PROJECT PERIODIC REPORT - 18 MONTH INTERIM REPORT

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Name, title and organisation of the scientific representative of the project's coordinator: Simon Riggs, CTO, 2ndQuadrant Limited
Tel: +44 870 766 7756
Fax: +44 870 838 1077
E-mail: simon@2ndquadrant.com
Project website: http://axleproject.eu
Version History

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<tr>
<td>0.1</td>
<td>23/03/2014</td>
<td>Jo Dix 2ndQ</td>
<td>Initial version</td>
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<td>0.1</td>
<td>08/05/14</td>
<td>Jo Dix 2ndQ</td>
<td>Prepared for internal review</td>
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<tr>
<td>0.1</td>
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<td>changes to various sections based on comments</td>
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<td>1.0</td>
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<td>Jo Dix</td>
<td>Final version</td>
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Reviewers

Olivier Marchesini (PV)
Janez Demsar (UL)

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## Abbreviations

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<td>BRAM</td>
<td>Block RAM</td>
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<tr>
<td>CDA</td>
<td>Clinical Document Architecture</td>
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<td>Char14</td>
<td>PostgreSQL conference on clustering, HA and replication techniques</td>
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<td>CPU</td>
<td>Central Processing Unit</td>
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<tr>
<td>CSV</td>
<td>comma separated values</td>
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<td>DBMS</td>
<td>Database Management System</td>
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<td>DDL</td>
<td>Data Definition Language</td>
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<td>DML</td>
<td>Data Manipulation Language</td>
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<td>DMA</td>
<td>Direct Memory Access</td>
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<td>ELT</td>
<td>Extract Load Transform</td>
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<tr>
<td>FCCM 2014</td>
<td>The 22nd IEEE International Symposium on Field-Programmable Custom Computing Machines</td>
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<td>FHIR</td>
<td>Fast Health-care Interoperability Resources</td>
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<td>FPGA</td>
<td>Field-Programmable Gate Array</td>
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<td>GA</td>
<td>General Assembly</td>
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<td>GPU</td>
<td>Graphic Processing Unit</td>
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<td>HCS</td>
<td>Health Classification System</td>
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<td>HL7</td>
<td>Health Level 7</td>
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<tr>
<td>HL7v3</td>
<td>Health Level 7, version 3</td>
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<td>HLS</td>
<td>High-level Synthesis</td>
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<td>IAB</td>
<td>Industrial Advisory Board</td>
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<td>JIT</td>
<td>Just in Time</td>
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<td>LFSR</td>
<td>Linear Feedback Shift Register</td>
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<td>NVRAM</td>
<td>Non-Volatile Random Access Memory</td>
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<td>OLAP</td>
<td>Online analytical processing</td>
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<td>OpenCL</td>
<td>Open Compute Language</td>
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<tr>
<td>PACT 2014</td>
<td>Parallel Architectures and Compilation Techniques Conference</td>
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<td>PCIe</td>
<td>Peripheral Component Interconnect</td>
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<td>PCM</td>
<td>Phase Change Memory</td>
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<tr>
<td>PDGF</td>
<td>Parallel Data Generation Framework</td>
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<td>PGCon 2014</td>
<td>PostgreSQL Conference for Users and Developers</td>
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<td>ptr</td>
<td>pointer</td>
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<td>RLS</td>
<td>Row Level Security</td>
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<td>ReRAM</td>
<td>Resistive RAM</td>
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<td>SIMD</td>
<td>Single Instruction, Multiple Data</td>
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<td>SQL</td>
<td>Structured Query Language</td>
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<td>SSB</td>
<td>Star Schema Benchmark</td>
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<td>SSD</td>
<td>Solid-state drive</td>
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<td>STT-RAM</td>
<td>Spin-transfer torque RAM</td>
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<td>TPC-H</td>
<td>Transaction Processing Council Benchmark H</td>
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<td>TPC-C</td>
<td>Transaction Processing Council Benchmark C</td>
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<td>VSR</td>
<td>Vectorised Serial Radix</td>
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<td>WP</td>
<td>Work Package</td>
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<td>XACML</td>
<td>eXtensible Access Control Markup Language</td>
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<td>XML</td>
<td>Extensible Markup Language</td>
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Publishable Summary

The Publishable Summary (Appendix 1) remains the same as the one presented in the Period 1 Report.

Work Package Update

Work Package 2: Security, Privacy and Audit

WP2: Project objectives for the period

The primary objective of WP 2 is to determine how to make analytics available in a timely manner without compromising confidentiality.

Security requires high quality software, so we discuss task completion for database kernel tasks in term of viable submissions into the PostgreSQL development process for the forthcoming 9.4 release. Our work here is required to go far beyond research.

The objectives of the third half year of the project were:

- delivery of D2.1 Row Level Security in PostgreSQL
- commence work on T2.2 Prepare SEPostgreSQL MAC for RLS
- continue work on T2.4 Map HL7v3, OpenEHR, Snomed-CT onto SELinux/SEPostgreSQL
- start Task T2.6 Visual Analytics and High Security

WP2: Work progress and achievements during the period

During the Period 1 Review the relevance of this work package was questioned, and following several partner discussions we have clarified the importance of security within the project from the legal and exploitation perspective.

Legal -

The main dataset being used in the AXLE project is that of Portavita and consists of real data that needs to be protected. Dealing with personal data raises big concerns about how access is carried out. In particular, patient data is considered a specific kind of personal data, and is 'sensitive data' in the sense of Directive 95/46 EC. This implies that there are strict limitations on who can access this data and under what circumstances. Our goal is to make sure that specific parts of patient data are only accessed by authorized users and that datasets are properly anonymised for data analytics purposes.
Exploitation -
Portavita aims to integrate AXLE into a system that will allow healthcare organizations to gain enhanced medical knowledge through large-scale data analytics. Experience has shown that healthcare organisations are reluctant to cooperate unless we ensure (and can prove) that their patients’ medical data is secure. In order to fully exploit the results of the AXLE project, it is fundamental to address the security and privacy of personal data.

Within T2.4 (Map HL7v3, OpenEHR, SNOMED-CT onto SELinux/SEPsql) PV has defined the requirements and sketched the design of a system that allows a secure and privacy-aware way to access patient data for analytical purposes. In January 2014, the design of their data access system was presented to the community of interoperability and standards in healthcare (HL7), where it was confirmed to be in line with the security community’s current work. This increases the relevance of AXLE results beyond the scope of the project and paves the way for further exploitation of the project.

Upon reflection, there are three tasks that are crucial to meeting the legal and end-user needs: The goal of task 2.5 (Create a Medical Security Policy Generator) is to implement scalable security for healthcare analytics by automating policy authoring from the data sources with the mapping made in task 2.4. Combined with results from task 2.1 (Row Level Security in PostgreSQL), task 2.5 will allow us to implement policy decisions on a relational database with RLS. Automated access management to protected health information is essential for analytics on healthcare databases on a large scale.

The remaining tasks in WP2 are not fundamental to the security and privacy of the queries on the PV dataset (T6.2) and time allocated to these tasks will be reallocated.

T2.1 Row Level Security (RLS) in PostgreSQL
Work on T2.1 changed direction at a technical level during Period 1. That change has been successful and the resulting infrastructure is now part of PostgreSQL 9.4.

A great deal of work on row security centred on meeting community expectations and requirements, rather than delivering the features themselves. The code has been feature-complete since the 9.3 cycle, but it was necessary to re-work it completely to meet community expectations around maintainability, modularity, clarity and style. Instead of manipulating query planner structures directly as the patch did originally, it had to be rebuilt on top of the security barrier views infrastructure, which itself required a major enhancement to support updateable security barrier views before it could meet the needs of row security.

A major pre-requisite for row security support, updatable security barrier views, was successfully committed to 9.4. This will greatly ease the process of getting the
redesigned row security patch committed early in 9.5.

This design is far better than the original, and it is optimisable so can make queries that utilise row level security faster through the potential use of indexing. And this is a considerable improvement on what we had originally planned.

There are three outstanding technical requirements that need to be completed before the feature can be committed, and we estimate approximately one month for this.

T2.2 Prepare SEPostgreSQL MAC for RLS
This task has not been started following the Period 1 Review recommendation to halt work on Security. The decision taken at the April 2014 GA was to cancel this task and re-allocate resources elsewhere. This is acceptable to the PV use case.

T2.3 Auditing in PostgreSQL
Auditing capabilities in the “event triggers” feature have been augmented with the ability to record object creation and modification (SQL commands CREATE and ALTER); previously only object removal information was available (SQL command DROP). A community-approved design is being implemented that allows access to SQL commands as they are executed, in a structured format (JSON). This allows programmatic access to the various parts of the command, as well as long-term storage in an audit log table or similar. A normalized version of the original command, or of a modified version of the command, should the user decide to modify it, can also be obtained. As a bonus, since the event triggers run in the same transaction as the command, business rules can be enforced by raising errors from the user-written code.

An audit module has also been developed as an extension to PostgreSQL that can use the latest event trigger support to log an unambiguous representation of DDL commands (but works on 9.3 and 9.4 with slightly reduced functionality). It can log DDL (using event triggers and a utility command hook) and DML (including read access to tables via SELECT). The code is available at https://github.com/2ndQuadrant/pgaudit.

T2.4 Map HL7v3, OpenEHR, SNOMED-CT onto SELinux/SEPostgreSQL
The work we are conducting on security and privacy can be grouped into the following parts:

Access control

The goal of this task is to build a mechanism that allows only authorized users to perform determined actions on patient data. Actions, in a large healthcare database setting, include view data for primary/secondary use. Considering the complexity of the database, it should be possible to easily and unambiguously determine data access policies and enforce them against the dataset. As policies may vary over time, the system should allow users to modify and integrate them. We use XACML, a well-known
standard for expressing access policies and controlling access in accordance with such policies. This approach follows the guidelines of Health Classification System (HCS), a document released by the community of interoperability and standards in healthcare, HL7. HCS is the result of a long consultation with experts and interest groups in healthcare, having in mind issues related to security and privacy of patient data.

While various implementations of XACML are already available, the challenging aspect of this task is related to the scale of patient data. A large-scale healthcare database is not only characterized by large volume, but also many different sources and interacting parties. Consequently, a large variety of policies may govern access to health data. To speed up the process of access control we use natively supported database controls. More specifically, we compile access policies into Row Level Security (RLS) statements.

To date, we have completed the analysis of requirements for access control management of health records in a HL7v3 data model and sketched a preliminary design of the system. Moreover, we have tested the current version of RLS (PostgreSQL 9.4) against a small HL7v3 database.

De-identification
To perform analytics in a dataset containing personal data it is a legal requirement to properly anonymise the dataset. Suppressing direct identifiers of personal records (e.g. name, social security number and so on) may not be enough. In fact, other attributes, such as age group, gender, profession, details about the disease, and/or location can under some circumstances indirectly identify individuals.

K-anonymity algorithms are the prevailing approach to de-identification. They ensure that the number of records sharing the same attributes (equivalence class) is high enough so as to minimize the risk of re-identification. This is typically done by reducing the precision of high-risk attributes. For example, dates can be generalized to years, zip codes can be generalized to the first three digits and so on. A major issue with these algorithms is finding a balance between the utility of de-identified data and the risk of data disclosure: too much generalization reduces data utility, whereas too little may expose individuals to the risk of re-identification. To find an optimal generalization of the attributes, k-anonymity algorithms perform a large number of iterative computations on the dataset that is to be de-identified. Adopting state-of-the-art k-anonymity algorithms on very large datasets may be unrealistic. In this context, we are working to improve a selected k-anonymity algorithm to efficiently de-identify large datasets.

To date, we have investigated possible de-identification techniques for healthcare data and implemented a k-anonymity algorithm. We aim at estimating computational costs for very large datasets and seek possible optimizations (may involve cooperation with UNIMAN for implementation in GPUs).
T2.5 Create a Medical Security Policy Generator
This task is not scheduled to begin until Month 25 of the project.

T2.6 Visual Analytics and High Security
Following the suggestions from the review meeting and the discussions at the April GA, it has been decided to abandon this task and reallocate the remaining project months to other tasks.

Work Package 3: Scalability Engineering

WP3: Project objectives for the period
The objective of this work package is to innovate, design and implement different kinds of SQL queries on multi-cores, heterogeneous many-cores and clouds in order to determine how to execute queries efficiently on these environments.

M13 - M18 activity description:
- Augment set of queries covered and by hand transformation. Generate training dataset (M13-M16)
- Implement in JIT GPU generation and introduce learning mechanism for scheduling (M17-M24)

WP3: Work progress and achievements during the period

T3.1 Dynamic Compilation and Optimization SQL Searches
We are investigating ways of using GPUs with current limitations, high PCIe transfer overhead and small memory (relative to CPUs). We have started developing and implementing database operators for GPUs. We are currently focused on the four basic operators: select, join, aggregate and sort. The operators are generic (i.e. are not targeting any particular platform) so should be easily integrated into any DBMS. We will be using the Star Schema Benchmark (SSBM) - best described as the star schema version of TPC-H - for our initial evaluation workload as it has fewer operators. However, the techniques/ algorithms developed are not tied to SSBM. We anticipate using the operators to accelerate TPC-H. The language of implementation is OpenCL which relies on JIT code generation to achieve binary portability.

We are improving our CPU performance counters based query execution time predictor (the predictor is described in Period 1 Report). The predictor will be the basis of our machine learning query scheduler (see Period 1 Report). We have improved prediction accuracy dramatically by using regression trees (which employ decision trees as the
predictive model). We have now started extending our query predictor to handle multiple query prediction. We are also investigating, using PostgreSQL’s query planner, cost estimates to predict query execution time.

During the Period 1 Review meeting, the reviewers made two suggestions with relation to Task 3.1.

1. AXLE team should consider entering the http://sortbenchmark.org competition.

UNIMAN did investigate the competition and decided against entering. The bitonic sorter relies heavily on CPU vector (SIMD) instructions. It is primarily efficient because n input records can be held in a single register and sorted by “mimicking” a bitonic network. However, sortbenchmark.org requires sorting input records of 100 bytes in length which would not fit in any SIMD register presently. It may be possible to sort byte-by-byte but that would result in a very inefficient implementation.

2. In the future better machine learning methods (e.g., online learning) will be used for JIT optimizations. The outcome of this effort should be published in a major database journal or conference, and presented in the next project review.

UNIMAN is already looking into applying machine learning to JIT code generation. And although our aim is to publish or present our findings, We are not sure of having a system that is sufficiently “polished” for the prestigious conferences by the next project review as JIT code generation involves a lot of “engineering” in addition to the research aspects.

**T3.2 Outboard Sort with GPUs**

Following discussions at the April GA, it has been decided to cancel this task as it duplicates work being done in T3.1 by UNIMAN.

**T3.3 Autopartitioning**

Autopartitioning has taken the form of a new type of index, which we call the “MinMax indexes”. This gives users a large degree of flexibility in defining the tables (and columns therein) that are considered for MinMax data collection.

MinMax indexes represent a novel way of characterising data in very large tables that allows very rapid scanning of such tables during queries, without imposing the performance cost that normal (B-Tree, etc) indexes do. This works by storing the greatest and least values for each indexed column of portions of the indexed table.
During querying, these stored values can be used to skip scanning those portions of the table that do not match the query conditions; in essence, each such portion is an automatically-maintained partition of the table.

The performance cost imposed by having such an index is constant and small, rather than linearly growing as would be with other indexes. This enables maintaining Minmax indexes for several columns of each table, something that would be prohibitive with B-trees because of the decreasing performance as the table grows.

The implementation that has been coded for T3.3 has gone through user community testing and development community design discussion, and there's been great interest from both communities.

**T3.4 Bitmap indexing and GPUs**
This task is divided into several sub-projects, and work had commenced on several elements of the task during Period 1.

During the Period 1 Review meeting it was recommended that 2ndQ investigate column orientation. This task was already outlined in the Description of Work, but named incorrectly. Work on column orientation has started but won't fully complete until the end of the project as it is such a long task. Detailed design for the column orientation aspect begins on 20th May 2014. To be effective 2ndQ must gain “buy in” from the wider PostgreSQL community, and our attendance in strength at PGCon 2014 (PostgreSQL Conference for Users and Developers) is very important to that goal.

**Work Package 4: Advanced Architectures**

**WP4: Project objectives for the period**

The overall WP4 objective is to investigate and to propose advanced hardware architectures that can accelerate and facilitate the design of database management systems.

The following section outlines the objectives for the current period and reports on current progress.

**WP4: Work progress and achievements during the period**

**T4.1 Characterize the DBMS execution and describe the potential hardware extensions**

This task was completed in Period 1 and was reported on in the Period 1 Report (December 2013). However, further characterization might be needed when analyzing workloads other than TPC-H on different platforms/machines and in other tasks.
T4.2 Acceleration with novel vector operations

In the Period 1 Report we introduced our proposed vector extensions which accelerate hash join operations. In order to provide further acceleration using vector operations, we are now focusing on sorting acceleration. To this end, we are working on a novel variant of a vectorized radix sort that parallelizes the algorithm more efficiently. This new technique, called VSR, makes use of two novel vector instructions that require simple microarchitectural changes. As is the case with the instructions that were proposed for hash joins, these new instructions might have other uses beyond sorting. The work was submitted to the PACT 2014 conference, and is currently under review.

![Performance numbers for the VSR vector sorting algorithm](image)

**Figure 1:** Performance numbers for the VSR vector sorting algorithm

Preliminary results show significant speedups (2-3x) over the next best data parallel algorithm, and ~10x over scalar algorithms for large datasets. The reported results are obtained using a column-store-like DBMS (VectorWise) in our simulations. In order to perform experiments using PostgreSQL, certain changes in the way the data is presented for processing are needed to take advantage of these vector instructions. Solutions to feed the PostgreSQL data in a suitable way to be processed by vector instructions are being discussed and will be explored in the following months.

T4.3 Accelerating database queries using FPGAs

Database operations that join two tables using a common column are frequent and time-consuming. The hash join algorithm consists of first building a hash table using the
smaller table (T1) and then probing it with all the rows of the larger table (T2). In our implementation, each hash table entry contains the matching key and a pointer (ptr) to a list of all the rows with that key in T1. The hash function was implemented as a Linear Feedback Shift Register (LFSR). If the hash indexes of two keys collide, the latter key is inserted in the next consecutive empty bucket of the hash table.

We first preload the hash table into the BRAMs of the FPGA. Then, for each (key, rowID) input tuple of table T2, a hash index is calculated and the hash table is probed for matches. Starting from that index, all the non-empty consecutive entries of the hash table are checked. If the keys in the hash table entry and the T2 tuple match, the result (T1 ptr, T2 rowID) is outputted. If an empty bucket is found, the current T2 tuple does not exist in the hash table and is skipped.

As an acceleration example, we joined two tables of 400MB and 600MB of size. The measured throughput numbers for the probe algorithm were 433MB/s on our optimized server, and up to 1GB/s for the specialized hardware unit that we designed. We expect further speedups by also implementing the hash table build phase in hardware.

Additionally, we have also built an experimental environment on an older Virtex-5 board, where we can access an SSD at speeds of 250 MB/s and hence work with very large tables on the FPGA. We will port this design to our new Virtex-7 board and interface PostgreSQL server (by building foreign tables) with a 5 GB/s PCIe connection through DMA. This will help us to work with real I/O constraints, which was also pointed out to us in the first year review meeting.

Our first publication attempt in FCCM 2014 resulted in acceptance as a poster, so we have skipped that and resubmitted our HLS comparison paper to FPL 2014 (under review). The new submission also includes the hash probe benchmark, as well as addressing other issues that were raised by the FCCM reviewers.

T4.4 A simulation platform for the emerging memory technologies
Activities related to this task were confined within Period 1. However, the simulator platform continues to be extended in the context of task T4.5 with the addition of NVRAM and 3D stacking features.
Note regarding simulator base infrastructure: Our initial evaluation for the Period 1 Report was done using SniperSim. However, the fork-based model used in PostgreSQL makes the execution of multiple simultaneous queries on SniperSim impossible. Since we want to explore scenarios where multiple queries run simultaneously, and despite the great user experience we had with Sniper, we migrated to another Pin-based simulator, called ZSim, which was also mentioned as an option in deliverable D4.4. ZSim implements a virtualization layer that allows multiple processes to run within the simulator, supporting applications like PostgreSQL with multiple clients.

T4.5 Emerging memory technologies: Non-Volatile RAM Memory and 3D stacking
We developed a comprehensive profiler infrastructure to run several workloads (i.e., TPC-H and TPC-C). The infrastructure allows us to run single or multiple query streams in two different environments. The first being the AXLE server deployed in Barcelona, and the second is the simulation infrastructure that we are developing. When running in the AXLE server, we make use of hardware performance counters -- using the perf toolset -- to gather statistics of query executions on PostgreSQL. These statistics allow us to compute several metrics of interest -- i.e. instructions per cycle or misses experienced in the different levels of the memory hierarchy -- and observe the inefficiencies that are present in current processors. We can also execute the same queries within the simulator (based on ZSim) and extract similar metrics. We are currently validating the simulator by comparing obtained metrics with runs done in the AXLE server.

The next step is to integrate within the simulator platform the possibility to choose different NVRAM technologies. To achieve this, we are going to integrate a cycle-accurate main memory simulator (NVMAIN), which contains performance and power models for all the relevant technologies of interest to the AXLE project. These include Phase Change Memory (PCM), Spin-transfer torque RAM (STT-RAM) and Resistive RAM (ReRAM). This will be part of the open source simulator release planned for M24. The simulator infrastructure will then be used to propose architectural improvements to simplify DBMS design or to accelerate its execution.
Work Package 5: Visual Analytics

WP5: Project objectives for the period
Over the lifetime of the project, the objective in WP5 is to explore the techniques for visual analysis of large volume data and to provide working prototypes of a practical implementation.

In this period we focused on addressing the comments made at the annual review at M12, which concur with our observations and set the goals for the second year.

- UL, which leads this work package, should collaborate closely with 2ndQ to optimize the execution of queries passed between widgets.
- It is essential to start testing the code on larger databases so appropriate adjustments can be made as soon as possible.
- Take the potential users, such as PV, into consideration.

Description of the work, which follows below, is written from the perspective of these points.

WP5: Work progress and achievements during the period

T5.1. Integration between Orange and PostgreSQL
This task has been completed and reported on in the first year. In this period we added minor improvements and bug fixes to the code.

T5.2 Adaptation of standard visualizations for large datasets
We have completed porting a selection of the most common standard visualization techniques to the new platform, which can handle the data stored in databases.

Scatter plots are represented as heat maps, which are constructed iteratively. The process starts with a 10-by-10 grid; the database is queried for target value distribution for each grid element and the user is given the first rough image of the emerging heat map. Next, the algorithm computes the p-value of the chi-square significance tests for all neighbouring cells, organizes them into a priority queue and keeps refining the image by further dividing the cells by the borders with the lowest p-values. The resulting finer-resolution borders are put into the same priority queue. Details of the algorithm will be described in the annual report.

The way in which algorithms works will help in optimizing for large data in two ways. First, the algorithm executes multiple similar queries at once, so database should be able to combine them. Second, since the algorithm does not show individual data points but only distributions, we can speed it up by implementing approximate queries in the database.

Box plots are computed from aggregated data (distributions). Although this widget was
finished at M12, we have been using it as a test bed for approximate queries and incremental updates. We are investigating possible protocols to be used for this setup.

For **Parallel coordinates**, we have developed a new method for aggregating the lines, which is similar to Gaussian mixture models. The prototype, which we described in the report at M12, has been completed and we are preparing a publication about it. The algorithm solves the problems appearing with the commonly used methods, shown in Figure 3. Algorithms that cluster instances based on all variables might join the top most clusters (Region 2) and instead decide to split the bottom cluster. Region 1 would prove problematic for algorithms that cluster each variable separately. Cluster covering this region would be connected to a large interval of values on the neighbouring variables, resulting in an uninformative bar that covers too many instances.

![Figure 3: Potential problems when using k-means for optimizing parallel coordinates](image)

The algorithm shows favourable results, both quantitatively and visually, in comparison with both obvious alternatives, that is, using k-means clustering on each variable separately or computing the Gaussian mixture models across all variables.

**Mosaic plots** and **Sieve diagrams** have been ported to the new platform in such a way that they do not require any other data than contingency matrices of appropriate dimensions.

**T5.3. Intelligent visualization algorithms for very large data bases**

We have modified the definition of Tukey’s Projection pursuit to be able to compute it from contingency tables. We are preparing a technical report and we are working on the actual implementation of the algorithm.

**T5.4. Interactive data exploration in server based architecture and T5.5. Data-flow visual analytic tools for large data bases**

For the sake of this report, we will treat these two tasks together. Reviewers questioned the usefulness of the Orange to end-users in the light of the conclusions from the joint PV-UL workshop. These stem from the wrong perception of what Orange is: Orange is a
data mining tool, while the attendees of the workshop expected a business reporting tool. In line with this, users of Orange need to understand the (common) data mining methods it implements. Among the users of Portavita’s services are, however, also researchers that need a proper data mining tool like Orange.

Changing Orange to a business reporting tool would downgrade the project goals to reinventing OLAP-like data warehousing or data marts. However, as a possible middle path, we have designed a new architecture consisting of a back-end which performs off-line pre-processing of the data as programmed by skilled users, and front-ends for different types of users.

This new architecture will also help push Orange to work on terabyte data: having the same responsive, interactive interface as for in-memory data may be unreachable with the current technology, so the back-end would pre-process the data to facilitate interactive data analysis with interactive front-ends.

We have started implementing the proposed framework. The back-end (Figure 4) implements a data flow in a way that resembles the widgets and signals used in Orange Canvas. The user, who needs to have a good knowledge of the system, can use (or, if he knows how to program, even define) processors, which like Orange’s widgets, read the data and write it. The input to a processor is a file with data or meta data, such as SQL queries. Processors are triggered by user-specified triggers, which are typically based on data availability.

The front-end will resemble a much simplified version of Orange Canvas. Its actual configuration can be tailored to different end users.

Unlike the versatile widgets of Orange Canvas, processors in this system are more rigid and do not interact with the user. This makes it easier to control their execution and optimize it by observing the regularities in the data queries. This approach alleviates the problem we detected in the first year: the coding complexity of providing large scale data processing, while dynamically responding to user actions. Even the simplest actions, like cancelling of the analysis tended to be difficult to implement. This new system has, on one hand, less user interaction since the processing is done offline and in the background; on the other hand, processes can be interrupted by simply stopping the corresponding shell script through an appropriate (web) interface.
Work Package 6: Evaluation on Real Data

WP6: Project objectives for the period
The main objective for WP6 is to evaluate all techniques developed as part of the AXLE project against real or very realistic data.

The objectives for the third half year were:
- enhancements of the AXLE dataset generator for performance improvements and adding queries
- evaluation testing

WP6: Work progress and achievements during the period

T6.1 Set up and run evaluation environment
As reported in the Period 1 report (submitted December 2013), two evaluation environments have been set up - Barcelona and Manchester. Baseline testing has been completed and benchmark documentation produced, although we expect this to be a living document with changes made as necessary during the project.

T6.2 Synthetically expand and anonymise the Portavita data
In the last six months we have focused our work on three areas: (1) adding benchmark queries, (2) speeding up the data generation process, and (3) increasing the types of data that can be generated. The first focus point is necessary in order for the dataset to be useful as a benchmark. The work is further described in section T6.3. Earlier, generating terabytes of data took weeks, which was unacceptable. Therefore, we decided to put effort into speeding it up. Finally, to make the benchmark queries more diverse, it was necessary to generate more types of data.
Structured clinical data is complex and it is essential to capture the intricate details between its parts correctly. To this end, the dataset generator was designed to consist of two components: (1) the generator that generates messages in standard health-care formats, and (2) a Extract Load Transform (ELT) component that takes health-care messages, pre-processes the data, and inserts it into the data warehouse. The two components communicate through a message broker. This main advantages of this approach are that the generated messages can be used in other datasets and databases, and that other sources that generate such messages can be added to the dataset. The drawback is that this architecture requires more computation than directly generating CSV, as is done by generators such as TPC-H and PDGF\(^1\). Nonetheless, in the previous period, the generation speed has been improved drastically such that the datasets for AXLE can be generated in a matter of days.

More types of data
Before this period, we focused on generating observation data such as blood pressure and weight, because this is the essential data most queries are interested in: observations represent the core of Portavita’s data. Furthermore, realistic observations are by far the most complex to generate. However, while writing the benchmark queries, it became apparent that many queries require more different types of data. For example, the queries that compare the performance of organizations require that every observation is related to an organization. The types of data that have been added are treatments, organizations, organization hierarchies, practitioners, patient records, and more extensive observations.

The benchmark queries that we have written have dictated what extra types of data were required. Next, we searched for appropriate standard representations for these types of data. Treatment data is encoded using CDA\(^2\) and for the other types FHIR\(^3\) was chosen. Both are international standards for medical data. We chose to use two different kinds of representations because FHIR was significantly simpler than CDA for a number of types of data.

Performance
The ELT process of the first dataset generator, delivered in M6 of the project, was slow: it took weeks to generate multiple TBs of data. Several bottlenecks were identified and addressed. The new version removes one transformation step in the process since the integration schema is used as warehouse schema. Also, we have worked on an architecture that enables running multiple ELT processes in parallel in a distributed system. The ELT process can be divided into four stages: (1) validate the incoming data, (2) transform the data into SQL insert statements, (3) load batches of statements into an intermediary database and pre-process the data, and (4) load them into the data

\(^{1}\) Parallel Data Generation Framework, see http://www.paralleldatageneration.org/

\(^{2}\) Clinical Document Architecture (CDA) is a XML-based HL7 standard for encoding and exchanging clinical documents

\(^{3}\) Fast Health-care Interoperability Resources (FHIR) is another HL7 standard for encoding and exchanging clinical documents

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warehouse. This division allows scaling every stage to as many nodes as required, which greatly speeds up the generation process. Currently the speed is as follows. On a setup with 11 virtual machines (8 cores each) running both the message generator and ELT components we now generate ~1.5GB of data per minute, which means it takes ~4 days to generate 10TB. This number can be increased even more with the current architecture (by just adding more virtual machines), however it depends mostly on the speed in which the data warehouse can load the resulting data.

Conclusion
We consider the implementation of the data generator completed, highly performing and ready for use by our partners. During the last GA in Manchester (April 2014) we presented the data generator and gave a demo on how the data generator can be used. During this presentation, a request was made from the partners to do a more extensive validation of the generated data against the real patient dataset of Portavita. We will take action on this in the coming two months.

T6.3 Benchmark result framework/web access
Providing a set of queries to run on the dataset is essential for it to be used as a benchmark. We have investigated Portavita’s application to find queries that relevant for a data analytics benchmark and we selected 15 queries. The selected queries can roughly be categorized as:

- **comparative analysis**: compare the performance of organizations and practitioners
- **extreme values**: find all patients whose observation values are troublesome
- **data analysis**: retrieve data for analysis and research, e.g. to measure the effects of medication
- **trend analysis**: find trends, e.g. how often examinations are performed
- **scientific research**: find relevant patients (satisfying inclusion criteria) and data about them

We have written a document that describes these queries and their business case. For every query we describe what types of users perform these queries. For the data analytics use case in real life, it is essential that a user can only access those data that he is allowed to access. For example, a doctor should only see the data of his patients. In the document we also describe several conditions for when a user can see a particular piece of data.

To ease the use of the data generator by the partners, we are working on rewriting the above-mentioned benchmark queries to work on the data warehouse. While the document describing the queries is complete, we plan to finish rewriting the benchmark queries in the coming two months.
**T6.4 Evaluation Testing**

2ndQ configured the Manchester server and has assisted with the BSC set up. In order to show any improvements made in the analysis of big data, a baseline/ benchmark of results was required. To this end, a modified version of the TPC’s “TPC-H” benchmark has been installed. The benchmark contains 22 different queries, two of which have been replaced with logically equivalent queries following 2ndQuadrant’s investigation into optimal planning. The TPC-H benchmark works with datasets of variable sizes which can be chosen for each run and baseline timings have been taken with datasets of 1GB, 10GB, 100GB, and 1000GB. These baselines are recorded on the server using the labels baseline_1GB, baseline_10GB, baseline_100GB, and baseline_1000GB respectively.

Each run of the benchmark records the time taken for the individual queries, detailed breakdowns (EXPLAIN ANALYZE output) of the execution of the queries, and operating-system-level i/o counts during the benchmark.

This baseline represents the performance of a PostgreSQL installation appropriately configured for a server of this size but not specifically optimized for this workload. It can be used to measure the improvement given by a modified PostgreSQL server or a modified configuration. Performance changes made relative to this baseline may be further analyzed by reference to the benchmark outputs.

**Work Package 7: Exploitation and Dissemination**

**WP7: Project objectives for the period**
Throughout the project, efforts in WP7 are to formalise a cohesive campaign of awareness of the project and project results to generate a pool of interested technology transfer partners.

This is an area of great importance to the project, but also one which has proved challenging in the early stages as there have not been vast changes to report while systems were established and research initiated. As deliverables have been submitted, there is more to disseminate and exploit.

**WP7: Work progress and achievements during the period**

*T7.1. Dissemination & technology transfer strategy definition*
Completed and reported in Period 1.
T7.2. Press releases

Although our initial strategy was to submit press releases every six months of the project lifetime, this has not proved feasible in practice. Dissemination effort was discussed at length during the April 2014 GA, particularly the negative impact of releasing information about results or product development before these are sufficiently established.

PV will publish a press release about the data set generator later in period 2, but in the meantime all partners will review their work and determine topics for press releases.

T7.3. Dissemination tools

The majority of our dissemination tools were developed in Period 1, but the poster template was completed (with 3 options) early in Period 2 to be used at conferences and dissemination events.

T7.4. Partner dissemination

Partner dissemination was not as prolific as expected in Period 1, but we have improved upon this in Period 2:

Unfortunately, some dissemination that took place during Period 1 was not reported internally, highlighting some shortcomings within the Consortium communication channels. This issue was addressed during the April GA.

Blogs

<table>
<thead>
<tr>
<th>Partner</th>
<th>Period 1 activity (not reported)</th>
<th>Period 2 activity (up to and incl. PM18)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2ndQ</td>
<td></td>
<td>• Row Level Security (February 2014)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• AXLE Plans for 9.5 and 9.6 (April 2014)</td>
</tr>
<tr>
<td>PV</td>
<td>• 1 (launch of project - translated from the original Dutch to English, French and German)</td>
<td>• 2 regarding HL7 security (Dutch and English)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 1 about access to patient data</td>
</tr>
<tr>
<td>BSC</td>
<td>• 1 (launch of project)</td>
<td></td>
</tr>
<tr>
<td>UNIMAN</td>
<td>• 1 (launch of project)</td>
<td></td>
</tr>
<tr>
<td>UL</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Blog Activity
During the April GA, it was agreed that individual researchers and developers should blog about their chosen areas. Topics and deadlines were obtained for future blogs from all partners, including:

- May 2014 - PV - De-identification
- June 2014 - UL - Parallel Coordinates
- July 2014 - 2ndQ - Binning
- August 2014 - BSC - Performance Analysis
- September 2014 - UL - Scatter Plots and Heat Maps
- October 2014 - BSC - Simulator release

There will be at least one blog per month, and these blogs will be linked to the AXLE project website. There is discussion about creating a blog page on the project website if this provides a more accessible blog platform for contributors.

**Virtual Networks**

Although the partners had joined virtual networks during Period 1; the Consortium has created an AXLE group within linkedin during Period 2: https://www.linkedin.com/groups/AXLE-Advanced-Analytics-Extremely-Large-8104478 to further expand their networking activity.

**Presentations**

Portavita presented to the HL7 working group in San Antonio, Texas on 21st January 2014. The presentation was a use case on using HL7 standards on privacy, entitled “Privacy-aware analytics on healthcare data”.

Simon Riggs has been represented 2ndQ and AXLE at the following events, where he was a speaker and covered AXLE within each of his talks.

- PGConf.DE 8/11/13 - PostgreSQL & Business Intelligence
- PGDay Argentina 14/11/13 - PostgreSQL Futures
- PGDay Ecuador 27/11/13 - PostgreSQL Futures
- PGConf NYC 3-4/4/14 - Row Level Security for PostgreSQL
- Prague SQL Developer 6/2/14 - PostgreSQL & Business Intelligence
- FLOSS UK 19/03/14 - State of PostgreSQL Database

Further dissemination events are included in the 2ndQ calendar with PGCon 2014 (May 2014, Canada - Postgres Conference for Users and Developers) and Char14 (July 2014, UK - PostgreSQL conference on clustering, HA and replication techniques) coming up in the second half of this reporting period.
Publications
BSC, UNIMAN and UL have submitted papers during this period for review:

<table>
<thead>
<tr>
<th>Partner</th>
<th>Publication Title</th>
<th>Type</th>
<th>Conference/Publication Title</th>
<th>Accepted? yes/ no</th>
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</thead>
<tbody>
<tr>
<td>UL</td>
<td>Concurrent software architectures for exploratory data analysis</td>
<td>Journal</td>
<td>Knowledge and Information Systems</td>
<td>pending</td>
</tr>
<tr>
<td>BSC/UNIMAN</td>
<td>Using FPGA design tools for database acceleration</td>
<td>Conference</td>
<td>FCCM</td>
<td>n</td>
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<tr>
<td>BSC/UNIMAN</td>
<td>Using FPGA design tools for database acceleration</td>
<td>Conference</td>
<td>FPL</td>
<td>pending</td>
</tr>
</tbody>
</table>

Table 2: Publications

Work Package 1: Coordination and Management

The overarching objective of WP1 is to provide efficient operational management support to ensure the project delivers on its scientific and technical objectives.

WP1: Work progress and achievements during the period

In terms of project coordination and management, this six month period has been mostly concerned with reporting and face-to-face progress meetings.

- There have been six monthly GA teleconferences and one face-to-face GA (Manchester, April 2014)
- Electronic reporting was implemented
- The Period 1 Report was delivered (after several attempts), accepted and payments distributed to all partners
- All partners attended the Period 1 Review Meeting in Luxembourg (January 2014)

Project management during the period

- There have not been any changes to the consortium within this period
- There have been no changes to legal status.
Problems which have occurred and how they were solved or envisaged solutions

- 2ndQ, UNIMAN and UL were all significantly below plan on anticipated effort during Period 1. The project month split has been altered to reflect the project months available to each partner, and this will be re-evaluated at the end of Period 2. At this stage in the reporting period, all partners have used between 40% and 50% of their allocated time for Period 2.

Project meetings, dates and venues

- Month 13 Conference Call, 20th November 2013, powwownow
- Month 14 Conference Call, 11th December 2013, powwownow
- Month 15 Conference Call, 15th January 2014, powwownow
- Month 16 Conference Call, 19th February 2014, powwownow
- Month 17 Conference Call, 19th March 2014, powwownow
- Month 18 Conference Call, 16th April 2014, powwownow
- Face-to-face GA, 29th April - 1st May 2014, UNIMAN Manchester

Project planning and status

- The project is still proceeding broadly as planned at this stage. The Period 1 review recommendations have caused several tasks to be reconsidered, but the changes will not affect the overall outcome of the project.
- Scientific work is progressing well with encouraging results emerging in all work packages.
- Dissemination is still a challenge for the consortium. A different approach to dissemination is being attempted to ensure that the partners not only catch up on the dissemination and exploitation missing from Period 1, but exceed that planned for Period 2. To this end a blogging timetable has been established, and topics for press releases discussed.
- The deliverables for Period 2 are largely loaded towards the end of the period. This could present challenges for the partners as there are 8 deliverables and 2 reports due at almost the same time. At the 18 month stage, the partners are confident that they can achieve these targets.
- The consortium struggled with staff deployment in Period 1. Fortunately all partners have increased their staffing levels and the benefits of this are already being seen.
Impact of possible deviations from the planned milestones and deliverables, if any

Significant changes to the project plan have been brought about by the Period 1 Review and the reviewers’ recommendations:

- WP2: work on security has been re-assessed and D2.1 (Row Level Security) will be realised but T2.2 (SEPostgreSQL MAC for Row Level Security) - and resulting D2.2 - will be cancelled. 2ndQ will reallocate resources to other parts of the project as outlined in the Period 1 Review Response. As part of the assessment of the work package, T2.6 (Visual Analytics and High Security) - and therefore, D2.6 - has also been cancelled.

WP3: It was determined that T3.2 (Outboard Sort with GPUs) - a task that had been deferred from Period 1 due to work being conducted within the PostgreSQL community - overlaps significantly with T3.1 (Dynamic Compilation and Optimization SQL Searches) and so this task will be cancelled and resources re-allocated where they will be of most benefit to the project.

The overall project will not be negatively affected by any changes made to the original plan.

Development of the project website

Updates are ongoing, in particular after each GA or Period end. In addition, the partners are researching a blog page rather than a series of links to external partner blogs from the news page.

Communication

Communication within, and to the outside community, is improving as the project develops. The April GA in Manchester was an excellent example of this - the GA was an opportunity to update each other on progress to date, but also to work together. Working sessions were allocated to various topics throughout the GA, and strong channels of communication opened between partners and individuals who had not worked together face to face in the past. The new team members found this GA particularly beneficial.

The consortium is embracing Twitter as a further means of dissemination, and although it is “early days” there does appear to be interest in this social media format.
Explanation of the use of resources

Effort and Activity

With changes being made to the resource allocation following the Period 1 Review meeting, the data to accurately calculate the actual effort vs planned effort will only be available later in the period. Using the original plan figures (with Period 2 adjusted for Period 1 over/under “spend”), the actual effort is as follows:

2ndQ
2ndQuadrant has used 45% of its allocated man months in Period 2. This is a marked improvement on Period 1 where 2ndQ was 22% lower on time than expected.

A new developer commenced work on Row Level Security in Month 12 of the project, and further recruitment has led to another developer starting on the AXLE Project in Month 17. In addition, two further developers joined 2ndQuadrant in the first six months of this reporting period. This increase in team number coupled with intensive work on the PostgreSQL commit cycle has resulted in greater person-months than anticipated.

BSC
BSC has utilised approximately 57% of its allocated time budget for Period 2 in the last 6 months.

A new PhD student commenced work on the project in M16 and his contribution will assist BSC in maintaining their current work plan.

PV
PV has used c.77% of its planned time in Period 2.

With several new recruits, PV has increased its efforts on the dataset generator and de-identification of data.

UNIMAN
UNIMAN is operating at 41% of its planned effort/activity.

UNIMAN has employed a further member of the AXLE team during the last 6 months, hence a dramatic improvement over Period 1.

UL
In the first five months of Period 2 UL had utilised 40% of their anticipated time for this period, indicating that they should be on track for the rest of year 2.
IAB Feedback

The IAB meeting held during the October 2013 GA was very useful to the project. Following detailed partner updates at the GA, IAB members reflected on the project and identified four main areas for further consideration by the partners:

- **the business proposition for the project**
  - the IAB members wished for more clarity on what problems the AXLE project solves for industry, and how the project could be monetized
  - they also recommended that we have a simple story to communicate to the general public (this will help with dissemination and exploitation)

  *action taken:*
  - a discussion was held during the April GA to outline options for how the project could be monetized (this included discussion about the PostgreSQL hardware option).
  - the website updates are kept simple, and the blogs written to date have been aimed at the general public. Future written dissemination will continue to be “simple” to allow for wider audience access.

- **security/privacy**
  - this was identified as a crucial work package to underpin the project and encourage take up.

  *action taken:*
  - The partners agreed with the IAB on this point. This work package has been a challenging one for both PV and 2ndQ as developers with the specific skill set required for the tasks were difficult to find and bring up to speed. In the last 6 months vast progress has been made by both partners in their respective tasks (see work package updates for details).

- **PostgreSQL hardware outcome**
  - the IAB members thought that a “Postgres box” would be a viable product to take to market.

  *action taken:*
  - The partners agreed to discuss this topic at a future GA. The review meeting also outlined a similar outcome. The IAB and Reviewers’ suggestions regarding hardware have been investigated and discussions started within the consortium.

- **good visualisations**
  - the IAB was interested in the ability to suggest good visualisations and were hoping to see significant progress at the next IAB meeting.

  *action taken:*
  - further work was already planned for this work package.

It was hoped that there could be a second IAB meeting at the April 2014 GA, but several of the IAB members could not attend due to work commitments. It was decided to postpone the IAB meeting until October 2014 and involve as many of the IAB members as possible in an agenda similar to that of the April GA.
Review Meeting 24th January 2014
The Consortium attended the Period 1 Review Meeting in Luxembourg in January. Work has already commenced on several recommendations voiced during the meeting. The Review Report has been received and a response has been delivered.
Appendix 1: Publishable Summary

Rationale
The AXLE project seeks to improve Business Intelligence capabilities for Europe. AXLE’s approach focuses on very large and growing databases, while addressing the full and complete requirements of real world data. Real data sources have many difficult characteristics. Data sets often grow extremely large as business initiatives succeed, so managing large data volumes once you know you have them is important.

AXLE's main concerns are

- Database Performance, Scalability & Manageability
- Security, Privacy & Auditability
- Visual Analytics & Data Mining
- Advanced Architectures for Hardware & Software

Our direction takes in novel approaches in both hardware and software that may offer a way around using brute force strategies to providing value from what has latterly become known as “Big Data”.

Software features will be released as commercially usable open source code, and submitted for wider use as core features or pluggable extensions of the PostgreSQL database (and its derivatives) and/or Orange data mining and visualisation tool.

Validation will be carried out by industrial consortium partners with access to large volumes of private medical data, as well as standard industry benchmarks and further wide-ranging data from other interested parties. In addition, a strong Industry Advisory Board has been assembled to ensure our work has deep relevance.

Technical Expertise
The AXLE consortium includes top research and system integration organisations with non-overlapping skills in the areas of computer architecture, databases, reconfigurable systems, runtime environments, programming models and benchmark design.

The academic partners are hardware and compilation/ runtime experts. In addition, they are experts in accelerators and multi- and many-cores as well as reconfigurable computing. They provide the industry partners (who are experts in databases) with the necessary knowledge and tools to develop database engines for future architectures, as well as for the cutting edge many-core processors of today.
Intended Target Groups and Domain

AXLE targets databases which contain **Important** data, and thus will be **Complex**, which when successfully used will become **Extremely Large**, which will in turn require strong **Privacy & Security** controls.

The improvements will focus on functionality and performance for use in business intelligence applications on very large datastores, especially with the proviso that transforming and re-formatting data into a data warehouse is not a viable option at very large data volumes.

Expected Results

The AXLE project aims to greatly improve the speed and quality of decision making on real-world data sets and to make those improvements generally available through high quality open source implementations via the PostgreSQL and Orange products.

AXLE will deliver:

- Advanced analytical hardware/software techniques that show significant measurable improvements in database processing speed over existing techniques when applied to extremely large and realistic data volumes.
- Advanced techniques for addressing the scalability challenge of extremely large datasets, specifically the ability for many common queries to return in the same time no matter how large the data by using flexible proof-based approaches to query handling.
- Visual analytics capable of exploring extremely large data volumes without significant loss of speed or functionality as data volumes grow.
- A capability to measure and evaluate performance against extremely large volumes of real data, with a mechanism for more easily publishing and comparing results.
- More scalable data management with integrated security controls.
- High security database software capable of securing and auditing data in its application context, as well as pass external assessment as being suitable for Common Criteria for IT Security Evaluation. [http://www.commoncriteriaportal.org/](http://www.commoncriteriaportal.org/)

Results so far

- Benchmark environments fully set-up
  - Benchmark workloads and data sets specified in detail, including appropriate anonymisation to ensure privacy of real data
  - Hardware resources purchased and usable
  - Benchmark recording and analysis application available
Baseline benchmarks suggest that sorting, hash joins, fixed point arithmetic operations, compression/decompression and deform tuple operations could profit from hardware acceleration

- Orange is now working with PostgreSQL
  - A basic interface between Orange and PostgreSQL has been implemented ahead of schedule.
  - A radical new approach to data mining transformations allows direct generation of SQL, moving the workload completely into the database

- Production ready implementations have been submitted to PostgreSQL 9.4
  - MinMax Indexes - a new index type towards automatic partitioning for very large and growing database tables
  - Event Triggers for auditing of data definition statements
  - Scalability improvements for core PostgreSQL locks and memory

- Initial prototypes are working towards production readiness for
  - Row Level Security
  - On-disk Bit Map Indexes

- Preliminary analysis suggests that machine learning could be applied at different levels to improve the performance of the database. Selecting an appropriate algorithm/technique for the different functionalities (currently sorting) or foreseeing accesses (currently the next memory address) are just a few examples of where machine learning can have a significant impact.

- A prototype sorting algorithm that exploits JIT vectorization to boost performance by 2X on the average has been implemented.

- Sorting implementations on FPGA have been completed. Working on a paper that compares the different hardware design language approaches, that will be sent to the FCCM 2014 conference.

At a glance

**Project title:** AXLE - Advanced Analytics for EXtremely Large European Databases

**Project coordinator:** Simon Riggs, 2ndQuadrant Limited (UK)

**Partners:** 2ndQuadrant Limited (UK), Barcelona Supercomputing Center (ES), Portavita B.V. (NL), The Univ. of Manchester (UK), The Univ. of Ljubljana (SI)

**Duration:** 1st November 2012 - 30 October 2015

**EU contribution:** EUR2.9M

**Further information:** [http://axleproject.eu](http://axleproject.eu)