Institution: University of the West of England (UWE), Bristol

Unit of Assessment: 11 - Computer Science and Informatics

Title of case study: Facilitating System Evolution during Design and Implementation: CRISTAL

1. Summary of the impact

The volume and diversity of data that companies need to handle are increasing exponentially. In order to compete effectively and ensure companies' commercial sustainability, it is becoming crucial to achieve robust traceability in both their data and the evolving designs of their systems. The CRISTAL software addresses this. It was originally developed at CERN, with substantial contributions from UWE Bristol, for one of the Large Hadron Collider (LHC) experiments, and has been transferred into the commercial world. Companies have been able to demonstrate increased agility, generate additional revenue, and improve the efficiency and cost-effectiveness with which they develop and implement systems in various areas, including business process management (BPM), healthcare and accounting applications. CRISTAL's ability to manage data and their provenance at the terabyte scale, with full traceability over extended timescales, based on its description-driven approach, has provided the adaptability required to future proof dynamically evolving software for these businesses.

This case study embodies a non-linear relationship between underpinning research, software development and deployment. It involves computer science research at UWE in conjunction with its applied development for the world's largest particle physics laboratory and onward deployment commercially into private sector industry.

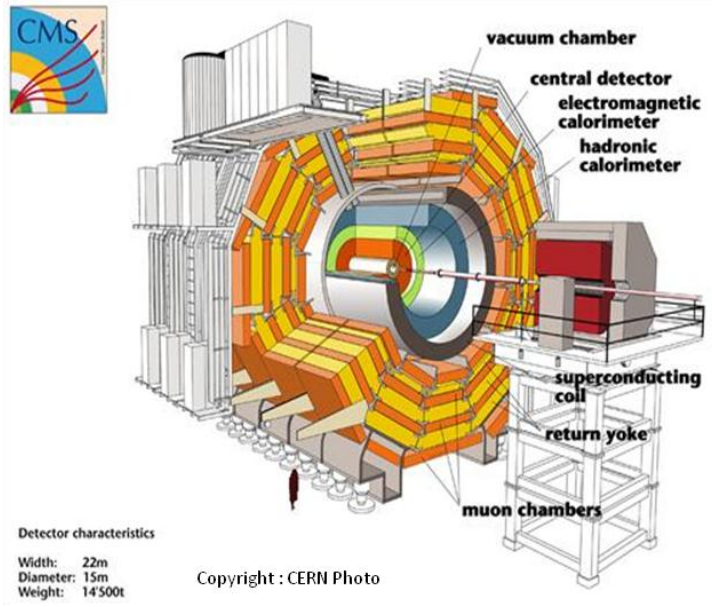
2. Underpinning research

Organisations are increasingly operating within environments that present unforeseeable change. Systems must evolve dynamically in response to changes in technology and consequently there must be full traceability between the design and evolving system specifications.

Underpinning research to address this challenge at UWE's Centre for Complex Cooperative Systems (CCCS) from 1997 onwards (see [1] and [2]) has been led by Richard McClatchey (UWE Professor 2000-present, Reader 1997-2000, Senior Lecturer 1991-1997), Jean-Marie Le Goff (UWE Visiting Professor from CERN 2003-2009) and Andrew Branson (UWE Research Associate 2006-present). It has also involved key input from Nigel Baker (UWE Reader 1999-2011, Senior Lecturer 1988-1999), Tony Solomonides (UWE Reader 1999-2010, Head of Department 1992-1999) and Wayne Harris (UWE Senior Lecturer 1990-2004).

The research has identified the importance of developing software whose specifications evolve beyond the design phase, a process which may have no definite endpoint. CCCS has pioneered a development approach that allows systems to reconfigure themselves dynamically, enabling software to be versioned and rolled out into production to sit seamlessly alongside existing live systems without designer intervention.

This approach has been applied, in collaboration with CERN (Switzerland) and CNRS (France), to the creation of a novel development environment called CRISTAL initially for CERN's CMS (Compact Muon Solenoid) experiment [5], to address that experiment's software needs over extended design timelines. McClatchey is co-inventor of CRISTAL and Branson is the lead software architect. The production version of the software was developed by McClatchey & Branson with assistance from UWE PhD students and post-docs from 2001-2003. In 2006, Branson joined UWE to continue the project. CRISTAL embodies a "description-driven" approach [2]: all logic and data structures are described by metadata, which can be modified and versioned online as the design of the system changes. McClatchey and UWE colleagues have shown that the creation of a flexible system can be facilitated by carefully modelling the metadata: the resulting software is reusable across applications and can handle complexity, version control and system evolution. CRISTAL was used to calibrate CMS and thus aided its discovery of the Higgs Boson (2012). The advantages of separating design, implementation and instantiation further vindicate the use of such "meta-models" (see [3] and [4]).



The strength and validation of McClatchey and colleagues' research findings is demonstrated in the robust CRISTAL solutions realised at CERN and in industry. During the construction period of the CMS Electromagnetic Calorimeter (ECAL) from 1999 to 2008, over 70,000 individual lead tungstate crystals were characterised and their data and full provenance captured in CRISTAL. Each ECAL crystal generated between 3-5 Mbytes of information which was gathered in a crystal characterisation system, called ACCOS (see [5]). CRISTAL provided round-the-clock information logging and only needed to be upgraded seven times during eight years of continuous operation, only one being a major update (see http://cms.web.cern.ch/news/cristal-database). The CRISTAL research was released by UWE to industry and became the basis for the programme of external exploitation by M1i, France, in Business Process Management (BPM) solutions between 2003 to the present. CRISTAL has demonstrated its ability to be responsive to changing user requirements and to support on-the-fly system evolution over extended product lifecycles, as evidenced by its use and exploitation by M1i.

CRISTAL has been targeted at scientific data provenance and workflow orchestration [6] in the neuGRID project (2008-2011) and its follow up neuGRIDforUsers project (N4U, 2011-2014). Clinical researchers across Europe have been using CRISTAL on the neuGRID infrastructure to support ongoing studies of Alzheimer's Disease biomarkers. It is also being used for tracking by hospitals in the FP7 EndoTOFPET-US project which is developing next generation PET scanners.

Thus the underpinning research reaches beyond its academic discipline of computer science leading to impact in other 'academic' fields such as physics and medicine. Its further impact beyond research and particularly in terms of commercial relevance is set out in Section 4.

3. References to the research

[1] Kovacs, Z., Le Goff, J-M. and McClatchey, R. (1998). Support for Product Data from Design to Production. *Computer Integrated Manufacturing Systems*, 11(4), pp. 285-290. http://dx.doi.org/10.1016/S0951-5240(98)00026-3

[2] McClatchey, R., Le Goff, J-M., Baker, N., Harris, W. and Kovacs, Z. (1998). A Distributed Workflow and Product Data Management Application for the Construction of Large Scale Scientific Apparatus. *NATO ASI Series F: Computer & Systems Sciences*, 164, pp. 18-34. http://dx.doi.org/10.1007/978-3-642-58908-9_2

[3] Baker, N., Bazan, A., Chevenier, G., Estrella, F., Kovaks, Z., Le Goff, J-M., McClatchey, R. and Martin, P. (2001). Design Patterns for Description-Driven Systems in High Energy Physics. *Computer Physics Communications*, 140(1-2), pp. 1-12. http://dx.doi.org/10.1016/S0010-4655(01)00250-8

[4] Estrella, F., Kovaks, Z., Le Goff, J-M., McClatchey, R., Solomonides, T. and Toth, N. (2003). Pattern Reification as the Basis for Description-Driven Systems. *Journal of Software and System Modeling*, 2(2), pp. 108-119 http://dx.doi.org/10.1007/s10270-003-0023-0

[5] Chatrchyan, S *et al*. (The CMS Collaboration) (2008). The CMS Experiment at the CERN LHC. *The Journal of Instrumentation,* 3 S08004. http://dx.doi.org/10.1088/1748-0221/3/08/S08004

[6] McClatchey, R., Branson, A. et al (2013). Providing Traceability for Neuroimaging Analyses. *International Journal of Medical Informatics*, 82(9), pp. 882-894. http://dx.doi.org/10.1016/j.ijmedinf.2013.05.005

Key external grants supporting aspects of this research:

CRISTAL: Cooperating Repositories and an Information System for Tracking Analysis Lifecycles. CERN Project 1998-2002 Total budget ChF 230k from CERN awarded to McClatchey, UWE

MammoGrid EC Framework 5 ICT STREP 2002-2005 Total Budget €3.2M (€400k awarded to McClatchey, UWE)

neuGRID EC Framework 7 Integrated Information Infrastructure 2008-2011 Total Budget €3.1M (€700k awarded to McClatchey, UWE)

NeuGRIDforUsers (N4U) EC Framework 7 Integrated Information Infrastructure 2011-2014 Total Budget €3.5M (€550k awarded to McClatchey, UWE)

CRISTAL-ISE EC Framework 7 Marie Curie IAPP 2012-16 Total Budget €1.35M (€650k awarded to McClatchey, UWE)

4. Details of the impact

Agilium software for Business Process Management

The development of CRISTAL was conducted in close consultation with user communities – initially physicists and engineers at CERN [see source S1] and latterly in commerce for eBusiness users. This enabled its rapid adoption by industry and in 2003 a version of CRISTAL was developed and sold as support for applications of business process management (BPM) by the M1i company in France. It can handle the complexity of data-intensive systems and provide the flexibility to adapt to the changing scenarios required by any process in which workflow and data traceability is crucial.

It has been sold by M1i under the product name Agilium (2003 – 2013) into the retail, finance and manufacturing sectors of European industry, for use in the area of BPM. UWE advised on the adaptation of the CRISTAL kernel to enable M1i to develop BPM support. Agilium used the kernel for workflow and process traceability, and also for the integration and co-operation of multiple business processes in business-to-business (B2B) applications. The M1i product enables commercial processes to be harmonised using a CRISTAL database, tracks their workflows and integrates multiple potentially heterogeneous processes, such as order processing, sales management and business logistics.

Benefits of Agilium realised in a variety of businesses

CRISTAL-Agilium has found application in, for example, the systems used by Nexcis for photovoltaic cell production, by the Ville de Lyon (France) for managing operational procedures, and by the STTS specialist aerospace painting/sealing company for managing its internal business process controls. In particular Agilium enables these customers to trace their data across applications and to adapt to system evolution with little or no disruption to their live systems.

CRISTAL-Agilium also integrates the management of data coming from different sources and unites Business Process Management with Business Activity Management (BAM) through the capture and management of their designs in CRISTAL. This has been applied at the Bayer Group, where CRISTAL-Agilium has enabled customers to conduct and handle B2B transactions and to facilitate the management of targeted domains (e.g. logistics, retail and government domains). Other CRISTAL-Agilium clients of M1i include Dynastar, GDP Vendome, the ski resort of Tignes, Photowatt Technologies, SoTRADEL and Midor. The software is used to manage the processes of and between these commercial companies enabling M1i to gain a unique position in the BPM market (recognised by the Gartner Group, 2009 [S2] and IT advisors CXP [S3]). Commercial income generated by CRISTAL-Agilium licence sales by M1i in the period 2008-2013 top €1.0M. To quote the CEO of M1i: "*the quality of the (CRISTAL) research transfer gives us key benefits to differentiate our solutions on the market*" and to "*justify our position as an innovative SME company for our customers and partners*" [S4].

M1i and Alpha-3i companies commercialise further applications of CRISTAL

In 2011 UWE and M1i, together with the Alpha-3i company (France), were awarded €1.5M under

the FP7 Marie Curie Industry-Academic Partnership Pathways (IAPP) programme to develop CRISTAL for the next generation of business applications. This CRISTAL-ISE partnership has already enhanced CRISTAL with distribution and semantic features. Since its inception both companies have benefitted from CRISTAL's design flexibility and ability to evolve dynamically in order to upgrade their commercial offerings for a growing customer base more rapidly that was previously possible.

Application and commercialisation beyond BPM – Technoledge start-up

CRISTAL has been recently further exploited by the Technoledge start-up company. Starting in early 2012, Technoledge has been working closely with UWE to adapt CRISTAL to domains outside of BPM [S5]. Amongst other areas, application of CRISTAL at CEA (France) has demonstrated, for the first time, full traceability from raw materials to final product facilitated by the use of CRISTAL in manufacturing execution systems. This has led to the following outcomes:

- Technoledge use CRISTAL to provide the support for the development of production lines at CEA to manufacture next-generation sustainable fuel cells for future electric vehicles.
- In collaboration with the COGEP consortium (one of the five largest accountancy consortia across France), Technoledge has exploited CRISTAL to integrate several previously outsourced software packages for a major French accountancy firm, taking advantage of CRISTAL's ability to manage several contrasting models in the same workspace.
- In the summer of 2013 the Advanced Accelerator Applications group adopted CRISTAL as the basis of its production management system for the production of radiopharmaceuticals for distribution to hospitals in the Rhone-Alpes region of France.

Since 2008, CCCS has also collaborated with the neuGRID and N4U ('neuGRID for Users') projects to provide a system for clinicians investigating biomarkers for Alzheimer's disease [S6]. CRISTAL has been used to track the analysis of algorithms and large data sets to help identify patients who may be susceptible to mild cognitive impairment that could lead to dementia. Early identification of such conditions is enabling doctors in medical centres across Europe to diagnose Alzheimer's Disease and thereby to prescribe suitable drug therapies to slow its onset.

The provenance of data and processes is central to these business operations. CRISTAL has enabled the systematic management of data and processes in a maintainable, flexible and evolvable, and thus profitable, manner.

5. Sources to corroborate the impact

Testimonials listed below are available from UWE, Bristol.

S1. **Testimonial** [1 on REF system] from CERN corroborating CRISTAL's use in the CMS Experiment at CERN and the CNRS research body in France (www.cern.ch; http://www.cnrs.fr).
S2. Corroboration of CRISTAL-Agilium's unique position in the BPM market: the Gartner Group. (Report purchasable at www.gartner.com/technology/research/cool-vendors/ under subheading "Cool Vendors in Business Process Management".)
S3. Favourable review of Agilium from CXP, a Paris-based IT advice company, freely available at http://www.inst-informatica.pt/servicos/informacao-e-documentacao/biblioteca-digital/gestao-de-si-ti-1/bpm/01_Agilium_CXP_EN_060324.pdf
S4. **Testimonial** [2 on REF system] from CEO of M1i company (www.m1i.fr) corroborating the exploitation of CRISTAL as the Agilium product, the resulting sales and corporate clients.
S5. **Testimonial** [3 on REF system] from President and CEO of Technoledge SAS company (www.technoledge.ch) corroborating its start-up to commercialise CRISTAL technology, its subsequent growth and increasing turnover.
S6. **Testimonial** [4 on REF system] from neuGRID and N4U FP7 projects (see www.neugrid.eu and www.neugrid4you.eu) corroborating use of CRISTAL as its central neuroscientific provenance management system and analysis service, and resulting cost savings.