インテル® Itanium® 2プロセッサのプログラミング手法

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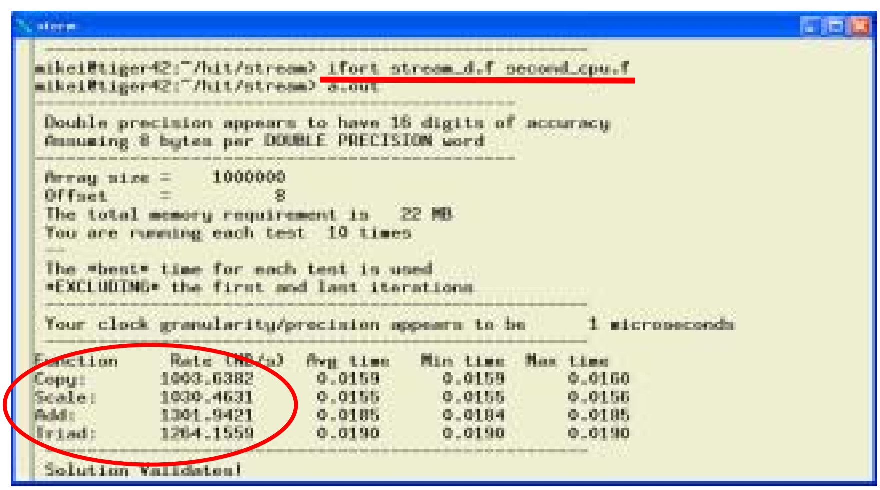
stream_d.fの実行ループ

```
       DO 70 k = 1,ntimes

           t = mysecond()
...
           DO 30 j = 1,n
               c(j) = a(j)
 30        CONTINUE
…
           DO 40 j = 1,n
               b(j) = scalar*c(j)
 40        CONTINUE
...
           DO 50 j = 1,n
               c(j) = a(j) + b(j)
 50        CONTINUE
...
           DO 60 j = 1,n
               a(j) = b(j) + scalar*c(j)
 60        CONTINUE
...
 70    CONTINUE
```


単純コンパイルと実行結果



コンパイルとリンク･オプションの確認


```
mikei@tiger42:~/hit/stream>
mikei@tiger42:~/hit/stream> ifort -dryrun stream_d.f second_cpu.f
/opt/intel_fc_80/bin/fortcom   \
      -D__INTEL_COMPILER=800 \
      -D__ELF__ \
      -D__unix__ \
      -D__unix \
      -D__linux__ \
      -D__linux \
      -D__gnu_linux__ \
      -Dunix \
      -Dlinux \
      -D__ia64 \
      -D__ia64__ \
      -Dia64 \
      -mGLOB_pack_sort_init_list \
      -I. \
      -I/opt/intel_fc_80/include \
      -I/opt/intel_fc_80/include \
      -I/opt/intel_fc_80/substitute_headers \
      -I/usr/include \
      -I/usr/local/electron/include64 \
      -I/usr/include \
      -O2 \
      -mP1OPT_version=802 \
      -mGLOB_source_language=GLOB_SOURCE_LANGUAGE_F90 \
      -mGLOB_tune_for_fort \
      -mGLOB_use_fort_dope_vector \
      -mP2OPT_static_promotion \
      -mP1OPT_print_version=FALSE \
      "-mGLOB_options_string=-I /opt/intel_fc_80/include -dryrun" \
      -mGLOB_cxx_limited_range=FALSE \
```


最適化(-O2)の内容確認


```
mikei@tiger42:~/hit/stream>
mikei@tiger42:~/hit/stream>
mikei@tiger42:~/hit/stream> ifort stream_d.f second_cpu.f -opt_report 2> rep
mikei@tiger42:~/hit/stream>
mikei@tiger42:~/hit/stream> ifort stream_d.f -c -opt_report 2> rep2
mikei@tiger42:~/hit/stream> ifort second_cpu.f -c -opt_report 2>>rep2
mikei@tiger42:~/hit/stream>
mikei@tiger42:~/hit/stream> diff rep rep2
3c3
< SWP REPORT LOG OPENED ON Fri Nov 28 15:54:53 2003
---
> SWP REPORT LOG OPENED ON Fri Nov 28 15:55:18 2003
854c854
< SWP REPORT LOG OPENED ON Fri Nov 28 15:54:53 2003
---
> SWP REPORT LOG OPENED ON Fri Nov 28 15:55:34 2003
mikei@tiger42:~/hit/stream> head rep

================================================================================
SWP REPORT LOG OPENED ON Fri Nov 28 15:54:53 2003
================================================================================

Optimization Report for: MAIN__()
Phase : Lowering
Counts:
    TOTAL transformations          :      0
```

最適化のレポート･オプション

- **関数名の指定**

  –opt_report_routine<name>
- **レポート･ファイル名の指定**

  –opt_report_file<name>
- **最適化フェーズの指定**

  -opt_report_phase<name>
- **最適化レポートのレベル**

  -opt_report_level[min|med|max]

最適化のレポート

-opt_report_phase<*phase*>

最適化論理名	**最適化の内容**	**関連する最適化オプション等**
ipo	Interprocedural Optimizer	-ipo, -ip
hlo	High-level Language Optimizer	-O3 (Loop unrolling)
ilo	Intermediate Language Scalar Optimizer	
ecg	Itanium Compiler Code Generator	(Software Pipelining)
pgo	Profile Guided Optimizer	-prof_gen, -prof_use
all	All optimizers	

stream_d.f メインプログラム

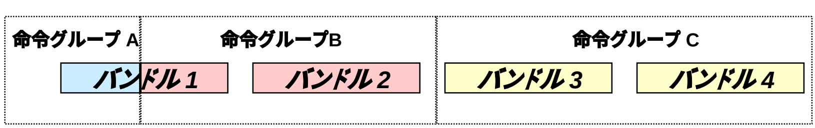
```
Code emission report for function MAIN__ (1) in file stream_d.f
Caveat: All dynamic data based on static profiles
Code size:
          Static bundle count                                  = 519
          Static instruction count (excluding nops)            = 958
          Static instruction count (Pre) (excluding nops)      = 0 (0.0%)
          Static instruction count (SWP) (excluding nops)      = 41 (4.3%)
          Static instruction count (GCS) (excluding nops)      = 6 (0.6%)
          Static instruction count (Post) (excluding nops)     = 911 (95.1%)
          Static instruction count (Unknown) (excluding nops) = 0 (0.0%)
          Static nop count                                     = 594
          Static nop count compared to total instructions      = 38.3%
          Dynamic bundle count                                 = 6.700006e+07
          Dynamic instruction count (excluding nops)           = 1.620015e+08
          Dynamic nop count                                    = 3.900104e+07
          Dynamic nop count compared to dynamic instructions = 19.4%
          Dynamic hot instruction count (excluding nops)       = 0.000000e+00
          Dynamic cold instruction count (excluding nops)      = 0.000000e+00
Estimated exec time. in cycles                                 = 4.600022e+08
Estimated exec time. in cycles (Pre)                    = 0.000000e+00 (0.0%)
Estimated exec time. in cycles (SWP)                    = 4.659997e+08 (99.6%)
Estimated exec time. in cycles (GCS)                    = 2.000008e+06 (0.4%)
Estimated exec time. in cycles (Post)                   = 2.503679e+03 (0.0%)
Estimated exec time. in cycles (Unknown)                = 0.000000e+00 (0.0%)
Average IPC = 0.35
"rep" 986L, 45587C                                        198,1-8        18%
```


命令バンドル

127 ... 87	86 ... 46	45 ... 5	4 ... 0
命令 2	命令 1	命令 0	テンプレート

バンドルフォーマット

- バンドル
  - 3つの命令スロット (各41-ビット)とテンプレートフィールド(5ビット)
  - 命令グループは幾つかのバンドルにまたがることができる
  - *例:*



柔軟性のある発行と並列実行

命令グループ

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- 同時に実行可能な1つ以上の命令の固まり (命令数の制限無し)
  - お互いに依存性のない隣接する命令は並列して実行することができる
- ブレーク・コード (;;) をアセンブリ・コード中に記述することによって、命令グループの境界を指示する、もしくは実行時に分岐によってターミネートする
- *例:*

add	r31 = r5, r6 ;;	Instr Group A
mov	r4 = r31	Instr Group B
add	r2 = r8, r9 ;;	
mov	r7 = r2	
mov	r15 = r27	
mov	r16 = r28	Instr Group C
mov	r17 = r29	
add	r3 = r11, r20 ;;	
mov	r10 = r3	Instr Group D

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stream_d.f メインプログラム

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```
Code emission report for function MAIN__ (1) in file stream_d.f
Caveat: All dynamic data based on static profiles
Code size:
          Static bundle count                                    = 519
          Static instruction count (excluding nops)              = 958
          Static instruction count (Pre) (excluding nops)        = 0 (0.0%)
          Static instruction count (SWP) (excluding nops)        = 41 (4.3%)
          Static instruction count (GCS) (excluding nops)        = 6 (0.6%)
          Static instruction count (Post) (excluding nops)       = 911 (95.1%)
          Static instruction count (Unknown) (excluding nops)    = 0 (0.0%)
          Static nop count                                       = 594
          Static nop count compared to total instructions        = 38.3%
          Dynamic bundle count                                   = 6.700006e+07
          Dynamic instruction count (excluding nops)             = 1.620015e+08
          Dynamic nop count                                      = 3.900104e+07
          Dynamic nop count compared to dynamic instructions     = 19.4%
          Dynamic hot instruction count (excluding nops)         = 0.000000e+00
          Dynamic cold instruction count (excluding nops)        = 0.000000e+00
Estimated exec time, in cycles                                   = 4.680022e+08
Estimated exec time, in cycles (Pre)                     = 0.000000e+00 (0.0%)
Estimated exec time, in cycles (SWP)                     = 4.659987e+08 (99.6%)
Estimated exec time, in cycles (GCS)                     = 2.000008e+06 (0.4%)
Estimated exec time, in cycles (Post)                    = 2.503679e+03 (0.0%)
Estimated exec time, in cycles (Unknown)                 = 0.000000e+00 (0.0%)
Average IPC = 0.35
                                                          198,1-8        18%
```

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ソフトウエア・パイプライン

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- **考察**

C コード:
```
for (i = 0; i < n; i++)
        y[i] = a * x[i];
```

擬似コード:
```
loop:
        load xi
        fmul yi = a, xi
        store yi
        branch loop
```

4サイクル

2サイクル

- **仮定**
  - **命令のレーテンシー**:
    - load 4 **サイクル***
    - fmul 2 **サイクル***
    - store 1 **サイクル***
    - branch 1 **サイクル***
  - Load, fmul, store **そして** branch **は同じ命令グループで発行可能**

* **ここでのサイクルカウントは実際の動作とは異なります。**

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ソフトウエア・パイプライン

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For n = 8

Cycle 1:	load x1			プロローグ
Cycle 2:	load x2			
Cycle 3:	load x3			
Cycle 4:	load x4			
Cycle 5:	load x5	fmul y1=a,x1		
Cycle 6:	load x6	fmul y2=a,x2		
Cycle 7:	load x7	fmul y3=a,x3	store y1	カーネル
Cycle 8:	load x8	fmul y4=a,x4	store y2	
Cycle 9:		fmul y5=a,x5	store y3	エピローグ
Cycle 10:		fmul y6=a,x6	store y4	
Cycle 11:		fmul y7=a,x7	store y5	
Cycle 12:		fmul y8=a,x8	store y6	
Cycle 13:			store y7	
Cycle 14:			store y8	

* **ここでのサイクルカウントは実際の動作とは異なります**

この例では1回あたりのループに7サイクル必要

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stream_d.fの207行ループ

```
 nop.i   0 ;;
// Block 42: lentry lexit ltail collapsed pipelined  Pred: 41 42     Succ:
   42 43
  -S
// Freq 9.0e+06
 }
.b1_42:
 {   .mfi
  (p16) ldfd    f32=[r18],8                            //0:207  395
  (p27) fma.d   f56=f6,f43,f55                         //11:207  397
        nop.i   0
 }
 {   .mmb
  (p16) ldfd    f44=[r17],8                            //0:207  396
  (p31) stfd    [r16]=f60,8                            //15:207  398
// Branch taken probability 0.99
        br.ctop.sptk    .b1_42 ;;                      //0:206  402
// Block 43: epilog  Pred: 42     Succ: 44  -O
// Freq 9.0e+00
 }
```

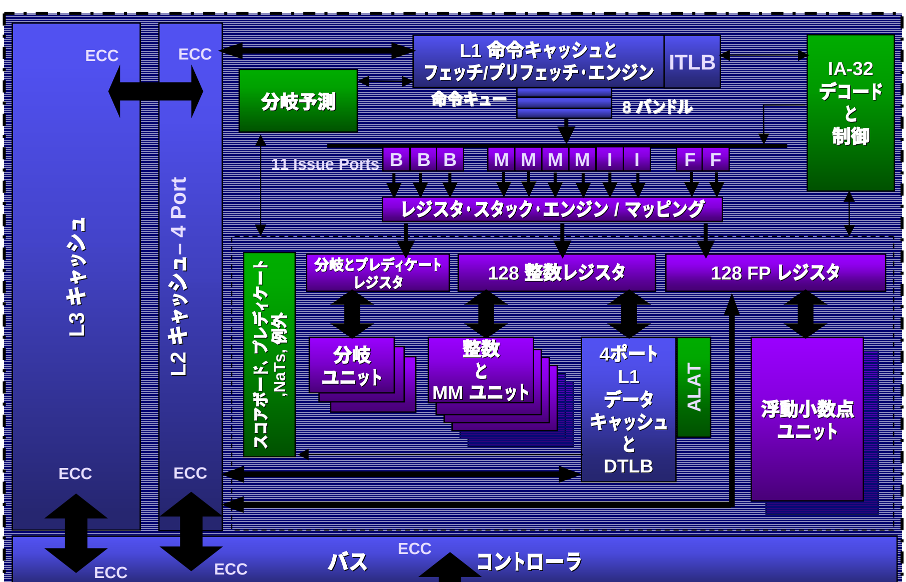

stream_d.fの207行ループ

```
===========================================================================
SWP REPORT LOG OPENED ON Sun Nov 30 16:39:51 2003
===========================================================================
...
--------------------------------------------------------------------------
---------------------------------------------------------------------------
Swp report for loop at line 207 in MAIN__ in file stream_d.f

         Resource II   =        1
         Recurrence II =        0
         Minimum II    =        1
         Scheduled II  =        1

         Percent of Resource II needed by arithmetic ops     = 100%
         Percent of Resource II needed by memory ops         = 100%
         Percent of Resource II needed by floating point ops = 100%

         Number of stages in the software pipeline =    16
---------------------------------------------------------------------------
```

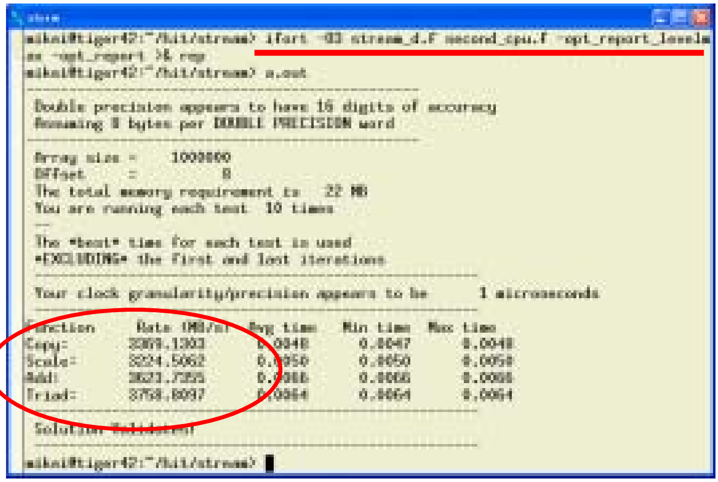
Initiation Interval (II)

- ループの繰り返しの<u>開始間隔</u>サイクル
  - ループ内の処理を実行するために必要な最小サイクル数
- リソースII
  - プロセッサの演算リソースの制限によるII
- 再帰 (リカーランス) II
  - ループ内のデータ依存性により必要なII
- 最小II
  - MAX (リソースII, 再帰II) : 必要最小II
- スケジュールII
  - 実際にコンパイラが適用したII

Intel® Itanium® 2プロセッサのブロック·ダイアグラム



-O3コンパイルと実行結果



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プリフェッチとロードペア

```
===========================================================================
High Level Optimizer Report for: MAIN__
...
Estimate of max_trip_count of loop at line 206=125001
Total #of lines prefetched in MAIN__ for loop in line 206=3
   # of spatial prefetches in MAIN__ for loop in line 206=3, dist=100
#
...
Load-pair formed at line 197 , 197   [Method = Aligned]
Load-pair formed at line 197 , 197   [Method = Aligned]
Load-pair formed at line 207 , 207   [Method = Aligned]
Load-pair formed at line 207 , 207   [Method = Aligned]
Load-pair formed at line 207 , 207   [Method = Aligned]
Load-pair formed at line 207 , 207   [Method = Aligned]
Load-pair formed at line 207 , 207   [Method = Aligned]
Load-pair formed at line 207 , 207   [Method = Aligned]
Load-pair formed at line 207 , 207   [Method = Aligned]
Load-pair formed at line 207 , 207   [Method = Aligned]
Load-pair formed at line 215 , 215   [Method = Aligned]
```

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プリフェッチとロードペア

```
Block, Unroll, Jam Report:
(loop line numbers, unroll factors and type of transformation)
Loop at line 151 unrolled without remainder by 4
Loop at line 158 unrolled without remainder by 8
Loop at line 176 unrolled without remainder by 4
Loop at line 186 unrolled without remainder by 4
Loop at line 196 unrolled without remainder by 4
Loop at line 206 unrolled without remainder by 8
Loop at line 216 completely unrolled by 4
...
------------------------------------------------------------------------
Swp report for loop at line 207 in MAIN__ in file stream_d.f

         Resource II   =        6
         Recurrence II =        0
         Minimum II    =        6
         Scheduled II  =        7

         Percent of Resource II needed by arithmetic ops     =  83%
         Percent of Resource II needed by memory ops         =  83%
         Percent of Resource II needed by floating point ops =  67%

         Number of stages in the software pipeline =    3
------------------------------------------------------------------------
```


ループ・アンローリング

```
...
206          DO 60 j = 1,n
207              a(j) = b(j) + scalar*c(j)
208     60   CONTINUE
...


...
206          DO jj = 1,n/8
207              j=(jj-1)*8
207              a(j) = b(j) + scalar*c(j)
207              a(j+1) = b(j+1) + scalar*c(j+1)
207              a(j+2) = b(j+2) + scalar*c(j+2)
207              a(j+3) = b(j+3) + scalar*c(j+3)
207              a(j+4) = b(j+4) + scalar*c(j+4)
207              a(j+5) = b(j+5) + scalar*c(j+5)
207              a(j+6) = b(j+6) + scalar*c(j+6)
207              a(j+7) = b(j+7) + scalar*c(j+7)
207          END DO
207          DO 60 j = (n/8)*8, n+mod(n,8)
207              a(j) = b(j) + scalar*c(j)
208     60   CONTINUE
...
```

プリフェッチとロードペア

```
// Block 44: lentry lexit ltail collapsed pipelined  Pred: 44 43     Succ: 44
      45
  -S
// Freq 2.7e+07
 }
.b1_44:
 {   .mfi
  (p16) ldfpd   f41,f32=[r39]                        //0:207  574
  (p18) fma.d   f55=f6,f72,f45                       //14:207  594
        nop.i   0
 }
 {   .mfi
  (p16) ldfpd   f53,f50=[r38]                        //0:207  575
  (p18) fma.d   f56=f6,f69,f36                       //14:207  596
        nop.i   0 ;;
 }
[illegible]
 {   .mmi
  (p16) ldfpd   f48,f39=[r46]                        //2:207  586
  (p16) ldfpd   f65,f62=[r37]                        //2:207  587
        nop.i   0
 }
 {   .mmi
  (p18) stfd    [r27]=f34,64                         //16:207  583
  (p18) stfd    [r26]=f43,64                         //16:207  585
        nop.i   0 ;;
 }
[illegible]
 {   .mmf
  (p16) add     r36=64,r37                           //4:206  617
  (p16) lfetch.nt1      [r34]                        //4:206  598
  (p17) fma.d   f47=f6,f51,f33                       //11:207  578
 }
 {   .mmf
  (p18) stfd    [r23]=f56,64                         //18:207  597
  (p18) stfd    [r22]=f55,64                         //18:207  595
  (p17) fma.d   f38=f6,f54,f42 ;;                    //11:207  576
 }
[illegible]
 {   .mfi
  (p16) lfetch.nt1      [r21],64                     //6:206  602
  (p17) fma.d   f37=f6,f66,f49                       //13:207  588
  (p16) add     r32=128,r34                          //6:206  599
 }
 {   .mfb
  (p16) add     r38=64,r39                           //6:206  612
  (p17) fma.d   f46=f6,f63,f40                       //13:207  590
// Branch taken probability 1.00
        br.ctop.sptk    .b1_44 ;;                    //6:206  620
// Block 45: epilog  Pred: 44     Succ: 46  -O
```

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Itanium® 2 プロセッサ メモリ 構造

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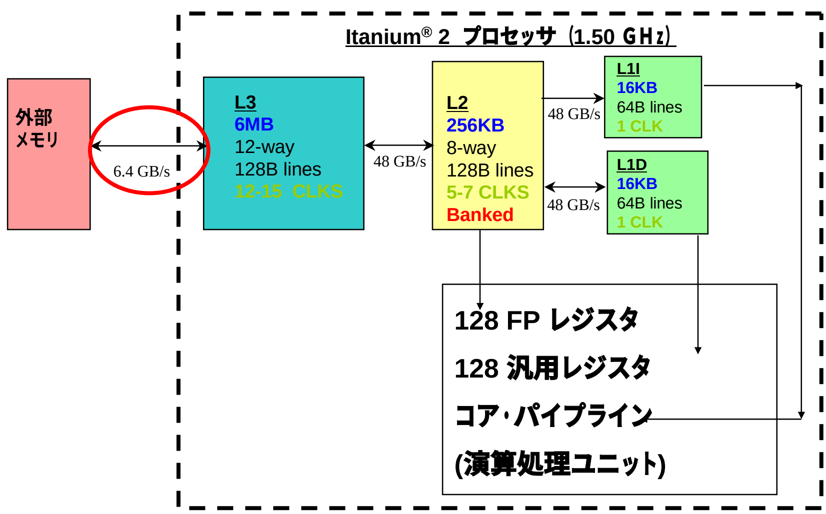

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-openmp 並列化コンパイルと実行結果

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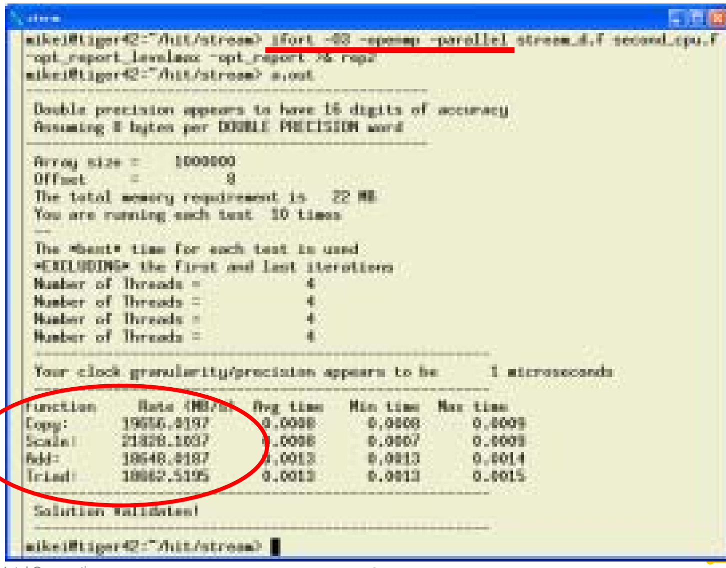

```
mikei@tiger42:~/hit/stream> ifort -O3 -openmp -parallel stream_d.f second_cpu.f
-opt_report_levelmax -opt_report >& rep2
mikei@tiger42:~/hit/stream> a.out
----------------------------------------------
 Double precision appears to have 16 digits of accuracy
 Assuming 8 bytes per DOUBLE PRECISION word
----------------------------------------------
 Array size =     1000000
 Offset     =           8
 The total memory requirement is    22 MB
 You are running each test  10 times
 --
 The *best* time for each test is used
 *EXCLUDING* the first and last iterations
 Number of Threads =               4
 Number of Threads =               4
 Number of Threads =               4
 Number of Threads =               4
 ----------------------------------------------------
 Your clock granularity/precision appears to be      1 microseconds
 ----------------------------------------------------
Function      Rate (MB/s)   Avg time    Min time   Max time
Copy:       19656.0197      0.0008      0.0008      0.0009
Scale:      21828.1037      0.0008      0.0007      0.0009
Add:        18648.0187      0.0013      0.0013      0.0014
Triad:      18862.5195      0.0013      0.0013      0.0015
 ----------------------------------------------------
 Solution validates!
 ----------------------------------------------------
mikei@tiger42:~/hit/stream>
```

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  - 最適化ディレクティブ
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  - プロファイル・ガイド最適化 (PGO)

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multiply_d.c プログラム

```
#include "multiply_d.h"

// matrix multiply routine

void multiply_d(double a[][DIM], double  b[][DIM], double  c[][DIM])
{
        int i,j,k;
        double temp;
        for(i=0;i<NUM;i++) {
            for(k=0;k<NUM;k++) {
                for(j=0;j<NUM;j++) {
                         c[i][j] = c[i][j] + a[i][k] * b[k][j];
                }
            }
        }
}
```


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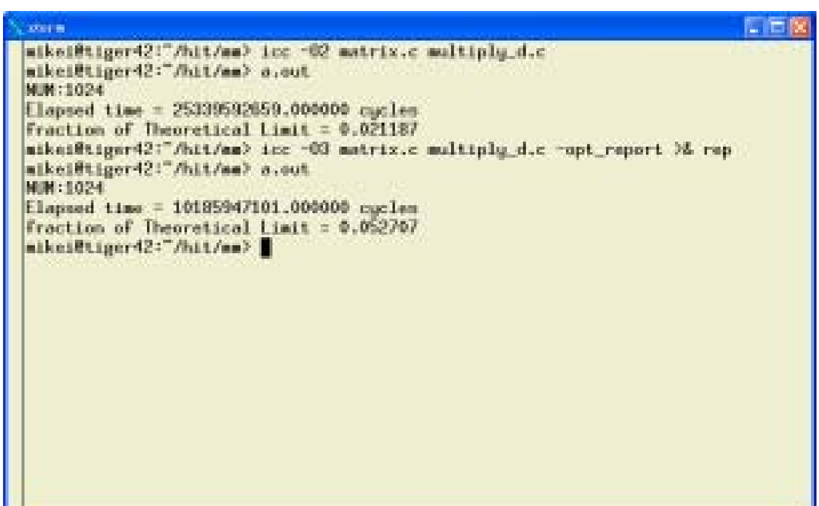
単純コンパイルと実行結果



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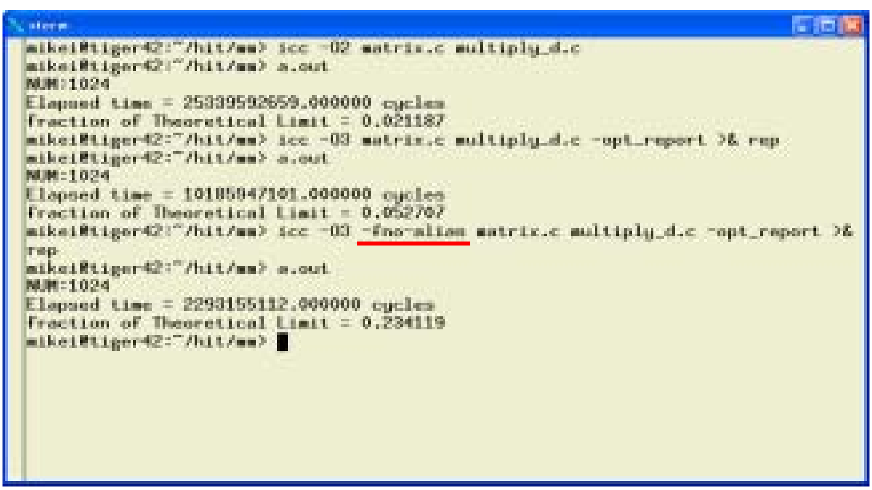
multiply_d.cの12行ループ

```
--------------------------------------------------------------------------
Swp report for loop at line 12 in multiply_d in file multiply_d.c

         Resource II   =        4
         Recurrence II =        15
         Minimum II    =        15
         Scheduled II  =        18

         Percent of Resource II needed by arithmetic ops     = 100%
         Percent of Resource II needed by memory ops         = 100%
         Percent of Resource II needed by floating point ops =  25%

         Number of stages in the software pipeline =    2

         Following are the loop-carried memory dependence edges:
         Store  at line    12 --> Load   at line    12
         Store  at line    12 --> Load   at line    12
         Store  at line    12 --> Load   at line    12
         Store  at line    12 --> Load   at line    12
         Load   at line    12 --> Store  at line    12
         Load   at line    12 --> Store  at line    12
         Store  at line    12 --> Load   at line    12
         Store  at line    12 --> Load   at line    12
--------------------------------------------------------------------------
```


-fno_alias による依存性解消



multiply_d.cの12行ループ

- --
- Swp report for loop at line 12 in multiply_d in file multiply_d.c

- Resource II = 3
- Recurrence II = 0
- Minimum II = 3
- Scheduled II = 3

- Percent of Resource II needed by arithmetic ops = 100%
- Percent of Resource II needed by memory ops = 100%
- Percent of Resource II needed by floating point ops = 33%

- Number of stages in the software pipeline = 6
- --

#pragma ivdep の挿入

```
1 #include "multiply_d.h"
2
3 // matrix multiply routine
4
5 void multiply_d(double a[][DIM], double  b[][DIM], double  c[][DIM])
6 {
7         int i,j,k;
8         double temp;
9         for(i=0;i<NUM;i++) {
10            for(k=0;k<NUM;k++) {
11 #pragma ivdep
12                for(j=0;j<NUM;j++) {
13                         c[i][j] = c[i][j] + a[i][k] * b[k][j];
14                }
15            }
16        }
17 }
18
```

ivdep による依存性解消

最適化のディレクティブ

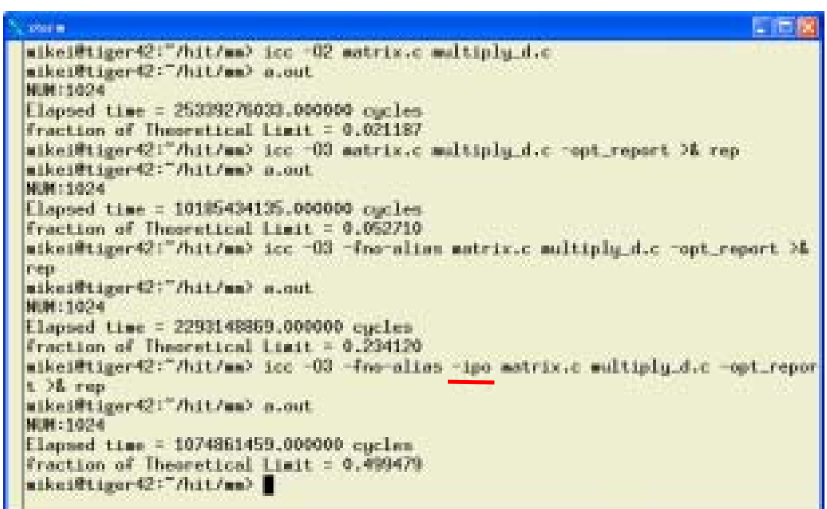
C言語シンタックス	Fortranシンタックス
#pragma [no]swp	!DEC$ [NO]SWP
#pragma loop count (10000)	!DEC$ LOOP COUNT (n)
#pragma distribute point	!DEC$ DISTRIBUTE POINT
#pragma [no]unroll(n)	!DEC$ [NO]UNROLL(n)
#pragma [no]prefetch a,b	!DEC$ [NO]PREFETCH
#pragma ivdep	!DEC$ IVDEP

ディレクティブの使用例

```
#pragma swp
for (i=0; i<m ; i++)
{
  if (a[i]==0)
  {
     b[i]=a[i]+1;
  }
  else
  {
     b[i]=a[i]*2;
  }
}
```

```
!DEC$ IVDEP
   do j=1,n
      a(b(j)) = a(b(j))+1
   enddo
```


プロシジャ間 (IPO) 最適化



目次

- ストリーム・ベンチのコンパイル(Fortran)
  - 最適化レポートの出力方法
  - Itanium® 2 プロセッサの演算リソース
  - ソフトウェア・パイプライニング
- 行列乗算のコンパイル (C)
  - 最適化オプション
  - 最適化ディレクティブ
- ＳＰＥＣintのコンパイル
  - プロシジャ間最適化（ＩＰＯ）
  - プロファイル・ガイド最適化（ＰＧＯ）

Spec*2000 から gzipの性能

- gcc **のコンパイル実行結果** 185.151s
- ecc 45.146s (4.10x)
- -O3 **オプション** 44.726s (4.14x)
- -O3 –ipo 43.341s (4.27x)
- -O3 –prof_gen ….
- -O3 –ipo –prof_use **34.305 (5.40x)**

Linux kernel 2.4.19-smp,Intel®C/C++ compiler 7.1 #20030703,gcc 2.96
Tiger4 system Intel® Itanium 2 プロセッサ1.5ＧＨｚ6MB Cache 2-way

gcc によるコンパイル実行

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```
[mikei@tiger2 00000001]$ gcc --version
2.96
[mikei@tiger2 00000001]$ gcc *.c
[mikei@tiger2 00000001]$ time ./a.out >/dev/null

real    3m5.151s
user    3m5.015s
sys     0m0.124s
[mikei@tiger2 00000001]$ 
```

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eccによるコンパイル実行

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```
[mikei@tiger2 00000001]$ gcc --version
2.96
[mikei@tiger2 00000001]$ gcc *.c
[mikei@tiger2 00000001]$ time ./a.out >/dev/null

real    3m5.151s
user    3m5.015s
sys     0m0.124s
[mikei@tiger2 00000001]$ ecc -w0 *.c
[mikei@tiger2 00000001]$ time ./a.out >/dev/null

real    0m45.146s
user    0m45.027s
sys     0m0.119s
[mikei@tiger2 00000001]$ 
```

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-O3によるコンパイル実行

```
[mikei@tiger2 000000001]$ gcc --version
2.96
[mikei@tiger2 000000001]$ gcc *.c
[mikei@tiger2 000000001]$ time ./a.out >/dev/null

real    3m5.151s
user    3m5.015s
sys     0m0.124s
[mikei@tiger2 000000001]$ ecc -w0 *.c
[mikei@tiger2 000000001]$ time ./a.out >/dev/null

real    0m45.146s
user    0m45.027s
sys     0m0.119s
[mikei@tiger2 000000001]$ ecc -O3 -w0 *.c
[mikei@tiger2 000000001]$ time ./a.out >/dev/null

real    0m44.726s
user    0m44.604s
sys     0m0.125s
[mikei@tiger2 000000001]$ █
```

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-O3によるコンパイル実行(ls)

```
2.96
[mikei@tiger2 000000001]$ gcc *.c
[mikei@tiger2 000000001]$ time ./a.out >/dev/null

real    3m5.151s
user    3m5.015s
sys     0m0.124s
[mikei@tiger2 000000001]$ ecc -w0 *.c
[mikei@tiger2 000000001]$ time ./a.out >/dev/null

real    0m45.146s
user    0m45.027s
sys     0m0.119s
[mikei@tiger2 000000001]$ ecc -O3 -w0 *.c
[mikei@tiger2 000000001]$ time ./a.out >/dev/null

real    0m44.726s
user    0m44.604s
sys     0m0.125s
[mikei@tiger2 000000001]$ ls *.[ch]
bits.c     getopt.c  gzip.h     lzw.h       tailor.h  unlzw.c   util.c
crypt.h    getopt.h  inflate.c  revision.h  trees.c   unpack.c  zip.c
deflate.c  gzip.c    lzw.c      spec.c      unlzh.c   unzip.c
[mikei@tiger2 000000001]$ █
```

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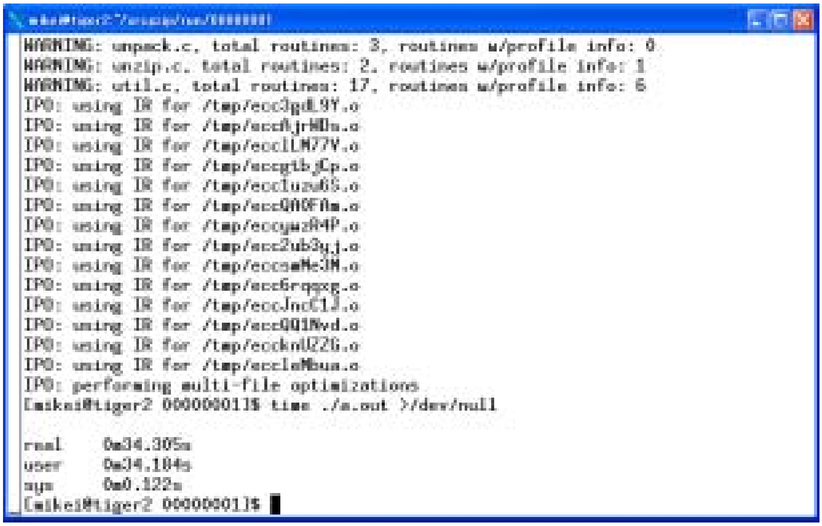
-ipoによるコンパイル実行

```
crypt.h     getopt.h  inflate.c  revision.h  trees.c   unpack.c  zip.c
deflate.c   gzip.c    lzw.c      spec.c      unlzh.c   unzip.c
[mikei@tiger2 00000001]$ ecc -O3 -ipo -w0 *.c
IPO: using IR for /tmp/eccdbFc9H.o
IPO: using IR for /tmp/eccSPrIHM.o
IPO: using IR for /tmp/ecciAdufR.o
IPO: using IR for /tmp/eccr61CNV.o
IPO: using IR for /tmp/eccpkYL10.o
IPO: using IR for /tmp/eccC5RUT4.o
IPO: using IR for /tmp/eccHI03r9.o
IPO: using IR for /tmp/eccbN5c0d.o
IPO: using IR for /tmp/eccm20lyi.o
IPO: using IR for /tmp/eccp67u6m.o
IPO: using IR for /tmp/ecc0riEEr.o
IPO: using IR for /tmp/eccHQzNcw.o
IPO: using IR for /tmp/ecc2yUWKA.o
IPO: using IR for /tmp/eccqKc6iF.o
IPO: performing multi-file optimizations
[mikei@tiger2 00000001]$ time ./a.out >/dev/null

real    0m43.341s
user    0m43.216s
sys     0m0.127s
[mikei@tiger2 00000001]$ 
```


-prof_genによるコンパイル実行

```
[mikei@tiger2 00000001]$ ecc -O3  -prof_gen -w0 *.c
[mikei@tiger2 00000001]$ time ./a.out >/dev/null

real    2m32.316s
user    2m32.190s
sys     0m0.122s
[mikei@tiger2 00000001]$ ecc -O3 -ipo -prof_use -w0 *.c
/opt/intel/compiler70/ia64/bin/profmerge: WARNING: existing ./pgopti.dpi will be
 overwritten.
/opt/intel/compiler70/ia64/bin/profmerge: merging dynamic file: 3f717dfd_11283.d
yn
WARNING: gzip.c, total routines: 3, routines w/profile info: 1
WARNING: inflate.c, total routines: 8, routines w/profile info: 7
WARNING: lzw.c, total routines: 1, routines w/profile info: 0
WARNING: spec.c, total routines: 16, routines w/profile info: 11
WARNING: trees.c, total routines: 14, routines w/profile info: 13
WARNING: unlzh.c, total routines: 12, routines w/profile info: 0
WARNING: unlzw.c, total routines: 1, routines w/profile info: 0
WARNING: unpack.c, total routines: 3, routines w/profile info: 0
WARNING: unzip.c, total routines: 2, routines w/profile info: 1
WARNING: util.c, total routines: 17, routines w/profile info: 6
IPO: using IR for /tmp/ecc3gdL9Y.o
IPO: using IR for /tmp/eccAjrWDs.o
IPO: using IR for /tmp/ecclLM77V.o
```

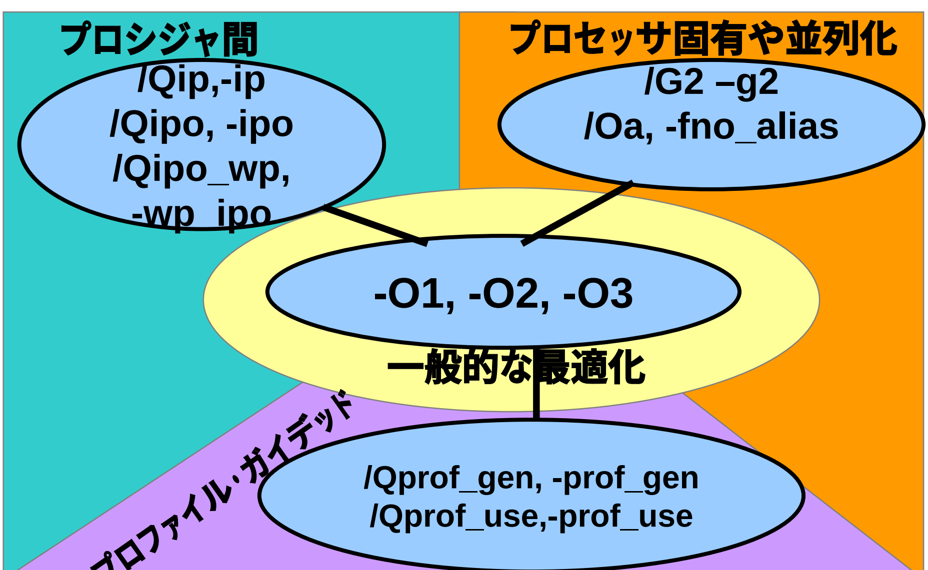
-prof_useによるコンパイル実行



```
WARNING: unpack.c, total routines: 3, routines w/profile info: 0
WARNING: unzip.c, total routines: 2, routines w/profile info: 1
WARNING: util.c, total routines: 17, routines w/profile info: 6
IPO: using IR for /tmp/ecc3gdL9Y.o
IPO: using IR for /tmp/eccAjrHDs.o
IPO: using IR for /tmp/ecclLM77V.o
IPO: using IR for /tmp/eccgtbjCp.o
IPO: using IR for /tmp/eccluzu6S.o
IPO: using IR for /tmp/eccQA0FAm.o
IPO: using IR for /tmp/eccywzR4P.o
IPO: using IR for /tmp/ecc2ub3yj.o
IPO: using IR for /tmp/eccsaMe3M.o
IPO: using IR for /tmp/ecc6rqgxg.o
IPO: using IR for /tmp/eccJncC1J.o
IPO: using IR for /tmp/eccQQ1Nvd.o
IPO: using IR for /tmp/eccknU2ZG.o
IPO: using IR for /tmp/ecclaMbua.o
IPO: performing multi-file optimizations
[mikei@tiger2 00000001]$ time ./a.out >/dev/null

real    0m34.305s
user    0m34.104s
sys     0m0.122s
[mikei@tiger2 00000001]$
```


最適化コンパイラ

Performance Switches



IPO

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使用方法

1. Compile program
`icc -c -ipo foo.c`

→ foo.o (fake object file)

→ foo.il (un-optimized intermediate language files)

2. Link program
`icc -o foo -ipo foo.o`

2a. Compiler performs whole-program optimizations

2b. Compiler invokes linker to produce executable

→ foo (optimized executable)

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PGO

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使用方法

1. Compile+link to add instrumentation
`icc –o foo -prof_gen foo.c`

→ foo (instrumented executable)

2. Execute instrumented program
`./foo`

→ 12345678.dyn (dynamic profile)

3. Compile+link using feedback
`icc –o foo -prof_use foo.c`

→ pgopti.dpi (merged .dyn files)

→ foo (optimized executable)

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まとめ

- コンパイラの最適化レポートを利用して重要ループのソフトウェア･パイプライン化を確認しましょう
  - プロセッサのリソースは有効に活用されていますか？
  - 偽の依存性はないでしょうか？
- ディレクティブやコンパイル時のオプションを用いてコンパイラの最適化をサポートしましょう
  - 依存性を無視したら最適化されますか？
  - コンパイラを助ける適切なデイレクティブはどれでしょうか？
  - 適用可能な場合はインテルのパフォーマンス･ライブラリを使用しましょう
- プロシジャ間最適化 (IPO) とプロファイル･ガイド最適化 (PGO) は必ず試みましょう
  - Itanium® アーキテクチャでは特に有効です

御参考

- 開発を用意にするインテルのパフォーマンス･ツールを利用しましょう
  - インテル®　パフォーマンス コンパイラ
  - インテル® VTune™ パフォーマンス　アナライザ
  - インテル® パフォーマンス　ライブラリ
  - http://www.intel.co.jp/jp/developer/software/products/compilers
- 弊社のパートナXLsoft (株) により日本語のサポートが得られます
  - http://www.xlsoft.com/jp/products/vtune/perftool.htm
  - https://premier.intel.com　(英語によるサポート)
- インテルSWカレッジによるトレーニング
  - http://www.intel.com/software/products/college　(日本でのトレーニングについては要相談)
- パフォーマンスのチューニングやカウンタの説明には
  - IA-64 プロセッサ基本講座　池井　満著　2000年8月　オーム社
  - インテル® Itanium® 2 プロセッサ　リファレンス･マニュアル　ソフトウェアの開発と最適化

http://developer.intel.com/design/itanium2/manuals/