Acceleration of Electromagnetic Scattering from Discrete Bodies of Revolution (DBOR)

GPU Technology Conference 2015

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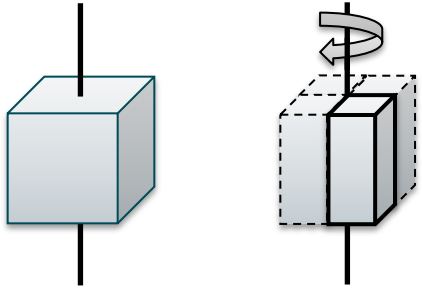
Acceleration of Electromagnetic Scattering from Discrete Bodies of Revolution (DBOR)

- **Acceleration**
  - Using the Graphics Processing Unit (GPU) to reduce run-time

- **Electromagnetic Scattering**
  - Solving a linear system of equations that comes from discretizing the Electric Field Integral Equation (EFIE)

- **Discrete Bodies of Revolution**
  - An object that has *K-fold* symmetry (discrete rotational symmetry)



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Acknowledgements

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- Glen MacLachlan (GW)
- Tim Wickberg (GW)

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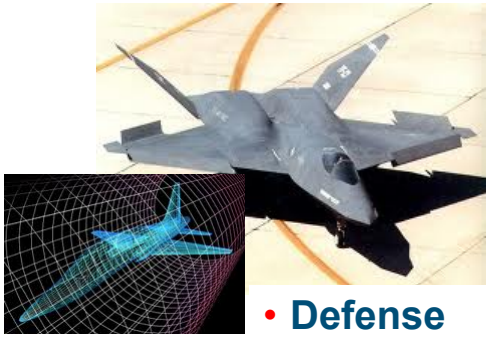
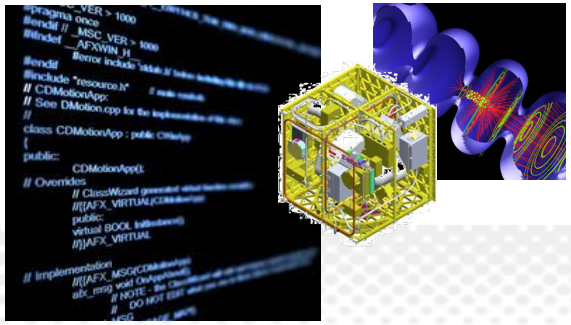
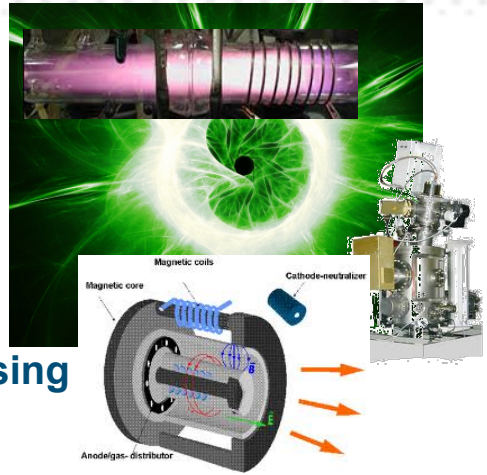
- Electromagnetics



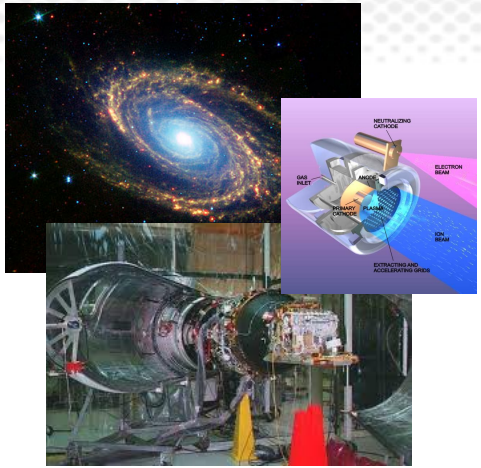
- Defense

- Software development / testing



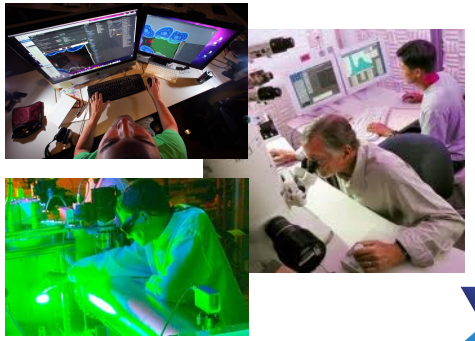


- Plasma processing



- Space physics

- Research / education



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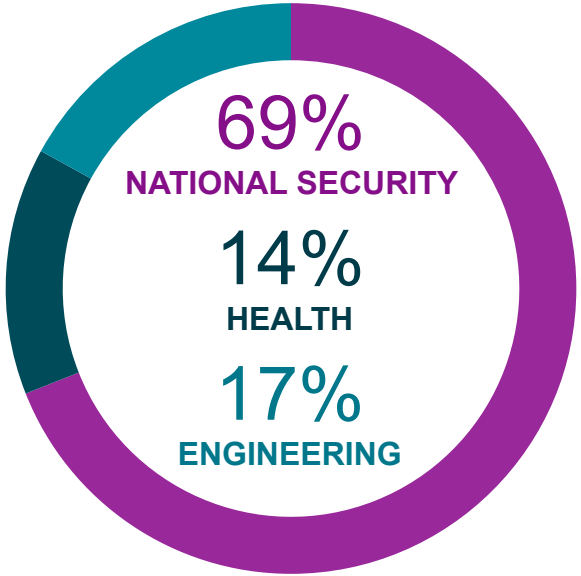


FY2014 REVENUES: ~$6B

National Security Sector

- ~$4B revenue
- 13,500 employees
- 99% government, <1% commercial
- Critical mission support for intelligence community
- C4ISR R&D and solutions for DoD
- Industry-leading cybersecurity capabilities

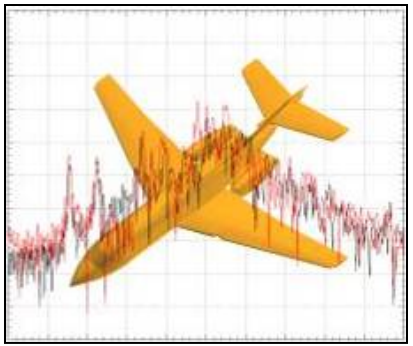
Health & Engineering Sector

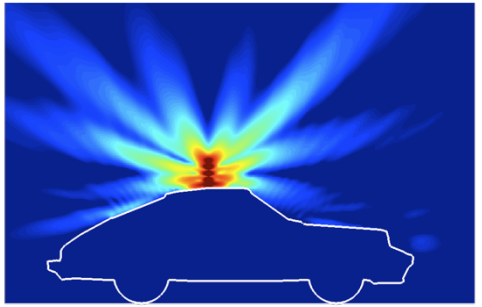
- ~$2B revenue
- 9,500 employees
- 63% commercial, 37% government
- Healthcare information technology, electronic health records, and advanced data analytics
- Health and life science / clinical research
- Energy grid and critical infrastructure design and integration

Computational Electromagnetics (CEM)

http://leidos.com/products/software/emtools

- ACAL
- AntFarm
- BTS
- CASTACK
- CATS
- CrossFlux
- DUCTSCAT
- EMTM
- INSSITE
- McCavity
- McFSS
- McPTD
- MMADTO
- SAF
- SIGLBC
- URBANA
- Xpatch





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Motivation

- Evaluate how to invest in new machines
- Continually improve tools (to enable larger, more complex problems)
  - GTC 2010 ... “Acceleration of Asymptotic Computational Electromagnetics Physical Optics – Shooting and Bouncing Ray (PO-SBR) using CUDA”
  - GTC 2012 ... “Application of the GPU to a Two-Part Computational Electromagnetic Algorithm”
- Access to resources
  - 1x TK40 card (and interns!)
  - 4x TK40 machine
  - 64x TK20 cluster

Motivation

“next monthly report”

CPU
double-precision
(complex)
out-of-core
LU decomposition
250,000 unknowns
weeks

GPU **weekend** **DBOR** **overnight**

(10x goal) (4x goal)

“tomorrow”

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Electromagnetic Scattering

- Unknowns associated with induced surface currents
  - Rao, Wilton, and Glisson (RWG) basis functions
- Electric Field Integral Equation (EFIE) → linear system of equations
  - LU decomposition

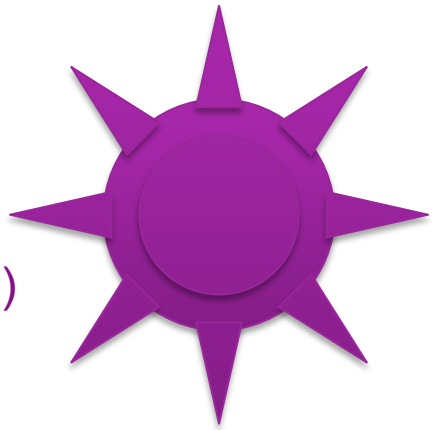
$$[Z][I] = [V]$$

$[Z] = N \times N$ reactions between all unknowns

$[I] = N \times 1$ unknowns

$[V] = N \times 1$ excitations

3D scatterer
(N degrees of freedom)



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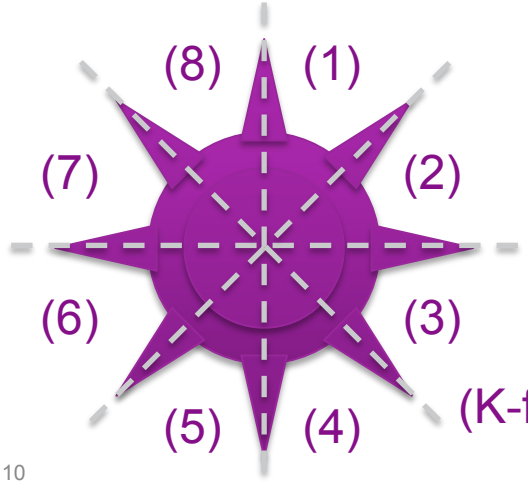
Discrete Body of Revolution (DBOR)

- Rotationally symmetric objects
  - missile with fins, turbine engine with blades, parabolic reflector antenna with support struts, spiral antenna, ...

- EFIE → block-circulant matrices



(K-fold symmetry)

$$\begin{bmatrix} Z^{(1)} & Z^{(2)} & \cdots & Z^{(K)} \\ Z^{(K)} & Z^{(1)} & \cdots & Z^{(K-1)} \\ \vdots & \vdots & \ddots & \vdots \\ Z^{(2)} & Z^{(3)} & \cdots & Z^{(1)} \end{bmatrix} \begin{bmatrix} I^{(1)} \\ I^{(2)} \\ \vdots \\ I^{(K)} \end{bmatrix} = \begin{bmatrix} V^{(1)} \\ V^{(2)} \\ \vdots \\ V^{(K)} \end{bmatrix}$$

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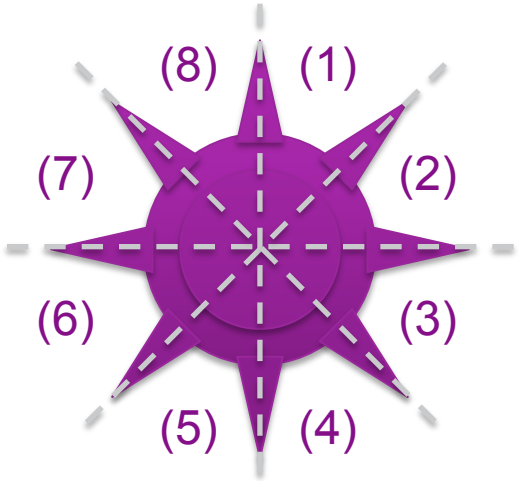
Discrete Body of Revolution (DBOR)

- Discrete Fourier Transform (DFT) reduces single large system of block-circulant matrices into smaller set of independent systems



(Fourier mode *m*)

$$[Z]_m [I]_m = [V]_m$$

$$[Z]_m = \sum_{k=1}^{K} Z^{(k)} e^{+jm(k-1)\frac{2\pi}{K}} \quad \leftarrow \quad \frac{N}{K} \times \frac{N}{K}$$

$$[V]_m = \sum_{k=1}^{K} V^{(k)} e^{-jm(k-1)\frac{2\pi}{K}}$$

$$I^{(k)} = \frac{1}{K} \sum_{m=1}^{K} [I]_m \, e^{+jm(k-1)\frac{2\pi}{K}}$$

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Discrete Body of Revolution (DBOR)

- Implemented on GPU with PGI® compiler
- Fill
  - Standard parallelization (matrix elements → thread processors)
  - Code loop over unknowns vs. surface element
  - DFT operation meant more computation required per matrix element than standard non-DBOR problems
- Factor/Solve
  - Matrix Algebra on GPU and Multicore Architectures (MAGMA)

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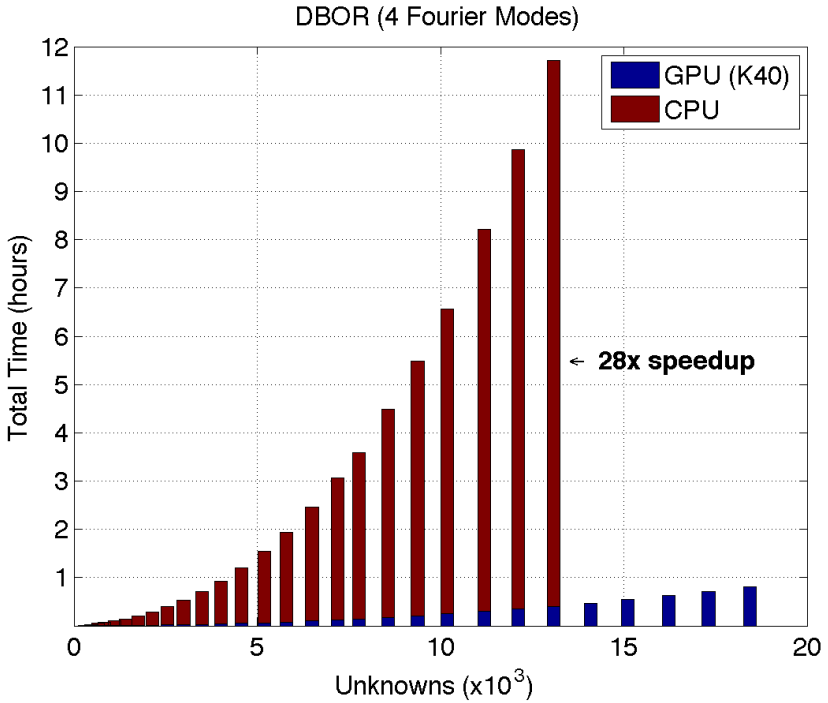
Discrete Body of Revolution (DBOR)



- In-core implementation
- Metal scatterer (research code)
- Older machine (Dell T3400)
- Fourier modes processed sequentially

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Momentous

- Suite of GPU accelerated libraries for large scale method of moment computations
  - Based on patched version of PLAPACK with cuBLAS and custom CUDA®
- LU factorization and forward/backward substitution
  - Distributed, multi-GPU
  - Out-of-core capability
  - Checkpointing
- Cross platform support (Linux®, Microsoft Windows®, Apple OS X)

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Resources

- **parsec** computer (Leidos)
  - 1.67 TB drive
  - 4x TK40m gpu
  - 256 GB ram, 16 cores
- **colonial one** cluster (GW)
  - 32 nodes
  - 250 TB lustre scratch space
  - 2x TK20 gpu / node
  - 128 GB ram, 12 cores / node

http://colonialone.gwu.edu

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Results

Factor (90,000 dof)
Double-Precision Complex

Processes	Nodes	GPUs	Time (min)	GFLOPs
16	1	4x **TK40**	10	3272
24	2	4x TK20	77	418
48	4	8x TK20	55	587
96	8	16x TK20	29	1121
192	16	32x TK20	27	1212
360	30	60x TK20	19	1669

MAGMA on parsec **(in-core)**

(out-of-core)

Momentous on colonial one

- Number of processes equals number of partitions for out-of-core solver

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Conclusion

- GPU continues to offer significant potential for CEM applications
  - DBOR shifts computation to fill, which parallelizes very nicely
  - Matrix factor and solve can be handled by libraries like MAGMA or Momentous
- Unclear whether production runs are better off on a GPU cluster
  - MAGMA (single node in-core) appears to outperform Momentous
  - MAGMA limited by RAM (up to 125k dof on parsec - *real world problems need more*)
  - Momentous setup time was greater than factor time
- Next steps
  - Continue to run more benchmarks
  - Extend DBOR matrix-fill to support multiple GPUs
  - Compare performance to existing production codes (wall-time)

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