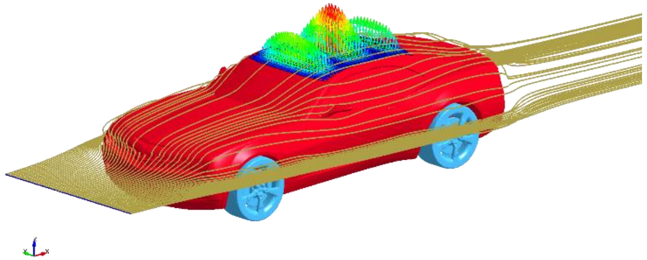
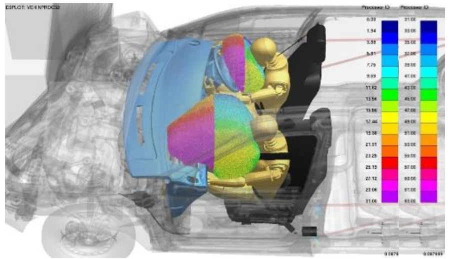
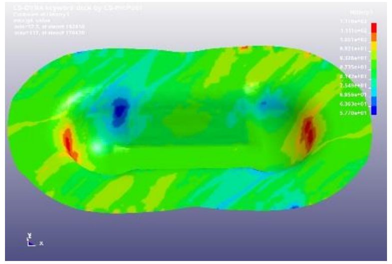
Recent Development – Part I

Presented by Jason Wang







15. Deutsches LS-DYNA Forum
15.-17. Oktober 2018, Bamberg

Outline – Part I

Introduction

Multi-Physics, Multi-formulation, Multi-scale, Multi-stage

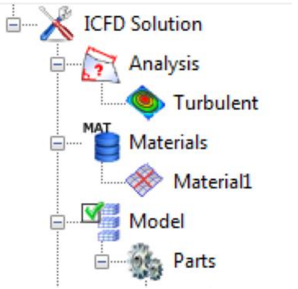
- **Electromagnetics**
- **ICFD**
- **PARTICLE Methods**

Scalable code

- **MPP**
- **Parallel efficiency**
- **HYBRID**

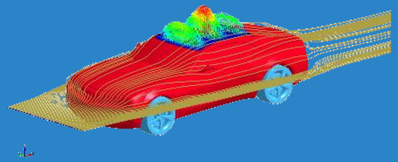
LSTC | Products

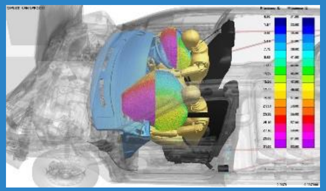
Multi-Physics Solver, Pre-and-Post Processor, Optimization, and Library of Validated Dummies and Barriers

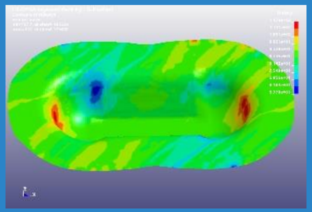


LS-PrePost

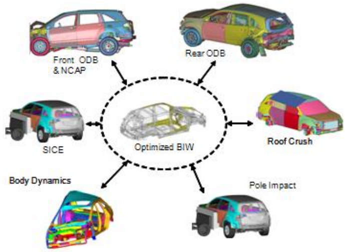
Dummies & Barriers



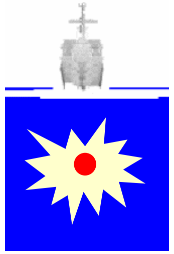




LS-DYNA®



LS-OPT/LS-TaSC



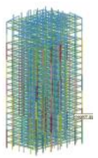
USA

No additional license cost

LS-DYNA | Applications

Development costs are spread across many industries

Automotive
Crash and safety
NVH & Durability
FSI

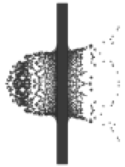


Structural
Earthquake safety
Concrete and composite structures
Homeland security

Aerospace
Bird strike
Containment
Crash

Electronics
Drop analysis
Package analysis
Thermal

Manufacturing
Stamping
Forging
Welding



Defense
Weapons design
Blast and penetration
Underwater Shock Analysis

Consumer Products

Biosciences

LS-DYNA | Current Capabilities

Includes coupled Multi-Physics, Multi-Scale, and Multi-Stage in one Scalable Code

- Explicit/Implicit
- Heat Transfer
- ALE & Mesh Free
  EFG, SPH, Airbag Particle
- User Interface
  Elements, Materials, Loads
- Acoustics, Frequency Response, Modal Methods
- Discrete Element Methods
- Incompressible Fluids
- CESE Compressible Fluids
- Electromagnetics
- Control Systems

LS-DYNA | One Code, One Model

Single Model for Multiple Disciplines – Manufacturing, Durability, NVH, Crash, and FSI

Multi-Physics and Multi-Stage

Structure + Fluid + EM + Heat Transfer

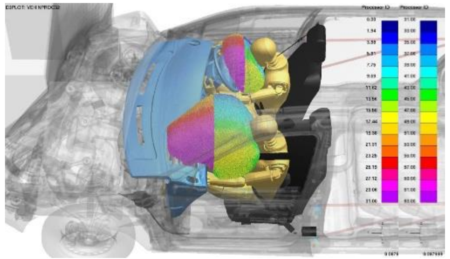
Implicit + Explicit ….

Multi-Scale

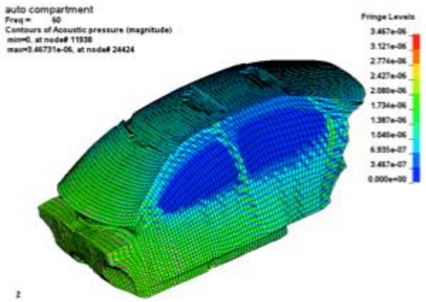
Failure predictions, i.e., spot welds

Multi-Formulations

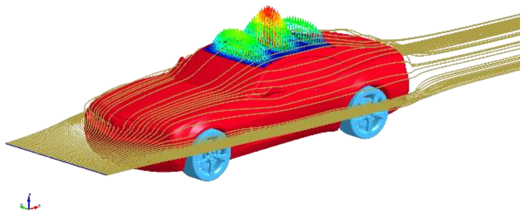
Linear + Non-Linear + Peridynamics + …



Crash



NVH/E-Coat/Paint Bake



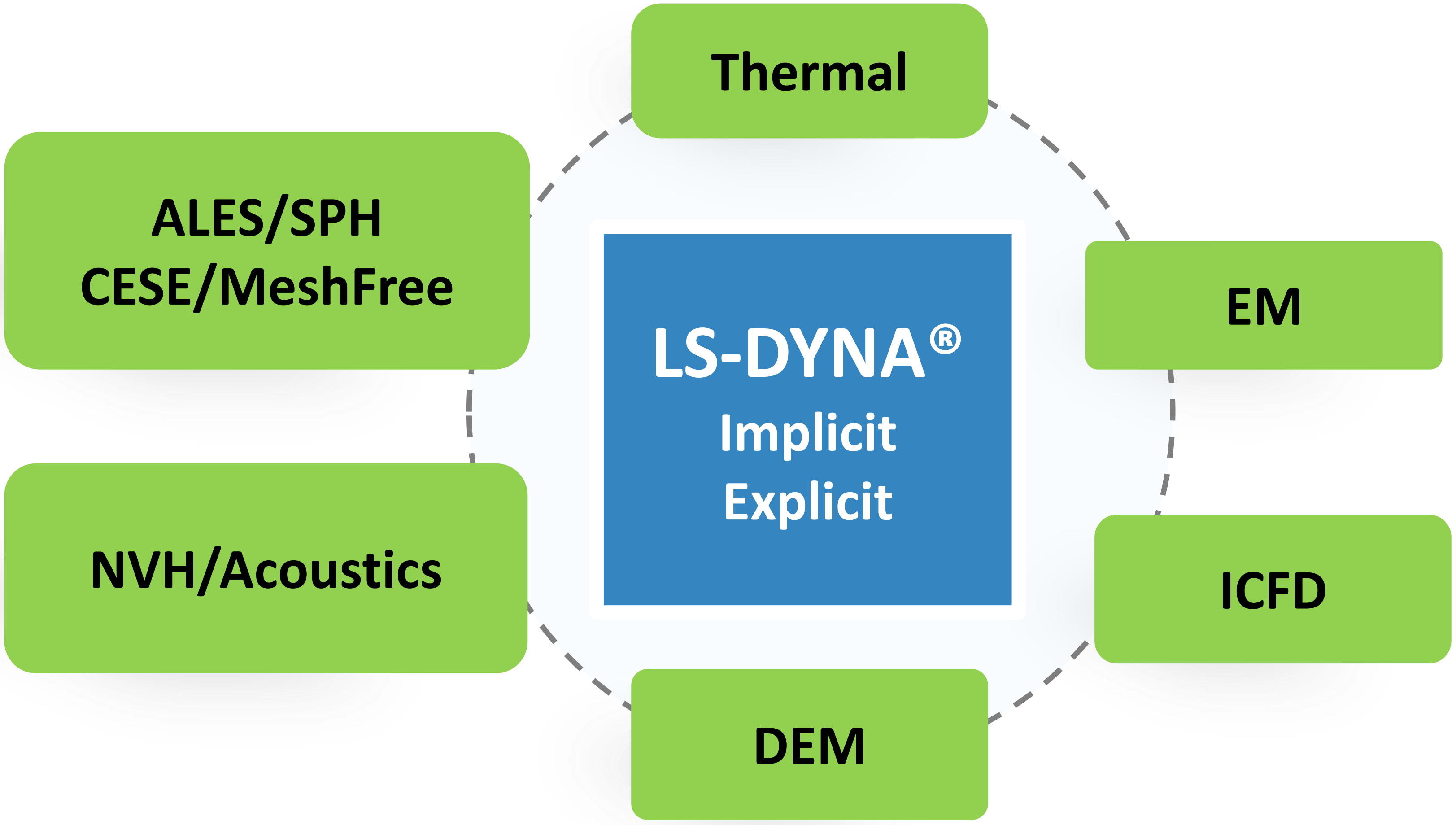
Structure + Fluid

The neon crash model is courtesy of FHWA/NHTSA National Crash Analysis Center

LS-DYNA | Strong Coupled Multi-Physics Solver

Computers capable of multi-physics simulations are becoming affordable.

Scalability is rapidly improving for solving multi-physics problem.



Multi-Physics, Multi-formulation, Multi-scale, Multi-stage

Pierre L'Eplattenier

Facundo Del Pin

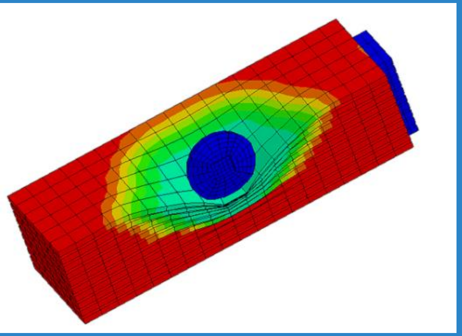
Iñaki Çaldichoury

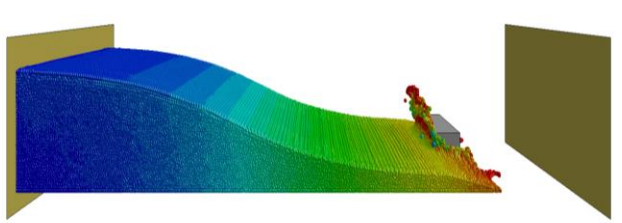
Rodrigo R. Paz

Chien-Jung Huang

Edouard Yreux

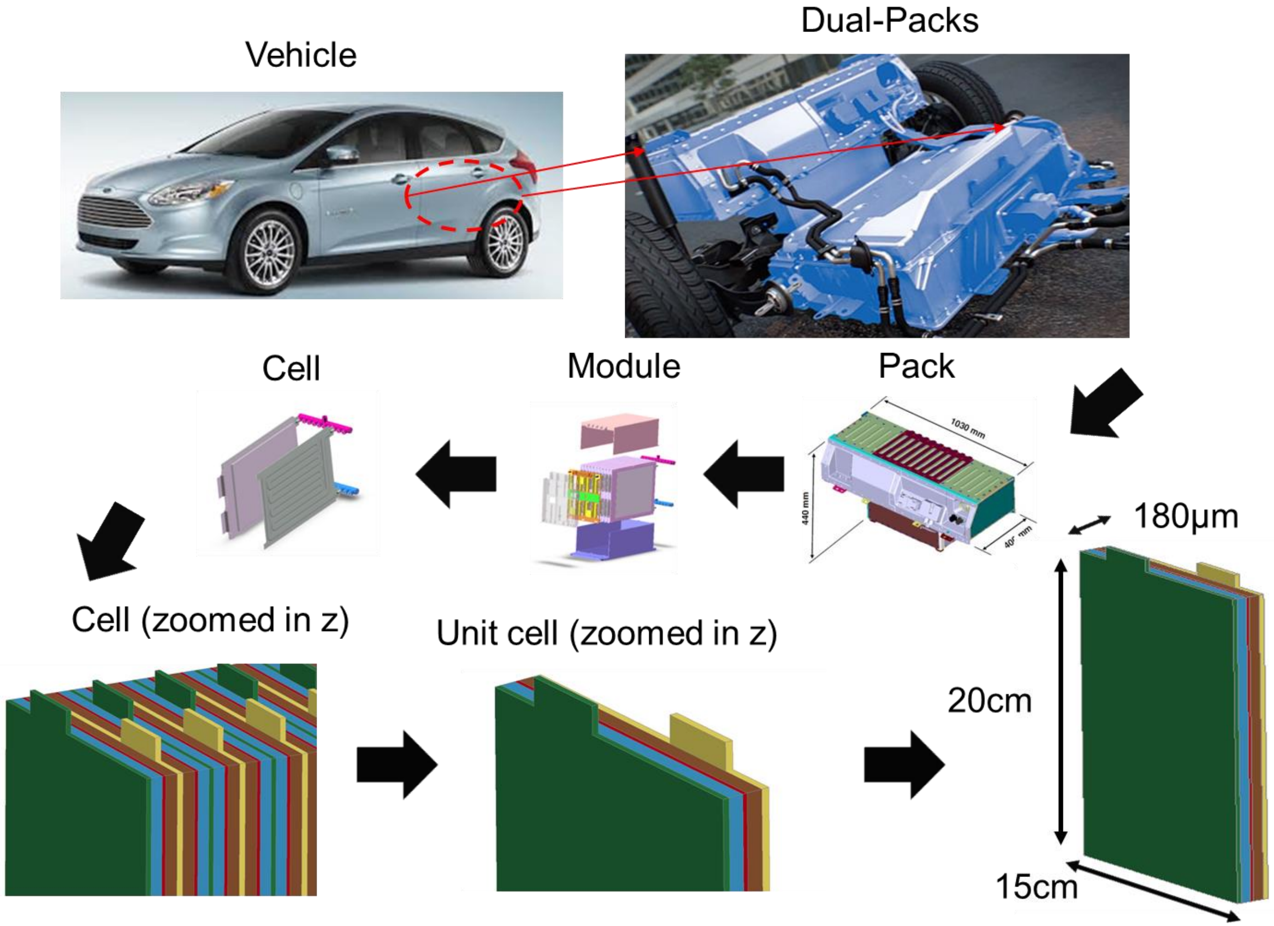
Jason Wang

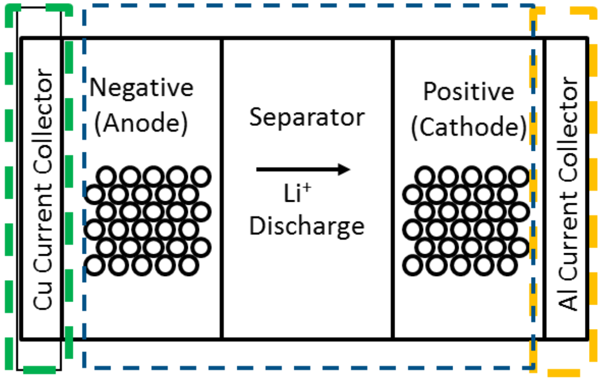




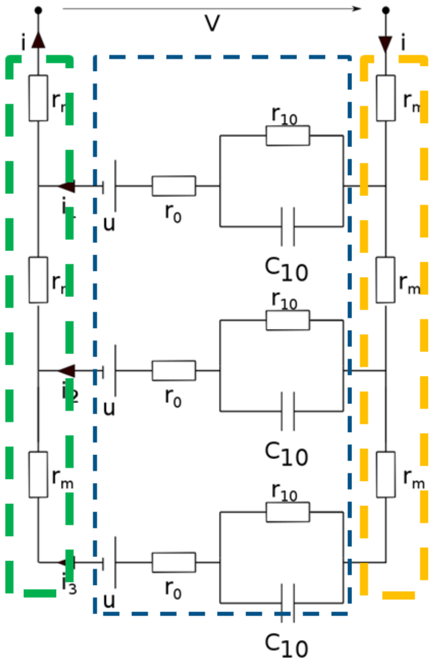
Battery – Distributed Randles circuit model

Electro-chemistry in the electrodes simulated by equivalent electrical circuits (Randles circuits)





- Current collectors transport electrons to/from tabs; modeled by resistive elements
- Jelly roll (anode – separator – cathode) transports Li+ ions; modeled with Randle circuit



r_0: Ohmic & kinetic

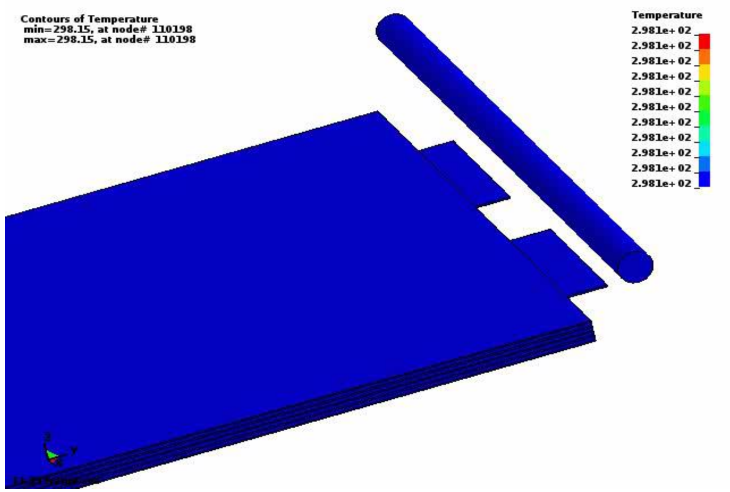
r_{10} & c_{10}: Diffusion

u: Equilibrium voltage (OCV)

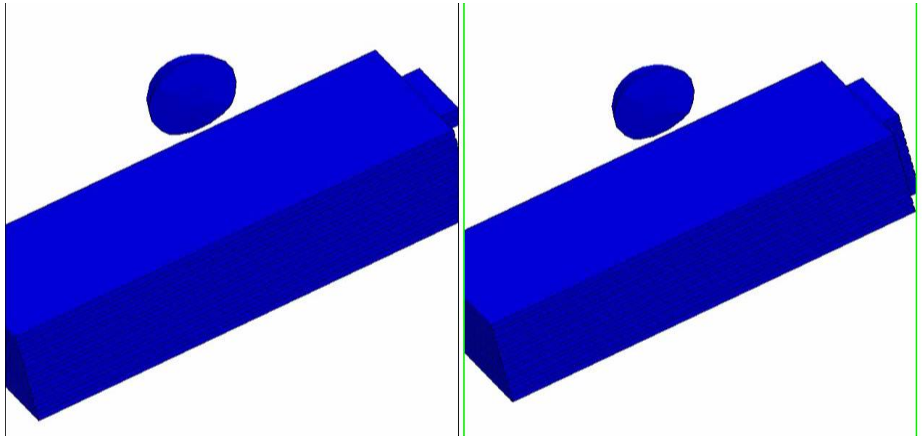
r_m: Current collectors

Battery abuse simulations

- Pouch cells, cylindrical cells available, soon prismatic cells
- Battery abuse simulations on cells, modules, packs
- Coupled with mechanical and thermal solvers
- Solid, shells and composite thick shells
- External and internal shorts
- Battery packaging application in LS-PrePost



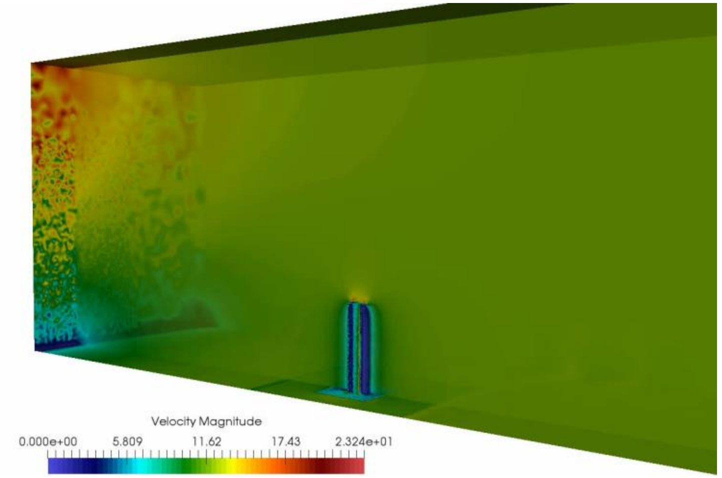
External short
5 cells module

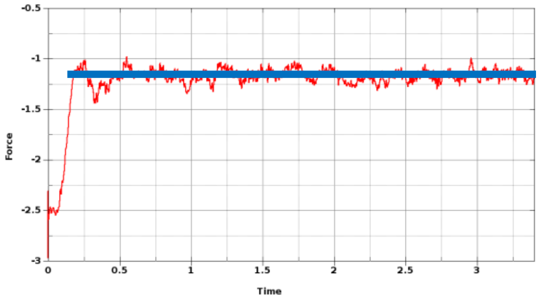


Internal short
10 cells module

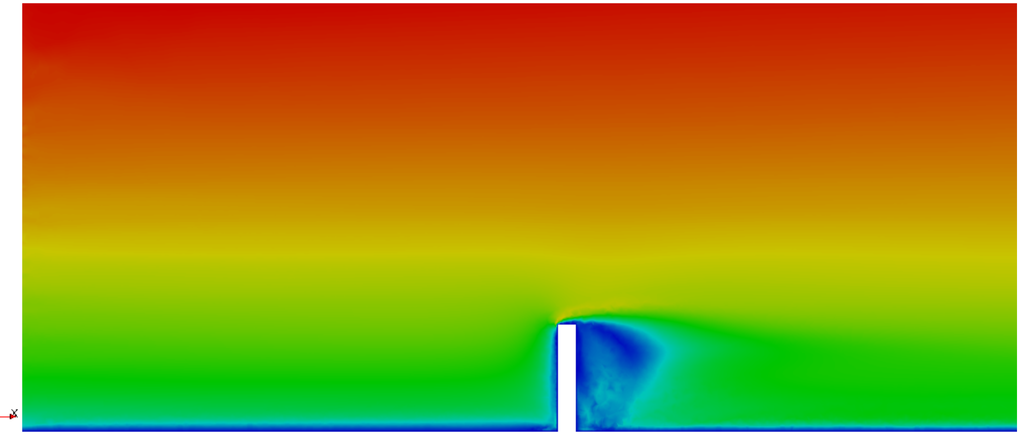
Steady State for Conjugate Heat and FSI

The steady state solver or the potential flow solver allow for a fast linearization of Fluid Structure Interaction (FSI) and/or Conjugate Heat transfer (CH) problems



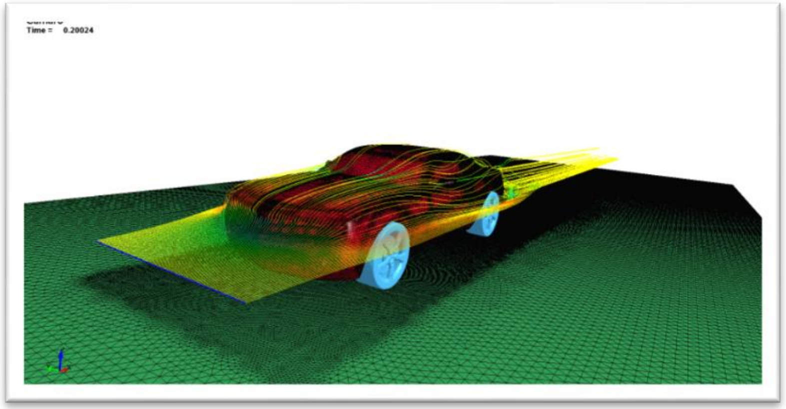


Steady state analysis allows engineers to study physical problems in a time average fashion.

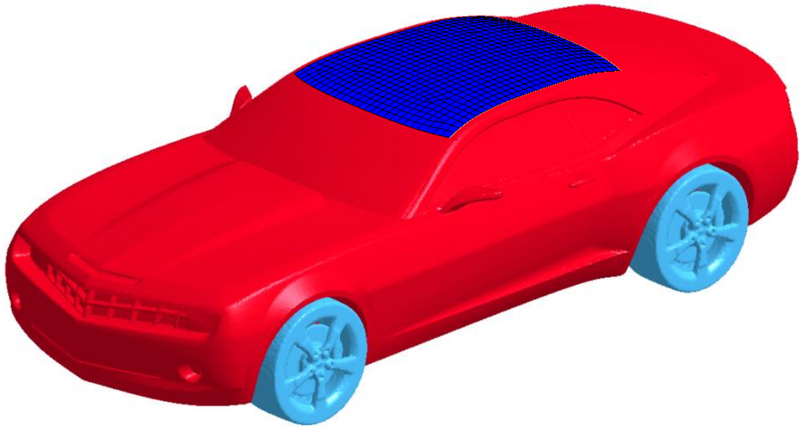


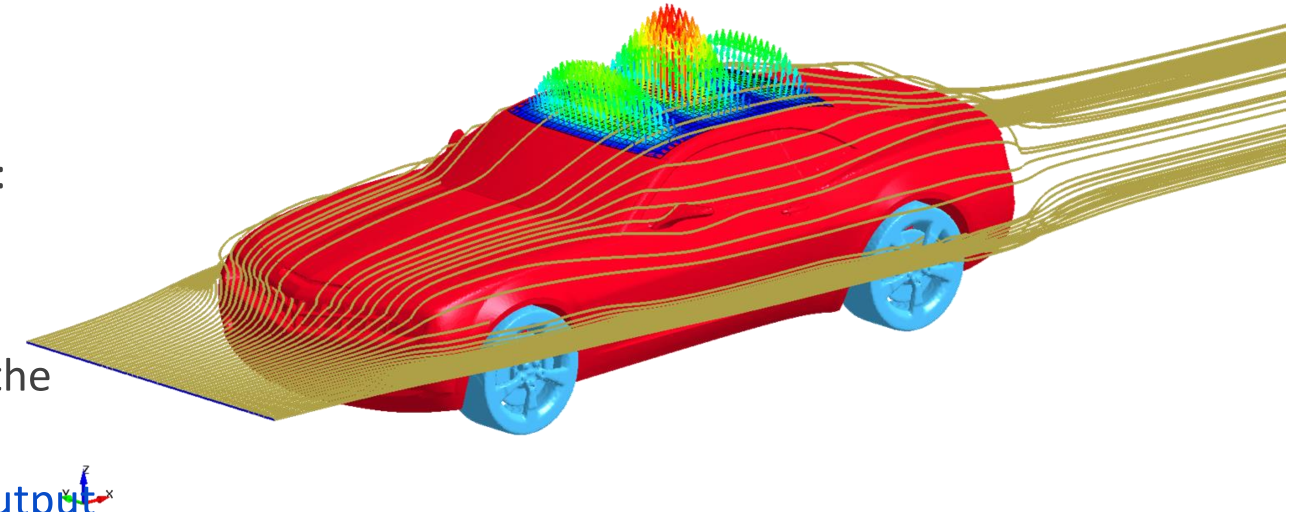
These simulation provide valuable insight faster useful for prototyping.

Steady State + Fluid Structure Interaction



- CFD analysis of full vehicle.
- Couple parts of the structure to analysis the response in a realistic environment.



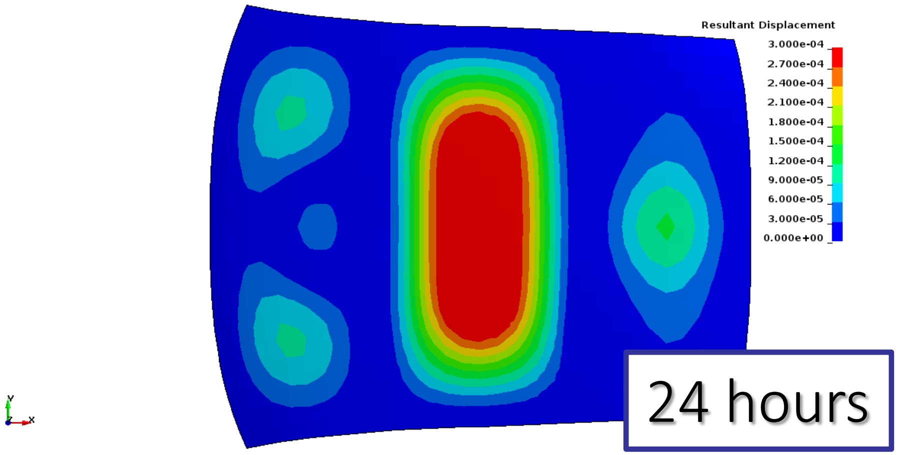


Three different option to solve the same problem:

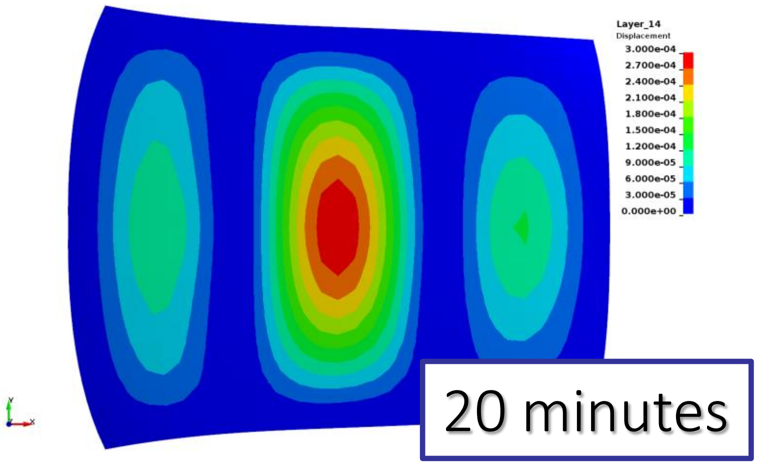
- Solve Full Navier –Stokes with FSI non linear coupling.
- Solve Potential flow with a non-linear step at the end.
- Solve the structural analysis alone using the output from Navier-Stokes and the *LOAD_SEGMENT automatically generated input deck. Use *ICFD_DATABASE_DRAG write the files.

Steady State + Fluid Structure Interaction

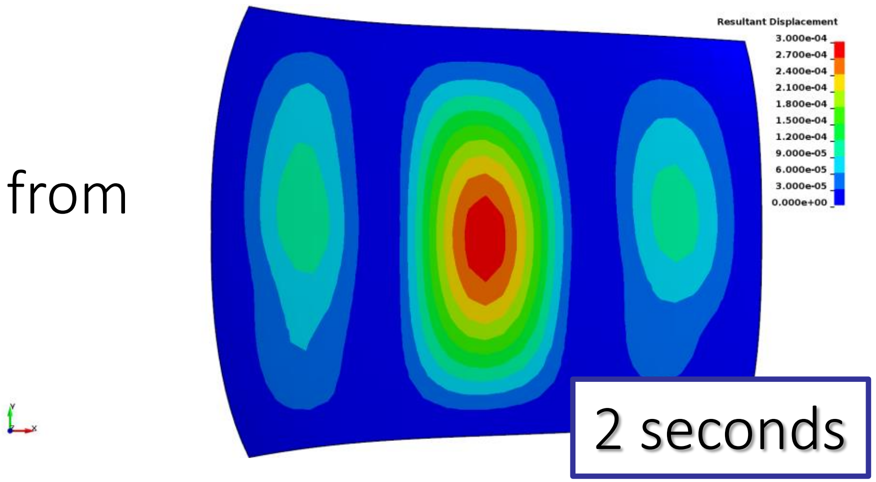
Navier Stokes



Potential Flow



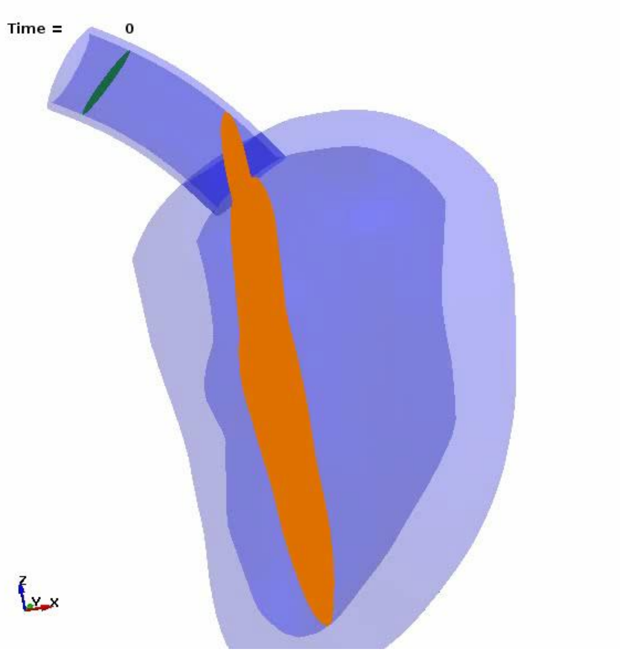
Using *LOAD_SEGMENT from Navier-Stokes solution



Multi-physics – Cardiac simulations (EM + ICFD + Structure)

Healthy ventricle

Fibrillation with spiral waves



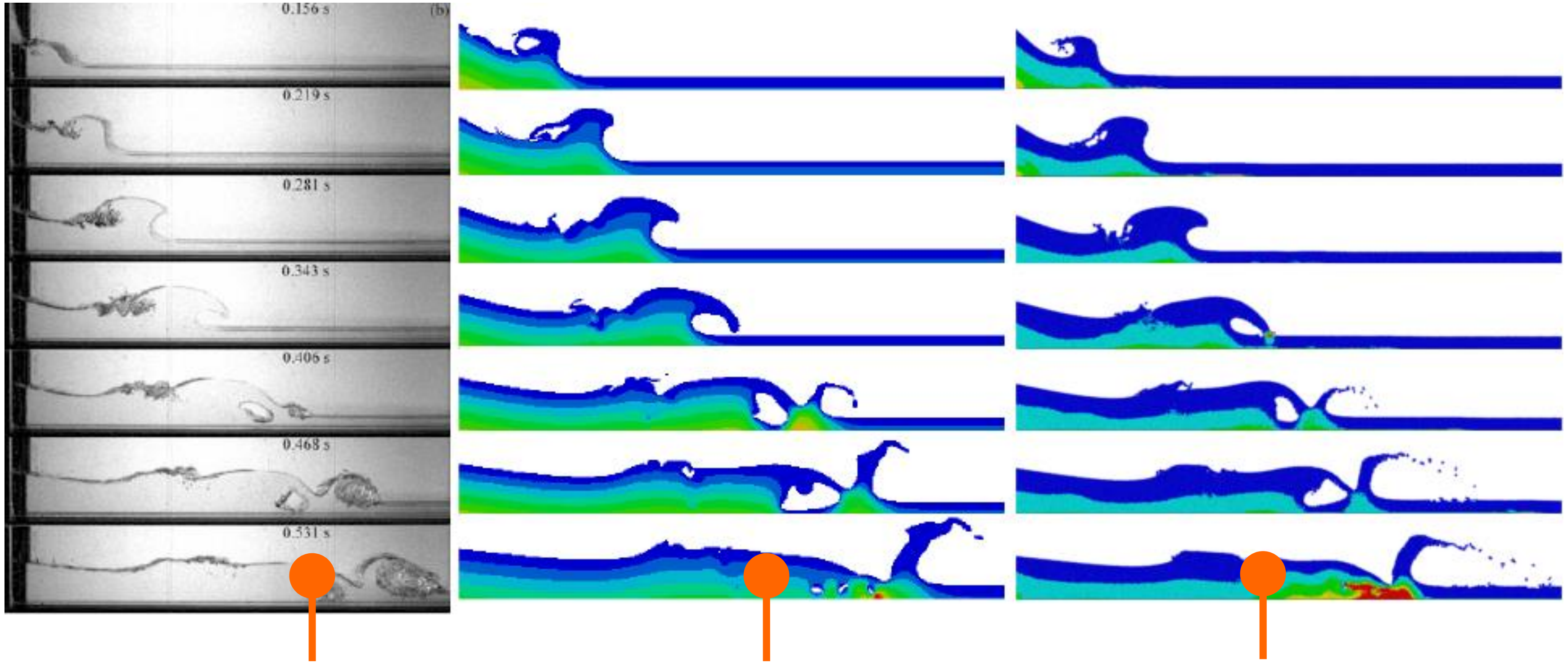
SPH | Fluid Simulation

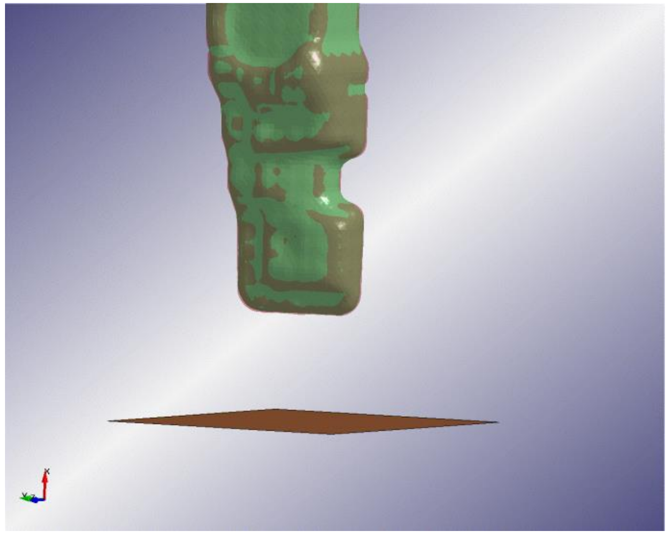
- Density smoothing: $$\tilde{\rho}_I = \frac{\sum_J \rho_J \phi_{IJ}}{\sum_J \phi_{IJ}} \quad \text{with} \quad \phi_{IJ} = W_{IJ} m_J / \rho_J$$

- Murnaghan Equation of State for weakly compressible modeling

$$p = k_0 \left[\left(\frac{\rho}{\rho_0} \right)^{\gamma} - 1 \right]$$

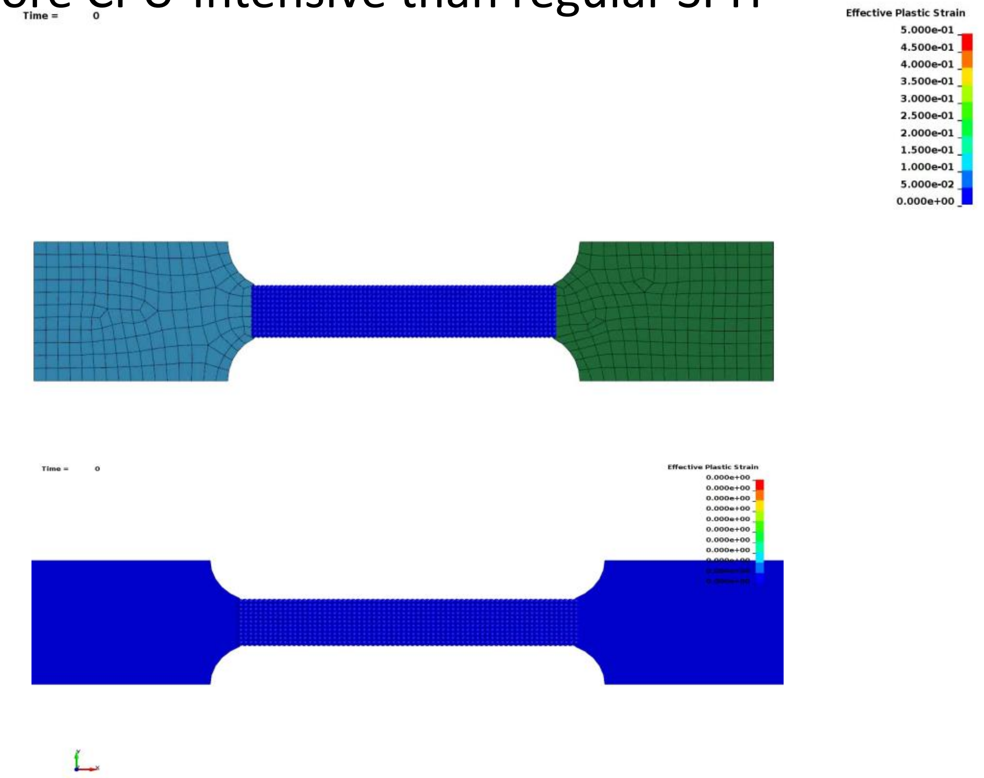
- Low artificial viscosity



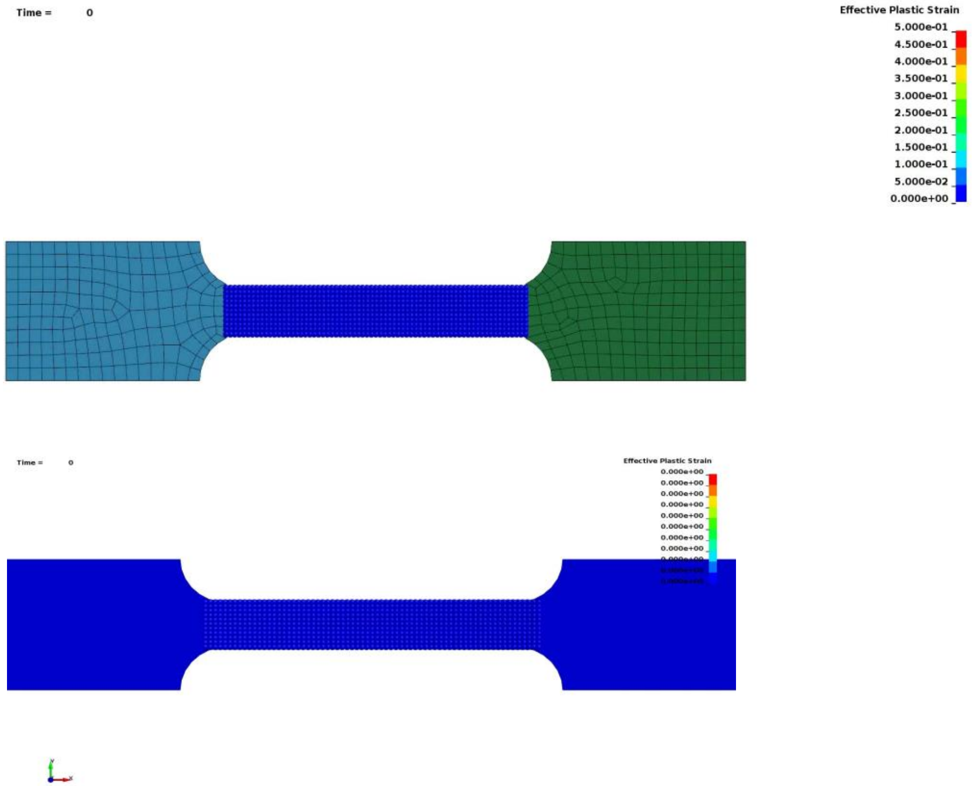


SPH | MLS-Based formulation

- Quasi-Linear Moving Least-Squares formulation for accuracy and consistency
- Stabilized nodal integration for better stability
- More CPU-Intensive than regular SPH



Traditional SPH



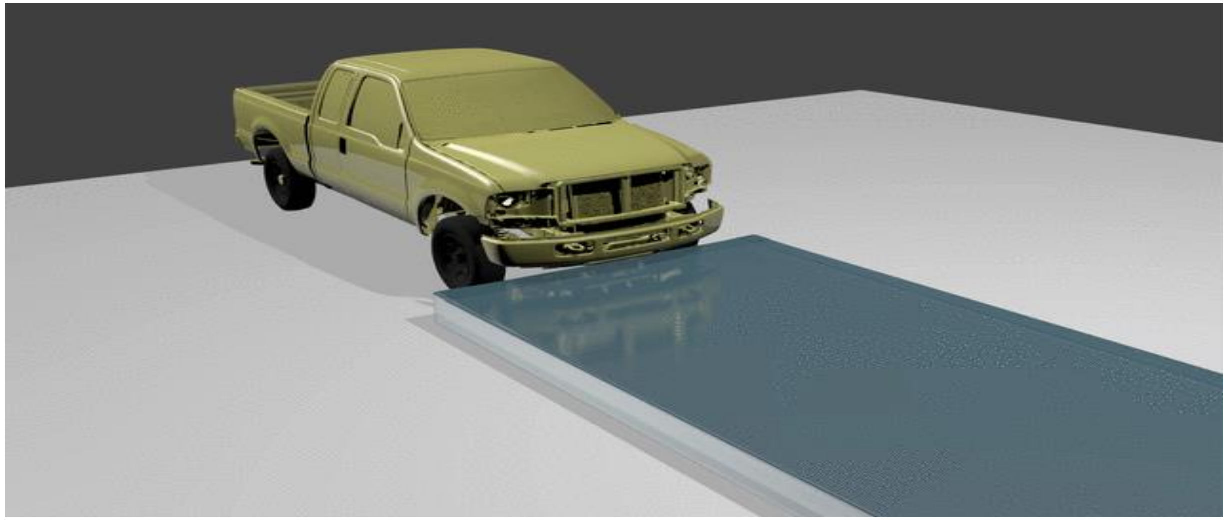
MLS-Based SPH

Higher accuracy – Better consistency – Alleviated tensile instability

SPH | Implicit formulation

- Implicit, incompressible SPH formulation allows larger timestep size
- Tailored for wading-type problems
- Example with 9.1 million particles:

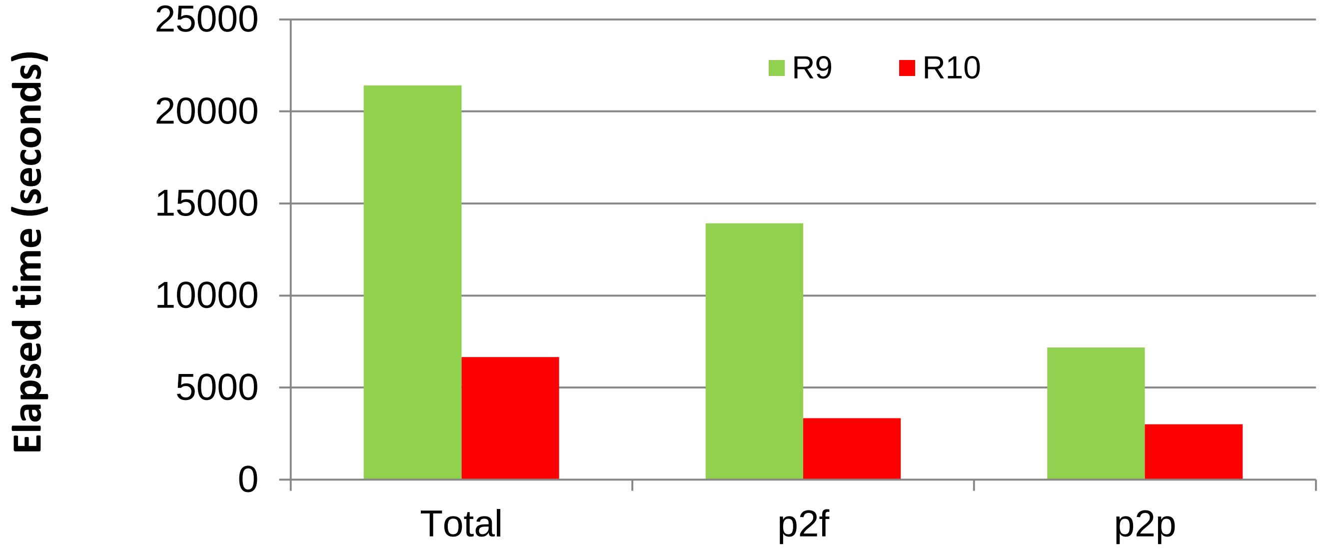
Implicit SPH
Color-coded by velocity



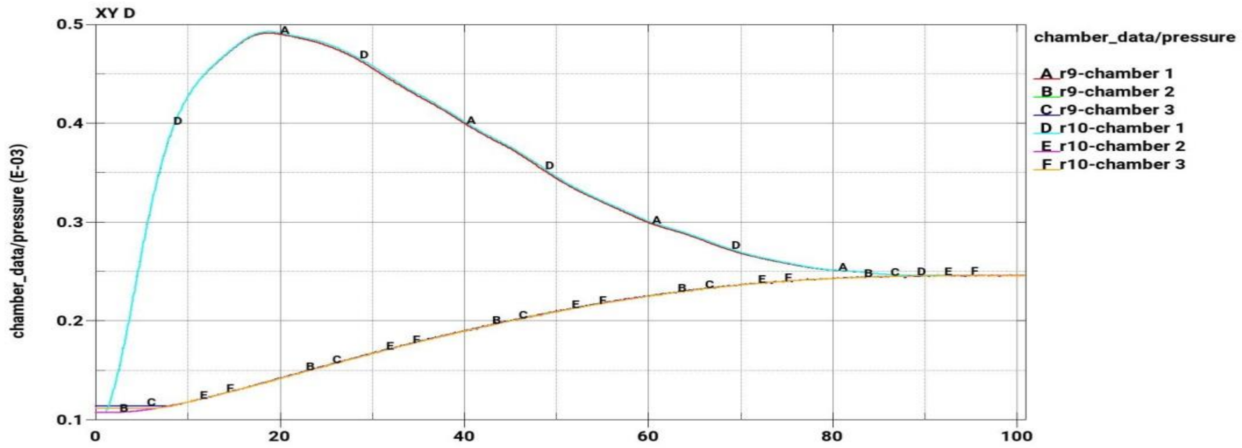
Blender rendering

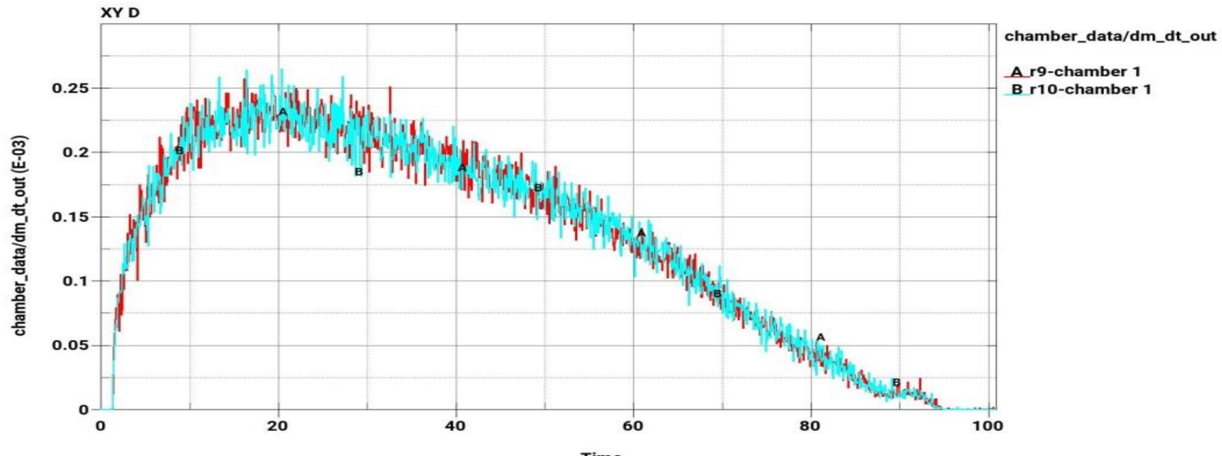
CPM | New CPM for AIRBAG Simulations

- Main cost for airbag simulation, (1)airbag self contact, (2)p2f and (3)p2p
- New and faster particle to fabric (p2f) contact algorithm
- Redistribute CPM particles among processors to achieve better scaling and efficient particle to particle (p2p) collisions

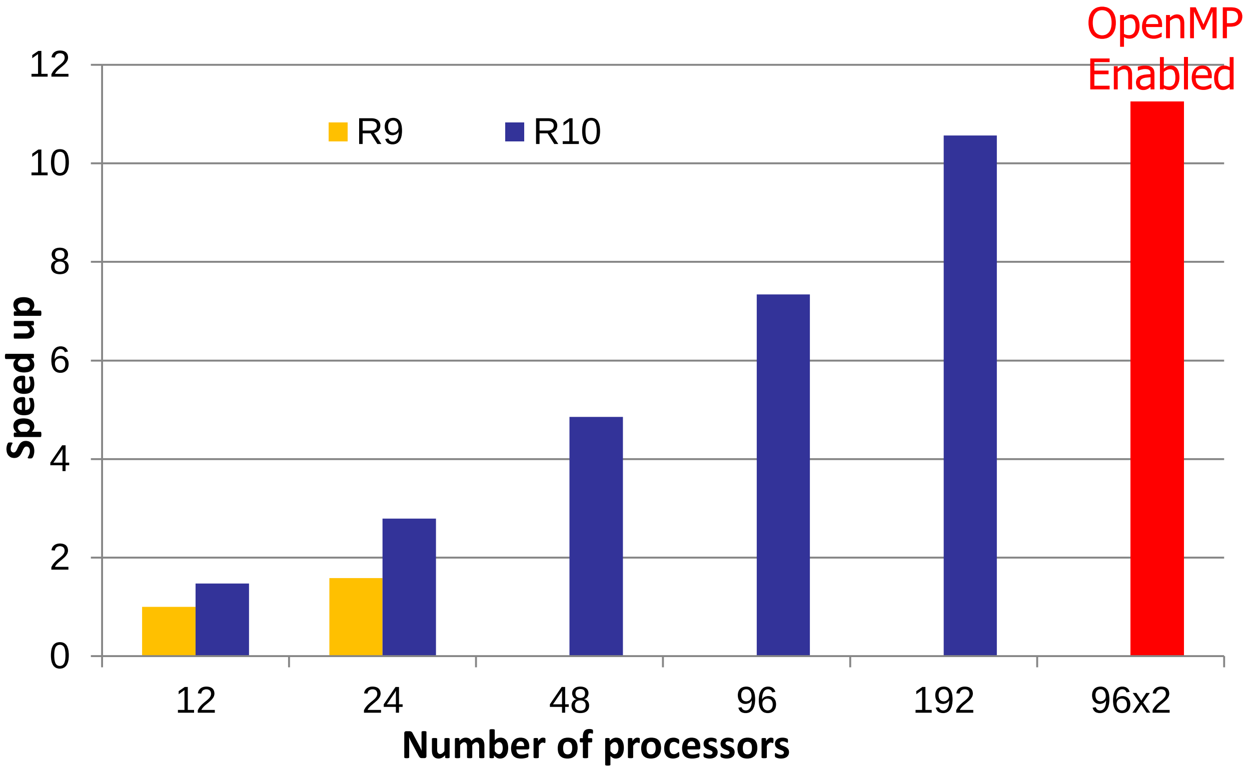


- *3x speedup for tank test*
- *Pressure history are consistent between releases*

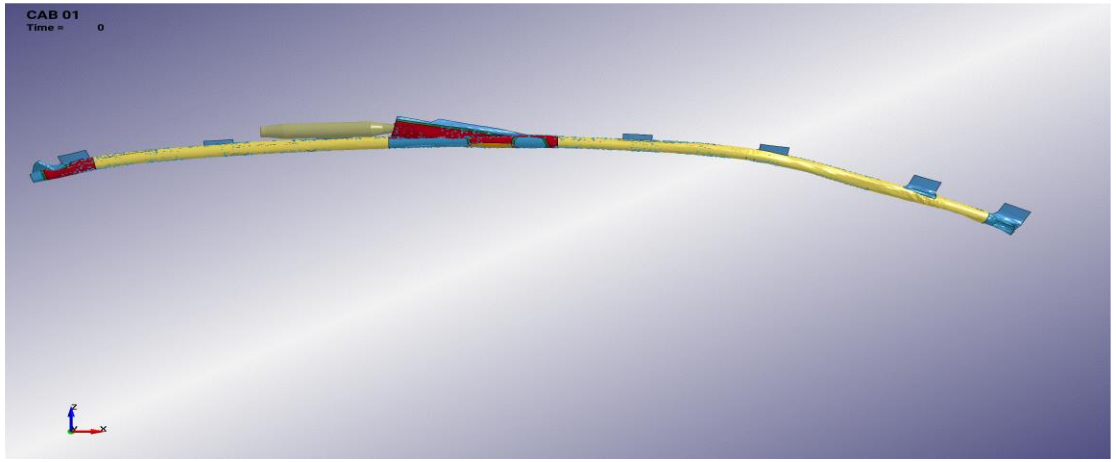




CPM | CAB Performance Improvement



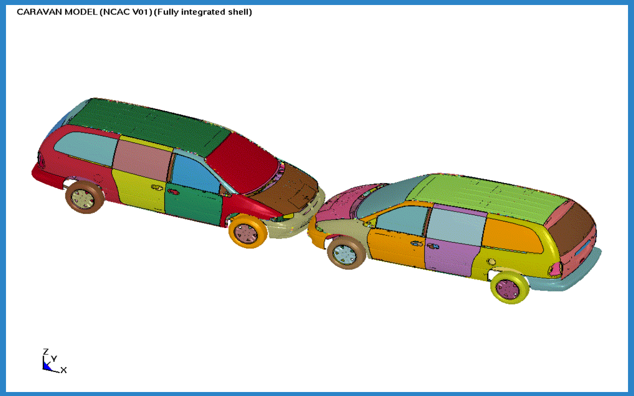
CAB

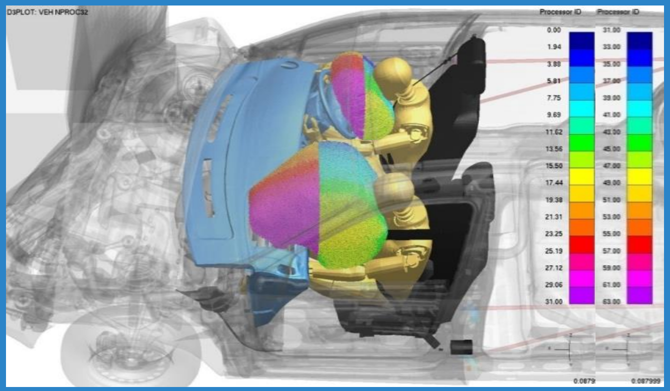


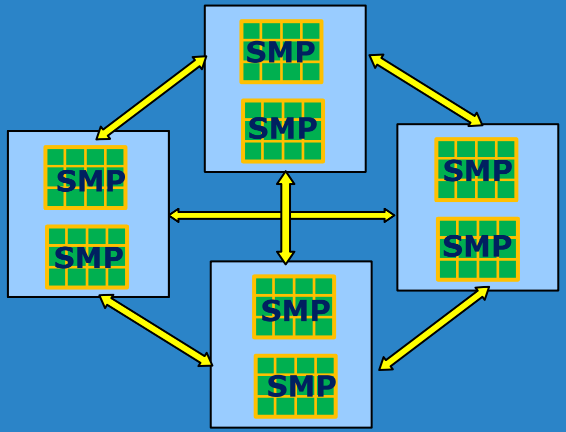
- OpenMP (HYBRID) enabled
- Reduced amount of data transferring between processors for better scaling
- It is more efficient for the full vehicle simulation which uses more than 200 processors
- Same input faster turn around time

Scalable Code
MPP and Hybrid Enhancements

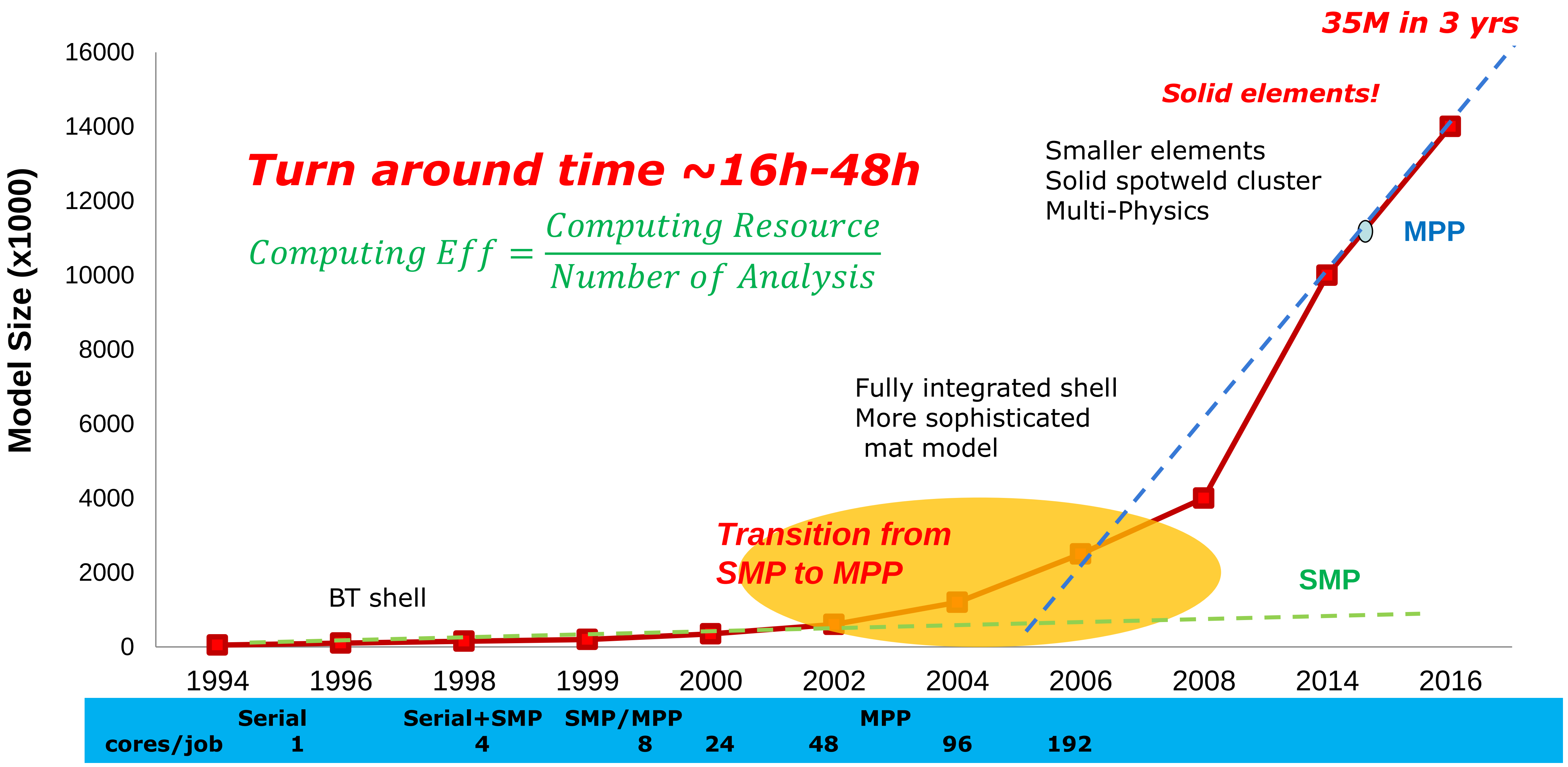
Jason Wang
Tobias Erhart
Gunther Blankenhorn
Lee Bindeman
Edward Helwig





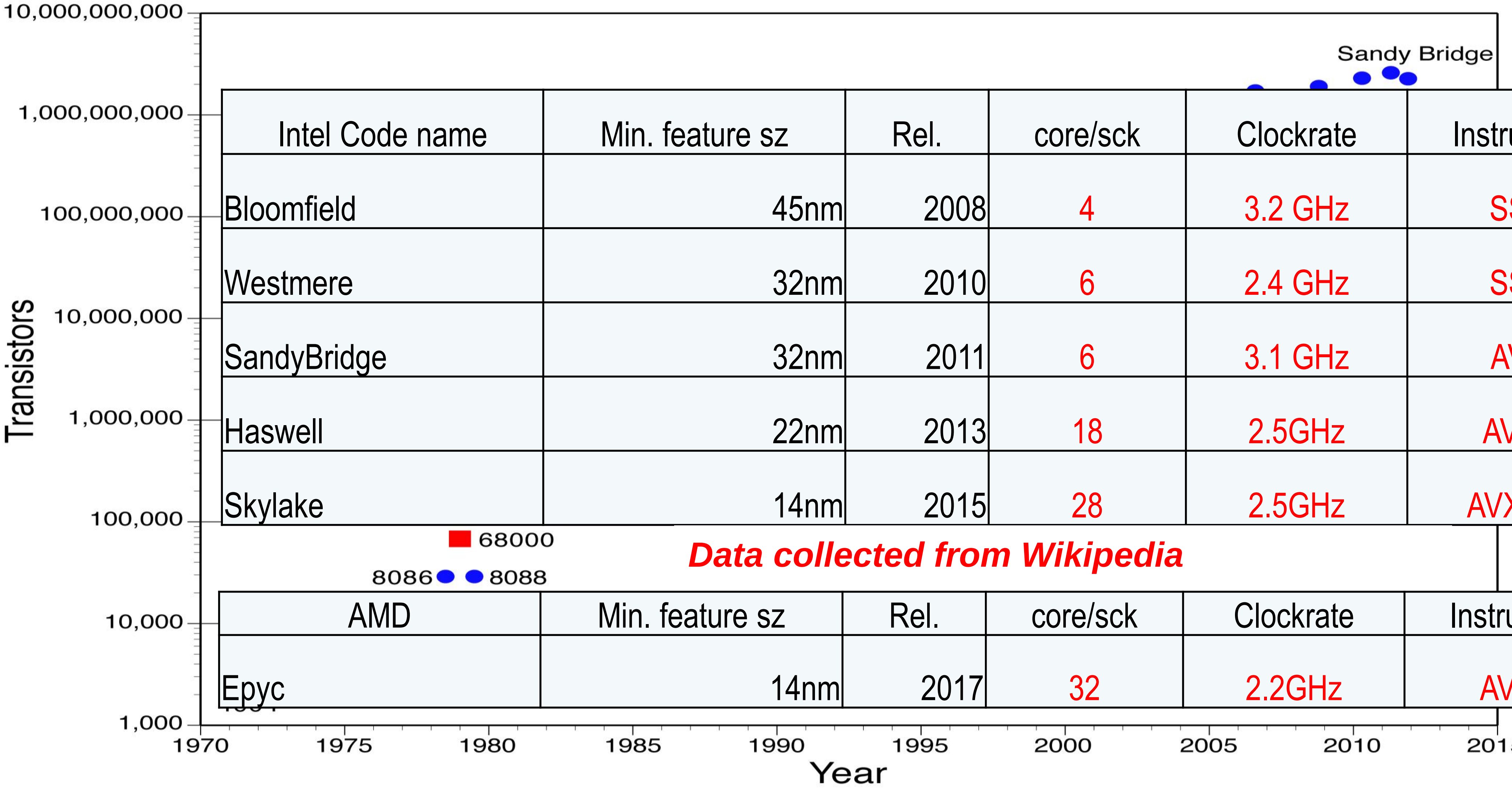


Model size for Safety Analysis



$$Computing\ Eff = \frac{Computing\ Resource}{Number\ of\ Analysis}$$

CPU technology - Moore’s Law

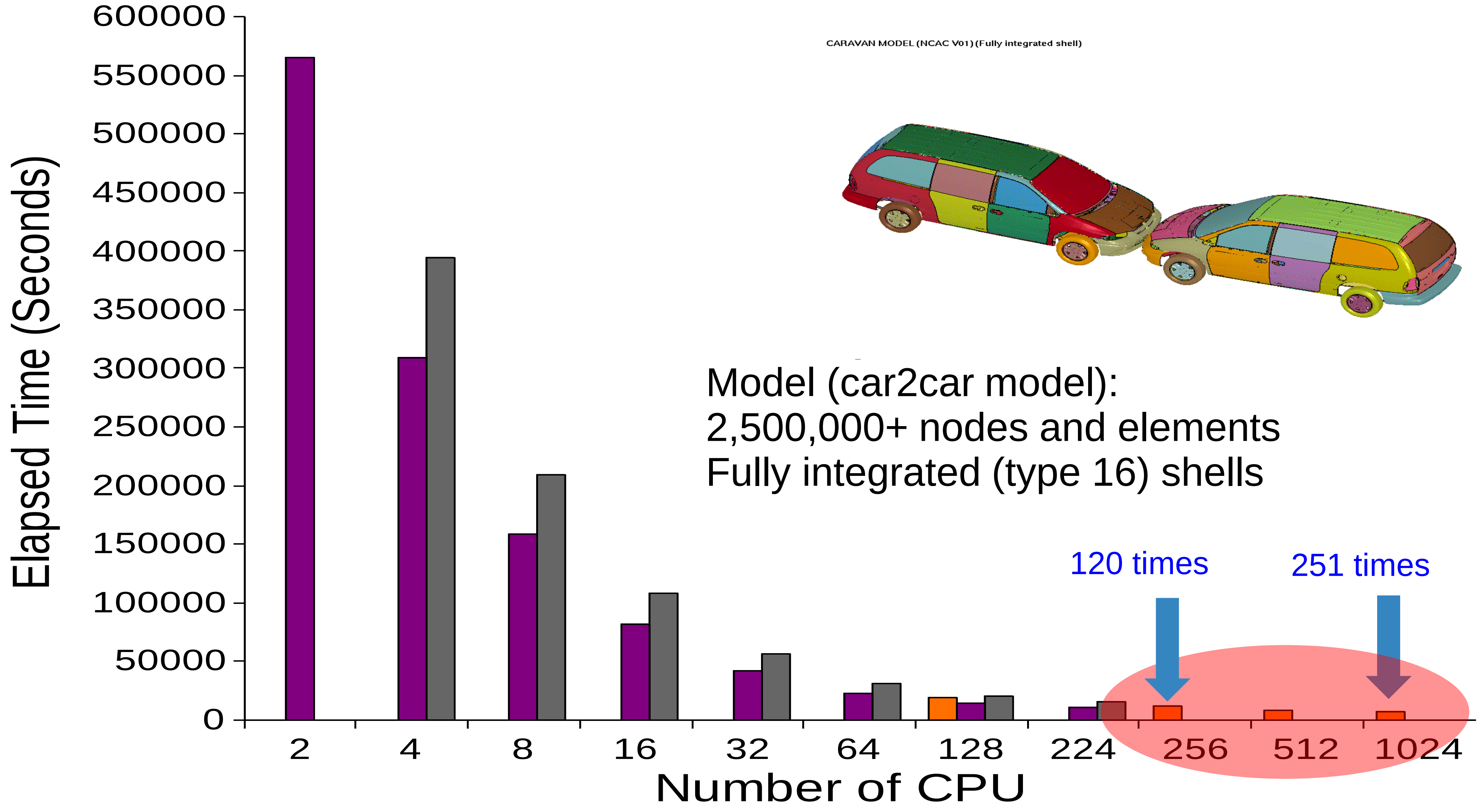


Intel Code name	Min. feature sz	Rel.	core/sck	Clockrate	Instruction
Bloomfield	45nm	2008	4	3.2 GHz	SSE
Westmere	32nm	2010	6	2.4 GHz	SSE
SandyBridge	32nm	2011	6	3.1 GHz	AVX
Haswell	22nm	2013	18	2.5GHz	AVX2
Skylake	14nm	2015	28	2.5GHz	AVX512

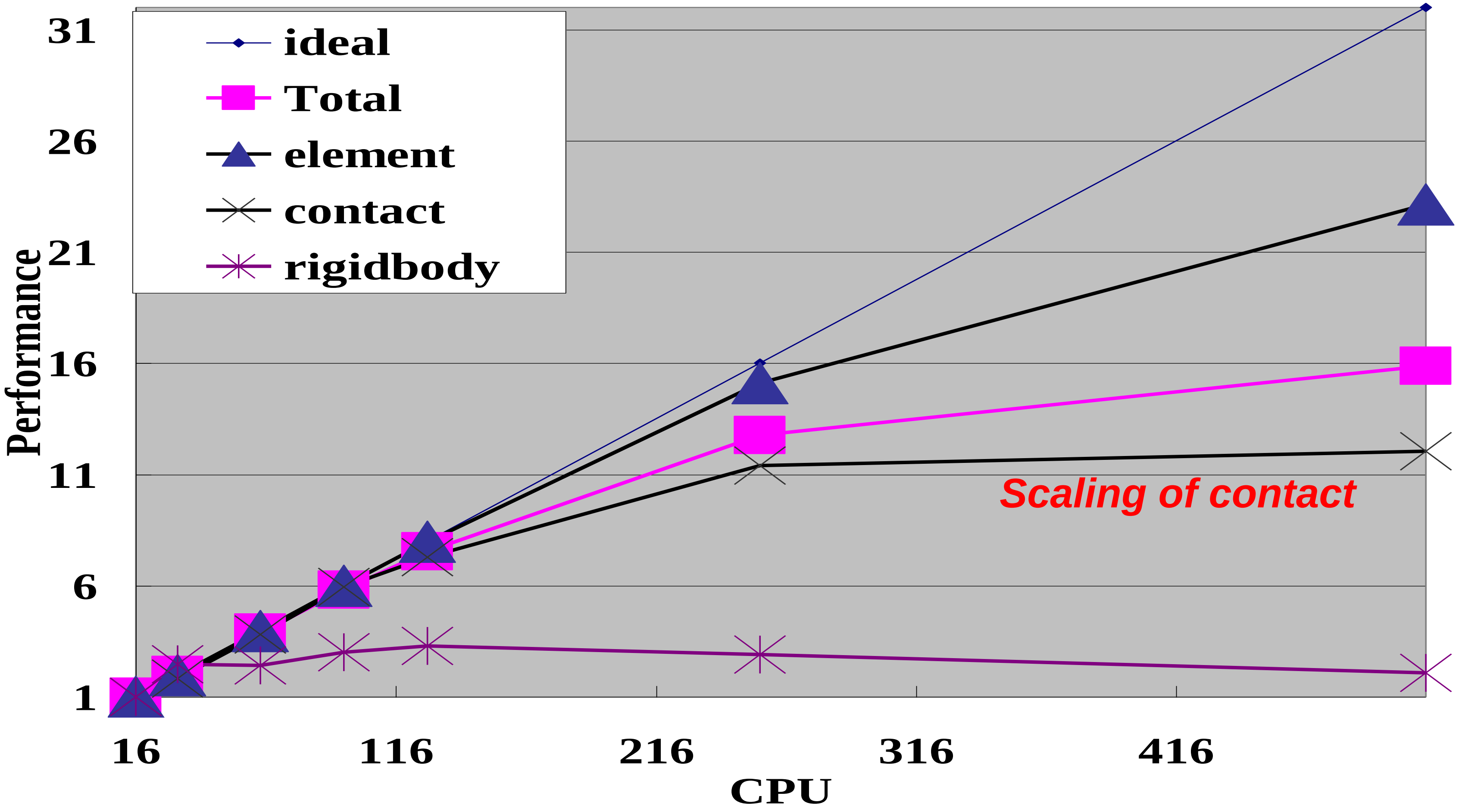
Data collected from Wikipedia

AMD	Min. feature sz	Rel.	core/sck	Clockrate	Instruction
Epyc	14nm	2017	32	2.2GHz	AVX2

MPP performance – topcrunch.org (2007)

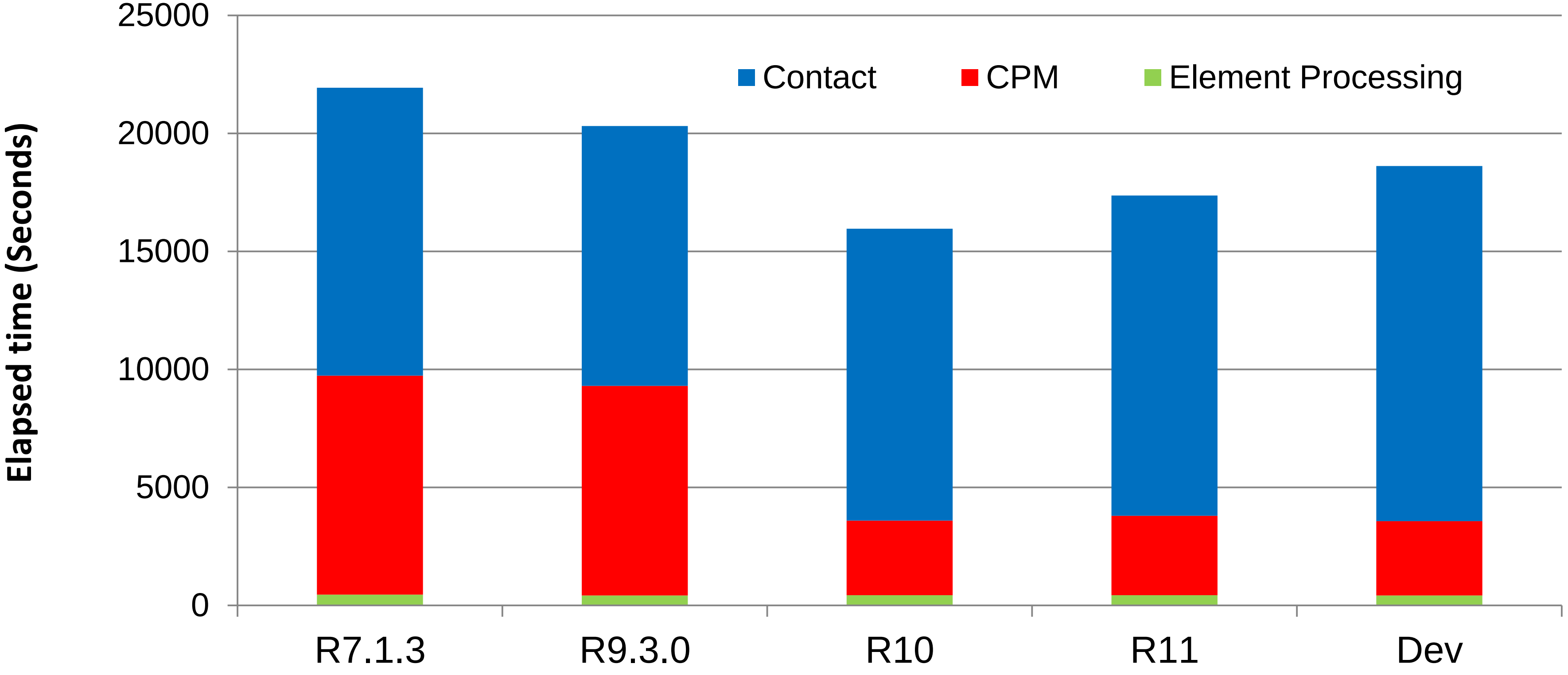


MPP Scaling

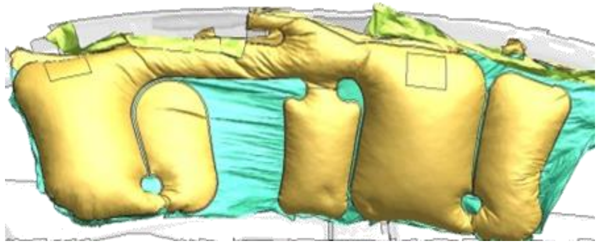


- Contact occurs in a small region
- Initial decomposition cannot keep contacts in local during simulation
- Element cost increases in the contact region

Special decomposition

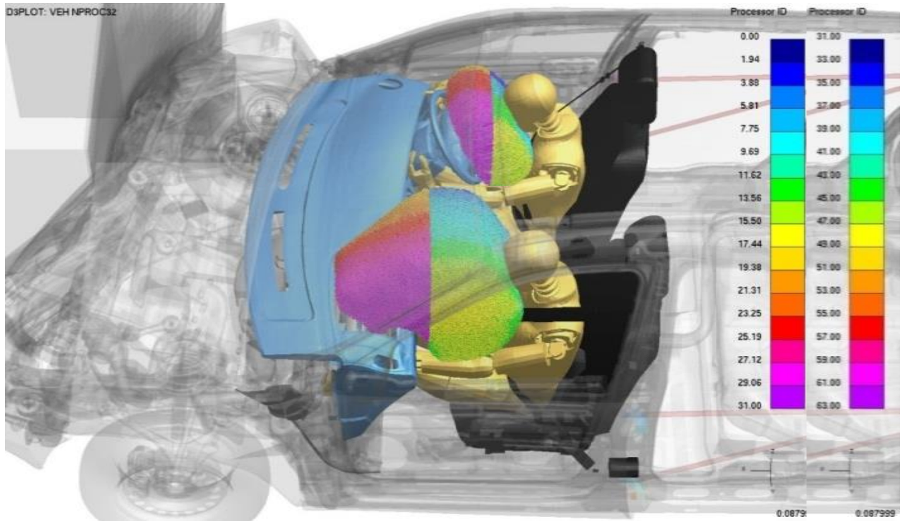


CAB



- Performance was measured with 96 processors
- CPM is about 3x faster from R7 to R10
- Self contact about the same
- The overall speed up is about ~20% for bag, ~5% for full car

*CONTROL_MPP_DECOMPOSITION_ARRANGE_PARTS



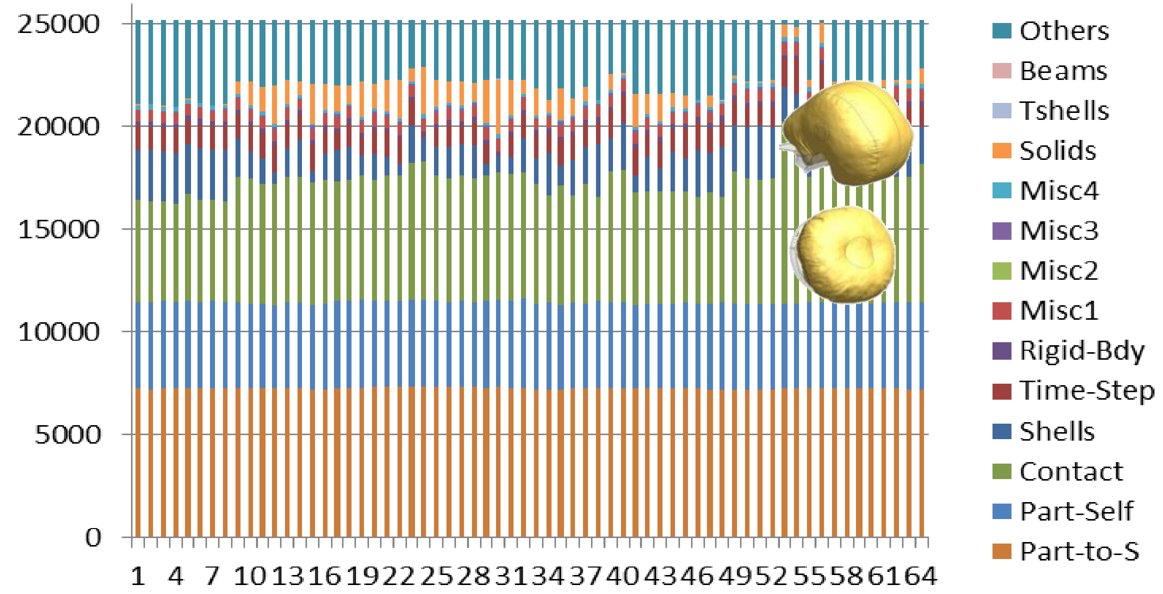
Runtime reduced from 7hrs 5min to 5hrs 53min. 20% faster!

Bags in parallel

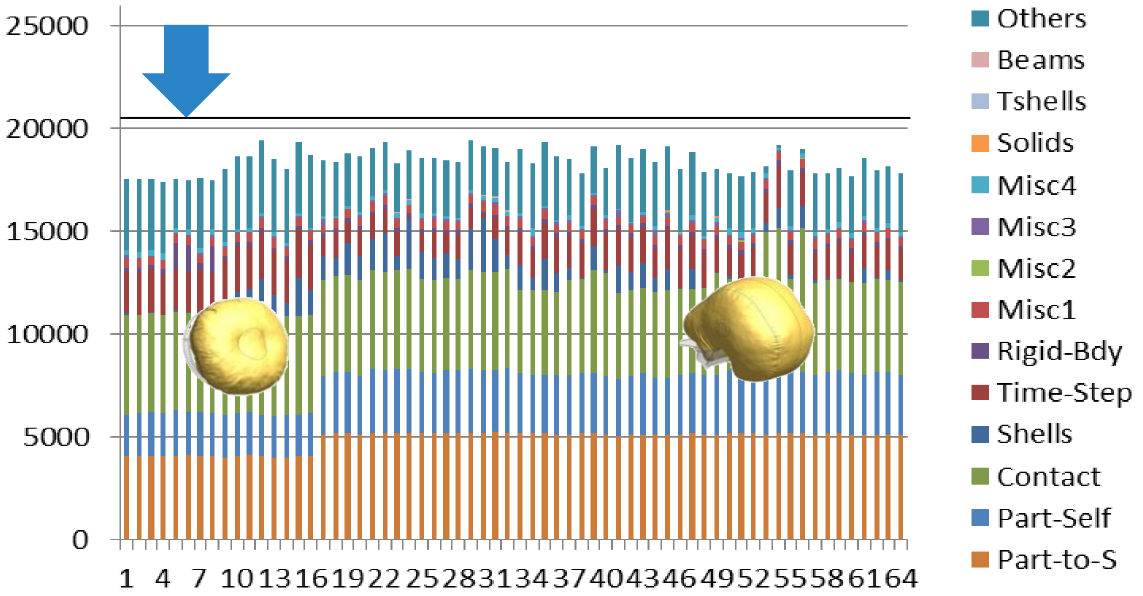
Bag self contacts in parallel

Contacts between bag and dummy in parallel

- set 16 for the DAB
- Set 48 for the PAB



DAB & PAB 64cpu, Default

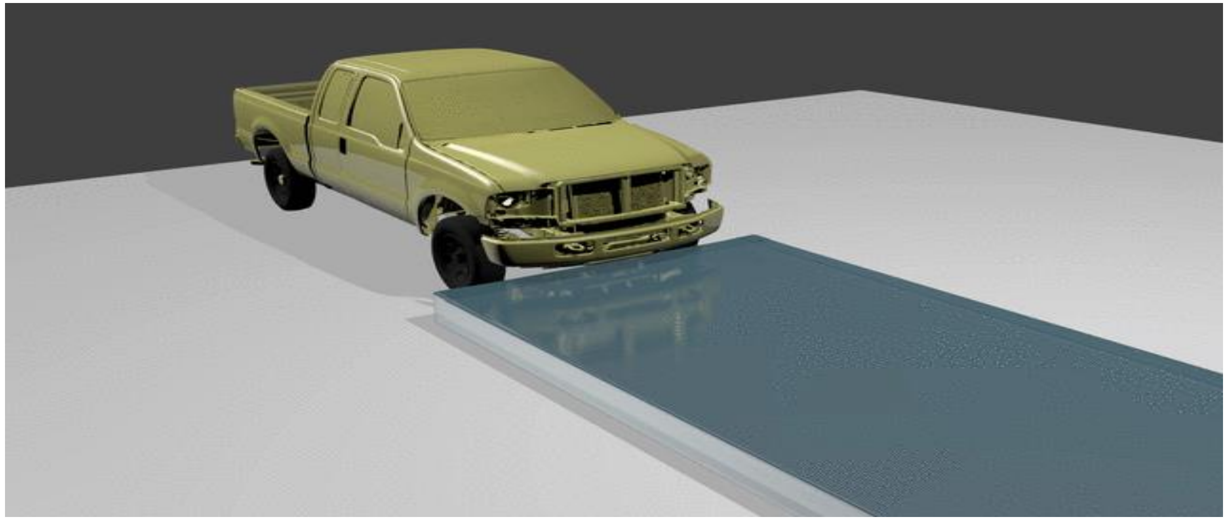


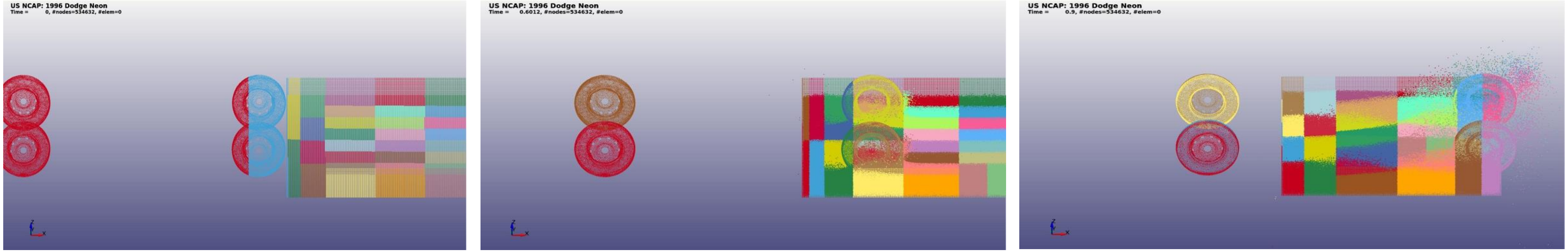
DAB & PAB 16/48 Distributed

Courtesy of: Richard Taylor, Arup

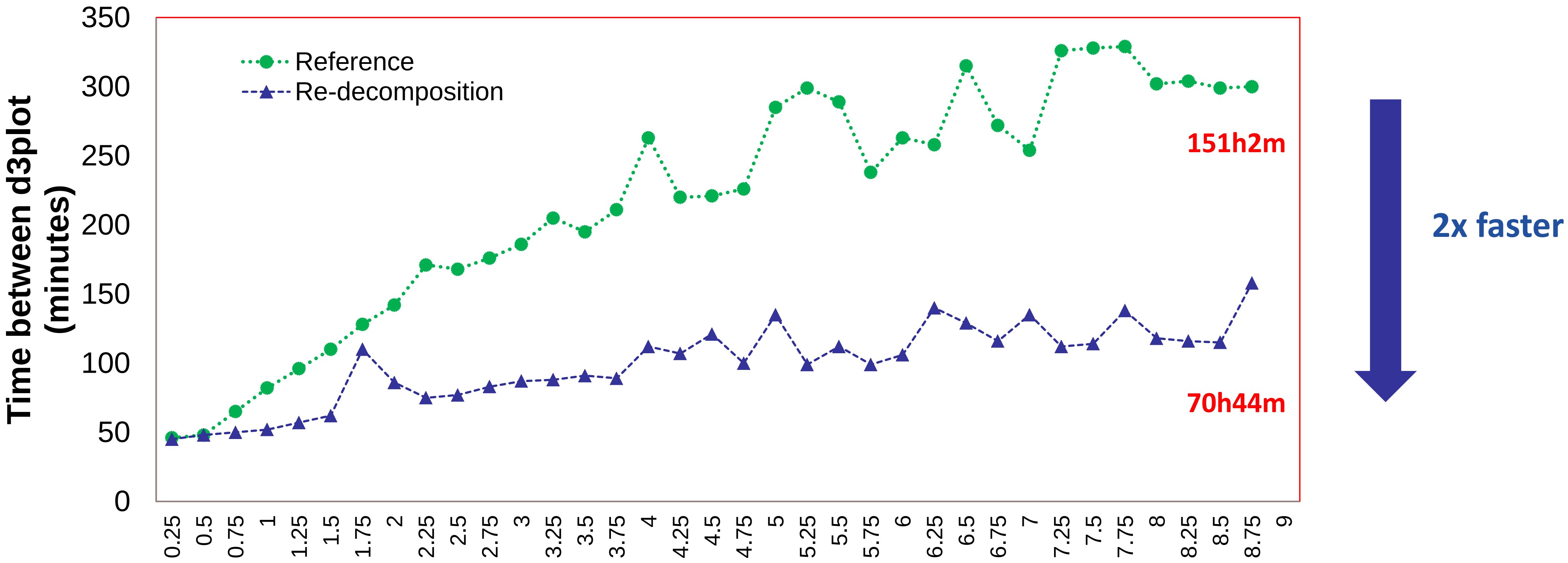
Re-decomposition

- Deformation/translation creates extra communication and causes load unbalancing.
- decomp { defgeo } : The model is decomposed using the current geometry.
- Re-decomposition rearranges partition and reduces network traffic.





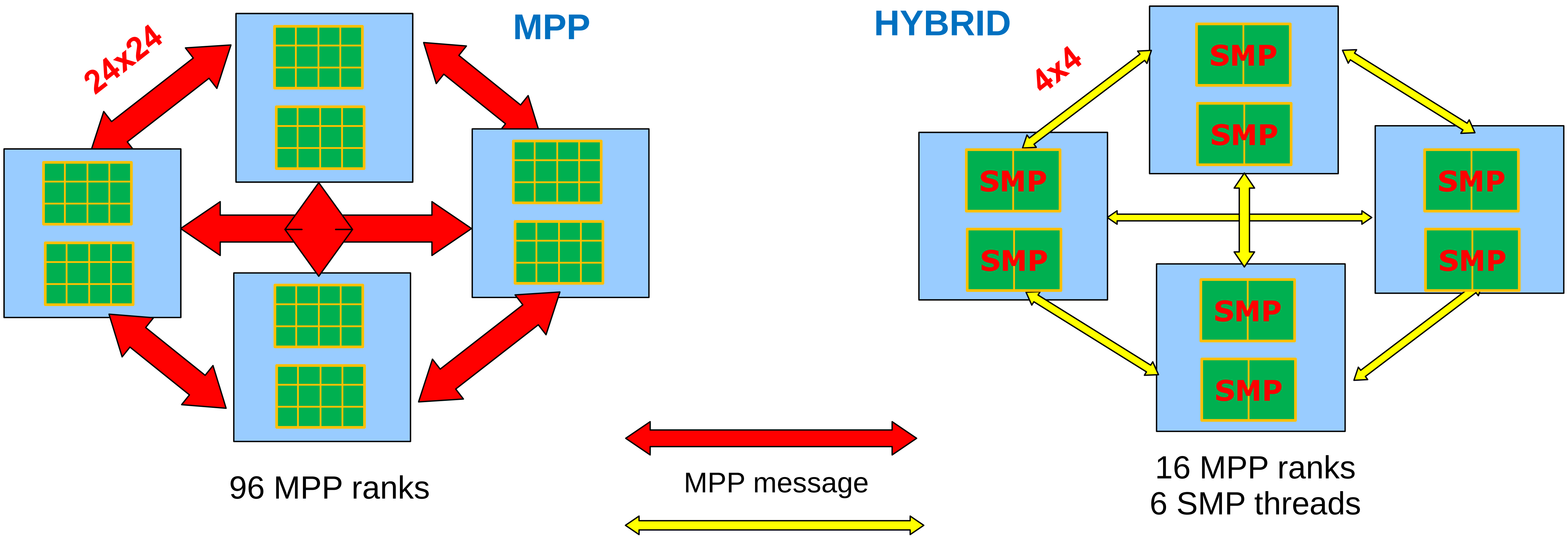
Re-decomposition



- More development work to make an automated process similar to adaptive simulation.
- Currently it uses fulldeck restart capability, user has full control to get better performance.
- Testing other problems, i.e. bird strike, small offset, ODB, etc.

SMP and MPP >> HYBRID

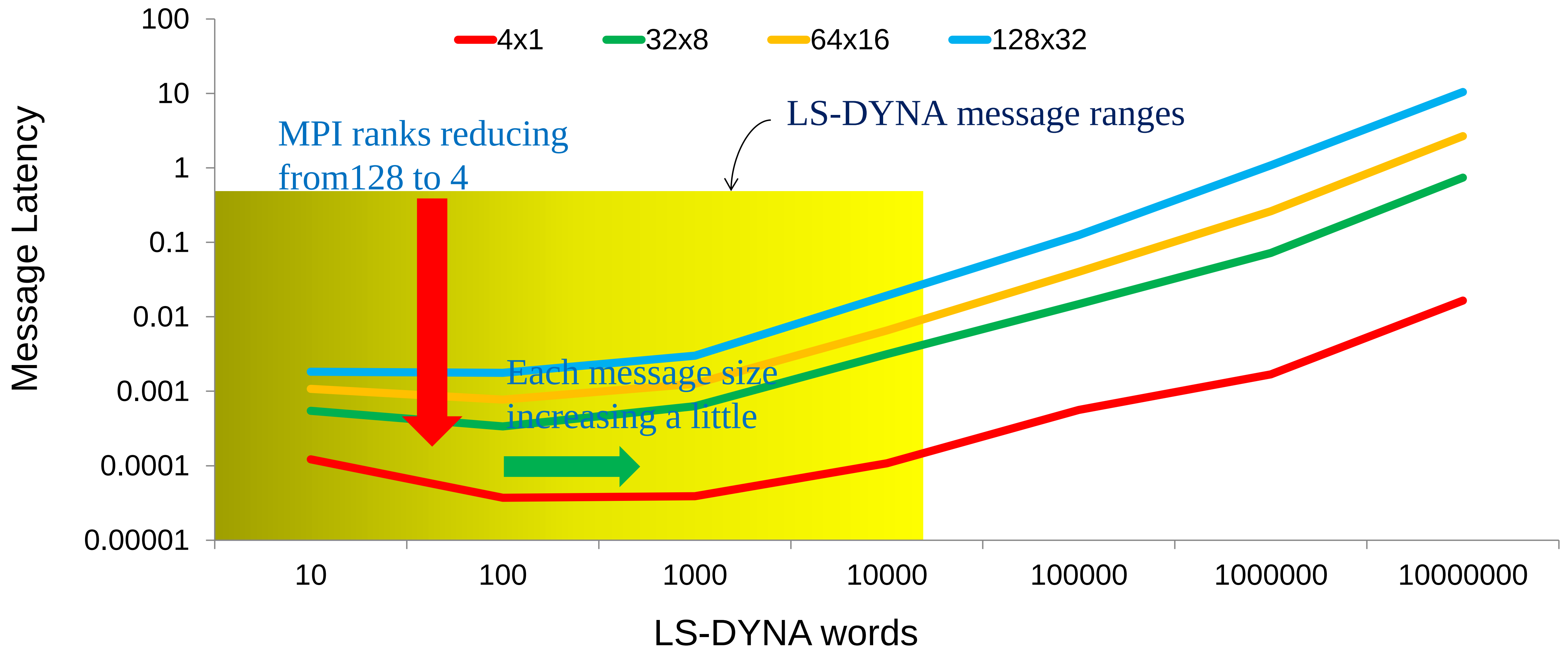
12core/2socket 4 nodes clusters



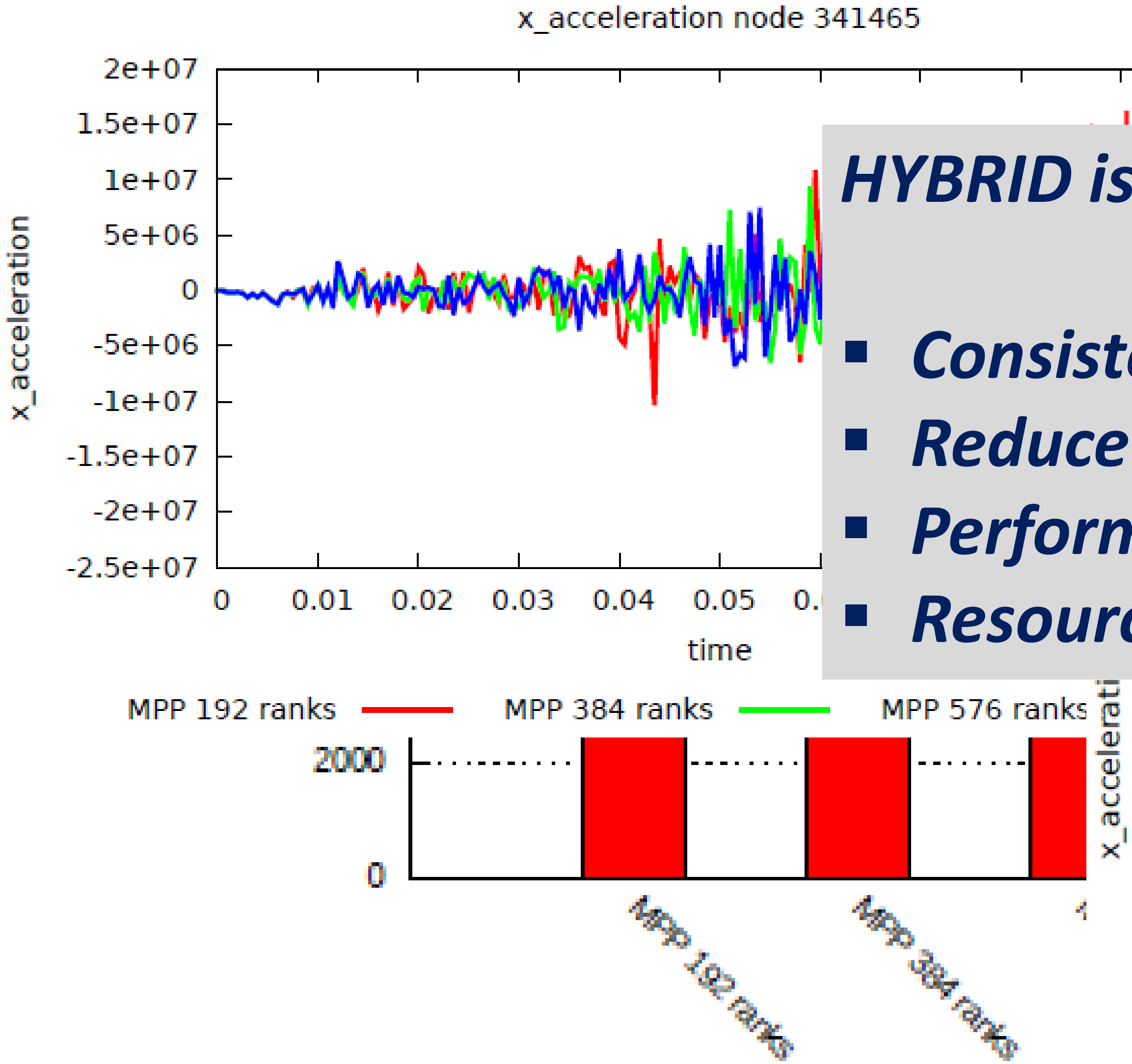
Number of messages reduce by 36x

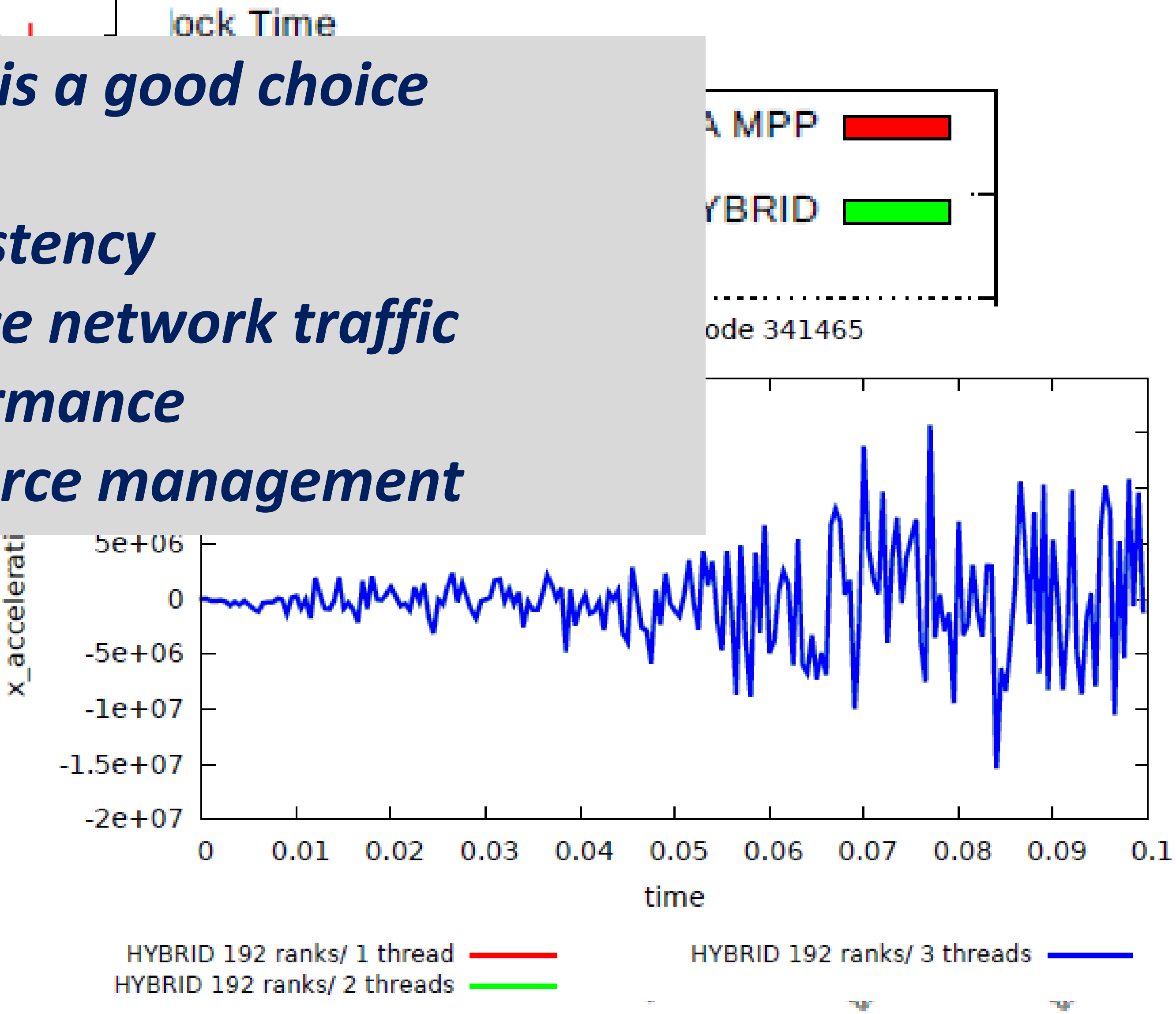
Message latency between 4 nodes

PFILE: decomposition { vspeed }



Explicit MPP/Hybrid Scaling and Consistency





HYBRID is a good choice

- ***Consistency***
- ***Reduce network traffic***
- ***Performance***
- ***Resource management***

Implicit MPP/Hybrid Performance

Performance on Linux AMD64 systems

No. of cores (node x socket x core)	WCT of Factor Matrix (seconds)	WCT for job to complete (seconds)
16 x 4 x 1	2055	14417
	985	13290
	582	29135
	960	9887

HYBRID is an obvious choice

- ***Performance***
- ***Reduce network traffic***
- ***Reduce memory requirement***
- ***Reduce I/O requirement***

Scalability - To Infinity and beyond

Hardware

- More cores
- Higher clock rate
- Wider instructions
- Higher memory bandwidth
- Faster interconnect

- Quantum computer

Software

- Efficient algorithm
- MPP/HYBRID
- Special decomposition
- Re-decomposition
- In-network computing
- Dynamic load balancing

- AI

Recent Development – Part II

Presented by Yun Huang and Tobias Erhart

Thank you!