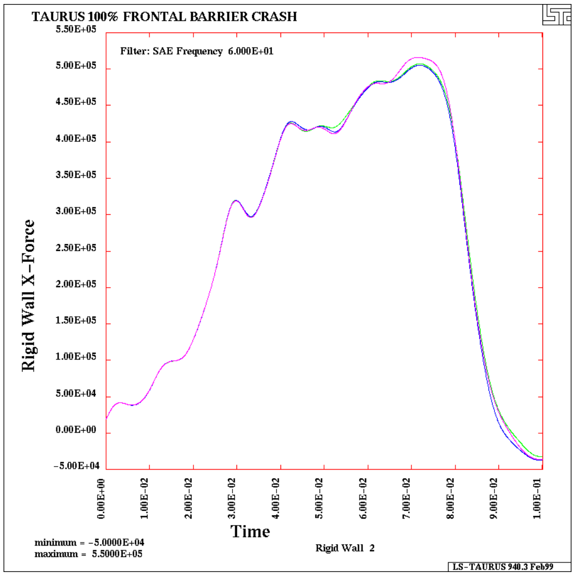
No. of shell elements: ~28,000

Simulation time: 0.10 second



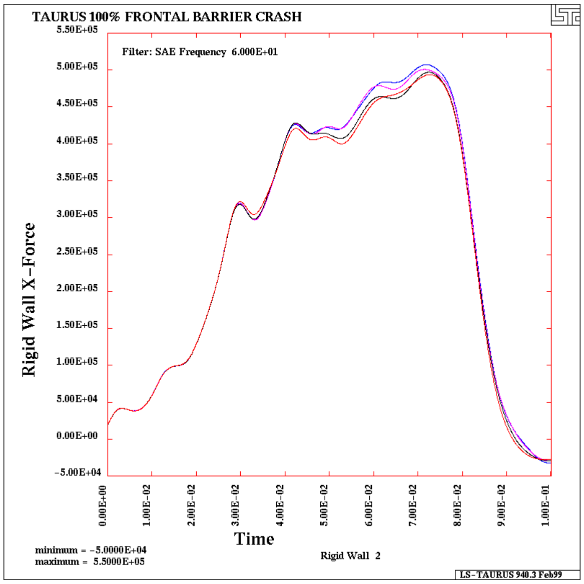
Numerical Variations

Single Processor(SMP)/Different Platforms



Numerical Variations

Multiple processors(MPP)/1,2,4,8 CPUs



Numerical Variations

- Round off error – DP may give less error
- DP may not help, finer mesh may help
- Changing number of processors 5% (MPP), however for a good stable model the difference is small (2009)
- Look for errors in the model – different platforms handles the division by zero differently
- Differences in MPP and SMP contact

- For SMP use consistency command (ncpu=-integer)

Performance Comparison

Example: Neon Refined Model

- Frontal crash with initial speed at 31.5 miles/hour
- Model size
  - Number of nodal points: 532077
  - Number of shell elements: 535K
- Simulation length: 30 ms
- Model created by National Crash Analysis Center (NCAC) at George Washington University
  - One of the few publicly available models for vehicle crash analysis
  - Based on 1996 Plymouth Neon
  - Modified by LSTC (refined the mesh)

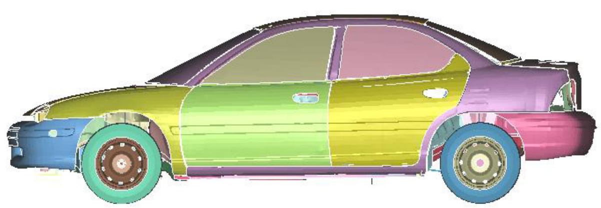
Performance Comparison

1996 Plymouth Neon

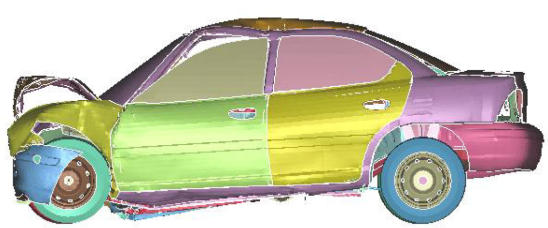
Performance Comparison

Simulation Results

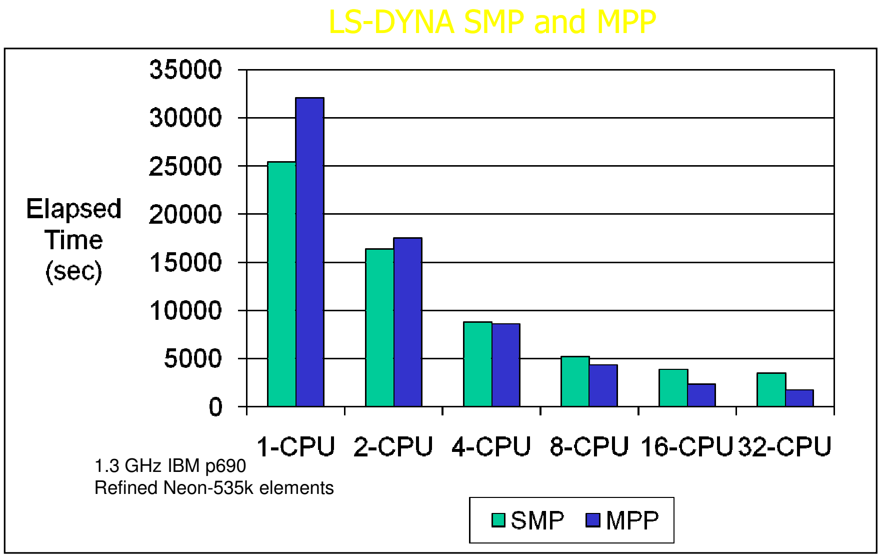
Before Crash



After Crash



Performance Comparison



SMP, MPP breakeven point: 2-4 processors

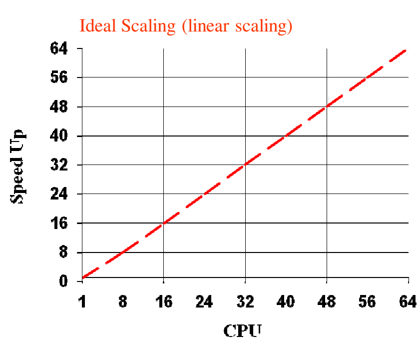
MPP-DYNA Scalability

MPP-DYNA Scalability

- "Scalability"
- Effects of Interconnects
- Effect of Compiler
- Distribution of the CPU time
- Effect of Decomposition
- Summary

"Scalability"

- Scalability: *"the ability of a problem to be solved n times faster using n processors"* [Wainscott et al, 98]
- The % scalability: Can be calculated as [Galbraith et al, 2002]:
  (Elapsed time for 1 CPU / elapsed time for N CPU's) x 100/N
- Speed Up: Elapsed time for 1 CPU / Elapsed time for N CPU's



“Scalability”

Main factors that influence scalability/performance:

- Decomposition of the model, due to load balance
  (Will be discussed in “Decomposition” section)
- Single node computational performance
- Characteristics of the interconnection
  - Ethernet, IB, etc
  - NFS, local disks
- Message Passing details
- Memory/Cache System
- Model size and problem type

“Scalability”

Developement of faster mashines

~493,000 elements , 370,815 cycles
LS-DYNA/MPP 960, 6/2001

CPU#	Time	Speedup
1	~21 days	1.00
4	127.03hrs	4.00
8	64.18hrs	7.92
16	32.26hrs	15.75
32	19.52hrs	26.03
64	11.05hrs	45.98
96	8.80hrs	57.74

"Scalability"

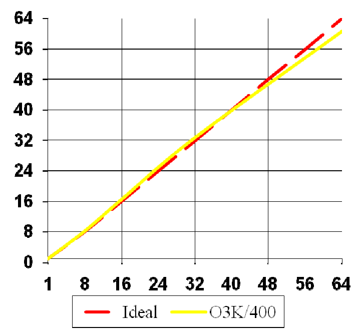
Why MPP-DYNA ?

DaimlerChrysler Model w168, 429,970 elements, 100 ms simulation time.
MPI Version on SGI Origin3000

Ncpu	O3K/400	Speedup
1	206 h	1.0
4	52.7 h	3.9
8	24.7 h	8.3
16	12.5 h	16.48
32	6.3 h	32.7
64	3.4 h	60.6

206 hours

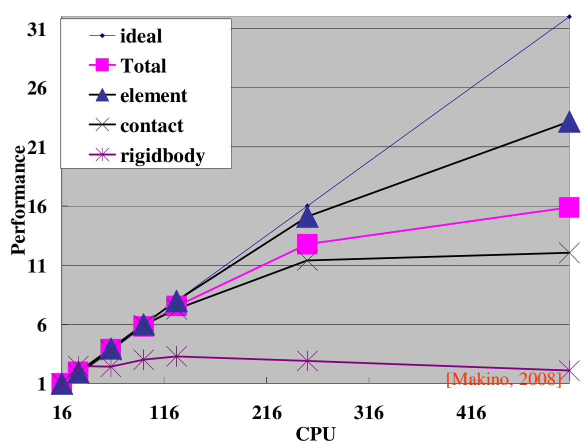
3.4 Hours



Simulation time down from 206 hours to 3.4 hours

"Scalability"

- The scalability depends on the numbers of CPU's. There is not an ideal scaling for a large numbers of CPU's.



- However, the new Hybrid version shows very promising results. Results are shown in the "Resent Development" Section.

Effects of Interconnects

- Computation is split up into:

  T_elapsed = T_computation + T_communication + T_IO

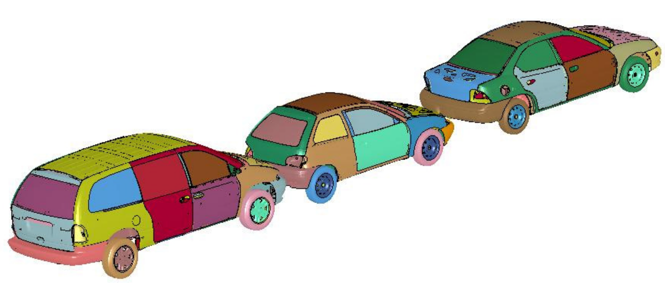
  – For a cluster the communication time is the time required for messages passing through the interconnection [Lin et al, 2000]

- Different types of interconnects
  – 100 BASET (TCP/IP) (2009: less used)
  – Gegi (TCP/IP) (2009: less used)
  – Myrinet (MyriCom)
  – InfiniBand (Popular)

Effects of Interconnects

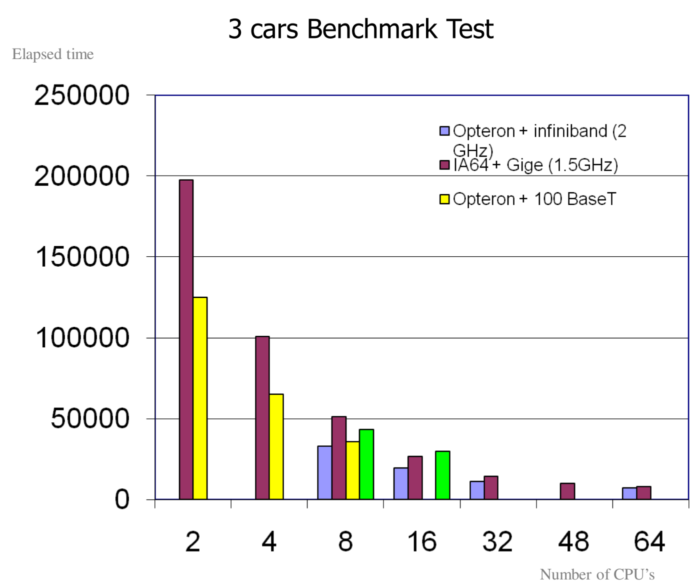
3 cars Benchmark Test

- Effect for the Benchmark test called 3 car Model. More on the model in the "Benchmark Test" Section.

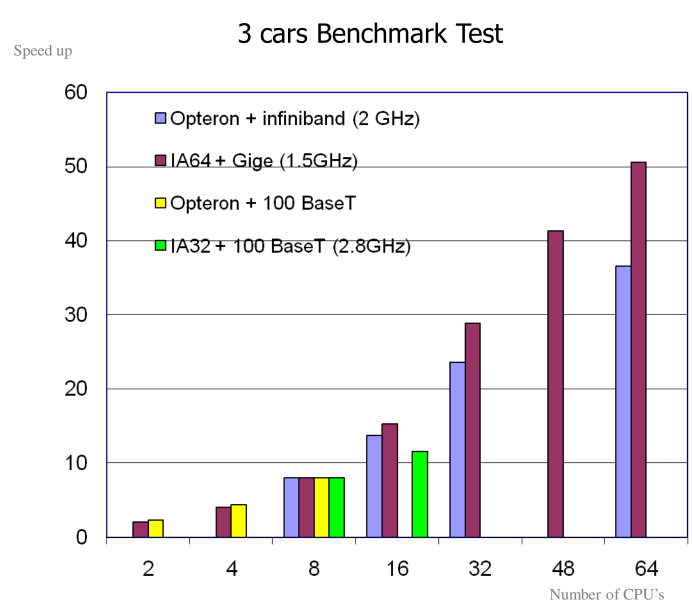


794776 Elements and 1046 parts.

Effects of Interconnects

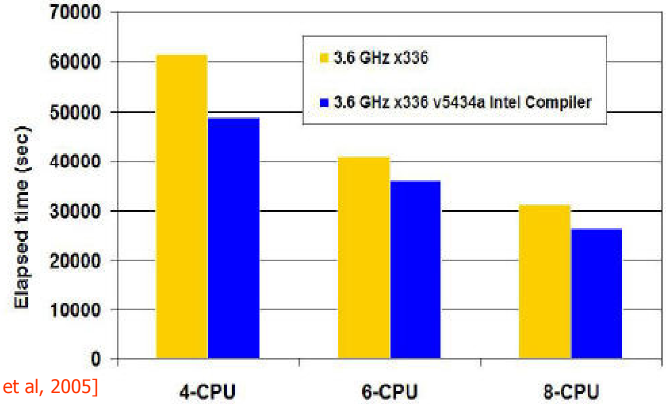


Effects of Interconnects



Effects of Compiler

- Typical LSTC uses two different compilers:
  - PGI compiler
  - Intel compiler



[Li et al, 2005]

- It is seen that the used compiler effects the performance [Li et al, 2005]. Input deck is a confidential customer model (IBM).

Distribution of CPU time

In order to investigate the scaling of different phases of the MPP run [Zhu, 2005] made runs with the Neon (and the 3 car) benchmark test. He looked at 3 different phases of the run:

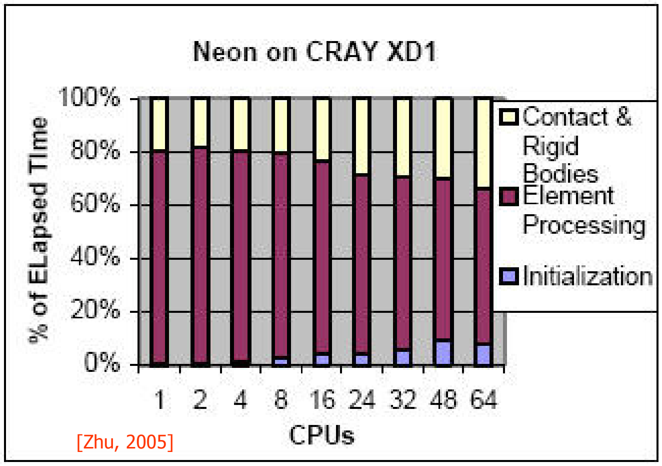
- Initialization: The time spend on reading the deck, allocate memory, domain composition does not scale since this is done serial on 1 CPU. However, the time is relative small.

- Element Processing: The phase for element processing i.e., calculation of motion, forces, stresses etc. is almost perfect parallel and is one of the phases where most time is used.

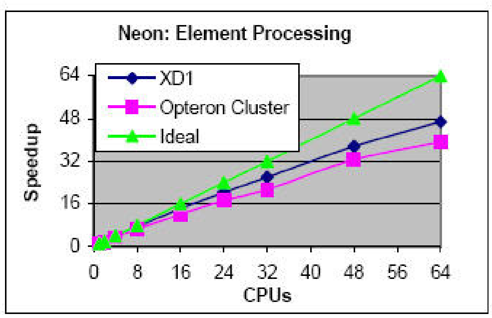
- Contact and Rigid Bodies: The time spend in contact can also be significant depending of the problem. Both the contact and the rigid body routines are scalable.

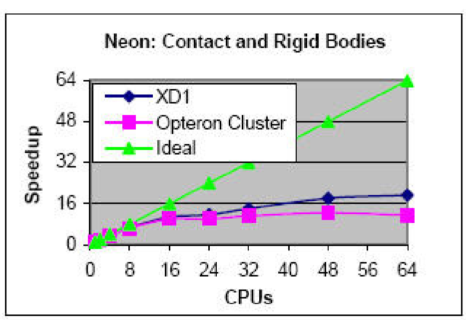
Distribution of CPU time

- The figure shows that the time spend in initialization and contact & rigid body routines are increased relatively to the time spend for element processing. These routines shows limited scaling for the specific model.



Distribution of CPU time

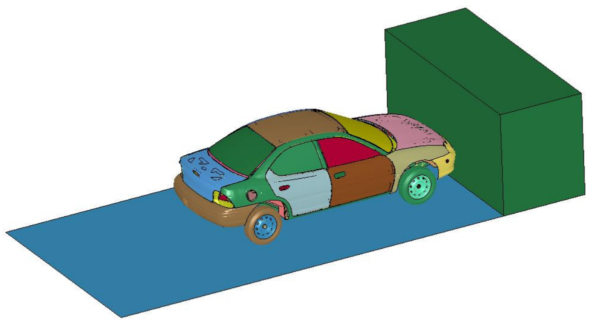




[Zhu, 2005]

Effects of Decompositon

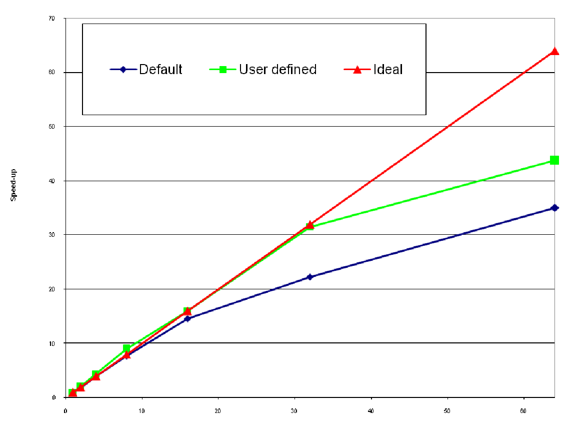
- Effect for the Benchmark test called Neon Model. The model consists of 267K elements, 30 millisecond frontal impact simulation. More on the model in the “Benchmark Test” Section.



267000 Elements and 322 parts.

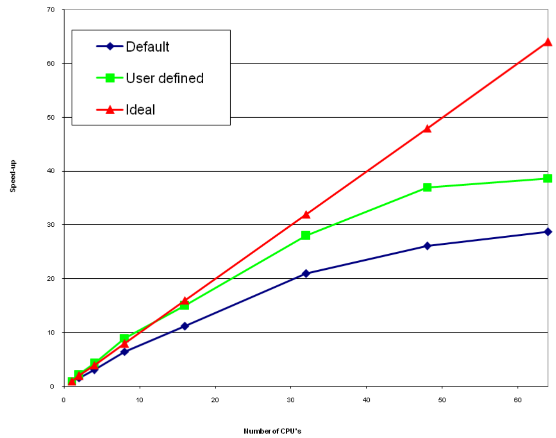
Effects of Decomposition

- The data plotted are based on the work published in [Chu et. al, 2000]. SGI machine (MIPS) running 30msec simulation.

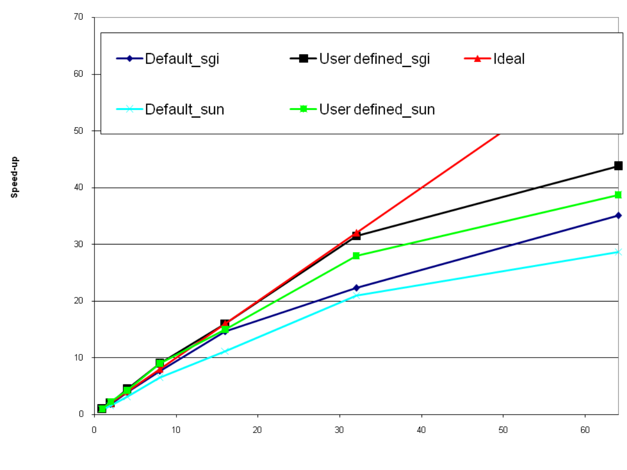


Effects of Decomposition

- The data plotted are based on the work published in [Roh, 2000]. Sun Machine (SPARC) running 10msec simulation.



Effects of Decomposition



- Be careful with performance conclusions between platforms ! Different termination time, memory, interconnections, version of the code etc.

Summary

- During the years LSTC has tested many different set-up for MPP. As shown there are many potential parameters that influence the scaling of the MPP code. Some of the most important ones are:
  - Decomposition (user controlled)
  - Memory/Cache System
  - Interconnections
  - MPI (2009: more or less same performance)
  - Compiler (not user controlled)

Special Decomposition

Special Decomposition

- Decomposition Methods in LS-DYNA®
- General pfile and *CONTROL_MPP commands
- Load Balancing
- Case Study for
  Crash
  Metal Forming
  ALE
- General Guidelines

Decomposition Methods in LS-DYNA ®

- Decomposition splits up the model in domains, which are done by the primary processor. Ideally the computational cost for each domain should be the same. Then there is an equal load balance.

- There are many factors affect the parallel performance
  - Boundaries of the generated domains.
  - Contact definitions
  - Special features used in the modeling

- The default decomposition used in the code is RCB (Recursive Coordinate Bisection)
  - RCB divides the model in half, each time slicing the current piece of the model perpendicular to one of the three axes
  - The axis along which the current piece of the model is longest is chosen
  - The method tends to generate cube shaped domains aligned along the coordinate axes

Decomposition Methods in LS-DYNA ®

- The user decomposition can only control through the p-file in the early releases. It can be included in the keyword commands (*CONTROL_MPP_*option)* from 970. There are four sections: Directory, Decomposition, Contact and General. Each section has relevant commands, see Appendix O.

- One processor is doing the decomposition, which can require a large amount of memory, more than necessary in the simulation.
  - Therefore, there are two memory options on the command line when executing LS-DYNA® MPP:

    mpirun –np 64 mpp971 i=test.k memory=80m memory2=20m

  memory is for decomposition and memory2 is for the actually simulation

  - Performing multiple steps run
    1. Get keyword translated to structure input
    2. Use structure input to get pre-decomposition file
    3. Restart job with pre-decomposition file

Decomposition Methods in LS-DYNA ®

To View the Decomposition

mpirun –np 64 mpp_executable i=input p=pfile

decomp { show }

show : output the decomposition to d3plot and stop

Or in the input deck:

*CONTROL_MPP_DECOMPOSITION_SHOW

Decomposition Methods in LS-DYNA ®

To View the Decomposition

mpirun –np 64 mpp_executable i=input p=pfile

decomp { outdecomp }

outdecomp : output the decomposition file and job keep running

This output file can be read back by lsprepost

lsprepost > view > MPP > load

General pfile and *CONTROL_MPP Commands

P-file

```
directory { global  tempdir local /torch2/nmeng/tempdir }
decomposition { C2R 0 0 0 0 0 1 1 0 0 sy 1000 show }
contact { bucket 100 }
general { nodump }
```

- The *p-file* is case insensitive and have a free format input.
- Words and brackets must have either a space, tab or a newline character on each side.
- Consists of four sections: directory, decomposition, contact and general

P-file

directory

The directory option holds directory specific options

- global *path*

Path to a directory accessible to all processors. This directory will be created if necessary. Default = current working directory

- local *path*

Path to a processor specific local directory for scratch/local files. This directory will be created if necessary. This is of primary use on systems where each processor has a local disk attached to it. Default = global path

P-file

decomposition

- rx ry rz sx sy sz c2r s2r 3vec mat

  See the section Decompositions for details about these decomposition options.

- rcblog filename

  This option is ignored unless the decomposition method is RCB. If the indicated file does not exist, then a record is stored of the steps taken during decomposition. If the file exists, then this record is read and applied to the current model during decomposition. This results in a decomposition as similar as possible between the two runs. For example, suppose a simulation is run twice, but the second time with a slightly different mesh. Because of the different meshes the problems will be distributed differently between the processors, resulting in slightly different answers due to roundoff errors. If an rcblog is used, then the resulting decompositions would be as similar as possible.

P-file

decomposition

- slist n1,n2,n3,...

  This option changes the behavior of the decomposition in the following way. n1,n2,n3 must be a list of sliding interfaces occurring in the model (numbered according to the order in which they appear, starting with 1) delimited by commas and containing no spaces (eg "1,2,3" but not "1, 2, 3"). Then all elements belonging to the first interface listed will be distributed across all the processors. Next, elements belonging to the second listed interface will be distributed among all processors, and so on, until the remaining elements in the problem are distributed among the processors. Up to 5 interfaces can be listed. It is generally recommended that at most 1 or 2 interfaces be listed, and then only if they contribute substantially to the total computational cost. Use of this option can increase speed due to improved load balance.

- sidist n1,n2,n3,...

  This is the opposite of the silist option: the indicated sliding interfaces are each forced to lie wholly on a single processor (perhaps a different one for each interface). This can improve speed for very small interfaces by reducing sychronization between the processors.

P-file

general

The general option holds general options.

- nodump

  If this keyword appears, all restart dump file writing will be suppressed

- nofull

  If this keyword appears, writing of d3full (full deck restart) files will be suppressed.

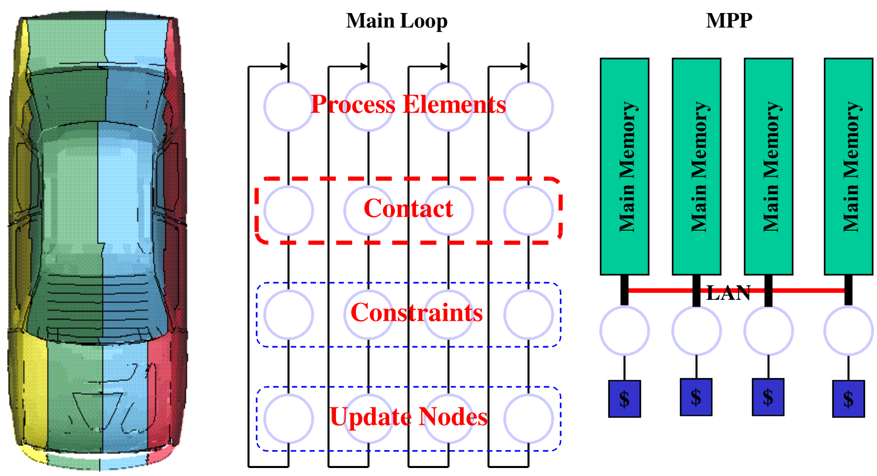
P-file

There are many more option and correspondent *COTROL_MPP keyword.
Please check the User's Manual Appendix O

Load Balancing

- Different element formulation (minor)
- Force summation over shared nodes (minor)
- Contact or coupling definitions (major)

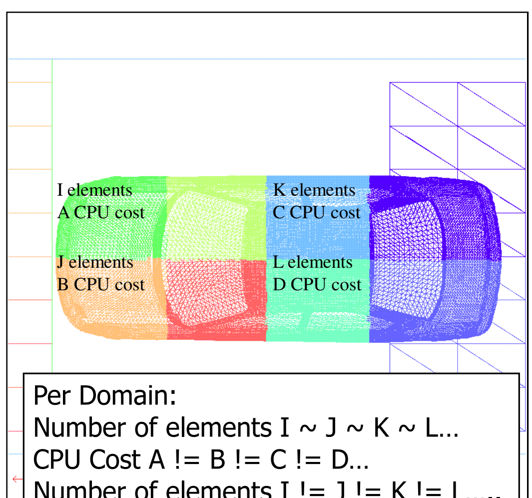
Load Balancing



Load Balancing

(a) Elements cost

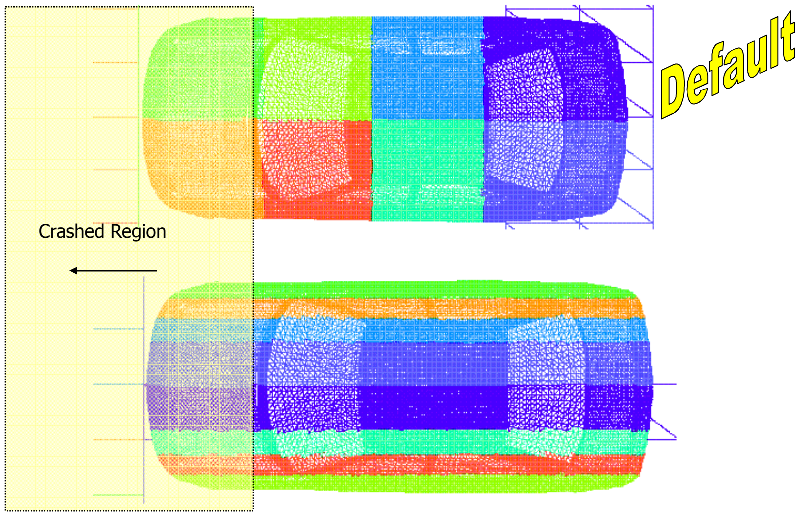
The Domains are based on element cost not number of elements



Per Domain:
Number of elements I ~ J ~ K ~ L…
CPU Cost A != B != C != D…
Number of elements I != J != K != L…..
CPU Cost A ~ B ~ C ~ D….

Load Balancing

(b) Contact Cost



Load Balancing

information during execution

host1

29593	jason	15	0	190M	190M	6164	R	***79.2***	4.8	***1476m*** mpp970
29586	jason	9	0	404M	404M	6960	S	6.7	10.3	125:38 mpp970

host2

7599	jason	18	0	178M	178M	6104	S	10.2	4.5	178:25 mpp970
7590	jason	10	0	170M	170M	5828	S	3.6	4.3	84:47 mpp970

host3

20275	jason	18	0	186M	185M	6072	R	***54.8***	4.7	***1019m*** mpp970
20284	jason	9	0	166M	166M	5936	S	1.5	4.2	44:04 mpp970

host4

20849	jason	13	0	169M	169M	5884	S	16.8	4.3	56:09 mpp970
20858	jason	12	0	167M	167M	5824	S	12.8	4.2	102:27 mpp970

Load Balancing

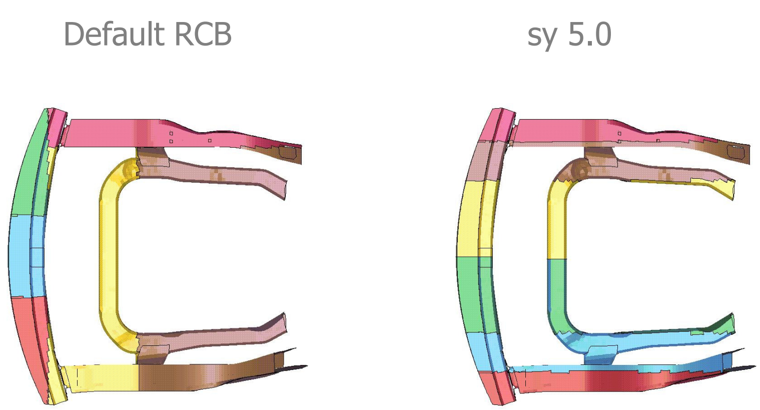
information after execution

```
mes0000
 Element processing ... 3.4474E+02   57.61     6.7254E+02   47.54
 -----
 Contact algorithm .... 1.4906E+02   24.91     4.2288E+02   29.89
   Interface ID       1 1.4536E+02   24.29     4.1547E+02   29.37

mes0001
 Element processing ... 2.9436E+02   52.75     6.5738E+02   46.46
 Contact algorithm .... 2.2382E+02   40.11     4.5323E+02   32.03
   Interface ID       1 2.1671E+02   38.84     4.2008E+02   29.69
   Interface ID      20 2.2295E+00    0.40     1.0072E+01    0.71
   Interface ID      21 1.4300E+00    0.26     1.0603E+01    0.75

mes0002
 Element processing ... 2.7035E+02   50.00     6.7720E+02   47.86
 Contact algorithm .... 2.3439E+02   43.35     4.5477E+02   32.14
   Interface ID       1 2.1606E+02   39.96     4.1339E+02   29.21
   Interface ID      20 7.2402E+00    1.34     2.2589E+01    1.60
   Interface ID      21 6.2605E+00    1.16     1.0594E+01    0.75
-----
```

Case Studies

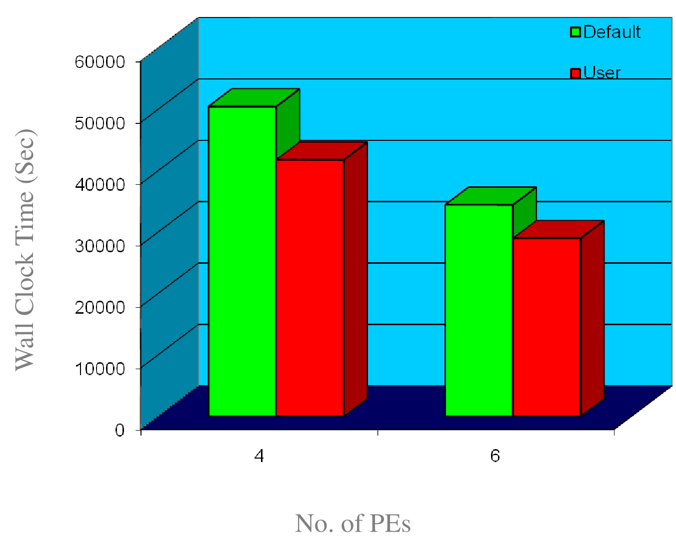
- Bumper Impact
- Side Impact
- ODB
- Metal Forming
- ALE Airbag Simulation

Case Study for Crash: Bumper

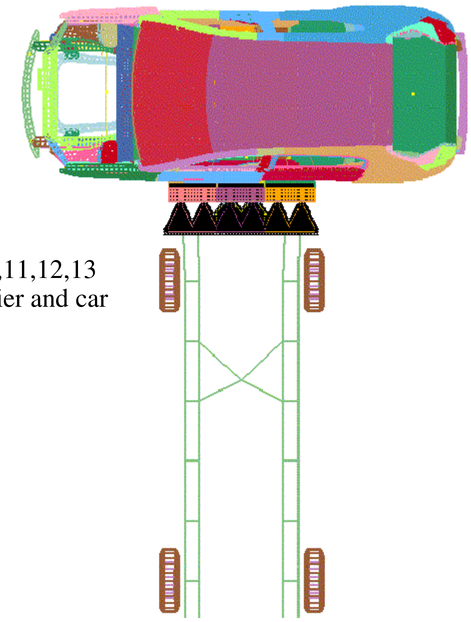


Case Study for Crash: Bumper

Performance Improvement via Changing Partition



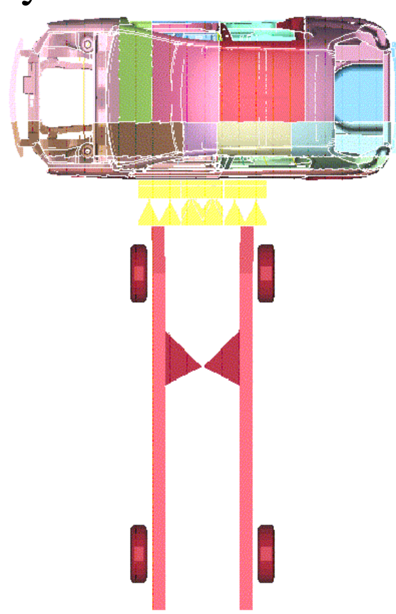
Case Study for Crash: Side Impact



13 contacts and 10,11,12,13 are around barrier and car

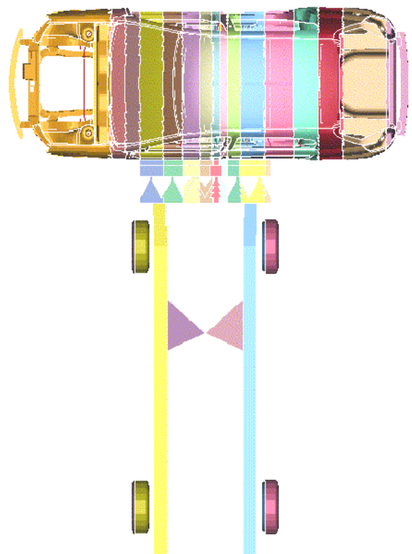
Case Study for Crash: Side Impact

Default



Case Study for Crash: Side Impact

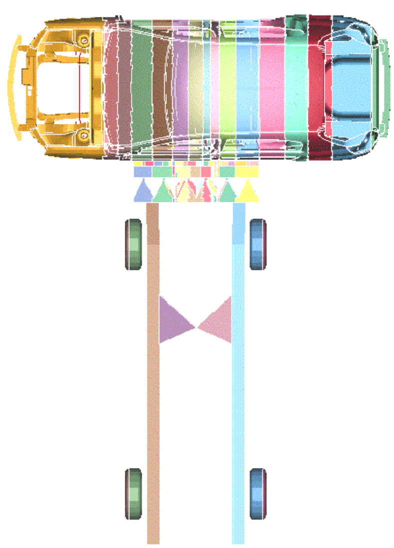
Method 1



Decomp { sx 1000 numproc 16 show }

Case Study for Crash: Side Impact

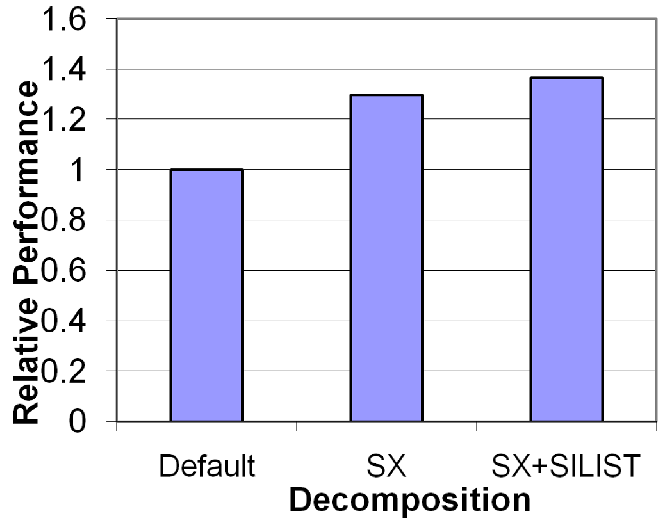
Method 2



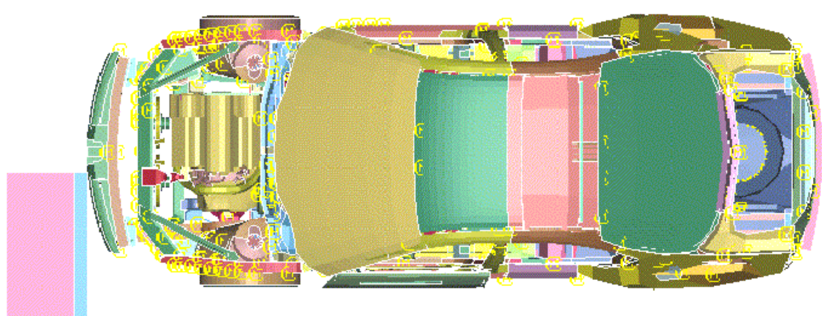
Decomp {sx 1000 silist 10,11,12,13 numproc 16 show }

Case Study for Crash: Side Impact

Timing Comparison first 5000 cycles, 8 CPU's



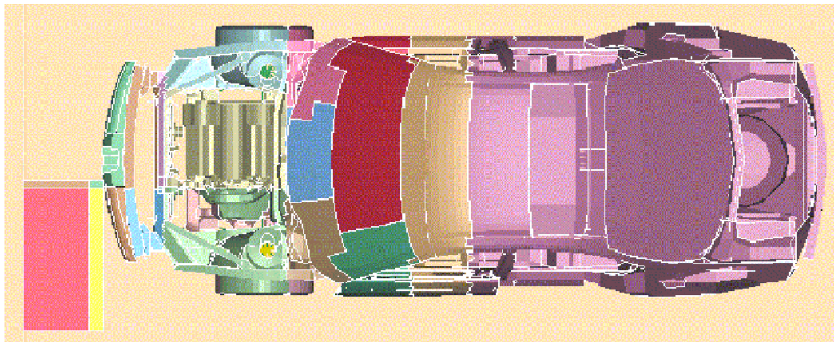
Case Study for Crash: ODB



One single surface contact

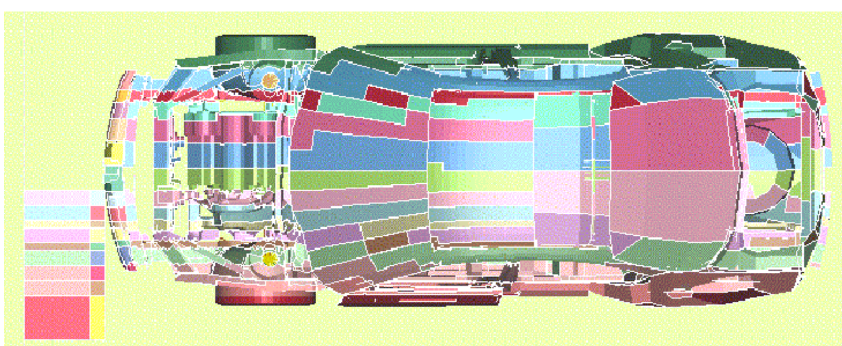
Case Study for Crash: ODB

Default



Case Study for Crash: ODB

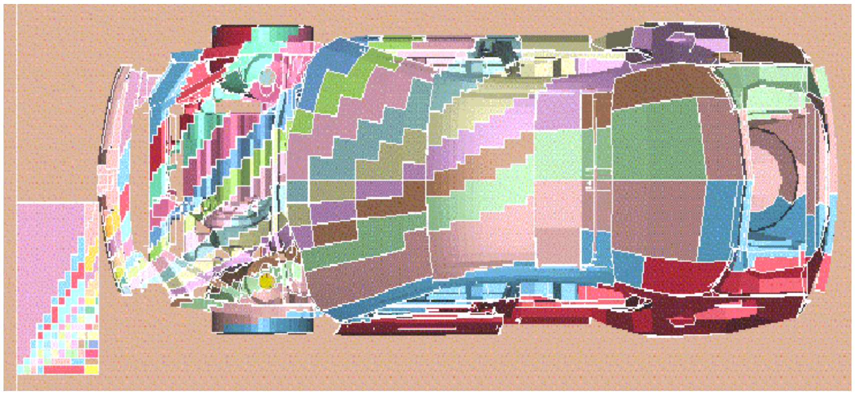
Method 1



Decomp { sy 1000 numproc 16 show }

Case Study for Crash: ODB

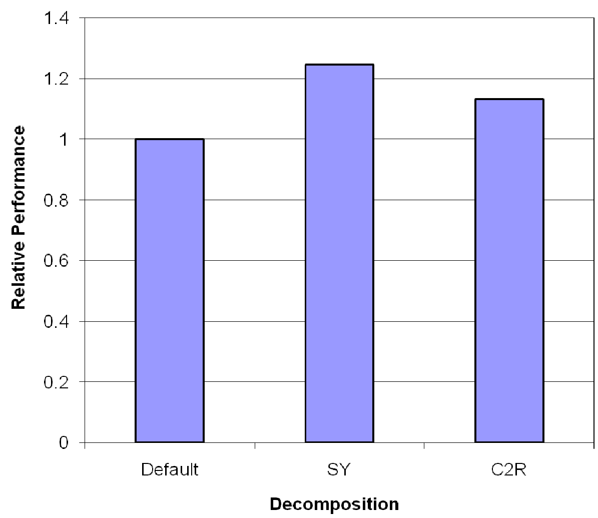
Method 2



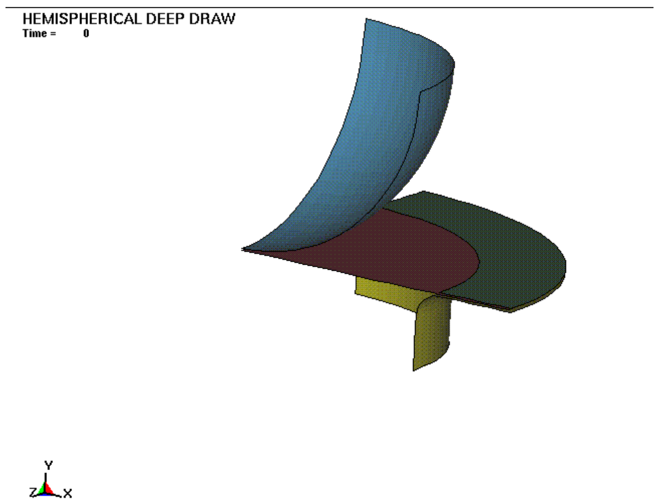
Decomp { C2R 177 –1134 1143 0 0 1 1 0 0 sy 10000 numproc 16 show }

Case Study for Crash: ODB

Timing Comparison first 5000 cycles, 8 CPU



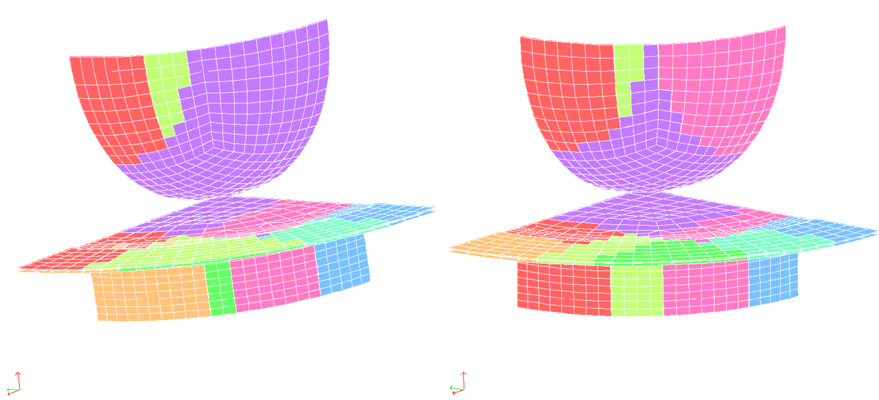
Case Study for Metal Forming: CDD



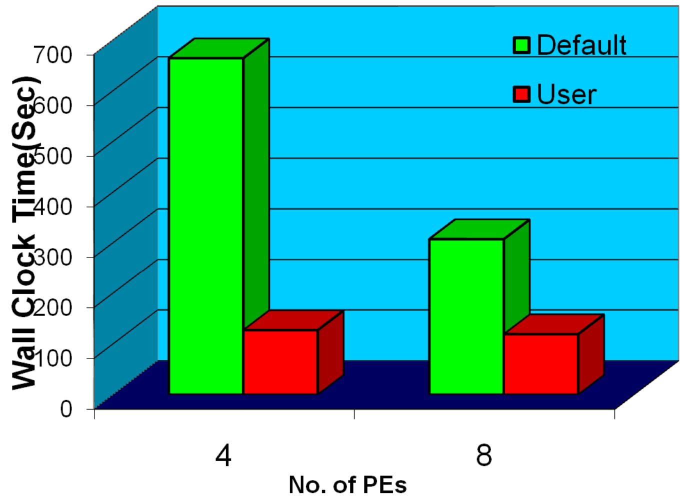
Case Study for Metal Forming: CDD

Default RCB

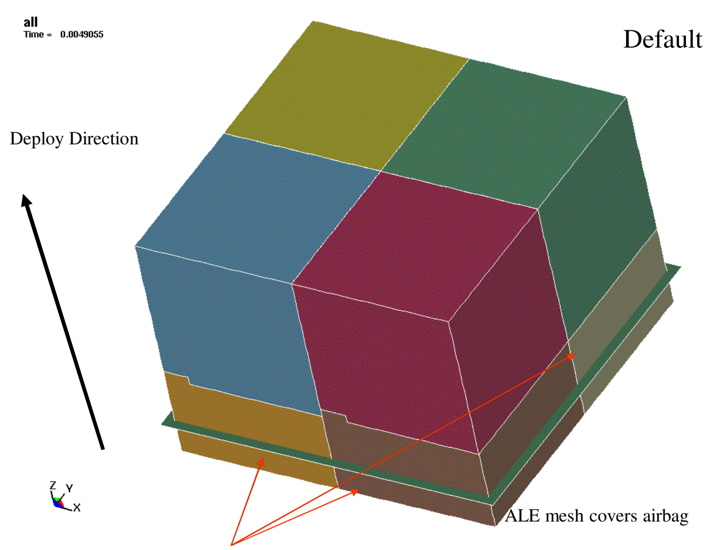
sz 0.



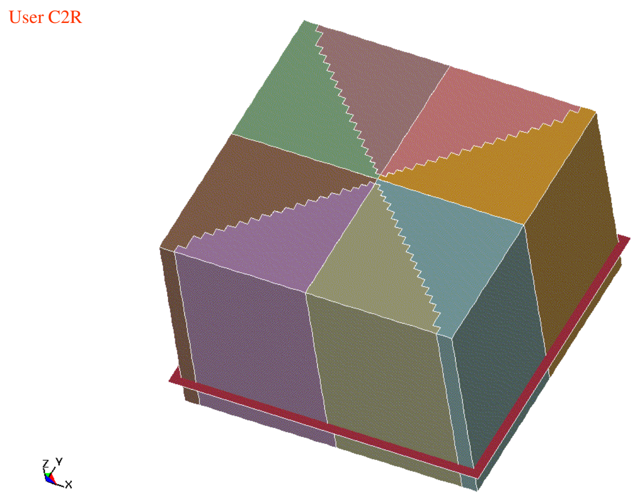
Case Study for Metal Forming: CDD



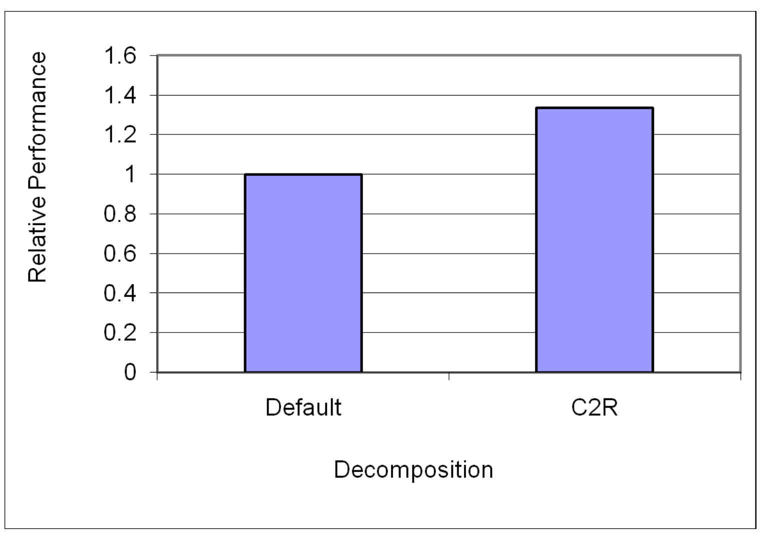
Case Study for ALE



Case Study for ALE



ALE Airbag Timing Comparison first 5000 cycles, 8 CPU



Special Features

Better consistency

LSTC_REDUCE

- Results changes while changing from dual core to quad core system while using same number of MPP processors

RCBLOG

- Preserver the cut line for subsequent runs to reduce the decomposition noise

General Guidelines

- For number of processors < 16, try to partition model along the direction of initial velocity (use e.g. automatic decomposition (*CONTROL_MPP_DECOMPOSITION_AUTO)
- Merge small contact definitions into big one
- Distribute large contact area evenly among processors via pfile

    decomp { SILIST 1,2,3 }

Or in input deck

**CONTROL_MPP_DECOMPOSITION_CONTACT_DISTRIBUTE*

- In forming simulation make the decomposition in the direction of the punch travel
- *Please see more pfile options in Appendix O of the user manual The optimal decomposition is model and CPU depended.*

MPP Contact

MPP Contact

- MPP Contact Algorithms
- MPP Contact Options
- Groupable Contact
- *CONTACT_FORCE_TRANSDUCER
- Contact General Guidelines

MPP Contact Algorithm

- Node to segment based contacts(nodal normal)
  - Penalty: soft=0, 1
  - Constraint: soft= 4, 5
- Segment based contacts(type 3, 13)
  - Soft= 2
- Beam to Beam contact (type 26)
- One of the main differences between MPP-DYNA and LS-DYNA® is the implementation of the contact algorithms.

MPP Contact Options

- There are different flag that can be set for the MPP contact – the regular flags under *CONTACT are not all valid or have different implementations.

Card 1

Variable	SSID	MSID	SSTYP	MSTYP	SBOXID	MBOXID	SPR	MPR

Card 2

Variable	FS	FD	DC	VC	VDC	PENCHK	BT	DT
						X		

Card 3

Variable	SFS	SFM	SST	MST	SFST	SFMT	FSF	VSF
							X	X

Optional Card A

Variable	SOFT	SOFSCL	LCIDAB	MAXPAR	SBOPT	DEPTH	BSORT	FRCFRQ
				X		X	X	

Optional Card B

Variable	PENMAX	THKOPT	SHLTHK	SNLOG	ISYM	I2D3D	SLDTHK	SLDSTF

Optional Card C

Variable	IGAP	IGNORE	DPRFAC	DTSTIF				
			X	X				

MPP Contact Options

- MPP now has two cards that only works for MPP contact
- E.g. *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_MPP
- Two additional lines are expected before the mandatory contact cards (Card 1-3)

Variable	IGNORE	BUCKET	LCBUCKET	NS2TRACK	INITITER	PARMAX		CPARM8
Type	I	I	I	I	I	F		I
Default	0	200	none	3	2	1.0005		0

- The following card is only read if & is defined in column 1 of the first field.

Variable		CHKSEGS	PENSF	GRPABLE				
Type		I	F	I				
Default		0	1.0	0				

MPP Contact Options

- *IGNORE (IPTRACK):* Is the same as the "ignore initial penetrations" option on the *CONTROL_CONTACT card and also can be specified in the normal contact optional card C. It predates both of those, and isn't really needed anymore since both of those ARE honored by the MPP code.
- BUCKET (BSORTFQ): Bucket sort frequency. This field is the only way to specify the bucket sort frequency for the MPP code. The BSORT option on optional card A is ignored. Default BUCKET is 200 cycles (MPP), which is larger than default BSORT (SMP).
- LCBUCKET (BSORTLC): Load curve for bucket sort frequency. Again, the normal input for this is ignored by MPP.
- NS2TRACK (#TRACK): Numbers of potential contact segments to track for each slave node. The normal input for this (DEPTH on optional card A) is ignored. Default is 3.
- *INITITER:* Numbers of iterations to perform when trying to eliminate initial penetrations.

MPP Contact Options

- PARMAX: The parametric extension distance for contact segments. The MAXPAR parameter on optional card A is not used. The default for PARMAX is 1.0005 (MPP) while the default for MAXPAR (SMP) is 1.025.

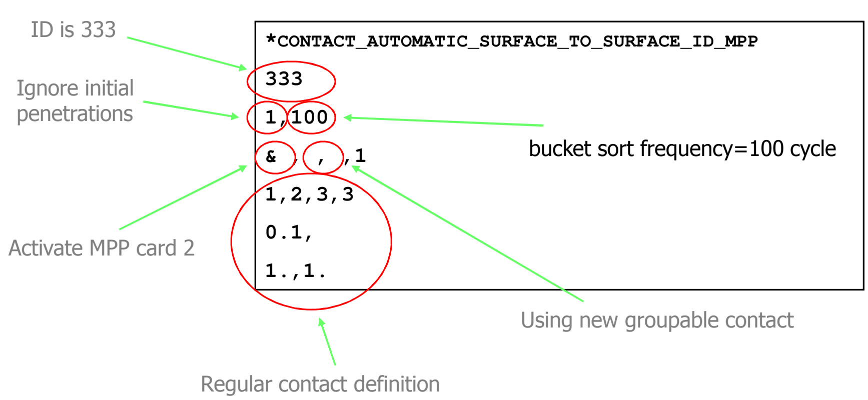
- CPARM8:
  1: Exclude beam to beam contact from the same part ID. This is for *CONTACT_AUTOMATIC_GENERAL.
  2: Consider Spotweld beams in contact

- CHKSEGS: Special element check is done and elements are removed from the contact, if the elements are badly shaped. Valid for SURFACE_TO_SURFACE and NODE_TO_SURFACE contacts.

- GRPABLE: This is still under development. It activates a new set of contacts that are faster and scales better that the regular contacts. Some contacts uses this option already when running MPP.

MPP Contact Options

- In the earlier versions of MPP-DYNA, the special contact flags were given in the *p-file*.



Groupable Contact

- Users often prefer multiple contact definitions and resist changing to a single surface definition with force transducers
- For these customers the *groupable* contact option is available. The contact definitions are internally combined in LS-DYNA to allow all contacts to be treated simultaneously across all processors

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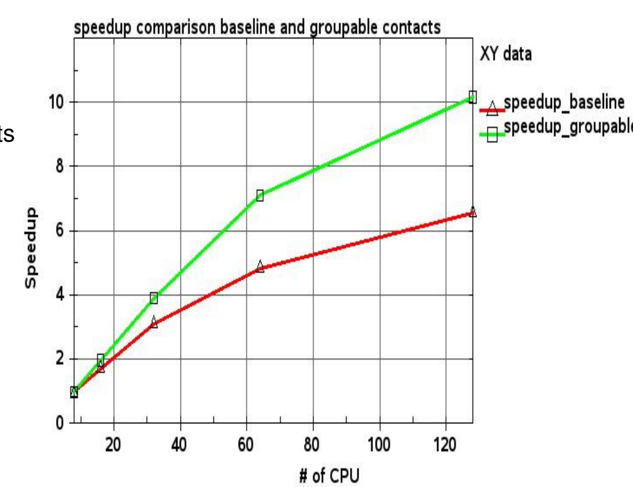
Baseline vs Groupable

Test conditions
- 75 S2S contacts
- 1151856 nodes
- 1116160 shell elements
- Runs quad core dual socket nodes



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*CONTACT_FORCE_TRANSDUCER

- Scalability of LS-DYNA to hundred's of processors is limited by contact
  - Scalability for 1-2 contact definitions covering the entire vehicle is excellent
  - Scalability for 100's of contact definitions diminishes significantly as the number of processors increase
- Starting in version 971_R2 an optional master surface can be defined such that the reaction force is accumulated by the interactions of the slave and master surface

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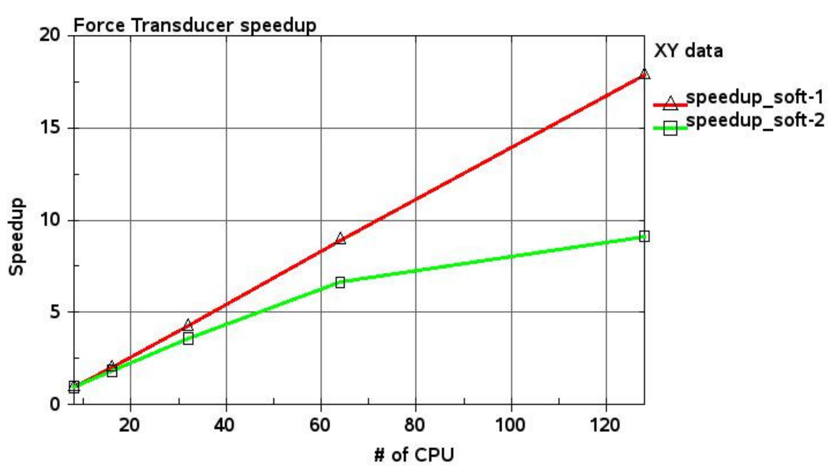
Force Transducers : soft=1 vs. 2



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Contact General Guidelines

- If changes is to be made to the contact, then use the cards in the input deck instead of the p-file.
- To isolate any given contact to a single processor, use *CONTROL_MPP_DECOMPOSITION_CONTACT_ISOLATE
- Forming contact in MPP is not meant to be used with solid elements (slave side). SMP may behave okay in such a case.
- BUCKET can be decreased to e.g. 100 if contact is not determined.
- *The ONE_WAY_SURFACE in MPP is similar to the SURFACE_TO_SURFACE contact in SMP.
- The use of *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE with SOFT=2 will be the contact that will give most similar results between MPP-DYNA and SMP.
- It can be beneficial to use SOFT=2 for ERODING contact since the contact search is good.

General Guidelines

General Guidelines

- Numerical Consistency
- Debugging
- Cluster Tuning
- Pre-decomposition
- Restart

General Guidelines

- If error termination or unstable behavior occur, check for unsupported features. There is in general no error trap that indicates that a feature not is in MPP.
- 12-32 processors is sometimes preferred for smaller models but the optimal number of CPU's strongly depends on the model.
- Single processor performance of LS-DYNA/MPP ~= LS-DYNA/SMP
- Will run efficiently with large contact definition – ease of modeling
- MPP is beneficial for more than 10k elements/processor
- If contact problems occur
    - Turn on IGNORE option
    - Try to use SOFT=2 at Optional card A.

General Guidelines

- Same decomposition = same answer
- Changing number of processors < 5% variation in results (new Hybrid could be tried to reduce the difference, see the “Recent Development” section).
- Double precision may not help, finer mesh will help for the numerical variations

Numerical Consistency

LSTC_REDUCE

Problem: Results changes while changing from dual core to quad core system while using same number of MPP processors

Solution: Fixed summation operation is performed in the code

RCBLOG

Problem: Decomposition changes during model development

Solution: Preserver the cut line for subsequent runs to reduce the decomposition noise

Debugging

- The error messages from MPP-DYNA can be different from LS-DYNA®
- To locate an error one often has to search each of the messag files mes#### in order to find any information. These files are written for each processor.
- The code will trap the segmentation violation (SEGV) and output the rank number. One could rerun the job and attach the debugger to the running thread and get the trace back map. This usually gives good information for changing input.

  gdb path_to_mpp_code/mpp971 PID
  > continue
  SEGV
  > where

- As for LS-DYNA® a debugger can be used if a core file is written:

  gdb path_to_mpp_code/mpp971 core
  - Type where to get more info and quit for exit
  - Can indicate which subroutine is the problem and hence ease the model debugging.

Debugging

Problem

```
Memory required to process keyword     :       222197

MPP execution with       2 procs

Initial reading of file                                             04/09/2009 13:22:01

*** Error cross-section interface #            1
          has a non-orthogonal tangential edge vector
          with finite length edges.

input phase completed with    1 fatal errors
please check messag file

   0 E r r o r   t e r m i n a t i o n
MPI Application rank 0 exited before MPI_Finalize() with status 13

forrtl: error (78): process killed (SIGTERM)
Image              PC        Routine            Line        Source
libc.so.6          0083720E  Unknown               Unknown  Unknown
libc.so.6          008372EC  Unknown               Unknown  Unknown
libc.so.6          008370EB  Unknown               Unknown  Unknown
mpp971             0A1A3CB1  Unknown               Unknown  Unknown
libc.so.6          008372B8  Unknown               Unknown  Unknown
libmpi.so.1        00A98568  Unknown               Unknown  Unknown
libmpi.so.1        00ADFAB7  Unknown               Unknown  Unknown
libmpi.so.1        00AF688B  Unknown               Unknown  Unknown
mpp971             0A1B2CD6  Unknown               Unknown  Unknown
mpp971             09FD17F0  decomps_                 1763  decomps.f
mpp971             0A06E01E  mppdecomp_               4411  mppdecomp.f
mpp971             08183D49  overly_                  1998  overly.f
mpp971             0805036D  lsinput_                 1704  lsinput.f
mpp971             0804E7AF  Unknown               Unknown  Unknown
mpp971             0804DF29  Unknown               Unknown  Unknown
libc.so.6          00825BD1  Unknown               Unknown  Unknown
mpp971             0804DE61  Unknown               Unknown  Unknown
ibm325_jri [189]%
```

In MPP the error can look serious!

Debugging

WRITE ERROR: iam=0 file=d3plot which=34 where=8192 wrote 0 of 65536
52562 t 1.7000E-03 dt 3.17E-08 write d3plot file

This means that there is no disk space on node 0 (the iam tells the rank).
Notice that on some machines the "no space left on device" message will not be showed, this is the case for Linux Cluster.

This error was from a MPP Linux run:

Performing Recursive Coordinate Bisection

p1_3586: (479.788216) xx_shmalloc: returning NULL; requested 1585896 bytes
p1_3586: (479.788313) p4_shmalloc returning NULL; request = 1585896 bytes
You can increase the amount of memory by setting the environment variable
P4_GLOBMEMSIZE (in bytes)
p1_3586: p4_error: alloc_p4_msg failed: 0
bm_list_3583: p4_error: net_recv read: probable EOF on socket: 1

p4 error is normal from MPICH, i.e. this is a MPI error, in this case is suggested to set an environment variable

Debugging

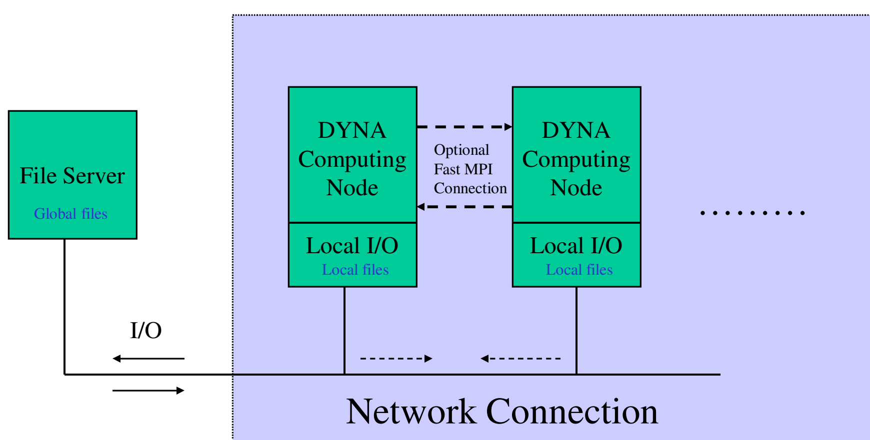
```
*** Error Memory is set       1235165 words short
        Current memory size       50000000
        Increase the memory size by one of the following
        where #### is the number of words requested:
         1) On the command line set - memory=####
         2) In the input file define memory with *KEYWORD
            i.e., *KEYWORD #### or *KEYWORD memory=####
```

- The memory unit is in WORD. For single precision is 4 Bytes/word and for double precision is 8 Bytes/word.
- LS-DYNA® uses real memory to store all data. However, the amount of static memory requested is controlled by “memory=“ option and the amount of dynamic memory is adjusted automatically.
- Please use “top” command to check the available memory in the system and you DO NOT want your job using swap space

Cluster Tuning

- LS-DYNA® explicit is CPU bounded application
- Lots of message passing activities through network
- IO is small but should avoid collision with MP

Cluster Tuning



Pre-decomposition

- Mesh is getting finer and memory requirement increases. Since the decomposition is done on the primary processor, it needs great amount of memory.
- Due to the economy reason, the memory on cluster is limited – 2GB/core.
- It is easier to decompose model in a separated machine with lots of memory.

Run 1: Keyword to structure

mpirun –np 1 path_to_mpp/mpp971 i=input.k outdeck=t memory=800m

This will convert the keyword input "input.k" to structure file "dyna.str" and stop the execution

Pre-decomposition

Run 2: Create pre-decompose file

pfile:
decomp { numproc 16 file input_de }

mpirun –np 1 path_to_mpp/mpp971 i=dyna.str p=pfile memory=800m

This will create pre-decomp database for 16 domains and write necessary information into "input_de.lsda" file. Please note, the job could be restart on a cluster with a node number divided in whole.

Run 3: Restart MPP job on clusters

Move pfile and input_de.lsda to the working directory of target clusters

mpirun –np 8 path_to_mpp/mpp971 i=dyna.str p=pfile memory=100m

Job could start on clusters with much less memory requirement.

Restart

- Restart is in MPP-DYNA is different from LS-DYNA, The files are called d3dump##.xxxx or d3fulll##, where ## is a number.

  Simple restart: mpirun –np 5 mpp970 r=d3dump09

  MPP-DYNA finds the child files

  Small restart: mpirun –np 5 mpp970 i=small.k r=d3dump09

  The small restart may have problems. If it does, please report it to LSTC and we will fix it.

  Full restart: mpirun –np 5 mpp970 i=full.k n=d3full09

  Remember *stress_initialization in the inputdeck
  Can change ncpu in full restart
  The full restart can have problems

- Since the Small and Full restart can give problems – check carefully the results

Restart

- Can do stamping in MPP and implicit springback in SMP. Important since implicit is under development in MPP-DYNA 971

- Since the Small and Full restart can give problems – check carefully the results

Current Benchmark Tests

Current Benchmark Tests

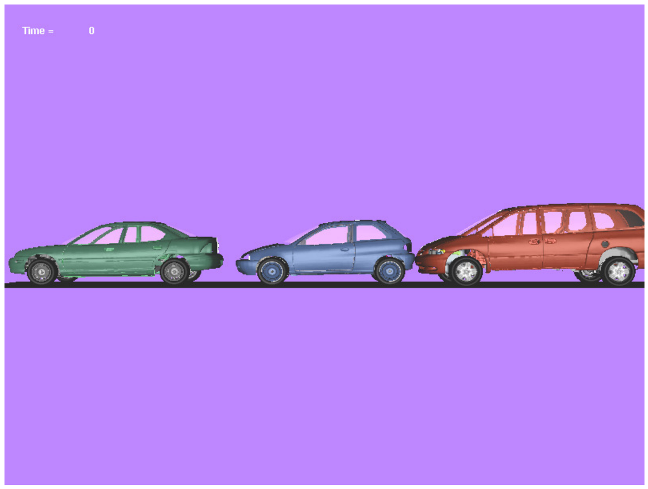
- Benchmark models are provided by LSTC
  - Three car impact model (794776 elements)
  - Refined Neon model (535068 elements)
  - Car to Car crash (2448596 elements)
- Benchmark results for LS-DYNA® and MPP-DYNA

  http://www.topcrunch.org

  - Top Crunch was sponsored by DARPA, and the sever is placed in San Diego where Professor David Benson now maintain and sponsor the site. Users download the models together with the p-file(s).

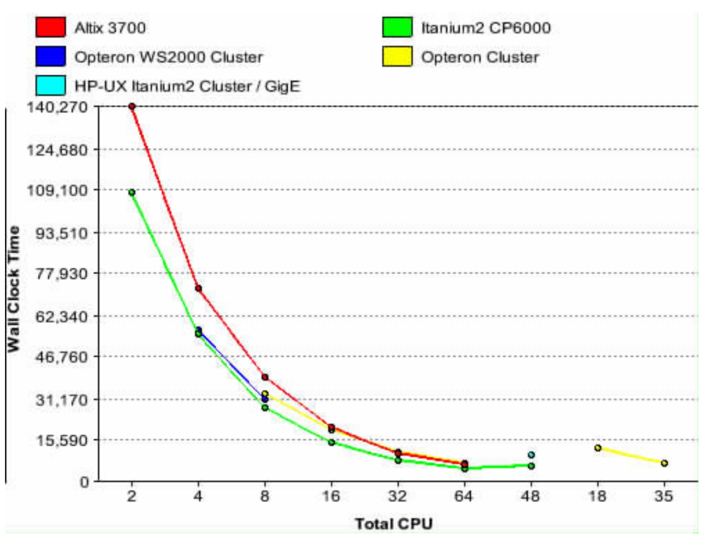
Three Car Impact Model

- A van crashes into the rear of a compact car, which, inturn, crashes into a midsize car. Vehicle models created by NCAC, and assembled into the input file and provided by LSTC.



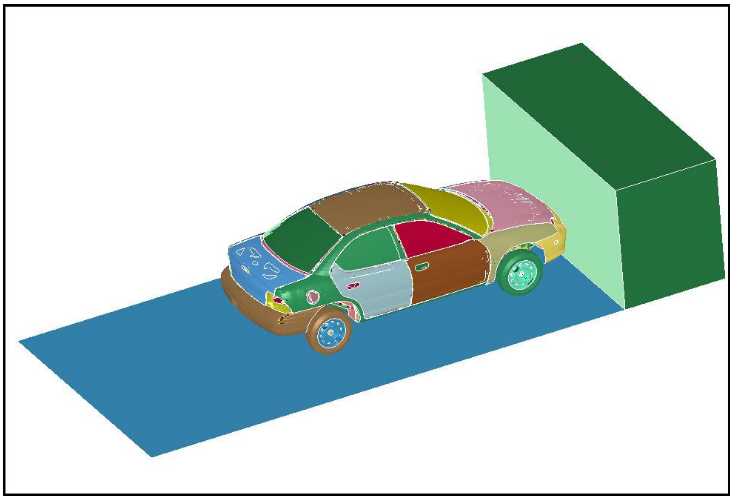
Three Car Impact Model

- The Top Crunch project makes it possible to compare different systems since users upload results. These can then be plotted against each other.

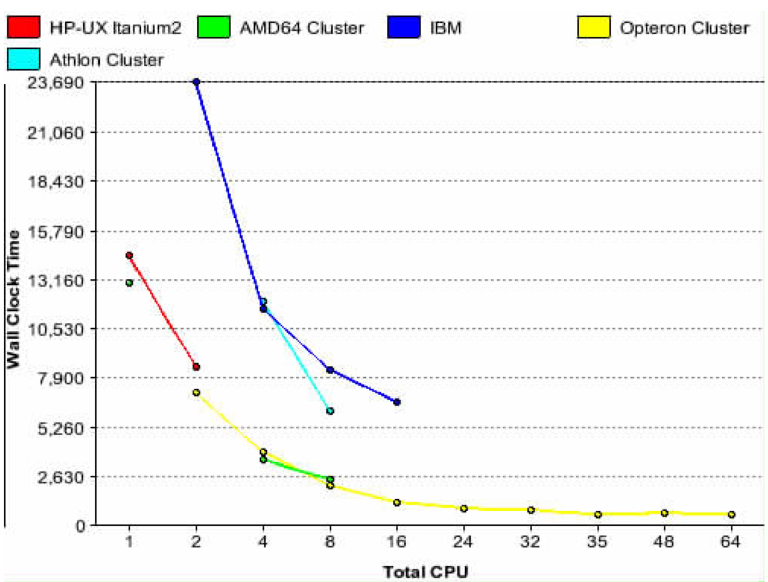


Refined Neon Car Model

- Frontal crash with initial speed at 31.5 miles/hour, model size 535k elements, simulation length: 150 ms. Model created by National Crash Analysis Center (NCAC) at George Washington University.

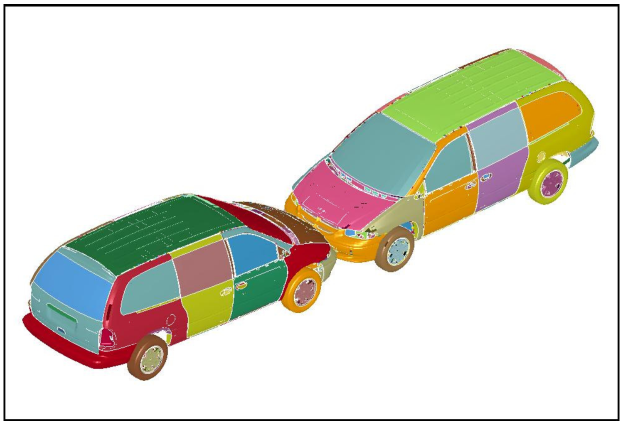


Refined Neon Car Model



Car 2 Car Impact Model

- This model is based on NCAC minivan model and created by Dr. Makino. Supplied by Dr. Tsay, LSTC, on Feb. 13, 2006, termination time modified per John Hallquist to .120 on March 7, 2006. It is two mini vans in frontal collision.
- Type 16 shell elements are used instead of type 2



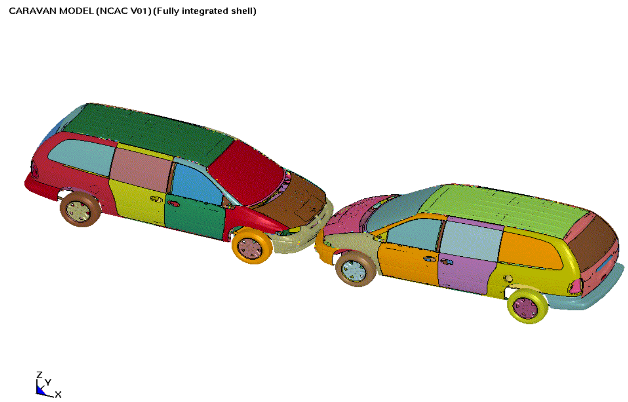
Current Development

Current Development

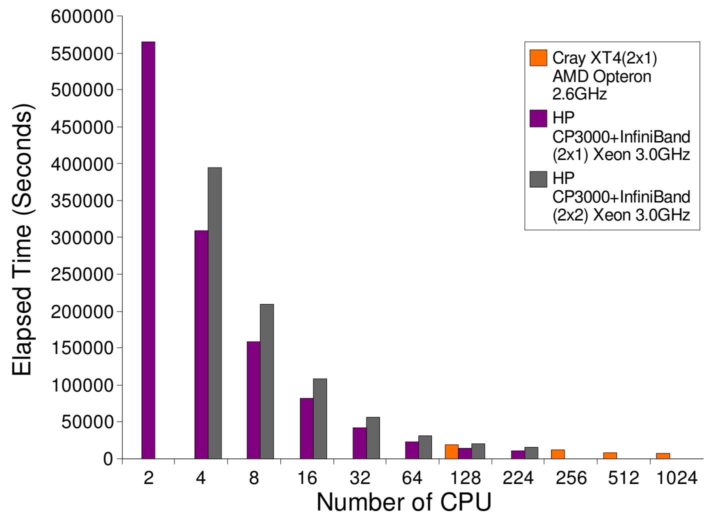
- Many new options are implemented in MPP-DYNA in recent years. Both in versions of 970 and 971
  - Pinball Contact (SOFT = 2) - 970
  - ALE FSI applications - 970
  - SPH method – 970
  - Automatic decomposition - 970
  - Implicit solvers - 971
  - EFG – 971
  - Thermal – 971
  - Particle Method 971
  - ………

Scalability on Large Number of CPUs

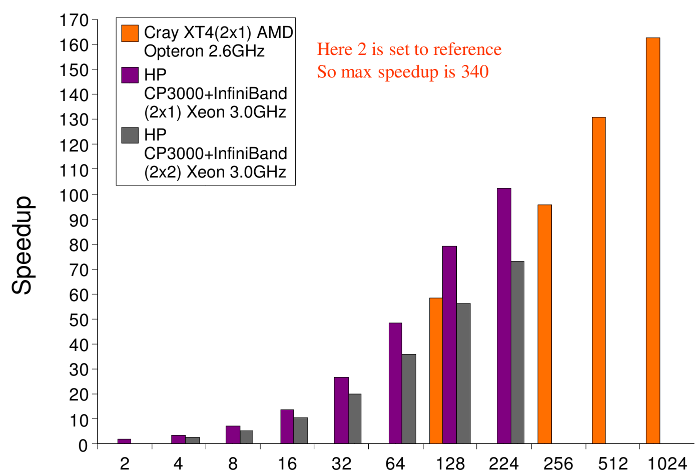
Model statistic (car2car model)
~2,500,000 nodes and elements
53 contacts
Fully integrated (type 16) shells



Scalability on Large Number of CPUs



Scalability on Large Number of CPUs



Note: Not ideal scaling for large number of CPU's

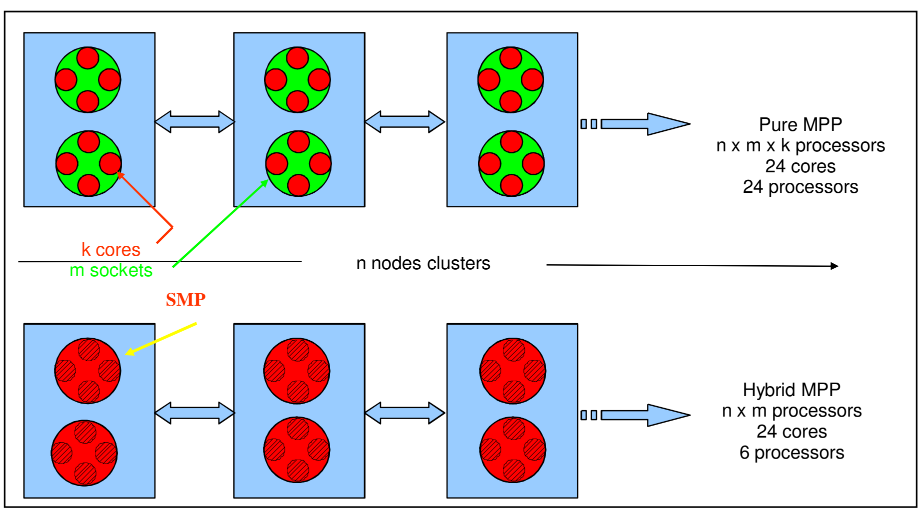
Scalability on Large Number of CPUs

Multi-core/Multi-socket clusters

- It has been seen that scaling for a large number of processors, typically larger than 128, not always is good.
- Sometimes the results can varies with number of CPU's due to the decomposition, especially if the model is unstable.
- A new approach is currently being tested, it runs SMP within each CPU and MPP between the CPU's.
- It is named Hybrid.
- If the number of SMP threads is increased it will give identical results.
- To run Hybrid both SMP and MPP variables will have to be set.

Scalability on Large Number of CPUs

Multi-core/Multi-socket clusters



Scalability on Large Number of CPUs

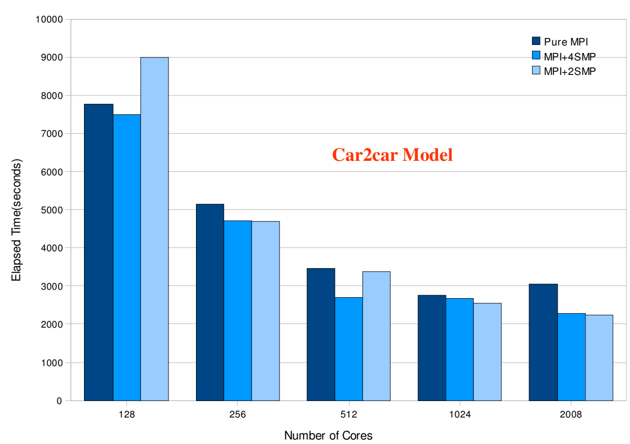
Multi-core/Multi-socket clusters

- There is a special syntax that is required for the Hybrid approach.
- If e.g. the set-up is a system with 16 nodes, dual socket quad core system (as previous slide) the variable is:
  - Set OMP_NUM_THREAD=4 (max four cores in each SMP)
  - The system is a 128 core system
- Mpirun –np 32 mpp971_hybrid i=input ncpu=-1
  - 32 MPP Processors (green circle) and 1 core in each which then is a total of 32 cores.
- Mpirun –np 32 mpp971_hybrid i=input ncpu=-2
  - 32 Processors and 2 cores in each = 64 cores
- Mpirun –np 32 mpp971_hybrid i=input ncpu=-4
  - Total of 128 cores is used

Scalability on Large Number of CPUs

Multi-core/Multi-socket clusters

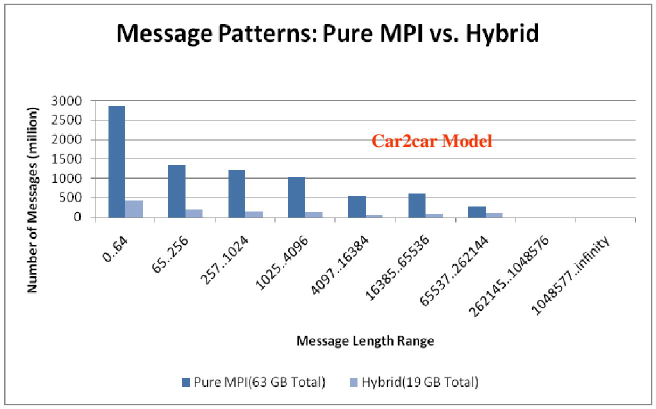
Performance Comparison on Windows Server 2008



Scalability on Large Number of CPUs

Multi-core/Multi-socket clusters

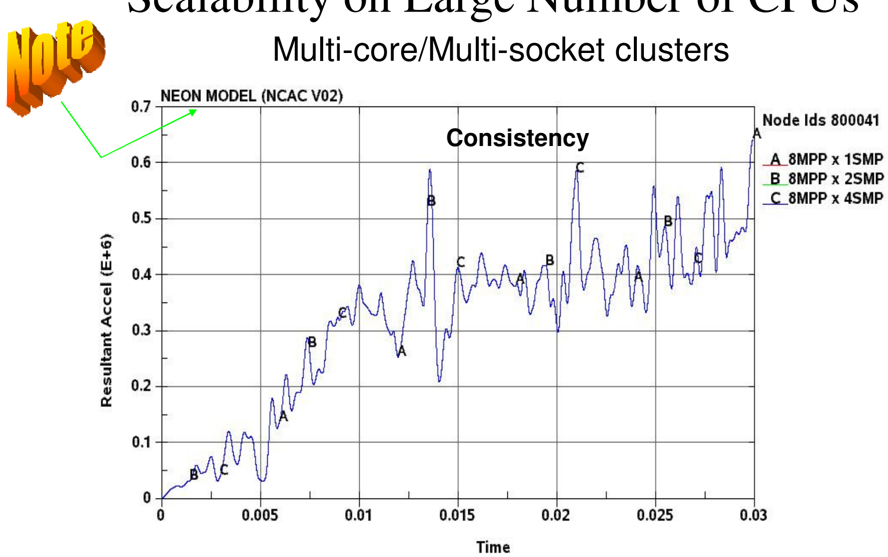
Message Across Network



Hybrid greatly reduce the amount of data through network and provide better scaling to large number of processors

Scalability on Large Number of CPUs

Multi-core/Multi-socket clusters



Consistent results is be obtained with fix decomposition and changing number of SMP threads

Scalability on Large Number of CPUs

Multi-core/Multi-socket clusters

consistency tests and performance comparison of HYBRID and pure MPP code.

	12p	12x-1	12x-2	12x-4
Case 1	108118	124035	81380	60215
Case 2	75028	85367	50467	33728
Case 3	68047	87924	55599	35773
Case 4	16610	22677	13073	8759
Case 5	36522	44622	28397	20215
Case 6	14253	18898	12169	8705
Case 7	9485	12753	7600	5800
Case 8	937	1260	773	569
Case 9	12640	16012	10486	6926