MACHINE-GROUND INTERACTION CONSORTIUM (MAGIC)

~ SPRING 2015 MEETING ~
MAY 12-13, 2015 – MADISON, WISCONSIN

Dan Negrut
University of Wisconsin-Madison
Event General Info

- Event Sponsor: Red Cedar Technology

- More than 50 participants
  - US Army TARDEC, US Army Corps of Engineers Engineer Research and Development Center, Caterpillar, MSC.Software, Simertis Gmbh, BAE Systems, Harley-Davidson, Oshkosh Corporation, Red Cedar Technology, John Deere, Energid, Dynamic Simulation Technologies, Mevea (Finland), SimLab Soft (Jordan), Progeneric, Hendrickson, Computational Dynamics Inc., Intuitive Machines, University of Wisconsin-Madison, University of Iowa, University of Parma, University of Aarhus, University of Illinois at Chicago, Georgia Tech, Indiana University-Purdue University Indianapolis, Beijing Institute of Technology

- Next meeting: Madison, Dec. 8 through 10, 2015 (Tu-Th).
  - Less lectures and more interaction (1.5 days)
  - 1 day of Chrono tutorials and demos
MaGIC Spring Meeting, In a Nutshell

• DAY 1: Discussion Forum/Idea Marketplace
  • Terramechanics
  • Vehicle dynamics (real time/non-real time)
  • Trends in high performance computing
  • Virtual prototyping at large

• DAY 2: Highlight software used/developed as a UW-Madison/U. Parma/U. Iowa collaboration
  • Talks related to Chrono-Engine, Chrono-Parallel, Chrono::Vehicle, and Chrono::FSI
Schedule, Tuesday

07:45 – 08:15 Guest check in
08:15 – 08:30 Introductions, Logistics and Goals of the Meeting, Prof. Dan Negrut, UW-Madison
08:30 – 09:00 “Real Time Simulation for Off-Road Vehicle Analysis,” Pasi Korkealaakso, Technical Director, Mevea (Finland)
09:00 – 09:30 “Some Thoughts About Vehicle Dynamics Modeling & Correlation,” Dr. Xiaobo Yang, Oshkosh Corporation
09:30 – 09:45 Coffee Break
10:15 – 10:45 “Advances in Modern Design Exploration,” Dr. Bob Ryan, President and CEO at Red Cedar Technology
10:45 – 11:00 Coffee Break
11:00 – 11:30 “Future Mechanics-Based CAD/Analysis Systems” Prof. Ahmed Shabana, University of Illinois at Chicago
11:30 – 12:30 Lunch (catered)
12:30 – 13:00 “Game Theory-Inspired Evaluation of Ground Vehicle Autonomy,” Dr. Ryan Penning, Energid
13:00 – 13:30 “State of the Lab,” Prof. Dan Negrut, University of Wisconsin-Madison
13:30 – 14:15 Networking Break
14:45 – 15:30 “Recent Advances in NATO Reference Mobility Model,” Dr. Paramsothy Jayakumar, US Army TARDEC
15:30 – 16:15 Networking Break
16:15 – 16:45 “Advances and Open Problems in Soil Modeling,” Prof. William Likos, University of Wisconsin-Madison
17:15 – 18:00 Networking Break
18:00 – 18:30 “Modeling Ground Vehicle with Soft Soil and Fluid Interaction using Multibody Dynamics and Particle Methods,” Prof. T. Wasfy, Indiana University-Purdue University Indianapolis
18:30 – 19:00 Group Discussion. Wrap up.
19:00 – 21:00 Happy Hour and Dinner, Steenbock’s on Orchard (Wisconsin Institute for Discovery)
Schedule, Wednesday

09:00 – 09:15 “Overview of 2nd Day, logistics issues,” Prof. Dan Negrut, UW-Madison
09:15 – 09:45 “Machine Design from a Soil Point of View,” Prof. Ole Balling, Aarhus University, Denmark
09:45 – 10:15 “Integration of Chrono in a CAD Tool,” Ashraf Sultan, CEO, Simlab Soft
10:15 – 11:00 Networking break
11:00 – 11:30 “Chrono Fluid-Solid Interaction,” Dr. Arman Pazouki, UW-Madison
11:30 – 12:00 “Interfacing Chrono and PhysBam,” Mridul Aanjaneya, Post-Doc student, UW-Madison
12:00 – 13:00 Lunch (catered)
13:00 – 14:00 “Chrono-Engine Overview,” Professor Alessandro Tasora, University of Parma, Italy
14:00 – 14:30 “Chrono-Parallel Overview,” Dr. Radu Serban, UW-Madison
14:30 – 15:00 “Support for DEM Simulation in Chrono,” Dr. Jonathan Fleischmann, UW-Madison
15:00 – 15:30 Networking break
15:30 – 16:00 “Chrono::Vehicle Overview,” Dr. Radu Serban, UW-Madison
16:00 – 16:30 “Preview of Tracked Vehicle Support in Chrono::Vehicle,” Dr. Holger Haut, UW-Madison
16:30 – 17:00 Wrap up, Networking
Why Do We Run These Meetings?

• Keep you informed on what we’re up to

• Learn about the problems you struggle with – focuses our research

• Informal discussions with other colleagues – an idea marketplace

• Connect students and partners from industry

• Meetings such as this help us as a community talk with one voice
  • Helpful to make others understand that there are plenty of open problems in this field
Let’s Get Going...

• Busy schedule today
  • 12 people will share their thoughts with you over a 10 hour span

• Dinner and host bar included in the registration
  • Sponsored by Red Cedar Technology

• Please contact Gavin or me for help with any other logistics issues
Thank you indeed for being here.
SIMULATION-BASED ENGINEERING LAB (SBEL)

~ STATE OF THE LAB ~

Dan Negrut
Vilas Associate Professor
NVIDIA CUDA Fellow
SBEL Technical Lead
University of Wisconsin-Madison
The Lab
[as of May 12, 2015]
Ongoing Lab Sponsors/Research Partners

• Federal/Government
  • US Army TARDEC
  • National Science Foundation
  • Army Research Office
  • US Army ERDC

• Industry
  • NVIDIA
  • Caterpillar
  • Intuitive Machines

• Individuals
  • Eckrose Innovation Award
Vision, Strategy, Application Areas

• Vision: become a top notch Applied Computational Dynamics program

• Applications: two broad areas
  • Ground/Vehicle Interaction
  • Fluid-Solid Interaction

• Strategy: carry out research along three axes
  • Modeling techniques
  • Solution methods
  • Parallel computing
We Are Committed to Sharing/Enabling Technology Transfer

• Share everything*
  • Knowledge/Know-How
  • Data/Models
  • Software

• It’s all out there and it’s all free
  • http://sbel.wisc.edu/
Ground Vehicle Mobility Analysis
Tracked Vehicle in Chrono::Vehicle

- Talk on Wednesday afternoon [Dr. Holger Haut]
Tracks for Chrono::Vehicle – Concept Summary

- Modeling and simulation systems for tracked vehicles (tanks)
- Template based middleware software
- Different kinematic systems of the track chain
- Tracked vehicle model includes a full vehicle with a full modeled track systems (no hybrid- or analytical-track chain)
- Automated positioning of the shoes as a track chain around the sprocket, idler, wheels
- Interaction between each track shoe and soil (force based)
- Different tension systems for the road whee (torsion bar, hydro-pneumatic suspension)
- Powertrain template
Chrono::Vehicle

• Talk on Wednesday afternoon [Dr. Radu Serban]
Chrono::Vehicle/Chrono-Engine/Chrono::Granular

- Talks on Wd [Radu Serban, Alessandro Tasora, Jonathan Fleischmann]
Chrono::Vehicle & Chrono::FSI

- Talk on Wednesday morning [Dr. Arman Pazouki]
• Pretty movies draw on basic research
Smoothed Particle Hydrodynamics (SPH) method, 1/2

- Smoothing, or averaging

\[ f(x) = \int_S f(x') \delta(x - x') dV \]

\[ = \int_S f(x') W(x - x', h) dV + O(h^2) \]

\[ = \langle f(x) \rangle + O(h^2) \]

- Expression of gradient

\[ \nabla f(x) = \int_{\partial\Omega} f(x') W(x - x', h) \cdot n \, dA \]

\[ - \int_{\Omega} f(x') \nabla W(x - x', h) dV \]

Kernel function properties

1. \( \lim_{h \to 0} W(r, h) = \delta(r) \)

2. \( W(r, h) = W(-r, h) \)

3. \( \int_S W(r, h) dV = 1 \)
Smoothed Particle Hydrodynamics (SPH) method, 2/2

• How particles come into play

\[ f(x) = \int_S \frac{f(x')}{\rho(x')} W(x - x', h) \rho(x')dV \]

\[ \approx \sum_b \frac{f(x_b)}{\rho_b} W(x - x_b, h) m_b \]

• Example

\[ \rho(x_a) = \sum_b W(x_a - x_b, h) m_b \]

• Example kernel (cubic spline with spherical compact support)

\[ W(q, h) = \frac{1}{4\pi h^3} \begin{cases} 
(2 - q)^3 - 4(1 - q)^3, & 0 \leq q < 1 \\
(2 - q)^3, & 1 \leq q < 2 \\
0, & \text{otherwise}
\end{cases} \]

where \( q = \frac{\|r\|}{h} \)

• Value for \( h \): each particle has about 30-50 neighbors within the smoothing volume

• The term “marker” used herein to differentiate from particles of the granular material
Smoothed Particle **Hydrodynamics (SPH)** method

- **Continuity:**
  \[
  \frac{d\rho_a}{dt} = \rho_a \sum_b \frac{m_b}{\rho_b} (v_a - v_b) \cdot \nabla_a W_{ab}
  \]

- **Momentum (Navier-Stokes):**
  \[
  \frac{dv_a}{dt} = - \sum_b m_b \left[ \left( \frac{p_a}{\rho_a^2} + \frac{p_b}{\rho_b^2} \right) \nabla_a W_{ab} - \frac{(\mu_a + \mu_b)x_{ab} \cdot \nabla_a W_{ab}}{\rho_{ab}(x_{ab}^2 + \varepsilon h_{ab}^2)} v_{ab} \right] + f_{FSI} + f_a
  \]

- **Lagrangian Kinematics:**
  \[
  \frac{dx_a}{dt} = v_a
  \]

- **Weakly Compressible (< 1%):**
  - Tait’s equation of state
  \[
  p = \frac{c_s^2 \rho_0}{\gamma} \left\{ \left( \frac{\rho}{\rho_0} \right)^\gamma - 1 \right\}
  \]

- **XSPH:**
  \[
  \hat{v}_a = v_a + \Delta v_a, \ \Delta v_a = \zeta \sum_b \frac{m_b}{\rho_{ab}} (v_b - v_a) W_{ab}
  \]

- **Shepard Filtering:**
  \[
  \rho_a = \sum_b m_b W_{ab}
  \]

---


5/12/2015

MaGIC Spring 2015
Particle migration in 3D Poiseuille flow

- Transient Poiseuille flow
  \[ Re \approx 5 \]

- Sphere in pipe flow, \( Re \approx 1 \)

Particle migration in 2D and 3D Poiseuille flow [Re≈0.5]

- Cylinder in channel flow
- Within 1% of Pan & Glowinski experiments
- Sphere in pipe flow
- Segre & Silberberg experiments: r/R=0.6
Radial distribution of particles in suspension

- 192, 10 hour long GPU simulations
- 14 seconds real time
- Bootstrapping method, 95% confidence interval

\[ a/R = 0.07 \]
\[ L = \left( \frac{a}{R} \right) \left( \frac{\rho \mu}{\mu} \right) \left( \frac{l}{R} \right) = [0, 0.69] \]
\[ Re \approx 60, \ \phi = 0.027\% \]

Effect of Reynolds Number

Effect of rigid body rotation [Magnus Effect]

- Body off-center migration partly due to body rotation

- Empirical methods that apply Reynolds number dependent point forces on the particles cannot accurately capture the particle migration in suspension
Effect of body asymmetry, size, and distance

\[ \mathbf{r} = (0.4, 0.4, r_3) \]
Hanging flexible beam in viscose fluid

- Flexible cantilever in contained fluid
- Track position of beam tip

$L = 1.0 \text{ m}$
$\rho_s = 7200 \text{ kg/m}^3$
$E = 20 \text{ MPa}$
$d = 0.04 \text{ m}$
$\rightarrow \mu_{\text{trans.}} \approx 10 \text{ N s/m}^2$
Interacting Rigid and Flexible Objects in Channel Flow

Fluid:
\[ \rho = 1000 \text{ kg/m}^3 \]
\[ \mu = 1 \text{ N s/m}^2 \]
\[ (l_x, l_y, l_z) = (1.4, 1, 1) \text{ m} \]
\[ Re = 45 \]

Ellipsoids:
\[ \rho_s = 1000 \text{ kg/m}^3 \]
\[ (a_1, a_2, a_3) = (2.25, 2.25, 3) \text{ cm} \]
\[ N_r = 2000 \]
\[ Re_p = 2 \]

Beams:
\[ \rho_s = 1000 \text{ kg/m}^3 \]
\[ E = 0.2 \text{ MPa} \]
\[ \alpha = 1.5 \text{ cm} \]
\[ l = 64 \text{ cm} \]
\[ N_f = 40 \]
\[ n_e = 4 \]
Interacting Rigid and Flexible Objects in Channel Flow

Fluid:
\[ \rho = 1000 \ \text{kg/m}^3 \]
\[ \mu = 1 \ \text{N s/m}^2 \]
\[ (l_x, l_y, l_z) = (1.4, 1, 1) \ \text{m} \]
\[ Re = 45 \]

Ellipsoids:
\[ \rho_s = 1000 \ \text{kg/m}^3 \]
\[ (a_1, a_2, a_3) = (2.25, 2.25, 3) \ \text{cm} \]
\[ N_r = 2000 \]
\[ Re_p = 2 \]

Beams:
\[ \rho_s = 1000 \ \text{kg/m}^3 \]
\[ E = 0.2 \ \text{MPa} \]
\[ a = 1.5 \ \text{cm} \]
\[ l = 64 \ \text{cm} \]
\[ N_f = 40 \]
\[ n_e = 4 \]
SPH w/ GPUs

- GPU Computing
  - High bandwidth: 192 GB/s global memory
  - High flop rate: 1.5 Tflops

- Where can GPUs be best leveraged?
  - Single Instruction Multiple Data (SIMD)

- What does GPU computing require?
  - Rewriting parts of the code
Lab’s Research Cluster
Lab’s Research Cluster

- More than 50,000 GPU scalar processors
- More than 1,200 CPU cores
- Fast Mellanox Infiniband Interconnect (QDR), 40Gb/sec
- About 2.7TB of RAM
- More than 20 TFlops Double Precision
We’re Living in a Heterogeneous World: CPUs + GPUs
Fording Scenarios, Different Physics

- Fluid represented in three different ways:
  - Collection of rigid spheres (Lagrangian)
  - Using an SPH-like approach (Lagrangian)
  - Using Navier-Stokes on Eulerian grid
Linear Algebra Dictates Performance

• Compute as fast as possible $\mathbf{D}^\top \mathbf{M}^{-1} \mathbf{D} \gamma$
  
  Step 1: $\mathbf{a} = \mathbf{M}^{-1} \mathbf{D} \gamma$
  
  Step 2: $\mathbf{b} = \mathbf{D}^\top \mathbf{a}$ (the result)

• $\mathbf{D}$ (Jacobian) matrix:
  • Size $= 3,135,048 \times 3,459,487$
  • Non zeros $= 20,626,143$

• Vector of unknowns, $\gamma$
  • Size $= 3,459,487$
AMD A10-7850K DDR3 1600 MHz

- OpenCL Framework: AMD
- GFLOPS = 1.095
- Bandwidth = 5.854 Gb/s
AMD Radeon R7750

- OpenCL Framework: AMD
- GFLOPS = 1.347
- Bandwidth = 7.199 Gb/s
Intel Xeon CPU E5-2630 v @ 2.30GHz DDR3 1333 MHz

- OpenCL Framework: Intel
- GFLOPS = 4.151
- Bandwidth = 22.177 Gb/s
- 2 sockets each with 6 physical and 12 virtual for a total of 24 cores
Intel Xeon CPU E5-2690 v2 @ 3.00GHz DDR3 1600 MHz

- OpenCL Framework: Intel
- GFLOPS = 2.214
- Bandwidth = 11.831 Gb/s
- 2 sockets, each CPU 10 physical cores for total of 40 threads
Intel Core i7-5960X DDR4 2400 MHz

- OpenCL Framework: Intel
- GFLOPS = 4.100
- Bandwidth = 21.902 Gb/s
- One socket, 8 cores, 16 threads
Intel Many Integrated Core Acceleration Card (Xeon Phi 5110P)

- OpenCL Framework: Intel
- GFLOPS = 2.770
- Bandwidth = 14.801 Gb/s
- One accelerator, 60 Pentium-type cores
4 x AMD Opteron Processor 6274 DDR3 1333 MHz

- OpenCL Framework: AMD
- GFLOPS = 3.265
- Bandwidth = 17.445 Gb/s
- 4 sockets, 16 cores per CPU, total of 64 cores
GeForce GTX 680

- OpenCL Framework: NVIDIA
- GFLOPS = 4.312
- Bandwidth = 23.034 Gb/s
GeForce GTX 770

- OpenCL Framework: NVIDIA
- GFLOPS = 7.605
- Bandwidth = 40.627 Gb/s
Tesla K20c

- OpenCL Framework: NVIDIA
- GFLOPS = 10.683
- Bandwidth = 57.068 Gb/s
Tesla K20x

- OpenCL Framework: NVIDIA
- GFLOPS = 11.894
- Bandwidth = 63.537 Gb/s
2x Tesla K20x

- OpenCL Framework: NVIDIA
- GFLOPS = 18.962
- Bandwidth = 101.290 Gb/s
3x Tesla K20x

- OpenCL Framework: NVIDIA
- GFLOPS = 24.798
- Bandwidth = 132.468 Gb/s
Results FLOP rate

- 3x Tesla K20x
- 2x Tesla K20x
- Tesla K20x
- Tesla K20c
- GeForce GTX 770
- GeForce GTX 680
- Intel Xeon E5-2630
- Intel Core i7-5960X
- AMD Opteron 6274
- Intel MIC
- Intel Xeon E5-2690 v2
- AMD Radeon R7
- AMD A10-7850K

GFLOPs
Results Memory Bandwidth

- 3x Tesla K20x: 140 Gb/s
- 2x Tesla K20x: 100 Gb/s
- Tesla K20x: 60 Gb/s
- Tesla K20c: 60 Gb/s
- GeForce GTX 770: 40 Gb/s
- GeForce GTX 680: 40 Gb/s
- Intel Xeon E5-2630: 20 Gb/s
- Intel Core i7-5960X: 20 Gb/s
- AMD Opteron 6274: 20 Gb/s
- Intel MIC: 20 Gb/s
- Intel Xeon E5-2690 v2: 10 Gb/s
- AMD Radeon R7: 10 Gb/s
- AMD A10-7850K: 10 Gb/s

Gb/s
SpMV Accelerators

- K20X
- K20C
- GTX770
- GTX680
- 2xK20X
- 3xK20X
- MIC
- Radeon R7

GFLOPs

- T=3.0s
- T=4.0s
- T=5.0s
- T=6.0s
- T=7.0s
- T=8.0s
- T=9.0s
Tracked Bulldozer

Vehicle:
- Total Mass: 7,300 kg
- 114 Parts
- 111 Kinematic Constraints

Granular Material:
- 200,000 ellipsoids
- Cohesion = 500N
- Density 2000kg/m^3
- ~0.7 million contacts
Better Numerical Methods

- Step away from first order methods, look at second order methods (Hessian based)
- Example: Interior Point methods
- Useful when solving convex optimization problems [like ours]

\[
\gamma^* = \arg \min_{\gamma_i \in \mathcal{F}_i, \ 1 \leq i \leq N_c} \left( \frac{1}{2} \gamma^T N \gamma + r^T \gamma \right)
\]

\[
\min f_0(x) \\
\text{subject to } f_i(x) \leq 0, \ i = 1, \ldots, m
\]
Karush-Kuhn-Tucker (KKT) Optimality Conditions

- KKT: Necessary conditions satisfied at optimal point

\[
\begin{align*}
    f_i (x^*) & \leq 0, \quad i = 1, \ldots, m \quad (1) \\
    \lambda_i^* & \geq 0, \quad i = 1, \ldots, m \quad (2) \\
    \nabla f_0 (x^*) + \sum_{i=1}^{m} \lambda_i^* \nabla f_i (x^*) & = 0 \quad (3) \\
    \lambda_i^* f_i (x^*) & = 0, \quad i = 1, \ldots, m \quad (4)
\end{align*}
\]
A Different Angle of Attack: An Interior Point Method

- Introduce barrier function, defined for $z < 0$ and a parameter $b > 0$:

  $$B(z) = -\frac{1}{b} \log (-z)$$

- Write QP problem with conic constraints as unconstrained problem:

  $$\min f_0(x) + \sum_{i=1}^{m} B(f_i(x))$$

- How do the KKT conditions look for this optimization problem?
KKT – Now and Then

- KKT, unconstrained problem, using barrier function

\[
\begin{align*}
  f_i(x) &< 0, \quad i = 1, \ldots, m \\
  \lambda_i &> 0, \quad i = 1, \ldots, m \\
  \nabla f_0(x) + \sum_{i=1}^{m} \lambda_i \nabla f_i(x) &= 0 \\
  \lambda_i f_i(x) &= -\frac{1}{b}, \quad i = 1, \ldots, m
\end{align*}
\]

- KKT, original constrained quadratic problem

\[
\begin{align*}
  f_i(x^*) &\leq 0, \quad i = 1, \ldots, m \\
  \lambda_i^* &\geq 0, \quad i = 1, \ldots, m \\
  \nabla f_0(x^*) + \sum_{i=1}^{m} \lambda_i^* \nabla f_i(x^*) &= 0 \\
  \lambda_i^* f_i(x^*) &= 0, \quad i = 1, \ldots, m
\end{align*}
\]
The Nonlinear Problem and its Jacobian

\[ r_t(x, \lambda) = \begin{bmatrix} \nabla f_0(x) + \nabla f(x)^T \lambda \\ -\text{diag}(\lambda) f(x) - \frac{1}{b} 1 \end{bmatrix} = 0. \]

\[
\begin{bmatrix}
\nabla^2 f_0(x) + \sum_{i=1}^{m} \lambda_i \nabla^2 f_i(x) & \nabla f(x)^T \\
-d\text{diag}(\lambda) \nabla f(x) & -d\text{diag}(f(x))
\end{bmatrix}
\begin{bmatrix}
\Delta x \\
\Delta \lambda
\end{bmatrix} = -r_t(x, \lambda)
\]

All the Way to the Very Basics

$$Ax = b$$
SaP - Handling Large Linear Systems

- 10,000 to 500,000 equations
- Sparse linear systems
- Leverages GPU computing
SaP: Algorithmic Details

[1/5]

- Partition $A$ into $p$ blocks $A_1$ to $A_p$ with coupling blocks $B$'s and $C$'s
- Then factorize $A$ into block diagonal matrix $D$ and spike matrix $S$
SaP: Algorithmic Details [2/5]

- The problem of solving $Ax=b$ is transferred into two steps
  - $Dg=b$
  - $Sx=g$

- Solving $Dg=b$
  - Reduced to solving $p$ independent systems
  - Map these systems to $p$ blocks on GPU
  - Apply classical LU methods to each sub-system
  - It’s fast! 😊
SaP: Algorithmic Details

[3/5]

- Solving $Sx=g$
  - Combine all squared sub-matrices
  - Recursively solve the reduced system to refine the spike part of solution corresponding to the orange parts
  - Use the accurate solution of spike part to refine other parts

- Accurate 👍
- Slow to process 😞

$k \ll N$ implies the dimension of reduced system is significantly smaller than the original system
SaP: Algorithmic Details – The Truncated Version

For diagonal dominant systems only

Solving $Sx=g$ in one step
- All $W$’s and $V$’s are approximated
- $(p-1)$ small independent systems are achieved

Much faster than recursive SaP

Doesn’t work well for non-diagonal dominant systems, generality is a problem

Diagonal dominance $d_m = \sup \{d: |a_{ii}| \geq d \sum_{j \neq i} |a_{ij}| \}$

Diagonal dominant: $d_m \geq 1$
SaP: Algorithmic Details – The Truncated Version

[5/5]

• Truncated SaP works as a preconditioner in several Krylov methods
  • BiCGStab
  • BiCGStab(l)
  • CG
    • For symmetric positive definite (SPD) systems only

• SaP::Hybrid in general
  • BiCGStab(2) for non-SPD systems
  • CG for SPD systems
When All is Said and Done

- Best three sparse solvers in the world: Pardiso, SuperLU, MUMPS
- Compared SaP against these three solvers for 114 benchmark tests

Robustness results (64 GB vs. 6 GB)

- SuperLU failed 22 times
- SaP failed 28 times
- MUMPS failed 35 times
- Pardiso failed 40 times

Speed results (2 CPUs vs. 1 GPU)

- SuperLU vs. SaP score card: 33-38
- MUMPS vs. SaP score card: 33-27
- Pardiso vs. SaP score card: 37-20
Faster Than Intel’s Math Kernel Library (MKL): 2 to 8 times
Vision, Strategy, Application Areas

- **Vision**: become a top notch Applied Computational Dynamics program

- **Applications**: two broad areas
  - Ground/Vehicle Interaction
  - Fluid-Solid Interaction

- **Strategy**: carry out research along three axes
  - Modeling techniques
  - Solution methods
  - Parallel computing
Can We Work Together?

• Q: Can BAE Systems an Oshkosh Corporation, or MSC.Software and FunctionBay, or P&H Mining and Caterpillar and Deere be part of this consortium?

• A: Most definitely
  • The five scientists and eight grad students in the lab are not going to change the trajectory of BAE Systems or Oshkosh (we tried a couple of times ;-)

5/12/2015

MaGIC Spring 2015
Looking Ahead

- We’ll invent the technology that’ll let us do what we’ve always wanted to do but couldn’t
  - Oshkosh or BAE will not fail or succeed because of SBEL’s research
  - Our joint effort will enable us to do our job better. No more, no less.

- We’ll be the ones inventing the technology
  - If not, we’ll scare the competition into doing it ;-) 

- Bottom line: MaGIC is a precompetitive collaboration opportunity.
Thank you for being here.