NAVGEM on the Cloud: Computational Evaluation of Commercial Cloud HPC with a Global Atmospheric Model

Daniel Arevalo, DeVine Consulting; Tim Whitcomb, NRL
Outline

- Background
  - Computing Resources
  - Cloud Migration

- Test Workload
  - Navy Global Environmental Model
  - Benchmark Specification

- Low resolution forecast performance

- Elastic Fabric Adapter on AWS EC2

- High resolution forecast performance

- Next Steps
**Background: Computing Resources**

**Navy Supercomputing**

- Navy's arm of DoD HPC Modernization Program
- One of five DoD HPC Centers
- Headquartered with Naval Meteorology and Oceanography Command
- Supports various defense computational areas:
  - Climate/Weather/Ocean Modeling and Simulation
  - Computational Structural Mechanics
  - Computational Electromagnetics and Acoustics
  - Space and Astrophysical Science

**Navy DSRC**
Stennis Space Center, Mississippi

- **HPE SGI 8600**
  - 3.05 PFLOPS
  - Gaffney

- **Cray XC40**
  - 2 PFLOPS
  - Conrad

- **Koehr**

- **Gordon**
Background: Cloud Migration

DoD Priority: Modernization, Cost-Savings, Redundancy

Directive History
- 2012 National Defense Authorization Act
- 2012-2014 Navy Approach to Cloud Computing
- 2015 Acquisition and Use of Cloud Services
- 2017 Navy Cloud First Policy

Navy’s Emphasis
- Transition public facing websites
- Reduce data centers
- Increasing secure capabilities

Success with Enterprise Applications
- Public-facing Navy websites
  - Fleet and Family has shifted 100 web-based systems to AWS GovCloud.
  - My Navy Portal team awarded for implementing the first Level 4 data enterprise architecture to the cloud.

Performance Plan for Reduction of Resources Required for Data Servers and Centers:
“Migration… to cloud computing services… that provide a better capability at a lower cost with the same or greater degree of security.”
- NDAA FY 2012

“… reduce investment in traditional, on-premises… data centers … [including] Special Purpose Processing Nodes…”
- Navy Cloud First Policy

“… agencies must cultivate an organizational mindset of constant improving and learning.”
NAVGEM

- Global (synoptic) scale weather prediction program written in Fortran/MPI.

- Dynamical core composed of Semi-Lagrangian/Semi-Implicit numerical methods to solve primitive equations on a sphere.

- Output products feed into numerous external programs and organizations.

Test Workload: Navy Global Environmental Model
### Benchmark Specifications

<table>
<thead>
<tr>
<th>Software Configuration</th>
<th>Platform Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Intel Fortran 2018 update 1</td>
<td>- Hyperthreading disabled</td>
</tr>
<tr>
<td>- MPI:</td>
<td>- <strong>AWS</strong></td>
</tr>
<tr>
<td>- Intel 2018 update 1</td>
<td>- us-west-2 (OR) region</td>
</tr>
<tr>
<td>- EFA: Open MPI 3.1.4</td>
<td>- Placement Groups</td>
</tr>
<tr>
<td>- HDF5 1.8.20</td>
<td>- CloudFormation</td>
</tr>
<tr>
<td>- HDF5 1.8.20</td>
<td>- <strong>Azure</strong></td>
</tr>
<tr>
<td></td>
<td>- US Gov Arizona</td>
</tr>
<tr>
<td></td>
<td>- VMSS</td>
</tr>
<tr>
<td>- <strong>Penguin on Demand</strong></td>
<td>- <strong>AWS</strong></td>
</tr>
<tr>
<td></td>
<td>- US Gov Arizona</td>
</tr>
<tr>
<td></td>
<td>- VMSS</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CPU</th>
<th>AWS c4.8xlarge</th>
<th>Azure H16r</th>
<th>Penguin B30 queue</th>
<th>AWS c5n.18xlarge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.3 GHz Intel Xeon E5-2698 v3 Broadwell</td>
<td>2.9 GHz Intel Xeon E5-2666 v3 Haswell</td>
<td>3.2 GHz Intel Xeon E5-2667 v3</td>
<td>2.4 GHz Intel Xeon E5-2680 v4 Broadwell</td>
</tr>
<tr>
<td></td>
<td>32 core nodes</td>
<td>18 core nodes</td>
<td>14 core nodes</td>
<td>28 core nodes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Network</th>
<th>AWS c4.8xlarge</th>
<th>Azure H16r</th>
<th>Penguin B30 queue</th>
<th>AWS c5n.18xlarge</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Cray Aries / Dragonfly</td>
<td>- 25 Gbps ethernet with SRIOV</td>
<td>- FDR Infiniband</td>
<td>- Intel OmniPath</td>
<td>- AWS EFA</td>
</tr>
</tbody>
</table>

Low Resolution Forecast: Performance - Navy DSRC

Platform Specifications:
- 2.3 GHz Intel Xeon E5-2698 v3 Broadwell
- 32 core nodes
- Cray Aries / Dragonfly
- Cray Linux

Results
• Tested on Conrad
• Good scaling
  - minimal variability
  - minor increase in slope.
Platform Specifications:
- 2.9 GHz Intel Xeon E5-2666 v3 Haswell
- 18 core nodes
- 25 Gbps ethernet with SRIOV
- Amazon Linux

Results

• AWS’s most powerful compute optimized instance at time of testing.

• Adjusted variety of configurations
  - System clocksource
  - Attached storage type
  - Cluster creation tools
  - Processors per node

![Cloud Scaling, 5 Day Long, 31km Resolution Forecast - no I/O](chart)
Low Resolution Forecast: Performance - Azure

**Platform Specifications:**
- 3.2 GHz Intel Xeon E5-2667 v3
- 14 core nodes
- FDR Infiniband
- CentOS Linux

**Results**
- Infiniband networking likely contributed to improvement.
- Improved performance (plotted) using 14/16 processors per node.
- Eventual flattening of performance.
Low Resolution Forecast: Performance - Penguin

Platform Specifications:
- 2.4 GHz Intel Xeon E5-2680 v4 Broadwell
- 28 core nodes
- Intel OmniPath

Results
- Improved scaling expected considering Penguin’s “traditional” system design.
- Required use of batch scheduler and waiting for system resources at larger cluster sizes.
- Variability and unexplained spikes at higher core counts.
Low Resolution Forecast: Performance - AWS EC2 EFA

Platform Specifications:
- 3.0 GHz Intel Xeon Platinum w/ AVX-512
- 36 core nodes
- AWS Elastic Fabric Adapter
- Amazon Linux 2

Results
• Smooth scaling up to ~450 cores.
• Slight variability beyond – “stair step” performance beyond.
• Required use of Open MPI; Intel MPI now supported but not yet tested successfully with NAVGEM.
Low Resolution Forecast: Performance - Comparison

Performance Improvements:
c5n with EFA on AWS EC2

- At the highest core counts:
  - 13% faster than Penguin
  - 39% faster than Azure
  - 192% faster than previous AWS
  - 6% faster than Navy DSRC

- Min size estimated to meet 7.5 min:
  - 6% faster than Penguin
  - 16% faster than Azure
  - 74% faster than previous AWS
  - 29% faster than Navy DSRC

- Min size cost estimate:
  - Penguin: $12.95
  - Azure: $21.31
  - Previous AWS: $18.65
  - C5n with EFA: $13.76
Elastic Fabric Adapter

- Updated networking capability launched April 2019

- Hardware:
  - 3rd gen Nitro chip

- Software:
  - Scalable Reliable Datagram

- EFA provider has been upstreamed to most recent libfabric release

- Currently available on 4 large instance types.

- Supports Open MPI 3.1.4 and Intel MPI 2019 update 4.
Elastic Fabric Adapter

- Updated networking capability launched April 2019.
- Hardware:
  - 3rd gen Nitro chip
- Software:
  - Scalable Reliable Datagram
- EFA added as network fabric provider supported by libfabric library.
- Currently available on 4 large instance types.
- Supports Open MPI 3.1.4 and Intel MPI 2019 update 4.

<table>
<thead>
<tr>
<th>TCP</th>
<th>InfiniBand</th>
<th>SRD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stream</td>
<td>Messages</td>
<td>Messages</td>
</tr>
<tr>
<td>In-order</td>
<td>In-order</td>
<td>Out-of-order</td>
</tr>
<tr>
<td>Single path</td>
<td>Single(ish) path</td>
<td>ECMP spraying with load balancing</td>
</tr>
<tr>
<td>High limit on retransmit timeout (&gt;50ms)</td>
<td>Static user-configured timeout (log scale)</td>
<td>Dynamically estimated timeout (usec resolution)</td>
</tr>
<tr>
<td>Loss-based congestion control</td>
<td>Semi-static rate limiting (limited set of supported rates)</td>
<td>Dynamic rate limiting</td>
</tr>
<tr>
<td>Inefficient software stack</td>
<td>Transport offload with scaling limitations</td>
<td>Scalable transport offload (same number of QPs regardless of cluster size)</td>
</tr>
</tbody>
</table>
**Platform Specifications:**
- 2.3 GHz Intel Xeon E5-2698 v3 Broadwell
- 32 core nodes
- Cray Aries / Dragonfly
- Cray Linux

**Results**
- Good scaling maintained on Navy resources.
- Larger cluster sizes required to meet 7.5 min/day standard.
High Resolution Forecast: Performance - AWS EC2 1

Platform Specifications:
- 2.9 GHz Intel Xeon E5-2666 v3 Haswell
- 18 core nodes
- 25 Gbps ethernet with SRIOV
- Amazon Linux

Results
• Variability and performance flattening delayed.
• Cannot meet 7.5 min/day goal.
High Resolution Forecast: Performance - Azure

Platform Specifications:
- 3.2 GHz Intel Xeon E5-2667 v3
- 14 core nodes
- FDR Infiniband
- CentOS Linux

Results
- Similar improvement in variability and performance over AWS compared to low resolution forecast.
- Slight performance improvement over Navy DSRC in low resolution forecast has disappeared.
High Resolution Forecast: Performance - Penguin

Platform Specifications:
- 2.4 GHz Intel Xeon E5-2680 v4 Broadwell
- 28 core nodes
- Intel OmniPath

Results
- Good scaling and slight improvement over Navy DSRC until ~500 cores.
- Unable to obtain larger cluster runs due to system limitations and excessive job queue wait times.
High Resolution Forecast: Performance - AWS EC2 EFA

Platform Specifications:
- 3.0 GHz Intel Xeon Platinum w/ AVX-512
- 36 core nodes
- AWS Elastic Fabric Adapter
- Amazon Linux 2

Results
• Similar performance improvement over all platforms as exhibited in low resolution forecast.
High Resolution Forecast: Performance - Comparison

Performance Improvements: C5n with EFA on AWS EC2

- At the highest core counts:
  - 107% faster than Penguin
  - 43% faster than Azure
  - 160% faster than previous AWS
  - 25% faster than Navy DSRC

- Min size estimated to meet 7.5 min:
  - 33% faster than Azure
  - 23% faster than Navy DSRC

- Min size forecast cost estimate:
  - Azure: $82.97
  - C5n with EFA: $44.02
Next Steps

Incorporate I/O
- Initial testing looks promising.
- More “tuning” necessary to optimize results.

Future Areas of Research
- Test full NAVGEM ensemble
- Test next-generation forecast programs – NEPTUNE
- Incorporate on-going updates to cloud systems to further reduce costs and optimize performance.
Email contact: daniel.arevalo@icloud.com