PCL - The Performance Counter Library: A Common Interface to Access Hardware Performance Counters on Microprocessors (Version 2.2)

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Abstract

A performance counter is that part of a microprocessor that measures and gathers performance-relevant events on the microprocessor. The number and type of available events differ significantly between existing microprocessors, because there is no commonly accepted specification, and because each manufacturer has different priorities on analyzing the performance of architectures and programs. Looking at the supported events on the different microprocessors, it can be observed that the functionality of these events differs from the requirements of an expert application programmer or a performance tool writer.
PCL, the Performance Counter Library, establishes a common platform for performance measurements on a wide range of computer systems. With a common interface on all systems and a set of application-oriented events defined, the application programmer is able to do program optimization in a portable way and the performance tool writer is able to rely on a common interface on different systems. A low-level interface gives the user direct access to the hardware performance counters to measure non-standard events.
PCL has functions to query the functionality, to start and to stop counters, and to read the values of counters. Performance counter values are returned as 64 bit integers (or floating point numbers for some events) on all systems. PCL supports nested calls to PCL functions thus allowing hierarchical performance measurements. Counting may be done either in system or in user mode. All interface functions are callable in C, C++, Fortran, and Java.

Contents

Chapter 1

Introduction

This report describes performance counters on all major microprocessors families and introduces a common interface to access these counters. With performance counters, performance critical events can be counted. This includes all aspects concerning the memory hierarchy (loads/stores, misses/hits, different cache levels, etc.), functional units or pipelines (operation counts, stalls, issues), duration of requests, etc.
As will be shown, the number of, type of, and access to events differs significantly between the processors and the type of supported events might be not very helpful to the application programmer or tool builder who might have different demands of countable events.
To overcome this lack of common platform, we developed PCL, the Performance Counter Library. We first defined a set of events useful to the application programmer and tool builder, and second, established a set of access functions to control and access the performance counters on different platforms. PCL is implemented on many of todays machines ranging from a PC running Linux to parallel systems capable of Teraflops and it is callable from application programs as well as from tools.
The Performance Counter Library PCL is available at

http://www2.inf.fh-bonn-rhein-sieg.de/∼rberre2m/PCL/

and

http://www.fz-juelich.de/zam/PCL/.

Chapter 2

Requirements of Application Programmers

People from different areas of computer science and electrical engineering may see different events as most useful for their optimization purposes. Most of the events described so far in the description of the microprocessors are likely most useful to the computer architect, hardware engineer, or low-level device driver writer.

Application programmers optimizing their programs or performance tool writers wish to get performance relevant information related to their programs rather than counting signal switches on certain pins of a chip module. Therefore, those parts of the microprocessor which have appropriate counterparts in a program are most likely to be used by the application programmer to optimize programs. The memory hierarchy in a computer system corresponds directly to program variables and the functional units execute the operations specified in a program. Therefore, we concentrate on those aspects of a computer system.

Our impression is, that taking the union of all available events of all microprocessors is not the right way to define an application interface for an application programmer or tool writer. Our approach is to define a set of events *relevant* to the user. If microprocessor architecture or programming methodology precedes in a different direction (we don't see that for the near future!), the set of events might then be extended or changed.

Although hardware counters give numbers for a processor, performance numbers should be related to a process (representing the program). Therefore, either the executing process should be bound to a processor, or migrating a process to another processor should be transparent to the process (related to performance counting). Using the second approach needs support of the operating system.

We have categorized the useful events into categories as shown in the following sections.

2.1 Memory Hierarchy

Currently, most computer systems support four levels in the memory hierarchy: registers, 1st level cache, 2nd level cache, main memory. Registers are directly controlled by a compiler, so for example, the information how many registers keep live values could be better managed by a compiler. Although main memory statistics could be quite useful in performance analysis (e.g. bank conflicts), performance counters in microprocessors mostly see the main memory as a black box. Therefore, we concentrate on 1st and 2nd level caches.

Accesses to caches can be distinguished by read or write accesses, instruction loads and instruction stores (fetches from a higher level in the hierarchy), or data load/stores. An important performance aspect is the hit and miss rate, which can be calculated from the total number of accesses and either the number of misses or hits. Most microprocessors use (small) translation look-aside buffers (TLB) to speed up the translation of virtual to physical addresses. As misses in the TLB are time consuming, this number (and its relation to the number of hits or the total number of address lookups) is a relevant number for performance optimization.

We distinguish between instruction and data caches on each level. For unified caches (i.e. instruction and data are buffered in the same cache), it is often possible to distinguish instruction and data loads. Therefore on those caches, *PCL_LxICACHE_xxx* and *PCL_LxDCACHE_xxx* refer to events concerning instruction and data accesses, respectively.

The available events concerning memory hierarchy are given in table 2.1.

Due to the definition, the sum of cache reads and cache writes should be equal to cache read/writes and the the sum of cache hits and cache misses should be equal to cache read/writes, too. Additionally, if two first

cache	
PCL_LxCACHE_READ	number of level-x cache reads
PCL_LxCACHE_WRITE	number of level-x cache writes
PCL_LxCACHE_READWRITE	number of level-x cache reads or writes
PCL_LxCACHE_HIT	number of level-x cache hits
PCL_LxCACHE_MISS	number of level-x cache misses
data cache	
PCL_LxDCACHE_READ	number of level-x data cache reads
PCL_LxDCACHE_WRITE	number of level-x data cache writes
PCL_LxDCACHE_READWRITE	number of level-x data cache reads or writes
PCL_LxDCACHE_HIT	number of level-x data cache hits
PCL_LxDCACHE_MISS	number of level-x data cache misses
instruction cache	
PCL_LxICACHE_READ	number of level-x instruction cache reads
PCL_LxICACHE_WRITE	number of level-x instruction cache writes
PCL_LxICACHE_READWRITE	number of level-x instruction cache reads or writes
PCL_LxICACHE_HIT	number of level-x instruction cache hits
PCL_LxICACHE_MISS	number of level-x instruction cache misses
TLB	
PCL_TLB_HIT	number of hits in TLB
PCL_TLB_MISS	number of misses in TLB
Instruction TLB	
PCL_ITLB_HIT	number of hits in instruction TLB
PCL_ITLB_MISS	number of misses in instruction TLB
Data TLB	
PCL_DTLB_HIT	number of hits in data TLB
PCL_DTLB_MISS	number of misses in data TLB

Table 2.1: Events concerning memory hierarchy (x=1 or 2 for 1st or 2nd level cache)

level caches exist (instruction and data), the sum of instruction cache reads and data cache reads should be equal to cache reads (and so on).

2.2 Instructions

Instructions correspond to operations and flow control specified in a program. There are several categories of operations (e.g. integer, logical, floating point) which might be executed by different functional units in the microprocessor. Another aspect (in multiprocessor systems) is atomic operations (e.g. a primitive for a test-and-set-operations) which can be executed successful (the lock could be set) or unsuccessful (the lock could not be acquired as it was already set). We distinguish between the instruction categories as shown in table 2.2.
Additionally, we have included a cycle count which gives the number of cycles spent in this process or on behalf of the process/thread (when counting in user-and-system mode). For clarification, it should be noted that the cycle count should not be used to count the number of elapsed cycles as on multiprogramming systems other processes might be scheduled to the same processor. To count the number of elapsed cycles, an additional event can be used (*PCL_ELAPSED_CYCLES*).
On some systems, the number of issued instructions might be different to the number of completed instructions due to some error conditions. We have chosen completed instructions, as they correspond more closely to the operations the programmer specified in his program.
Getting the number of operations out of the number of instructions is difficult. For example, on some systems a floating-point add and a floating-point multiply can be initiated by a single add-and-multiply instruction. Therefore, 1 floating point instruction is counted but 2 floating point operations are executed. With PCL (and most of all hardware performance counter implementations) it is not possible to count the number of floating point *operations* and related number.

2.3 Status of Functional Units

Functional units might be stalled due to blocked resources, missing operands etc. Table 2.3 gives the events defined for stalls. Measuring such an event results (different to all other events) not in the number of stalls

PCL_CYCLES	spent cycles in process/thread (and eventually in system calls)
PCL_ELAPSED_CYCLES	elapsed cycles
PCL_INTEGER_INSTR	number of completed integer (or logical) instructions
PCL_FP_INSTR	number of completed floating point instructions
PCL_LOAD_INSTR	number of completed load instructions
PCL_STORE_INSTR	number of completed store instructions
PCL_LOADSTORE_INSTR	number of completed load or store instructions
PCL_INSTR	sum of all completed instructions
PCL_JUMP_SUCCESS	number of correctly predicted branches
PCL_JUMP_UNSUCCESS	number of mispredicted branches
PCL_JUMP	sum of all branches
PCL_ATOMIC_SUCCESS	number of successful atomic instructions
PCL_ATOMIC_UNSUCCESS	number of unsuccessful atomic instructions
PCL_ATOMIC	sum of all instructions concerning atomic operations

Table 2.2: Events concerning instruction categories

PCL_STALL_INTEGER	number of cycles the integer/logical unit is stalled
PCL_STALL_FP	number of cycles the floating point unit is stalled
PCL_STALL_JUMP	number of cycles the branch unit is stalled
PCL_STALL_LOAD	number of cycles the load unit is stalled
PCL_STALL_STORE	number of cycles the store unit is stalled (write buffer)
PCL_STALL	sum of all cycles a unit is stalled

Table 2.3: Events concerning functional unit stalls (numbers given in cycles)

but in the number of cycles all stalls of this event type have taken.

2.4 Rates and Ratios

Often, it is useful to get a ratio or rate rather than an absolute number. Good examples are cache miss rates or floating point operations per second. Table 2.4 gives the events defined for such rates and ratios. Measuring these events will mostly be done by deriving the values from other performance numbers (see [1]). The definitions are as follows:

- PCL_MFLOPS : $\frac{PCL\_FP\_INSTR}{PCL\_CYCLES} \times MHzrate$
- PCL_IPC : $\frac{PCL\_INSTR}{PCL\_CYCLES}$
- PCL_L1DCACHE_MISSRATE : $\frac{PCL\_L1DCACHE\_MISS}{PCL\_LOADSTORE\_INSTR}$
- PCL_L2DCACHE_MISSRATE : $\frac{PCL\_L2DCACHE\_MISS}{PCL\_L1DCACHE\_MISS}$
- PCL_MEM_FP_RATIO : $\frac{PCL\_LOADSTORE\_INSTR}{PCL\_FP\_INSTR}$

PCL_MFLOPS	number of million floating point instructions per second
PCL_IPC	number of completed instructions per cycle
PCL_L1DCACHE_MISSRATE	miss rate of L1 data cache
PCL_L2DCACHE_MISSRATE	miss rate for L2 data cache
PCL_MEM_FP_RATIO	ratio of memory references to floating point operations

Table 2.4: Events concerning rates and rations (numbers are floating point values)

Chapter 3

PCL – The Performance Counter Library

The Performance Counter Library has a programming interface to access a set of performance counters with a defined set of countable events. In section 3.1, we specify which of the events defined in chapter 2 are available on what systems and in section 3.2 we define the programming interface. Additionally, we provide a uniform low-level interface to directly access performance counters on a microprocessor to measure non-standard events.

3.1 Countable Events

In the following tables we compare the events defined in the last section in tables 2.1 to 2.3 with the available events on the microprocessors currently supported by PCL.
The tables are given in the following scheme. Each entry in the tables specifies if a processor supports the PCL event, and if so, what the corresponding event is. The entry names correspond to the event names in the description of the microprocessors (see chapter A. Empty entries signal that such an event is not available on that microprocessor. Entries in itaic are indirect events as a combination of several other events directly countable by a (hardware) performance counter. Counters used for indirect events can not be used at the same time to measure their own events. Therefore, on a processor any combination of PCL events is possible which does not generate any ressource conflict.
Table 3.1 shows events relevant to the 1st level cache (instruction and data), table 3.2 shows events relevant to the 1st level data cache, and table 3.3 shows events relevant to the 1st level instruction cache. Tables 3.4, 3.5, and 3.6 show events relevant to the 2nd level cache (instruction and data, data, instruction, respectively). If there is a unified cache for data and instructions (as it is on most systems), events defined for 2nd level instruction cache refer to cache references done by instruction fetches, and for the data cache accordingly. Table 3.7 shows events for the translation look-aside buffers (instruction, data, instruction and data). Table 3.8 shows spent cycles, tables 3.10 and 3.9 shows events relevant to instructions, table 3.11 shows events regarding branch instructions, and table 3.12 shows events ragarding atomic instructions. Table 3.13 shows events concerning units which are blocked/stalled. Instead of counting the number of events, the number in this table gives the number of cycles for the event type. Table 3.14 shows the events concerning rates and ratios.

processor	PCL_L1CACHE_READ	PCL_L1CACHE_WRITE	PCL_L1CACHE_READWRITE	PCL_L1CACHE_HIT	PCL_L1CACHE_MISS
Alpha 21164 21264					
MIPS R10k R12k					 R10k_C1_9+R10k_C0_9 R12k_9+R12k_25
SPARC Ultra I/II Ultra III					
PowerPC PPC604 PPC604e POWER3 POWER3-II					 PPC604_C0_5+PPC604_C1_6 PPC604e_C0_5+PPC604e_C1_6 POWER3_C0_6+POWER3_C1_9 POWER3II_C0_6+POWER3II_C1_9
Intel Pentium MMX Pro,PII,PIII Pentium 4					
AMD Athlon					
Hitachi SR8000					

Table 3.1: 1st level cache

processor	PCL_L1DCACHE_READ	PCL_L1DCACHE_WRITE	PCL_L1DCACHE_READWRITE	PCL_L1DCACHE_HIT	PCL_L1DCACHE_MISS
Alpha					
21164			21164_C1_14	21164_C1_14-21164_C2_5	21164_C2_5
21264					
MIPS					
R10k					R10k_C1_9
R12k					R12k_25
SPARC					
Ultra I/II	ULTRA_C0_5	ULTRA_C0_6			ULTRA_C0_1
Ultra III	ULTRA3_C0_9	ULTRA3_C0_10			
PowerPC					
PPC604					PPC604_C1_6
PPC604e					PPC604e_C1_6
POWER3					POWER3_C0_17,POWER3_C1_19,POWER3_C5_0
POWER3-II					POWER3II_C0_17,POWER3II_C1_19,POWER3II_C5_0
Intel					
Pentium MMX	Pentium_0	Pentium_1	Pentium_0+Pentium_1		Pentium_37
Pro,PII,PIII					PPro_1
Pentium 4					P4_CG4_16
AMD					
Athlon			ATHLON_2	ATHLON_2-ATHLON_3	ATHLON_3
Hitachi					
SR8000					SR8000_C3

Table 3.2: 1st level data cache

processor	PCL_L1ICACHE_READ	PCL_L1ICACHE_WRITE	PCL_L1ICACHE_READWRITE	PCL_L1ICACHE_HIT	PCL_L1ICACHE_MISS
Alpha					
21164			21164_C1_13	21164_C1_13-21164_C2_3	21164_C2_3
21264					
MIPS					
R10k					R10k_C0_9
R12k					R12k_9
SPARC					
Ultra I/II			ULTRA_C0_4	ULTRA_C1_4	ULTRA_C0_4-ULTRA_C1_4
Ultra III	ULTRA3_C0_8			ULTRA3_C0_8-ULTRA3_C1_8	ULTRA3_C1_8
PowerPC					
PPC604					PPC604_C0_5
PPC604e					PPC604e_C0_5
POWER3				POWER3_C4_1	POWER3_C0_5,POWER3_C6_0
POWER3-II				POWER3II_C4_1	POWER3II_C0_5,POWER3II_C6_0
Intel					
Pentium MMX	Pentium_12				Pentium_14
Pro,PII,PIII	PPro_5				PPro_6
Pentium 4					
AMD					P4_CG1_0
Athlon	ATHLON_18			ATHLON_18-ATHLON_19	ATHLON_19
Hitachi					
SR8000					SR8000_C2

Table 3.3: 1st level instruction cache

processor	PCL_L2CACHE_READ	PCL_L2CACHE_WRITE	PCL_L2CACHE_READWRITE	PCL_L2CACHE_HIT	PCL_L2CACHE_MISS
Alpha 21164 21264	21164_C1_16	21164_C1_17	21164_C1_15	21164_C1_15-21164_C2_14	21164_C2_14
MIPS R10k R12k					R10k_C1_10+R10k_C0_10 R12k_26+R12k_10
SPARC Ultra I/II Ultra III			ULTRA_C0_8 ULTRA3_C0_12	ULTRA_C1_8 ULTRA3_C0_12-ULTRA3_C1_12	ULTRA_C1_9 ULTRA3_C1_12
PowerPC PPC604 PPC604e POWER3 POWER3-II					POWER3_C1_21 POWER3II_C1_21
Intel Pentium MMX Pro,PII,PIII Pentium 4	P4_CG1_10,11,12,13		PPro_17	P4_CG1_10,11,12	PPro_13 P4_CG1_13
AMD Athlon			ATHLON_16		
Hitachi SR8000					

Table 3.4: 2nd level cache

processor	PCL_L2DCACHE_READ	PCL_L2DCACHE_WRITE	PCL_L2DCACHE_READWRITE	PCL_L2DCACHE_HIT	PCL_L2DCACHE_MISS
Alpha					
21164					
21264					
MIPS					
R10k					R10k_C1_10
R12k					R12k_26
SPARC					
Ultra I/II					
Ultra III					
PowerPC					
PPC604					
PPC604e					
POWER3					
POWER3-II					
Intel					
Pentium MMX					
Pro,PII,PIII	PPro_11	PPro_12	PPro_11+PPro_12		
Pentium					
AMD					
Athlon					
Hitachi					
SR8000					

Table 3.5: 2nd level data cache

processor	PCL_L2ICACHE_READ	PCL_L2ICACHE_WRITE	PCL_L2ICACHE_READWRITE	PCL_L2ICACHE_HIT	PCL_L2ICACHE_MISS
Alpha					
21164					
21264					
MIPS					
R10k					R10k_C0_10
R12k					R12k_10
SPARC					
Ultra I/II					
Ultra III					
PowerPC					
PPC604					
PPC604e					
POWER3					
POWER3-II					
Intel					
Pentium MMX					
Pro,PII,PIII					
Pentium 4					
AMD					
Athlon					
Hitachi					
SR8000					

Table 3.6: 2nd level instruction cache

processor	PCL_TLB_HIT	PCL_TLB_MISS	PCL_ITLB_HIT	PCL_ITLB_MISS	PCL_DTLB_HIT	PCL_DTLB_MISS
Alpha						
21164				21164_C2_4		21164_C2_6
21264				21264_C1_5		
MIPS						
R10k		R10k_C1_7				
R12k		R12k_23				
SPARC						
Ultra I/II						
Ultra III				ULTRA3_C1_17		ULTRA3_C1_18
PowerPC						
PPC604		PPC604_C0_6+PPC604_C1_7		PPC604_C1_7		PPC604_C0_6
PPC604e		PPC604e_C0_6+PPC604e_C1_7		PPC604e_C1_7		PPC604e_C0_6
POWER3		POWER3_C0_19,POWER3_C8_0				
POWER3-II		POWER3II_C0_19,POWER3II_C8_0				
Intel						
Pentium MMX				Pentium_13		Pentium_2
Pro,PII,PIII				PPro_7		
Pentium 4				P4_CG1_9		P4_CG1_8
AMD						
Athlon				ATHLON_23		ATHLON_8
Hitachi						
SR8000				SR8000_C0		SR8000_C1

Table 3.7: Transfer-Look-aside-Buffer

processor	PCL_CYCLES	PCL_ELAPSED_CYCLES
Alpha		
21164	21164_C0_0	21164_PCC[1]
21264	21264_C0_0, 21264_C1_0	21264_PCC
MIPS		
R10k	R10k_C0_0, R10k_C1_0	
R12k	R12k_0	
SPARC		
Ultra I/II	ULTRA_C0_0, ULTRA_C1_0	ULTRA_TC
Ultra III	ULTRA3_C0_0,ULTRA3_C1_0	ULTRA3_TC
PowerPC		
PPC604	PPC604_C0_1, PPC604_C1_1	
PPC604e	PPC604e_C0_1,PPC604e_C1_1,PPC604e_C2_1,PPC604e_C3_1	
POWER3	POWER3_C0_1 and other	
POWER3-II	POWER3II_C0_1 and other	
Intel		
Pentium MMX	Pentium_C0_4[2]	Pentium_TSC
Pro,PII,PIII	PPro_61	PPro_TSC
Pentium 4	P4_CYCLES	P4_TSC
AMD		
Athlon	ATHLON_15	ATHLON_TSC
Hitachi		
SR8000	SR8000_C6	special register

Table 3.8: Cyles

[1]On Cray T3E systems not as 64-bit register.
[2]only on Pentium MMX
[3]Floating point operations instead of floating point instructions are counted.
[4]Issued instructions are counted instead of completed instructions.
[5]Integer multiplication and division increments the counter by two
[6]Currently, the software interface doesn't support that.
[7]See comments on *Pentium_30*.
[8]only on Pentium MMX
[9]only on Pentium MMX
[10]only on Pentium MMX

processor	PCL_INTEGER_INSTR	PCL_FP_INSTR
Alpha		
21164	21164_C1_9	21164_C1_10[3]
21264		
MIPS		
R10k		R10k_C1_5
R12k		R12k_21
SPARC		
Ultra I/II		
Ultra III		ULTRA3_C0_24+ULTRA3_C1_39
PowerPC		
PPC604	PPC604_C0_14	PPC604_C0_15
PPC604e	PPC604e_C0_14	PPC604e_C0_15
POWER3	POWER3_C5_2+POWER3_C6_1+POWER3_C7_4	POWER3_C1_35+POWER3_C4_5
POWER3-II	POWER3II_C5_2+POWER3II_C6_1+POWER3II_C7_4	POWER3II_C1_35+POWER3II_C4_5
Intel		
Pentium MMX		Pentium_30[4]
Pro,PII,PIII		PPro_C0_0
Pentium 4		P4_CG4_14
AMD		
Athlon		
Hitachi		
SR8000		SR8000_C7

Table 3.9: Instructions (2)

processor	PCL_LOAD_INSTR	PCL_STORE_INSTR	PCL_LOADSTORE_INSTR	PCL_INSTR
Alpha				
21164	21164_C1_11	21164_C1_12		21164_C0_1[5]
21264				AL264_0_1
MIPS				
R10k	R10k_C1_2	R10k_C1_3		R10k_C0_15,R10k_C1_1[6]
R12k	R12k_18	R12k_19	R12k_18+R12k_19[7]	R12_15
SPARC				
Ultra I/II				ULTRA_C0_1
Ultra III				ULTRA3_C0_1,ULTRA3_C1_1
PowerPC				
PPC604	PPC604_C1_18			PPC604_C0_2, PPC604_C1_2
PPC604e	PPC604e_C1_18			PPC604e_C0_2, PPC604e_C1_2, PPC604e_C2_2, PPC604e_C3_2
POWER3	POWER3_C0_4,POWER3_C3_5	POWER3_C2_9	POWER3_C3_5+POWER3_C2_9	POWER3_C0_1,POWER3_C1_0,POWER3_C2_2,POWER3_C3_2
POWER3-II	POWER3II_C0_4,POWER3II_C3_5	POWER3II_C2_9	POWER3II_C3_5+POWER3II_C2_9	POWER3II_C0_1,POWER3II_C1_0,POWER3II_C2_2,POWER3II_C3_2
Intel				
Pentium MMX			Pentium_36	Pentium_20
Pro,PII,PIII			PPro_0	PPro_44
Pentium 4	P4_CG4_12	P4_CG4_12	P4_CG4_12	P4_CG4_18, 19
AMD				
Athlon				ATHLON_28
Hitachi				
SR8000			SR8000_C4	SR8000_C5

Table 3.10: Instructions (1)

processor	PCL_JUMP_SUCCESS	PCL_JUMP_UNSUCCESS	PCL_JUMP
Alpha			
21164		21164_C2_2	
21264			21264_C1_1
MIPS			
R10k	R10k_C0_6-R10k_C1_8	R10k_C1_8	R10k_C0_6
R12k	R12k_6-R12k_24	R12k_24	R12k_6
SPARC			
Ultra I/II			
Ultra III		ULTRA3_C0_21+ULTRA3_C1_29	ULTRA3_C0_22
PowerPC			
PPC604	PPC604_C1_8-PPC604_C0_7	PPC604_C0_7	PPC604_C1_8
PPC604e	PPC604e_C1_8-PPC604e_C0_7	PPC604e_C0_7	PPC604e_C1_8
POWER3	POWER3_C1_8	POWER3_C3_22-POWER3_C1_8	POWER3_C3_22
POWER3-II	POWER3II_C1_8	POWER3II_C3_22-POWER3II_C1_8	POWER3II_C3_22
Intel			
Pentium MMX	Pentium_4[8]	Penntium_16-Pentium_4[9]	Pentium_16
Pro,PII,PIII	PPro_52	PPro_51	PPro_50
Pentium 4	P4_CG4_2	P4_CG4_4	P4_CG4_4+P4_CG4_0, 2
AMD			
Athlon	ATHLON_32	ATHLON_31	ATHLON_35
Hitachi			
SR8000			

Table 3.11: Branch instructions

processor	PCL_ATOMIC_SUCCESS	PCL_ATOMIC_UNSUCCESS	PCL_ATOMIC
Alpha			
21164	21164_C2_13		
21264			
MIPS			
R10k	R10k_C1_4-R10k_C0_5	R10k_C0_5	R10k_C1_4
R12k	R12k_20-R12k_5	R12k_5	R12k_20
SPARC			
Ultra I/II			
Ultra III			
PowerPC			
PPC604	PPC604_C1_9		
PPC604e	PPC604e_C1_9		
POWER3		POWER3_C1_13	
POWER3-II		POWER3II_C1_13	
Intel			
Pentium MMX			
Pro,PII,PIII			
Pentium 4			
AMD			
Athlon			
Hitachi			
SR8000			

Table 3.12: Atomic instructions

processor	PCL_STALL_INTEGER	PCL_STALL_FP	PCL_STALL_JUMP	PCL_STALL_LOAD	PCL_STALL_STORE	PCL_STALL
Alpha						
21164						
21264						
MIPS						
R10k						
R12k						
SPARC						
Ultra I/II						
Ultra III					ULTRA3_C0_5	
PowerPC						
PPC604						
PPC604e		PPC604e_C2_19	PPC604e_C2_12			
POWER3						
POWER3-II						
Intel						
Pentium MMX		Pentium_C0_5[10]		Pentium_24	Pentium_23	
Pro,PII,PIII						PPro_58
Pentium 4						
AMD						
Athlon		ATHLON_49				
Hitachi						
SR8000						

Table 3.13: Blocked units

processor	PCL_MFLOPS	PCL_IPC	PCL_L1DCACHE_MISSRATE	PCL_L2DCACHE_MISSRATE	PCL_MEM_FP_RATIO
Alpha					
21164	21164_C1_10/21164_C2_11*Mhz	21164_C0_1/21164_C2_11	21164_C2_5/21164_C1_14	21164_C2_14/21164_C1_15[11]	
21264					
MIPS					
R10k	R10k_C1_5/R10k_C0_0*Mhz	R10k_C0_15/R10k_C1_0			
R12k	R12k_21/R12k_0*Mhz				
SPARC					
Ultra I/II		ULTRA_C0_1/ULTRA_C1_0		ULTRA_C1_9/ULTRA_C0_11	
Ultra III	(ULTRA_C0_24+ULTRA_C1_39)/MHz	ULTRA_C0_1/ULTRA_C1_1		ULTRA_C1_12/ULTRA_C0_12	
PowerPC					
PPC604	PPC604_C0_15/PPC604_C1_1*Mhz	PPC604_C0_2/PPC604_C1_1			
PPC604e	PPC604e_C0_15/PPC604e_C1_1*Mhz	PPC604e_C0_2/PPC604e_C1_1			
POWER3	POWER3_C1_35/POWER3_C4_5*Mhz	POWER3_C0_1/POWER3_C1_1			
POWER3-II	POWER3II_C1_35/POWER3II_C4_5*Mhz	POWER3II_C0_1/POWER3II_C1_1			
Intel					
Pentium MMX	Pentium_30/Pentium_C0_4*Mhz	Pentium_20/Pentium_C0_4	Pentium_37/Pentium_36		Pentium_36/Pentium_30
Pro,PII,PIII	PPro_C0_0/PPro_61*Mhz	PPro_44/PPro_61	PPro_1/PPro_0		P4_CG4_12/P4_CG4_14
Pentium 4	P4_CG4_14/P4_CYCLES*MHz	P4_CG4_18, 19/P4_CYCLES		P4_CG1_13/P4_CG1_10,11,12,13	
AMD					
Athlon		ATHLON_28/ATHLON_15	ATHLON_3/ATHLON_2		
Hitachi					
SR8000					

Table 3.14: Rates and Ratios

3.2 Interface Functions

The interface functions to control the performance counters are given below. All functions are callable from C, C++, Fortran, and Java. All functions return status codes with the following meaning:

PCL_SUCCESS function successful finished

PCL_NOT_SUPPORTED requested event is not supported on this hardware

PCL_TOO_MANY_EVENTS more events requested than performance counters are available

PCL_TOO_MANY_NESTINGS there are more nested calls than allowed (*PCL_MAX_NESTING_LEVEL*)

PCL_TOO_ILL_NESTING either a different number or different types of events are requested in nested calls

PCL_ILL_EVENT event identifier illegal

PCL_MODE_NOT_SUPPORTED performance counting for that mode is not supported

PCL_FAILURE failure for some unspecified reason

Every PCL call needs a handle (denoted by *descr*) to work in a multi-threaded environment. Such a handle needs to be allocated once with a call to *PCLinit* before any other PCL function is called. A handle should be deallocated with *PCLexit* after all PCL functions were called.

3.2.1 High-Level Interface

The high-level interface is the usual interface as it allows a portable access to performance counters.

PCLinit

Allocates a thread-specific descriptor which must be passed to all subsequent PCL calls. The address of a descriptor must be passed.

```
int PCLinit(
             PCL_DESCR_TYPE* addr_descr   /* I/O: addr of handle */
           );
```

PCLexit

Releases the thread-specific descriptor.

```
int PCLexit(
             PCL_DESCR_TYPE  & descr      /* I: handle */
           );
```

PCLquery

With this function, queries are done if a certain functionality is available on this machine. The user supplies in *counter_list* an array of size *ncounter* of event names (of type integers). Event names are any of those introduced in the tables 3.1 to 3.13 in the last section. In *mode*, the user specifies the execution mode for which performance data should be gathered: *PCL_MODE_USER* specifies counting in user mode, *PCL_MODE_SYSTEM* specifies counting in system mode, and *PCL_MODE_USER_SYSTEM* specifies either of both modes. The function returns *PCL_SUCCESS* if the requested functionality is possible (i.e. if the requested events can be counted in parallel), otherwise an error code is returned why the requested events are not supported on this system. No resources are allocated on this call.

```
int PCLquery(
              PCL_DESCR_TYPE & descr,  /* I: handle */
              int *counter_list,       /* I: requested event counters */
              int ncounter,            /* I: number of counters */
              unsigned int mode        /* I: mode flags (PCL_MODE_xxx) */
            );
```

PCLstart

With *PCLstart*, performance counting is started (if it is possible). The user supplies in *counter_list* an array of size *ncounter* of event names. Event names are any of those introduced in the tables 3.1 to 3.13 in the last section. *mode* has the same meaning as in the description of *PCLquery*. If the requested functionality is available, the appropriate performance counters are cleared and started. On success, *PCL_SUCCESS* is returned, otherwise an error code is returned.

```
int PCLstart(
             PCL_DESCR_TYPE descr,   /* I: handle */
             int *counter_list,      /* I: events to be counted */
             int ncounter,           /* I: number of counters */
             unsigned int mode       /* I: mode flags (PCL_MODE_xxx) */
            );
```

PCLread

Reads out performance counters and returns counter values. Each of the the result values is either written into the (user supplied) integer-typed buffer *i_results_list* or into the (user supplied) floating point typed buffer *fp_results_list* both of size *ncounter*. *PCL_CNT_TYPE* is a 64-bit integer type, *PCL_FP_CNT_TYPE* is a 64-bit floating point type. Which of the buffers is used for the i-th result depends on the requested i-th event type. If the i-th event type is less than PCL_MFLOPS, the result is an integer value which is stored in *i_results_list[i]*. If the i-th event type is greater than or equal to PCL_MFLOPS (i.e. belongs to the category *rates and ratios*), the result is a floating point value stored in *fp_results_list[i]*. If the i-th result is stored in *i_results_list[i]*, the content of *fp_results_list[i]* is undefined, and the same holds for the other way.
The arguments supplied with the call to *PCLread* must correspond to the latest call to *PCLstart*, i.e. the number of requested performance counters must be equal. If no error occurs, *PCL_SUCCESS* is returned, otherwise an error code. The performance counters are (logically) not stopped.

```
int PCLread(
            PCL_DESCR_TYPE descr,              /* I: handle */
            PCL_CNT_TYPE *i_result_list,       /* O: int counter values */
            PCL_FP_CNT_TYPE * fp_result_list,  /* O: fp counter values */
            int ncounter                       /* I: number of events */
            );
```

PCLstop

Stops performance counting and returns counter values. Result values are written into the (user supplied) buffers *i_result_list* or *fp_result_list* both of size *ncounter*. See *PCLread* for a description how the results are stored in the two arrays. The arguments supplied with the call to *PCLstop* must correspond to the latest call to *PCLstart*, i.e. the number of requested performance counters must be equal. If no error occurs, *PCL_SUCCESS* is returned, otherwise an error code.

```
int PCLstop(
            PCL_DESCR_TYPE descr,               /* I: handle */
            PCL_CNT_TYPE *i_result_list,        /* O: int counter values */
            PCL_FP_CNT_TYPE * fp_result_list,   /* O: fp counter values */
            int ncounter                        /* I: number of events */
           );
```

3.2.2 Low-Level Interface

The low-level interface should only be used in rare circumstances. It allows a direct access to hardware performance counters in a uniform way. The user has to be aware of events and events codings for the processor in use. This is different to the high-level interface where an abstract layer exists which hides all low-level and non-portable details. The low-level interface is only accessible from C/C++.
The low-level interface was introduced in version 2.0 and feedback on its design and usage is welcome. The interface may change in the future.
Before using any of the driver functions, a handle need to be allocated by a call to *PCLinit(PCL_DESCR_TYPE *descr)*. After using the driver routines, a call to *PCLexit(PCL_DESCR_TYPE descr)* must be issued to release the handle.

PCL_driver_info

This function returns information on the processor in use. The function returns *PCL_SUCCESS* if the operation didn't produce any error.

```
int PCL_driver_open(
                    PCL_PROCESSOR_INFO *info /* I: address of info struct */
                    );
```

The type *PCL_PROCESSOR_INFO* is a struct with at least the following components:

```
typedef struct
{
    char *vendor;   /* processor vendor */
    char *family;   /* processor family */
    char *model;    /* processor model */
    int mhz;        /* MHz rate */
    int ncounters;  /* number of counters (at least this number) */
}  PCL_PROCESSOR_INFO;
```

PCL_driver_open

This function has to be called once and before any other driver call to open the hardware driver interface. The function returns *PCL_SUCCESS* if the operation could be successfully done.

```
int PCL_driver_open(
                     PCL_DESCR_TYPE descr /* I: handle */
                   );
```

PCL_driver_start

Starts performance counting. *max_counter* specifies the maximum counter index (≤ PCL_COUNTER_MAX). *counter_used_mask* is a bit field where the bits 0-*max_counter* speciy which counters should be started. E.g. if you want to measure counter 0,3, and 4 you may pass 4 or higher for *max_counter* and a bit field which has at bit position 0, 3, and 4 a 1 and otherwise a 0 (starting bit counting with 0) . If no error occurs, *PCL_SUCCESS* is returned, otherwise an error code.

```
int PCL_driver_start(
        PCL_DESCR_TYPE descr                 /* I: handle */
        int max_counter,                     /* I: max. counter index */
        PCL_BIT_MASK_TYPE counter_used_mask, /* I: bit-field of counters to use */
        PCL_DRIVER_COMMAND_TYPE *commands,   /* I: event commands for counters */
        unsigned int count_mode              /* I: count mode */
        );
```

PCL_driver_read

Reads out performance counters. The read values are returned in *counter_values*, a user-supplied buffer capable of storing *max_counter* values. *max_counter* specifies the maximum counter index (≤ PCL_COUNTER_MAX). *counter_used_mask* gives in a bit field the hardware counters which should be read. If no error occurs, *PCL_SUCCESS* is returned, otherwise an error code.

```
int PCL_driver_read(
   PCL_DESCR_TYPE descr     /* I: handle */
   int max_counter,         /* I: max. counter index */
   PCL_BIT_MASK_TYPE counter_used_mask,  /* I: bit-field of counters to be read */
   PCL_CNT_TYPE *counter_values     /* I/O: buffer for results */
   );
```

PCL_driver_stop

Stops performance counting. If no error occurs, *PCL_SUCCESS* is returned, otherwise an error code.

```
int PCL_driver_stop(
      PCL_DESCR_TYPE descr   /* I: handle */
      );
```

PCL_driver_close

Closes the driver and releases all allocated ressources. If no error occurs, *PCL_SUCCESS* is returned, otherwise an error code.

```
int PCL_driver_close(
         PCL_DESCR_TYPE descr /* I: handle */
        );
```

3.2.3 Useful Macros

There are two macros defined:

1. *PCL_EVENT_IS_INT(e)* determines whether the result of an event e is of type integer (64 bits) or has a floating point type (64 bits)

2. *PCL_EVENT_IS_RATE(e)* determines whether the result for an event means and event count or an event rate (counts may be added, adding rates makes less sense)

3.3 Programming Aspects

The allowed calling sequence is one call to *PCLstart* followed by zero or more calls to *PCLread* followed by one call to *PCLstop*. Between a call to *PCLstart* and *PCLstop* (and possible calls to *PCLread*) may be nested calls to other allowed calling sequences with the same number of events and the same event types.
On system with virtual (low level) performance counters, migrating a process to another processor is possible (SGI, AIX). On the other systems, we bind the executing process to a processor (DEC, SOLARIS)[11], or the process can not migrate (CRAY). On Solaris systems, if the process is not bound to a specific processor, the process gets bound to the processor 0 when executing the *PCLstart* function. On DEC systems, the process gets bound to the processor the process is currently running on. If you use pthreads on Solaris systems, you must bind each thread to a processor.
Currently, performance counters are not saved on context switches on Linux systems by our library and therefore performance measurements should be done only on a lightly loaded system.
Currently, we do not check if any other process uses the performance counters as well[12]. Therefore, on certain systems if two distinct processes use performance counters in parallel, they may disturb each other.
To avoid overflow e.g. on systems with 32-bit hardware counters, an interval timer is called on these systems (Solaris, AIX, Linux) which interrupts the process every second. Programs which use the *setitimer* system call (or the *SIGVTALRM* signal), may be in conflict with PCL.

3.4 Supported Systems

Currently, the Performance Counter Library is available on the systems listed above:

- Alpha 21164 on Digital Unix 4.0x
- Alpha 21264 on Digital Unix $>=$ 4.0e
- Alpha 21164 on CRAY T3E Unicos/mk
- R10000,R12000 on SGI IRIX 6.x
- UltraSPARC I/II/III on Solaris 2.x and above
- PowerPC 604,604e,POWER3,POWER3-II in AIX $>=$ 4.3
- Pentium/PPro/Pentium II/Pentium III, Pentium 4 on Linux 2.x.x
- AMD Athlon

[11]On Linux systems, currently it is not possible to bind a process to a processor.
[12]This may be a program using the performance counters directly, or through a different application interface.

3.5 Examples

3.5.1 Simple Example

Below is a simple example program how to use the Performance Counter Library. First, the list of requested events (*PCL_LOAD_INSTR* for load instructions, and *PCL_L1DCACHE_MISS* for 1st level data cache misses) is put into the array *counter_list*. With the call to *PCLquery* we test, if it is possible to serve these two requested events simultaneously on the computer system where the program is executed. If this is possible, event counting is started with the call to *PCLstart*. After that follows the code to be measured and a call to *PCLstop* to stop performance counting and to read out the performance counter values. Then, the results are printed.

```
#include <pcl.h>

void do_work(){}

int main(int argc, char **argv)
{
    int counter_list[2];
    int ncounter;
    unsigned int mode;
    PCL_CNT_TYPE i_result_list[2];
    PCL_FP_CNT_TYPE fp_result_list[2];
    PCL_DESCR_TYPE descr;


    /* Allocate a handle */
    if(PCLinit(&descr) != PCL_SUCCESS)
        printf("cannot get handle\n");

    /* Define what we want to measure. */
    ncounter = 2;
    counter_list[0] = PCL_CYCLES;
    counter_list[1] = PCL_INSTR;

    /* define count mode */
    mode = PCL_MODE_USER;

    /* Check if this is possible on the machine. */
    if(PCLquery(descr, counter_list, ncounter, mode) != PCL_SUCCESS)
        printf("requested events not possible\n");

    /* Start performance counting.
       We have checked already the requested functionality
       with PCL_query, so no error check would be necessary. */
    if(PCLstart(descr, counter_list, ncounter, mode) != PCL_SUCCESS)
        printf("something went wrong\n");

    /* Here comes the work to be measured. */
    do_work();

    /* Stop performance counting and get the counter values. */
    if(PCLstop(descr, i_result_list, fp_result_list, ncounter) != PCL_SUCCESS)
        printf("problems with stopping counters\n");

    /* print out results */
    printf("%f instructions in %f cycles\n",
           (double)i_result_list[1], (double)i_result_list[0]);

    /* Deallocate handle */
    if(PCLexit(descr) != PCL_SUCCESS)
```

```
        printf("cannot release handle\n");

    return 0;
}
```

3.5.2 Example with Nested Calls

Below is an example how to use nested calls. In this example, for the outer loop as well as for each iteration the number of cycles spent in this code section is measured.

```
#include <pcl.h>

#define NITER 4

void do_work(){}

int main(int argc, char **argv)
{
    int counter_list[1];
    int ncounter, res, iter;
    unsigned int mode;
    PCL_CNT_TYPE i_all_result_list, i_result_list[NITER];
    PCL_FP_CNT_TYPE fp_all_result_list, fp_result_list[NITER];
    PCL_DESCR_TYPE descr;


    /* Allocate a handle */
    if(PCLinit(&descr) != PCL_SUCCESS)
        printf("cannot get handle\n");

    /* Define what we want to measure. */
    ncounter = 1;
    counter_list[0] = PCL_CYCLES;

    /* define count mode */
    mode = PCL_MODE_USER;

    /* Start performance counting. */
    res = PCLstart(descr,counter_list, ncounter, mode);

    for(iter = 0; iter < NITER; ++iter)
      {
        /* Start performance counting. */
        res = PCLstart(descr, counter_list, ncounter, mode);

        /* Here comes the work to be measured. */
        do_work();

        /* Stop performance counting and get counter values. */
        res = PCLstop(descr, &i_result_list[iter], &fp_result_list[iter], ncounter);
      }

    /* Stop performance counting and get the counter values. */
    res = PCLstop(descr, &i_all_result_list, &fp_all_result_list, ncounter);

    /* print out results */
    printf("used cycles: %f %f %f %f, total: %f\n",
           (double)i_result_list[0], (double)i_result_list[1],
           (double)i_result_list[2], (double)i_result_list[3],
           (double)i_all_result_list);
    /* Deallocate handle */
    if(PCLexit(descr) != PCL_SUCCESS)
        printf("cannot release handle\n");

    return 0;
}
```

3.5.3 Example in Java

Below is an example how to use PCL in Java.

```
public class pcl_jtest {
  static final int N = 200;               // matrix dimension
  static double[][] a = new double[N][N];
  static double[][] b = new double[N][N];
  static double[][] c = new double[N][N];

  // test method
  static void matadd(double[][] a, double[][] b, double[][] c) {
    int i, j;
    for (i = 0; i < N; ++i)
      for (j = 0; j < N; ++j)
        a[i][j] = b[i][j] + c[i][j];
  }

  // main program
  public static void main(String[] args) {
    int event;
    long descr = 0;                     // descriptor
    PCL pcl = new PCL();                // instantiate PCL
    int mode = pcl.PCL_MODE_USER_SYSTEM; // count mode
    int[] events = new int[1];          // events; array required
    long[] i_result = new long[1];      // int results; array required
    double[] fp_result = new double[1];  // fp results


    if(pcl.PCLinit(descr) != pcl.PCL_SUCCESS)
      System.out.println("problem with init");

    // test supported events
    for(event = 0; event < pcl.PCL_MAX_EVENT; ++event) {
        events[0] = event;
        if(pcl.PCLquery(descr, events, 1, mode) == pcl.PCL_SUCCESS) {
            // start counting
            if(pcl.PCLstart(descr, events,1,mode) != pcl.PCL_SUCCESS)
                System.out.println("problem with starting event");

            // test program
            matadd(a,b,c);

            // stop counting
            if(pcl.PCLstop(descr,i_result,fp_result,1) != pcl.PCL_SUCCESS)
                System.out.println("problem with stopping event");

            // print result for event i
            if(event < pcl.PCL_MFLOPS)
              // integer result
              System.out.println(pcl.PCLeventname(event)+":"+i_result[0]);
            else
              // floating point result
              System.out.println(pcl.PCLeventname(event)+":"+fp_result[0]);
```

```
          }
      }

    if(pcl.PCLexit(descr) != pcl.PCL_SUCCESS)
      System.out.println("problem with exit");
   }
}
```

3.5.4 Using the low-level Interface

Below is an example how to use low-level interface.

```
#include <pcl.h>

void do_work(){}

int main(int argc, char **argv)
{
    int res, counter_index;
    unsigned int count_mode;
    PCL_DESCR_TYPE descr;
    PCL_PROCESSOR_INFO info;
    PCL_BIT_MASK_TYPE counter_used_mask;
    PCL_DRIVER_COMMAND_TYPE commands[PCL_COUNTER_MAX];
    PCL_CNT_TYPE counter_values[PCL_COUNTER_MAX];


    /* Allocate a handle */
    if(PCLinit(&descr) != PCL_SUCCESS)
        printf("cannot get handle\n");

    /* get processor info */
    if((res = PCL_driver_info(&info)) != PCL_SUCCESS)
      printf("error on PCL_driver_info (%d)\n", res);
    else
      {
        printf("processor vendor  : %s\n", info.vendor);
        printf("processor family  : %s\n", info.family);
        printf("processor model   : %s\n", info.model);
        printf("processor speed   : %d MHz\n", info.mhz);
        printf("number of counters: >=%d\n", info.ncounters);
      }

    /* open driver */
    if((res = PCL_driver_open(descr)) != PCL_SUCCESS)
      printf("error on PCL_driver_open (%d)\n", res);

    /* This is for a DEC Alpha 21164: count FP operations */
    counter_index = 1;
    commands[counter_index] = 0x0a;

    counter_used_mask = (0x1 << counter_index);
    count_mode = PCL_MODE_USER;
    if((res = PCL_driver_start(descr, PCL_COUNTER_MAX, counter_used_mask,
       commands, count_mode)) != PCL_SUCCESS)
      printf("error on PCL_driver_start (%d)\n", res);

    /* do some work */
    do_work();

    /* read counter */
    if((res = PCL_driver_read(descr, PCL_COUNTER_MAX, counter_used_mask,
      counter_values)) != PCL_SUCCESS)
      printf("error on PCL_driver_read (%d)\n", res);
    else
      printf("%.0f floating point instructions\n",
     (double)counter_values[counter_index]);

    /* stop counting */
    if((res = PCL_driver_stop(descr)) != PCL_SUCCESS)
      printf("error on PCL_driver_stop (%d)\n", res);

    /* close driver */
    if((res = PCL_driver_close(descr)) != PCL_SUCCESS)
      printf("error on PCL_driver_close (%d)\n", res);

    /* deallocate handle */
    if(PCLexit(descr) != PCL_SUCCESS)
        printf("cannot release handle\n");

    return 0;
}
```

Chapter 4

Related Projects

In the Parallel Tools Consortium there is a subproject defined called PAPI. Its main aspect is to define an API to access all system specific hardware performance counters, i.e. to start/read out/stop all hardware performance counters on a microprocessor with all events available on that system. This is a different approach than ours as we focus on a single framework on all systems, i.e. a uniform application interface as well as a well-defined set of events accessible with uniform names on all systems. For the PerfAPI project, have a look at http://www.cs.utk.edu/ mucci/pdsa/.
There are a lot of interfaces to access performance counters on one specific system, e.g. *libperfex* on SGI systems with the R10000-processor or the *pfm*-device on Digital Unix systems (21064 or 21164 processors). To establish a common platform for performance counting on all POWER and PowerPC microprocessors, IBM has defined an application interface called PMapi. Their approach is as well, to define the set of possible events as the union of all possible events on all POWER and PowerPC microprocessors. On Linux systems, libpperf supports all Pentium, PentiumPro, and Pentium II processors through a common interface.

Chapter 5

Summary

PCL – the Performance Counter Library – is a common interface for portable performance counting on modern microprocessors. It is intended to be used by the expert application programmer who wishes to do detailed analysis on program performance, and it is intended to be used by tool writers who need a common platform to base their work on.
The application interface supports query for functionality, start and stop of performance counting and reading out the values of the performance counters. Nested calls to the functions are possible (with the same events) therefore allowing to do hierarchical performance measurements on sections and subsections of a program. Further, performance counting in user mode, system, and user-or-system mode can be distinguished. Language bindings are available for C, C++, Fortran, and Java.
PCL is available at

http://www2.inf.fh-bonn-rhein-sieg.de/∼rberre2m/PCL/

and

http://www.fz-juelich.de/zam/PCL/

.

Chapter 6

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Appendix A

Performance Counters on Microprocessors

This chapter introduces performance counting aspects of commonly used microprocessors. Each section introduces a microprocessor family and is divided into three subsections: base information on the microprocessor, performance counter events sorted by each performance counter, and in the third subsection additional comments and references to existing implementations to access the performance counters on that specific microprocessor. The second part of each section, the description of the performance counters and their events, is given for each event as follows. The first line contains an event identifier which is composed of the name of the microprocessor (e.g. *21164* for the Alpha 21164), the number of the performance counter (e.g. *C0* for counter 0), and a number giving the event number. We will refer to the whole name as a unique identifier in all chapters. The next line contains a manufacturer-specific name or definition (in italics) of the event as found in the manufacturer's literature. After that, a description of the event follows.

A.1 DEC Alpha

To use performance counters on DEC Alpha microprocessors, additional software support is necessary as the low-level interface is given in PAL-Code. Tru64 (formely Digital Unix) has the pseudo device *pfm* [2] which has a high-level interface based on *ioctl*-calls to access the performance counters. The *pfm*-device on systems distinguishes between user and system mode event counting. Only one process per CPU can open the device, but child processes can be spawned which influence the performance counters as well.
On the CRAY T3E, which uses the 21164 microprocessor too, there is no software interface published to access the performance counters.

A.1.1 DEC Alpha 21164

The RISC-processor DEC Alpha 21164 has 3 performance counters. First, let's have a closer look at the architecture of the microprocessor. The first level of caches contain an instruction (*ICACHE*) and a data cache (*DCACHE*), each having a size of 8 KB. The second level cache (*SCACHE*) has a size of 96 KB buffering instructions and data. An additional option is an external third level cache (*BCACHE*). A detailed description of the Alpha architecture can be found in [3].
The 21164 contains pipelines of the following types:

- 7-stage integer pipelines
- 9-stage floating point pipelines
- 13-stage memory reference pipeline

The performance counter part on the DEC Alpha 21164 contains 3 counters with distinct purposes. Roughly speaking, counter 0 counts machine cycles or issued instructions, counter 1 counts successful operations, and counter 2 counts unsuccessful operations. For the counters, 2, 24, and 23 different events are defined, respectively, and the counters can operate in parallel. There is one restriction that when counting certain events on counter 2, counter 1 gathers special events. The counters are 16 bit (counter 0,1) and 14 bit (counter 2) wide. The cycle counter is 64 bit wide, but only the lower 32 bits contain cycle values, the upper 32 bit are OS specific.
Events countable on the DEC Alpha 21164 are:

- **Processor Cycle Counter:**
  - 21164_PCC
    elapsed machine cycles
- **Counter 0:**
  - 21164_C0_0
    CYCLES
    machine cycles
  - 21164_C0_1
    ISSUES
    issued instructions
- **Counter 1:**
  - 21164_C1_0
    NON_ISSUE_CYCLES
    Either no instructions have been issued to the pipeline in the number of cycles, or the pipeline has been stalled for that number of cycles.
  - 21164_C1_1
    SPLIT_ISSUE_CYCLES
    Not all startable instructions have been included into the instruction pipeline.
  - 21164_C1_2
    PIPELINE_DRY
    A parallel execution of instructions was not possible.
  - 21164_C1_3
    REPLAY_TRAP
    If a started instruction could not be further processed, the instruction is issued again in the instruction pipeline, which is called a replay trap.

- 21164_C1_4
  SINGLE_ISSUE_CYCLES
  Exactly 1 instruction was issued in a cycle.
- 21164_C1_5
  DUAL_ISSUE_CYCLES
  Exactly 2 instructions were issued in a cycle.
- 21164_C1_6
  TRIPLE_ISSUE_CYCLES
  Exactly 3 instructions were issued in a cycle.
- 21164_C1_7
  QUAD_ISSUE_CYCLES
  Exactly 4 instructions were issued in a cycle.
- 21164_C1_8
  FLOW_CHANGE
  A jump instruction was executed. Conditional and unconditional jumps are distinguished.

  Remark:

  - If counter 3 counts branch-mispredictions, then branches are counted.
  - If counter 3 counts pc-mispredictions, then jsr (subroutine calls, returns) are counted.
- 21164_C1_9
  INTEGER_OPERATE
  Executed operations in the integer pipelines.
- 21164_C1_10
  FP_INSTRUCTIONS
  Executed operations in the floating point pipelines.
- 21164_C1_11
  LOAD_INSTRUCTIONS
  Executed load instructions.
- 21164_C1_12
  STORE_INSTRUCTIONS
  Executes store instructions.
- 21164_C1_13
  ICACHE_ACCESS
  Accesses to the 1st level instruction cache (ICACHE).
- 21164_C1_14
  DCACHE_ACCESS
  Accesses to the 1st level data cache (DCACHE).
- 21164_C1_15-21164_C1_21
  "CBOX1"
  Accesses to 2nd or 3rd level cache. There need to be defined additional options [3]:

  - 21164_C1_15
    SCACHE_ACCESS
    Accesses to 2nd level cache (SCACHE).
  - 21164_C1_16
    SCACHE_READ
    Read accesses to 2nd level cache (SCACHE).
  - 21164_C1_17
    SCACHE_WRITE
    Write accesses to 2nd level cache (SCACHE).
  - 21164_C1_18
    SCACHE_VICTIM
    Number of non-completed memory frees in 2nd level cache (SCACHE).
  - 21164_C1_19
    BCACHE_HIT
    Hits in 3rd level cache (BCACHE).

    * 21164_C1_20
      BCACHE_VICTIM
      Number of non-completed memory frees in 3rd level cache (SCACHE).
    * 21164_C1_21
      SYS_REQ
      Requests of additional hardware (multiprocessor system).

- **Counter 2:**
  - 21164_C2_0
    LONG_STALLS
    Number of events that instruction pipeline was blocked for more than 12 cycles.
  - 21164_C2_1
    PC_MISPR
    Program counter mispredictions.
  - 21164_C2_2
    BRANCH_MISPREDICTS
    Branch mispredictions.
  - 21164_C2_3
    ICACHE_MISSES
    Misses in the 1st level instruction cache (ICACHE).
  - 21164_C2_4
    ITB_MISSES
    Misses in instruction TLB.
  - 21164_C2_5
    DCACHE_MISSES
    Misses in 1nd level data cache (DCACHE).
  - 21164_C2_6
    DTB_MISS
    Misses in data TLB.
  - 21164_C2_7
    LOADS_MERGED
    An entry in the Miss-Address-File corresponds to a memory request.
  - 21164_C2_8
    LDU_REPLAYS
    A replay trap was triggered by a missed load operation.
  - 21164_C2_9
    WB_MAF_FULL_REPLAYS
    A replay trap was triggered by a missed write-back operation or by an inconsistency in the miss-address-file.
  - 21164_C2_10
    EXTERNAL
    A signal change at the pin ”*perf_mon_h*” occurred.
  - 21164_C2_11
    CYCLES
    Number of cycles.
  - 21164_C2_12
    MEM_BARRIER
    Executed memory barrier instructions.
  - 21164_C2_13
    LOAD_LOCKED
    A locked load instruction was executed.
  - 21164_C2_14-21164_C2_21
    ”CBOX2”
    Accesses to 2nd or 3rd level cache. There need to be defined additional options [3]:

      * 21164_C2_14
        SCACHE_MISS
        Misses on 2nd level cache.
      * 21164_C2_15
        SCACHE_READ_MISS
        Read misses on 2nd level cache.
      * 21164_C2_16
        SCACHE_WRITE_MISS
        Write misses on 2nd level cache.
      * 21164_C2_17
        SCACHE_SH_WRITE
        Number of write-operations which go to caches other than the processor-specific 2nd level cache.
      * 21164_C2_18
        SCACHE_WRITE
        Write accesses to 2nd level cache.
      * 21164_C2_19
        BCACHE_MISS
        Misses in 3rd level cache.
      * 21164_C2_20
        SYS_INV
        Requests of additional hardware to invalidate a cache line (multiprocessor).
      * 21164_C2_21
        SYS_READ_REQ
        Requests of additional hardware to read-copy a cache line (multiprocessor).

A.1.2 DEC Alpha 21264

The DEC Alpha 21264 is a four-way out-of-order-issue microprocessor that performs dynamic scheduling, register renaming, and speculative execution. There are 4 integer execution units and 2 floating-point execution units. The processor includes a 64 KB 1st level instruction cache and a 64 KB 1st level data cache. The 21264 has 2 performance counters of 20 bit width each. Counters 0 is capable of counting one of 2 different events, and counter 1 is capable of counting one of 7 different events. Therefore, the ability to do a detailled performance analysis on the 21264 is significantly reduced compared to the 21164.
Events countable on the DEC Alpha 21264 are:

- **Processor Cycle Counter:**
  - 21264_PCC
    elapsed machine cycles
- **Counter 0:**
  - AL264_0_0
    machine cycles
  - AL264_0_1
    retired instructions
- **Counter 1:**
  - 21264_C1_0
    machine cycles
  - 21264_C1_1
    retired conditional branches
  - 21264_C1_2
    retired branch mispredicts
  - 21264_C1_3
    *retired DTB single misses * 2*
  - 21264_C1_4
    retired DTB double double misses

- 21264_C1_5
  retired ITB misses
- 21264_C1_6
  retired unaligned traps
- 21264_C1_7
  replay traps

A.2 MIPS Family

The microprocessors R10000 and R12000 of MIPS are 64 Bit RISC-microprocessors with integrated performance counters.
Software support for the performance counters on R10000 processors is available either on a lower level in IRIX 6.x through the */proc* file system or on a higher level through the *perfex* library [4]. The kernel maintains data structures for 32 virtual performance counters with a size of 64 bits each. It is possible to distinguish between counting in user mode, system mode, or both. When running in user mode, performance counters are saved on context switches. For the *perfex* library, the routine *start_counters* zeroes out the internal counters, and *read_counters* stops the counters after reading them.

A.2.1 R10000

The R10000 processor has 64 physical registers and 32 logical registers. The 1st level cache is split between a data cache and an instruction cache, both of size 32 KB. The 2nd level cache can be between 512 KB and 16 MB and the cache is a unified buffer at it caches data as well as instructions. The main memory can be up to 1 TB.
The R10000 microprocessor has 2 performance counters (a description can be found at http://www.sgi.com/processors/r10k/performance.html) each capable of counting one of 16 different events. The hardware counters are 32 bit wide. The R10000 has 5 execution pipelines executing decoded instructions. There are 2 integer pipelines (*ALU1*, *ALU2*), 2 floating point pipelines (*FPU1*, *FPU2*), and 1 address pipeline (*LOAD/STORE*). The integer and floating point pipelines can operate in parallel. For a better understanding we define the two following terms:

- *issued*: An instruction was decoded and supplied to the executing unit.
- *graduated*: An execution of an instruction has finished and all instruction issued before the instruction have finished, too.

Another term to be defined is *SCTP-Logic* which is the Secondary Cache Transaction Processing Logic, which has the task to store up to 4 internally generated or 1 externally generated 2nd level cache transactions.

- **Counter 0:**
  - R10k_C0_0
    Cycles
    Machine cycles.
  - R10k_C0_1
    Instructions issued
    The counter is incremented with the sum of the following events:
    - integer operations completed at this cycle. There can be 0-2 operations each cycle.
    - floating-point-operations completed at this cycle. There can be 0-2 operations each cycle.
    - load/store operations which have been delivered in the last cycle to the address pipeline. There can be 0 or 1 each cycle.
  - R10k_C0_2
    Load/prefetch/sync/CacheOp issued
    Each of these instructions is counted when started.
  - R10k_C0_3
    Stores(including store-conditional) issued
    Each time a store operations is delivered to the address calculation unit, the counter is incremented.
  - R10k_C0_4
    Store conditional issued
    Each time a conditional store operations is delivered to the address calculation unit, the counter is incremented.
  - R10k_C0_5
    Failed store conditional
    The counter is incremented each time a conditional store failed.

  - R10k_C0_6
    Conditional Branch resolved
    Count all resolved conditional branches.
  - R10k_C0_7
    Quadwords written back from secondary cache
    Counter is incremented each time a quad-word is written from the 2nd level cache to the output buffer.
  - R10k_C0_8
    Correctable ECC errors on secondary cache data
    A correctable 1-bit ECC error occurred while reading a quadword from the 2nd level cache.
  - R10k_C0_9
    Instruction cache misses
    Misses in the instruction cache.
  - R10k_C0_10
    Secondary cache misses (instruction)
    Instruction misses in the 2nd level cache.
  - R10k_C0_11
    Secondary cache way mispredicted (instruction)
    An attempt was made to load an instruction from the 2nd level cache and the entry is marked as invalid.
  - R10k_C0_12
    External intervention requests
    Number of requests to the *SCTP-Logic* from outside of the processor (I/O devices, multiprocessor etc.) for a copy of a cache line marked as *shared*.
  - R10k_C0_13
    External invalidate requests
    Number of requests to the *SCTP-Logic* from outside of the processor (I/O devices, multiprocessor etc.) for invalidation of a cache line marked.
  - R10k_C0_14
    Functional unit completion cycles
    The counter is incremented if at least one of the functional units has completed an operations in this cycle.
  - R10k_C0_15
    Instruction graduated
    The counter is incremented with the number of instructions which have been completed in the last cycle. An integer multiplication or division increments the counter by 2.

- **Counter 1:**
  - R10k_C1_0
    Cycles
    Machine cycles.
  - R10k_C1_1
    Instructions graduated
    The counter is incremented by the number of instructions which have been completed in the last cycle. An integer multiplication and division increments by 2.
  - R10k_C1_2
    Load/prefetch/sync/CacheOp graduated
    Every completed instruction of this type is counted.
  - R10k_C1_3
    Stores (including store-conditionals) graduated
    Every completed store operation is counted.
  - R10k_C1_4
    Store conditionals graduated
    Every conditional store is counted independently of success. This is possible at most once a cycle.

  - R10k_C1_5
    Floating-point instructions graduated
    Floating point instructions completed in the last cycle (0-4 each cycle).
  - R10k_C1_6
    Quadwords written back from primary cache
    The counter is incremented by 1, if in a cycle at least one quadword is written back from the 1st level cache to the 2nd level cache.
  - R10k_C1_7
    TLB refill exceptions
    TLB misses are counted in the cycle after they occur.
  - R10k_C1_8
    Branches mispredicted
    The counter is incremented on every mispredicted branch.
  - R10k_C1_9
    Primary data cache misses
    Miss in the primary data cache.
  - R10k_C1_10
    Secondary cache misses (data)
    Miss in the secondary cache caused by a data access.
  - R10k_C1_11
    Secondary cache way mispredicted (data)
    The counter is incremented if the 2nd level cache controller tries to access the 2nd level cache after a previous access failed.
  - R10k_C1_12
    External intervention request is determined to have hit in secondary cache
    The processor got an external request for a copy of a 2nd level cache block.
  - R10k_C1_13
    External invalidate request is determined to have hit in secondary cache
    The processor got an external request to invalidate a 2nd level cache block.
  - R10k_C1_14
    Stores/prefetches with store hint to CleanExklusive secondary cache blocks
    The SCTP-logic got a request for status change of a cache line from *CleanExclusive* to *DirtyExklusive*.
  - R10k_C1_15
    Stores/prefetches with store hint to Shared secondary cache blocks
    The status of a cache line was changed from *Shared* to *DirtyExklusive*.

A.2.2 R12000

Different to the R10000, the R12000 has 4 counters each capable of counting one of 32 events. For counter 1, a trigger mechanism was included such that an event is counted by counter 1 if any of the other counters reached a certain value. Additionally, conditional counting is possible. For example, it is possible to count the number of cycles in which 4 instructions have been completed. Also, some semantic inaccuracies concerning the definition of events have been clarified [5]. An introduction to measurement and interpretation of events can be found in [6]. The counters are 32 bit wide.
The 4 counters may count any of the 32 events:

- R12k_0
  Cycles
  Machine cycles.
- R12k_1
  Decoded instructions
  Incremented by the total number of instructions decoded on the previous cycle.
- R12k_2
  Decoded loads
  Incremented when a load instruction was decoded on the previous cycle. Prefetch, cache operations, and synchronization instructions are not included.

- R12k_3
  Decoded stores
  Incremented if a store instruction was decoded on the previous cycle. Store conditionals are not included.

- R12k_4
  Mishandling table occupancy
  Incremented each cycle by the number of currently valid entries in the Miss Handling Table (MHT).

- R12k_5
  Failed store conditionals
  Incremented when a store-conditional instruction fails.

- R12k_6
  Resolved condition branches
  Incremented both when a branch is determined to have been mispredicted and when a branch is determined to have been correctly predicted.

- R12k_7
  Quadwords written back from secondary cache
  Counter is incremented each cycle a quad-word is written from the 2nd level cache to the system interface unit.

- R12k_8
  Correctable secondary cache data array ECC errors
  Incremented each cycle following the correction of a 1-bit ECC error when reading a quadword from the 2nd level cache.

- R12k_9
  Primary instruction cache misses
  Misses in the instruction cache.

- R12k_10
  Secondary instruction cache misses
  Instruction misses in the 2nd level cache.

- R12k_11
  Instruction misprediction from secondary cache way prediction table
  Incremented when the secondary cache control begins to retry an access because it hit in the unpredicted way, provided the access that initiated the access was an instruction fetch.

- R12k_12
  External interventions
  Incremented on the cycle after an intervention is entered into the Miss Handling Table, provided that the intervention is not an invalidated type.

- R12k_13
  External invalidations
  Incremented on the cycle after an intervention is entered into the Miss Handling Table, provided that the intervention is an invalidated type.

- R12k_14
  ALU/FPU progress cycles
  Incremented on the cycle after either ALU1, ALU2, FPU1, or FPU2 amrks an instruction as done.

- R12k_15
  Graduated instructions
  The counter is incremented with the number of instructions which have been completed in the last cycle. An integer multiplication or division increments the counter by 2.

- R12k_16
  Executed prefetch instruction
  Incremented on the cycle after a prefetch instruction does its tag-check, regardless of whether a data cache line refill is initiated.

- R12k_17
  Prefetch primary data cache misses
  Incremented on the cycle after a prefetch instruction does its tag-check and a refill of the corresponding data cache line is initiated.

- R12k_18
  Graduated Loads
  Incremented by the number of loads that graduated on the previous cycle. Prefetch instructions are included in this count. Up to four loads can graduate in one cycle.

- R12k_19
  Graduated Stores
  Incremented on the cycle after a store graduates. Only one store can graduate pre cycle. Store conditionals are included in this count.

- R12k_20
  Graduated store conditions
  Incremented on the cycle following the graduation of a store-conditional instruction. Both failed and successful store-conditional instructions are included in this count. So successful store-conditionals can be determined as the difference between this event and event R12k_5.

- R12k_21
  Graduated floating-point instructions
  Incremenetd by the number of floatig-point instructions that graduated on the previous cycle. There can be 0 to 4 such instructions.

- R12k_22
  Quadwords written back from primary data cache
  Incremented on each cycle that a quadword of data is valid and is written from primary data cache to secondary cache.

- R12k_23
  TLB misses
  Incremented on the cycle after the TLB miss handler is invoked.

- R12k_24
  Mispredicted branches
  Incremented on the cycle after a branch is restored because it was mispredicted.

- R12k_25
  Primary data cache misses
  Incremented one cycle after a request is entered into the SCTP logic, provided that the request was initially targeted at the primary data cache. Such requests fall into three categories: primary data cache misses, requests to change the state of secondary and primary data cache lines from clean to dirty due to stores that hit a clen line in the primary data cache, and requests initiated by cache instructions.

- R12k_26
  Secondary data cache misses
  Incremented the cycle after a refill request is sent to the system interface module of the CPU.

- R12k_27
  Data mispredictions from secondary cache way prediction table
  Incremented when the secondary cache control begins to retry an access because it hit in th eunpredicted way. The counter is incremented only if access that initiated the access was not an instruction fetch.

- R12k_28
  State of external intervention hits in secondary cache
  Set on the cycle after an external intervention is determined to have hit in the secondary cache. The value of the event is equal to the state of the secondary cache line that was hit. Setting a performance control register to select this event has a special effect on the conditional counting behavour.

- R12k_29
  State of invalidation hits in secondary cache (L2)
  Set on the cycle after an external invalidate request is determined to have hit in secondary cache. Its value is equivalent to that dscribed for event R12k_28.

- R12k_30
  Miss Handling Table entries accessing memory
  Incremented on each cycle by the number of entries in the Miss Handling Table waiting for a memory operation to complete.

- R12k_31
  Store/prefetch exclusive to shared block in secondary cache (L2)
  Incremented on the cycle after an update request is issued for a line in the secondary cache. If the line is in the clean state, the counter is incremented by one. If the line is in the shared state, the counter is incremented by two. The conditional counting mechanism can be used to select whether one, both, or neither of these events is chosen.

A.3 SUN ULTRASparc

Performance registers of UltraSPARC processors are controlled by the Performance Control Register (PCR) which can be accessed only in privileged mode. Accesses to the PIC-registers may be either in user or privileged mode, dependent on a bit in the PCR which can be changed in privileged mode. Event counting can be done either for the user mode, system mode, or both. Overflow of the counters is silently. For accurate timing, event counting should be done as taking the difference between two reads of a performance counter.
Actual versions of the Solaris operating system have support for performance counters in form of a programming interface (see man cpc).

A.3.1 UltraSPARC I/II

The UltraSPARC I/II 64-bit microprocessors of SUN have the possibility to count performance relevant events. A detailed description of the SPARC V9 architecture can be found in [7]. Both variants have 8 times 24 64-bit registers which are organized in so-called windows to optimize argument passing on subroutine calls without time-consuming copying of registers to memory. The 1st level cache has a 16 KB data (D-cache) and a 16 KB instruction cache (I-Cache). The 2nd level cache (E-cache) has a size of 512 KB up to 4 MB on UltraSPARC I, and 512 KB up to 16 MB on UltraSPARC II. The main memory can be as large as 2 TB. Another important component of the supporting logic is the *UPA*, the Universal Port Architecture, which connects several processors over a high-speed crossbar-switch.
The microprocessor contains two performance counters (PIC0, PIC1), which are able to count different events. Each counter can count one of 12 different events, two events can be counted on both counters, which sums up to a total of 22 different events [8]. The counters are 32 bit wide. Additionally, there exists a 64-bit elapsed cycle counter.

- **Tick Counter:**
  - ULTRA_TC
    elapsed machine cycles
- **Counter PIC0:**
  - ULTRA_C0_0
    Cycle_cnt
    Machine cycles.
  - ULTRA_C0_1
    Instr_cnt
    Instructions graduated.
  - ULTRA_C0_2
    Dispatch0_IC_miss
    Number of cycles waiting after a miss in the 1st level instruction cache (including handling of a follow-on E-cache miss).
  - ULTRA_C0_3
    Dispatch0_storeBuf
    Number of cycles a write buffer could not store new values (next instruction is a store instruction).
  - ULTRA_C0_4
    IC_ref
    1st level instruction cache references.
  - ULTRA_C0_5
    DC_rd
    1st level data cache read references.
  - ULTRA_C0_6
    DC_wr
    1st level data cache write references.
  - ULTRA_C0_7
    Load_use
    Number of cycles instructions are waiting on a previous load operation.

  - ULTRA_C0_8
    EC_ref
    Number of 2nd level cache references.
  - ULTRA_C0_9
    EC_write_hit_RDO
    Number of hits on 2nd level cache read accesses in a *read for ownership*-UPA-transaction.
  - ULTRA_C0_10
    EC_snoop_inv
    Number of cache line invalidations due to a UPA-transactions.
  - ULTRA_C0_11
    EC_rd_hit
    Number of E-cache read hits caused by 1st level data cache miss.

- **Counter PIC1 counts:**
  - ULTRA_C1_0
    Cycle_cnt
    Machine cycles.
  - ULTRA_C1_1
    Instr_cnt
    Instructions graduated.
  - ULTRA_C1_2
    Dispatch0_mispred
    Number of cycles waiting with an empty instruction buffer after a wrong branch prediction.
  - ULTRA_C1_3
    Dispatch0_FP_use
    Number of cycles which waits the first instruction in a group because the result of a previous floating-point operation is not available.
  - ULTRA_C1_4
    IC_hit
    Number of 1st level instruction cache hits.
  - ULTRA_C1_5
    DC_rd_hit
    Number of 1st level data cache read hits.
  - ULTRA_C1_6
    DC_wr_hit
    Number of 1st level data cache write hits.
  - ULTRA_C1_7
    Load_use_RAW
    Number of cycles load operations spent in the instruction pipeline while at the same time a read-write-inconsistency exists because of a not-completed load operation.
  - ULTRA_C1_8
    EC_hit
    Number of 2nd level cache hits.
  - ULTRA_C1_9
    EC_wb
    Number of 2nd level cache misses causing a write-back operation.
  - ULTRA_C1_10
    EC_snoop_cb
    Number of UPA-transactions which caused a copy-back of a 2nd level cache line.
  - ULTRA_C1_11
    EC_ic_hit
    Number of 2nd level cache read hits caused by a 1st level instruction cache miss.

There are hardware erratas documenting problems in counting certain events. These problems might affect events of type PCL_L2CACHE_MISS, PCL_L1DCACHE_MISS, PCL_L1ICACHE_READWRITE, PCL_L1ICACHE_HIT, PCL_L1ICACHE_MISS.

A.3.2 UltraSPARC III

The microprocessor contains two performance counters (PIC0, PIC1), each of them 32 bit wide. Additionally, there exists a 64-bit elapsed cycle counter.

- **Tick Counter:**
  - ULTRA3_TC
    elapsed machine cycles
- **Counter PIC0:**
  - ULTRA3_C0_0
    Cycle_cnt
    Machine cycles.
  - ULTRA3_C0_1
    Instr_cnt
    Instructions completed.
  - ULTRA3_C0_2
    Dispatch0_IC_miss
    Number of cycles waiting after a miss in the 1st level instruction cache (including handling of a follow-on E-cache miss).
  - ULTRA3_C0_3
    Dispatch0_br_target
    Number of cycles waiting caused by a branch target address calculation
  - ULTRA3_C0_4
    Dispatch0_2nd_br
    Number of cycles waiting caused by a refetch of a second branch
  - ULTRA3_C0_5
    RStall_storeQ
    Store queue full
  - ULTRA3_C0_6
    Rstall_IU_use
    Number of stall because integer result is not available
  - ULTRA3_C0_8
    IC_ref
    Number of references to 1st level instruction cache
  - ULTRA3_C0_9
    DC_rd
    Number of reads from 1st level data cache
  - ULTRA3_C0_10
    DC_wr
    Number of writes to 1st level data cache
  - ULTRA3_C0_12
    EC_ref
    Number of 2nd level cache (E-cache) references
  - ULTRA3_C0_13
    EC_write_hit_RTO
    E-cache hits with read-to-own bus transaction
  - ULTRA3_C0_14
    EC_snoop_inv
    Number of E-cache invalidations caused by an external snoop
  - ULTRA3_C0_15
    EC_rd_miss
    Number of E-cache read misses caused by 1st level data cache requests
  - ULTRA3_C0_16
    PC_port0_rd
    Prefetch cache read references to 1st port

- ULTRA3_C0_17
  SI_snoop
  Number of snoops from other processors
- ULTRA3_C0_18
  SI_ciq_flow
  Number of system cycles with flow control asserted from this processor
- ULTRA3_C0_19
  SI_owned
  Number of times owned_in is asserted on requests of this processor
- ULTRA3_C0_20
  SW_count_0
  Number of occurences of special sethi-instructions
- ULTRA3_C0_21
  IU_Stat_Br_miss_taken
  Number of retired branches, that were predicted to be taken but that were not taken
- ULTRA3_C0_22
  IU_Stat_Br_count_taken
  Number of retired taken branches
- ULTRA3_C0_23
  Dispatch_rs_mispred
  Number of times instruction queue is empty because of return address stack misprediction
- ULTRA3_C0_24
  FA_pipe_completion
  Number of instructions completed on Floating Point / Graphics ALU pipeline
- ULTRA3_C0_32
  MC_reads_0
  Number of completed read requests on memory bank 0
- ULTRA3_C0_33
  MC_reads_1
  Number of completed read requests on memory bank 1
- ULTRA3_C0_34
  MC_reads_2
  Number of completed read requests on memory bank 2
- ULTRA3_C0_35
  MC_reads_3
  Number of completed read requests on memory bank 3
- ULTRA3_C0_36
  MC_stalls_0
  Number of cycles memory controller was stalled because of bank busy 0
- ULTRA3_C0_37
  MC_stalls_2
  Number of cycles memory controller was stalled because of bank busy 2

• **Counter PIC1 counts:**

- ULTRA3_C1_0
  Cycle_cnt
  Machine cycles.
- ULTRA3_C1_1
  Instr_cnt
  Instructions completed.
- ULTRA3_C1_2
  Dispatch0_mispred
  Number of cycles waiting with an empty instruction buffer after a wrong branch prediction.
- ULTRA3_C1_3
  IC_miss_cancelled
  Number of I-cache misses cancelled

- ULTRA3_C1_4
  Re_endian_miss
  Number of little endian loads that were predicted to be a big-endian load
- ULTRA3_C1_5
  Re_FPU_bypass
  Number of times a FPU bypass condition occured that does not have a direct bypass pass occured
- ULTRA3_C1_6
  Re_DC_miss
  Number of 1st level data cache misses
- ULTRA3_C1_7
  Re_EC_miss
  Number of 2nd level cache misses
- ULTRA3_C1_8
  IC_miss
  Number of 1st level instructions cache misses
- ULTRA3_C1_9
  DC_rd_miss
  Number of 1st level data cache read misses
- ULTRA3_C1_10
  DC_write_miss
  Number of 1st level data cache write misses
- ULTRA3_C1_11
  Rstall_FP_use
  Number of stalls because FP results are not available
- ULTRA3_C1_12
  EC_misses
  Number of 2nd level cache misses
- ULTRA3_C1_13
  EC_wb
  Number of 2nd level cache writebacks (dirty blocks) caused by cache misses
- ULTRA3_C1_14
  EC_snoop_cb
  Number of 2nd level cache copybacks due to external snoops
- ULTRA3_C1_15
  EC_ic_miss
  Number of 2nd level cache read misses from 1st level instruction cache requests
- ULTRA3_C1_16
  Re_PC_miss
  Number of prefetch cache misses on a second load
- ULTRA3_C1_17
  ITLB_miss
  Number of misses of the instruction TLB
- ULTRA3_C1_18
  DTLB_miss
  Number of misses of the data TLB
- ULTRA3_C1_19
  WC_miss
  Number of write cache misses
- ULTRA3_C1_20
  WC_snoop_cb
  Number of write cache copybacks caused by external snoop
- ULTRA3_C1_21
  WC_scrubbed
  Number of write cache hits to clean lines

– ULTRA3_C1_22
  WC_wb_wo_read
  Number of write cache writebacks without reads

– ULTRA3_C1_24
  PC_soft_hit
  Number of software prefetched prefetch cache hits

– ULTRA3_C1_25
  PC_snoop_inv
  Number of prefetch cache invalidates generated by external snoops and internal stores

– ULTRA3_C1_26
  PC_hard_hit
  Number of hardware prefetched prefetch cache hits

– ULTRA3_C1_27
  PC_port1_rd
  Number of prefetch cache cacheable read references to 1st port

– ULTRA3_C1_28
  SW_count_1
  Number of occurences of special sethi-instructions

– ULTRA3_C1_29
  IU_Stat_Br_mis_untaken
  Number of retired braches that were predicted to be untaken but were taken

– ULTRA3_C1_30
  IU_Stat_Br_count_untaken
  Number of retired untaken branches

– ULTRA3_C1_31
  PC_MS_misses
  Number of prefetch cache address misses

– ULTRA3_C1_32
  MC_writes_0
  Number of completed write requests to memory bank 0

– ULTRA3_C1_33
  MC_writes_1
  Number of completed write requests to memory bank 1

– ULTRA3_C1_34
  MC_writes_2
  Number of completed write requests to memory bank 2

– ULTRA3_C1_35
  MC_writes_3
  Number of completed write requests to memory bank 3

– ULTRA3_C1_36
  MC_stalls_1
  Number of cycles memory controller was stalled because of bank busy 1

– ULTRA3_C1_37
  MC_stalls_3
  Number of cycles memory controller was stalled because of bank busy 3

– ULTRA3_C1_38
  Re_RAW_miss
  Number of load stalls because of stores

– ULTRA3_C1_39
  FM_pipe_completion
  Number of instructions completed on Floating Point / Graphics multiply pipeline

A.4 PowerPC

A.4.1 PowerPC 604

The PowerPC 604 has 2 performance counters.

- **Counter 1 counts:**
  - PPC604_C0_0
    PM_NOTHING
    No events counted. Register counter holds current value.
  - PPC604_C0_1
    PM_CYC
    Processor cycles are counted.
  - PPC604_C0_2
    PM_INST_CMPL
    Count the numbers of instructions completed every cycle.
  - PPC604_C0_3
    PM_TB_BIT_TRANS
    RTCSELECT bit transition. 0 = 47, 1 = 51, 2 = 55, 3 = 63 (bits from the time base lower register).
  - PPC604_C0_4
    PM_INST_DISP
    Number of instructions dispatched.
  - PPC604_C0_5
    PM_IC_MISS
    Instruction cache misses.
  - PPC604_C0_6
    PM_DTLB_MISS
    Data TLB misses (not speculative).
  - PPC604_C0_7
    PM_BR_MPRED
    Branch incorrectly predicted.
  - PPC604_C0_8
    PM_RESRV_RQ
    Number of reservations requested.
  - PPC604_C0_9
    PM_LD_MISS_EXCEED_L2
    Number of data cache load misses exceeding the threshold value with lateral L2 cache intervention.
  - PPC604_C0_10
    PM_ST_MISS_EXCEED_L2
    Number of data cache store misses exceeding the threshold value with lateral L2 cache intervention.
  - PPC604_C0_11
    PM_MTSPRS_DISP
    Number of mtspr instructions dispatched.
  - PPC604_C0_12
    PM_SYNC
    Number of sync instructions completed.
  - PPC604_C0_13
    PM_EIEIO
    Number of eieio instructions completed.
  - PPC604_C0_14
    PM_FXU_CMPL
    Number of integer instructions completed every cycle (no loads or stores).

- PPC604_C0_15
  PM_FPU_CMPL
  Number of floating-point instructions completed every cycle (no loads or stores).
- PPC604_C0_16
  PM_LS_EXEC
  LSU produced result without an exception condition.
- PPC604_C0_17
  PM_SFX1_FINISH
  SCIU1 produced result. (add, subtract, compare, rotate, shift, or logical instruction.)
- PPC604_C0_18
  PM_FPU_FINISH
  FPU produced result.
- PPC604_C0_19
  PM_LS_DISP
  Number of instructions dispatched to the LSU.
- PPC604_C0_20
  PM_SFX1_DISP
  Number of instructions dispatched to the SCIU1.
- PPC604_C0_21
  PM_FPU_DISP
  Number of instructions dispatched to the FPU.
- PPC604_C0_22
  PM_SNOOP_RECV
  Snoop requests received. Valid snoop from outside the 604. Does not know if it is a hit or miss.
- PPC604_C0_23
  PM_LD_MISS_EXCEED_NO_L2
  Number of data cache load misses exceeding the threshold value without lateral L2 intervention.
- PPC604_C0_24
  PM_ST_MISS_EXCEED_NO_L2
  Number of data cache store misses exceeding the threshold value without lateral L2 intervention.

- **Counter 2 counts:**
  - PPC604_C1_0
    PM_NOTHING
    No events counted. Register counter holds current value.
  - PPC604_C1_1
    PM_CYC
    Processor cycles 0b1. Count every cycle.
  - PPC604_C1_2
    PM_INST_CMPL
    Number of instructions completed. Legal values are 000, 001, 010, 011, 100.
  - PPC604_C1_3
    PM_TB_BIT_TRANS
    RTCSELECT bit transition. 0 = 47, 1 = 51, 2 = 55, 3 = 63 (bits from the time base lower register).
  - PPC604_C1_4
    PM_INST_DISP
    Number of instructions dispatched (0 to 4 instructions per cycle).
  - PPC604_C1_5
    PM_LD_MISS_CYC
    Number of cycles a load miss takes.
  - PPC604_C1_6
    PM_DC_MISS
    Data cache misses (in order).

- PPC604_C1_7
  PM_ITLB_MISS
  Number of instruction TLB misses.
- PPC604_C1_8
  PM_BR_CMPL
  Number of branches completed. Indicates the number of branch instructions being completed every cycle (00 = none, 10 = one, 11 = two, 01 is an illegal value).
- PPC604_C1_9
  PM_RESRV_CMPL
  Number of reservations successfully obtained (stwcx. operation completed successfully).
- PPC604_C1_10
  PM_MFSPR_DISP
  Number of mfspr instructions dispatched (in order).
- PPC604_C1_11
  PM_ICBI
  Number of icbi instructions. It may not hit in the cache.
- PPC604_C1_12
  PM_SYNCHRO_INST_CMPL
  Number of pipeline ”flushing” instructions (sc, isync, mtspr (XER), mcrxr, floating-point operation with divide by 0 or invalid operand and MSR[FE0, FE1] = 00, branch with MSR[BE] = 1, load string indexed with XER = 0, and SO bit getting set).
- PPC604_C1_13
  PM_BR_FINISH
  BPU produced result.
- PPC604_C1_14
  PM_SFX0_FINISH
  SCIU0 produced result (of an add, subtract, compare, rotate, shift, or logical instruction).
- PPC604_C1_15
  PM_CFX_FINISH
  MCIU produced result (of a multiply/divide or SPR instruction).
- PPC604_C1_16
  PM_BR_DISP
  Number of instructions dispatched to the branch unit.
- PPC604_C1_17
  PM_SFX=_DISP
  Number of instructions dispatched to the SCIU0.
- PPC604_C1_18
  PM_LD_CMPL
  Number of loads completed. These include all cache operations and tlbie, tlbsync, sync, eieio, and icbi instructions.
- PPC604_C1_19
  PM_CFX_DISP
  Number of instructions dispatched to the MCIU.
- PPC604_C1_20
  PM_SNOOP_HIT
  Number of snoop hits occurred.

A.4.2 PowerPC 604e

The PowerPC 604e is a 32-bit microprocessor with 32 32-bit integer and 32 32-bit floating point registers. The 1st level cache consists of a 32 KB data cache (D-cache) and a 32 KB instruction cache (I-cache). Different to other microprocessors, the PowerPC 604e has no on-chip logic to control a 2nd level chip but signals are available for additional cache logic [9]. Additionally, there exist performance counter events concerning the 2nd level cache. A detailed description of the PowerPC architecture can be found in [10]. The performance counters are 32 bit wide.
The pipelines of the PowerPC 604e consist of:

- a 5-stage branch unit (BPU/CRU)
- a 6-stage integer unit (SCIU1/SCIU2/MCIU)
- a 7-stage load/store unit (LSU)
- an 8-stage floating-point unit (FPU)

Sub-unit names are:

- *BPU* branch prediction unit
- *CRU* control register unit
- *SCIUx* single-cycle integer unit
- *MCIU* multiple-cycle integer unit

The PowerPC 604e has 4 performance counters (PMC1/PMC2/PMC3/PMC4) capable of counting 116 different events [11].

- **Counter PMC1 counts:**
  - PPC604e_C0_0
    000 0000 Nothing. Register counter holds current value.
    The counter keeps its current value.
  - PPC604e_C0_1
    000 0001 Processor cycles 0b1. Count every cycle.
    Number of cycles the processor executes ”0b1”.
  - PPC604e_C0_2
    000 0010 Number of instructions completed every cycle.
    Number of instructions completed each cycle.
  - PPC604e_C0_3
    000 0011 RTCSELECT bit transition. 0 = 47, 1 = 51, 2 = 55, 3 = 63 (bits from the time base lower register).
    Bit-transitions on the RTCSELECT-Pin.
  - PPC604e_C0_4
    000 0100 Number of instructions dispatched.
    Number of instructions arrived at the 3rd stage of the instruction pipeline.
  - PPC604e_C0_5
    000 0101 Instruction cache misses.
    Number of 1st level instruction cache misses.
  - PPC604e_C0_6
    000 0110 Data TLB misses (in order).
    Number of misses in the translation look-aside buffer for data.
  - PPC604e_C0_7
    000 0111 Branch misprediction correction from execute stage.
    Number of correctable branch misses in the execution phase of the 4th stage of the pipeline.
  - PPC604e_C0_8
    000 1000 Number of reservations requested. The lwarx instruction is ready for execution in the LSU.
    Number of reservations for an atomic load instruction in the LSU.
  - PPC604e_C0_9-PPC604e_C0_10
    000 1001 Number of data cache load misses exceeding the threshold value with lateral L2 cache intervention.
    000 1010 Number of data cache store misses exceeding the threshold value with lateral L2 cache intervention.
    Number of 1st level data cache misses which exceeded a limit value and additionally, L2_INT signal was active.
  - PPC604e_C0_11
    000 1011 Number of mtspr instructions dispatched.
    Number of *mtspr* instructions arrived at the 3rd stage of the pipeline.

- PPC604e_C0_12-PPC604e_C0_15
  000 1100 Number of sync instructions completed.
  000 1101 Number of eieio instructions completed.
  000 1110 Number of integer instructions completed every cycle (no loads or stores).
  000 1111 Number of floating-point instructions completed every cycle (no loads or stores).
  Number of completed mtspr/sync/eieio/integer/floating-point instructions.
- PPC604e_C0_16-PPC604e_C0_18
  001 0000 LSU produced result.
  001 0001 SCIU1 produced result for an add, subtract, compare, rotate, shift, or logical instruction.
  001 0010 FPU produced result.
  Number of results generated at the LSU/SCIU1/FPU units.
- PPC604e_C0_19-PPC604e_C0_21
  001 0011 Number of instructions dispatched to the LSU.
  001 0100 Number of instructions dispatched to the SCIU1.
  001 0101 Number of instructions dispatched to the FPU.
  Number of instructions issued from the 3rd stage of the instruction pipeline to the LSU/SCIU1/FPU unit.
- PPC604e_C0_22
  001 0110 Valid snoop requests received from outside the 604e. Does not distinguish hits or misses.
  Number of snoop requests.
- PPC604e_C0_23-PPC604e_C0_24
  001 0111 Number of data cache load misses exceeding the threshold value without lateral L2 intervention.
  001 1000 Number of data cache store misses exceeding the threshold value without lateral L2 intervention.
  Number of 1st level data cache misses which exceeded a limit value and additionally, L2_INT signal was not active.
- PPC604e_C0_25-PPC604e_C0_27
  001 1001 Number of cycles the branch unit is idle.
  001 1010 Number of cycles MCIU0 is idle.
  001 1011 Number of cycles the LSU is idle. No new instructions are executing; however, active loads or stores may be in the queues.
  Number of cycles the BPU/MCIU0/LSU units were idle.
- PPC604e_C0_28
  001 1100 Number of times the L2_INT is asserted (regardless of TA state).
  Number of times L2_INT signal was asserted.
- PPC604e_C0_29
  001 1101 Number of unaligned loads.
  Number of unaligned loads.
- PPC604e_C0_30
  001 1110 Number of entries in the load queue each cycle (maximum of five). Although the load queue has four entries, a load miss latch may hold a load waiting for data from memory.
  Number of load queue entries per cycle (max. of 5).
- PPC604e_C0_31
  001 1111 Number of instruction breakpoint hits.
  Number of times instructions hit a breakpoint.

- **Counter PMC2 counts:**
  - PPC604e_C1_0
    00 0000 Nothing. Register counter holds current value.
    The counter keeps its current value.
  - PPC604e_C1_1
    00 0001 Processor cycles 0b1. Count every cycle.
    Number of cycles the processor executes ”0b1”.

– PPC604e_C1_2
00 0010 Number of instructions completed every cycle.
Number of instructions completed every cycle.

– PPC604e_C1_3
00 0011 RTCSELECT bit transition. 0 = 47, 1 = 51, 2 = 55, 3 = 63 (bits from the time base lower register).
Number of bit transitions on the RTCSELECT-pin.

– PPC604e_C1_4
00 0100 Number of instructions dispatched.
Number of instructions dispatched to the 3rd stage of the instruction pipeline.

– PPC604e_C1_5
00 0101 Number of cycles a load miss takes.
Number of load miss cycles.

– PPC604e_C1_6
00 0110 Data cache misses (in order).
Number of 1st level data cache misses.

– PPC604e_C1_7
00 0111 Number of instruction TLB misses.
Number of misses in the translation look-aside buffer for instructions.

– PPC604e_C1_8
00 1000 Number of branches completed. Indicates the number of branch instructions being completed every cycle (00 = none, 10 = one, 11 = two, 01 is an illegal value).
Number of completed branch instructions every cycle (max. of 2).

– PPC604e_C1_9
00 1001 Number of reservations successfully obtained (stwcx. operation completed successfully).
Number of successfully completed atomic store instructions.

– PPC604e_C1_10
00 1010 Number of mfspr instructions dispatched (in order).
Number of *mfspr*-instructions arrived at the 3rd stage of the instruction pipeline.

– PPC604e_C1_11
00 1011 Number of icbi instructions. It may not hit in the cache.
Number of *icbi*-instructions without necessary hitting the cache.

– PPC604e_C1_12
00 1100 Number of pipeline "flushing" instructions (sc, isync, mtspr (XER), mcrxr, floating-point operation with divide by 0 or invalid operand and MSR[FE0, FE1] = 00, branch with MSR[BE] = 1, load string indexed with XER = 0, and SO bit getting set)
Number of instructions flushing the pipeline.

– PPC604e_C1_13-PPC604e_C1_15
00 1101 BPU produced result.
00 1110 SCIU0 produced result (of an add, subtract, compare, rotate, shift, or logical instruction).
00 1111 MCIU produced result (of a multiply/divide or SPR instruction).
Number of results produced by the BPU/SCIU0/MCIU-units.

– PPC604e_C1_16-PPC604e_C1_17
01 0000 Number of instructions dispatched to the branch unit.
01 0001 Number of instructions dispatched to the SCIU0.
Number of instructions issued from the 3rd stage of the instruction pipeline to the BPU/SCIU0-units.

– PPC604e_C1_18
01 0010 Number of loads completed. These include all cache operations and tlbie, tlbsync, sync, eieio and icbi instructions.
Number of completed load instructions.

– PPC604e_C1_19
01 0011 Number of instructions dispatched to the MCIU.
Number of instructions issued from the 3rd stage of the instruction pipeline to the MCIU-unit.

- PPC604e_C1_20
  01 0100 Number of snoop hits occurred.
  Number of snoop hits.
- PPC604e_C1_21
  01 0101 Number of cycles during which the MSR[EE] bit is cleared.
  Number of cycles during which the MSR[EE] bit is cleared.
- PPC604e_C1_22-PPC604e_C1_24
  01 0110 Number of cycles the MCIU is idle.
  01 0111 Number of cycles SCIU1 is idle.
  01 1000 Number of cycles the FPU is idle.
  Number of cycles the SCIU1/MCIU/FPU-unit is idle.
- PPC604e_C1_25
  01 1001 Number of cycles the L2_INT signal is active (regardless of TA state).
  Number of cycles the L2_INT-pin had an active level.
- PPC604e_C1_26-PPC604e_C1_30
  01 1010 Number of times four instructions were dispatched.
  01 1011 Number of times three instructions were dispatched.
  01 1100 Number of times two instructions were dispatched.
  01 1101 Number of times one instruction was dispatched.
  Number of times 1/2/3/4 instructions arrived at the 3rd stage of the instruction pipeline.
- PPC604e_C1_31
  01 1110 Number of unaligned stores.
  Number of unaligned stores.
- PPC604e_C1_32
  01 1111 Number of entries in the store queue each cycle (maximum of six).
  Number of entries in the store-queue every cycle (max. of 6).

- **Counter PMC3 counts:**
  - PPC604e_C2_0
    0 0000 Nothing. Register counter holds current value.
    The counter keeps its current value.
  - PPC604e_C2_1
    0 0001 Processor cycles 0b1. Count every cycle.
    Number of cycles the processor executes ”0b1”.
  - PPC604e_C2_2
    0 0010 Number of instructions completed every cycle.
    Number of instructions completed every cycle.
  - PPC604e_C2_3
    0 0011 RTCSELECT bit transition. 0 = 47, 1 = 51, 2 = 55, 3 = 63 (bits from the time base lower register).
    Number of bit-transitions on the RTCSELECT-pin.
  - PPC604e_C2_4
    0 0100 Number of instructions dispatched.
    Number of instructions arrived at the 3rd stage of the instruction pipeline.
  - PPC604e_C2_5-PPC604e_C2_7
    0 0101 Number of cycles the LSU stalls due to BIU or cache busy. Counts cycles between when a load or store request is made and a response was expected. For example, when a store is retried, there are four cycles before the same instruction is presented to the cache again. Cycles in between are not counted.
    0 0110 Number of cycles the LSU stalls due to a full store queue.
    0 0111 Number of cycles the LSU stalls due to operands not available in the reservation station.
    Number of cycles the LSU-unit was blocked either because the LSU-unit was busy or the cache was busy or the store queue was full or an operand was not available.
  - PPC604e_C2_8
    0 1000 Number of instructions written into the load queue. Misaligned loads are split into two transactions with the first part always written into the load queue. If both parts are cache hits, data is returned to the rename registers and the first part is flushed from the load queue. To count

the instructions that enter the load queue to stay, the misaligned load hits must be subtracted.
Number of instructions in the load queue.

- PPC604e_C2_9
  0 1001 Number of cycles that completion stalls for a store instruction.
  Number of cycles that completion stalls for a store instruction.
- PPC604e_C2_10
  0 1010 Number of cycles that completion stalls for an unfinished instruction.
  Number of cycles that completion stalls for an unfinished instruction.
- PPC604e_C2_11
  0 1011 Number of system calls.
  Number of system calls.
- PPC604e_C2_12
  0 1100 Number of cycles the BPU stalled as branch waits for its operand.
  Number of cycles the BPU waits for an operand.
- PPC604e_C2_13
  0 1101 Number of fetch corrections made at the dispatch stage. Prioritized behind the execute stage.
  Number of fetch corrections made at the 3rd stage of the instruction pipeline.
- PPC604e_C2_14
  0 1110 Number of cycles the dispatch stalls waiting for instructions.
  Number of cycles the 1st stage of the instruction pipeline waited for instructions.
- PPC604e_C2_15
  0 1111 Number of cycles the dispatch stalls due to unavailability of reorder buffer (ROB) entry. No ROB entry was available for the first non-dispatched instruction.
  Number of cycles the 1st stage of the instruction pipeline waited because the reorder buffer was not available.
- PPC604e_C2_16
  1 0000 Number of cycles the dispatch unit stalls due to no FPR rename buffer available. First non-dispatched instruction required a floating-point reorder buffer and none was available.
  Number of cycles the 1st stage of the instruction pipeline waited because the FPR-rename buffer was not available.
- PPC604e_C2_17-PPC604e_C2_18
  1 0001 Number of instruction table search operations.
  1 0010 Number of data table search operations. Completion could result from a page fault or a PTE match.
  Number of search operations in the data/instruction table.
- PPC604e_C2_19-PPC604e_C2_20
  1 0011 Number of cycles the FPU stalled.
  1 0100 Number of cycles the SCIU1 stalled.
  Number of cycles the FPU-/SCIU1-unit was blocked.
- PPC604e_C2_21
  1 0101 Number of times the BIU forwards non-critical data from the line-fill buffer.
  Number of transfers of uncritical data from the line-fill buffer done by the bus-interface unit and initiated by the BIU. to the
- PPC604e_C2_22
  1 0110 Number of data bus transactions completed with pipelining one deep with no additional bus transactions queued behind it.
  Number of completed data bus transactions without additional bus transactions queued.
- PPC604e_C2_23
  1 0111 Number of data bus transactions completed with two data bus transactions queued behind.
  Number of completed data bus transactions with two additional bus transactions queued.
- PPC604e_C2_24
  1 1000 Counts pairs of back-to-back burst reads streamed without a dead cycle between them in data streaming mode
  Number of paired *back-to-back-burst*-read accesses without intervening idle cycles.

- PPC604e_C2_25
  1 1001 Counts non-$\overline{ARTRY}$d processor kill transactions caused by a write-hit-on-shared condition
  Number of invalidated cache lines caused by a write hit to a shared line.
- PPC604e_C2_26
  1 1010 This event counts non-$\overline{ARTRY}$d write-with-kill address operations that originate from the three castout buffers. These include high-priority write-with-kill transactions caused by a snoop hit on modified data in one of the BIU's three copy-back buffers. When the cache block on a data cache miss is modified, it is queued in one of three copy-back buffers. The miss is serviced before the copy-back buffer is written back to memory as a write-with-kill transaction.
  Number of *Write-with-kill*-address operations.
- PPC604e_C2_27
  1 1011 Number of cycles when exactly two castout buffers are occupied.
  Number of cycles when exactly two castout buffers are occupied. *Castout*-buffer are used to write 1st level data cache lines to memory.
- PPC604e_C2_28
  1 1100 Number of data cache accesses retried due to occupied castout buffers.
  Number of retried 1st ;level data cache accesses due to occupied castout buffer.
- PPC604e_C2_29
  1 1101 Number of read transactions from load misses brought into the cache in a shared state.
  Number of read transactions which (after a miss) brought a 1st level cache line into the cache with a status of *shared*.
- PPC604e_C2_30
  1 1110 CRU Indicates that a CR logical instruction is being finished.
  Number of logical instructions completed in the CRU.

- **Counter PMC4 counts:**
  - PPC604e_C3_0
    0 0000 Nothing. Register counter holds current value.
    The counter keeps its current value.
  - PPC604e_C3_1
    0 0001 Processor cycles 0b1. Count every cycle.
    Number of cycles the processor executes "0b1".
  - PPC604e_C3_2
    0 0010 Number of instructions completed every cycle.
    Number of instructions every cycle.
  - PPC604e_C3_4
    0 0011 RTCSELECT bit transition. 0 = 47, 1 = 51, 2 = 55, 3 = 63 (bits from the time base lower register).
    Number of bit-transitions on the RTCSELECT-pin.
  - PPC604e_C3_5
    0 0100 Number of instructions dispatched.
    Number of instructions arrived at the 3rd stage of the instruction pipeline.
  - PPC604e_C3_6-PPC604e_C3_8
    0 0101 Number of cycles the LSU stalls due to busy MMU.
    0 0110 Number of cycles the LSU stalls due to the load queue full.
    0 0111 Number of cycles the LSU stalls due to address collision.
    Number of cycles the LSU stalled because of a busy MMU, full load queue, or address collision.
  - PPC604e_C3_9
    0 1000 Number of misaligned loads that are cache hits for both the first and second accesses.
    Number of misaligned loads that are cache hits for both the first and second accesses.
  - PPC604e_C3_10
    0 1001 Number of instructions written into the store queue.
    Number of instructions written into the store queue.
  - PPC604e_C3_11
    0 1010 Number of cycles that completion stalls for a load instruction.
    Number of cycles the completion of an instructions stalled because of a load instruction.

- PPC604e_C3_12
  0 1011 Number of hits in the BTAC. Warning-if decode buffers cannot accept new instructions, the processor re-fetches the same address multiple times.
  Number of hits in the *Branch Target Address Cache*.
- PPC604e_C3_13
  0 1100 Number of times the four basic blocks in the completion buffer from which instructions can be retired were used
  Number of times the four basic blocks in the completion buffer from which instructions can be retired were used.
- PPC604e_C3_14
  0 1101 Number of fetch corrections made at decode stage.
  Number of corrections made between the 1st and 2nd stage of the instruction pipeline.
- PPC604e_C3_15-PPC604e_C3_18
  0 1110 Number of cycles the dispatch unit stalls due to no unit available. First non-dispatched instruction requires an execution unit that is either full or a previous instruction is being dispatched to that unit.
  0 1111 Number of cycles the dispatch unit stalls due to unavailability of GPR rename buffer. First non-dispatched instruction requires a GPR reorder buffer and none are available.
  1 0000 Number of cycles the dispatch unit stalls due to no CR rename buffer available. First non-dispatched instruction requires a CR rename buffer and none is available.
  1 0001 Number of cycles the dispatch unit stalls due to CTR/LR interlock. First non-dispatched instruction could not dispatch due to CTR/LR/mtcrf interlock.
  Number of cycles spent at the 3rd stage of the instruction pipeline waiting for any of the conditions:
  - ∗ in the 4th stage of the pipeline (MCIU/SCIU0/SCIU1..) was no unit available
  - ∗ no GPR-Rename-Buffer was available
  - ∗ no CR-Rename-Buffer was available
  - ∗ the Counter- or Link-Register was locked
- PPC604e_C3_19-PPC604e_C3_20
  1 0010 Number of cycles spent doing instruction table search operations.
  1 0011 Number of cycles spent doing data table search operations.
  Number of cycles spent searching in the data/instruction table.
- PPC604e_C3_21-PPC604e_C3_22
  1 0100 Number of cycles SCIU0 was stalled.
  1 0101 Number of cycles MCIU was stalled.
  Number of cycles the MCIU/SCIU0 was stalled.
- PPC604e_C3_23
  1 0110 Number of bus cycles after an internal bus request without a qualified bus grant.
  Number of bus-cycles after an internal bus request without a qualified bus grant.
- PPC604e_C3_24
  1 0111 Number of data bus transactions completed with one data bus transaction queued behind
  Number of completed data-bus transactions with one data bus transaction queued behind.
- PPC604e_C3_25
  1 1000 Number of write data transactions that have been reordered before a previous read data transaction using the DBWO feature
  Number of write data transactions that have been reordered before a previous read data transaction.
- PPC604e_C3_26
  1 1001 Number of $\overline{ARTRY}d$ processor address bus transactions.
  Number of address bus transactions caused by a signal change at the $\overline{ARTRY}d$-pin.
- PPC604e_C3_27
  1 1010 Number of high-priority snoop pushes. Snoop transactions, except for write-with-kill, that hit modified data in the data cache cause a high-priority write (snoop push) of that modified cache block to memory. This operation has a transaction type of write-with-kill. This event counts the number of non-$\overline{ARTRY}d$ processor write-with-kill transactions that were caused by a snoop hit on modified data in the data cache. It does not count high-priority write-with-kill transactions caused by snoop hits on modified data in one of the BIU's three copy-back buffers.
  Number of high-priority snoop pushes.

- PPC604e_C3_28-PPC604e_C3_29
  1 1011 Number of cycles for which exactly one castout buffer is occupied
  1 1100 Number of cycles for which exactly three castout buffers are occupied
  Number of cycles for which exactly one/three castout buffer is/are occupied.
- PPC604e_C3_30
  1 1101 Number of read transactions from load misses brought into the cache in an exclusive (E) state
  Number of read transactions caused by a load miss and which got brought into the cache in exclusive state.
- PPC604e_C3_31
  1 1110 Number of un-dispatched instructions beyond branch
  Number of undispatched instructions beyond branch.

IBM has the PMapi library which supports access to the performance counters on different PowerPC and POWER chips. PMapi supports the distinction between supervisor mode, problem (user) mode, or both. On AIX versions 4.2 and higher, performance counter status is saved and restored on context switches.

A.4.3 POWER3

The POWER3 has 8 performance counters. Missing counter/event pairs mean an unused event for that counter. To be consistent with the numbering scheme with start numbering with POWER3_C0_xx for counter 1.

- **Counter 1 counts:**
  - POWER3_C0_0
    PM_CYC
    Processor clock cycles
  - POWER3_C0_1
    PM_INST_CMPL
    Number of instructions completed
  - POWER3_C0_2
    PM_TB_BIT_TRANS
    Selected Time Base output
  - POWER3_C0_3
    PM_INST_DISP
    Number of instructions dispatched
  - POWER3_C0_4
    PM_LD_CMPL
    Number of load instructions completed (max. 4 per cycle)
  - POWER3_C0_5
    PM_IC_MISS
    L1 I-cache miss
  - POWER3_C0_6
    PM_LD_MISS_L2HIT
    A load miss occured in L1
  - POWER3_C0_7
    PM_LD_MISS_EXCEED_NO_L2
    Thresholder counting tagged loads (no L2 intervention)
  - POWER3_C0_9
    PM_ST_MISS_EXCEED_NO_L2
    Thresholder counting a tagged store (no L2 intervention)
  - POWER3_C0_10
    PM_BURSTRD_L2MISS_W_INT
    L2 burst read miss & another processor has a modified copy
  - POWER3_C0_12
    PM_PM_IC_MISS_USED
    An icache miss line was brought in and used

- POWER3_C0_13
  PM_DU_ECAM/RCAM_OFFSET_HIT
  The ECAM/RCAM logic detected an offset hit from DU
- POWER3_C0_14
  PM_GLOBAL_CANCEL_INST_DEL
  Number of instructions deleted on global cancel
- POWER3_C0_15
  PM_CHAIN_1_TO_8
  Chain counter History Mode with PMC1[msb] chained to PMC[lsb]
- POWER3_C0_16
  PM_FPU0_BUSY
  Floating Point Unit 0 busy
- POWER3_C0_17
  PM_DSLB_MISS
  D-cache SLB miss occured
- POWER3_C0_18
  PM_TAG_ST_DISP_LSU0
  LSU0 issued a tagged store request to D-cache
- POWER3_C0_19
  PM_TLB_MISS
  TLB miss. Includes both D-cache and I-cache misses
- POWER3_C0_20
  PM_EE_OFF
  The MSR EE bit is off
- POWER3_C0_21
  PM_BRU_IDLE
  Branch Unit is idle
- POWER3_C0_22
  PM_SYNCHRO_INST
  A single instruction serialization is executing
- POWER3_C0_24
  PM_CYC_1STBUF_OCCP
  Number of cycles 1 and only 1 store buffer is occupied
- POWER3_C0_25
  PM_SNOOP_L1_M_TO_E_OR_S
  Number of snoop based L1 transitions from M to E or S
- POWER3_C0_26
  PM_ST_CMPL_BF_AT_GC
  Number of stores in the completion bffer at global cancel
- POWER3_C0_27
  PM_LINK_STACK_FULL
  Link register stack is full
- POWER3_C0_28
  PM_CBR_RESOLV_DISP
  A conditional branch was resolved at dispatch
- POWER3_C0_29
  PM_LD_CMPL_BF_AT_GC
  Numbr of loads in the completion buffer at global cancel
- POWER3_C0_30
  PM_ENTRY_CMPL_BF
  Number of entries in the completion buffer
- POWER3_C0_32
  PM_BIU_ST_RTRY6xx
  6xx master transaction retried on bus for store op

- POWER3_C0_33
  PM_EIEIO_WT_ST
  Number of cycles EIEIO stalls a store
- POWER3_C0_35
  PM_I=1_ST_TO_BUS
  Number of I=1 store operations to bus
- POWER3_C0_36
  PM_CRB_BUSY_ENT
  Number of CRB busy block entries
- POWER3_C0_37
  PM_DC_PREF_STREAM_ALLOC_BLK
  Number of D-cache prefetch data stream allocatons blocked due to four stream
- POWER3_C0_38
  PM_W=1_ST
  Number of W=1 accesses (store)
- POWER3_C0_39
  PM_LD_CI
  Number of cache inhibit (I=1) loads
- POWER3_C0_40
  PM_4MISS
  Number of cycles with 4 outstanding misses
- POWER3_C0_41
  PM_ST_GATH_BYTES
  Number of store bytes gathered
- POWER3_C0_42
  PM_DC_HIT_UNDER_MISS
  Number of D-cache hit under misses (max of 2/cycles)
- POWER3_C0_43
  PM_INTLEAVE_CONFL_STALLS
  Number of cycles a store stalls due to interleave conflict or other resource conflicts
- POWER3_C0_44
  PM_DU1_REQ_ST_ADDR_XTION_DU1
  A store address translation was requested from DU1
- POWER3_C0_45
  PM_BTC/BTL_BLK
  Number of cycles branch-to-count/branch-to-link is blocked from dispatch
- POWER3_C0_46
  PM_FPU_SUCCESS_OOO_INST_SCHE
  Number of FPU successful out-of-order instruction scheduling to both FPU units
- POWER3_C0_47
  PM_FPU_LD/ST_ISSUES
  Number of FPU loads and stores issued by LSU to DU
- POWER3_C0_48
  PM_FPU_EXEC_FPSCR_FPU
  FPU exceeded an FPSCR (count both FPUs)
- POWER3_C0_49
  PM_FPU0_EXEC_FSQRT_FPU0
  FPU0 executed an FSQRT instruction
- POWER3_C0_50
  PM_FPU0_EXEC_ESTIMATE_FPU0
  FPU0 executed Estimate instructions, FRSQRTE, FRES

- **Counter 2 counts:**
  - POWER3_C1_0
    PM_INST_CMPL
    Number of instructions completed

- POWER3_C1_1
  PM_CYC
  Processor clock cycles
- POWER3_C1_2
  PM_TB_BIT_TRANS
  Time Base bit transition
- POWER3_C1_3
  PM_INST_DISP
  Number of instructions dispatched (Max 4 per cycle)
- POWER3_C1_4
  PM_SNOOP_L2ACC
  Snooped operation which accesses L2
- POWER3_C1_5
  PM_DU0_REQ_ADDR_XTION_DU0
  A store address translation was requested from DU0
- POWER3_C1_6
  PM_TAG_BURSTRD_L2MISS
  L2 miss caused by tagged burst read
- POWER3_C1_7
  PM_FPU_IQ_FULL
  Number of cycles the FPU instruction queue is full
- POWER3_C1_8
  PM_BR_PRED
  A conditional branch was predicted
- POWER3_C1_9
  PM_ST_MISS
  Store miss occurred in L1
- POWER3_C1_10
  PM_LD_MISS_EXCEED_L2
  Thresholder counting a tagged load (with L2 intervention)
- POWER3_C1_11
  PM_L2ACC_BY_RWITM
  RWITM caused an L2 access
- POWER3_C1_12
  PM_ST_MISS_EXCEED_L2
  Store data cache misses that exceeded threshold with lateral L2 cache intervention
- POWER3_C1_13
  PM_ST_COND_FAIL
  Store conditional (stcx) instruction failed
- POWER3_C1_14
  PM_CI_STORE_WAIT_CI_STORE
  Number of cycles a cache-inhibited store waited on a cache-inhibited store
- POWER3_C1_15
  PM_CHAIN_2_TO_1
  Chain counter History Mode with PMC2[msb] chained to PMC1[lsb]
- POWER3_C1_16
  PM_TAG_BURSTRD_L2MISS_W_INT
  Tagged L2 burst read miss and another processor has a modified copy
- POWER3_C1_17
  PM_FXU2_IDLE
  FXU2 idle
- POWER3_C1_18
  PM_SC_INST
  Number of system calls

- POWER3_C1_19
  PM_DSLB_MISS
  D-cache SLB miss occurred
- POWER3_C1_20
  PM_2CASTOUT_BF
  Number of cycles 2 and only 2 store buffers are occupied
- POWER3_C1_21
  PM_BIU_LD_NORTRY
  Master generated load operation is not retried
- POWER3_C1_22
  PM_RESRV_RQ
  Number of larx executed (non speculative)
- POWER3_C1_23
  PM_SNOOP_E_TO_S
  Number of snoop-based L2 transitions from E to S
- POWER3_C1_25
  PM_IBUF_EMPTY
  Instruction buffer empty this cycle
- POWER3_C1_26
  PM_SYNC_CYC
  Number of cycles a sync instruction is at the bottom of the completion buffer
- POWER3_C1_27
  PM_TLBSYNC_CYC
  Number of cycles a tlbsync instruction is at the bottom of the completion buffer
- POWER3_C1_28
  PM_DC_PREF_L2_INV
  Number of D-cache lines invalidated in L2 due to a prefetch load data
- POWER3_C1_29
  PM_DC_PREF_FILT_1STR
  Number of cycles D-cache prefetch filter has 1 and only 1 stream entry
- POWER3_C1_30
  PM_ST_CI_PREGATH
  Number of I=1 stores (before gathering)
- POWER3_C1_31
  PM_ST_GATH_HW
  Number of store halfword gathered
- POWER3_C1_32
  PM_LD_WT_ADDR_CONF
  Number of cycles load stalls due to interleave conflict
- POWER3_C1_33
  PM_TAG_LD_DATA_RECV
  LSU1 received data from memory side
- POWER3_C1_34
  PM_FPU1_DENORM
  FPU1 received denormalized data
- POWER3_C1_35
  PM_FPU1_CMPL
  FPU1 produced a result
- POWER3_C1_36
  PM_FPU_FEST
  FPU executed Estimate instructions FRSQRTE, FRES (count both FPUs)
- POWER3_C1_37
  PM_FPU_LD
  Number of FPU loads issued by the LSU to the DU

  - POWER3_C1_38
    PM_FPU0_FDIV
    FPU0 executed a divide
  - POWER3_C1_39
    PM_FPU0_FPSCR
    FPU0 executed an FPSCR

- **Counter 3 counts:**
  - POWER3_C2_0
    PM_IC_MISS_USED
    An icache miss line was brought in and used
  - POWER3_C2_1
    PM_CYC
    Processor clock cycles
  - POWER3_C2_2
    PM_INST_CMPL
    Number of instructions completed per cycle
  - POWER3_C2_3
    PM_TB_BIT_TRANS
    Selected Time Base outputs
  - POWER3_C2_4
    PM_INST_DISP
    Number of instructions dispatched (max. 4 per cycle)
  - POWER3_C2_5
    PM_LD_MISS_L1
    A load miss occured in L1
  - POWER3_C2_6
    PM_TAG_ST_L2MISS
    Tagged RWITM caused L2 miss
  - POWER3_C2_7
    PM_BRQ_FILLED_CYC
    Number of cycles the branch queue is full
  - POWER3_C2_8
    PM_TAG_ST_L2MISS_W_INT
    Tagged L2 RWITM miss, another processor has a modified copy
  - POWER3_C2_9
    PM_ST_CMPL
    Number of store instructions completed
  - POWER3_C2_10
    PM_TAG_ST_CMPL
    Number of tagged stores completed
  - POWER3_C2_11
    PM_LD_NEXT
    LOad instruction is at the bottom of the completion buffer
  - POWER3_C2_12
    PM_ST_L2MISS
    RWITM caused L2 miss
  - POWER3_C2_13
    PM_TAG_BURSTRD_L2ACC
    Tagged burst read caused L2 access
  - POWER3_C2_14
    PM_CI_ST_WT_CI_ST
    Number of cycles a cache-inhibited store waited on a cache-inhibited store
  - POWER3_C2_15
    PM_CHAIN_3_TO_2
    Chain counter History Mode with PMC3[msb] chanied to PMC2[lsb]

- POWER3_C2_16
  PM_UNALIGNED_ST
  Number of unaligned stores (one occurence per valid unaligned store AGEN)
- POWER3_C2_17
  PM_CORE_ST_N_COPYBACK
  Number of all core-originated stores and copybacks
- POWER3_C2_18
  PM_SYNC_RERUN
  Number of sync rerun operations initiated by the master
- POWER3_C2_19
  PM_3CASTOUT_BF
  Number of cycles 3 and only 3 store buffers are occupied
- POWER3_C2_20
  PM_BIU_RETRY_DU_LOST_RES
  Number of time BIU sends a retry but DU already lost reservation (I=1 only)
- POWER3_C2_21
  PM_SNOOP_L2_E_OR_S_TO_I
  Number of snoop-based L2 transitions from E or S to I
- POWER3_C2_22
  PM_FPU_FDIV
  FPU divides executed (count both FPUs)
- POWER3_C2_24
  PM_IO_INTERPT
  Number of I/O interrupts detected
- POWER3_C2_25
  PM_DC_PREF_HIT
  Number of D-cache prefetch request and data in prefetch buffer
- POWER3_C2_26
  PM_DC_PREF_FILT_2STR
  Number of cycles D-cache prefetch filter has 2 and only 2 stream entries
- POWER3_C2_27
  PM_PREF_MATCH_DEM_MISS
  Prefetch matches a demand miss
- POWER3_C2_28
  PM_LSU1_IDLE
  LSU1 idle

- **Counter 4 counts:**
  - POWER3_C3_1
    PM_CYC
    Processor clock cycles
  - POWER3_C3_2
    PM_INST_CMPL
    Number of instructions completed
  - POWER3_C3_3
    PM_TB_BIT_TRANS
    Selected Time Base outputs
  - POWER3_C3_4
    PM_INST_DISP
    Number of instructions dispatched (Max 4 per cycle)
  - POWER3_C3_5
    PM_LD_CMPL
    Number of load instructions completed (max 4 per cycle)
  - POWER3_C3_6
    PM_FPU0_DENORM
    FPU0 received denormalized data

- POWER3_C3_7
  PM_TAG_LD_DC
  LSU0 issued a tagged load request to D-cache
- POWER3_C3_8
  PM_TAG_ST_L2ACC
  Tagged RWITM caused L2 access
- POWER3_C3_9
  PM_LSU0_LD_DATA
  LSU0 received data from memory side (L1/L2/6xx)
- POWER3_C3_10
  PM_ST_L2MISS_W_INT
  L2 RWITM miss, another processor has modified copy
- POWER3_C3_11
  PM_SYNC
  Sync request was made to the BIU
- POWER3_C3_13
  PM_FXU2_BUSY
  FXU2 was busy executing an instruction
- POWER3_C3_14
  PM_BIU_ST_NORTRY
  Master generated store operation is not retried
- POWER3_C3_15
  PM_CHAIN_4_TO_3
  Chain counter History Mode with PMC4[msb] chained to PMC3[lsb]
- POWER3_C3_16
  PM_DC_ALIAS_HIT
  ECAM/RCAM logic detected an aliased hit
- POWER3_C3_17
  PM_FXU1_IDLE
  FXU1 idle
- POWER3_C3_18
  PM_UNALIGNED_LD
  Number of unaligned loads (one occurence per valid load AGEN)
- POWER3_C3_19
  PM_CMPLU_WT_LD
  Completion unit is stalled on load operations
- POWER3_C3_20
  PM_BIU_ARI_RTRY
  A master-generated Bus operation received an ARespIn (ARI) retry
- POWER3_C3_21
  PM_FPU_FSQRT
  Number of FPU FSQRT executed (count both FPUs)
- POWER3_C3_22
  PM_BR_CMPL
  Branch completed
- POWER3_C3_23
  PM_DISP_BF_EMPTY
  Dispatch buffer is empty this cycle
- POWER3_C3_24
  PM_LNK_REG_STACK_ERR
  Link register stack error
- POWER3_C3_25
  PM_CRLU_PROD_RES
  CR logical unit produced a result

- POWER3_C3_26
  PM_TLBSYNC_RERUN
  Number of tlbsync rerun operations initiated by the master
- POWER3_C3_27
  PM_SNOOP_L2_M_TO_E_OR_S
  Number of snoop-based L2 transition from M to E or S
- POWER3_C3_29
  PM_DEM_FETCH_WT_PREF
  Number of demand fetch blocked by outstanding prefetch
- POWER3_C3_30
  PM_FPU0_EXEC_FRSP/FCONV
  FPU0 executed FRSP or FCONV

* **Counter 5 counts:**

  - POWER3_C4_1
    PM_IC_HIT
    The IC was accessed and a block was fetched
  - POWER3_C4_2
    PM_0INST_CMPL
    No instructions were completed
  - POWER3_C4_3
    PM_FPU_DENORM
    FPU sent denormalized data (count both FPUs)
  - POWER3_C4_4
    PM_BURSTRD_L2ACC
    Burst read caused L2 access
  - POWER3_C4_5
    PM_FPU0_CMPL
    FPU0 produced a result
  - POWER3_C4_6
    PM_LSU_IDLE
    LSU idle (count both LSUs)
  - POWER3_C4_7
    PM_BTAC_HITS
    Number of hits in the BTAC
  - POWER3_C4_8
    PM_STQ_FULL
    Store queue is full
  - POWER3_C4_9
    PM_BIU_WT_ST_BF
    A master-generated store operation is stalled waiting for a store buffer
  - POWER3_C4_10
    PM_SNOOP_L2_M_TO_I
    Number of snoop-based L2 transitions from M to I
  - POWER3_C4_11
    PM_FRSP/FCONV_EXEC
    Float FRSP or FCONV executed (count both FPUs)
  - POWER3_C4_12
    PM_CYC
    Processor clock cycles
  - POWER3_C4_13
    PM_BIU_ASI_RTRY
    A master-generated bus operation received a AStatIn (ASI) Retry
  - POWER3_C4_15
    PM_CHAIN_5_TO_4
    Chain Counter History mode with PMC5[msb] chained to PMC4[lsb]

  - POWER3_C4_16
    PM_DC_REQ_HIT_PREF_BUF
    Number of D-cache request hit on prefetch buffer
  - POWER3_C4_17
    PM_DC_PREF_FILT_3STR
    Number of cycles D-cache prefetch filter has 3 and only 3 stream entries
  - POWER3_C4_18
    PM_3MISS
    Number of cycles D-cache with 3 and only 3 outstanding misses
  - POWER3_C4_19
    PM_ST_GATH_WORD
    Number of Word gathered (store)
  - POWER3_C4_20
    PM_LD_WT_ST_CONF
    Number of cycles load stalls due to store conflict
  - POWER3_C4_21
    PM_LSU1_ISS_TAG_ST
    LSU1 issued a tagged store request to D-cache
  - POWER3_C4_22
    PM_FPU1_BUSY
    FPU1 was busy
  - POWER3_C4_23
    PM_FPU0_FMOV_FEST
    FPU0 executed MOVE, or EST, or FSEL
  - POWER3_C4_24
    PM_4CASTOUT_BUF
    Number of cycles 4 and only 4 castout push buffers used

- **Counter 6 counts:**
  - POWER3_C5_0
    PM_DSLB_MISS
    D-cache SLB miss occured
  - POWER3_C5_1
    PM_ST_L1HIT
    A store hit occured in L1
  - POWER3_C5_2
    PM_FXU2_PROD_RESULT
    FXU2 produced a result
  - POWER3_C5_3
    PM_BTAC_MISS
    A BTAC miss was detected
  - POWER3_C5_5
    PM_CBR_DISP
    A conditional branch was dispatched
  - POWER3_C5_6
    PM_LQ_FULL
    Miss (load) queue is full
  - POWER3_C5_8
    PM_SNOOP_PUSH_INT
    Number of snoop pushes and interventions
  - POWER3_C5_9
    PM_EE_OFF_EXT_INT_MSR
    EE bit os off and an external interrupt is pending
  - POWER3_C5_10
    PM_BIU_LD_RTRY
    A master generated load operation is retried

- POWER3_C5_11
  PM_FPU_EXE_FCMP
  Float FCMP executed (count both FPUs)
- POWER3_C5_12
  PM_CYC
  Processor clock cycles
- POWER3_C5_13
  PM_DC_PREF_BF_INV
  Number of D-cache prefetch buffer invalidates
- POWER3_C5_14
  PM_DC_PREF_FILT_4STR
  Number of cycles D-cache prefetch filter has 4 and only 4 stream entries
- POWER3_C5_15
  PM_CHAIN_6_TO_5
  Chain counter History Mode with PMC6[msb] chained to PMC5[lsb]
- POWER3_C5_16
  PM_1MISS
  Number of cycles with 1 and only 1 outstanding miss
- POWER3_C5_17
  PM_ST_GATH_DW
  Number of Doubleword gathered (stored)
- POWER3_C5_18
  PM_LSU1_ISS_TAG_LD_LSU1
  LSU1 issued a tagged load request to D-cache
- POWER3_C5_19
  PM_FPU1_IDLE
  FPU1 idle
- POWER3_C5_20
  PM_FPU0_FMA
  FPU0 executed a Multiply-Add
- POWER3_C5_21
  PM_SNOOP_PUSH_BUF
  Number of cycles snoop push buffer used

- **Counter 7 counts:**
  - POWER3_C6_0
    PM_IC_MISS
    L1 I-cache misses
  - POWER3_C6_1
    PM_FXU0_PROD_RESULT
    FXU0 produced a result
  - POWER3_C6_2
    PM_BR_DISP
    Instrs dispatched to the branch unit
  - POWER3_C6_3
    PM_MPRED_BR_CAUSED_GC
    Global cancel due to branch guessed wrong
  - POWER3_C6_4
    PM_SNOOP
    Snoop requests received
  - POWER3_C6_6
    PM_0INST_DISP
    No instructions were dipatched
  - POWER3_C6_7
    PM_FXU_IDLE
    Number of cycles the FXU units are idle

- POWER3_C6_8
  PM_6XX_RTRY_CHNG_TRTP
  Bus retried transaction that change transaction type
- POWER3_C6_9
  PM_EXEC_FMA
  Float Multiply-Adds executed (count both FPUs)
- POWER3_C6_10
  PM_ST_DISP
  Number of store instructions were dispatched
- POWER3_C6_11
  PM_CYC
  Processor clock cycles
- POWER3_C6_12
  PM_TLBSYNC_CMPLBF
  Number of cycles a tlbsync instruction is at the bottom of the completion buffer
- POWER3_C6_14
  PM_DC_PREF_L2HIT
  Number of D-cache prefetch request and data in L2
- POWER3_C6_15
  PM_CHAIN_7_TO_6
  Chain Counter History Mode with PMC7[msb] chained to PMC6[lsb]
- POWER3_C6_16
  PM_DC_PREF_BLOCK_DEMAND_MISS
  Number of cycles demand miss blocked with 1 or more prefetches outstanding
- POWER3_C6_17
  PM_2MISS
  Number of cycles with 2 and only 2 outstanding misses
- POWER3_C6_18
  PM_DC_PREF_USED
  Number of D-cache prefetch and used
- POWER3_C6_19
  PM_LSU_WT_SNOOP_BUSY
  Number of cycles load/store stall due to snoop busy
- POWER3_C6_20
  PM_IC_PREF_USED
  Number of I prefetch miss in progress changed to a normal, non-prefetch
- POWER3_C6_22
  PM_FPU0_FADD_FCMP_GMUL
  FPU0 executed an Add, Compare, Multiply, Subtract
- POWER3_C6_23
  PM_1WT_THRU_BUF_USED
  Number of cycles 1 write-through buffer used

• **Counter 8 counts:**

- POWER3_C7_0
  PM_TLB_MISS
  TLB misses. Includes both D-cache and I-cache misses
- POWER3_C7_1
  PM_SNOOP_L2HIT
  Snoop hit occured and L2 has the valid block
- POWER3_C7_2
  PM_BURSTRD_L2MISS
  A burst read caused L2 miss
- POWER3_C7_3
  PM_RESRV_CMPL
  Store conditional (stcx) instruction executed successfully

  - POWER3_C7_4
    PM_FXU1_PROD_RESULT
    FXU1 produced a result
  - POWER3_C7_5
    PM_RETRY_BUS_OP
    Retry 6xx bus operation
  - POWER3_C7_6
    PM_FPU_IDLE
    FPU idle (count both FPUs)
  - POWER3_C7_7
    PM_FETCH_CORR_AT_DISPATCH
    Fetch corrections made at dispatch stage
  - POWER3_C7_8
    PM_CMPLU_WT_ST
    Completion unit is stalled on store operations
  - POWER3_C7_9
    PM_FPU_FADD_FMUL
    Float Add, Multiply, Subtract executed (count both FPUs)
  - POWER3_C7_10
    PM_LD_DISP
    Number of load instructions dispatched (lm and lst counted as 1)
  - POWER3_C7_11
    PM_ALIGN_INT
    An alignment interrupt was executed
  - POWER3_C7_12
    PM_CYC
    Processor clock cycles
  - POWER3_C7_13
    PM_SYNC_CMPL_BF_CYC
    Number of cycles a sync instruction is at the bottom of the completion buffer
  - POWER3_C7_14
    PM_2WT_THRU_NUF_USED
    Number of cycles 2 write-through buffer used
  - POWER3_C7_15
    PM_CHAIN_8_TO_7
    Chain counter History Mode with PMC8[msb] chained to PMC6[lsb]

A.4.4 POWER3-II

The POWER3-II has 8 performance counters. Missing counter/event pairs mean an unused event for that counter. To be consistent with the numbering scheme with start numbering with POWER3II_C0_xx for counter 1.

- **Counter 1 counts:**
  - POWER3II_C0_0
    PM_CYC
    Processor clock cycles
  - POWER3II_C0_1
    PM_INST_CMPL
    Number of instructions completed
  - POWER3II_C0_2
    PM_TB_BIT_TRANS
    Selected Time Base output
  - POWER3II_C0_3
    PM_INST_DISP
    Number of instructions dispatched

– POWER3II_C0_4
  PM_LD_CMPL
  Number of load instructions completed (max. 4 per cycle)

– POWER3II_C0_5
  PM_IC_MISS
  L1 I-cache miss

– POWER3II_C0_6
  PM_LD_MISS_L2HIT
  A load miss occured in L1

– POWER3II_C0_7
  PM_LD_MISS_EXCEED_NO_L2
  Thresholder counting tagged loads (no L2 intervention)

– POWER3II_C0_9
  PM_ST_MISS_EXCEED_NO_L2
  Thresholder counting a tagged store (no L2 intervention)

– POWER3II_C0_10
  PM_BURSTRD_L2MISS_W_INT
  L2 burst read miss & another processor has a modified copy

– POWER3II_C0_12
  PM_PM_IC_MISS_USED
  An icache miss line was brought in and used

– POWER3II_C0_13
  PM_DU_ECAM/RCAM_OFFSET_HIT
  The ECAM/RCAM logic detected an offset hit from DU

– POWER3II_C0_14
  PM_GLOBAL_CANCEL_INST_DEL
  Number of instructions deleted on global cancel

– POWER3II_C0_15
  PM_CHAIN_1_TO_8
  Chain counter History Mode with PMC1[msb] chained to PMC[lsb]

– POWER3II_C0_16
  PM_FPU0_BUSY
  Floating Point Unit 0 busy

– POWER3II_C0_17
  PM_DSLB_MISS
  D-cache SLB miss occured

– POWER3II_C0_18
  PM_TAG_ST_DISP_LSU0
  LSU0 issued a tagged store request to D-cache

– POWER3II_C0_19
  PM_TLB_MISS
  TLB miss. Includes both D-cache and I-cache misses

– POWER3II_C0_20
  PM_EE_OFF
  The MSR EE bit is off

– POWER3II_C0_21
  PM_BRU_IDLE
  Branch Unit is idle

– POWER3II_C0_22
  PM_SYNCHRO_INST
  A single instruction serialization is executing

– POWER3II_C0_24
  PM_CYC_1STBUF_OCCP
  Number of cycles 1 and only 1 store buffer is occupied

- POWER3II_C0_25
  PM_SNOOP_L1_M_TO_E_OR_S
  Number of snoop based L1 transitions from M to E or S
- POWER3II_C0_26
  PM_ST_CMPL_BF_AT_GC
  Number of stores in the completion bffer at global cancel
- POWER3II_C0_27
  PM_LINK_STACK_FULL
  Link register stack is full
- POWER3II_C0_28
  PM_CBR_RESOLV_DISP
  A conditional branch was resolved at dispatch
- POWER3II_C0_29
  PM_LD_CMPL_BF_AT_GC
  Numbr of loads in the completion buffer at global cancel
- POWER3II_C0_30
  PM_ENTRY_CMPL_BF
  Number of entries in the completion buffer
- POWER3II_C0_32
  PM_BIU_ST_RTRY6xx
  6xx master transaction retried on bus for store op
- POWER3II_C0_33
  PM_EIEIO_WT_ST
  Number of cycles EIEIO stalls a store
- POWER3II_C0_35
  PM_I=1_ST_TO_BUS
  Number of I=1 store operations to bus
- POWER3II_C0_36
  PM_CRB_BUSY_ENT
  Number of CRB busy block entries
- POWER3II_C0_37
  PM_DC_PREF_STREAM_ALLOC_BLK
  Number of D-cache prefetch data stream allocatons blocked due to four stream
- POWER3II_C0_38
  PM_W=1_ST
  Number of W=1 accesses (store)
- POWER3II_C0_39
  PM_LD_CI
  Number of cache inhibit (I=1) loads
- POWER3II_C0_40
  PM_4MISS
  Number of cycles with 4 outstanding misses
- POWER3II_C0_41
  PM_ST_GATH_BYTES
  Number of store bytes gathered
- POWER3II_C0_42
  PM_DC_HIT_UNDER_MISS
  Number of D-cache hit under misses (max of 2/cycles)
- POWER3II_C0_43
  PM_INTLEAVE_CONFL_STALLS
  Number of cycles a store stalls due to interleave conflict or other resource conflicts
- POWER3II_C0_44
  PM_DU1_REQ_ST_ADDR_XTION_DU1
  A store address translation was requested from DU1

- POWER3II_C0_45
  PM_BTC/BTL_BLK
  Number of cycles branch-to-count/branch-to-link is blocked from dispatch
- POWER3II_C0_46
  PM_FPU_SUCCESS_OOO_INST_SCHE
  Number of FPU successful out-of-order instruction scheduling to both FPU units
- POWER3II_C0_47
  PM_FPU_LD/ST_ISSUES
  Number of FPU loads and stores issued by LSU to DU
- POWER3II_C0_48
  PM_FPU_EXEC_FPSCR_FPU
  FPU exceeded an FPSCR (count both FPUs)
- POWER3II_C0_49
  PM_FPU0_EXEC_FSQRT_FPU0
  FPU0 executed an FSQRT instruction
- POWER3II_C0_50
  PM_FPU0_EXEC_ESTIMATE_FPU0
  FPU0 executed Estimate instructions, FRSQRTE, FRES

- **Counter 2 counts:**

  - POWER3II_C1_0
    PM_INST_CMPL
    Number of instructions completed
  - POWER3II_C1_1
    PM_CYC
    Processor clock cycles
  - POWER3II_C1_2
    PM_TB_BIT_TRANS
    Time Base bit transition
  - POWER3II_C1_3
    PM_INST_DISP
    Number of instructions dispatched (Max 4 per cycle)
  - POWER3II_C1_4
    PM_SNOOP_L2ACC
    Snooped operation which accesses L2
  - POWER3II_C1_5
    PM_DU0_REQ_ADDR_XTION_DU0
    A store address translation was requested from DU0
  - POWER3II_C1_6
    PM_TAG_BURSTRD_L2MISS
    L2 miss caused by tagged burst read
  - POWER3II_C1_7
    PM_FPU_IQ_FULL
    Number of cycles the FPU instruction queue is full
  - POWER3II_C1_8
    PM_BR_PRED
    A conditional branch was predicted
  - POWER3II_C1_9
    PM_ST_MISS
    Store miss occurred in L1
  - POWER3II_C1_10
    PM_LD_MISS_EXCEED_L2
    Thresholder counting a tagged load (with L2 intervention)
  - POWER3II_C1_11
    PM_L2ACC_BY_RWITM
    RWITM caused an L2 access

- POWER3II_C1_12
  PM_ST_MISS_EXCEED_L2
  Store data cache misses that exceeded threshold with lateral L2 cache intervention
- POWER3II_C1_13
  PM_ST_COND_FAIL
  Store conditional (stcx) instruction failed
- POWER3II_C1_14
  PM_CI_STORE_WAIT_CI_STORE
  Number of cycles a cache-inhibited store waited on a cache-inhibited store
- POWER3II_C1_15
  PM_CHAIN_2_TO_1
  Chain counter History Mode with PMC2[msb] chained to PMC1[lsb]
- POWER3II_C1_16
  PM_TAG_BURSTRD_L2MISS_W_INT
  Tagged L2 burst read miss and another processor has a modified copy
- POWER3II_C1_17
  PM_FXU2_IDLE
  FXU2 idle
- POWER3II_C1_18
  PM_SC_INST
  Number of system calls
- POWER3II_C1_19
  PM_DSLB_MISS
  D-cache SLB miss occurred
- POWER3II_C1_20
  PM_2CASTOUT_BF
  Number of cycles 2 and only 2 store buffers are occupied
- POWER3II_C1_21
  PM_BIU_LD_NORTRY
  Master generated load operation is not retried
- POWER3II_C1_22
  PM_RESRV_RQ
  Number of larx executed (non speculative)
- POWER3II_C1_23
  PM_SNOOP_E_TO_S
  Number of snoop-based L2 transitions from E to S
- POWER3II_C1_25
  PM_IBUF_EMPTY
  Instruction buffer empty this cycle
- POWER3II_C1_26
  PM_SYNC_CYC
  Number of cycles a sync instruction is at the bottom of the completion buffer
- POWER3II_C1_27
  PM_TLBSYNC_CYC
  Number of cycles a tlbsync instruction is at the bottom of the completion buffer
- POWER3II_C1_28
  PM_DC_PREF_L2_INV
  Number of D-cache lines invalidated in L2 due to a prefetch load data
- POWER3II_C1_29
  PM_DC_PREF_FILT_1STR
  Number of cycles D-cache prefetch filter has 1 and only 1 stream entry
- POWER3II_C1_30
  PM_ST_CI_PREGATH
  Number of I=1 stores (before gathering)

- POWER3II_C1_31
  PM_ST_GATH_HW
  Number of store halfword gathered
- POWER3II_C1_32
  PM_LD_WT_ADDR_CONF
  Number of cycles load stalls due to interleave conflict
- POWER3II_C1_33
  PM_TAG_LD_DATA_RECV
  LSU1 received data from memory side
- POWER3II_C1_34
  PM_FPU1_DENORM
  FPU1 received denormalized data
- POWER3II_C1_35
  PM_FPU1_CMPL
  FPU1 produced a result
- POWER3II_C1_36
  PM_FPU_FEST
  FPU executed Estimate instructions FRSQRTE, FRES (count both FPUs)
- POWER3II_C1_37
  PM_FPU_LD
  Number of FPU loads issued by the LSU to the DU
- POWER3II_C1_38
  PM_FPU0_FDIV
  FPU0 executed a divide
- POWER3II_C1_39
  PM_FPU0_FPSCR
  FPU0 executed an FPSCR

- **Counter 3 counts:**
  - POWER3II_C2_0
    PM_IC_MISS_USED
    An icache miss line was brought in and used
  - POWER3II_C2_1
    PM_CYC
    Processor clock cycles
  - POWER3II_C2_2
    PM_INST_CMPL
    Number of instructions completed per cycle
  - POWER3II_C2_3
    PM_TB_BIT_TRANS
    Selected Time Base outputs
  - POWER3II_C2_4
    PM_INST_DISP
    Number of instructions dispatched (max. 4 per cycle)
  - POWER3II_C2_5
    PM_LD_MISS_L1
    A load miss occured in L1
  - POWER3II_C2_6
    PM_TAG_ST_L2MISS
    Tagged RWITM caused L2 miss
  - POWER3II_C2_7
    PM_BRQ_FILLED_CYC
    Number of cycles the branch queue is full
  - POWER3II_C2_8
    PM_TAG_ST_L2MISS_W_INT
    Tagged L2 RWITM miss, another processor has a modified copy

– POWER3II_C2_9
  PM_ST_CMPL
  Number of store instructions completed
– POWER3II_C2_10
  PM_TAG_ST_CMPL
  Number of tagged stores completed
– POWER3II_C2_11
  PM_LD_NEXT
  LOad instruction is at the bottom of the completion buffer
– POWER3II_C2_12
  PM_ST_L2MISS
  RWITM caused L2 miss
– POWER3II_C2_13
  PM_TAG_BURSTRD_L2ACC
  Tagged burst read caused L2 access
– POWER3II_C2_14
  PM_CI_ST_WT_CI_ST
  Number of cycles a cache-inhibited store waited on a cache-inhibited store
– POWER3II_C2_15
  PM_CHAIN_3_TO_2
  Chain counter History Mode with PMC3[msb] chanied to PMC2[lsb]
– POWER3II_C2_16
  PM_UNALIGNED_ST
  Number of unaligned stores (one occurence per valid unaligned store AGEN)
– POWER3II_C2_17
  PM_CORE_ST_N_COPYBACK
  Number of all core-originated stores and copybacks
– POWER3II_C2_18
  PM_SYNC_RERUN
  Number of sync rerun operations initiated by the master
– POWER3II_C2_19
  PM_3CASTOUT_BF
  Number of cycles 3 and only 3 store buffers are occupied
– POWER3II_C2_20
  PM_BIU_RETRY_DU_LOST_RES
  Number of time BIU sends a retry but DU already lost reservation (I=1 only)
– POWER3II_C2_21
  PM_SNOOP_L2_E_OR_S_TO_I
  Number of snoop-based L2 transitions from E or S to I
– POWER3II_C2_22
  PM_FPU_FDIV
  FPU divides executed (count both FPUs)
– POWER3II_C2_24
  PM_IO_INTERPT
  Number of I/O interrupts detected
– POWER3II_C2_25
  PM_DC_PREF_HIT
  Number of D-cache prefetch request and data in prefetch buffer
– POWER3II_C2_26
  PM_DC_PREF_FILT_2STR
  Number of cycles D-cache prefetch filter has 2 and only 2 stream entries
– POWER3II_C2_27
  PM_PREF_MATCH_DEM_MISS
  Prefetch matches a demand miss

  - POWER3II_C2_28
    PM_LSU1_IDLE
    LSU1 idle

- **Counter 4 counts:**

  - POWER3II_C3_1
    PM_CYC
    Processor clock cycles
  - POWER3II_C3_2
    PM_INST_CMPL
    Number of instructions completed
  - POWER3II_C3_3
    PM_TB_BIT_TRANS
    Selected Time Base outputs
  - POWER3II_C3_4
    PM_INST_DISP
    Number of instructions dispatched (Max 4 per cycle)
  - POWER3II_C3_5
    PM_LD_CMPL
    Number of load instructions completed (max 4 per cycle)
  - POWER3II_C3_6
    PM_FPU0_DENORM
    FPU0 received denormalized data
  - POWER3II_C3_7
    PM_TAG_LD_DC
    LSU0 issued a tagged load request to D-cache
  - POWER3II_C3_8
    PM_TAG_ST_L2ACC
    Tagged RWITM caused L2 access
  - POWER3II_C3_9
    PM_LSU0_LD_DATA
    LSU0 received data from memory side (L1/L2/6xx)
  - POWER3II_C3_10
    PM_ST_L2MISS_W_INT
    L2 RWITM miss, another processor has modified copy
  - POWER3II_C3_11
    PM_SYNC
    Sync request was made to the BIU
  - POWER3II_C3_13
    PM_FXU2_BUSY
    FXU2 was busy executing an instruction
  - POWER3II_C3_14
    PM_BIU_ST_NORTRY
    Master generated store operation is not retried
  - POWER3II_C3_15
    PM_CHAIN_4_TO_3
    Chain counter History Mode with PMC4[msb] chained to PMC3[lsb]
  - POWER3II_C3_16
    PM_DC_ALIAS_HIT
    ECAM/RCAM logic detected an aliased hit
  - POWER3II_C3_17
    PM_FXU1_IDLE
    FXU1 idle
  - POWER3II_C3_18
    PM_UNALIGNED_LD
    Number of unaligned loads (one occurence per valid load AGEN)

  - POWER3II_C3_19
    PM_CMPLU_WT_LD
    Completion unit is stalled on load operations
  - POWER3II_C3_20
    PM_BIU_ARI_RTRY
    A master-generated Bus operation received an ARespIn (ARI) retry
  - POWER3II_C3_21
    PM_FPU_FSQRT
    Number of FPU FSQRT executed (count both FPUs)
  - POWER3II_C3_22
    PM_BR_CMPL
    Branch completed
  - POWER3II_C3_23
    PM_DISP_BF_EMPTY
    Dispatch buffer is empty this cycle
  - POWER3II_C3_24
    PM_LNK_REG_STACK_ERR
    Link register stack error
  - POWER3II_C3_25
    PM_CRLU_PROD_RES
    CR logical unit produced a result
  - POWER3II_C3_26
    PM_TLBSYNC_RERUN
    Number of tlbsync rerun operations initiated by the master
  - POWER3II_C3_27
    PM_SNOOP_L2_M_TO_E_OR_S
    Number of snoop-based L2 transition from M to E or S
  - POWER3II_C3_29
    PM_DEM_FETCH_WT_PREF
    Number of demand fetch blocked by outstanding prefetch
  - POWER3II_C3_30
    PM_FPU0_EXEC_FRSP/FCONV
    FPU0 executed FRSP or FCONV

- **Counter 5 counts:**

  - POWER3II_C4_1
    PM_IC_HIT
    The IC was accessed and a block was fetched
  - POWER3II_C4_2
    PM_0INST_CMPL
    No instructions were completed
  - POWER3II_C4_3
    PM_FPU_DENORM
    FPU sent denormalized data (count both FPUs)
  - POWER3II_C4_4
    PM_BURSTRD_L2ACC
    Burst read caused L2 access
  - POWER3II_C4_5
    PM_FPU0_CMPL
    FPU0 produced a result
  - POWER3II_C4_6
    PM_LSU_IDLE
    LSU idle (count both LSUs)
  - POWER3II_C4_7
    PM_BTAC_HITS
    Number of hits in the BTAC

  - POWER3II_C4_8
    PM_STQ_FULL
    Store queue is full
  - POWER3II_C4_9
    PM_BIU_WT_ST_BF
    A master-generated store operation is stalled waiting for a store buffer
  - POWER3II_C4_10
    PM_SNOOP_L2_M_TO_I
    Number of snoop-based L2 transitions from M to I
  - POWER3II_C4_11
    PM_FRSP/FCONV_EXEC
    Float FRSP or FCONV executed (count both FPUs)
  - POWER3II_C4_12
    PM_CYC
    Processor clock cycles
  - POWER3II_C4_13
    PM_BIU_ASI_RTRY
    A master-generated bus operation received a AStatIn (ASI) Retry
  - POWER3II_C4_15
    PM_CHAIN_5_TO_4
    Chain Counter History mode with PMC5[msb] chained to PMC4[lsb]
  - POWER3II_C4_16
    PM_DC_REQ_HIT_PREF_BUF
    Number of D-cache request hit on prefetch buffer
  - POWER3II_C4_17
    PM_DC_PREF_FILT_3STR
    Number of cycles D-cache prefetch filter has 3 and only 3 stream entries
  - POWER3II_C4_18
    PM_3MISS
    Number of cycles D-cache with 3 and only 3 outstanding misses
  - POWER3II_C4_19
    PM_ST_GATH_WORD
    Number of Word gathered (store)
  - POWER3II_C4_20
    PM_LD_WT_ST_CONF
    Number of cycles load stalls due to store conflict
  - POWER3II_C4_21
    PM_LSU1_ISS_TAG_ST
    LSU1 issued a tagged store request to D-cache
  - POWER3II_C4_22
    PM_FPU1_BUSY
    FPU1 was busy
  - POWER3II_C4_23
    PM_FPU0_FMOV_FEST
    FPU0 executed MOVE, or EST, or FSEL
  - POWER3II_C4_24
    PM_4CASTOUT_BUF
    Number of cycles 4 and only 4 castout push buffers used

- **Counter 6 counts:**

  - POWER3II_C5_0
    PM_DSLB_MISS
    D-cache SLB miss occured
  - POWER3II_C5_1
    PM_ST_L1HIT
    A store hit occured in L1

- POWER3II_C5_2
  PM_FXU2_PROD_RESULT
  FXU2 produced a result
- POWER3II_C5_3
  PM_BTAC_MISS
  A BTAC miss was detected
- POWER3II_C5_5
  PM_CBR_DISP
  A conditional branch was dispatched
- POWER3II_C5_6
  PM_LQ_FULL
  Miss (load) queue is full
- POWER3II_C5_7
  PM_6XXBUS _CMPL_LOAD
  Instrunction load op completed on 6XX bus and bus op to receive instruction
- POWER3II_C5_8
  PM_SNOOP_PUSH_INT
  Number of snoop pushes and interventions
- POWER3II_C5_9
  PM_EE_OFF_EXT_INT_MSR
  EE bit os off and an external interrupt is pending
- POWER3II_C5_10
  PM_BIU_LD_RTRY
  A master generated load operation is retried
- POWER3II_C5_11
  PM_FPU_EXE_FCMP
  Float FCMP executed (count both FPUs)
- POWER3II_C5_12
  PM_CYC
  Processor clock cycles
- POWER3II_C5_13
  PM_DC_PREF_BF_INV
  Number of D-cache prefetch buffer invalidates
- POWER3II_C5_14
  PM_DC_PREF_FILT_4STR
  Number of cycles D-cache prefetch filter has 4 and only 4 stream entries
- POWER3II_C5_15
  PM_CHAIN_6_TO_5
  Chain counter History Mode with PMC6[msb] chained to PMC5[lsb]
- POWER3II_C5_16
  PM_1MISS
  Number of cycles with 1 and only 1 outstanding miss
- POWER3II_C5_17
  PM_ST_GATH_DW
  Number of Doubleword gathered (stored)
- POWER3II_C5_18
  PM_LSU1_ISS_TAG_LD_LSU1
  LSU1 issued a tagged load request to D-cache
- POWER3II_C5_19
  PM_FPU1_IDLE
  FPU1 idle
- POWER3II_C5_20
  PM_FPU0_FMA
  FPU0 executed a Multiply-Add

  - POWER3II_C5_21
    PM_SNOOP_PUSH_BUF
    Number of cycles snoop push buffer used

- **Counter 7 counts:**
  - POWER3II_C6_0
    PM_IC_MISS
    L1 I-cache misses
  - POWER3II_C6_1
    PM_FXU0_PROD_RESULT
    FXU0 produced a result
  - POWER3II_C6_2
    PM_BR_DISP
    Instrs dispatched to the branch unit
  - POWER3II_C6_3
    PM_MPRED_BR_CAUSED_GC
    Global cancel due to branch guessed wrong
  - POWER3II_C6_4
    PM_SNOOP
    Snoop requests received
  - POWER3II_C6_6
    PM_0INST_DISP
    No instructions were dipatched
  - POWER3II_C6_7
    PM_FXU_IDLE
    Number of cycles the FXU units are idle
  - POWER3II_C6_8
    PM_6XX_RTRY_CHNG_TRTP
    Bus retried transaction that change transaction type
  - POWER3II_C6_9
    PM_EXEC_FMA
    Float Multiply-Adds executed (count both FPUs)
  - POWER3II_C6_10
    PM_ST_DISP
    Number of store instructions were dispatched
  - POWER3II_C6_11
    PM_CYC
    Processor clock cycles
  - POWER3II_C6_12
    PM_TLBSYNC_CMPLBF
    Number of cycles a tlbsync instruction is at the bottom of the completion buffer
  - POWER3II_C6_14
    PM_DC_PREF_L2HIT
    Number of D-cache prefetch request and data in L2
  - POWER3II_C6_15
    PM_CHAIN_7_TO_6
    Chain Counter History Mode with PMC7[msb] chained to PMC6[lsb]
  - POWER3II_C6_16
    PM_DC_PREF_BLOCK_DEMAND_MISS
    Number of cycles demand miss blocked with 1 or more prefetches outstanding
  - POWER3II_C6_17
    PM_2MISS
    Number of cycles with 2 and only 2 outstanding misses
  - POWER3II_C6_18
    PM_DC_PREF_USED
    Number of D-cache prefetch and used

- POWER3II_C6_19
  PM_LSU_WT_SNOOP_BUSY
  Number of cycles load/store stall due to snoop busy
- POWER3II_C6_20
  PM_IC_PREF_USED
  Number of I prefetch miss in progress changed to a normal, non-prefetch
- POWER3II_C6_22
  PM_FPU0_FADD_FCMP_GMUL
  FPU0 executed an Add, Compare, Multiply, Subtract
- POWER3II_C6_23
  PM_1WT_THRU_BUF_USED
  Number of cycles 1 write-through buffer used

- **Counter 8 counts:**
  - POWER3II_C7_0
    PM_TLB_MISS
    TLB misses. Includes both D-cache and I-cache misses
  - POWER3II_C7_1
    PM_SNOOP_L2HIT
    Snoop hit occured and L2 has the valid block
  - POWER3II_C7_2
    PM_BURSTRD_L2MISS
    A burst read caused L2 miss
  - POWER3II_C7_3
    PM_RESRV_CMPL
    Store conditional (stcx) instruction executed successfully
  - POWER3II_C7_4
    PM_FXU1_PROD_RESULT
    FXU1 produced a result
  - POWER3II_C7_5
    PM_RETRY_BUS_OP
    Retry 6xx bus operation
  - POWER3II_C7_6
    PM_FPU_IDLE
    FPU idle (count both FPUs)
  - POWER3II_C7_7
    PM_FETCH_CORR_AT_DISPATCH
    Fetch corrections made at dispatch stage
  - POWER3II_C7_8
    PM_CMPLU_WT_ST
    Completion unit is stalled on store operations
  - POWER3II_C7_9
    PM_FPU_FADD_FMUL
    Float Add, Multiply, Subtract executed (count both FPUs)
  - POWER3II_C7_10
    PM_LD_DISP
    Number of load instructions dispatched (lm and lst counted as 1)
  - POWER3II_C7_11
    PM_ALIGN_INT
    An alignment interrupt was executed
  - POWER3II_C7_12
    PM_CYC
    Processor clock cycles
  - POWER3II_C7_13
    PM_SYNC_CMPL_BF_CYC
    Number of cycles a sync instruction is at the bottom of the completion buffer

- POWER3II_C7_14
  PM_2WT_THRU_NUF_USED
  Number of cycles 2 write-through buffer used
- POWER3II_C7_15
  PM_CHAIN_8_TO_7
  Chain counter History Mode with PMC8[msb] chained to PMC6[lsb]

A.5 Intel Pentium Family

A.5.1 Intel Pentium

The Intel Pentium is a 32-bit CISC microprocessor. The Pentium has 2 performance counters with most of the events countable by either of the counters and only some events countable only by a specific counter (as noted). With the introduction of the MMX-extensions, Pentium's with MMX have defined more events as stated (*MMX-extensions*). We have left out all events which are specific to the MMX functional unit as compilers normally do not generate code for this unit. The performance counters are 40 bit wide, the time stamp counter is 64 bit wide.
The Time Stamp Counter counts the elapsed machine cycles:

- Pentium_TSC
  elapsed machine cycles

The events countable by both counters are:

- Pentium_0
  00H DATA_READ
  Number of memory data read operations.

- Pentium_1
  01H DATA_WRITE
  Number of memory data write operations.

- Pentium_2
  02H DATA_TLB_MISS
  Number of misses to the data cache translation look-aside buffer.

- Pentium_3
  03H DATA_READ_MISS
  Number of memory read accesses that miss the internal data cache.

- Pentium_4
  04H DATA_WRITE_MISS
  Number of memory write accesses that miss the internal data cache.

- Pentium_5
  05H WRITE_HIT_TO_M-_OR_E-STATE_LINES
  Number of write hits to exclusive or modified lines in the data cache.

- Pentium_6
  06H DATA_CACHE_LINES_WRITTEN_BACK
  Number of dirty lines that are written back.

- Pentium_7
  07H EXTERNAL_SNOOPS
  Number of accepted external snoops.

- Pentium_8
  08H EXTERNAL_DATA_CACHE_SNOOP_HITS
  Number of external snoops to the data cache.

- Pentium_9
  09H MEMORY ACCESSES IN BOTH PIPES
  Number of data memory reads or writes that are paired in both pipes of the pipeline.

- Pentium_10
  0AH BANK CONFLICTS
  Number of actual bank conflicts.

- Pentium_11
  0BH MISALIGNED DATA MEMORY OR I/O REFERENCES
  Number of memory or I/O reads or writes that are misaligned.

- Pentium_12
  0CH CODE READ
  Number of instruction reads.
- Pentium_13
  0DH CODE TLB MISS
  Number of instruction reads that miss the code TLB.
- Pentium_14
  0EH CODE CACHE MISS
  Number of instruction reads that miss the internal code cache.
- Pentium_15
  0FH ANY SEGMENT REGISTER LOADED
  Number of writes into any segment register in real or protected mode.
- Pentium_16
  12H Branches
  Number of taken or not taken branches, including conditional branches, jumps, calls, returns, software interrupts, and interrupt returns.
- Pentium_17
  13H BTB_HITS
  Number of BTB hits that occur.
- Pentium_18
  14H TAKEN_BRANCH_OR_BTB_HIT
  Number of taken branches or BTB hits that occur.
- Pentium_19
  15H PIPELINE FLUSHES
  Number of pipeline flushes that occur.
- Pentium_20
  16H INSTRUCTIONS_EXECUTED
  Number of instructions executed (up to two per clock).
- Pentium_21
  17H INSTRUCTIONS_EXECUTED_VPIPE
  Number of instructions executed in the V_pipe. It indicated the number of instructions that were paired.
- Pentium_22
  18H BUS_CYCLE_DURATION
  Number of clocks while a bus cycle is in progress. This event measures bus use.
- Pentium_23
  19H WRITE_BUFFER_FULL_STALL_DURATION
  Number of clocks while the pipeline is stalled due to full write buffers.
- Pentium_24
  1AH WAITING_FOR_DATA_MEMORY_READ_STALL_DURATION
  Number of clocks while the pipeline is stalled while waiting for data memory reads.
- Pentium_25
  1BH STALL_ON_WRITE_TO_AN_E-_OR_M-STATE_LINE
  Number of stalls on writes to E- or M-state lines..
- Pentium_26
  1CH LOCKED_BUS_CYCLE
  Number of locked bus cycles that occur as the result of the LOCK prefix or LOCK instruction, page-table updates, and descriptor table updates.
- Pentium_27
  1DH I/O_READ_OR_WRITE_CYCLE
  Number of bus cycles directed to I/O space.

- Pentium_28
  1EH NONCACHEABLE_MEMORY_READS
  Number of non-cacheable instruction or data memory read bus cycles.

- Pentium_29
  1FH PIPELINE_AGI_STALLS
  Number of address generation interlock (AGI) stalls.

- Pentium_30
  22H FLOPS
  Number of floating-point operations that occur. Transcendental instructions consist of multiple adds and multiplies and will signal this event multiple times. Instructions generating the divide-by-zero, negative square root, special operand, or stack exceptions will not be counted. Instructions generating all other floating-point exceptions will be counted. The integer multiply instructions and other instructions which use the FPU will be counted.

- Pentium_31
  23H BREAKPOINT_MATCH_ON_DR0_REGISTER
  Number of matches on register DR0 breakpoint.

- Pentium_32
  24H BREAKPOINT_MATCH_ON_DR1_REGISTER
  Number of matches on register DR1 breakpoint.

- Pentium_33
  25H BREAKPOINT_MATCH_ON_DR2_REGISTER
  Number of matches on register DR2 breakpoint.

- Pentium_34
  26H BREAKPOINT_MATCH_ON_DR3_REGISTER
  Number of matches on register DR3 breakpoint.

- Pentium_35
  27H HARDWARE_INTERRUPTS
  Number of taken INTR and NMI interrupts.

- Pentium_36
  28H DATA_READ_OR_WRITE
  Number of memory data reads and/or writes.

- Pentium_37
  29H DATA_READ_MISS_OR_WRITE_MISS
  Number of memory read and/or write accesses that miss the internal data cache.

- **Counter-specific events:**

  - **Specific to counter 0:**

    - Pentium_C0_0
      2AH BUS_OWNERSHIP_LATENCY
      The time from LRM bus ownership request to bus ownership granted (*MMX extension*).
    - Pentium_C0_1
      2CH CACHE_M-STATE_LINE_SHARING
      Number of times a processor identified a hit to a modified line due to a memory access in the other processor (*MMX extension*).
    - Pentium_C0_2
      2DH EMMS_INSTRUCTIONS_EXECUTED
      Number of EMMS instructions executed (*MMX extension*).
    - Pentium_C0_3
      2EH BUS_UTILIZATION_DUE_TO_PROCESSOR_ACTIVITY
      Number of clocks the bus is busy due to the processor's own activity (*MMX extension*).
    - Pentium_C0_4
      30H NUMBER_OF_CYCLES_NOT_IN_HALT_STATE
      Number of cycles the processor is not idle due to HLT instruction (*MMX extension*).

    * Pentium_C0_5
      32H FLOATING_POINT_STALLS_DURATION
      Number of clocks while pipe is stalled due to a floating-point freeze (*MMX extension*).
    * Pentium_C0_6
      33H D1_STARVATION_AND_FIFO_IS_EMPTY
      Number of times D1 stage cannot issue ANY instructions since the FIFO buffer is empty (*MMX extension*).
    * Pentium_C0_7
      35H PIPELINE_FLUSHES_DUE_TO_WRONG_BRANCH_PREDICTIONS
      Number of pipeline flushes due to wrong branch predictions resolved in either the E-stage or the WB-stage (*MMX extension*).
    * Pentium_C0_8
      37H MISPREDICTED_OR_UNPREDICTED_RETURNS
      Number of returns predicted incorrectly or not predicted at all (*MMX extension*).
    * Pentium_C0_9
      39H RETURNS
      Number of returns executed (*MMX extension*).
    * Pentium_C0_10
      3AH BTB_FALSE_ENTRIES
      Number of false entries in the Branch Target Buffer (*MMX extension*).
  - **Specific to counter 1:**
    * Pentium_C1_0
      2AH BUS_OWNERSHIP_TRANSFERS
      Number of bus ownership transfers (*MMX extension*).
    * Pentium_C1_1
      2CH CACHE_LINE_SHARING
      Number of shared data lines in the L1 cache (*MMX extension*).
    * Pentium_C1_2
      2EH WRITES_TO_NONCACHEABLE_MEMORY
      Number of write accesses to non-cacheable memory (*MMX extension*).
    * Pentium_C1_3
      30H DATA_CACHE_TLB_MISS_STALL_DURATION
      Number of clocks the pipeline is stalled due to a data cache translation look-aside buffer miss (*MMX extension*).
    * Pentium_C1_4
      31H TAKEN_BRANCHES
      Number of branches taken (*MMX extension*).
    * Pentium_C1_5
      33H D1_STARVATION_AND_ONLY_ONE_INSTRUCTION_IN_FIFO
      Number of times the D1 stage issues just a single instruction since the FIFO buffer had just one instruction ready (*MMX extension*).
    * Pentium_C1_6
      35H PIPELINE_FLUSHES_DUE_TO_WRONG_BRANCH_PREDICTIONS_RESOLVED_IN_WB-STAGE
      Number of pipeline flushes due to wrong branch predictions resolved in the WB-stage (*MMX extension*).
    * Pentium_C1_7
      37H PREDICTED_RETURNS
      Number of predicted returns (*MMX extension*).
    * Pentium_C1_8
      3AH BTB_MISS_PREDICTION_ON_NOT_TAKEN_BRANCH
      Number of times the BTB predicted a not-taken branch as taken (*MMX extension*).

By default, the instructions *RDMSR* and *WRMSR* to access the performance counter registers are kernel-mode instructions (ring 0).
In [12] are software tools concerning the performance counters on Pentium-like processors described. On Linux systems, libpperf is available to access the performance counters. It was written by M. Patrick Goda and Michael S. Warren from Los Alamos National Laboratory. *libpperf* itself is based on the msr device implemented by Stephan Meyer for Linux 2.0.x and 2.1.x.

Mikael Pettersson has written a kernel patch for all recent kernel versions and a user library to access performance counters on Intel IA32-processors (see here) for the package.

A.5.2 Intel PentiumPro/Pentium II/Pentium III

To keep binary compatibility with the predecessor processors, the PentiumPro, Pentium II, and Pentium III have 8 registers, 32 bit width each. First level cache is 8 KB for instructions (ICache) and 8 KB for data (DCache) on PentiumPro, and 16 KB for both caches on Pentium II and Pentium III. As the PentiumPro, Pentium II, and Pentium III are CISC-microprocessors (complex instruction set computer), every instruction is divided internally into micro-operations (UOP's) of fixed length. Dependent on the complexity of the instruction, the instruction is divided into 1-4 UOP's.
The PentiumPro, Pentium II, and Pentium III has 2 performance counters capable of counting a total of 77 different events (at most two at a time), some of them with an additional unit mask as parameter to further subdivide the event type. Some of the events are countable only by a specific counter. The Pentium III has 4 additional events concerning Streaming SIMD Extensions. Performancxe counter registers are 40 bit wide, the time stamp counter is 64 bit wide. With special instructions it is possible to write values into the performance counter registers (WRMSR). Care has to be taken as this instruction writes only the lower 32 bits, the upper 8 bits are sign extended from bit 31. For the time stamp counter, the upper 8 bits are set to 0.
The Time Stamp Counter counts the elapsed machine cycles:

- PPro_TSC
  elapsed machine cycles

The events countable by both performance counters are:

- PPro_0
  43H DATA_MEM_REFS
  All memory references, both cacheable and non-cacheable.

- PPro_1
  45H DCU_LINES_IN
  Number of allocated lines in the 1st level data cache.

- PPro_2
  46H DCU_M_LINES_IN
  Number of allocated lines in the 1st level data cache which have the status *modified*.

- PPro_3
  47H DCU_M_LINES_OUT
  Number of evicted lines in the 1st level data cache which were marked as *modified*.

- PPro_4
  48H DCU_MISS_OUTSTANDING
  Weighted number of cycles while a 1st level data cache miss is outstanding. An access that also misses the L2 is short-changed by 2 cycles. (i.e. if counts N cycles, should be N+2 cycles.) Subsequent loads to the same cache line will not result in any additional counts. Count value not precise, but still useful.

- PPro_5
  80H IFU_IFETCH
  Number of 1st level instruction cache loads.

- PPro_6
  81H IFU_IFETCH_MISS
  Number of 1st level instruction cache misses.

- PPro_7
  85H ITLB_MISS
  Number of instruction transfer look-aside buffer misses.

- PPro_8
  86H IFU_MEM_STALL
  Number of cycles in which the instruction fetch pipe stage is stalled.

- PPro_9
  87H ILD_STALL
  Number of cycles the instruction length decoder is stalled.

- PPro_10
  28H L2_IFETCH
  Number of instruction fetches from the 2nd level cache.

- PPro_11
  29H L2_LD
  Number of data loads from the 2nd level cache.

- PPro_12
  2AH L2_ST
  Number of data stores to the 2nd level cache.

- PPro_13
  24H L2_LINES_IN
  Number of lines allocated in the 2nd level cache.

- PPro_14
  26H L2_LINES_OUT
  Number of cache lines removed from the 2nd level cache.

- PPro_15
  25H L2_M_LINES_INM
  Number of allocated cache lines in the 2nd level cache which have been modified.

- PPro_16
  27H L2_M_LINES_OUTM
  Number of modified cache lines in the 2nd level cache which have been removed.

- PPro_17
  2EH L2_RQSTS Number of requests to the 2nd level cache.

- PPro_18
  21H L2_ADS
  Number of address strobes at 2nd level cache address bus.

- PPro_19
  22H L2_DBUS_BUSY
  Number of cycles during which the data bus was busy.

- PPro_20
  23H L2_DBUS_BUSY_RD
  Number of cycles during which the data bus was busy transferring data from 2nd level cache to the processor.

- PPro_21
  62H BUS_DRDY_CLOCKS
  Number of cycles the DRDY-signal was active.

- PPro_22
  63H BUS_LOCK_CLOCKS
  Number of processor clock cycles during which the LOCK-signal is asserted.

- PPro_23
  60H BUS_REQ_OUTSTANDING
  Number of outstanding bus requests which either result out from a cacheable read request of 1st level data cache lines or a to be completed bus operation.

- PPro_24
  65H BUS_TRAN_BRD
  Number of burst read transactions.

- PPro_25
  66H BUS_TRAN_RFO
  Number of read for ownership transactions.

- PPro_26
  67H BUS_TRANS_WB
  Number of write back transactions.

- PPro_27
  68H BUS_TRAN_IFETCH
  Number of completed instruction fetch transactions.

- PPro_28
  69H BUS_TRAN_INVAL
  Number of completed bus invalidate transactions.

- PPro_29
  6AH BUS_TRAN_PWR
  Number of completed partial write transactions.

- PPro_30
  6BH BUS_TRANS_P
  Number of completed partial transactions.

- PPro_31
  6CH BUS_TRANS_IO
  Number of completed I/O transactions.

- PPro_32
  6DH BUS_TRAN_DEF
  Number of completed deferred transactions.

- PPro_33
  6EH BUS_TRAN_BURST
  Number of completed burst transactions.

- PPro_34
  70H BUS_TRAN_ANY
  Number of all completed transactions.

- PPro_35
  6FH BUS_TRAN_MEM
  Number of completed memory transactions.

- PPro_36
  64H BUS_DATA_RCV
  Number of bus clock cycles during which this processor is receiving data.

- PPro_37
  61H BUS_BNR_DRV
  Number of bus clock cycles during which this processor is driving the BNR pin.

- PPro_38
  7AH BUS_HIT_DRV
  Number of bus clock cycles during which this processor is driving the HIT pin including cycles due to snoop stalls.

- PPro_39
  7BH BUS_HITM_DRV
  Number of bus clock cycles during which this processor is driving the HITM pin including cycles due to snoop stalls.

- PPro_40
  7EH BUS_SNOOP_STALL
  Number of clock cycles during which the bus is snoop stalled.

- PPro_41
  03H LD_BLOCKS
  Number of store buffer locks.

- PPro_42
  04H SB_DRAINS
  Number of cycles in which the store buffer blocks.
- PPro_43
  05H MISALIGN_MEM_REF
  Number of misaligned data memory references.
- PPro_44
  C0H INST_RETIRED
  Number of instructions retired.
- PPro_45
  C2H UOPS_RETIRED
  Number of micro-operations retired.
- PPro_46
  D0H INST_DECODER
  Number of instructions decoded and translated to UOP's.
- PPro_47
  C8H HW_INT_RX
  Number of hardware interrupts received.
- PPro_48
  C6H CYCLES_INT_MASKED
  Number of processor cycles for which interrupts are disabled.
- PPro_49
  C7H CYCLES_INT_PENDIND_AND_MASKED
  Number of ptrocessor cycles for which interrupts are disabled and interrupts are pending.
- PPro_50
  C4H BR_INST_RETIRED
  Number of branch instructions retired.
- PPro_51
  C5H BR_MISS_PRED_RETIRED
  Number of completed but mispredicted branches.
- PPro_52
  C9H BR_TAKEN_RETIRED
  Number of completed taken branches.
- PPro_53
  CAH BR_MISS_PRED_TAKEN_RET
  Number of completed taken, but mispredicted branches.
- PPro_54
  E0H BR_INST_DECODED
  Number of decoded branch instructions.
- PPro_55
  E2H BTB_MISSES
  Number of branches that missed the BTB.
- PPro_56
  E4H BR_BOGUS
  Number of bogus branches.
- PPro_57
  E6H BACLEARS
  Number of times BACLEAR-signal is asserted.
- PPro_58
  A2H RESOURCE_STALLS
  Number of cycles during which there are resource related stalls.

- PPro_59
  D2H PARTIAL_RAT_STALLS
  Number of cycles or events for partial stalls.

- PPro_60
  06H SEGMENT_REG_LOADS
  Number of segment register loads.

- PPro_61
  79H CPU_CLK_UNHALTED
  Number of cycles during which the processor is not halted.

- PPro_62
  B0H MMX_INSTR_EXEC
  Number of MMX-instructions executed.

- PPro_63
  B3H MMX_INSTR_TYPE_EXEC
  Number of MMX-instructions executed. The further parameter unit mask specifies which category should be counted.

- PPro_64
  B1H MMX_SAT_INSTR_EXEC
  MMX saturated instructions executed.

- PPro_65
  B2H MMX_uOPS_EXEC
  Number of MMX uops executed.

- PPro_66
  CCH FP_MMX_TRANS
  Transitions from MMX instructions to FP instructions.

- PPro_67
  CDH MMX_ASSIST
  Number of MMX assists (EMMS instructions executed).

- PPro_68
  CEH MMX_INSTR_RET
  Number of MMX instructions retired.

- PPro_69
  D4H SEG_RENAME_STALLS
  Segment register renaming stalls.

- PPro_70
  D5H SEG_REG_RENAMES
  Segment registers renamed.

- PPro_71
  D6H RET_SEG_RENAMES
  Number of segement register rename events retired.

- PPro_72
  D8H EMON_SSE_INST_RETIRED
  Number of Streaming SIMD extensions retired.

- PPro_73
  D9H EMON_SSE_COMP_INST_RET
  Number of Streaming SIMD Extensions computation instructions retired.

- PPro_74
  07H EMON_SSE_PRE_DISPATCHED
  Number of prefetch/weakly ordered instructios dispatched (inclusive speculative prefetches).

- PPro_75
  4BH EMON_SSE_PRE_MISS
  Number of prefetch/weakly-ordered instructions that miss all caches.

- **Counter-specific events:**
  - **Specific to counter 0:**
    - PPro_C0_0
      C1H FLOPS
      Number of retired floating point instructions.
    - PPro_C0_1
      10H FP_COMP_OPS_EXE
      Number of floating point operations started (but which may not have been all completed.)
    - PPro_C0_2
      14H CYCLES_DIV_BUSY
      Number of cycles during which the divider is busy.
  - **Specific to counter 1:**
    - PP1_0
      11H FP_ASSIST
      Number of floating-point exception cases handled by microcode.
    - PP1_1
      12H MUL
      Number of multiplies (integer and floating-point).
    - PP1_2
      13H DIV
      Number of divides (integer and floating-point).

All of the events can be counted on PentiumPro as well as on Pentium II and Pentium III. The Pentium II and Pentium III have additional events defined mainly for MMX-extensions [13].
The same remarks as stated above in the Pentium-section concerning software environments apply to the Pentium Pro, Pentium II, and Pentium III as well.

A.5.3 Intel Pentium 4

The performance monitoring mechanism provided in the Intel Pentium 4 processors is considerably different from that provided in the P6 family and Pentium processors (and all other microprocessors). The setup mechanism and MSR layouts are different and incompatible with the P6 family and Pentium processor mechanism.
There are 3 types of registers relevant fpr performance counting:

- 45 ESCR (Event Selection Control Register) for selecting events to be monitored by speficic performance counters. Each ESCR is usually associated with a pair of PMC.
- 18 PMC (Performance Counter) organized in 9 pairs.
- 18 CCCR (Counter Configuration Contro Register) with one CCCR accociated with each performance counter

The performance counters in conjunction with the counter configuration control registers (CCCRs) are used for filtering and counting the events selected by the ESCRs. The Pentium 4 and Intel Xeon processors provide 18 performance counters organized into 9 pairs. A pair of performance counters is associated with a particular subset of events and ESCR's. Each performance counter is 40-bits wide.
The counter pairs are partitioned into four groups:

- The BPU group, includes two performance counter pairs:
  MSR_BPU_COUNTER0 and MSR_BPU_COUNTER1
  MSR_BPU_COUNTER2 and MSR_BPU_COUNTER3

- The MS group, includes two performance counter pairs:
  MSR_MS_COUNTER0 and MSR_MS_COUNTER1
  MSR_MS_COUNTER2 and MSR_MS_COUNTER3

- The FLAME group, includes two performance counter pairs:
  MSR_FLAME_COUNTER0 and MSR_FLAME_COUNTER1
  MSR_FLAME_COUNTER2 and MSR_FLAME_COUNTER3

- The IQ group, includes three performance counter pairs:
  MSR_IQ_COUNTER0 and MSR_IQ_COUNTER1
  MSR_IQ_COUNTER2 and MSR_IQ_COUNTER3
  MSR_IQ_COUNTER4 and MSR_IQ_COUNTER5

The Time Stamp Counter counts the elapsed machine cycles:

- P4_TSC
  elapsed machine cycles

The Pentium 4 has 18 performance counters. The following list shows all measurable events. Each event can only be measured on specific counter pairs, which belong to a specific counter group. To be consistent with the numbering scheme we start numbering with P4_CG0_xx for counter group 0.
Some events take more than one counter/CCCR/ESCR. See the Intel manual for the details. Therefore the 1-to-1 mapping of low-level events and counters doesn't hold for the P4 anymore.
The following short description of an event contains the hexadecimal values for the ESCR event select, ESCR event mask and the CCCR select (e.g. IOQ_allocation: Bus request type 03H (ESCR event select) 01H (ESCR event mask) 06H (CCCR select)). Below the short description a combination of event class and event name is shown. All events of a class can be combined to a new one. By an addition of the event mask values you can measure a specific combination of events (e.g. branch_retired: If you want to count all taken branches you have to combine branch taken predicted (04H) and branch taken mispredicted (08H). In order to activate both events you must write 0CH in the event mask field.).
Counter group 0 (Counter 1/2) is an exception and do not belong to the counter groups above.
Currently, the generic low level driver interface does not work with the P4.

- **Counter 1-2 counts:**
  - Event class: IOQ_allocation
    This event counts various types of transactions on the bus. A count will be generated each time a transaction is allocated into the IOQ that matches the specified mask bits. Note that requests are counted once per retry.
    * P4_CG0_0
      03H 01H 06H
      IOQ_allocation: Bus request type
    * P4_CG0_1
      03H 20H 06H
      IOQ_allocation: Count read entries
    * P4_CG0_2
      03H 40H 06H
      IOQ_allocation: Count write entries
    * P4_CG0_3
      03H 80H 06H
      IOQ_allocation: Count UC memory access entries
    * P4_CG0_4
      03H 100H 06H
      IOQ_allocation: Count WC memory access entries
    * P4_CG0_5
      03H 2000H 06H
      IOQ_allocation: Count all store requests driven by processor, as opposed to other processor or DMA
    * P4_CG0_6
      03H 4000H 06H
      IOQ_allocation: Count all requests driven by other processor or DMA
    * P4_CG0_7
      03H 8000H 06H
      IOQ_allocation: Include HW and SW prefetch requests in the count

  - Event class: BSQ_allocation
    This event counts allocations in the bus sequence unit (BSQ) according to specified mask bit encodings.
    * P4_CG0_8
      05H 00H 07H
      BSQ_allocation: request type encodings (read)
    * P4_CG0_9
      05H 01H 07H
      BSQ_allocation: request type encodings (read invalidate)
    * P4_CG0_10
      05H 02H 07H
      BSQ_allocation: request type encodings (write)
    * P4_CG0_11
      05H 03H 07H
      BSQ_allocation: request type encodings (writeback)
    * P4_CG0_12
      05H 00H 07H
      BSQ_allocation: request length encodings (0 chunks)
    * P4_CG0_13
      05H 04H 07H
      BSQ_allocation: request length encodings (1 chunk)
    * P4_CG0_14
      05H 12H 07H
      BSQ_allocation: request length encodings (8 chunks)
    * P4_CG0_15
      05H 200H 07H
      BSQ_allocation: request type is a demand
    * P4_CG0_16
      05H 00H 07H
      BSQ_allocation: memory type encodings (UC)
    * P4_CG0_17
      05H 800H 07H
      BSQ_allocation: memory type encodings (USWC)
    * P4_CG0_18
      05H 2000H 07H
      BSQ_allocation: memory type encodings (WT)
    * P4_CG0_19
      05H 2800H 07H
      BSQ_allocation: memory type encodings (WP)
    * P4_CG0_20
      05H 3000H 07H
      BSQ_allocation: memory type encodings (WB)

- **Counter 1-4 counts:**
  - Event class: BPU_fetch_request
    This event counts instruction fetch requests of specified request type by the branch prediction unit.
    * P4_CG1_0
      03H 01H 00H
      BPU_fetch_request: Trace cache lookup miss
  - Event class: ITLB_reference
    This event counts translations using the instruction translation lookaside buffer.
    * P4_CG1_1
      18H 01H 03H
      ITLB_reference: ITLB hit
    * P4_CG1_2
      18H 02H 03H
      ITLB_reference: ITLB miss

    * P4_CG1_3
      18H 04H 03H
      ITLB_reference: Uncacheable ITLB hit

- Event class: MOB_load_replay
  This event triggers if the memory order buffer caused a load operation to be replayed.
    * P4_CG1_4
      03H 02H 02H
      MOB_LOAD_replay: Replayed because of unknown store address
    * P4_CG1_5
      03H 04H 02H
      MOB_LOAD_replay: Replayed because of unknown store data
    * P4_CG1_6
      03H 08H 02H
      MOB_LOAD_replay: Replayed because of partially overlapped data access between the load and store operations
    * P4_CG1_7
      03H 10H 02H
      MOB_LOAD_replay: Replayed because the lower four bits of the linear address do not match between the load and store operations
- Event class: page_walk_type
  This event counts various types of page walks that the page miss handler (PMH) performs.
    * P4_CG1_8
      01H 01H 04H
      page_walk_type: Page walk for a data TLB miss (either load or store)
    * P4_CG1_9
      01H 02H 04H
      page_walk_type: Page walk for an instruction page miss
- Event class: BSQ_2ndL_cache_reference
  This event counts second level cache references as seen by the bus unit.
    * P4_CG1_10
      0CH 01H 07H
      BSQ_2ndL_cache_reference: Read 2nd level cache hit (shared)
    * P4_CG1_11
      0CH 02H 07H
      BSQ_2ndL_cache_reference: Read 2nd level cache hit (exclusive)
    * P4_CG1_12
      0CH 04H 07H
      BSQ_2ndL_cache_reference: Read 2nd level cache hit (modified)
    * P4_CG1_13
      0CH 100H 07H
      BSQ_2ndL_cache_reference: Read 2nd level cache miss
    * P4_CG1_14
      0CH 400H 07H
      BSQ_2ndL_cache_reference: Write 2nd level cache miss
- Event class: FSB_data_activity
  This event increments once for each DRDY or DBSY event that occurs on the front side bus.
    * P4_CG1_15
      17H 01H 06H
      FSB_data_activity: Count DRDY event that we drive
    * P4_CG1_16
      17H 02H 06H
      FSB_data_activity: Count DRDY event sampled that we own
    * P4_CG1_17
      17H 04H 06H
      FSB_data_activity: Count DRDY event driven by the chipset or a another processor

  * P4_CG1_18
    17H 08H 06H
    FSB_data_activity: Count DBSY event that we drive
  * P4_CG1_19
    17H 10H 06H
    FSB_data_activity: Count DBSY event sampled that we own
  * P4_CG1_20
    17H 20H 06H
    FSB_data_activity: Count DBSY event driven by the chipset or a another processor

- **Counter 5-8 counts:**
  - Event class: TC_deliver_mode
    This event counts the duration (in clock cycles) of the trace cache operating modes.
    * P4_CG2_0
      01H 04H 01H
      TC_deliver_mode: TC is delivering traces
    * P4_CG2_1
      01H 20H 01H
      TC_deliver_mode: TC is building traces while encoding instructions

- **Counter 9-12 counts:**
  - Event class: memory_cancel
    This event counts the canceling of various type of requests the data cache address control unit (DAC).
    * P4_CG3_0
      02H 04H 05H
      memory_cancel: replayed because no store request buffer is available
    * P4_CG3_1
      02H 80H 05H
      memory_cancel: replayed due to missing from all onchip caches
  - Event class: memory_complete
    This event counts the completion of a load split, store split, uncacheable split or UC load.
    * P4_CG3_2
      08H 01H 02H
      memory_complete: load split completed, excluding UC, WC loads
    * P4_CG3_3
      08H 02H 02H
      memory_complete: any split store completed
  - Event class: load_port_replay
    This event counts replayed events at the load port.
    * P4_CG3_4
      04H 02H 02H
      load_port_replay: split load
    * P4_CG3_5
      05H 02H 02H
      load_port_replay: split store
  - Event class: SSE_input_assist
    This event counts the number of times an assist is requestet to handle problems with input operands for SSE and SSE2 operation.
    * P4_CG3_6
      34H 8000H 02H
      SSE_input_assist: count assists for all SSE and SSE2 ops
  - Event class: packed_SP_uop
    This event increments for each packed single-precision op.

    - P4_CG3_7
      08H 8000H 01H
      packed_SP_uop: count all ops operating on packed single-precision operands
  - Event class: packed_DP_uop
    This event increments for each packed double-precision op, specified through the event mask for detection.
    - P4_CG3_8
      0CH 8000H 01H
      packed_DP_uop: count all ops operating on packed double-precision operands
  - Event class: scalar_SP_uop
    This event increments for each scalar singe-precicion op.
    - P4_CG3_9
      0AH 8000H 01H
      scalar_SP_uop: count all ops operating on scalar single-precision operands
  - Event class: scalar_DP_uop
    This event increments for each scalar double-precicion op.
    - P4_CG3_10
      0EH 8000H 01H
      scalar_DP_uop: count all ops operating on scalar double-precision operands
  - Event class: 64bit_MMX_uop
    This event counts all ops operationg on 64bit SIMD integer operands in memory or MMX registers.
    - P4_CG3_11
      02H 8000H 01H
      64bit_MMX_uop: count all ops operating on 64bit SIMD integer operands in memeory or MMX registers
  - Event class: 128bit_MMX_uop
    This event counts all ops operationg on 128bit SIMD integer operands in memory or MMX registers.
    - P4_CG3_12
      1AH 8000H 01H
      128bit_MMX_uop: count all ops operating on 128bit SIMD integer operands in memeory or MMX registers
  - Event class: x87_FP_uop
    This event increments for each x87 floating point op.
    - P4_CG3_13
      04H 8000H 01H
      x87_FP_uop: count all x87 floating point ops
  - Event class: x87_SIMD_moves_uop
    This event incements for each x87, MMX, SSE or SSE2 op related to load data, store data, or register-to-register moves.
    - P4_CG3_14
      2EH 08H 01H
      x87_SIMD_moves_uop: count all x87/SIMD store/moves op
    - P4_CG3_15
      2EH 10H 01H
      x87_SIMD_moves_uop: count all x87/SIMD load op

- **Counter 13-18 counts:**
  - Event class: branch_retired
    This event counts the retirement of a branch.
    - P4_CG4_0
      06H 01H 05H
      branch_retired: branch not-taken predicted

    - P4_CG4_1
      06H 02H 05H
      branch_retired: branch not-taken mispredicted
    - P4_CG4_2
      06H 04H 05H
      branch_retired: branch taken predicted
    - P4_CG4_3
      06H 08H 05H
      branch_retired: branch taken mispredicted

  - Event class: mispred_branch_retired
    This event represents the retirement of mispredicted IA32 branch instructions.
    - P4_CG4_4
      03H 01H 04H
      mispred_branch_retired: the retired instruction is not bogus

  - Event class: x87_assist
    This event counts the retirement of x87 instruction that required special handling.
    - P4_CG4_5
      03H 01H 05H
      x87_assist: handle FP stack underflow
    - P4_CG4_6
      03H 02H 05H
      x87_assist: handle FP stack overflow
    - P4_CG4_7
      03H 04H 05H
      x87_assist: handle x87 output overflow
    - P4_CG4_8
      03H 08H 05H
      x87_assist: handle x87 output underflow
    - P4_CG4_9
      03H 10H 05H
      x87_assist: handle x87 input assist

  - Event class: machine_clear
    This event increments according to the mask bit specified while the entire pipline of the machine is cleared.
    - P4_CG4_10
      02H 01H 05H
      machine_clear: counts for a portion of the many cycles while the machine is cleared for any cause
    - P4_CG4_11
      02H 02H 05H
      machine_clear: increments each time the machine is cleared due to memory ordering issues

  - Event class: front_end_event
    This event counts the retirement of tagged ops which are specified through the front end tagging mechanism.
    - P4_CG4_12
      08H 01H 05H
      front_end_event: the marked ops are not bogus
    - P4_CG4_13
      08H 02H 05H
      front_end_event: the marked ops are bogus

  - Event class: execution_event
    This event counts the retirement of tagged ops which are specified through the execution tagging mechanism.
    - P4_CG4_14
      0CH 0FH 05H
      execution_event: the marked ops are not bogus

    - P4_CG4_15
      0CH F0H 05H
      execution_event: the marked ops are bogus

- Event class: replay_event
  This event counts the retirement of tagged ops which are specified through the replay tagging mechanism.
    - P4_CG4_16
      09H 01H 05H
      replay_event: the marked ops are not bogus
    - P4_CG4_17
      09H 02H 05H
      replay_event: the marked ops are bogus

- Event class: instr_retired
  This event counts instructions that are retired during a clock cycle.
    - P4_CG4_18
      02H 01H 04H
      instr_retired: Non-bogus instructions that are not tagged
    - P4_CG4_19
      02H 02H 04H
      instr_retired: Non-bogus instructions that are tagged
    - P4_CG4_20
      02H 04H 04H
      instr_retired: bogus instructions that are not tagged
    - P4_CG4_21
      02H 08H 04H
      instr_retired: bogus instructions that are tagged

- Event class: uops_retired
  This event counts ops that are retired during a clock cycle.
    - P4_CG4_22
      01H 01H 04H
      uops_retired: the marked ops are not bogus
    - P4_CG4_23
      01H 02H 04H
      uops_retired: the marked ops are bogus

A.6 AMD Athlon Family

A.6.1 AMD Athlon

The AMD Athlon is a 32-bit CISC microprocessor. The Athlon has 4 performance counters. The performance counters are 48 bit wide, the time stamp counter is 64 bit wide.
The Time Stamp Counter counts the elapsed machine cycles:

- Athlon_TSC
  elapsed machine cycles

The events countable on all four counters are:

- ATHLON_0
  20H
  Segment register loads.
- ATHLON_1
  21H
  Stores to active instruction stream (self-modifying code occurences).
- ATHLON_2
  40H
  Data cache accesses.
- ATHLON_3
  41H
  Data cache misses.
- ATHLON_4
  42H
  Data cache refills from L2.
- ATHLON_5
  43H
  Data cache refills from system.
- ATHLON_6
  44H
  Data cache writebacks.
- ATHLON_7
  45H
  L1 DTLB misses and L2 DTLB hits.
- ATHLON_8
  46H
  L1 and L2 DTLB misses.
- ATHLON_9
  47H
  Missaligned data references.
- ATHLON_10
  64H
  DRAM system requests.
- ATHLON_11
  65H
  System request with the selected type.
- ATHLON_12
  73H
  Snoop hits.

- ATHLON_13
  74H
  Single bit ecc errors detected or corrected.
- ATHLON_14
  75H
  Internal cache line invalidates.
- ATHLON_15
  76H
  Cycles processor is running.
- ATHLON_16
  79H
  L2 request.
- ATHLON_17
  7AH
  Cycles that at least one fill request waited to use the L2.
- ATHLON_18
  80H
  Instruction cache fetches.
- ATHLON_19
  81H
  Instruction cache misses.
- ATHLON_20
  82H
  Instruction cache refills from L2.
- ATHLON_21
  83H
  Instruction cache refills from system.
- ATHLON_22
  84H
  L1 ITLB misses and L2 ITLB hits.
- ATHLON_23
  85H
  L1 and L2 ITLB misses.
- ATHLON_24
  86H
  Snoop resyncs.
- ATHLON_25
  87H
  Instruction fetch stall cycles.
- ATHLON_26
  88H
  Return stack hits.
- ATHLON_27
  89H
  Return Stack overflow.
- ATHLON_28
  C0H
  Retired instructions (includes exceptions, interrupts, resyncs).
- ATHLON_29
  C1H
  Retired Ops.

- ATHLON_30
  C2H
  Retired branches (conditional, unconditional, exceptions, interrupts).
- ATHLON_31
  C3H
  Retired branches misspredicted.
- ATHLON_32
  C4H
  Retired taken branches.
- ATHLON_33
  C5H
  Retired taken branches misspredicted.
- ATHLON_34
  C6H
  Retired far control transfers.
- ATHLON_35
  C7H
  Retired resync branches (only non-control transfer branches counted).
- ATHLON_36
  C8H
  Retired near returns.
- ATHLON_37
  C9H
  Retired near returns mispredicted.
- ATHLON_38
  CAH
  Retired indirect branches with target mispredicted.
- ATHLON_39
  CDH
  Interruptes masked cycles (IF=0).
- ATHLON_40
  CEH
  Interrupts masked while pending cycles (INTR while IF=0).
- ATHLON_41
  CFH
  Number of taken hardware interrupts.
- ATHLON_42
  D0H
  Instruction decorder empty.
- ATHLON_43
  D1H
  Dispatch stalls.
- ATHLON_44
  D2H
  Branch aborts to retire.
- ATHLON_45
  D3H
  Serialize.
- ATHLON_46
  D4H
  Segment load stall.

- ATHLON_47
  D5H
  ICU full.
- ATHLON_48
  D6H
  Reservation stations full.
- ATHLON_49
  D7H
  FPU full.
- ATHLON_50
  D8H
  LS full.
- ATHLON_51
  D9H
  All quiet stall.
- ATHLON_52
  DAH
  Far transfer or resync brach pending.
- ATHLON_53
  DCH
  Breakpoint matches for DR0.
- ATHLON_54
  DDH
  Breakpoint matches for DR1.
- ATHLON_55
  DEH
  Breakpoint matches for DR2.
- ATHLON_56
  DFH
  Breakpoint matches for DR3.

A.7 Intel IA64 Family

A performance counter is called in Intel's literature [14] a PMC. In the Itanium 1 processor there are 4 counters numbered PMC4 to PMC7. To be consistent with the rest of the document we map those counter numbers to the names PMC0, PMC1, PMC2, PMC3, e.g. PMC 4 is called in our document PMC0.

- **Tick Counter:**
  - IA64ITAN_TC
    elapsed machine cycles

  Events common to all performance counters:

  - IA64ITAN_0
    BRANCH_MISPRED_CYCLE
    branch mispredict stall cycle
  - IA64ITAN_1
    INST_ACCESS_CYCLE
    instruction access cycle
  - IA64ITAN_2
    EXEC_LATENCY_CYCLE
    execution latency stall cycle
  - IA64ITAN_3
    DATA_ACCESS_CYCLE
    data access stall cycle
  - IA64ITAN_4
    BRANCH_CYCLE
    combined branch stall cycle
  - IA64ITAN_5
    INST_FETCH_CYCLE
    combined instruction fetch stall cycle
  - IA64ITAN_6
    EXECUTION_CYCLE
    combined execution stall cycle
  - IA64ITAN_7
    MEMORY_CYCLE
    combined memory stall cycle
  - IA64ITAN_11
    FP_FLUSH_TO_ZERO
    FP result flushed to zero
  - IA64ITAN_12
    FP_SIR_FLUSH
    FP SIR flush cycles
  - IA64ITAN_13
    BR_TAKEN_DETAIL
    taken branch detail
  - IA64ITAN_14
    BR_MWAY_DETAIL
    multiway branch detail
  - IA64ITAN_15
    BR_PATH_PREDICTION
    branch path prediction
  - IA64ITAN_16
    BR_MISPREDICT_DETAIL
    branch mispredict detail
  - IA64ITAN_18
    CPU_CYCLES
    CPU cycles.

- IA64ITAN_30
  ISA_TRANSITIONS
  IA64 to IA32 transitions.
- IA64ITAN_31
  IA32_INSTR_RETIRED
  IA32 instructions retired.
- IA64ITAN_32
  L1I_READS
  L1 instruction cache reads
- IA64ITAN_33
  L1I_FILLS
  L1 instruction cache fills
- IA64ITAN_34
  L1I_MISSES
  L1 instruction cache misses
- IA64ITAN_35
  INSTRUCTION_EAR_EVENTS
  instruction EAR events
- IA64ITAN_36
  L1I_IPREFETCHES
  L1 instruction prefetch requests
- IA64ITAN_37
  L2_INST_PREFETCHES
  L2 instruction prefetch requests
- IA64ITAN_38
  ISB_LINES_IN
  instruction streaming buffer lines in
- IA64ITAN_39
  ITLB_MISSES_FETCH
  ITLB misses demand fetch
- IA64ITAN_40
  ITLB_INSERTS_HPW
  ITLB hardware page walker inserts
- IA64ITAN_45
  INST_DISPERSED
  instructions dispersed.
- IA64ITAN_46
  EXPL_STOPS
  explicit stops.
- IA64ITAN_47
  IMPL_STOPS_DISPERSED
  implicit stops.
- IA64ITAN_50
  RSE_LOADS_RETIRED
  RSE load accesses
- IA64ITAN_51
  PIPELINE_FLUSH
  pipeline flush
- IA64ITAN_51
  L1D_WAY_MISPREDICT
  L1 data cache way mispredict (umask 2)
- IA64ITAN_52
  CPU_CPL_CHANGES
  privilege level changes

- IA64ITAN_53
  INST_FAILED_CHKS_RETIRED
  failed speculative check loads
- IA64ITAN_54
  ALAT_INST_CHKA_LDC
  advanced check loads
- IA64ITAN_55
  ALAT_INST_FAILED_CHKA_LDC
  failed advanced check loads
- IA64ITAN_56
  ALAT_CAPACITY_MISS
  ALAT entry replaced
- IA64ITAN_94
  EXTERN_BPM_PINS_0_TO_3
  counts the number of times external BPM pins 0 through 3 were asserted
- IA64ITAN_95
  EXTERN_BPM_PINS_4_TO_5
  counts the number of times external BPM pins 4 and 5 were asserted
- IA64ITAN_96
  DTC_MISSES
  DTC misses
- IA64ITAN_97
  DTLB_MISSES
  DTLB misses
- IA64ITAN_98
  DTLB_INSERTS_HPW
  hardware page walker installs to DTLB
- IA64ITAN_99
  DATA_REFERENCES_RETIRED
  retired data memory references
- IA64ITAN_100
  L1D_READS_RETIRED
  L1 data cache reads
- IA64ITAN_101
  RSE_REFERENCES_RETIRED
  RSE accesses
- IA64ITAN_102
  L1D_READ_MISSES_RETIRED
  L1 data cache read misses
- IA64ITAN_103
  DATA_EAR_EVENTS
  L1 data cache EAR events
- IA64ITAN_104
  L2_REFERENCES
  L2 references
- IA64ITAN_105
  L2_DATA_REFERENCES
  L2 data references
- IA64ITAN_106
  L2_MISSES
  L2 misses
- IA64ITAN_107
  L1D_READ_FORCED_MISSES_RETIRED
  L1 data cache forced load misses

  - IA64ITAN_108
    LOADS_RETIRED
    retired loads
  - IA64ITAN_109
    STORES_RETIRED
    retired stores
  - IA64ITAN_110
    UC_LOADS_RETIRED
    retired uncacheable loads
  - IA64ITAN_111
    UC_STORES_RETIRED
    retired uncacheable stores
  - IA64ITAN_112
    MISALIGNED_LOADS_RETIRED
    retired misaligned load instructions
  - IA64ITAN_113
    MISALIGNED_STORES_RETIRED
    retired misaligned store instructions
  - IA64ITAN_118
    L2_FLUSHES
    L2 flushes
  - IA64ITAN_119
    L2_FLUSHE_DETAILS
    L2 flushe details
  - IA64ITAN_123
    L3_REFERENCES
    L3 references
  - IA64ITAN_124
    L3_MISSES
    L3 misses
  - IA64ITAN_125
    L3_READS
    L3 reads
  - IA64ITAN_126
    L3_WRITES
    L3 writes
  - IA64ITAN_127
    L3_LINES_REPLACED
    L3 cache lines replaced

Events specific to some performance counters:

- **Counter PMC0:**
  - IA64ITAN_C0_8
    IA64_INST_RETIRED
    instructions retired.
  - IA64ITAN_C0_48
    NOPS_RETIRED
    retired NOP instructions.
  - IA64ITAN_C0_49
    PREDICATE_SQUASHED_RETIRED
    instructions squashed due to predicate off
- **Counter PMC1:**
  - IA64ITAN_C1_8
    IA64_INST_RETIRED
    instructions retired.

- IA64ITAN_C1_48
  NOPS_RETIRED
  retired NOP instructions.
- IA64ITAN_C1_49
  PREDICATE_SQUASHED_RETIRED
  instructions squashed due to predicate off

A.8 Hitachi SR8000

The SR8000 processors have 8 performance counter registers, each counting exactly one hard-coded event type.

- SR8000_C0
  ITLB misses
  Instruction TLB misses
- SR8000_C1
  DTLB misses
  Data TLB misses
- SR8000_C2
  Icache misses
  L1 instruction cache misses
- SR8000_C3
  Dcache misses
  L1 data cache misses
- SR8000_C4
  Loadstore
  Load or store operations
- SR8000_C5
  Instructions
  Instructions completed
- SR8000_C6
  Cycle_cnt
  Machine cycles.
- SR8000_C7
  FP-ops
  Floating point operations