Workload balancing in heterogeneous grid environment: A Virtual Reactor case study

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Outline

- High Performance Simulation on the RIDGrid: Russian-Icelandic-Dutch Grid testbed (talk by Irina Shoshmina on June 27)
- Virtual Reactor Application
- Issues in porting Virtual Reactor to the Grid
- Virtual Reactor on heterogeneous resources: adaptive load balancing
- Functional decomposition on the Grid
- Conclusions and future work
High Performance Simulation on the Grid

- Russia - Netherlands - Iceland Grid testbed: heterogeneous Grid
- The Virtual Reactor application:
  - To drive and validate the testbed development
  - Case study to research HPC simulation performance on Grid resources
- Final system - a distributed environment for high performance simulation with parameter sweep, interaction and visualization facilities

- Participants: University of Amsterdam, Institute for High-Performance Computing & Databases (St.Petersburg), IHED-IVTAN (Russian Academy of Sciences, Moscow), Institute of Computational Mathematics (Siberian Branch of Russian Academy of Sciences, Novosibirsk)
PECVD Virtual reactor

Software for numerical simulation of plasma enhanced chemical vapour deposition reactors (PECVD). PECVD is one of the most wide-spread technologies for production of silicon-based films, the important material in microelectronics.

Requires significant computational resources:
- complex geometry of industrial reactors
- complicated phys-chemical processes
- dozens of chemical species and hundreds of chemical reactions
Virtual reactor architecture

GUI, Web/Grid Portal

Simulation

Interpolation, preprocessing

Visualization

Results archiving

DB
Chemical elements and species
Reactions

Verification

Generation of chemical kinetic equations

Physical properties of gases

Postprocessing the results

Simulation workflow:
- Problem description
- Mesh generator
- Chemistry editor
- Gas properties editor
- Plasma simulation
- Reactive flow simulation
- Results archiving

Database (DB):
- Chemical elements
- Species
- Reactions
- Reaction rates

Numerical schemes
- Computational parameters
- Computational mesh
- Number of processes
Porting VR to Grid: issues

- Functional decomposition and hierarchical resource management
- Benchmarking VR components to discover performance dependencies for better allocation
- Adjusting parallel components to heterogeneous environment: adaptive load balancing
- Support for interactivity and visualization
- Support for parameter sweep
Initially parallel solvers were developed for homogeneous clusters.

Adaptation is necessary in order to achieve performance.

Develop an algorithm for efficient workload distribution between heterogeneous nodes.
Domain Decomposition

Workload (beams) distribution in homogeneous case

Reactor geometry, decomposition for multi-block meshes
Resource-adaptive load balancing

**Theoretically:**
- Resource parameter: \( \mu \sim \frac{t_{comm}}{t_{calc}} \)
- Application parameter: \( f_c \sim \frac{N_{comm}}{N_{calc}} \)

With full knowledge on \( \mu \) and \( f_c \) it’s possible to perform optimal domain decomposition in heterogeneous environment

**In practice:**
- \( f_c \) is difficult to determine explicitly
- Heuristic: derive a weighting factor \( w_i \) for each participating processor such as:

\[
W_i = Ww_i
\]

where \( W \) is total workload, \( W_i \) – workload on processor \( i \), \( w_i \) – determines capacity of the processor \( i \)
Resource-adaptive load balancing

- Distribution of workload between processors during runtime by weighting processors:

\[ w_i = c_p p_i + c_n n_i \]

- Benchmarking of \( p_i, n_i \) and estimation of optimal coefficients \( c_p, c_n \) on heterogeneous resources \( (F_c \sim c_n/c_p) \)

- Metric: load balancing speedup

\[ S^* = \frac{T_{unbalanced}}{T_{balanced}(c_p, c_n, p_i, n_i)} \]
Resource-adaptive load balancing: steps

Target: experimentally determine optimal weighting for the application on given resources to provide efficient workload distribution

- Perform benchmarking of underlying resources, constitute the resource parameter $\mu$
- Search through the space of possible $Fc$: measure the performance of mapping this $Fc$ to current $\mu$; discover $Fc$ which corresponds to best performance on this resource set (small part of simulation is executed for each benchmark), determine optimal workload distribution
- Using discovered $Fc$ perform the remaining simulation
- In case of dynamic resources periodic re-estimation of $\mu$ and $Fc$ might be performed
SPb site, different cases with different processors of various capacity using heterogeneous links
Functional decomposition: approaches

- **Web portal**
  - Porting existing cluster web interface; enable Grid job submissions
  - Introduce support for parameter sweep

- **Workflow**
  - Abstract VR application components as services
  - Integrate the services using a workflow tool (e.g. VLAM-G, [http://www.vl-e.nl](http://www.vl-e.nl) or Kepler)
  - Enable support for interactivity, visualization and parameter sweep
  - ‘Smart’ services responsible for resource management

- Web portal: easier to port from existing version but not easily extensible
- Workflow: more complicated but more promising
VR in VLAM-G: Virtual Lab for e-Science
Conclusions and future work

- An algorithm for workload distribution in heterogeneous environment proposed end evaluated
- Approaches to functional decomposition of VR on the Grid outlined

- Enhance the algorithm and experiment using synthetic parallel application with tunable application requirements, introduce memory influence factor:
  - Enable direct specification of communications and computations (thus the application parameter \( f_c \))
  - Develop ideal distribution for particular cases, compare with "rough" distribution by the presented algorithm
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2. V. Krzhizhanovskaya, V. Korkhov. Problem-Solving Environments for Simulation and Optimization on Heterogeneous Distributed Computational Resources of the Grid, accepted to Parallel Computations and Control Problems (PACO ‘2006) conference, Moscow, Russia, October 2-4, 2006


4. V. Korkhov, V. Krzhizhanovskaya and P.M.A. Sloot. A Grid Based Virtual Reactor: A case study of parallel performance and adaptive load balancing, submitted to a journal

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