Engineering Design using Commodity Technology

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Project Team
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Introduction

- Commercial, off-the-shelf (COTS) hardware is ubiquitous
- Can COTS software be used in engineering?
  - Proprietary and Linux is ubiquitous
  - Legacy interoperability key
- Illustrate challenges of using COTS software technology through work with engineering aerospace sector
- COTS hardware (GPUs) for photonic device modelling
TAGtivity
Organizing thoughts and reference materials

A component of the Research Desktop from Microsoft Research

- Expands traditional desktop, assisting with resource management.
- Apply tags and metadata to resources
- View and switch between activities using the TAGtivity toolbar.
- Adapting to embrace the engineering design concept

TAGtivity Toolbar

TAGtivity Manager
Rolls-Royce
Orchestration of gas turbine design calculations

- Design search and optimisation coupling large scale heterogeneous computing
- Using Windows Workflow Foundation to orchestrate these calculations.
- Using the Spitfire Windows cluster and interoperate with Linux running processes

(Left) Contours of static pressure on parametric geometry for NASA compressor rotor 37 (Rolls-Royce)
(Right) Design search optimisation
Rolls-Royce
Orchestration of gas turbine design calculations

• Microsoft Workflow Runtime provides:
  – tracking
  – checkpointing
  – persistence
  – comprehensive audit trail.
BAE Systems
Software + Services for connecting engineers and experts to users and data

- Capture and produce the audit trail of an engineer undertaking a new task
  - Documents and simulation data
  - Knowledge and decisions
- Retained for reuse by others
- Integration with live communicator
BAE Systems
Software + Services for connecting engineers and experts to users and data

- We show how commodity technologies already available on the desktop (e.g. Office Communicator) can be brought together, underpinned by tools such as Sharepoint, to assist in the collaborative process.

- The value of a given engineering tool lies in ‘applying the tool’ rather than the tool itself.
Airbus
Robust, reliable and scalable data intensive collaboration

- The engineering design process produces large volumes of data
  - worldwide networks / transnational collaboration
  - secure
  - fault tolerant
  - scalable

- The engineering data infrastructure supports
  - data searching & retrieval
  - integrate with existing business applications
  - heterogeneous infrastructure

The Spitfire Windows cluster is now the main computing resource for the Airbus Noise Technology Centre at the University of Southampton, led by Prof Xin Zhang.
Airbus Noise Technology Centre (ANTC)

- First Airbus-University Technology Centre in the World
- Opened November 2008
- Focussing on future aircraft technologies for noise reduction
- Fifteen academic staff and research students
ANTC Simulation Work

• SotonCAA high-fidelity simulation code
  – Originally developed on Windows 2000+MPI a decade ago

• All production runs moved from Linux to Spitfire Windows HPC cluster

• Continuous Windows HPC upgrades to keep pace with Airbus research programme
Wiki
Semantic structure, search and reasoning

• Wikis are used as a focal point for experts to contribute, discuss, and record their knowledge.

• The emergent organisational structure of the semantic wiki forms a basic ontology

• The ontology is also used as a connector to other sources of knowledge or data which facilities semantically enriched searches.
<table>
<thead>
<tr>
<th>Service</th>
<th>Trident</th>
<th>CFMS – Engineering focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data storage and data access service</td>
<td>Data storage includes SQL Server and SQL Server Data Services (Cloud DB). The data access service is storage neutral.</td>
<td>Data storage is integrated and limited to local storage and file shares. Data storage layer translates between Windows/UNIX naming conventions. The workflow metadata/tracking is stored in SQL. Data intensive activities can be restricted to single active instances; i.e. to support large data copies to 100’s of compute nodes.</td>
</tr>
<tr>
<td>Registry and metadata service</td>
<td>Management of Trident resources, including Web or REST services, data products, and workflows. This will also provide versioning, annotation and curation support for workflows and services.</td>
<td>Workflow repository with basic user ACL. Workflow discovery supported using SQL iFilters providing keyword searching.</td>
</tr>
<tr>
<td>Ontology registry</td>
<td></td>
<td>Activity and workflow creation are separated from engineering and business logic. Only ‘approved’ workflows may be executed. Client applications only permit WF configuration and not creation.</td>
</tr>
<tr>
<td>Semantic provenance service for verification, validation and management of data and process</td>
<td>Providing provenance creation from workflow trace to expressive domain-specific provenance ontologies. Applicable to scientific results, processes, and evolution of workflows.</td>
<td></td>
</tr>
<tr>
<td>Fault-tolerance and recovery service</td>
<td>Providing fault-tolerance and recovery service for workflow processing.</td>
<td>Workflow checkpointing, restarting and complete tracking service to assist with fault rectification.</td>
</tr>
<tr>
<td>Monitoring service</td>
<td>Providing a framework and interfaces for monitoring workflow runtime activities.</td>
<td>Custom monitoring client software to monitor runtime based on user credentials.</td>
</tr>
<tr>
<td>HPC scheduling service</td>
<td>Supporting workflow job scheduling on HPC clusters.</td>
<td>Add, remove update status and full HPC integration is provided. Execution of code on *NIX infrastructure is possible, including support for load balancing across multiple machines.</td>
</tr>
<tr>
<td>Administration service</td>
<td>Providing administrative tools for deploying, managing, and monitoring Trident runtime services.</td>
<td>Users can deploying Workflows using a custom client.</td>
</tr>
<tr>
<td>Visualization service</td>
<td>Providing extensible framework and data visualization service for data presentation.</td>
<td>Intermediate results visualization is supported for basic CSV data types (real-time updates). Alternatively MIME types are used to launch visualization applications.</td>
</tr>
</tbody>
</table>
Observations

- WF hosting environment is limited
- ‘Cloud’ computing is here. Hybrid cloud and enterprise architectures need to use WF to orchestrate complex cloud interactions.
- WF debugging can be difficult - especially in a distributed heterogeneous environment
- Sharepoint scales to a vast number of users. It can get complex and requires experienced administration staff, though it can be leveraged for other activities corporately.
- How should users version/update and exchange workflows. The Rolls-Royce work shows this for a single project, but what about globally?
Photonic Crystals

- Photonic crystals are periodic dielectric structures that affect propagation of electromagnetic waves
- Disallowed bands of wavelengths are called photonic band gaps
- Current manmade devices are regular shapes
- Future devices:
  - irregular shapes (from nature)
  - specific and special optical effects

Transmission electron micrograph image showing a wing cross-section.

Model of a two dimensional photonic crystal with air rods in a material substrate.

Morpho Butterfly (M. Rhetenor).

Reproduced with permission of M. Molinari (2008).

P. Vukusic
Algorithms for Photonic Crystal Modelling

- **Plane Wave Methods**
  - Scale poorly + Gibbs Phenomenon

- **Finite Difference Method**
  - Simple to code
  - Requires fine mesh for accuracy
    » Large and Sparse Matrices

- **Finite Element Method**
  - Large amounts of code
  - Requires fine (complicated) mesh for accuracy
    » Large and Sparse Matrices

- **Meshless Method**
  - Simple to code & data parallel
  - Improved geometry handling
    » Small and Dense Matrices
Meshless Method Formulation

• Maxwell’s equations for 2D problem

\[
\begin{align*}
TE & : -\nabla \cdot \frac{1}{\varepsilon} \nabla \psi = \lambda \psi \quad \Rightarrow \quad -\left(\nabla + i \frac{k}{\varepsilon}\right) \frac{1}{\varepsilon} \left(\nabla + i \frac{k}{\varepsilon}\right) u = \lambda u \\
TM & : -\frac{1}{\varepsilon} \Delta \psi = \lambda \psi \quad \Rightarrow \quad -\frac{1}{\varepsilon} \left(\nabla + i \frac{k}{\varepsilon}\right) \left(\nabla + i \frac{k}{\varepsilon}\right) u = \lambda u
\end{align*}
\]

• Simplifying, the 2D elliptic Helmholtz equation takes the form:

\[
\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \lambda^2 u = 0
\]

• Introducing the following notation:

\[
\alpha = (\alpha_1, \alpha_2, \ldots, \alpha_N)^T, \quad g_j(x) = \phi(||x - x_j||), \quad l_j(x) = \phi''(||x - x_j||),
\]

\[
G = \begin{bmatrix} g_1(x_1) & \cdots & g_N(x_1) \\ \vdots & \ddots & \vdots \\ g_1(x_N) & \cdots & g_N(x_N) \end{bmatrix} \quad \& \quad L = \begin{bmatrix} l_1(x_1) & \cdots & l_N(x_1) \\ \vdots & \ddots & \vdots \\ l_1(x_N) & \cdots & l_N(x_N) \end{bmatrix}
\]

• Then use the Standard RBF approximation of a function to write the Helmholtz equation as a generalized eigenvalue problem:

\[
L\alpha = -\lambda G\alpha
\]
Meshless Method Breakdown

Steps:

1. Create Uniform point layout
   • Populate unit cell with nodes
2. Fill $L$ and $G$ Matrices
   • Calculate Radial Basis Functions for each node
3. Solve Generalized Eigenvalue Problem
   • Find specified number of the smallest eigenvalues

NEED Hybrid algorithm (mix of CPU and GPU)

Initial results show speedup of 10-20+ on key parts

Programming GPUs not straightforward...
## Hybrid Algorithm Breakdown

<table>
<thead>
<tr>
<th>SI Step</th>
<th>Input Matrix Sizes</th>
<th>Output Matrix Sizes</th>
<th>CPU or GPU</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>LU Decomposition</td>
<td>G = 1600x1600</td>
<td>l = 1600x1600, u = 1600x1600</td>
<td>GPU</td>
<td>G is already on GPU from fill step</td>
</tr>
<tr>
<td>Matrix Multiplication</td>
<td>L = 1600x1600, v0 = 1600x16</td>
<td>w = 1600x16</td>
<td>GPU</td>
<td>Simple on GPU</td>
</tr>
<tr>
<td>Back Substitution</td>
<td>l = 1600x1600, w = 1600x16</td>
<td>y = 1600x16</td>
<td>GPU</td>
<td>Maybe quicker on CPU but want to avoid copy to and from host</td>
</tr>
<tr>
<td>Forward Substitution</td>
<td>u = 1600x1600, y = 1600x16</td>
<td>v = 1600x16</td>
<td>GPU</td>
<td>Maybe quicker on CPU but want to avoid copy to and from host</td>
</tr>
<tr>
<td>3 Matrix Multiplications</td>
<td>v' = 16x1600, w = 1600x16</td>
<td>e = 16x16</td>
<td>GPU</td>
<td>Simple on GPU</td>
</tr>
<tr>
<td></td>
<td>L = 1600x1600, v = 1600x16</td>
<td>w = 1600x16</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>v' = 16x1600, w = 1600x16</td>
<td>a = 16x16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c = a\e</td>
<td>a = 16x16 (copy to host)</td>
<td>c = 16x16</td>
<td>CPU</td>
<td>Small data set</td>
</tr>
<tr>
<td></td>
<td>e = 16x16 (copy to host)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Find Eigenvalues and Eigenvectors of</td>
<td>c = 16 x 16</td>
<td>d = 16x1</td>
<td>CPU</td>
<td>Small data set</td>
</tr>
<tr>
<td>Matrix</td>
<td></td>
<td>v = 16x16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Matrix Multiply and w = w./norm(w)</td>
<td>w = 1600x16</td>
<td>w = 1600x16</td>
<td>GPU</td>
<td>Need to update w on GPU for next loop</td>
</tr>
</tbody>
</table>
Summary

• Commodity software can be used in the most challenging problems faced by the engineering sector

• Challenges remain but can be solved especially when motivated by specific industry problems

• Thanks to Rolls-Royce, Airbus, BAE Systems for collaborating through UK TSB (DTI) programme

• Thanks to Microsoft for funding and participating fully in activities – Microsoft Research (Cambridge) & Microsoft UK (Reading)