Institution: University of Westminster

Unit of Assessment: UoA11; Computer Science and Informatics

Title of case study: Component-based Highly Productive Methodology for Software Development in Grid and Cloud Computing

1. Summary of the impact

The invention of a novel component-based model and approach for rapid distributed software development are the core research results for this case study. Using our methodology we have built a fully functional platform – the Grid Integrated Development Environment (GIDE) – which has been used for the development of user applications by several industrial partners. The main economic impact of our work is the new component-based development process resulting in much higher productivity and shorter development cycle. In addition, the four new international standards approved by ETSI provide impact on the wider professional community in the areas of grid and cloud computing.

2. Underpinning research

The component-based abstract models and development methodology for complex distributed software systems has been one of the main research areas for the Distributed and Intelligent Systems Research Group since late 90s. The research team that has been contributing to these very important and challenging topics comprises: Professor Vladimir Getov, Dr Alexander Bolotov, Dr Stavros Isaiadis, Dr Thomas Weigold, Dr Artie Basukoski, Dr Jeyan Thiyagalingam, and Dr Alessandro Basso.

Message-passing for Java

- The message-passing for Java specification and reference implementation and the mixed-language software development and execution approach provided the foundation for the invention of a novel component-based model. As part of these important research projects and results, Vladimir Getov was a founding member of the Java Grande Forum (the international high-performance Java forum) and then chair of the Java Grande Message Passing Group.
- The multi-paradigm Java communications concepts and environments was the natural next research step which introduced the early ideas for component-based frameworks and environments. Subsequently, Vladimir was elected Research Group co-chair in the Open Grid Forum (2001 - 2004). The use of high-performance Java and the Message Passing for Java specification enabled the rapid development and wide adoption of component-oriented approaches in modern high-performance distributed systems such as grids and clouds.

Grid Component Model

- The grid component model (GCM) for autonomic distributed computing and the ‘invisible’ grid concepts introduced shortly before the cloud computing paradigm are the core theoretical research results underpinning this impact case study. Vladimir Getov was also Executive Committee member and leader of the European Institute on "Grid Systems, Tools, and Environments" within the CoreGRID Network of Excellence (2004-2008). This Institute's main objective has been the development of a new design methodology for future generation ‘invisible’ grids.

- At the end of the CoreGRID EU grant Vladimir Getov was one of the founding members of the ERCIM Working Group on Grids, P2P and Services Computing, where he has since been topic leader for "Tools and Environments for Application Development and Execution".

Grid Integrated Development Environment

- The complete methodology for component-based development of grid applications with relevant case studies in different application domains was developed and implemented in our Grid Integrated Development Environment (GIDE). Between 2005 and 2009, Vladimir Getov was also on the Steering Committee for the GridCOMP (Grid Programming with Components) project, which developed a new generation component-based and dynamically reconfigurable grid computing platform including our GIDE prototype.
- Further results on the architecture for component-based smart cloud infrastructures were based on our expanded methodology and GIDE.

3. References to the research

A. Key publications

Grid Integrated Development Environment

1. (*) V. Getov, *Component-oriented Approaches for Software Development in the Extreme-scale Computing Era*, In: High Performance Computing: From Grids and Clouds to Exascale, pp. 141-156, IOS Press, 2011, DOI: 10.3233/978-1-60750-803-8-141 (listed in REF2).
2. T. Weigold, P. Buhler, J. Thiyagalingam, A. Basukoski, V. Getov, *Advanced Grid Programming with Components: A Biometric Identification Case Study*, Proc. IEEE COMPSAC, pp. 401-408, IEEE CS Press, 2008, DOI: http://doi.ieeecomputersociety.org/10.1109/COMPSAC.2008.97.
3. J. Thiyagalingam, S. Isaiadis, V. Getov, *Towards Building a Generic Services Platform: A Components-oriented Approach*, In: Component Models and Systems for Grid Applications, pp. 39-56, Springer, 2005, DOI: 10.1007/0-387-23352-0_3.

Grid Component Model

4. (*) F. Baude, D. Caromel, C. Dalmasso, M. Danelutto, V. Getov, L. Henrio, C. Pérez, *GCM: A Grid Extension to Fractal for Autonomous Distributed Components*, Annals of Telecommunications, vol. 64(1-2), pp. 5-24, Springer, 2009, DOI: 10.1007/s12243-008-0068-8 (listed in REF2).

Message-passing for Java

5. (*) V. Getov, G. von Laszewski, M. Philippsen, I. Foster, *Multi-Paradigm Communications in Java for Grid Computing*, Communications of the ACM, vol. 44(10), pp. 118-125, ACM Press, 2001, DOI: 10.1145/383845.383872.
6. B. Carpenter, V. Getov, G. Judd, A. Skjellum, G. Fox, *MPJ: MPI-like Message Passing for Java*, Concurrency: Practice and Experience, vol. 12 (11), pp. 1019-1038, Wiley, 2000, DOI: 10.1002/1096-9128(200009)12:11<1019::AID-CPE518>3.0.CO;2-G.

(*) Indicator of best quality.

B. Key research grants

- 10/2009 – 03/2011 V. Getov, 'Feasibility Study into Smart Cloud Infrastructures', Faculty Award Research Grant from IBM, PI and Grant Holder, £ 9,201 ($ 15,000).
- 05/2009 – 06/2013 V. Getov, COST Action: "Open European Network for High Performance Computing on Complex Environments", ESF Grant, £ 16,710 (Total consortium grant 520 K EUR).

- 06/2006 – 02/2009 V. Getov, Grid Programming with COMPonents: An Advanced Component Platform for an Effective Invisible Grid (GridCOMP), STREP EU Project, PI and Grant Holder, £ 320,000 (Total consortium grant 1.75 M EUR).
- 02/2006 – 10/2006 V. Getov, Research Fellowship, European Commission, PI and Grant Holder, £ 14,117.
- 09/2004 – 11/2008 V. Getov, The European Research Network on Foundations, Software Infrastructures and Applications for Large-scale Distributed, Grid and Peer-to-Peer Technologies (CoreGRID) NoE EU Project, PI and Grant Holder, £ 224,000 (Total consortium grant 8.2 M EUR).

4. Details of the impact

Modern high-performance distributed systems such as grids and clouds have developed rapidly through the wide use of component-oriented approaches usually using the Java programming language. The main goal of our work in this area has been the design and implementation of a highly productive and efficient component-based framework for the rapid development of complex distributed applications. The impact created by this research is based on the invention of a new abstract model and corresponding implementation approach for a component-oriented distributed software development with much higher productivity.

Following the initial ideas and results introduced in the component-oriented approach for distributed and high-performance computing, the European Network of Excellence CoreGRID advanced significantly in this new field. Our conceptual research results have been used as an enabling approach for the 'invisible' grid concepts and for developing the Grid Component Model (GCM) specification, as well as initial proof-of-concept experiments. These have proved particularly successful within the vibrant collaboration environment established after the creation, and as part of the operation and management of the European Institute on "Grid Systems, Tools, and Environments" with more than 90 individuals participating from 12 different European countries.

The GIDE research team, led by Vladimir Getov, was a main partner in the European GridCOMP project working in close collaboration with other partners including INRIA Sophia Antipolis, University of Pisa, IBM-Research, Tsinghua University, and Atos Origin. GridCOMP designed and built a fully functional platform incorporating our GIDE prototype which has been used for highly productive development of user applications by industrial partners in the areas of grid and cloud computing.

- The reach of the impact (this is more than geographical): Demonstrated ground-breaking wide-ranging impacts of major significance at world level.
- The significance of the impact: Based on the high-performance Java component-oriented concepts and research results, Grid and Cloud computing represent a fundamental shift in the delivery of information technology services that has permanently changed the computing landscape.

Evidence of the impact:

- Following the initial ideas and results introducing the component-oriented approach for distributed and high-performance computing, the European Network of Excellence CoreGRID – http://coregrid.ercim.eu/ – advanced significantly this new field by using it as an enabling

approach for the 'invisible' grid concepts and developing the Grid Component Model (GCM) specification as well as initial proof-of-concept experiments.

- The GCM definition and specification have been approved and published in four official industrial standards documents by the Technical Committee GRID/CLOUD of the European Telecommunications Standards Institute (ETSI) – "GCM Interoperability Deployment", Aug 2008; "GCM Interoperability Application Description", Aug 2008; "GCM Fractal ADL", Mar 2009; and "GCM Management API (Java, C, WSDL)", Mar 2010.
- Following excellent technical results but most importantly because of the unique success in standardisation the EU GridCOMP project was announced the EC DG-INFSO project of the month for September 2009 – http://gridcomp.ercim.eu/
- Two large companies – IBM and Atos Origin – both partners in the GridCOMP project, have been using the GCM specification, standards, and results. Two other small enterprises – GridSystems and ActiveEon – have also been working on the integration and further development of the component-oriented framework.
- The following user applications are known to have been developed using our component-based methodology and framework http://gridcomp.ercim.eu/content/view/41/39/ :

    - Biometric Identification System – IBM;
    - Aircraft Wing Design – ActiveEon;
    - Computing of Days Sales Outstanding Value – Atos Origin;
    - Extended Data Record Processing – Grid Systems.

Note: The official participation in the ETSI standardisation process was done by INRIA on behalf of the GridCOMP consortium. ETSI and INRIA have agreed that they can provide appropriate letters confirming our participation and contribution to the four ETSI standards references above.

5. Sources to corroborate the impact

Reports and reviews:

- GridCOMP Sets New Standard for Grid Applications, IST News, European Commission, 20 July 2009, (similar articles were published by CORDIS Wire, AlphaGalileo Foundation and MarketPress), http://cordis.europa.eu/fetch?CALLER=NEWS_IST&ACTION=D&DOC=10&CAT=NEWS&QUERY=0121032a21f8:a2a5:00e9d79c&RCN=31048

International standards:

- GCM Interoperability Deployment, TC GRID/CLOUD, ETSI, Aug 2008.
- GCM Interoperability Application Description, TC GRID/CLOUD, ETSI, Aug 2008.
- GCM Fractal ADL, TC GRID/CLOUD, ETSI, Mar 2009.
- GCM Management API (Java, C, WSDL), TC GRID/CLOUD, ETSI, Mar 2010.

The following users / beneficiaries can be contacted by the REF team to corroborate claims:

- OASIS Team, INRIA Sophia Antipolis, France.
- Computer Science Department, IBM-Research, Zurich, Switzerland.
- Atos Origin, Barcelona, Spain.
- IBM Venture Capital Group, IBM Almaden Research Center, San Jose, USA.
- ActiveEon, Sophia Antipolis, France.