GLOBAL DETERMINISTIC AND STOCHASTIC OPTIMIZATION IN A SERVICE ORIENTED ARCHITECTURE

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http://people.cs.vt.edu/~thchang/SORCER.pdf
Multidisciplinary Design Optimization (MDO)

Consider the MDO of an aircraft design problem:

- Used during design space exploration (conceptual design step)
- Goal of achieving optimal design over multiple disciplines
- Reduces size of potential design space in future steps

Problem: Traditional MDO uses low fidelity models with poor accuracy

Potential Solution: Higher fidelity physics-based modeling tools

Drawback: High fidelity models can be prohibitively complex
Service Oriented Architectures & SORCER

Service Oriented Architecture (SOA) provides a framework for distributed computing:
- Homo- and/or heterogeneous resources are interoperable, reusable, and loosely coupled services
- Dynamically allocate resources upon service request
- Service ORiented Computing EnviRonment (SORCER) layered over FIPER metacompute grid
Optimization Algorithms

In this work we consider two optimization algorithms used in MDO:

**VTDirect95**
- For deterministic global optimization
- Fortran 95 implementations of D. R. Jones’ Dividing Rectangles (DIRECT) algorithm
- Parallel and serial codes

**QNSTOP**
- For stochastic global optimization
- Quasi-Newton method in Fortran 2003
- Parallel and serial codes
Objectives

Provide VTDirect95 and QNSTOP as services on a SORCER grid
  • Dynamically distribute function evaluations

Study the overhead of using SORCER for distributed optimization
Background: SORCER - SOOA

Service Object-Oriented Architecture (SOOA)
Background: SORCER - Implementation

Implementation
• Uses Jini (Apache River) connection technology
• Java based services (for interoperability)
• Leverages JavaSpaces for dynamically load balanced network

Service provider types:
• Analysis providers
• Model providers

Abstraction layers
• Exertion-oriented programming (EOP)
• Var-oriented programming (VOP)
• Var-oriented modelling (VOM)
Background: VTDIRECT95 - basic algorithm

Based on Dividing Rectangles (DIRECT) by D.R. Jones
The parallel VTDIRECT95 algorithm (pVTdirect) is fully distributed:

- Problem divided between multiple masters to share memory burden
- Function evaluation tasks distributed to workers
Background: QNSTOP - algorithm

Step 1 (regression experiment): Given a feasible set \( \Theta \), a current iterate \( X_k \), and a radius \( \tau_k \):
- Compute the ellipsoidal design region \( E_k(\tau_k) \) centered at \( X_k \)
- Compute LS estimate for the gradient \( \hat{g}_k \) from uniform sampling of \( E_k(\tau_k) \)

Step 2 (secant update): Estimate Hessian matrix \( \hat{H}_k \).

Step 3 (update iterate): Calculate the next iterate \( X_{k+1} \) from a scaling matrix \( W_k \) and lagrange multiplier \( \mu_k \)
- Project \( X_k \) onto the feasible set \( \Theta \)

Step 4 (update subsequent design ellipsoid): Compute an updated scaling matrix \( W_{k+1} \).

Step 5: If room for more function evaluations in budget go to Step 1. Otherwise, the algorithm terminates.
Background: QNSTOPP - parallelism

Parallel Algorithm QNSTOPP (w/ OpenMP)

Sources of parallelism:
- Individual function evaluations
- Loop over samples in experimental design
- Loop over start points
Method: JNI Wrappers

Java Native Interface (JNI) libraries used to wrap Fortran optimization code in Java (as SORCER analysis service)
- Leverage *invocation interface* to allow native C/C++ code to run in JVM
- C “glue code” needed to wrap Fortran routines
- Objective functions are analysis providers invoked by optimization algorithm
Method: pVTdirect

Parallel VTDIRECT95 subroutine (pVTdirect) fundamentally incompatible with SORCER
- SORCER assumes master/slave paradigm
- pVTdirect is fully distributed for scalability
Method: QNSTOPP

Parallel QNSTOP subroutine (QNSTOPP) parallelized over sampling of design region

- Chunked out so that $n$ function evaluations are requested at a time via SORCER service requests
- Leads to $n$ way parallelism wrt objective function evaluations
Experiment: EBF3PanelOpt

Framework for optimization of curvilinearly stiffened panels (wrt panel mass)
- Python based
Experiment: EBF3PanelOpt Implementation

EBF3PanelOpt is an analysis provider distributed over SORCER network using:
- JavaSpaces: exertions dropped into JavaSpace and discovered by providers via Jini
Experiment: Catalog Alternative

SORCER catalog matches services to predefined list of providers
Experiment: Setup

2 identical Intel i7-3770 machines (Ivy Bridge) @3.4 GHz
- Quad-core w/ hyperthreading
- 16 GB memory
- Optimization function & model provider run on one machine, EBF3PanelOpt analysis provider on the other
- For QNSTOPP # threads set to 4
- For VTdirect and QNSTOPS (serial), only 1 analysis provider used at a time
Experiment: Terminology

Parallel efficiency of QNSTOPP w/ and w/o SORCER modelled by:

\[ E_p = \frac{\left(\frac{\text{QNSTOPPS time}}{\text{QNSTOPP time}}\right)}{\left(\text{total number of OMP threads/analysis providers}\right)} \].

“Script Robustness” is a Java **GenericUtil** for increased robustness of scripts and communication links across different systems.
Results: Table 1

Execution times in seconds for pylon wing panel optimization with 2 stiffener panels

<table>
<thead>
<tr>
<th></th>
<th>VTdir</th>
<th>pVTdir</th>
<th>QNSTOPS</th>
<th>QNSTOPP</th>
<th>$E_p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SORCER and script robustness</td>
<td>13,009</td>
<td>N/A</td>
<td>11,388</td>
<td>3,545</td>
<td>0.80</td>
</tr>
<tr>
<td>SORCER w/o script robustness</td>
<td>8,957</td>
<td>N/A</td>
<td>7,994</td>
<td>2,542</td>
<td>0.79</td>
</tr>
<tr>
<td>SORCER/Catalog w/o script robust.</td>
<td>8,487</td>
<td>N/A</td>
<td>7,597</td>
<td>2,458</td>
<td>0.77</td>
</tr>
<tr>
<td>W/o SORCER, w/o script robust.</td>
<td>8,460</td>
<td>2,924</td>
<td>7,560</td>
<td>2,309</td>
<td>0.82</td>
</tr>
</tbody>
</table>
## Results: Table 2

Execution times in seconds for pylon wing panel optimization with 4 stiffener panels

<table>
<thead>
<tr>
<th>Method</th>
<th>VTdir</th>
<th>pVTdir</th>
<th>QNSTOPS</th>
<th>QNSTOPP</th>
<th>(E_p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SORCER w/ script robustness</td>
<td>14,450</td>
<td>N/A</td>
<td>10,370</td>
<td>3,676</td>
<td>0.71</td>
</tr>
<tr>
<td>SORCER w/o script robustness</td>
<td>10,384</td>
<td>N/A</td>
<td>7,451</td>
<td>2,697</td>
<td>0.69</td>
</tr>
<tr>
<td>SORCER/Catalog w/o script robust.</td>
<td>9,815</td>
<td>N/A</td>
<td>7,088</td>
<td>2,615</td>
<td>0.68</td>
</tr>
<tr>
<td>W/o SORCER, w/o script robust.</td>
<td>9,786</td>
<td>3,789</td>
<td>7,052</td>
<td>2,408</td>
<td>0.73</td>
</tr>
</tbody>
</table>
Results: Table 3

Objective function evaluation times in seconds for pylon wing panel (2 & 4 stiffeners)
Note: 2 stiffeners = 13 dimensional problem, 4 stiffeners = 25 dimensional problem

For 100 function evaluations done through VTdirect, average function evaluation cost:

<table>
<thead>
<tr>
<th></th>
<th>$n = 13$</th>
<th>$n = 25$</th>
</tr>
</thead>
<tbody>
<tr>
<td>With SORCER and script robustness</td>
<td>11.13</td>
<td>12.90</td>
</tr>
<tr>
<td>With SORCER, without script robustness</td>
<td>7.36</td>
<td>9.14</td>
</tr>
<tr>
<td>Without SORCER and script robustness</td>
<td>7.32</td>
<td>9.10</td>
</tr>
</tbody>
</table>
Discussion

Advantages:
- Dynamic distributed resource management
- High level of abstraction, tailored to modelling/design analyses
- Code reusability

Disadvantages:
- Heavyweight (in comparison to Condor, Globus, MPI)
- Overhead of wrapping existing code with JNI
Thanks for Your Time!

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