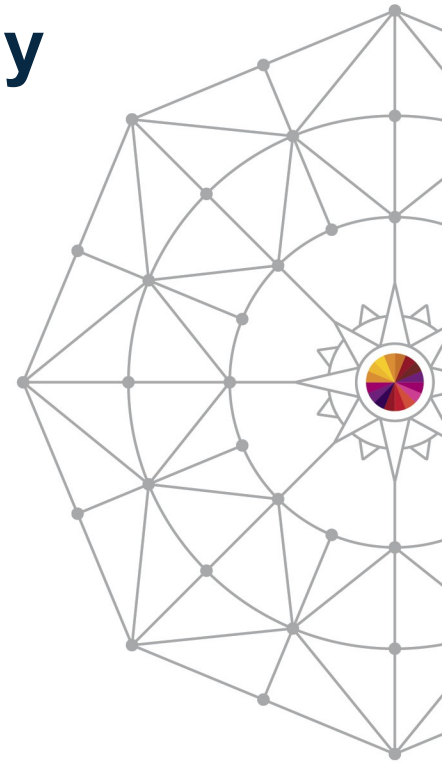
Make Your PL/I and C/C++ Code Fly With the Right Compiler Options

Dickson Chau
IBM

August 7, 2014
Session 16091



#SHAREorg

SHARE in Pittsburgh 2014

WHAT …

- does good application performance mean to you?
  - Fast Execution Time
  - Short Compile Time

HOW …

- to achieve good application performance?
  - Install New Hardware
  - Utilize Compiler Options
  - Code for Performance

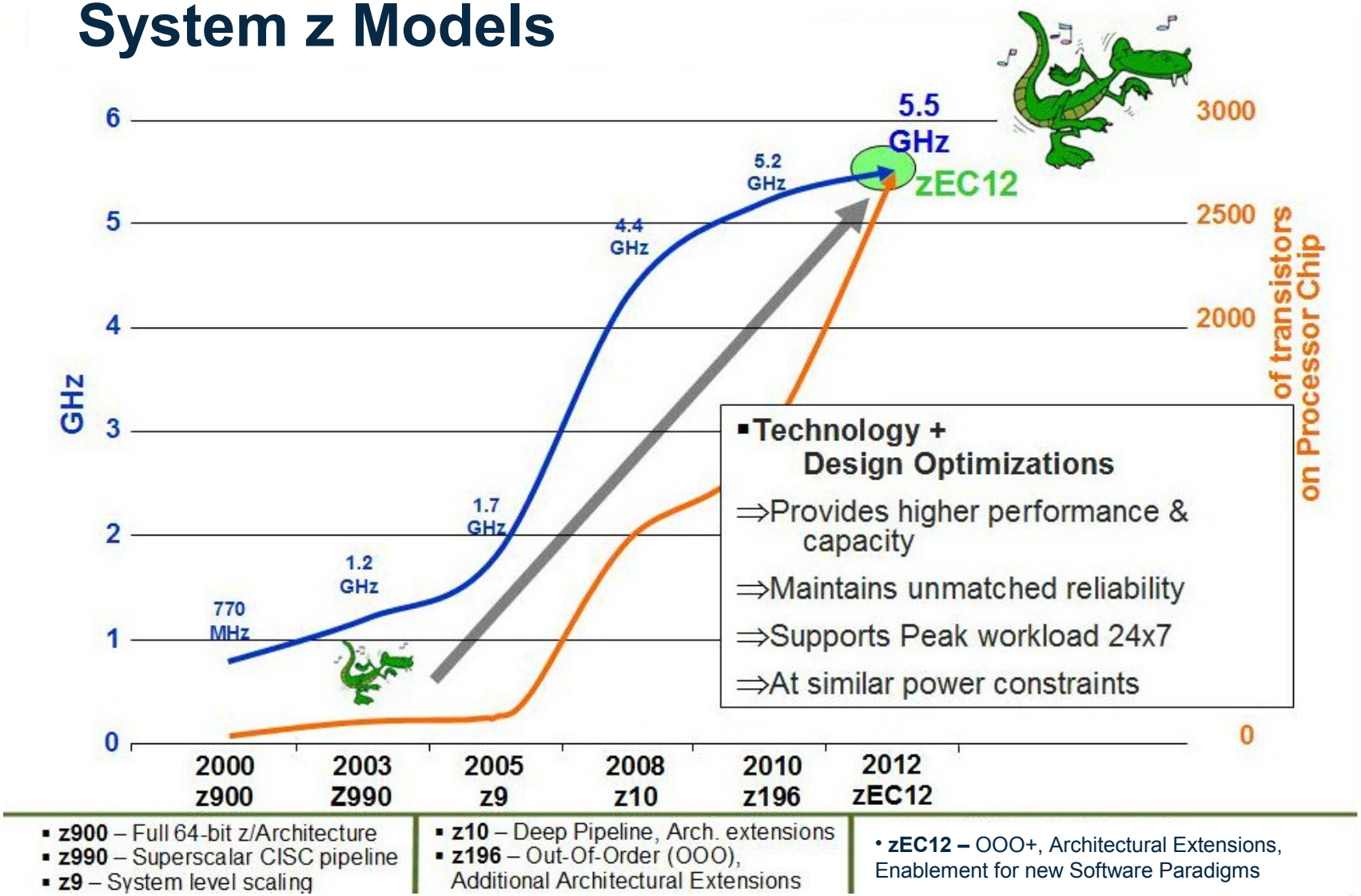
Install New Hardware

- Can make your code run faster

- Requires NO
  - Recompilation
  - Relinking
  - Migration to new release

- BUT, are you taking full advantage of all the new features from the new hardware?
  - i.e. the full ROI on the new piece of hardware

System z Models



- **z900** – Full 64-bit z/Architecture
- **z990** – Superscalar CISC pipeline
- **z9** – System level scaling

- **z10** – Deep Pipeline, Arch. extensions
- **z196** – Out-Of-Order (OOO), Additional Architectural Extensions

• **zEC12 –** OOO+, Architectural Extensions, Enablement for new Software Paradigms

Utilize Compiler Options

- Allows the compiler to exploit the hardware:
  - ARCH
  - HGPR
  - FLOAT(AFP)
- Balance between compile-time vs. execution-time:
  - OPT(2)
  - OPT(3)
  - HOT [C/C++]
  - IPA [C/C++]
    - PDF

Utilize Compiler Options (cont'd)

- Provide the details about the source or environment:
  - C/C++:
    - ANSIALIAS
    - IGNERRNO
    - LIBANSI
    - NOTHREADED
    - NOSTRICT
    - STRICT_INDUCTION
    - XPLINK
  - PL/I:
    - REDUCT
    - RESEXP
    - RULES(NOLAXCTL)
    - DEFAULT(CONNECTED REORDER NOOVERLAP)

Utilize Compiler Options (cont'd)

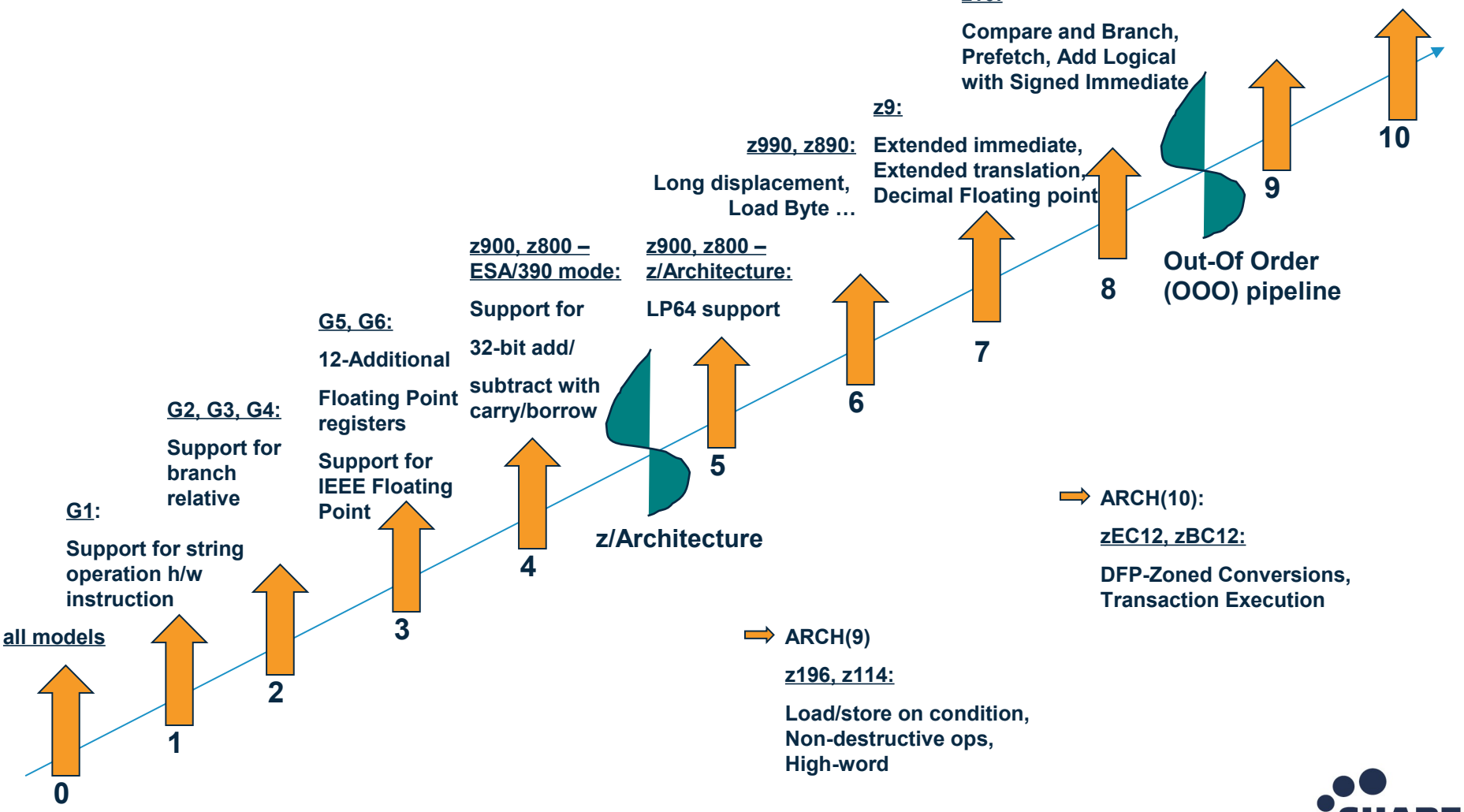
- Controls load module size:
  - COMPACT [C/C++]
  - INLINE [C/C++]
  - DEFAULT(INLINE) [PL/I]
  - UNROLL

ARCHitecture Option

- The ARCH option specifies the level of the hardware on which the generated code must run
  - C/C++ default – is ARCH(7)*
    - produces code that will run on z9 machines
  - PL/I default – is ARCH(6)
    - produces code that will run on z990/z980 machines
- Must set ARCH to the lowest level machine where your generated code will run
  - If you specify ARCH(n) and run the generated code on an ARCH(n-1) machine, you will most likely get an operation exception

* new default in z/OS XL C/C++ V2R1. Default architecture is ARCH(5) for all versions before this. ARCH(5) produces code that runs on z900 and newer

ARCHitecture - Timeline



ARCH(9): Load-on-condition Example

```
int bar(void);
int foo(void) {
  return ( (bar()==2) ? 1 : -1);
}

> xlc -c -O2 -qarch=8 -qlist loc.c
…
 000003 |       *    return ( (bar()==2) ? 1 : -1);
 0000D8  58F0  3000        000003 |                L        r15,=V(bar)(,r3,0)
 0000DC  0DEF              000003 |                BASR     r14,r15
 0000DE  A7FE  0002        000003 |                CHI      r15,H'2'
 0000E2  0700              000000 |                NOPR     0
 0000E4  A7F8  FFFF        000003 |                LHI      r15,H'-1'
 0000E8  A774  0004        000003 |                JNE      @1L3
 0000EC  41F0  0001        000003 |                LA       r15,1
                           000004 |       *  }
 0000F0                    000004 |         @1L3   DS       0H

> xlc -c -O2 -qarch=9 -qlist loc.c
…
 000003 |       *    return ( (bar()==2) ? 1 : -1);
 0000D8  58F0  3000        000003 |                L        r15,=V(bar)(,r3,0)
 0000DC  0DEF              000003 |                BASR     r14,r15
 0000DE  4100  0001        000003 |                LA       r0,1
 0000E2  A7FE  0002        000003 |                CHI      r15,H'2'
 0000E6  A7F8  FFFF        000003 |                LHI      r15,H'-1'
 0000EA  B9F2  80F0        000003 |                LOCRE    r15,r0
                           000004 |       *  }
```

HGPR Option

- Stands for High half of 64-bit General Purpose Register
- Permitted to exploit 64-bit GPRs in 32-bit programs
  - Compiler can now make use of
    - The 64-bit version of the z/Architecture instructions
    - The High-Word Facility [with ARCH(7) or above]
      - *Can be viewed as having an additional 16 GPRs*
- PRESERVE sub-option
  - Save/re-store in prolog/epilog the high halves of used GPRs
  - Only necessary if the caller is not known to be compiler-generated code
- Default is NOHGPR(NOPRESERVE)
  - Metal C defaults to HGPR(PRESERVE)

FLOAT(AFP) Option

- Additional Floating-Point (AFP) registers were added to ESA/390 models
- AFP sub-option enable use of the full set (16) of FPRs
- VOLATILE sub-option
  - FPR8 – FPR15 is considered volatile
    - i.e. compiler will not expect they're preserved by any called program
  - No longer required for CICS TS V4.1 or newer
- Default is AFP(NOVOLTILE)
  - [C/C++] for ARCH(3) or higher

OPTIMIZE Option

- The OPT option controls how much, or even if at all, the compiler tries to optimize your code
  - A trade-off between compile-time vs. execution-time

- NOOPT/OPT(0):
  - The compiler simply translates your code into machine code
  - Generated code could be large and slow
  - Good choice for:
    - Matching code generated with written source code
      - *for the purpose of debugging a problem*
    - Reducing compile time
  - Terrible choice if you care about run-time performance

OPTIMIZE Option (cont'd)

- When optimizing, the compiler will improve, often vastly, the code it generates by, for example
  - Keeping intermediate values in registers
  - Moving code out of loops
  - Merging statements
  - Reordering instructions to improve the instruction pipeline
  - Inlining functions

- Require more CPU and REGION during compilation

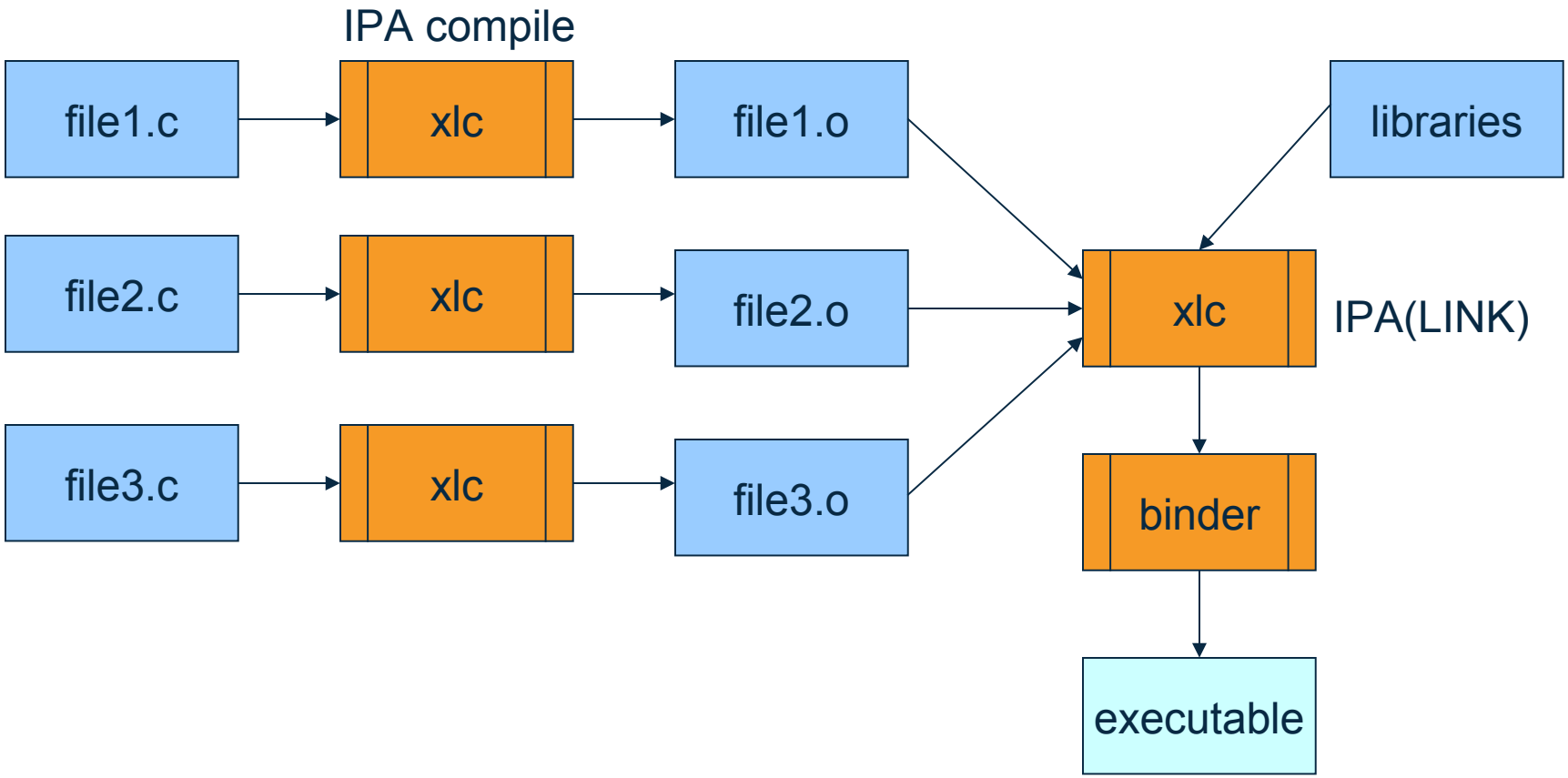
OPTIMIZE Option (cont'd)

- OPT(2):
  - Start enabling the optimizer
  - A balance between compile speed and code quality
- OPT(3):
  - Optimizer much more aggressive
  - Tips balance towards code quality over compile speed
  - C/C++ compiler will alter other options defaults:
    - ANSIALIAS, IGNERRNO, STRICT, etc
- The C/C++ and PL/I compilers use the same optimizing backend
  - But there are differences in what the OPT sub-options does

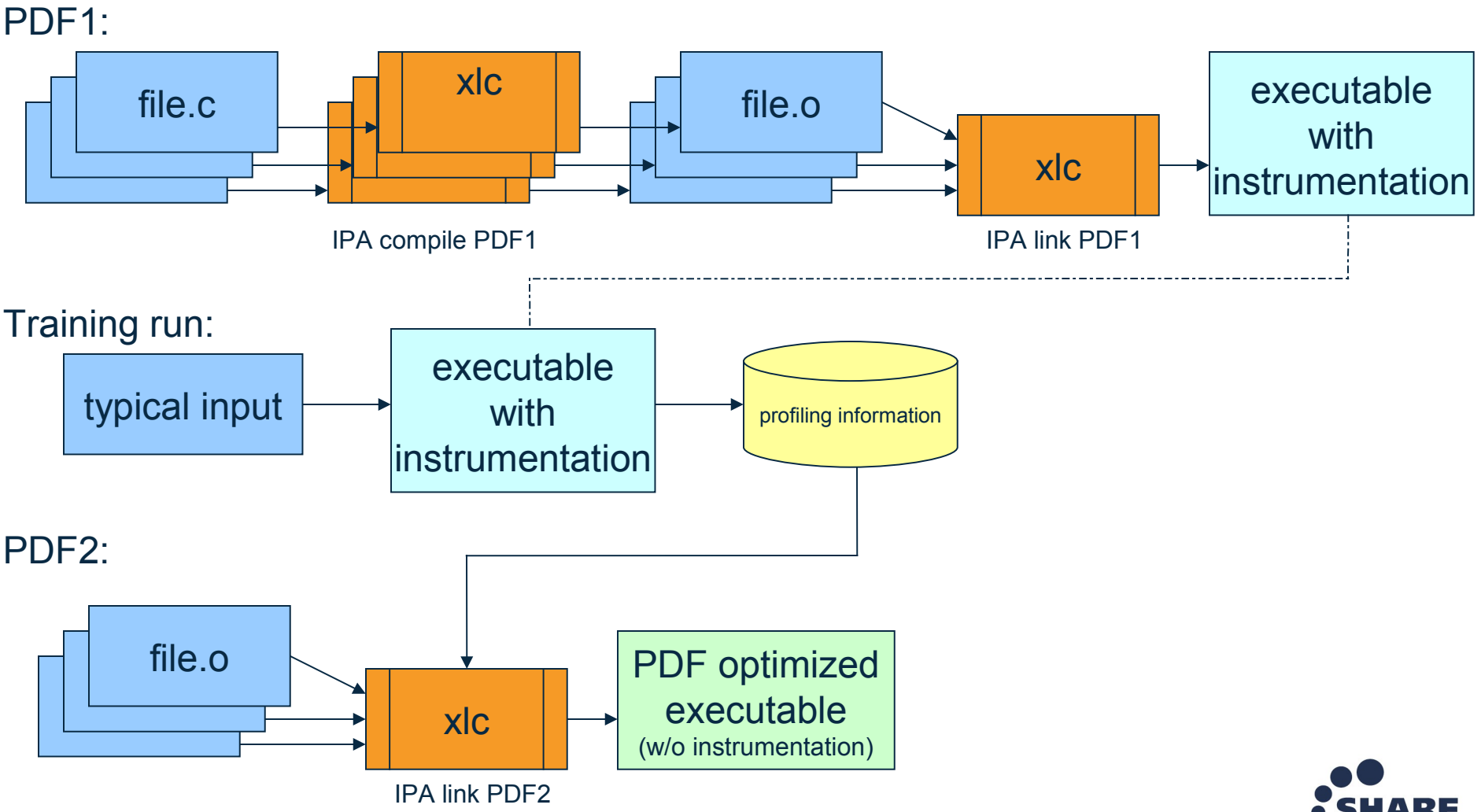
Other C/C++ Options Related to OPT

- HOT option
  - High-Order loop analysis and Transformations
    - More aggressive optimization on the loops
    - Requires to use with OPT(2) or higher
- IPA option
  - Inter-Procedural Analysis
    - Optimization decisions made based on the entire program
    - 3 sub-levels to control aggressiveness
    - Requires OPT(2) or higher
  - PDF sub-option
    - Profile Directed Feedback
      - *Sample program execution to help direct optimization*
      - *Requires a training run with representative data*

IPA Option [C/C++] (cont'd)



IPA PDF Sub-Option [C/C++]



ANSIALIAS Option [C/C++]

- Optimizer presumes pointers can point only to objects of the same type
  - The simplified rule is that you cannot safely dereference a pointer that has been cast to a type that is not closely related to the type of what it points at
    - The ISO C and C++ standards define the closely related types
- If this assumption is false, wrong code could be generated
  - The INFO(ALS) option might able to help you find potential violation of the ANSI type-based aliasing rule

- OPT(3) defaults to ANSIALIAS
- OPT(2) defaults is NOANSIALIAS
- Has no effect to NOOPT/OPT(0)

IGNERRNO Option [C/C++]

- Informs the compiler that the program is not using errno
- Allows the compiler more freedom to explore optimization opportunities for certain library functions
  - For example: sqrt
- Need to include the system header files to get the full benefit

- OPT(3) defaults to IGNERRNO
- NOOPT and OPT(2) defaults are NOIGNERRNO

LIBANSI Options [C/C++]

- Indicates the name of an ANSI C library function are in fact ANSI C library functions and behave as described in the ANSI standard
- The optimizer can generate better code based on existing behavior of a given function
  - Like, whether or not a particular library function has any side effects
- Provides additional benefits when used in conjunction with IGNERRNO

- Defaults is NOLIBANSI

NOTHREADED Option [C/C++]

- For user to assert their application is single-threaded
- Allows for non-thread-safe transformations be performed

- Defaults is THREADED

NOSTRICT Option [C/C++]

- Allows the optimizer to alter the semantics of a program
  - Performing code motion and scheduling on computations such as loads and floating-point computations that may trigger an exception
  - Relax conformance to IEEE rules
  - Reassociating floating-point expressions

- OPT(3) defaults is NOSTRICT
- NOOPT and OPT(2) defaults are STRICT

NOSTRICT_INDUCTION Option [C/C++]

- Asserts to the compiler the induction (loop counter) variables do not overflow or wrap-around
  - Use STRICT_INDUCTION only if your program logic has such intent
- Only affects loops which have an induction variable declared with a different size than a register

- Default is NOSTRICT_INDUCTION
  - Except with the c99 invocation command on USS

XPLINK Option [C/C++]

- XPLINK stands for eXtra Performance LINKage
  - A modern linkage convention that is 2.5 times more efficient than the conventional linkage conventions
  - We have seen some programs improved by 30%
  - XPLINK and non-XPLINK parts can work across DLL and fectch() boundaries
    - Must tell compiler about this, so the (expensive) switching code get executed
    - If your application contains few switches, then mixing will still be beneficial
- Defaults:
  - ILP32: NOXPLINK
  - LP64: XPLINK

REDUCE and RESEXP Options [PL/I]

- REDUCE option
  - Specifies that the compiler is permitted to reduce an assignment of a null string to a structure into a simpler operation
    - Even if that means padding bytes might be overwritten
      - *Padding bytes may be zerored out*

- RESEXP option
  - Specifies that the compiler is permitted to evaluate all restricted expressions at compile time even if this would cause a condition to be raised and the compilation to end with S-level messages

RULES(NOLAXCTL) Option [PL/I]

- Specifies that the compiler disallows a CONTROLLED variable to be declared with a constant extent and yet to be allocated with a differing extent
- To allocate a CONTROLLED variable with a variable extent, that extents must be declared either with an asterisk or with a non-constant expression.
- When the compiler sees a reference to a structure, or to any member of that structure, it knows the lengths, dimensions or offsets of the fields in it

DEFAULT Sub-Option CONNECTED REORDER NOOVERLAP

- CONNECTED sub-option
  - Compiler presumes application never passes nonconnected parameters
- REORDER sub-option
  - Indicates that the ORDER option is not applied to every block, meaning the compiler doesn't have to maintain variables in that block referenced in ON-units (or blocks dynamically descendant from ON-units) have their latest values
- NOOVERLAP sub-option
  - Compiler presumes the source and target in an assignment does not overlap

COMPACT Option [C/C++]

- Compiler favors optimizations that tend to limit the growth of the code
- Depending on your specific program, the object size may increase or decrease and the execution time may increase or decrease

- Default is NOCOMPACT

INLINE Option [C/C++]
DEFAULT(INLINE) Option [PL/I]

- Inlining eliminates the overhead of the function call and linkage, and also exposes the function's code to the optimizer
- Too much inlining can increase the size of the program

- AUTO sub-option [C/C++]
  - Inliner runs in automatic mode
  - Threshold sub-option
    - Maximum relative size of a subprogram to inline
  - LIMIT sub-option
    - Maximum relative size a subprogram can grow before auto-inlining stops

UNROLL Option

- Instructs the compiler to perform loop unrolling
- It replicates a loop body multiple times, and adjusts the loop control code accordingly
- It increases code size in the new loop body

- Auto sub-option
  - Compiler decides via heuristics the appropriate candidate and amount of unrolling

Code for Performance

- Writing good code
- Make use of built-in functions
- Make use of #pragmas [C/C++]
- Make use of attribute and keyword [C/C++]
- OpenMP [C/C++]

Writing Good Code

- Keep it simple and concise
  - Good for both the programmer and the compiler to understand the code easily
- Don’t ignore the compiler informational and warning messages, even if the program appears to work
- Attempts to be clever and produce “optimal” code might produce:
  - Code that is unreadable
  - Code that cannot be maintained
  - Code that performs worse than the straightforward solutions
  - Code that fails

Make Use Of Built-in Functions

- Library function example:
  - Less efficient comparison on a loop

```
int i, a[1000], b[1000];
…
for (i = 0; i < 1000; ++i)
  if (a[i] != b[i])
    break;
if (i == 1000)
  /* arrays are equal */
```

  - More efficient comparison with a memcmp() library function

```
int a[1000], b[1000];
…
if (!memcmp (a, b, sizeof(a)))
  /* arrays are equal */
```

Make Use Of Built-in Functions (cont'd)

- Hardware built-in function example
  - A naive implementation of population count

```
unsigned long popcount(unsigned long op) {
  unsigned long count = 0;
  unsigned long bit = 1;
  for (int i = 0; i < 64; i++) {
    if (op & bit)
     count++;
    bit = bit << 1;
  }
  return count;
}
```

  - with __popcnt() hardware built-in function

```
unsigned long __popcnt(unsigned long op)
```

    - Available from ARCH(9)
      - *A single POPCNT instruction*

Make Use Of #pragmas [C/C++]

- Provides more details about your code to help the optimizer
  - #pragma execution_frequency (C++only)
    - Marks program source code that you expect will be either very frequently or very infrequently executed
  - #pragma isolated_call
    - Lists functions that have no side effects (that do not modify global storage)
- For fine-grained control
  - #pragma inline (C only)
    - Hint to the compiler to inline this frequently used function
  - #pragma noinline
    - Prevents a function from being inlined
  - #pragma unroll
    - Informs the compiler how to perform loop unrolling on the body that immediately follows it

Make Use of Attributes & Keywords [C/C++]

- Provides more details about your code to help the optimizer
  - restrict keyword
    - Use with ASSERT(RESTRICT) to indicate disjointed pointers
      - *Defaults is ASSERT(RESTRICT)*
    - Two restrict qualified pointers, declared in the same scope, designate distinct objects and thus shouldn't alias each other
    - RESTRICT option (C only) can also be used to indicates to the compiler that pointer parameters in all functions or in specified functions are disjoint
      - *Defaults is NORESTRICT*
- For fine-grained control
  - inline keyword
    - Hint to the compiler to inline this frequently used function
  - always_inline function attribute
    - Instructs the compiler to inline a function

OpenMP API 3.1 [C/C++]

- Industry-standard API designed to create portable C/C++ applications to exploit shared-memory parallelism
- Users can create or migrate parallel applications to take advantage of the multi-core design of modern processors
- Consists of a collection of compiler directives and library routines
- New SMP option to allow OpenMP parallelization directives to be recognized
  - Only supported in 64-bit
  - Executable must be run under USS
  - Thread-safe version of standard library must be used inside the parallel regions
  - Not supported with Metal C

OpenMP API 3.1 Example [C/C++]

```
int bar(void) {
  #pragma omp parallel for
  for (int i = 0; i < N; i++) {
    // executed in parallel by a # of threads
    …
  }
}
```

Recap

- Let the compiler work for you by telling it
  - The hardware to exploit
  - The importance of compile-time vs. execution performance
  - More precise details about the source code
  - Sensitiveness of module size

- Work together with the compiler
  - Writing good code
  - Make use of BIFs and #pragmas
  - Exploit the language features

Additional Reading Materials

- z/OS C/C++ Programming Guide
  - Part 5. Performance optimization
  - http://pic.dhe.ibm.com/infocenter/zos/v2r1/topic/com.ibm.zos.v2r1.cbcpx01/cbc1p2399.htm

- Enterprise PL/I for z/OS Programming Guide
  - Chapter 13. Improving performance
  - http://publibfp.boulder.ibm.com/epubs/pdf/ibm4pg03.pdf

References

- Visda Vokhshoori, Make Your C/C++ and PL/I Code FLY With the Right Compiler Options,

  SHARE Boston, Aug. 2013
- Peter Elderon, Make Your C/C++ and PL/I Code FLY With the Right Compiler Options,

  SHARE San Francisco, Feb. 2013

Quick Survey

- Users of:
  - PL/I
  - C/C++
  - NOOPTIMIZE/OPTIMIZE(0), OPTIMIZE(2), OPTIMIZE(3)
  - ARCH(7), ARCH(8), ARCH(9), ARCH(10)
  - C/C++ only:
    - TUNE
    - LP64
    - PDF
    - HOT
    - IPA

Questions?

- Connect with us
  - Email me
  - Rational Café - the compilers user community & forum
    - C/C++: http://ibm.com/rational/community/cpp
    - PL/I: http://ibm.com/rational/community/pli
  - RFE community – for feature requests
    - C/C++: http://www.ibm.com/developerworks/rfe/?PROD_ID=700
    - PL/I: http://www.ibm.com/developerworks/rfe/?PROD_ID=699
  - Product Information
    - C/C++: http://www-03.ibm.com/software/products/us/en/czos
    - PL/I: http://www-03.ibm.com/software/products/en/plicompfami

Thank You!