Linux on the Cell processor

Linux Kernel Hacking Free Course — IV edition

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What is Cell?

- Cell is a multiprocessor system on single chip developed by IBM in collaboration with Sony and Toshiba

What's New in Cell?

- Many other multiprocessor architectures today:
- Intel Core duo
- Intel Xeon
- AMD Athlon 64 X2
- AMD Opteron
- All homogeneous architectures
- Cell has a non homogeneous architecture
- One general purpose processor (*PPE*)
- Eight special purpose processors (*SPE*)
- To fully exploit the Cell architecture a new programming approach is required

Architectural Overview

Power Processor Element (*PPE*) architectural overview

The Power Processor Element:

- The main processor: it executes both the operating system and the general purpose applications, and it spawns tasks to *SPE*
- A dual-threaded general purpose processor
- Based on a 64 bit RISC architecture conforming to the PowerPC Architecture version 2.02
- Has vector/SIMD multimedia extensions

PPE simple block diagram

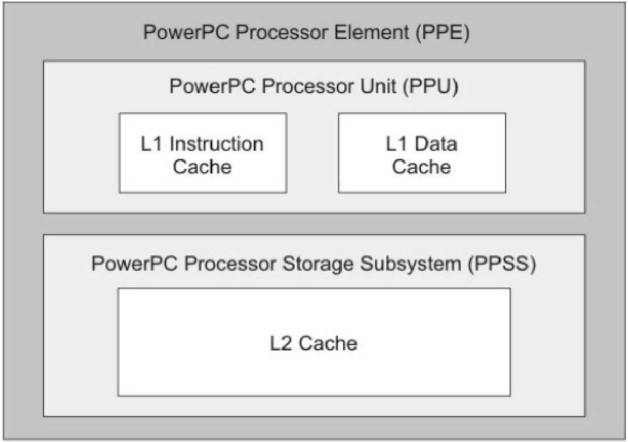


Image taken from CBE Programming Tutorial v. 3

Synergistic Processor Element (*SPE*)

Each *SPE* is:

- Slave processor: it execute tasks spawned from the *PPE*
- Based on a 128 bit RISC architecture specialized for computing intensive SIMD applications

SPE simple block diagram

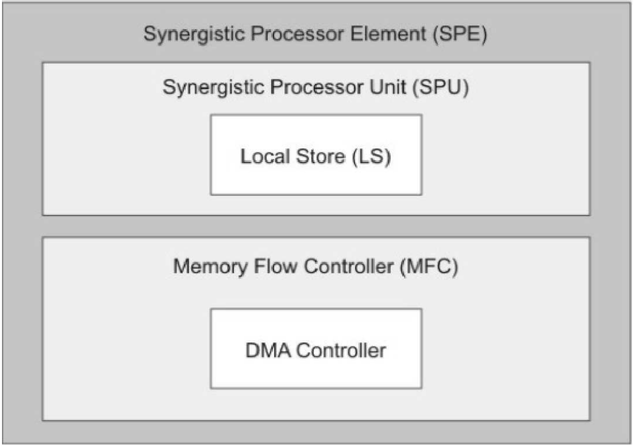


Image taken from CBE Programming Tutorial v. 3

Synergistic Processor Unit (*SPU*)

- Deals with instructions execution and control
- Single (unified) register file with 128 registers
- Unified 256 KB local memory for instructions and data named Local Store (*LS*)
- New SIMD (Single Instruction Multiple Data) instruction set

Local Store (*LS*)

- Each *SPE* is an indipendent processor with its own program counter
- The *SPU* fetches instructions and load/store data from/to its own Local Store

Memory Flow Controller (*MFC*)

- It's the interface between the SPE and the other system processors
- Contains a DMA controller for DMA transfers support
- In order to support the DMA controller, the MFC maintains a queue of DMA commands
- After a DMA command has been queued, the SPU can continue to execute instructions while the MFC processes the DMA command

DMA tranfers

- Each DMA transfer can move up to 16 KB.
- The *SPU* associated with *MFC* can issue a DMA-list of up to 2048 DMA

High level programming

High level programming — an introduction

- SPE and PPE are independent processors
- To fully exploit the Cell performance you must write two different software programs:
- *PPE program* — a program running on PowerPC core that offloads task to SPE
- *SPE program* — a program running on SPE processor that uses the SPU Instruction Set

Creating a SPE thread from PPE

- A PPE program spawns a task to an SPE by creating a thread on the SPE. It uses the following functions:
- *spe_context_create()* – creates a context for the SPE thread
- *spe_program_load()* – load an SPE program into the context
- *spe_context_run()* – execute a context on a physical SPE

Creating a SPE thread from PPE and libspe2

- The function aboves are in libspe2, which is an implementation of the *SPE Runtime Management Library* developed by IBM under GPL license and downlodable from http://sourceforge.net/projects/libspe

SPE Program

- Conceived and compiled for execution on the SPE
- This program can use SPE (vectorial) data types and SIMD instructions
- SIMD instructions are defined in the *SPU C/C++ language extensions* and are named *intrinsics*
- A SPE program transfers data from/to main memory to/from Local Store through DMA transfers

Tips for performance improvements (SPE side)

- Use vector data type instead of scalars
- Perform loop unrolling
- Use double buffering

Scalar and vector data types

- The SPE processor has a vectorial architecture. The SPU loads and stores one quadword at time
- Scalar types are stored in the left-most word in the register (*Preferred Slot*)
- We must avoid as much as possible scalar types because operations on scalar types are inefficient
- For example a scalar load must be rotated into the preferred slot

Loop unrolling

- Loop unrolling is a common technique for increasing the performances
- SPE processors have 128 registers
- Using loop unrolling can improve register utilization
- PROBLEM
- Loop unrolling increases the size of code
- Data and code must fit in 256 KB Local Store

Double buffering (1/2)

- The SPU moves data from/to main memory only with DMA tranfers
- The communication bus between SPE's and PPE is a bottleneck
- In the Cell architecture DMA transfers are asynchronous
- This feature allow the programmer to schedule the transfers so that the latency of memory accesses can be hidden by overlapping the transfers in one buffer with computations in another

Double buffering (2/2)

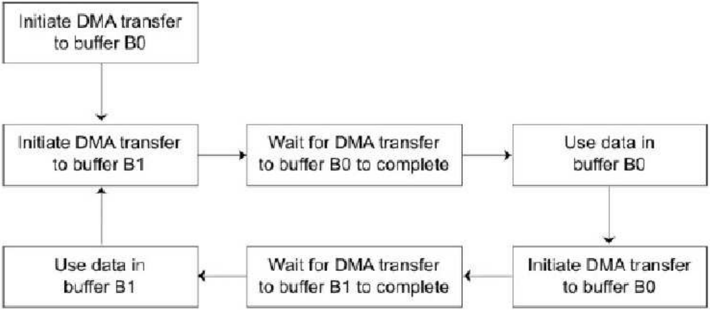


Image taken from CBE Programming Tutorial v. 3

Cell and the Linux Kernel

Linux Kernel support for Cell

- The Cell processor is fully supported by the Linux Kernel
- Cell is a PowerPC-based architecture
- If you look in /<path_linux_source>/arch/powerpc/platforms you can find two folders (among many others) named:
- cell
- ps3
- The first folder include code for supporting the native Cell
- The second folder include code for supporting the Cell on Sony PlayStation 3

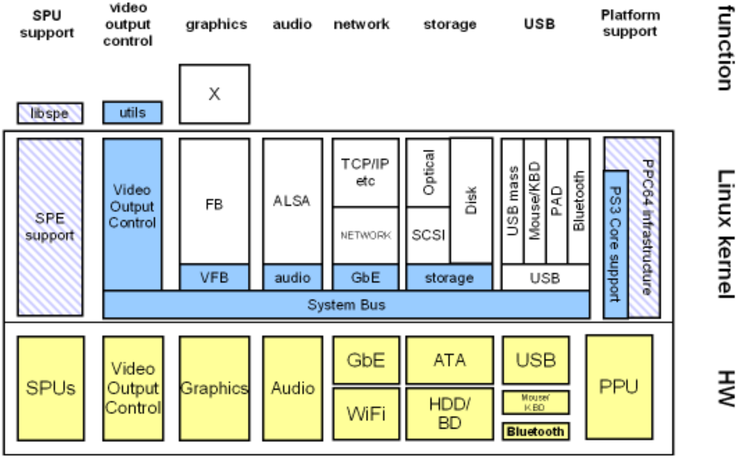
Differences between native Cell and Cell on ps3

- In native Cell the Linux kernel runs directly on hardware
- In ps3 the Linux kernel runs in a virtualized environment

Why different platforms?

- Why there are different platforms for Cell native and Cell on ps3?
- The presence of a virtualization layer imposes different low level interactions between hardware devices and kernel

Kernel execution overview on native Cell



Kernel execution overview on PlayStation3

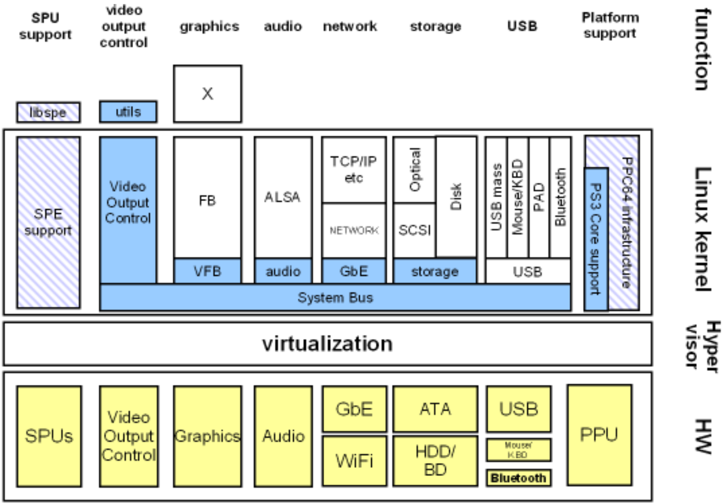


Image taken from http://www.kernel.org/pub/linux/kernel/people/geoff/cell/

How libspe2 create a SPE context – *spu_create()* syscall

- The *spu_create_context()* of libspe2 creates an *SPE context*
- An SPE context is, essentially, a directory in *spufs* pseudo file system (see later)
- The *spu_create_context()* function creates an entry in *spufs* through the *spu_create()* system call and maps some file created by *spu_create()*. For example the *mem* file (see later)
- The *spu_create()* system call creates a spu context in kernel memory and return an open file descriptor for the directory (in /spu) associated with it.

SPU File System (*spufs*)

- Similar to procfs and sysfs
- Purely virtual file system
- By convention mounted in /spu
- Directories in /spu represent SPE contexts whose properties are shown as regular files
- Interaction with these contexts can happen through file operations like open, read, write, etc.

Examples of files in a spufs sub-directory

- *mem* – The local memory of a SPE context. Mainly used to load the executable file of the program to be run onto the SPE
- *regs* – The general purpose registers of an SPE. Normally can't be accessed directly but they can be saved in a context in kernel memory

SPE context

- It is a data structure which represents a SPE task
- A context has all properties of a physical SPE
- The kernel can use this structure to save the state of a SPE thread
- Context switching on SPE is very inefficient

How libspe2 load a program in to SPE

- The *spe_program_load()* function of libspe2 loads an SPE ELF object file in an SPE
- This function does not call any syscall
- Instead, it makes use of a file memory mapping of the *mem* file
- Thus, the SPE ELF object file is loaded into the context directly from user space

Running a SPE program – spu_run() syscall

- The *spe_context_run()* function runs a SPE program previously loaded into a SPE context
- It calls the *spu_run()* system call
- *spu_run()* starts the SPE thread execution. The PPE thread that called *spu_run()* blocks in that system call
- Each SPE thread is associated with one PPE thread

Example of Cell application

- Cell is increasingly used in accademic and scientific world
- With ps3 Cell is incredibly low cost
- The University of Massachusetts Dartmouth uses a cluster of sixteen ps3 for astrophysics analysis

Performance scaling with implementation

- 2048x2048 float matrix multiplication on single SPE

Implementation	Execution time (ms)
Scalar	338687.230514
Vectorial	336059.746404 (-0,77%)
Vectorial - Unrolling	280815.662356 (-17%)
Vectorial - Unrolling con spu_madd	262594.693659 (-23%)
Vectorial - spu_madd	75076.210915 (-78%)
Vectorial - spu_madd - spu_gcc -O3	18072.911028 (-95%)
Vectorial - spu_madd - with Double Buffering	10509.868133 (-97%)

Conclusions

- Cell is a very interesting and (potentially) powerful architecture
- Each SPE is capable of 25.6 GFLOPS in integer and single precision arithmetic
- Fully exploiting Cell capabilities is not easy