```
./test/run-c2181031.sh
TEST: c2181031
./freess -exe program-c2181031 -wins 8 -pregs 8 -robs 10 -llat 2 -lqs 3 -sqs 3 -int no

LIST OF INITALIZATION PARAMETERS
---------------------------------------------[General]
Program Name           = program-c2181031
Silent                 = no
Interactive            = no
Mode                   = no
Iterations             = 3
Starting Clock Cycle   = 0
Tomasulo Mode          = no
-----------------------------------------[Architecture]
Logical Registers      = 8
Physical Registers     = 8
Pipeline Structure     = FDPIXWC
Unified LSU            = yes
Load over Store Pri    = yes
In-Order Issue         = no
In-Order Complete      = no
Unified Disp./Issue    = yes
Early RS Release       = yes
Data Mem. Pipe         = yes
Fetch Width            = 4
Decode Width           = 4
Dispatch Width         = 4
Issue Width            = 4
Write-Back Width       = 4
Commit Width           = 4
Window Size            = 8
ROB Size               = 10
Integer ALU Units      = 4
Integer ALU Latency    = 0
Int. ALU Res.Stat.     = 100
Integer Mult. Units    = 1
Integer Mul. Latency   = 4
Integer Mul. Pipe      = yes
Int. Mul. Res.Stat.    = 100
Integer Div. Units     = 1
Integer Div. Latency   = 4
Integer Div. Pipe      = yes
Int. Div. Res.Stat.    = 100
Floating Point Units   = 4
Floating Point Mul     = 1
Load Units             = 1
Load Latency           = 2
Load Pipe              = yes
Store Units            = 1
Store Latency          = 1
Store Pipe             = yes
Store Waits            = no
Load/Store Res.Stat.   = 100
Branch Units           = 1
Branch Latency         = 0
Branch Res.Stat.       = 100
Load Queue Size        = 3
Store Queue Size       = 3
Speculation            = yes
Write Back Latency     = 0
-----------------------------------------[Program Defaults]
Log File Name          = def.log
-----------------------------------------------
* Input program: 'program-c2181031'
  x1 <-- 00000010
  x4 <-- 00000040
  x5 <-- 00000050
  x6 <-- 00000060
  000)  1  2  1  0 --> LW   x2,0(x1)
  001)  7  4  2  2 --> MUL  x4,x2,x2
  002)  2  4  1  0 --> SW   x4,0(x1)
  003)  6  1  1  4 --> ADDI x1,x1,4
  004)  4  2  0 -5 --> BNE  x2,x0,-5
* TOTAL_ INSTRUCTIONS=5
* NUMBER_OF_ITERATIONS=3
       - STAGE = 4 entries.
   FETCH STAGE = 4 entries.
  DECODE STAGE = 4 entries.
DISPATCH STAGE = 4 entries.
   ISSUE STAGE = 4 entries.
 EXECUTE STAGE = 12 entries.
COMPLETE STAGE = 4 entries.
  COMMIT STAGE = 4 entries.
-------------------------------------------------------
================================================================================================================================================
Consider the following snippet of code running on 4-ways out-of-order superscalar processor.
Initially, x1=0x0010, x4=0x0040, x5=0x0050, x6=0x0060 and the other registers contain zero.

                lab1:   LW   x2,0(x1)
                        MUL  x4,x2,x2
                        SW   x4,0(x1)
                        ADDI x1,x1,4
                        BNE  x2,x0,lab1

Working hypothesis:
* the fetch, decode and commit stages are 4 instructions wide
* the instruction window has 8 slots
* we have 8 physical registers in the free pool (excluding P0 which is hardwired to 0)
* the reorder buffer has 10 entries
* the integer multiplier has 4 stages
* the load/store queues have 3 slots each and a common effective-address calculation unit
* there are 4 ALUs for arithmetic and logic operations and for branching
* an ALU/BRANCH performs its operation in the same cycle when the operation is issued
* reads require 1 clock cycle (after the addressing phase)
* when accessing memory (M), reads have precedence over writes and must be executed in-order
* the register file has 4 input- and 4 output-ports
* there are 8 logical registers (excluding x0 which is hardwired to 0)
* the store operation leaves the issue stage as it is inserted in the store queue
* when the X stage finds a free slot in the LQ/SQ, also a slot in the I stage is reserved
* branches are predicted taken

Calculate the total cycles, needed to execute 3 iterations of the above loop on such machine;
complete the following chart until the end of the third iteration of the code fragment above, including the
renamed stream the precise evolution of the free pool of the physical registers (the register map), the
Instruction Window, the Reorder Buffer (ROB) and the Load Queue (LQ) and Store Queue (SQ).
Note: Ci, Cj, Ck, Cl indicate the cycle when the corresponding physical registers are available in IW
================================================================================================================================================
PHYSICAL REGS:  1  2  3  4  5  6  7  8

          qi:   1  1  1  1  1  1  1  1
          vi:  00 00 00 00 00 00 00 00
================================================================================================================================================
REG.FILE: xi:         1        2        3        4        5        6        7        8
          Pi:         -        -        -        -        -        -        -        -
```

```
         Qi:         0         0         0         0         0         0         0         0
         Vi:  00000010 00000000 00000000 00000040 00000050 00000060 00000000 00000000
=================================================================================================================================================
STAGES:                  F  D  P  I  X  W  C RENAMED-STR    INSTRUCTION-WINDOW                  REORDER-BUFFER          A  M  L  S  B  F  X  D
TOTAL SLOTS:             4  4  4  4 12  4  4 8              8                                   10                      4  1  1  0  1  4  1  1
BUSY SLOTS:              4  0  0  0  0  0  0 0              0                                   0                       0  0  0  0  0  0  0  0
STALLS:                  0  0  0  0  0  0  0 0              0                                   0                       0  0  0  0  0  0  0  0
=================================================================================================================================================
PC   INSTRUCTION         F  D  P  I  X  W  C Pi,Pj Pk Pl    IW#  OPCD Pi  Pj  Pk I/Pl  Cj Ck Cl  ROB# PC  xi  oPi s x c  +--------------------+
000] LW   x2,0(x1)       0                                                                                                  |LQ(0 )              |
001] MUL  x4,x2,x2       0                                                                                                  |PC   OP Pi  EFAD Ci|
002] SW   x4,0(x1)       0                                                                                                  +--------------------+
003] ADDI x1,x1,4        0

                                                                                                                            +--------------------+
                                                                                                                            |SQ(0 )              |
                                                                                                                            |PC   OP Pl  EFAD Cl|
                                                                                                                            +--------------------+

------------------------------------------------- Press ENTER to continue (PC=4,IC=4,CK=0,CTOT=1,IPC=4.00)...
=================================================================================================================================================
PHYSICAL REGS:  1  2  3  4  5  6  7  8
                *  *  *  *
         qi:    0  1  1  1  1  1  1  1
         vi:   10 00 00 00 00 00 00 00
=================================================================================================================================================
REG.FILE: xi:            1        2        3        4        5        6        7        8
          Pi:            4        2        -        3        -        -        -        -
          Qi:            1        1        0        1        0        0        0        0
          Vi:  00000010 00000000 00000000 00000040 00000050 00000060 00000000 00000000
=================================================================================================================================================
STAGES:                  F  D  P  I  X  W  C RENAMED-STR    INSTRUCTION-WINDOW                  REORDER-BUFFER          A  M  L  S  B  F  X  D
TOTAL SLOTS:             4  4  4  4 12  4  4 8              8                                   10                      4  1  1  0  1  4  1  1
BUSY SLOTS:              1  4  0  0  0  0  0 4              0                                   0                       0  0  0  0  0  0  0  0
STALLS:                  0  0  0  0  0  0  0 0              0                                   0                       0  0  0  0  0  0  0  0
=================================================================================================================================================
PC   INSTRUCTION         F  D  P  I  X  W  C Pi,Pj Pk Pl    IW#  OPCD Pi  Pj  Pk I/Pl  Cj Ck Cl  ROB# PC  xi  oPi s x c  +--------------------+
000] LW   x2,0(x1)       0  1               P2,0(P1)                                                                        |LQ(0 )              |
001] MUL  x4,x2,x2       0  1               P3,P2,P2                                                                        |PC   OP Pi  EFAD Ci|
002] SW   x4,0(x1)       0  1               ,0(P1)<-P3                                                                      +--------------------+
003] ADDI x1,x1,4        0  1               P4,P1,4
004] BNE  x2,x0,-5       1                                                                                                  +--------------------+
                                                                                                                            |SQ(0 )              |
                                                                                                                            |PC   OP Pl  EFAD Cl|
                                                                                                                            +--------------------+

------------------------------------------------- Press ENTER to continue (PC=0,IC=5,CK=1,CTOT=2,IPC=2.50)...
=================================================================================================================================================
PHYSICAL REGS:  1  2  3  4  5  6  7  8
                *  *  *  *
         qi:    0  1  1  1  1  1  1  1
         vi:   10 00 00 00 00 00 00 00
=================================================================================================================================================
REG.FILE: xi:            1        2        3        4        5        6        7        8
          Pi:            4        2        -        3        -        -        -        -
          Qi:            1        1        0        1        0        0        0        0
          Vi:  00000010 00000000 00000000 00000040 00000050 00000060 00000000 00000000
=================================================================================================================================================
STAGES:                  F  D  P  I  X  W  C RENAMED-STR    INSTRUCTION-WINDOW                  REORDER-BUFFER          A  M  L  S  B  F  X  D
TOTAL SLOTS:             4  4  4  4 12  4  4 8              8                                   10                      4  1  1  0  1  4  1  1
BUSY SLOTS:              4  1  0  0  0  0  0 4              4                                   4                       0  0  0  0  0  0  0  0
STALLS:                  0  0  0  0  0  0  0 0              0                                   0                       0  0  0  0  0  0  0  0
=================================================================================================================================================
PC   INSTRUCTION         F  D  P  I  X  W  C Pi,Pj Pk Pl    IW#  OPCD Pi  Pj  Pk I/Pl  Cj Ck Cl  ROB# PC  xi  oPi s x c  +--------------------+
000] LW   x2,0(x1)       0  1  2               P2,0(P1)      000)   LW P2  P1  -   0    2  -  -   000) 000 x2  -   0 0 0  |LQ(0 )              |
001] MUL  x4,x2,x2       0  1  2               P3,P2,P2      001)  MUL P3  P2  P2  -    .  .  -   001) 001 x4  -   0 0 0  |PC   OP Pi  EFAD Ci|
002] SW   x4,0(x1)       0  1  2               ,0(P1)<-P3    002)   SW -   P3  P1  0    -  2  -   002) 002 -   -   1 0 0  +--------------------+
003] ADDI x1,x1,4        0  1  2               P4,P1,4       003) ADDI P4  P1  -   4    2  -  -   003) 003 x1  P1  0 0 0
004] BNE  x2,x0,-5       1  2                  ,P2,P0,-5                                                                   +--------------------+
005] LW   x2,0(x1)       2                                                                                                  |SQ(0 )              |
006] MUL  x4,x2,x2       2                                                                                                  |PC   OP Pl  EFAD Cl|
007] SW   x4,0(x1)       2                                                                                                  +--------------------+
008] ADDI x1,x1,4        2
------------------------------------------------- Press ENTER to continue (PC=4,IC=9,CK=2,CTOT=3,IPC=3.00)...
=================================================================================================================================================
PHYSICAL REGS:  1  2  3  4  5  6  7  8
                *  *  *  *  *  *  *  *
         qi:    0  1  1  1  1  1  1  1
         vi:   10 00 00 14 00 00 00 00
=================================================================================================================================================
REG.FILE: xi:            1        2        3        4        5        6        7        8
          Pi:            7        5        -        6        -        -        -        -
          Qi:            1        1        0        1        0        0        0        0
          Vi:  00000010 00000000 00000000 00000040 00000050 00000060 00000000 00000000
=================================================================================================================================================
STAGES:                  F  D  P  I  X  W  C RENAMED-STR    INSTRUCTION-WINDOW                  REORDER-BUFFER          A  M  L  S  B  F  X  D
TOTAL SLOTS:             4  4  4  4 12  4  4 8              8                                   10                      4  1  1  0  1  4  1  1
BUSY SLOTS:              1  4  0  0  1  0  0 7              3                                   5                       0  0  0  0  0  0  0  0
STALLS:                  0  0  0  0  0  0  0 0              0                                   0                       0  0  3  3  0  0  0  0
=================================================================================================================================================
PC   INSTRUCTION         F  D  P  I  X  W  C Pi,Pj Pk Pl    IW#  OPCD Pi  Pj  Pk I/Pl  Cj Ck Cl  ROB# PC  xi  oPi s x c  +--------------------+
000] LW   x2,0(x1)       0  1  2  3            P2,0(P1)      000>   LW P2  P1  -   0    3  3  -   000) 000 x2  -   0 0 0  |LQ(1 )              |
001] MUL  x4,x2,x2       0  1  2               P3,P2,P2      001)  MUL P3  P2  P2  -    .  .  -   001) 001 x4  -   0 0 0  |PC   OP Pi  EFAD Ci|
002] SW   x4,0(x1)       0  1  2               ,0(P1)<-P3    002)   SW -   P3  P1  0    -  2  -   002) 002 -   -   1 0 0  |000] LW P2  0010  3|
003] ADDI x1,x1,4        0  1  2  3  3         P4,P1,4       003> ADDI P4  P1  -   4    3  3  -   003) 003 x1  P1  0 0 0  +--------------------+
004] BNE  x2,x0,-5       1  2  3               ,P2,P0,-5     003)  BNE -   P2  P0  -5   .  3  -   004) 004 -   -   0 0 0
005] LW   x2,0(x1)       2  3                  P5,0(P4)                                                                    +--------------------+
006] MUL  x4,x2,x2       2  3                  P6,P5,P5                                                                    |SQ(0 )              |
007] SW   x4,0(x1)       2  3                  ,0(P4)<-P6                                                                  |PC   OP Pl  EFAD Cl|
008] ADDI x1,x1,4        2  3                  P7,P4,4                                                                     +--------------------+
009] BNE  x2,x0,-5       3
------------------------------------------------- Press ENTER to continue (PC=0,IC=10,CK=3,CTOT=4,IPC=2.50)...
@003 stall due to no S-unit available for SW/002
@003 stall due to no S-unit available for SW/002
@003 stall due to no S-unit available for SW/002

=================================================================================================================================================
PHYSICAL REGS:  1  2  3  4  5  6  7  8
                *  *  *  *  *  *  *  *
         qi:    0  1  1  0  1  1  1  1
         vi:   10 00 00 14 00 00 00 00
=================================================================================================================================================
REG.FILE: xi:            1        2        3        4        5        6        7        8
          Pi:            7        5        -        6        -        -        -        -
          Qi:            1        1        0        1        0        0        0        0
          Vi:  00000014 00000000 00000000 00000040 00000050 00000060 00000000 00000000
=================================================================================================================================================
STAGES:                  F  D  P  I  X  W  C RENAMED-STR    INSTRUCTION-WINDOW                  REORDER-BUFFER          A  M  L  S  B  F  X  D
TOTAL SLOTS:             4  4  4  4 12  4  4 8              8                                   10                      4  1  1  0  1  4  1  1
BUSY SLOTS:              4  1  0  0  1  1  0 7              6                                   9                       0  0  0  0  0  0  0  0
STALLS:                  0  0  0  0  0  0  0 0              0                                   0                       0  0  3  3  0  0  0  0
=================================================================================================================================================
PC   INSTRUCTION         F  D  P  I  X  W  C Pi,Pj Pk Pl    IW#  OPCD Pi  Pj  Pk I/Pl  Cj Ck Cl  ROB# PC  xi  oPi s x c  +--------------------+
000] LW   x2,0(x1)       0  1  2  3  4         P2,0(P1)      ----   LW P2  P1  -   0    3  3  -   000) 000 x2  -   0 0 0  |LQ(0 )              |
001] MUL  x4,x2,x2       0  1  2               P3,P2,P2      001)  MUL P3  P2  P2  -    .  .  -   001) 001 x4  -   0 0 0  |PC   OP Pi  EFAD Ci|
```

```
002] SW   x4,0(x1)       0  1  2  4          ,0(P1)<-P3      002>   SW -   P3  P1  0    -  4  -   002) 002 -   -   1 0 0  |---- LW P2  0010  3|
003] ADDI x1,x1,4        0  1  2  3  3  4    P4,P1,4         ---- ADDI P4  P1  -   4    3  3  -   003) 003 x1  P1  0 0 1  +-------------------+
004] BNE  x2,x0,-5       1  2  3             ,P2,P0,-5       003)  BNE -   P2  P0  -5   .  3  -   004) 004 -   -   0 0 0
005] LW   x2,0(x1)       2  3  4             P5,0(P4)        004)   LW P5  P4  -   0    4  -  -   005) 000 x2  P2  0 0 0  +-------------------+
006] MUL  x4,x2,x2       2  3  4             P6,P5,P5        005)  MUL P6  P5  P5  -    .  .  -   006) 001 x4  P3  0 0 0  |SQ(1 )             |
007] SW   x4,0(x1)       2  3  4             ,0(P4)<-P6      006)   SW -   P6  P4  0    -  4  -   007) 002 -   -   1 0 0  |PC   OP Pl  EFAD Cl|
008] ADDI x1,x1,4        2  3  4             P7,P4,4         007) ADDI P7  P4  -   4    4  -  -   008) 003 x1  P4  0 0 0  |   . SW P3  0010  .|
009] BNE  x2,x0,-5       3  4                ,P5,P0,-5                                           +-------------------+
010] LW   x2,0(x1)       4
011] MUL  x4,x2,x2       4
012] SW   x4,0(x1)       4
013] ADDI x1,x1,4        4
---------------------------------------------------- Press ENTER to continue (PC=4,IC=14,CK=4,CTOT=5,IPC=2.80)...
================================================================================================================================================
PHYSICAL REGS:  1  2  3  4  5  6  7  8
                *  *  *  *  *  *  *  *
          qi:   0  1  1  0  1  1  1  1
          vi:  10 00 00 14 00 00 18 00
================================================================================================================================================
REG.FILE: xi:          1        2        3        4        5        6        7        8
          Pi:          7        8        -        6        -        -        -        -
          Qi:          1        1        0        1        0        0        0        0
          Vi:  00000014 00000000 00000000 00000040 00000050 00000060 00000000 00000000
================================================================================================================================================
STAGES:                  F  D  P  I  X  W  C RENAMED-STR    INSTRUCTION-WINDOW                  REORDER-BUFFER          A  M  L  S  B  F  X  D
TOTAL SLOTS:             4  4  4  4 12  4  4 8              8                                   10                      4  1  1  0  1  4  1  1
BUSY SLOTS:              4  1  0  0  2  1  0 8              5                                   10                      0  0  0  0  0  0  0  0
STALLS:                  0  1  0  0  0  0  1 1              0                                   0                       0  0  6  6  0  0  0  0
================================================================================================================================================
PC   INSTRUCTION         F  D  P  I  X  W  C Pi,Pj Pk Pl    IW#  OPCD Pi  Pj  Pk I/Pl  Cj Ck Cl  ROB# PC  xi  oPi s x c  +-------------------+
000] LW   x2,0(x1)       0  1  2  3  4       P2,0(P1)        ----   LW P2  P1  -   0    3  3  -   000) 000 x2  -   0 0 0  |LQ(1 )             |
001] MUL  x4,x2,x2       0  1  2             P3,P2,P2        001)  MUL P3  P2  P2  -    .  .  -   001) 001 x4  -   0 0 0  |PC   OP Pi  EFAD Ci|
002] SW   x4,0(x1)       0  1  2  4          ,0(P1)<-P3      ----   SW -   P3  P1  0    -  4  -   002) 002 -   -   1 0 0  |---- LW P2  0010  3|
003] ADDI x1,x1,4        0  1  2  3  3  4    P4,P1,4         ---- ADDI P4  P1  -   4    3  3  -   003) 003 x1  P1  0 0 1  |005] LW P5  0014  5|
004] BNE  x2,x0,-5       1  2  3             ,P2,P0,-5       003)  BNE -   P2  P0  -5   .  3  -   004) 004 -   -   0 0 0  +-------------------+
005] LW   x2,0(x1)       2  3  4  5          P5,0(P4)        004>   LW P5  P4  -   0    5  5  -   005) 000 x2  P2  0 0 0
006] MUL  x4,x2,x2       2  3  4             P6,P5,P5        005)  MUL P6  P5  P5  -    .  .  -   006) 001 x4  P3  0 0 0  +-------------------+
007] SW   x4,0(x1)       2  3  4             ,0(P4)<-P6      006)   SW -   P6  P4  0    -  4  -   007) 002 -   -   1 0 0  |SQ(1 )             |
008] ADDI x1,x1,4        2  3  4  5  5       P7,P4,4         007> ADDI P7  P4  -   4    5  5  -   008) 003 x1  P4  0 0 0  |PC   OP Pl  EFAD Cl|
009] BNE  x2,x0,-5       3  4  5             ,P5,P0,-5       007)  BNE -   P5  P0  -5   .  5  -   009) 004 -   -   0 0 0  |   . SW P3  0010  .|
010] LW   x2,0(x1)       4  5                P8,0(P7)                                            +-------------------+
011] MUL  x4,x2,x2       4
012] SW   x4,0(x1)       4
013] ADDI x1,x1,4        4
014] BNE  x2,x0,-5       5
---------------------------------------------------- Press ENTER to continue (PC=0,IC=15,CK=5,CTOT=6,IPC=2.50)...
@005 stall due to DATA_WAIT in C when moving ADDI/003 from W to C.
@005 stall due to no S-unit available for SW/007
@005 stall due to no S-unit available for SW/007
@005 stall due to no S-unit available for SW/007
@005 stall due to Physical registers not available
@005 stall due to DATA_WAIT in D when moving MUL/011 from F to D.

================================================================================================================================================
PHYSICAL REGS:  1  2  3  4  5  6  7  8
                *  *  *  *  *  *  *  *
          qi:   0  0  1  0  1  1  0  1
          vi:  10 00 00 14 00 00 18 00
================================================================================================================================================
REG.FILE: xi:          1        2        3        4        5        6        7        8
          Pi:          7        8        -        6        -        -        -        -
          Qi:          0        1        0        1        0        0        0        0
          Vi:  00000018 00000000 00000000 00000040 00000050 00000060 00000000 00000000
================================================================================================================================================
STAGES:                  F  D  P  I  X  W  C RENAMED-STR    INSTRUCTION-WINDOW                  REORDER-BUFFER          A  M  L  S  B  F  X  D
TOTAL SLOTS:             4  4  4  4 12  4  4 8              8                                   10                      4  1  1  0  1  4  1  1
BUSY SLOTS:              4  1  0  0  2  1  0 8              2                                   10                      0  0  0  0  0  0  0  0
STALLS:                  0  2  1  0  0  0  2 2              0                                   1                       0  0  6  6  0  0  0  0
================================================================================================================================================
PC   INSTRUCTION         F  D  P  I  X  W  C Pi,Pj Pk Pl    IW#  OPCD Pi  Pj  Pk I/Pl  Cj Ck Cl  ROB# PC  xi  oPi s x c  +-------------------+
000] LW   x2,0(x1)       0  1  2  3  4  6    P2,0(P1)        ----   LW P2  P1  -   0    3  3  -   000) 000 x2  -   0 0 1  |LQ(0 )             |
001] MUL  x4,x2,x2       0  1  2  6  6       P3,P2,P2        001>  MUL P3  P2  P2  -    6  6  -   001) 001 x4  -   0 0 0  |PC   OP Pi  EFAD Ci|
002] SW   x4,0(x1)       0  1  2  4          ,0(P1)<-P3      ----   SW -   P3  P1  0    -  4  -   002) 002 -   -   1 0 0  |---- LW P2  0010  3|
003] ADDI x1,x1,4        0  1  2  3  3  4    P4,P1,4         ---- ADDI P4  P1  -   4    3  3  -   003) 003 x1  P1  0 0 1  |---- LW P5  0014  5|
004] BNE  x2,x0,-5       1  2  3  6  6  6    ,P2,P0,-5       003>  BNE -   P2  P0  -5   6  6  -   004) 004 -   -   0 0 1  +-------------------+
005] LW   x2,0(x1)       2  3  4  5  6       P5,0(P4)        ----   LW P5  P4  -   0    5  5  -   005) 000 x2  P2  0 0 0
006] MUL  x4,x2,x2       2  3  4             P6,P5,P5        005)  MUL P6  P5  P5  -    .  .  -   006) 001 x4  P3  0 0 0  +-------------------+
007] SW   x4,0(x1)       2  3  4  6          ,0(P4)<-P6      006)   SW -   P6  P4  0    -  6  -   007) 002 -   -   1 0 0  |SQ(2 )             |
008] ADDI x1,x1,4        2  3  4  5  5  6    P7,P4,4         ---- ADDI P7  P4  -   4    5  5  -   008) 003 x1  P4  0 0 1  |PC   OP Pl  EFAD Cl|
009] BNE  x2,x0,-5       3  4  5             ,P5,P0,-5       007)  BNE -   P5  P0  -5   .  5  -   009) 004 -   -   0 0 0  |   . SW P3  0010  .|
010] LW   x2,0(x1)       4  5                P8,0(P7)                                            |   . SW P6  0014  .|
011] MUL  x4,x2,x2       4                                                                        +-------------------+
012] SW   x4,0(x1)       4
013] ADDI x1,x1,4        4
014] BNE  x2,x0,-5       5
---------------------------------------------------- Press ENTER to continue (PC=0,IC=15,CK=6,CTOT=7,IPC=2.14)...
@006 stall due to DATA_WAIT in C when moving ADDI/003 from W to C.
@006 stall due to ROB full
@006 stall due to NO_ROB_SLOTS in P when moving LW/010 from D to P.
@006 stall due to Physical registers not available
@006 stall due to DATA_WAIT in D when moving MUL/011 from F to D.

================================================================================================================================================
PHYSICAL REGS:  1  2  3  4  5  6  7  8
                *  *  *  *  *  *  *  *
          qi:   0  0  1  0  1  1  0  1
          vi:  10 00 00 14 00 00 18 00
================================================================================================================================================
REG.FILE: xi:          1        2        3        4        5        6        7        8
          Pi:          7        8        -        6        -        -        -        -
          Qi:          0        1        0        1        0        0        0        0
          Vi:  00000018 00000000 00000000 00000040 00000050 00000060 00000000 00000000
================================================================================================================================================
STAGES:                  F  D  P  I  X  W  C RENAMED-STR    INSTRUCTION-WINDOW                  REORDER-BUFFER          A  M  L  S  B  F  X  D
TOTAL SLOTS:             4  4  4  4 12  4  4 8              8                                   10                      4  1  1  0  1  4  1  1
BUSY SLOTS:              4  0  0  0  2  0  0 8              3                                   10                      0  0  0  0  0  0  0  0
STALLS:                  0  3  1  0  0  0  2 3              0                                   1                       0  0  6  6  0  0  0  0
================================================================================================================================================
PC   INSTRUCTION         F  D  P  I  X  W  C Pi,Pj Pk Pl    IW#  OPCD Pi  Pj  Pk I/Pl  Cj Ck Cl  ROB# PC  xi  oPi s x c  +-------------------+
000] LW   x2,0(x1)       0  1  2  3  4  6  7 P2,0(P1)        ----   LW P2  P1  -   0    3  3  -   ---- 000 x2  -   0 0 1  |LQ(0 )             |
001] MUL  x4,x2,x2       0  1  2  6  6       P3,P2,P2        ----  MUL P3  P2  P2  -    6  6  -   001) 001 x4  -   0 0 0  |PC   OP Pi  EFAD Ci|
002] SW   x4,0(x1)       0  1  2  4          ,0(P1)<-P3      ----   SW -   P3  P1  0    -  4  -   002) 002 -   -   1 0 0  |---- LW P2  0010  3|
003] ADDI x1,x1,4        0  1  2  3  3  4    P4,P1,4         ---- ADDI P4  P1  -   4    3  3  -   003) 003 x1  P1  0 0 1  |---- LW P5  0014  5|
004] BNE  x2,x0,-5       1  2  3  6  6  6    ,P2,P0,-5       ----  BNE -   P2  P0  -5   6  6  -   004) 004 -   -   0 0 1  +-------------------+
005] LW   x2,0(x1)       2  3  4  5  6       P5,0(P4)        ----   LW P5  P4  -   0    5  5  -   005) 000 x2  P2  0 0 0
006] MUL  x4,x2,x2       2  3  4             P6,P5,P5        005)  MUL P6  P5  P5  -    .  .  -   006) 001 x4  P3  0 0 0  +-------------------+
007] SW   x4,0(x1)       2  3  4  6          ,0(P4)<-P6      ----   SW -   P6  P4  0    -  6  -   007) 002 -   -   1 0 0  |SQ(2 )             |
008] ADDI x1,x1,4        2  3  4  5  5  6    P7,P4,4         ---- ADDI P7  P4  -   4    5  5  -   008) 003 x1  P4  0 0 1  |PC   OP Pl  EFAD Cl|
009] BNE  x2,x0,-5       3  4  5             ,P5,P0,-5       007)  BNE -   P5  P0  -5   .  5  -   009) 004 -   -   0 0 0  |   . SW P3  0010  .|
010] LW   x2,0(x1)       4  5  7             P8,0(P7)        000)   LW P8  P7  -   0    7  -  -   000) 000 x2  P5  0 0 0  |   . SW P6  0014  .|
011] MUL  x4,x2,x2       4                                                                        +-------------------+
012] SW   x4,0(x1)       4
013] ADDI x1,x1,4        4
014] BNE  x2,x0,-5       5
```

```
------------------------------------------------ Press ENTER to continue (PC=0,IC=15,CK=7,CTOT=8,IPC=1.87)...
@007 stall due to Physical registers not available
@007 stall due to DATA_WAIT in D when moving MUL/011 from F to D.

================================================================================================================================================
PHYSICAL REGS:  1  2  3  4  5  6  7  8
                *  *  *  *  *  *  *  *
          qi:   0  0  1  0  0  1  0  1
          vi:  10 00 00 14 00 00 18 00
================================================================================================================================================
REG.FILE: xi:         1        2        3        4        5        6        7        8
          Pi:         7        8        -        6        -        -        -        -
          Qi:         0        1        0        1        0        0        0        0
          Vi:  00000018 00000000 00000000 00000040 00000050 00000060 00000000 00000000
================================================================================================================================================
STAGES:                  F  D  P  I  X  W  C RENAMED-STR    INSTRUCTION-WINDOW                  REORDER-BUFFER          A  M  L  S  B  F  X  D
TOTAL SLOTS:             4  4  4  4 12  4  4 8              8                                   10                      4  1  1  0  1  4  1  1
BUSY SLOTS:              4  0  0  0  2  1  0 8              0                                   10                      0  0  0  0  0  0  0  0
STALLS:                  0  4  1  0  0  0  2 4              0                                   1                       0  0  6  6  0  0  0  0
================================================================================================================================================
PC   INSTRUCTION         F  D  P  I  X  W  C Pi,Pj Pk Pl    IW#  OPCD Pi  Pj  Pk I/Pl  Cj Ck Cl  ROB# PC  xi  oPi s x c  +--------------------+
000] LW   x2,0(x1)       0  1  2  3  4  6  7 P2,0(P1)      ----   LW P2  P1  -   0     3  3  -   ---- 000 x2  -   0 0 1  |LQ(1 )              |
001] MUL  x4,x2,x2       0  1  2  6  6       P3,P2,P2      ----  MUL P3  P2  P2  -     6  6  -   001) 001 x4  -   0 0 0  |PC   OP Pi  EFAD Ci|
002] SW   x4,0(x1)       0  1  2  4          ,0(P1)<-P3    ----   SW -   P3  P1  0     -  4  -   002) 002 -   -   1 0 0  |---- LW P2  0010  3 |
003] ADDI x1,x1,4        0  1  2  3  3  4    P4,P1,4       ---- ADDI P4  P1  -   4     3  3  -   003) 003 x1  P1  0 0 1  |---- LW P5  0014  5 |
004] BNE  x2,x0,-5       1  2  3  6  6  6    ,P2,P0,-5     ----  BNE -   P2  P0  -5    6  6  -   004) 004 -   -   0 0 1  |010] LW P8  0018  8 |
005] LW   x2,0(x1)       2  3  4  5  6  8    P5,0(P4)      ----   LW P5  P4  -   0     5  5  -   005) 000 x2  P2  0 0 1  +--------------------+
006] MUL  x4,x2,x2       2  3  4  8  8       P6,P5,P5      005>  MUL P6  P5  P5  -     8  8  -   006) 001 x4  P3  0 0 0
007] SW   x4,0(x1)       2  3  4  6          ,0(P4)<-P6    ----   SW -   P6  P4  0     -  6  -   007) 002 -   -   1 0 0  +--------------------+
008] ADDI x1,x1,4        2  3  4  5  5  6    P7,P4,4       ---- ADDI P7  P4  -   4     5  5  -   008) 003 x1  P4  0 0 1  |SQ(2 )              |
009] BNE  x2,x0,-5       3  4  5  8  8  8    ,P5,P0,-5     007>  BNE -   P5  P0  -5    8  8  -   009) 004 -   -   0 0 1  |PC   OP Pl  EFAD Cl|
010] LW   x2,0(x1)       4  5  7  8          P8,0(P7)      000>   LW P8  P7  -   0     8  8  -   000) 000 x2  P5  0 0 0  |   . SW P3  0010  . |
011] MUL  x4,x2,x2       4                                                                                               |   . SW P6  0014  . |
012] SW   x4,0(x1)       4                                                                                               +--------------------+
013] ADDI x1,x1,4        4
014] BNE  x2,x0,-5       5
------------------------------------------------ Press ENTER to continue (PC=0,IC=15,CK=8,CTOT=9,IPC=1.67)...
@008 stall due to Physical registers not available
@008 stall due to DATA_WAIT in D when moving MUL/011 from F to D.

================================================================================================================================================
PHYSICAL REGS:  1  2  3  4  5  6  7  8
                *  *  *  *  *  *  *  *
          qi:   0  0  1  0  0  1  0  1
          vi:  10 00 00 14 00 00 18 00
================================================================================================================================================
REG.FILE: xi:         1        2        3        4        5        6        7        8
          Pi:         7        8        -        6        -        -        -        -
          Qi:         0        1        0        1        0        0        0        0
          Vi:  00000018 00000000 00000000 00000040 00000050 00000060 00000000 00000000
================================================================================================================================================
STAGES:                  F  D  P  I  X  W  C RENAMED-STR    INSTRUCTION-WINDOW                  REORDER-BUFFER          A  M  L  S  B  F  X  D
TOTAL SLOTS:             4  4  4  4 12  4  4 8              8                                   10                      4  1  1  0  1  4  1  1
BUSY SLOTS:              4  0  0  0  3  1  0 8              0                                   10                      0  0  0  0  0  0  0  0
STALLS:                  0  5  1  0  0  0  3 5              0                                   1                       0  0  6  6  0  0  0  0
================================================================================================================================================
PC   INSTRUCTION         F  D  P  I  X  W  C Pi,Pj Pk Pl    IW#  OPCD Pi  Pj  Pk I/Pl  Cj Ck Cl  ROB# PC  xi  oPi s x c  +--------------------+
000] LW   x2,0(x1)       0  1  2  3  4  6  7 P2,0(P1)      ----   LW P2  P1  -   0     3  3  -   ---- 000 x2  -   0 0 1  |LQ(0 )              |
001] MUL  x4,x2,x2       0  1  2  6  6       P3,P2,P2      ----  MUL P3  P2  P2  -     6  6  -   001) 001 x4  -   0 0 0  |PC   OP Pi  EFAD Ci|
002] SW   x4,0(x1)       0  1  2  4          ,0(P1)<-P3    ----   SW -   P3  P1  0     -  4  -   002) 002 -   -   1 0 0  |---- LW P2  0010  3 |
003] ADDI x1,x1,4        0  1  2  3  3  4    P4,P1,4       ---- ADDI P4  P1  -   4     3  3  -   003) 003 x1  P1  0 0 1  |---- LW P5  0014  5 |
004] BNE  x2,x0,-5       1  2  3  6  6  6    ,P2,P0,-5     ----  BNE -   P2  P0  -5    6  6  -   004) 004 -   -   0 0 1  |---- LW P8  0018  8 |
005] LW   x2,0(x1)       2  3  4  5  6  8    P5,0(P4)      ----   LW P5  P4  -   0     5  5  -   005) 000 x2  P2  0 0 1  +--------------------+
006] MUL  x4,x2,x2       2  3  4  8  8       P6,P5,P5      ----  MUL P6  P5  P5  -     8  8  -   006) 001 x4  P3  0 0 0
007] SW   x4,0(x1)       2  3  4  6          ,0(P4)<-P6    ----   SW -   P6  P4  0     -  6  -   007) 002 -   -   1 0 0  +--------------------+
008] ADDI x1,x1,4        2  3  4  5  5  6    P7,P4,4       ---- ADDI P7  P4  -   4     5  5  -   008) 003 x1  P4  0 0 1  |SQ(2 )              |
009] BNE  x2,x0,-5       3  4  5  8  8  8    ,P5,P0,-5     ----  BNE -   P5  P0  -5    8  8  -   009) 004 -   -   0 0 1  |PC   OP Pl  EFAD Cl|
010] LW   x2,0(x1)       4  5  7  8  9       P8,0(P7)      ----   LW P8  P7  -   0     8  8  -   000) 000 x2  P5  0 0 0  |   . SW P3  0010  . |
011] MUL  x4,x2,x2       4                                                                                               |   . SW P6  0014  . |
012] SW   x4,0(x1)       4                                                                                               +--------------------+
013] ADDI x1,x1,4        4
014] BNE  x2,x0,-5       5
------------------------------------------------ Press ENTER to continue (PC=0,IC=15,CK=9,CTOT=10,IPC=1.50)...
@009 stall due to DATA_WAIT in C when moving LW/005 from W to C.
@009 stall due to Physical registers not available
@009 stall due to DATA_WAIT in D when moving MUL/011 from F to D.

================================================================================================================================================
PHYSICAL REGS:  1  2  3  4  5  6  7  8
                *  *  *  *  *  *  *  *
          qi:   0  0  1  0  0  1  0  1
          vi:  10 00 00 14 00 00 18 00
================================================================================================================================================
REG.FILE: xi:         1        2        3        4        5        6        7        8
          Pi:         7        8        -        6        -        -        -        -
          Qi:         0        1        0        1        0        0        0        0
          Vi:  00000018 00000000 00000000 00000040 00000050 00000060 00000000 00000000
================================================================================================================================================
STAGES:                  F  D  P  I  X  W  C RENAMED-STR    INSTRUCTION-WINDOW                  REORDER-BUFFER          A  M  L  S  B  F  X  D
TOTAL SLOTS:             4  4  4  4 12  4  4 8              8                                   10                      4  1  1  0  1  4  1  1
BUSY SLOTS:              4  0  0  0  3  1  0 8              0                                   10                      0  0  0  0  0  0  0  0
STALLS:                  0  6  1  0  0  0  4 6              0                                   1                       0  0  6  6  0  0  0  0
================================================================================================================================================
PC   INSTRUCTION         F  D  P  I  X  W  C Pi,Pj Pk Pl    IW#  OPCD Pi  Pj  Pk I/Pl  Cj Ck Cl  ROB# PC  xi  oPi s x c  +--------------------+
000] LW   x2,0(x1)       0  1  2  3  4  6  7 P2,0(P1)      ----   LW P2  P1  -   0     3  3  -   ---- 000 x2  -   0 0 1  |LQ(0 )              |
001] MUL  x4,x2,x2       0  1  2  6  6       P3,P2,P2      ----  MUL P3  P2  P2  -     6  6  -   001) 001 x4  -   0 0 0  |PC   OP Pi  EFAD Ci|
002] SW   x4,0(x1)       0  1  2  4          ,0(P1)<-P3    ----   SW -   P3  P1  0     -  4  -   002) 002 -   -   1 0 0  |---- LW P2  0010  3 |
003] ADDI x1,x1,4        0  1  2  3  3  4    P4,P1,4       ---- ADDI P4  P1  -   4     3  3  -   003) 003 x1  P1  0 0 1  |---- LW P5  0014  5 |
004] BNE  x2,x0,-5       1  2  3  6  6  6    ,P2,P0,-5     ----  BNE -   P2  P0  -5    6  6  -   004) 004 -   -   0 0 1  |---- LW P8  0018  8 |
005] LW   x2,0(x1)       2  3  4  5  6  8    P5,0(P4)      ----   LW P5  P4  -   0     5  5  -   005) 000 x2  P2  0 0 1  +--------------------+
006] MUL  x4,x2,x2       2  3  4  8  8       P6,P5,P5      ----  MUL P6  P5  P5  -     8  8  -   006) 001 x4  P3  0 0 0
007] SW   x4,0(x1)       2  3  4  6          ,0(P4)<-P6    ----   SW -   P6  P4  0     -  6  -   007) 002 -   -   1 0 0  +--------------------+
008] ADDI x1,x1,4        2  3  4  5  5  6    P7,P4,4       ---- ADDI P7  P4  -   4     5  5  -   008) 003 x1  P4  0 0 1  |SQ(2 )              |
009] BNE  x2,x0,-5       3  4  5  8  8  8    ,P5,P0,-5     ----  BNE -   P5  P0  -5    8  8  -   009) 004 -   -   0 0 1  |PC   OP Pl  EFAD Cl|
010] LW   x2,0(x1)       4  5  7  8  9       P8,0(P7)      ----   LW P8  P7  -   0     8  8  -   000) 000 x2  P5  0 0 0  |   . SW P3  0010  . |
011] MUL  x4,x2,x2       4                                                                                               |   . SW P6  0014  . |
012] SW   x4,0(x1)       4                                                                                               +--------------------+
013] ADDI x1,x1,4        4
014] BNE  x2,x0,-5       5
------------------------------------------------ Press ENTER to continue (PC=0,IC=15,CK=10,CTOT=11,IPC=1.36)...
@010 stall due to DATA_WAIT in C when moving LW/005 from W to C.
@010 stall due to Physical registers not available
@010 stall due to DATA_WAIT in D when moving MUL/011 from F to D.

================================================================================================================================================
PHYSICAL REGS:  1  2  3  4  5  6  7  8
                *  *  *  *  *  *  *  *
          qi:   0  0  0  0  0  1  0  0
          vi:  10 00 00 14 00 00 18 00
================================================================================================================================================
REG.FILE: xi:         1        2        3        4        5        6        7        8
          Pi:         7        8        -        6        -        -        -        -
          Qi:         0        0        0        1        0        0        0        0
          Vi:  00000018 00000000 00000000 00000000 00000050 00000060 00000000 00000000
```

```
================================================================================================================================================
STAGES:                F  D  P  I  X  W  C RENAMED-STR    INSTRUCTION-WINDOW                  REORDER-BUFFER          A  M  L  S  B  F  X  D
TOTAL SLOTS:           4  4  4  4 12  4  4 8              8                                   10                      4  1  1  0  1  4  1  1
BUSY SLOTS:            4  0  0  0  1  1  0 8              0                                   10                      0  0  0  0  0  0  0  0
STALLS:                0  7  1  0  0  0  5 7              0                                   1                       0  0  6  6  0  0  0  0
================================================================================================================================================
PC   INSTRUCTION       F  D  P  I  X  W  C Pi,Pj Pk Pl    IW#  OPCD Pi  Pj  Pk I/Pl  Cj Ck Cl  ROB# PC  xi  oPi s x c  +--------------------+
000] LW   x2,0(x1)     0  1  2  3  4  6  7 P2,0(P1)      ----   LW P2  P1  -   0    3  3  -   ---- 000 x2  -   0 0 1  |LQ(0 )              |
001] MUL  x4,x2,x2     0  1  2  6  6 11    P3,P2,P2      ----  MUL P3  P2  P2  -    6  6  -   001) 001 x4  -   0 0 1  |PC   OP Pi  EFAD Ci|
002] SW   x4,0(x1)     0  1  2  4 11 11    ,0(P1)<-P3    ----   SW -   P3  P1  0    -  4  -   002) 002 -   -   1 0 1  |---- LW P2  0010  3 |
003] ADDI x1,x1,4      0  1  2  3  3  4    P4,P1,4       ---- ADDI P4  P1  -   4    3  3  -   003) 003 x1  P1  0 0 1  |---- LW P5  0014  5 |
004] BNE  x2,x0,-5     1  2  3  6  6  6    ,P2,P0,-5     ----  BNE -   P2  P0  -5   6  6  -   004) 004 -   -   0 0 1  |---- LW P8  0018  8 |
005] LW   x2,0(x1)     2  3  4  5  6  8    P5,0(P4)      ----   LW P5  P4  -   0    5  5  -   005) 000 x2  P2  0 0 1  +--------------------+
006] MUL  x4,x2,x2     2  3  4  8  8       P6,P5,P5      ----  MUL P6  P5  P5  -    8  8  -   006) 001 x4  P3  0 0 0
007] SW   x4,0(x1)     2  3  4  6          ,0(P4)<-P6    ----   SW -   P6  P4  0    -  6  -   007) 002 -   -   1 0 0  +--------------------+
008] ADDI x1,x1,4      2  3  4  5  5  6    P7,P4,4       ---- ADDI P7  P4  -   4    5  5  -   008) 003 x1  P4  0 0 1  |SQ(1 )              |
009] BNE  x2,x0,-5     3  4  5  8  8  8    ,P5,P0,-5     ----  BNE -   P5  P0  -5   8  8  -   009) 004 -   -   0 0 1  |PC   OP Pl  EFAD Cl|
010] LW   x2,0(x1)     4  5  7  8  9 11    P8,0(P7)      ----   LW P8  P7  -   0    8  8  -   000) 000 x2  P5  0 0 1  |---- SW P3  0010 11 |
011] MUL  x4,x2,x2     4                                                                                               |    . SW P6  0014  . |
012] SW   x4,0(x1)     4                                                                                               +--------------------+
013] ADDI x1,x1,4      4
014] BNE  x2,x0,-5     5
------------------------------------------------ Press ENTER to continue (PC=0,IC=15,CK=11,CTOT=12,IPC=1.25)...
@011 stall due to DATA_WAIT in C when moving LW/005 from W to C.
@011 stall due to Physical registers not available
@011 stall due to DATA_WAIT in D when moving MUL/011 from F to D.

================================================================================================================================================
PHYSICAL REGS:  1  2  3  4  5  6  7  8
                *  *  *  *  *  *  *  *
          qi:   1  0  0  0  0  1  0  0
          vi:  10 00 00 14 00 00 10 00
================================================================================================================================================
REG.FILE: xi:          1        2        3        4        5        6        7        8
          Pi:          7        8        -        1        -        -        -        -
          Qi:          0        0        0        1        0        0        0        0
          Vi:  00000010 00000000 00000000 00000000 00000050 00000060 00000000 00000000
================================================================================================================================================
STAGES:                F  D  P  I  X  W  C RENAMED-STR    INSTRUCTION-WINDOW                  REORDER-BUFFER          A  M  L  S  B  F  X  D
TOTAL SLOTS:           4  4  4  4 12  4  4 8              8                                   10                      4  1  1  0  1  4  1  1
BUSY SLOTS:            2  2  0  0  1  0  0 8              0                                   6                       0  0  0  0  0  0  0  0
STALLS:                0  8  1  0  0  0  5 8              0                                   1                       0  0  6  6  0  0  0  0
================================================================================================================================================
PC   INSTRUCTION       F  D  P  I  X  W  C Pi,Pj Pk Pl    IW#  OPCD Pi  Pj  Pk I/Pl  Cj Ck Cl  ROB# PC  xi  oPi s x c  +--------------------+
000] LW   x2,0(x1)     0  1  2  3  4  6  7 P2,0(P1)      ----   LW P2  P1  -   0    3  3  -   ---- 000 x2  -   0 0 1  |LQ(0 )              |
001] MUL  x4,x2,x2     0  1  2  6  6 11 12 P3,P2,P2      ----  MUL P3  P2  P2  -    6  6  -   ---- 001 x4  -   0 0 1  |PC   OP Pi  EFAD Ci|
002] SW   x4,0(x1)     0  1  2  4 11 11 12 ,0(P1)<-P3    ----   SW -   P3  P1  0    -  4  -   ---- 002 -   -   1 0 1  |---- LW P2  0010  3 |
003] ADDI x1,x1,4      0  1  2  3  3  4 12 P4,P1,4       ---- ADDI P4  P1  -   4    3  3  -   ---- 003 x1  P1  0 0 1  |---- LW P5  0014  5 |
004] BNE  x2,x0,-5     1  2  3  6  6  6 12 ,P2,P0,-5     ----  BNE -   P2  P0  -5   6  6  -   ---- 004 -   -   0 0 1  |---- LW P8  0018  8 |
005] LW   x2,0(x1)     2  3  4  5  6  8    P5,0(P4)      ----   LW P5  P4  -   0    5  5  -   005) 000 x2  P2  0 0 1  +--------------------+
006] MUL  x4,x2,x2     2  3  4  8  8       P6,P5,P5      ----  MUL P6  P5  P5  -    8  8  -   006) 001 x4  P3  0 0 0
007] SW   x4,0(x1)     2  3  4  6          ,0(P4)<-P6    ----   SW -   P6  P4  0    -  6  -   007) 002 -   -   1 0 0  +--------------------+
008] ADDI x1,x1,4      2  3  4  5  5  6    P7,P4,4       ---- ADDI P7  P4  -   4    5  5  -   008) 003 x1  P4  0 0 1  |SQ(1 )              |
009] BNE  x2,x0,-5     3  4  5  8  8  8    ,P5,P0,-5     ----  BNE -   P5  P0  -5   8  8  -   009) 004 -   -   0 0 1  |PC   OP Pl  EFAD Cl|
010] LW   x2,0(x1)     4  5  7  8  9 11    P8,0(P7)      ----   LW P8  P7  -   0    8  8  -   000) 000 x2  P5  0 0 1  |---- SW P3  0010 11 |
011] MUL  x4,x2,x2     4 12                 P1,P8,P8                                                                   |    . SW P6  0014  . |
012] SW   x4,0(x1)     4 12                 ,0(P7)<-P1                                                                 +--------------------+
013] ADDI x1,x1,4      4
014] BNE  x2,x0,-5     5
------------------------------------------------ Press ENTER to continue (PC=0,IC=15,CK=12,CTOT=13,IPC=1.15)...
@012 stall due to Physical registers not available
@012 stall due to DATA_WAIT in D when moving ADDI/013 from F to D.

================================================================================================================================================
PHYSICAL REGS:  1  2  3  4  5  6  7  8
                *  *  *  *  *  *  *  *
          qi:   1  1  0  0  0  0  0  0
          vi:  10 00 00 14 00 00 10 00
================================================================================================================================================
REG.FILE: xi:          1        2        3        4        5        6        7        8
          Pi:          2        8        -        1        -        -        -        -
          Qi:          1        0        0        1        0        0        0        0
          Vi:  00000010 00000000 00000000 00000000 00000050 00000060 00000000 00000000
================================================================================================================================================
STAGES:                F  D  P  I  X  W  C RENAMED-STR    INSTRUCTION-WINDOW                  REORDER-BUFFER          A  M  L  S  B  F  X  D
TOTAL SLOTS:           4  4  4  4 12  4  4 8              8                                   10                      4  1  1  0  1  4  1  1
BUSY SLOTS:            0  2  0  0  0  1  0 8              2                                   7                       0  0  0  0  0  0  0  0
STALLS:                0  8  1  0  0  0  5 8              0                                   1                       0  0  6  6  0  0  0  0
================================================================================================================================================
PC   INSTRUCTION       F  D  P  I  X  W  C Pi,Pj Pk Pl    IW#  OPCD Pi  Pj  Pk I/Pl  Cj Ck Cl  ROB# PC  xi  oPi s x c  +--------------------+
000] LW   x2,0(x1)     0  1  2  3  4  6  7 P2,0(P1)      ----   LW P2  P1  -   0    3  3  -   ---- 000 x2  -   0 0 1  |LQ(0 )              |
001] MUL  x4,x2,x2     0  1  2  6  6 11 12 P3,P2,P2      ----  MUL P3  P2  P2  -    6  6  -   ---- 001 x4  -   0 0 1  |PC   OP Pi  EFAD Ci|
002] SW   x4,0(x1)     0  1  2  4 11 11 12 ,0(P1)<-P3    ----   SW -   P3  P1  0    -  4  -   ---- 002 -   -   1 0 1  |---- LW P2  0010  3 |
003] ADDI x1,x1,4      0  1  2  3  3  4 12 P4,P1,4       ---- ADDI P4  P1  -   4    3  3  -   ---- 003 x1  P1  0 0 1  |---- LW P5  0014  5 |
004] BNE  x2,x0,-5     1  2  3  6  6  6 12 ,P2,P0,-5     ----  BNE -   P2  P0  -5   6  6  -   ---- 004 -   -   0 0 1  |---- LW P8  0018  8 |
005] LW   x2,0(x1)     2  3  4  5  6  8 13 P5,0(P4)      ----   LW P5  P4  -   0    5  5  -   ---- 000 x2  P2  0 0 1  +--------------------+
006] MUL  x4,x2,x2     2  3  4  8  8 13    P6,P5,P5      ----  MUL P6  P5  P5  -    8  8  -   006) 001 x4  P3  0 0 1
007] SW   x4,0(x1)     2  3  4  6 13 13    ,0(P4)<-P6    ----   SW -   P6  P4  0    -  6  -   007) 002 -   -   1 0 1  +--------------------+
008] ADDI x1,x1,4      2  3  4  5  5  6    P7,P4,4       ---- ADDI P7  P4  -   4    5  5  -   008) 003 x1  P4  0 0 1  |SQ(0 )              |
009] BNE  x2,x0,-5     3  4  5  8  8  8    ,P5,P0,-5     ----  BNE -   P5  P0  -5   8  8  -   009) 004 -   -   0 0 1  |PC   OP Pl  EFAD Cl|
010] LW   x2,0(x1)     4  5  7  8  9 11    P8,0(P7)      ----   LW P8  P7  -   0    8  8  -   000) 000 x2  P5  0 0 1  |---- SW P3  0010 11 |
011] MUL  x4,x2,x2     4 12 13              P1,P8,P8      000)  MUL P1  P8  P8  -   13 13  -   001) 001 x4  P6  0 0 0  |---- SW P6  0014 13 |
012] SW   x4,0(x1)     4 12 13              ,0(P7)<-P1    001)   SW -   P1  P7  0    - 13  -   002) 002 -   -   1 0 0  +--------------------+
013] ADDI x1,x1,4      4 13                 P2,P7,4
014] BNE  x2,x0,-5     5 13                 ,P8,P0,-5
------------------------------------------------ Press ENTER to continue (PC=0,IC=15,CK=13,CTOT=14,IPC=1.07)...
================================================================================================================================================
PHYSICAL REGS:  1  2  3  4  5  6  7  8
                *  *     *  *  *  *  *
          qi:   1  1  1  1  0  0  0  0
          vi:  00 00 00 14 00 00 10 00
================================================================================================================================================
REG.FILE: xi:          1        2        3        4        5        6        7        8
          Pi:          2        8        -        1        -        -        -        -
          Qi:          1        0        0        1        0        0        0        0
          Vi:  00000014 00000000 00000000 00000000 00000050 00000060 00000000 00000000
================================================================================================================================================
STAGES:                F  D  P  I  X  W  C RENAMED-STR    INSTRUCTION-WINDOW                  REORDER-BUFFER          A  M  L  S  B  F  X  D
TOTAL SLOTS:           4  4  4  4 12  4  4 8              8                                   10                      4  1  1  0  1  4  1  1
BUSY SLOTS:            0  0  0  0  1  0  0 6              2                                   5                       0  0  0  0  0  0  0  0
STALLS:                0  8  1  0  0  0  5 8              0                                   1                       0  0  6  6  0  0  0  0
================================================================================================================================================
PC   INSTRUCTION       F  D  P  I  X  W  C Pi,Pj Pk Pl    IW#  OPCD Pi  Pj  Pk I/Pl  Cj Ck Cl  ROB# PC  xi  oPi s x c  +--------------------+
000] LW   x2,0(x1)     0  1  2  3  4  6  7 P2,0(P1)      ----   LW P2  P1  -   0    3  3  -   ---- 000 x2  -   0 0 1  |LQ(0 )              |
001] MUL  x4,x2,x2     0  1  2  6  6 11 12 P3,P2,P2      ----  MUL P3  P2  P2  -    6  6  -   ---- 001 x4  -   0 0 1  |PC   OP Pi  EFAD Ci|
002] SW   x4,0(x1)     0  1  2  4 11 11 12 ,0(P1)<-P3    ----   SW -   P3  P1  0    -  4  -   ---- 002 -   -   1 0 1  |---- LW P2  0010  3 |
003] ADDI x1,x1,4      0  1  2  3  3  4 12 P4,P1,4       ---- ADDI P4  P1  -   4    3  3  -   ---- 003 x1  P1  0 0 1  |---- LW P5  0014  5 |
004] BNE  x2,x0,-5     1  2  3  6  6  6 12 ,P2,P0,-5     ----  BNE -   P2  P0  -5   6  6  -   ---- 004 -   -   0 0 1  |---- LW P8  0018  8 |
005] LW   x2,0(x1)     2  3  4  5  6  8 13 14 P5,0(P4)    ----   LW P5  P4  -   0    5  5  -   ---- 000 x2  P2  0 0 1  +--------------------+
006] MUL  x4,x2,x2     2  3  4  8  8 13 14 P6,P5,P5      ----  MUL P6  P5  P5  -    8  8  -   ---- 001 x4  P3  0 0 1
007] SW   x4,0(x1)     2  3  4  6 13 13 14 ,0(P4)<-P6    ----   SW -   P6  P4  0    -  6  -   ---- 002 -   -   1 0 1  +--------------------+
008] ADDI x1,x1,4      2  3  4  5  5  6 14 P7,P4,4       ---- ADDI P7  P4  -   4    5  5  -   ---- 003 x1  P4  0 0 1  |SQ(1 )              |
009] BNE  x2,x0,-5     3  4  5  8  8  8 14 ,P5,P0,-5     ----  BNE -   P5  P0  -5   8  8  -   ---- 004 -   -   0 0 1  |PC   OP Pl  EFAD Cl|
010] LW   x2,0(x1)     4  5  7  8  9 11    P8,0(P7)      ----   LW P8  P7  -   0    8  8  -   000) 000 x2  P5  0 0 1  |---- SW P3  0010 11 |
```

```
011] MUL  x4,x2,x2      4 12 13 14 14       P1,P8,P8       000>  MUL P1  P8  P8  -   14 14  -   001) 001 x4  P6  0 0 0  |---- SW P6  0014 13|
012] SW   x4,0(x1)      4 12 13 14          ,0(P7)<-P1     001>   SW -   P1  P7  0    - 14  -   002) 002 -   -   1 0 0  |   . SW P1  0010  .|
013] ADDI x1,x1,4       4 13 14             P2,P7,4        000) ADDI P2  P7  -   4   14  -   -   003) 003 x1  P7  0 0 0  +--------------------+
014] BNE  x2,x0,-5      5 13 14             ,P8,P0,-5      001)  BNE -   P8  P0  -5  14 14  -   004) 004 -   -   0 0 0
-------------------------------------------------- Press ENTER to continue (PC=0,IC=15,CK=14,CTOT=15,IPC=1.00)...
================================================================================================================================================

PHYSICAL REGS:  1  2  3  4  5  6  7  8
                *  *           *  *  *
          qi:   1  1  1  1  1  0  0  0
          vi:  00 14 00 14 00 00 10 00
================================================================================================================================================

REG.FILE: xi:          1        2        3        4        5        6        7        8
          Pi:          2        8        -        1        -        -        -        -
          Qi:          1        0        0        1        0        0        0        0
          Vi:  00000014 00000000 00000000 00000000 00000050 00000060 00000000 00000000
================================================================================================================================================

STAGES:                  F  D  P  I  X  W  C RENAMED-STR    INSTRUCTION-WINDOW                  REORDER-BUFFER          A  M  L  S  B  F  X  D
TOTAL SLOTS:             4  4  4  4 12  4  4 8              8                                   10                      4  1  1  0  1  4  1  1
BUSY SLOTS:              0  0  0  0  2  0  0 5              0                                   4                       0  0  0  0  0  0  0  0
STALLS:                  0  8  1  0  0  0  5 8              0                                   1                       0  0  6  6  0  0  0  0
================================================================================================================================================

PC   INSTRUCTION        F  D  P  I  X  W  C Pi,Pj Pk Pl    IW#  OPCD Pi  Pj  Pk I/Pl  Cj Ck Cl  ROB# PC  xi  oPi s x c  +--------------------+
000] LW   x2,0(x1)      0  1  2  3  4  6  7 P2,0(P1)      ----   LW P2  P1  -   0     3  3  -   ---- 000 x2  -   0 0 1  |LQ(0 )              |
001] MUL  x4,x2,x2      0  1  2  6  6 11 12 P3,P2,P2       ----  MUL P3  P2  P2  -     6  6  -   ---- 001 x4  -   0 0 1  |PC   OP Pi  EFAD Ci|
002] SW   x4,0(x1)      0  1  2  4 11 11 12 ,0(P1)<-P3     ----   SW -   P3  P1  0     -  4  -   ---- 002 -   -   1 0 1  |---- LW P2  0010  3|
003] ADDI x1,x1,4       0  1  2  3  3  4 12 P4,P1,4        ---- ADDI P4  P1  -   4     3  3  -   ---- 003 x1  P1  0 0 1  |---- LW P5  0014  5|
004] BNE  x2,x0,-5      1  2  3  6  6  6 12 ,P2,P0,-5      ----  BNE -   P2  P0  -5    6  6  -   ---- 004 -   -   0 0 1  |---- LW P8  0018  8|
005] LW   x2,0(x1)      2  3  4  5  6  8 13 P5,0(P4)       ----   LW P5  P4  -   0     5  5  -   ---- 000 x2  P2  0 0 1  +--------------------+
006] MUL  x4,x2,x2      2  3  4  8  8 13 14 P6,P5,P5       ----  MUL P6  P5  P5  -     8  8  -   ---- 001 x4  P3  0 0 1
007] SW   x4,0(x1)      2  3  4  6 13 13 14 ,0(P4)<-P6     ----   SW -   P6  P4  0     -  6  -   ---- 002 -   -   1 0 1  +--------------------+
008] ADDI x1,x1,4       2  3  4  5  5  6 14 P7,P4,4        ---- ADDI P7  P4  -   4     5  5  -   ---- 003 x1  P4  0 0 1  |SQ(1 )              |
009] BNE  x2,x0,-5      3  4  5  8  8  8 14 ,P5,P0,-5      ----  BNE -   P5  P0  -5    8  8  -   ---- 004 -   -   0 0 1  |PC   OP Pl  EFAD Cl|
010] LW   x2,0(x1)      4  5  7  8  9 11 15 P8,0(P7)       ----   LW P8  P7  -   0     8  8  -   ---- 000 x2  P5  0 0 1  |---- SW P3  0010 11|
011] MUL  x4,x2,x2      4 12 13 14 14       P1,P8,P8       ----  MUL P1  P8  P8  -   14 14  -   001) 001 x4  P6  0 0 0  |---- SW P6  0014 13|
012] SW   x4,0(x1)      4 12 13 14          ,0(P7)<-P1     ----   SW -   P1  P7  0    - 14  -   002) 002 -   -   1 0 0  |   . SW P1  0010  .|
013] ADDI x1,x1,4       4 13 14 15 15       P2,P7,4        000> ADDI P2  P7  -   4   15 15  -   003) 003 x1  P7  0 0 0  +--------------------+
014] BNE  x2,x0,-5      5 13 14 15 15 15    ,P8,P0,-5      001>  BNE -   P8  P0  -5  15 15  -   004) 004 -   -   0 0 1
-------------------------------------------------- Press ENTER to continue (PC=0,IC=15,CK=15,CTOT=16,IPC=0.94)...
================================================================================================================================================

PHYSICAL REGS:  1  2  3  4  5  6  7  8
                *  *           *  *  *
          qi:   1  0  1  1  1  0  0  0
          vi:  00 14 00 14 00 00 10 00
================================================================================================================================================

REG.FILE: xi:          1        2        3        4        5        6        7        8
          Pi:          2        8        -        1        -        -        -        -
          Qi:          0        0        0        1        0        0        0        0
          Vi:  00000014 00000000 00000000 00000000 00000050 00000060 00000000 00000000
================================================================================================================================================

STAGES:                  F  D  P  I  X  W  C RENAMED-STR    INSTRUCTION-WINDOW                  REORDER-BUFFER          A  M  L  S  B  F  X  D
TOTAL SLOTS:             4  4  4  4 12  4  4 8              8                                   10                      4  1  1  0  1  4  1  1
BUSY SLOTS:              0  0  0  0  1  1  0 5              0                                   4                       0  0  0  0  0  0  0  0
STALLS:                  0  8  1  0  0  0  5 8              0                                   1                       0  0  6  6  0  0  0  0
================================================================================================================================================

PC   INSTRUCTION        F  D  P  I  X  W  C Pi,Pj Pk Pl    IW#  OPCD Pi  Pj  Pk I/Pl  Cj Ck Cl  ROB# PC  xi  oPi s x c  +--------------------+
000] LW   x2,0(x1)      0  1  2  3  4  6  7 P2,0(P1)      ----   LW P2  P1  -   0     3  3  -   ---- 000 x2  -   0 0 1  |LQ(0 )              |
001] MUL  x4,x2,x2      0  1  2  6  6 11 12 P3,P2,P2       ----  MUL P3  P2  P2  -     6  6  -   ---- 001 x4  -   0 0 1  |PC   OP Pi  EFAD Ci|
002] SW   x4,0(x1)      0  1  2  4 11 11 12 ,0(P1)<-P3     ----   SW -   P3  P1  0     -  4  -   ---- 002 -   -   1 0 1  |---- LW P2  0010  3|
003] ADDI x1,x1,4       0  1  2  3  3  4 12 P4,P1,4        ---- ADDI P4  P1  -   4     3  3  -   ---- 003 x1  P1  0 0 1  |---- LW P5  0014  5|
004] BNE  x2,x0,-5      1  2  3  6  6  6 12 ,P2,P0,-5      ----  BNE -   P2  P0  -5    6  6  -   ---- 004 -   -   0 0 1  |---- LW P8  0018  8|
005] LW   x2,0(x1)      2  3  4  5  6  8 13 P5,0(P4)       ----   LW P5  P4  -   0     5  5  -   ---- 000 x2  P2  0 0 1  +--------------------+
006] MUL  x4,x2,x2      2  3  4  8  8 13 14 P6,P5,P5       ----  MUL P6  P5  P5  -     8  8  -   ---- 001 x4  P3  0 0 1
007] SW   x4,0(x1)      2  3  4  6 13 13 14 ,0(P4)<-P6     ----   SW -   P6  P4  0     -  6  -   ---- 002 -   -   1 0 1  +--------------------+
008] ADDI x1,x1,4       2  3  4  5  5  6 14 P7,P4,4        ---- ADDI P7  P4  -   4     5  5  -   ---- 003 x1  P4  0 0 1  |SQ(1 )              |
009] BNE  x2,x0,-5      3  4  5  8  8  8 14 ,P5,P0,-5      ----  BNE -   P5  P0  -5    8  8  -   ---- 004 -   -   0 0 1  |PC   OP Pl  EFAD Cl|
010] LW   x2,0(x1)      4  5  7  8  9 11 15 P8,0(P7)       ----   LW P8  P7  -   0     8  8  -   ---- 000 x2  P5  0 0 1  |---- SW P3  0010 11|
011] MUL  x4,x2,x2      4 12 13 14 14       P1,P8,P8       ----  MUL P1  P8  P8  -   14 14  -   001) 001 x4  P6  0 0 0  |---- SW P6  0014 13|
012] SW   x4,0(x1)      4 12 13 14          ,0(P7)<-P1     ----   SW -   P1  P7  0    - 14  -   002) 002 -   -   1 0 0  |   . SW P1  0010  .|
013] ADDI x1,x1,4       4 13 14 15 15 16    P2,P7,4        ---- ADDI P2  P7  -   4   15 15  -   003) 003 x1  P7  0 0 1  +--------------------+
014] BNE  x2,x0,-5      5 13 14 15 15 15    ,P8,P0,-5      ----  BNE -   P8  P0  -5  15 15  -   004) 004 -   -   0 0 1
-------------------------------------------------- Press ENTER to continue (PC=0,IC=15,CK=16,CTOT=17,IPC=0.88)...
================================================================================================================================================

PHYSICAL REGS:  1  2  3  4  5  6  7  8
                *  *           *  *  *
          qi:   1  0  1  1  1  0  0  0
          vi:  00 14 00 14 00 00 10 00
================================================================================================================================================

REG.FILE: xi:          1        2        3        4        5        6        7        8
          Pi:          2        8        -        1        -        -        -        -
          Qi:          0        0        0        1        0        0        0        0
          Vi:  00000014 00000000 00000000 00000000 00000050 00000060 00000000 00000000
================================================================================================================================================

STAGES:                  F  D  P  I  X  W  C RENAMED-STR    INSTRUCTION-WINDOW                  REORDER-BUFFER          A  M  L  S  B  F  X  D
TOTAL SLOTS:             4  4  4  4 12  4  4 8              8                                   10                      4  1  1  0  1  4  1  1
BUSY SLOTS:              0  0  0  0  1  1  0 5              0                                   4                       0  0  0  0  0  0  0  0
STALLS:                  0  8  1  0  0  0  6 8              0                                   1                       0  0  6  6  0  0  0  0
================================================================================================================================================

PC   INSTRUCTION        F  D  P  I  X  W  C Pi,Pj Pk Pl    IW#  OPCD Pi  Pj  Pk I/Pl  Cj Ck Cl  ROB# PC  xi  oPi s x c  +--------------------+
000] LW   x2,0(x1)      0  1  2  3  4  6  7 P2,0(P1)      ----   LW P2  P1  -   0     3  3  -   ---- 000 x2  -   0 0 1  |LQ(0 )              |
001] MUL  x4,x2,x2      0  1  2  6  6 11 12 P3,P2,P2       ----  MUL P3  P2  P2  -     6  6  -   ---- 001 x4  -   0 0 1  |PC   OP Pi  EFAD Ci|
002] SW   x4,0(x1)      0  1  2  4 11 11 12 ,0(P1)<-P3     ----   SW -   P3  P1  0     -  4  -   ---- 002 -   -   1 0 1  |---- LW P2  0010  3|
003] ADDI x1,x1,4       0  1  2  3  3  4 12 P4,P1,4        ---- ADDI P4  P1  -   4     3  3  -   ---- 003 x1  P1  0 0 1  |---- LW P5  0014  5|
004] BNE  x2,x0,-5      1  2  3  6  6  6 12 ,P2,P0,-5      ----  BNE -   P2  P0  -5    6  6  -   ---- 004 -   -   0 0 1  |---- LW P8  0018  8|
005] LW   x2,0(x1)      2  3  4  5  6  8 13 P5,0(P4)       ----   LW P5  P4  -   0     5  5  -   ---- 000 x2  P2  0 0 1  +--------------------+
006] MUL  x4,x2,x2      2  3  4  8  8 13 14 P6,P5,P5       ----  MUL P6  P5  P5  -     8  8  -   ---- 001 x4  P3  0 0 1
007] SW   x4,0(x1)      2  3  4  6 13 13 14 ,0(P4)<-P6     ----   SW -   P6  P4  0     -  6  -   ---- 002 -   -   1 0 1  +--------------------+
008] ADDI x1,x1,4       2  3  4  5  5  6 14 P7,P4,4        ---- ADDI P7  P4  -   4     5  5  -   ---- 003 x1  P4  0 0 1  |SQ(1 )              |
009] BNE  x2,x0,-5      3  4  5  8  8  8 14 ,P5,P0,-5      ----  BNE -   P5  P0  -5    8  8  -   ---- 004 -   -   0 0 1  |PC   OP Pl  EFAD Cl|
010] LW   x2,0(x1)      4  5  7  8  9 11 15 P8,0(P7)       ----   LW P8  P7  -   0     8  8  -   ---- 000 x2  P5  0 0 1  |---- SW P3  0010 11|
011] MUL  x4,x2,x2      4 12 13 14 14       P1,P8,P8       ----  MUL P1  P8  P8  -   14 14  -   001) 001 x4  P6  0 0 0  |---- SW P6  0014 13|
012] SW   x4,0(x1)      4 12 13 14          ,0(P7)<-P1     ----   SW -   P1  P7  0    - 14  -   002) 002 -   -   1 0 0  |   . SW P1  0010  .|
013] ADDI x1,x1,4       4 13 14 15 15 16    P2,P7,4        ---- ADDI P2  P7  -   4   15 15  -   003) 003 x1  P7  0 0 1  +--------------------+
014] BNE  x2,x0,-5      5 13 14 15 15 15    ,P8,P0,-5      ----  BNE -   P8  P0  -5  15 15  -   004) 004 -   -   0 0 1
-------------------------------------------------- Press ENTER to continue (PC=0,IC=15,CK=17,CTOT=18,IPC=0.83)...
@017 stall due to DATA_WAIT in C when moving ADDI/013 from W to C.

================================================================================================================================================

PHYSICAL REGS:  1  2  3  4  5  6  7  8
                *  *           *  *  *
          qi:   1  0  1  1  1  0  0  0
          vi:  00 14 00 14 00 00 10 00
================================================================================================================================================

REG.FILE: xi:          1        2        3        4        5        6        7        8
          Pi:          2        8        -        1        -        -        -        -
          Qi:          0        0        0        1        0        0        0        0
          Vi:  00000014 00000000 00000000 00000000 00000050 00000060 00000000 00000000
================================================================================================================================================

STAGES:                  F  D  P  I  X  W  C RENAMED-STR    INSTRUCTION-WINDOW                  REORDER-BUFFER          A  M  L  S  B  F  X  D
TOTAL SLOTS:             4  4  4  4 12  4  4 8              8                                   10                      4  1  1  0  1  4  1  1
BUSY SLOTS:              0  0  0  0  1  1  0 5              0                                   4                       0  0  0  0  0  0  0  0
STALLS:                  0  8  1  0  0  0  7 8              0                                   1                       0  0  6  6  0  0  0  0
================================================================================================================================================

PC   INSTRUCTION        F  D  P  I  X  W  C Pi,Pj Pk Pl    IW#  OPCD Pi  Pj  Pk I/Pl  Cj Ck Cl  ROB# PC  xi  oPi s x c  +--------------------+
000] LW   x2,0(x1)      0  1  2  3  4  6  7 P2,0(P1)      ----   LW P2  P1  -   0     3  3  -   ---- 000 x2  -   0 0 1  |LQ(0 )              |
```

```
001] MUL  x4,x2,x2       0  1  2  6  6 11 12 P3,P2,P2       ----  MUL P3  P2  P2  -    6  6  -    ---- 001 x4  -   0 0 1  |PC   OP Pi  EFAD Ci|
002] SW   x4,0(x1)       0  1  2  4 11 11 12 ,0(P1)<-P3      ----   SW -   P3  P1  0    -  4  -    ---- 002 -   -   1 0 1  |---- LW P2  0010  3|
003] ADDI x1,x1,4        0  1  2  3  3  4 12 P4,P1,4         ---- ADDI P4  P1  -   4    3  3  -    ---- 003 x1  P1  0 0 1  |---- LW P5  0014  5|
004] BNE  x2,x0,-5       1  2  3  6  6  6 12 ,P2,P0,-5       ----  BNE -   P2  P0  -5   6  6  -    ---- 004 -   -   0 0 1  |---- LW P8  0018  8|
005] LW   x2,0(x1)       2  3  4  5  6  8 13 P5,0(P4)        ----   LW P5  P4  -   0    5  5  -    ---- 000 x2  P2  0 0 1  +-------------------+
006] MUL  x4,x2,x2       2  3  4  8  8 13 14 P6,P5,P5        ----  MUL P6  P5  P5  -    8  8  -    ---- 001 x4  P3  0 0 1
007] SW   x4,0(x1)       2  3  4  6 13 13 14 ,0(P4)<-P6      ----   SW -   P6  P4  0    -  6  -    ---- 002 -   -   1 0 1  +-------------------+
008] ADDI x1,x1,4        2  3  4  5  5  6 14 P7,P4,4         ---- ADDI P7  P4  -   4    5  5  -    ---- 003 x1  P4  0 0 1  |SQ(1 )             |
009] BNE  x2,x0,-5       3  4  5  8  8  8 14 ,P5,P0,-5       ----  BNE -   P5  P0  -5   8  8  -    ---- 004 -   -   0 0 1  |PC   OP Pl  EFAD Cl|
010] LW   x2,0(x1)       4  5  7  8  9 11 15 P8,0(P7)        ----   LW P8  P7  -   0    8  8  -    ---- 000 x2  P5  0 0 1  |---- SW P3  0010 11|
011] MUL  x4,x2,x2       4 12 13 14 14       P1,P8,P8        ----  MUL P1  P8  P8  -   14 14  -    001) 001 x4  P6  0 0 0  |---- SW P6  0014 13|
012] SW   x4,0(x1)       4 12 13 14          ,0(P7)<-P1      ----   SW -   P1  P7  0    - 14  -    002) 002 -   -   1 0 0  |   . SW P1  0010  .|
013] ADDI x1,x1,4        4 13 14 15 15 16    P2,P7,4         ---- ADDI P2  P7  -   4   15 15  -    003) 003 x1  P7  0 0 1  +-------------------+
014] BNE  x2,x0,-5       5 13 14 15 15 15    ,P8,P0,-5       ----  BNE -   P8  P0  -5  15 15  -    004) 004 -   -   0 0 1
------------------------------------------------------ Press ENTER to continue (PC=0,IC=15,CK=18,CTOT=19,IPC=0.79)...
@018 stall due to DATA_WAIT in C when moving ADDI/013 from W to C.

================================================================================================================================================================
PHYSICAL REGS:  1  2  3  4  5  6  7  8
                *  *           *  *  *
          qi:   0  0  1  1  1  0  0  0
          vi:  00 14 00 14 00 00 10 00
================================================================================================================================================================
REG.FILE: xi:          1        2        3        4        5        6        7        8
          Pi:          2        8        -        1        -        -        -        -
          Qi:          0        0        0        0        0        0        0        0
          Vi:  00000014 00000000 00000000 00000000 00000050 00000060 00000000 00000000
================================================================================================================================================================
STAGES:                  F  D  P  I  X  W  C RENAMED-STR    INSTRUCTION-WINDOW                  REORDER-BUFFER          A  M  L  S  B  F  X  D
TOTAL SLOTS:             4  4  4  4 12  4  4 8              8                                   10                      4  1  1  0  1  4  1  1
BUSY SLOTS:              0  0  0  0  0  1  0 5              0                                   4                       0  0  0  0  0  0  0  0
STALLS:                  0  8  1  0  0  0  8 8              0                                   1                       0  0  6  6  0  0  0  0
================================================================================================================================================================
PC   INSTRUCTION        F  D  P  I  X  W  C Pi,Pj Pk Pl    IW#  OPCD Pi  Pj  Pk I/Pl  Cj Ck Cl  ROB# PC  xi  oPi s x c  +-------------------+
000] LW   x2,0(x1)       0  1  2  3  4  6  7 P2,0(P1)       ----   LW P2  P1  -   0    3  3  -    ---- 000 x2  -   0 0 1  |LQ(0 )             |
001] MUL  x4,x2,x2       0  1  2  6  6 11 12 P3,P2,P2        ----  MUL P3  P2  P2  -    6  6  -    ---- 001 x4  -   0 0 1  |PC   OP Pi  EFAD Ci|
002] SW   x4,0(x1)       0  1  2  4 11 11 12 ,0(P1)<-P3      ----   SW -   P3  P1  0    -  4  -    ---- 002 -   -   1 0 1  |---- LW P2  0010  3|
003] ADDI x1,x1,4        0  1  2  3  3  4 12 P4,P1,4         ---- ADDI P4  P1  -   4    3  3  -    ---- 003 x1  P1  0 0 1  |---- LW P5  0014  5|
004] BNE  x2,x0,-5       1  2  3  6  6  6 12 ,P2,P0,-5       ----  BNE -   P2  P0  -5   6  6  -    ---- 004 -   -   0 0 1  |---- LW P8  0018  8|
005] LW   x2,0(x1)       2  3  4  5  6  8 13 P5,0(P4)        ----   LW P5  P4  -   0    5  5  -    ---- 000 x2  P2  0 0 1  +-------------------+
006] MUL  x4,x2,x2       2  3  4  8  8 13 14 P6,P5,P5        ----  MUL P6  P5  P5  -    8  8  -    ---- 001 x4  P3  0 0 1
007] SW   x4,0(x1)       2  3  4  6 13 13 14 ,0(P4)<-P6      ----   SW -   P6  P4  0    -  6  -    ---- 002 -   -   1 0 1  +-------------------+
008] ADDI x1,x1,4        2  3  4  5  5  6 14 P7,P4,4         ---- ADDI P7  P4  -   4    5  5  -    ---- 003 x1  P4  0 0 1  |SQ(0 )             |
009] BNE  x2,x0,-5       3  4  5  8  8  8 14 ,P5,P0,-5       ----  BNE -   P5  P0  -5   8  8  -    ---- 004 -   -   0 0 1  |PC   OP Pl  EFAD Cl|
010] LW   x2,0(x1)       4  5  7  8  9 11 15 P8,0(P7)        ----   LW P8  P7  -   0    8  8  -    ---- 000 x2  P5  0 0 1  |---- SW P3  0010 11|
011] MUL  x4,x2,x2       4 12 13 14 14 19    P1,P8,P8        ----  MUL P1  P8  P8  -   14 14  -    001) 001 x4  P6  0 0 1  |---- SW P6  0014 13|
012] SW   x4,0(x1)       4 12 13 14 19 19    ,0(P7)<-P1      ----   SW -   P1  P7  0    - 14  -    002) 002 -   -   1 0 1  |---- SW P1  0010 19|
013] ADDI x1,x1,4        4 13 14 15 15 16    P2,P7,4         ---- ADDI P2  P7  -   4   15 15  -    003) 003 x1  P7  0 0 1  +-------------------+
014] BNE  x2,x0,-5       5 13 14 15 15 15    ,P8,P0,-5       ----  BNE -   P8  P0  -5  15 15  -    004) 004 -   -   0 0 1
------------------------------------------------------ Press ENTER to continue (PC=0,IC=15,CK=19,CTOT=20,IPC=0.75)...
@019 stall due to DATA_WAIT in C when moving ADDI/013 from W to C.

================================================================================================================================================================
PHYSICAL REGS:  1  2  3  4  5  6  7  8
                *  *              *
          qi:   0  0  1  1  1  1  1  0
          vi:  00 14 00 14 00 00 10 00
================================================================================================================================================================
REG.FILE: xi:          1        2        3        4        5        6        7        8
          Pi:          2        8        -        1        -        -        -        -
          Qi:          0        0        0        0        0        0        0        0
          Vi:  00000010 00000000 00000000 00000000 00000050 00000060 00000000 00000000
================================================================================================================================================================
STAGES:                  F  D  P  I  X  W  C RENAMED-STR    INSTRUCTION-WINDOW                  REORDER-BUFFER          A  M  L  S  B  F  X  D
TOTAL SLOTS:             4  4  4  4 12  4  4 8              8                                   10                      4  1  1  0  1  4  1  1
BUSY SLOTS:              0  0  0  0  0  0  0 3              0                                   0                       0  0  0  0  0  0  0  0
STALLS:                  0  8  1  0  0  0  8 8              0                                   1                       0  0  6  6  0  0  0  0
================================================================================================================================================================
PC   INSTRUCTION        F  D  P  I  X  W  C Pi,Pj Pk Pl    IW#  OPCD Pi  Pj  Pk I/Pl  Cj Ck Cl  ROB# PC  xi  oPi s x c  +-------------------+
000] LW   x2,0(x1)       0  1  2  3  4  6  7 P2,0(P1)       ----   LW P2  P1  -   0    3  3  -    ---- 000 x2  -   0 0 1  |LQ(0 )             |
001] MUL  x4,x2,x2       0  1  2  6  6 11 12 P3,P2,P2        ----  MUL P3  P2  P2  -    6  6  -    ---- 001 x4  -   0 0 1  |PC   OP Pi  EFAD Ci|
002] SW   x4,0(x1)       0  1  2  4 11 11 12 ,0(P1)<-P3      ----   SW -   P3  P1  0    -  4  -    ---- 002 -   -   1 0 1  |---- LW P2  0010  3|
003] ADDI x1,x1,4        0  1  2  3  3  4 12 P4,P1,4         ---- ADDI P4  P1  -   4    3  3  -    ---- 003 x1  P1  0 0 1  |---- LW P5  0014  5|
004] BNE  x2,x0,-5       1  2  3  6  6  6 12 ,P2,P0,-5       ----  BNE -   P2  P0  -5   6  6  -    ---- 004 -   -   0 0 1  |---- LW P8  0018  8|
005] LW   x2,0(x1)       2  3  4  5  6  8 13 P5,0(P4)        ----   LW P5  P4  -   0    5  5  -    ---- 000 x2  P2  0 0 1  +-------------------+
006] MUL  x4,x2,x2       2  3  4  8  8 13 14 P6,P5,P5        ----  MUL P6  P5  P5  -    8  8  -    ---- 001 x4  P3  0 0 1
007] SW   x4,0(x1)       2  3  4  6 13 13 14 ,0(P4)<-P6      ----   SW -   P6  P4  0    -  6  -    ---- 002 -   -   1 0 1  +-------------------+
008] ADDI x1,x1,4        2  3  4  5  5  6 14 P7,P4,4         ---- ADDI P7  P4  -   4    5  5  -    ---- 003 x1  P4  0 0 1  |SQ(0 )             |
009] BNE  x2,x0,-5       3  4  5  8  8  8 14 ,P5,P0,-5       ----  BNE -   P5  P0  -5   8  8  -    ---- 004 -   -   0 0 1  |PC   OP Pl  EFAD Cl|
010] LW   x2,0(x1)       4  5  7  8  9 11 15 P8,0(P7)        ----   LW P8  P7  -   0    8  8  -    ---- 000 x2  P5  0 0 1  |---- SW P3  0010 11|
011] MUL  x4,x2,x2       4 12 13 14 14 19 20 P1,P8,P8        ----  MUL P1  P8  P8  -   14 14  -    ---- 001 x4  P6  0 0 1  |---- SW P6  0014 13|
012] SW   x4,0(x1)       4 12 13 14 19 19 20 ,0(P7)<-P1      ----   SW -   P1  P7  0    - 14  -    ---- 002 -   -   1 0 1  |---- SW P1  0010 19|
013] ADDI x1,x1,4        4 13 14 15 15 16 20 P2,P7,4         ---- ADDI P2  P7  -   4   15 15  -    ---- 003 x1  P7  0 0 1  +-------------------+
014] BNE  x2,x0,-5       5 13 14 15 15 15 20 ,P8,P0,-5       ----  BNE -   P8  P0  -5  15 15  -    ---- 004 -   -   0 0 1
------------------------------------------------------ Press ENTER to continue (PC=0,IC=15,CK=20,CTOT=21,IPC=0.71)...
Program 'program-c2181031' FINISHED
------------------------------------------------------------
PC=0,IC=15,CK=21,IPC=0.71
Goodbye.
```