

# Study of Multicore processors: Advantages and Challenges

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**Abstract** Multi-core processors have reformed the digital world today which is inhabited by us and still the endless efforts are being carried out to generate faster and smarter chips. Since the most significant direction to expand the performance of processor is Multi-core, the manufacturers are highly focused on this technology. Multi-core processors allow higher performance at lower energy which can boost the performance of mobile devices that operate on batteries. Also, the consorting capability of these multiple cores upturns the multitasking ability of the system. That is the cores work together by executing multiple instructions simultaneously using parallelism in an efficient manner. In addition to this, the adjacency of multiple CPU cores on the same die grants the cache coherency to operate at a much higher speed than what would have happen if the signals had to travel off-chip. This in turn leads to the less degradation of signals since they had to travel shorter distances between different CPUs. All these factors have led to the evolution of many new multi-core processors like R65C00 and many others by Intel, AMD, etc. But, the improvement in performance achieved by the multi-core processor is very much depended and limited by the fraction of the software and its implementation which can run simultaneously on multiple cores whose effect is described by Amdahl's law. In spite of these indispensable benefits, there are certain biting challenges that need to be taken care of before going in for this technology. This paper introduces the technology of multi-core processors and its advantages in today's world. Finally, the paper concludes by detailing the challenges that are presently faced by multi-core processors.

**Keywords** — Amdahl's law, cache coherence, mobile devices, multi-core, parallelism, smart chips.

## I. INTRODUCTION

Until few years back, we have been working with the processors having a single central processing units that read and execute program instructions called a core. The first microprocessor had only 2200 transistors [1]. The performance of these single core processors cannot be boosted beyond the certain limit as the power dissipation increases with the escalation of the clock frequency. Parallelism is one of the finest ways to solve the issue of power along with the maintenance of performance which can be achieved with lower frequency and voltage. This will result in the bigger transistor count, but overall less power dissipation and power density. This idea led to the foundation of multi-core.

The flourishing market and the demand for increasing performance led the industries to manufacture quicker and

smarter chips. Some of the techniques that have been advised to improve the performance include pipelining and different levels of parallel processing like data level and instruction level parallelism which has proved to be very effective. One such technique that manufacturers came up with; which improves the performance significantly is a new design of processors called as multi-core processors. This concept of multi-core processors started evolving when Gordon Moore, the co-founder of Intel and Fairchild Semiconductor, in April 1965, wrote an article for Electronics magazine titled "Cramming more components onto integrated circuits" [2] which later came to be called as Moore's law. Obviously it should be considered as an observation or projection and not a physical or natural law. It is the consideration that the number of transistors in a dense integrated circuit doubles approximately every two years and projected this rate of growth would continue for at least another decade. In 1975, looking forward to the next decade, he revised the forecast to doubling every two years [3]. Thus A multi-core processor provides lot of advantages especially for those looking to expand their system's multitasking computing power. In this article, our main goal

is to describe some of the significant challenges of multi-core processors. In addition, the paper also discusses the advantages along with its basic concept.

## II. MULTICORE PROCESSORS

Multi-core processors have been in reality since the past decagon, but however it have earned more significance off late due to some of the technological limitations like large throughput and long-term battery life with tremendous energy efficiency.

A multi-core processor comprises of a single computing component with two or more independent actual computational or processing units, called as "cores", that which are the units that operate in parallel to read and execute programming instructions. These are simple CPU instructions like arithmetic operations, move data, and branch instructions, but the prime thing is that multiple cores can execute multiple instructions at the same time, thus increasing the overall speed for programs similar to parallel computing. Manufacturers typically fabricate the cores onto a single integrated circuit die or onto multiple dies in a single chip package. Hence it's also called as a Chip Multiprocessor (CMP). The prime factor about multicore processor is that the performance of these processors is not degraded as compared to a single processor even with lesser power dissipation and at a lower clock frequency. The performance of any processor mainly depends on following three major factors:

1. Instructions per cycle (IPC), which can be improved by increasing Instruction Level Parallelism and Thread Level Parallelism.
2. Clock cycles per instruction (CPI) which can be improved by the techniques of pipelining and
3. Clock frequency.

But if we increase the clock frequency beyond certain limit, the power dissipation increases which in turn causes since  $P$  is directly proportional to  $f$ . So, the idea of multicore technology is to use more than one core instead of one at a comparatively lower frequency. These cores execute multiple threads that is, multiple instructions while accessing multiple data from different parts of memory. Each core is having its own cache while the system bus and main memory is shared by all cores.

The single core processors where multiple programs are running simultaneously would assign different time slice to

work on programs. If one of the processes fails to complete on time then all the rest of the processes start lagging behind. However, In the case of multi-core processors if multiple tasks run in parallel at the same time, each of them will be executed by a separate core simultaneously thus promoting the performance [4]. Additionally, multi-core processors are generally designed in such a way that can run more efficiently than a single processor, since not all the cores need to be active unless needed. For example, the power is turned off to entire cores for Intel's "Turbo Boost Technology" when they are not being used. One important point to understand is that multiple cores are different than multiple CPUs.

There are number of topologies that are being practiced to interconnect multiple cores like Ring topology, Bus topology and Two-dimensional topologies such as mesh and crossbar. The performance parameters like speed; latency etc. is affected by the choice of particular topology. Hence its selection is an important factor as the type of topology also impacts area consumed on a chip and power dissipation.

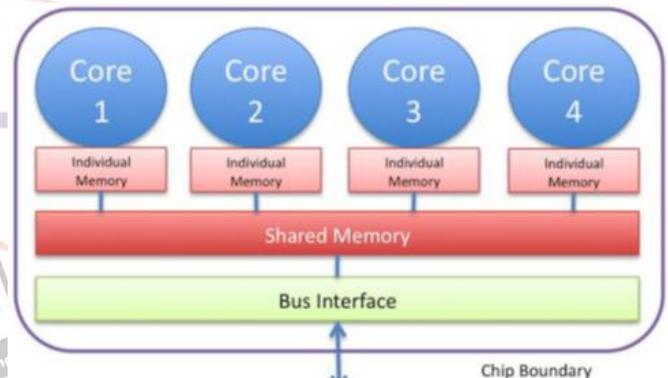


Figure 1: Multicore processors

In addition to this, there are two types of cores used by multicore technology namely homogeneous and heterogeneous cores. As the name suggest, in homogeneous configuration, all the cores are indistinguishable and each core has same hardware where as there are dedicated applications specific cores which work on specialized applications in heterogeneous cores. Sometimes Multicore Processors combine the positives of both homogeneous and heterogeneous configurations to improve their performance. The IBM multicore processor, CELL uses this approach. The wide range of applications for multi-core processors includes domains like general-purpose, embedded systems, digital signal and image processing, and networking. Also, the industrial applications of MCPs incorporate motion control, machine vision, automated test systems and CAD

systems.

Processors were originally developed with a single core. However, in the mid-1980s, Rockwell International manufactured versions as the R65C00, R65C21, and R65C29 with two cores on one chip sharing the chip's pins on alternate clock phases. In 1996, a hand-picked team of some 250 system and chip designers, software architects, researchers and semiconductor engineers successfully put two high-performance microprocessor cores on a single silicon chip called as IBM's POWER4 which combined the best of commercial, scientific and high-performance computing in a single design [5]. Intel came up with its first dual core processor in 2005. Multi-core processors may have two cores that is, dual-core CPUs, for example, AMD Phenom II X2 and Intel Core Duo, three cores i.e., tri-core CPUs, for example, AMD Phenom II X3, four cores that is, quad-core CPUs, for example, AMD Phenom II X4, Intel's i5 and i7 processors, six cores i.e., hexa-core CPUs, for example, AMD Phenom II X6 and Intel Core i7 Extreme Edition 980X, eight cores called as octa-core CPUs, for example, Intel Xeon E7-2820 and AMD FX-8350, ten cores i.e., deca-core CPUs, for example, Intel Xeon E7-2850, or more [3].

### III. ADVANTAGES OF MULTICORE PROCESSORS

1. The Multi-core processors can deliver a very high performance benefits for multi-threaded software by adding more and more processing power with minimal latency, given the proximity of the processors.

2. The most significant benefits will be viewed in many applications such as Customer Relationship Management, larger databases, Enterprise Resource Planning, ecommerce and virtualization.

3. The more threaded applications will clearly get more benefit. In a due course of time, this trend is beginning to and will shape the future of software development towards parallel processing.

4. Meantime, we can target the quad-core servers for those types of applications which can get the maximum work out of them.

### IV. CHALLENGES INVOLVED IN MULTI-CORE PROCESSORS

The two main characteristics that uniquely identify Multi-core architectures are heterogeneity and the massive parallelism in addition to any arbitrary topology for interconnection of processors or cores. Thus, parallel

programming for multi-core architecture is more complicated than conventional parallel programming. These challenges must be dealt with a holistic approach to support emerging programming models for multi-core processors and devise efficient methods of multi-core programming.

#### A. Memory Hierarchy

One of the most demanding challenges that are faced by multi-core processors today is its memory system. The execution of a program is often bounded by the memory bottleneck which happens not due to the non-availability of processor and its low speed but because of the fact that a heavy portion of applications always lies in main memory until it is executed by the processor. Moreover, multi-core processors can even make the situation more badly. Thus, care should be taken to conserve memory bandwidth and avoid memory contention. Also, it is significant to note that the memory hierarchies in parallel machines are more difficult than in the uni-processor's machines, especially in multi-core processors where L2 and L3 cache are shared by the multiple cores with in a chip. This leads to more complicated memory hierarchy design in CMPs.

#### B. Cache Levels

The current trend of multi-core processors which are general purpose use 3-level cache scheme consisting of L1, L2 and L3 cache. The present 3-level cache system is working fine with the current dual, quad and eight cores processors. In this cache model, the L2 cache may be private, shared or split. But as number of cores increases, this may cause the bottleneck and result in data traffic congestions and performance degradation.

#### C. Cache coherence

“Cache coherence is the discipline that ensures that changes in the values of shared operands or data are propagated throughout the system in a timely fashion” [6].

When caches of a common memory resource is maintained by the clients in a system, then complications may arise with the inconsistent data, which is especially a concern in a multi-core environment because of sharing of L1 and L2 cache. Let's take an example of a dual-core processor where each core transfers a block of data from memory into its private cache. First core writes a value to a specific memory location; when the second core tries to read that value from its cache it will not have the updated copy unless a cache miss occurs. This cache miss forces the update operation on the second cores cache entry. If this policy would not have been in place then invalid results would have been produced. Since the shared and private caches exist at

different levels in multi-core processors, this cache coherence problem becomes worse.

#### D. Developing Multicore Softwares

One of the significant issues seen with regard to software programs is that they run a bit slower on multi-core processors as compared to single core processors. It is being correctly pointed out that “Applications on multi-core systems don’t get faster automatically as cores are increased” [7]. So, the solution is that the programmers must develop programs and applications that can exploit use of the increasing number of processors in a multi-core environment. Also, the time needed to write these softwares cannot be stretched. Moreover, majority of applications used today are written to run on a single core processor, which failed to use the capability of multi-core processors. Hence, the dignified challenge the industry faces is how to port these software programs which were developed years ago to multi-core adaptable software programs. Although it sounds very possible to redesign programs, it’s really not a business profitable decision in today’s world where in companies have to keep in mind the key parameters like time to market, customer fulfillment and cost cut. It has however been correctly pointed out that “The throughput, energy efficiency and multitasking performance of multi-core processors will all be fully realized when application code is multi-core ready” [8].

#### E. Level of Parallelism

The level of parallelism of the process is one of the gigantic factors that affect the performance of a multicore processor significantly. Performance will increase with the decrease of completion time of a process. Parallelism can be achieved by Instruction Level Parallelism and Thread Level Parallelism. TLP increases overall parallelism by breaking a program into many small threads and execute them concurrently. Hence to achieve a high level of parallelism, software developers must write such algorithms that can take full advantage of multicore design. Also, companies like Microsoft and Apple have designed their operating systems which can run efficiently on multicore configuration [9].

#### F. False-Sharing

If two different processors operate on independent data in the same memory address region that reside on the same cache line and the mechanism may force the whole line to interconnect with every data write, forcing the wastage of system bandwidth is termed as False-sharing. In multi-core processors, with the increase in number of cores, the number of private and shared caches will also increase and this might result in increase of false-sharing.

#### G. Power and temperature

As the number of cores placed on a single chip increases without any modification, the chip will consume more power leading to the generation of large amount of heat, which can even cause your computer to become combust; if the processor overheats. To reduce this unnecessary power consumption, the multicore designs also incorporate a power control unit that can force the unused cores to shut down that are not required at times. The core which overheats in a multicore configuration is called a hot-spot. The chip is architected such that the amount of heat generated in the chip is well distributed across the chip. The majority of the heat in the CELL processor is dissipated in the Power Processing Element and the remaining is spread out across the Synergistic Processing Elements. There are various ways to tackle the problem of power dissipation and temperature which includes thread migration, DVFS (Dynamic Voltage and Frequency Scaling) etc. In the thread migration technique, a low power consuming process or thread is moved to an overheated core. In DVFS (Dynamic Voltage and Frequency Scaling) technique, voltage and frequency of the hot core is reduced since the power dissipation or heating is a function of both voltage and frequency which slightly affects the overall performance also [9].

#### H. Communication Minimization or Interconnect Issues

Another important feature which impacts the program execution and its performance in multi-core processors is the interaction between on chip components viz. cores, cache, memories and if integrated—memory controllers and network controllers which are used for memory-memory and memory-processor communication; where bus contention and latency are the key areas of concern. In multi-core processors, as the number of cores and respective caches increases, the inter-memory and memory-processor communication is expected to increase exponentially. So, the memory hierarchy of multi-core processors should be designed in such a way that these communications are contained. It is rightly pointed that: “The performance of the processor truly depends on how fast a CPU can fetch data rather than how fast it can operate on it to avoid data starvation scenario” [10]. Special crossbars or mesh technologies have been enforced on hardware to solve this issue. For instance, AMD CPUs employ a crossbar, and the Tiler TILE64 implements a fast non-blocking multi-link mesh [11].

## V. CONCLUSION

The limitations on power and frequency on single core systems have led the foundation for multicore processors. Also these processors differ from the Shared Memory Multi-processors (SMPs) in both hardware and software aspects and gave the solution of running chips at lower frequencies, but added interestingly some new problems. New memory hierarchy and cache designs, cores interconnection patterns and many related hardware issues including new programming models, libraries and related performance tools from software design aspect have to be worked out to use a multi-core processor at full capacity. However, in coming days, a lot of technological advancements are expected in this area of technology which may include a new multi-core programming language and there is large amount of research and development going on in this field to utilize multi-core processors more efficiently.

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