

# Design and Implementation of the Heterogeneous Multikernel Operating System

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**Abstract.** The design of the computer system was significantly changed due to the emergence and popularization of the multicore processors. Moving to the advanced multicore processors, moving to the heterogeneous computer systems and increasing of the integrity level between computer system components are the main trends of the computer systems development. Significant changes in the computer systems design make reasonable the attempt of reviewing the operating system design to make it optimal for the new hardware platform. The proposed operation system design assume moving from monolithic centralized operating system to the decentralized network of the distributed independent nodes, each of which will play the role of the processor driver and threads container. The proposed design provide the numbers of the benefits against ordinal operating systems: dynamics in space and time, improved level of reliability and flexibility, support of the heterogeneous computer systems.

**Keywords.** Multiprocessor computer system, heterogeneous computer system, real-time system

## Introduction

Computer systems design is changing much faster than the operating systems design. The internal architecture of the modern computer resembles a distributed network system consisting from the mix of processor cores, caches, internal communications, I/O devices and expansion cards. The modern computer is similar to the early parallel computer systems or multiprocessor systems of the last century. Multi-core computer systems, which are essentially the same multi-processor systems localized on the processor die, occupy an increasingly strong position in most segments of the computer market. Switching to multi-core computer systems is one of the main trends of the computer development, because processor manufacturers have already come close to the limits of the transistor microelectronics and further performance gains in this direction is no longer possible. Further growth of processor performance can be achieved only by intensive arrangements in core design development, and extensive arrangements in increasing number of processor cores. Research and development in the field of multi-core processors were considered as the main direction of processors development by leaders of the processor market, Intel, AMD and ARM. The same way follow the other companies producing processors such as Oracle (CPU SPARC) and IBM (CPU POWER, Cell etc.). Moreover, the development of multi-core processors

has the following trends: multiple increase in the number of processor cores located on the same die, transition from UMA-architecture to the NUMA-architecture, using more productive and advanced local inter-core interfaces and buses, and system interfaces and buses, the differentiation of processor cores and transition to the heterogeneous design of the computer system, equipping of main and peripheral components of computer system by advanced specialized processor cores. Thus, all goes towards decentralization and differentiation. It should also be noted that transition to an advanced multi-core is accompanied by a significant increase of the system bus traffic, so we should expect that in future the central system bus will be replaced by a distributed network of buses with NUMA memory architecture. The significant change in the computer system hardware platform leads to the significant change in the operating system design [1, 2]. Moving to the multicore processor based computer system can be considered as the next such significant change. Moreover, the Andrew Tanenbaum notes that the research of the multi-processor focused operating system design is one of the most promising [1].

Utilizing computing power of multicore processors is impossible without the support from the operating system side. Operating system designed for single-processor computer systems on multiprocessor computer systems will use only one processor of the entire array of those available. However, modern operating systems, written with support of multiprocessor computer systems, only mask the problem by involving other processors in the computational process, but trying to do these as if still working in a uniprocessor environment, in such a way that only few kernel modules are designed with the true multiprocessor support in the mind. This leads to the inefficient processor caches utilization and extensive locking of the system bus. The technology of modern computers and processing units, as well as trends and prospects, assumes development and use of new technologies of computing. And apparently, these technologies will be a symbiosis of computing technology for central processing units, massively parallel processors, parallel and distributed computing and networking technologies.

Basic element of the software is the operating system. It is a complex software system connecting the rest of the software with the hardware platform and represents the software system architecture designed to deal with user tasks and ensuring the autonomy of the computer system. Thus, the main functions of the operating system include the following:

- implementation of organized interaction between tasks and hardware;
- equitable sharing of hardware resources (especially RAM and CPU time, as well as access to services, hardware etc.) of computer system among all tasks;
- providing reliable and stable computer system autonomy.

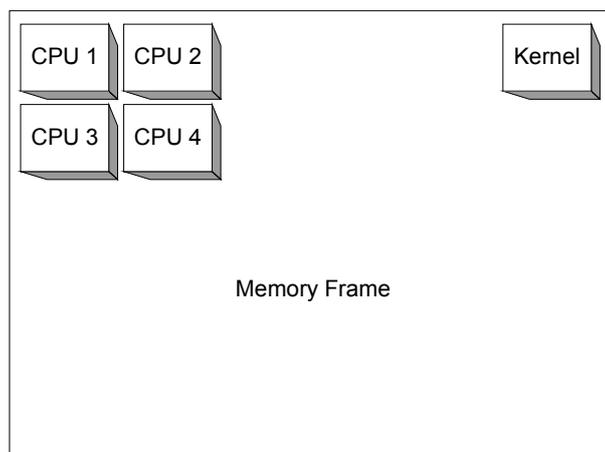
We can safely say that the technology of operating systems did not keep pace with changes in its hardware platforms - processors. If we carefully look at the IT-industry, it becomes clear that the developers of operating systems are kind of conservative on the IT market. This is probably partly due to the constant need to maintain backwards compatibility for a lot of software written for ordinary operating system. But on the other side gap between the manufacturability of hardware and software platforms can not grow indefinitely. Gradual mass migration to multicore processor device is a new opportunity to review the operating system architecture in which considering lessons learned in the theory of operating systems, and the accumulated innovations in processor architecture and the tendency of their further development are needed. The

most progressive in this regard is the concept of heterogeneous multi-core operating system.

### 1. Next generation Operating System Design

The main idea of the proposed operating system design is moving from the centralized monolithic operating system design to the design of the decentralized distributed network of operating system nodes with high level of autonomy.

The monolithic kernel can be divided to the numbers of separated true microkernels [3] each of which runs on its processor core. The system memory also divided between all operating system kernels in that way that each kernel control and manages its own part of the system memory and don't interfere with other kernels. As result one of the main system abstractions is kernel that incorporates the computation and memory resources with the policies of its management, and from one point of view represents one of the independent operating system node communicating with the other system nodes, and from another point of view plays role of the platform and container from the separated tasks. Migration of the task between operating system nodes during balancing of performance consuming processes is an explicit process managed by external policies that locates outside of the kernels. By default all tasks (threads) related to the same context (process) executes on the same kernel.

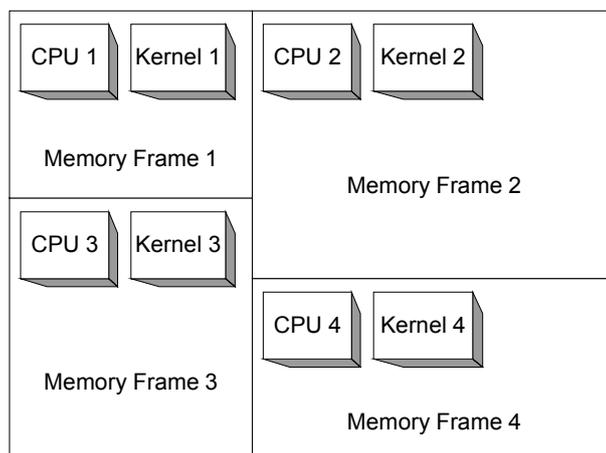


**Figure 1.** Hardware resources from the point of view of the commodity operating systems

Traditional operating systems design looks at the major hardware resources (CPU and memory) in the way that shown on the Figure 1. The single operating system kernel manages all system resources. From the point of view of the heterogeneous multikernel operating system design the computer system hardware is a set of the simple single processor quasi computer systems each of which includes its own CPU and its own amount of the memory (Figure 2). Consequently operating system is a network of the independent nodes each of which includes the already mentioned above simple quasi computer system and operating system kernel that manages it.

Independence of the operating system nodes is one of the major attributes of the proposed operating system design, because it provides not only distributed

management of the system resources, but also divides all operating system to the set of the security domains, that in its turn will lead to the improved flexibility, security and reliability of the overall system.



**Figure 2.** Hardware resources from the point of view of the heterogeneous multikernel operating system

Moving from the single kernel operating system design to the multikernel operating system design require including of the new function of the limited set of the functions of the classical microkernel's – inter-kernel communication. Implementation of this function on the kernel side links all separated kernels into a single operating system network. From the point of view the network consist from the number of communication scopes, one of which is global. Each of the operating system nodes by default is included to the global scope and to the arbitrary number of the other communication scopes. Upon attaching to the scope kernel automatically get access to the broadcast communication channel between all kernels of this scope and can register unicast communication channel. Implementation of the communication channels is based on the message passing on the shared memory region enforced by inter-processor interruptions.

It must be noted that the presented operating system design can be used for building operating systems of four types:

- Homogenous operating system on the homogenous hardware platform. (The classical SMP system where all kernels deliver the same interface.)
- Homogenous operating system on the heterogeneous hardware platform. (The system from mix of the different processors, where all kernels deliver the same interface.)
- Heterogeneous operating system on the homogenous hardware platform. (The classical SMP system, where API provided by kernels can differ from kernel to kernel.)
- Heterogeneous operating system on the heterogeneous hardware platform. (The system from mix of the different processors, where API provided by kernels can differ from kernel to kernel.)

Actually building OS from the source code could be replaced with constructing OS from the set of already compiled kernel binaries, which can be delivered by different distributors.

From the other point of view dividing operating system to the set of independent nodes improves the flexibility, security and reliability. Because the compromising of one of the kernels in the system from the one hand is almost impossible due to microkernel design and from another hand don't compromise the overall system. In the same way, crash in the kernel from one hand is almost impossible due microkernel design and from another hand the kernel crash won't stop all the system.

## **2. Conclusion**

This paper presents the research work focused on the field of operating system and kernel design. The purpose of the work is to develop the operating system design and architectural approaches for the most actual computer systems: heterogeneous computer systems based on multi-core processors and embedded, real-time computer systems focused on fully automatic, robotic and cyber-physical systems. The focus of our research is to get the qualitative changes benefits based on the hardware platform improvements in contrast to the goals of the Barellfish project focused on the performance and scalability [4]. The raw micro-kernel has been developed to check the proposed operating system design and other kernel features. Unfortunately, the limited amount of time and lack of hardware prevented the full performance analysis and comparison with other modern kernels.

The main result of this research project is concept of heterogeneous multi-kernel operating system design. This concept propose not only minimization of the kernel and excluding as much functionality as possible from it, but also splitting the traditionally sole kernel to the set of significantly independent micro-kernels, each utilizing one of the processors or processor cores in the system. In addition it proposes switching from centralized operating system kernel to decentralized set of the operating system kernels. As a result, it suggests to look at the operating system as at the decentralized distributed computer tightly coupled network. Also it tries to look at the parallelism problem from another point of view, at which application executes on the same processor all the time by default, and can be extended or moved to another processor only by direct request to the native kernel and approving of request from the kernel on with the application want to come. This approach provides the numbers of advantages:

- The kernel become simpler due to multiprocessor synchronization becomes unnecessary.
- The most of applications running on the computer systems don't need so big computation power to use more than one processor.
- Locking application on one processor offers more productive utilizing of processor cache and relieves locking and traffic of the CPU-RAM bus.
- Proposed design makes it easy to port operating system from the most popular SMP computer systems to the more perspective NUMA computer systems.
- Provides great level of configurability due to proposed design base on the microkernel architecture concept and inherits all its key advantages.

Along with already mentioned advantages, the proposed design of the heterogeneous multi-kernel provides a number of the unique features, that can't be produced by the modern operating systems.

The first advantage is native portability and supporting of heterogeneous computer systems that seems to be a very perspective way of computer systems development. We can just mention such projects as IBM Cell processor and project of hybrid notebook that incorporates both x86 and ARM processors at the same time. Development of processors with specialized cores looks as very attractive idea along with the achievements in transistor microelectronics limits. One more point must be noted according to this advantage. The rapid development of FPGA technologies makes it possible to create computer system that will combine the traditional processors with FPGA chips. Such computer systems will have possibility to form optimized specialized for some computation processor cores on the fly. Such systems would require rapid changing of the operating system kernel and other software that will be executed on the soft processor at the FPGA chip.

The second key advantage provided by proposed heterogeneous operating system design is full software dynamics. It means that in such systems all software components can be replaced on the fly without any rebooting or shutdown of the computer system and without stopping the service of clients. At the one hand, in long term perspective, it allows making full software upgrade, moving to the new operating system, patching the kernel and any other such stuff on the fly. At the other hand, in short term perspective, change the operating system features, properties and behavior on the fly in response to the rapidly changing requirements. For example, it will be possible to switch from general purpose or media focused operating system kernel to the kernel that can satisfy real-time requirements and after some critical work switch back to the general purpose kernel. It also will be possible to switch to the real-time mode not all computer system but only some part of the system. In perspective, it can lead to creation such type of the computer system in which it will be possible to change, add or remove any hardware and software components including processors and memory without shutdown (something like advanced plug and play technology that will cover all computer system but not only several types of the peripheral devices).

And finally the third key advantage provided by proposed heterogeneous operating system design is unprecedented fault tolerance based on combination of key microkernel design advantages, excellent fault tolerance features that are consequence from the decentralized autonomous nature of the design and advanced opportunities for critical functionality duplicating. It will be possible to build computer system based on this design that can be broken only due to overall hardware fault (for example, power off). The possible software faults on all levels, starting from level of applications and ending on the kernel level can be recovered without data loss and only with small loss of time estimated by several microseconds.

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