Overview of the IBM XL C/C++ and XL Fortran compiler family

Overview

This paper contains an overview of the latest IBM® XL C/C++ and XL Fortran compilers, outlining their unique capabilities and cross-platform support, as well as highlighting new features and performance. This paper also includes a brief discussion of IBM XL compiler team strategies that focus on delivering high performance compilers that take advantage of the latest language standards and technologies.

IBM XL compilers, a brief history

IBM XL compilers are the result of a joint effort of an Advanced Technology project between the IBM Toronto Lab, the Yorktown Heights Research Lab, and other IBM facilities. This collaboration began in the 1980s with the first POWER™ chips and continued with the introduction of the IBM XL Fortran for AIX® compiler in 1989, and subsequently, the IBM XL C and IBM XL C++ for AIX compilers in 1991. IBM announced the Blue Gene® program in December 1999 leading to the release of IBM XL compilers for both Blue Gene®/L™ and Blue Gene®/P™. z/OS® XL C/C++ was released in 2000 and is the successor to OS/390®. z/OS is a 64-bit operating system for mainframe computers. Always available on the AIX operating system, the IBM XL compiler family was released for Linux® operating systems running on Power hardware in 2003. The latest additions to the IBM XL compiler family are IBM XL C/C++ for Multicore Acceleration and IBM XL Fortran for Multicore Acceleration to exploit the performance capabilities of processors compliant with the new Cell Broadband Engine™ (Cell/B.E.) architecture.

Today IBM advances a more than twenty year investment in the development of Power series and the PowerPC® series chips, with the latest chip the POWER6™ chip. The compiler team’s quality assurance infrastructure is among the finest in the industry. Each compiler executes over a million C, C++, and Fortran test scenarios. IBM’s premier customer service ensures fast turn around time and mandates timely solutions to customer issues. Both the compiler and processor design teams are strongly committed to maximizing performance on all Power processors.

Multiple-Platform C/C++ and Fortran

IBM has developed an extensive and mature industry-leading optimization technology that covers multiple platforms including AIX, IBM Power systems, z/OS, z/VM®, Linux, Blue Gene/L, Blue Gene/P and Cell Broadband Engine architecture. The modular structure of these compilers delivers optimizations and functionality on all platforms to all languages. Further, each product derives from a common code base, so features and optimizations are tested in multiple languages on multiple platforms. A common code base makes source-level portability of applications between IBM platforms easier.

IBM compilers strive to maximize the performance of scientific, technical, and commercial applications on server platforms. Multiple operating system availability assists cross-platform portability, augmented by standards compliance. IBM XL compilers conform with:

- Information Technology - Programming languages - C, ISO/IEC 9899:1999
- Information Technology - Programming languages - C++, ISO/IEC 14882:2003(E)
- Information Technology - Programming languages - Extensions for the programming language C to support new character data types, ISO/IEC TR 19769
• ISO/IEC 1539-1:1991(E) and ANSI X3. 198- 1992 (Fortran 90)
• ISO/IEC 1539-1:1997 (Fortran 95)
• A significant majority of ISO/IEC 1539-1:2004 (Fortran 2003), the only major feature not supported is parameterized derived-types.
• Altivec Technology Programming Interface Manual
• OpenMP Application Program Interface Version 2.5
  – NOTE:
    - Released July 2008, IBM XL C for AIX, V10.1 and IBM XL C/C++ for AIX, V10.1 support Version 3.0. IBM XL Fortran for AIX, V12.1 supports a subset of Version 3.0
    - Released September 2008, IBM XL C/C++ for Linux, V10.1 supports Version 3.0. IBM XL Fortran for Linux, V12.1 supports a subset of Version 3.0
• XL UPC compilers support Universal Parallel C (UPC) Version 1.2 distributed shared memory parallel programming specification in a technology showcase available from the IBM alphaWorks® site

Standards conformance assists ease of code portability between multiple operating systems and hardware platforms. The IBM compilers also focus on showcasing processor performance against key UNIX® and SPEC benchmarks.

IBM compilers build key IBM products such as the AIX operating system, DB2®, and Lotus® Domino®. System houses and Independent Software Vendors (ISV) around the world use IBM compilers to build their applications and middleware. These applications cover a wide array of industries. IBM compilers play a key role in supercomputing. Supercomputing involves massive workstation server farms that demand the utmost in performance.

Table 1. TOP 500 Supercomputing list as of November 2008 [www.top500.org/list/2008/11/100]

<table>
<thead>
<tr>
<th>TOP 500 Position</th>
<th>Installation</th>
<th>Tera Flops/Second on Linpack</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DOE/NNSA/LANL. Roadrunner - BladeCenter® QS22/LS21 Cluster - IBM</td>
<td>1105.0 Tflops/s</td>
</tr>
<tr>
<td>2</td>
<td>Oak Ridge National Laboratory. Jaguar - Cray XT5 QC 2.3 GHz - Cray Inc.</td>
<td>1059.0</td>
</tr>
<tr>
<td>3</td>
<td>NASA/Ames Research Center/NAS. Pleiades - SGI Altix ICE 8200EX, Xeon® QC 3.0/2.66 GHz - SGI</td>
<td>487.0</td>
</tr>
<tr>
<td>4</td>
<td>DOE/NNSA/LLNL, BlueGene/L - eServer™ Blue Gene Solution - IBM</td>
<td>478.2</td>
</tr>
<tr>
<td>5</td>
<td>Argonne National Laboratory. Blue Gene/P Solution - IBM</td>
<td>450.3</td>
</tr>
</tbody>
</table>

For more information on IBM’s Blue Gene solutions see:

[www.ibm.com/systems/deepcomputing/bluegene/]

For more information on IBM’s BladeCenter technology see:

[www.ibm.com/systems/bladecenter/]
IBM compiler availability

Table 2. IBM C++ compilers currently available (November 2008)

<table>
<thead>
<tr>
<th>IBM XL C/C++ Compilers</th>
<th>Product Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>XL C/C++ for Blue Gene/P</td>
<td></td>
</tr>
<tr>
<td>ILE C/C++ (feature of WebSphere® Development Studio for System i®)</td>
<td><a href="http://www.ibm.com/software/awdtools/wds400/about/ile_ccpp.html">www.ibm.com/software/awdtools/wds400/about/ile_ccpp.html</a></td>
</tr>
</tbody>
</table>

Visit the i5/OS® Information Center, Version 5 Release 4 at:

and go down to Programming, Languages

<table>
<thead>
<tr>
<th>IBM XL C/C++ Compilers</th>
<th>Product Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>IBM XL UPC Alpha Edition Version 0.9</td>
<td><a href="http://www.alphaworks.ibm.com/tech/upccompiler">www.alphaworks.ibm.com/tech/upccompiler</a></td>
</tr>
</tbody>
</table>

Table 3. IBM Fortran compilers currently available (November 2008)

<table>
<thead>
<tr>
<th>IBM XL Fortran Compilers</th>
<th>Product Information</th>
</tr>
</thead>
</table>

For more information on PASE, see:

IBM XL compilers are 32-bit and 64-bit enabled, and wherever possible support as many common features across as many languages and platforms as possible. The compilers facilitate exploitation of new PowerPC hardware, including the brand new state of the art POWER6 processor. This is in addition to a wide portfolio of tunable optimizations such as:

- Instruction path length reduction
- Whole program analysis across compilation units
• Loop optimization for parallelism, locality and instruction scheduling
• User profile directed feedback incorporated in most optimizations
• Optimized OpenMP

For debugging capability on AIX, you have the choice of any symbolic debugger that supports the AIX XCOFF executable format including dbx, TotalView, DDT, and IBM Debugger for AIX (IBM XL C/C++ only). On Linux, you can use debuggers including DDT, gdb, or TotalView. TotalView also fully supports debugging OpenMP applications.

• IBM Debugger for AIX is included with IBM XL C for AIX and IBM XL C/C++ for AIX. For more information on IBM Debuggers, see:

Additionally, the compilers offer the SNAPSHOT directive and the `-qoptdebug` and `-qkeepparm` options to assist you in debugging optimized code.

**IBM XL compiler architecture**

IBM XL compilers use a modular design, beginning with multiple language-parsing front-ends (FE) that generate a unified intermediate language (IL). The low-level optimizing back-end (BE) processes the intermediate language, enabling common optimizations that apply to all languages.

**We have O5!**

The highest optimization level currently available to the IBM compiler family is `-O5`. This initiates aggressive optimization and the highest level of Interprocedural Analysis (IPA) currently available. The `-O5` optimization process begins with the front-end emitting an intermediate language which IPA analyzes and transforms. The optimized intermediate language is then processed by the low-level optimizing back end for further optimization and object code creation. The following diagram illustrates the `-O5` compile-step process:

**Figure 1:** Compile path with IPA used on the compile step
The IPA link-step optimization process combines many sources of information to achieve a view of the entire application. IPA performs the following tasks on the application link step:

- Examines libraries for all external symbols,
- Considers any profile-directed feedback (PDF) optimization information
- Processes IPA objects from the IPA compile step and normal non-IPA objects

The IPA optimizer separates the result into logically organized partitions. These partitions are subsequently processed by the low-level optimizing back end. The output of this process is an optimized set of objects which the system linker can use to create the final executable or shared library.

**Figure 2:** Link path when IPA is invoked
Performance and IBM chip design

The key strength of the IBM XL compiler family is performance. The IBM XL compilers are unmatched in their ability to optimize and tune code for execution on Power platforms. The performance gain from years of compiler optimization experience can be seen in the release-to-release compiler improvements for the POWER4™ processor developed in 2001. This was followed by POWER4+™ in 2002, and POWER5™ in 2004. The POWER5 was designed to maintain both binary and structural compatibility with existing POWER4 systems to ensure not only that binaries would continue to execute properly, but that all application optimizations would work on newer systems. The year 2005 saw the introduction of the POWER5+™ chip.

The PowerPC 970 was based on an early POWER5 design with reduced power consumption. This was achieved by reducing one processor, reducing the L2 cache from 1.5 MB to 0.5 MB and eliminating the L3 cache. However, it supports the AltiVec/VMX instruction set and runs at a core speed of 2GHz.

The AltiVec support in PowerPC 970 allowed for 32 128-bit registers, and 162 SIMD instructions. There are 4-way single precision vector FP instructions, and 4, 8, and 16 way vector fixed point instructions. The PowerPC 970 has two execution units: Permute and ALU. Permute handles vector permutation, and splat instructions. ALU handles vector add, subtract, and floating-point math. The ALU has three subunits: simple fixed, complex fixed, and float.

The POWER5 chip has a nominal clock speed of 1.5-2 GHz. It is a dual core out-of-order 8-issue superscalar simultaneous Multi-Threading CMOS. It supports up to 64-way SMP or 128-way SMT. There are a similar number of functional units (2 LSUs, 2 FXUs, 2 VFUs, 1 CRU and 1 BRU) as the POWER4
chip. While similar to the POWER4, the POWER5 chip has faster memory latencies and wider bandwidths in the interconnect between caches. The L1 I+D caches are similar in size as POWER4. But the I-cache is 2-way instead of being direct mapped. The D-cache is 4-way instead of 2-way. The L2 cache is 1.9MB instead of 1.4 MB and is 10-way. The off-chip L3 cache is 36 MB instead of 32 MB and is 12-way.

For more information on POWER5 system architecture:

The POWER6 is the very latest member of the POWERPC family, announced May 2007. Announced at the same time, the brand new IBM System p570 is an ultra-powerful server that leverages the many breakthroughs in energy conservation and in the virtualization technology of the POWER6. IBM System p570 was the first UNIX server ever to hold all four major benchmark speed records at once, SPECint2006, SPECfp2006, SPECjbb2005 and TPC-C (an on-line transaction processing benchmark).

The POWER6 chip has a nominal clock speed of 3.5-4.7 GHz, notably solving the power leakage problems associated with high frequency by using a combination of 90nm and 65nm parts. It has ultra-high frequency cores with two SMT threads per processor (four threads per chip), and 12b KN of L1 cache, 4 MB L2 cache, and 32 MB L3 cache. Each core has two integer units, two binary floating-point units, and the industry’s first decimal floating-point unit in hardware. There are more then 50 new floating point instructions supporting decimal math, and conversions between binary and decimal. There is also an Altivec unit in POWER6 which takes advantage of ViVA-2, Virtual Vector Architecture, thus enabling several POWER6 nodes to combine and act as a single vector processor.

Note:

For more information about POWER6 and the above benchmarks see:
- [www.spec.org](http://www.spec.org)
- [www.tpc.org/tpcC](http://www.tpc.org/tpcC)

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- [www.ibm.com/developerworks/power](http://www.ibm.com/developerworks/power)
- [www.ibm.com/power](http://www.ibm.com/power)
- [www.power.org](http://www.power.org)

### Language standards and industry specifications

The IBM XL compiler team maintains membership in the ISO C, C++, and Fortran committees representing IBM. This allows IBM to help drive the strategic direction of the languages as standards evolve, and deliver the changes as ratification occurs. Both the C/C++ and Fortran teams have membership in the OpenMP consortium.

**XL C/C++**

IBM XL C supports the latest C standard revision ISO/IEC 9899:1999, also known as C99, a major update to the previous C standard. C99 introduces a number of new language features to the C language, such as:
- Complex data type
- Support for variable length arrays
• Compound literals
• Flexible array members

The IBM XL C++ compiler supports the latest revised ISO C++ 2003 standard (ISO/IEC 14882:2003), as well as a subset of the C99 language functionality.

The main changes to the C++ standard are the Technical Corrigendum 1 which details ongoing work in defect reports collected worldwide. These items combine to form the 2003 C++ standard. These changes are available beginning with the V7.0 release of the IBM XL C++ compiler. Additional updates come in the form of the C++ Library Extensions Technical Report (TR1) in 2001. These reports proposed extensions to the C++ library. IBM already supports the hash and traits libraries from C++ Library Extensions Technical Report in Version 8 of the C++ compiler. Other additions include smart pointers, template metaprogramming utilities, and special math functions useful for research. A new TR2 proposal has been opened to accept new libraries while any existing TR1 implementations will be tested and refined for defect fixes before the TR1 library is officially sanctified in the C++ standard. A further report, the Technical Report on C++ Performance, was published in 2003 that is used internally by the development team to improve C++ compiler performance.

IBM XL C/C++, V10.1 introduces support for C++0x standard which is the working draft of the next C++ programming language standard. This standard has not yet been officially adopted but we are beginning to support some of its features. However, these features might change or be removed in future according to what is finally ratified in the Standards.

Specifically, in this release:
• a new language level has been created.
• new integer promotion rules for arithmetic conversions with added support for C++0x long long data types has been introduced.
• the C++ preprocessor now fully supports C99 features according to C++0x.

IBM compiler team members also participate in the GNU Committee which meets annually to examine the direction of the GNU compilers and tool chain.

**XL Fortran**

IBM XL Fortran supports the Fortran 77, 90, and 95 standards and the IBM XL Fortran, V12.1 product set supports a significant portion of the Fortran 2003 standard including the object-oriented programming model.

IBM XL Fortran consists of the following:
• The full American National Standard Fortran 90 language (Fortran 90) as defined in documents:
  – Information technology - Programming languages - Fortran, ISO/IEC 1539-1:1991(E)
• The full ISO Fortran 95 language standard (Fortran 95) as defined in:
• Extensions to the Fortran 95 standard:
  – Common industry extensions found in Fortran products from various compiler vendors.
  – Extensions specified in SAA® Fortran
  – Extensions to the Fortran 95 language are marked in the IBM XL Fortran Language Reference.
• The majority of the Fortran 2003 standard including full support of the object-oriented programming model with parameterized derived-types being the only major feature not available.
Other language influences

The IBM family of compilers is deeply involved in parallel computing and high performance computing. IBM implements both the Altivec/VMX programming interface and the OpenMP specification for shared memory programming model.

XL C for AIX, V10.1 and XL C/C++ for AIX, V10.1 support the OpenMP API Version 3.0. XL Fortran for AIX, V12.1 has added some of the features of OpenMP API Version 3.0 including task level parallelization and nesting support. Moving forward, the compilers have also begun to support the distributed shared memory models as described in the emerging Universal Parallel C specification.

IBM is a member of the Standard Performance Evaluation Corporation (SPEC). SPEC’s mission is to identify and maintain standardized benchmarks that will drive high performance computing for many years. SPEC released SPEC CPU2006 in 2006. CPU2006 is a benchmark focused on a system’s processor, memory subsystem and compiler. IBM continues to participate in the SPECOMP suite which measures the performance of parallel benchmarks using OpenMP.

For more information regarding SPEC CPU2006, CINT2006, and CFP2006 see:

[www.spec.org/](http://www.spec.org/)

Features of IBM XL C/C++ and IBM XL Fortran

IBM XL C compiler continues to be fully C99 standard compliant, as well as supporting previous C standards. The Universal Parallel C capability provided as a downloadable technology showcase available from alphaWorks, further enhances the compiler.

For more information on alphaWorks see:


IBM XL C++ compiler is fully compliant to International Standard 14882:1998 - Programming Language C++ and with Technical Corrigendum 1. IBM XL C/C++ also supports some C99 features such as complex, hex float, variable length array, and compound literal. IBM XL C/C++ compiler now offers support of Boost Version 1.34.1. Boost is an Open Source set of libraries that takes you beyond the C++ Standard Library. Boost makes C++ programming more elegant, robust, and productive. The IBM XL C++ compiler has attained a high degree of compatibility with Boost since Version 7.0 and continues to support Boost as new releases appear. Each version of the compiler is fully tested on one version of Boost, usually the latest. Both the C and C++ compilers continue to track close compatibility with the latest GNU compilers, allowing you to build many Open Source applications. Both compilers include enhancements to leverage automatic parallelization. The interprocedural optimizer includes enhancements to support many specialized C++ optimizations for templates, exception handling, and virtual functions. C++ also includes an alternate template compilation model called -qtmplateregistry in addition to the tempinc model.

All compilers are now compliant with the OpenMP API Version 2.5 with the IBM XL C/C++ for AIX, V10.1 compiler, released July 2008, being one of the first industrial compilers to conform to OpenMP 3.0. You have access to additional optimizations such as the ability to generate multiple architecture code paths. There is improved performance of quad precision floating point. We now have support of the BLAS routines tuned for POWER6. The compilers can also take advantage of IBM’s highly tuned ESSL mathematical library on supported platforms. There is support for auto-simdization and VMX intrinsic and datatype for direct VMX programming on AIX and Linux.

IBM XL C/C++ V9.0 introduced support for decimal float-type data, offering greater computational performance and precision in business and financial applications and IBM XL C/C++ V10.1 introduced support for the emerging C++0x standard by adding support for a number of initial features.
For more information on IBM's various C/C++ compilers, see Table 2.

IBM XL Fortran continues to be a fully compliant Fortran 77/90/95 compiler.

IBM XL Fortran V12.1 delivers support for the majority of the Fortran 2003 standard and is the most complete Fortran 2003 implementation currently available. parameterized derived-types is the only major feature not yet available in IBM XL Fortran.

For more information on IBM XL Fortran see:

www.ibm.com/software/awdtools/fortran/

For more information on IBM XL C/C++ see:

www.ibm.com/software/awdtools/xlcpp/

**IBM and GNU**

While ensuring that the IBM XL compiler family has always offered diverse functionality and excellent performance to their users, IBM also has a long standing interest in the development of the GNU compiler. IBM contributes to GCC development both financially and technically, including large parts of the original GCC code for RS/6000®, and the 64-bit retarget for Linux on PowerPC. Further technical contributions include an instruction scheduler, as well as the rights to the graph coloring register allocation patent for use in GCC. Today IBM still seeks to make contributions to the GNU effort in the areas of Single Static Assignment (SSA) optimizations, auto-vectorization, and loop optimization. With these additions, IBM and many others help the GNU compiler grow. Consequently, users have the unique opportunity to choose between the GNU rapid adoption of experimental new language features, and the IBM compiler family's drive for optimization to make the PowerPC processor the fastest possible, coupled with premium customer support. IBM compilers will continue to adopt the most useful GNU extensions.

A major enhancement was the implementation of the latest language extensions starting from GNU Version 3.2 to the current GNU Version 4.1. This enhancement enables a high degree of interoperability with specific GNU compilers. The intent of this GNU compatibility project is to provide support in the following stages:

- Enable compilation of POSIX compliant source on Linux using the compiler and the GNU headers
- Add the most common GNU language extensions
- Implement full support for enough of the extensions to compile the Linux kernel and most popular Linux applications

The latest C/C++ compilers include most of the common GNU language extensions.

The IBM compilers also have a close affinity with third party tool chains, and seek to adapt to GNU tools such as gdb. There are also specific AIX and Linux performance tools which can identify performance bottlenecks.

**Summary**

The IBM compiler family offers premier innovation and capability on AIX, Linux, z/OS, IBM Power systems, z/VM, Blue Gene/L, Blue Gene/P and Cell Broadband Engine architecture. Support for multiple PowerPC chips and platforms enables easier porting of applications and optimizations that the compiler team tailors to Power hardware. IBM’s stable compilers coupled with premium customer support lets large critical applications rely on the XL compiler family. The flexibility of the compilers allows you to control the type and the depth of optimization analysis through compiler options that specify the level
and kinds of optimization best suited to your application. Compatibility with GNU compilers gives you access to the vast array of Open Source software and libraries. Support of the leading standards assists compliance for the future. IBM’s long history of compiler development gives you control of mature optimization technology such as Interprocedural Analysis, and a unique set of Power optimizations that fully exploit the hardware architecture’s capabilities.

**Trial Versions and Purchasing**

You can download trial versions of the XL Fortran compiler from the Trials and Demos link at:


You can download trial versions of the XL C/C++ compiler from the Trials and Demos link at:


For a complete listing of our products available for purchase visit:


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