

Rate-based Page Fault Handling Mechanism for Soft Real-time Task

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Abstract

In virtual memory system, whenever a new task is dynamically launched, it suffers from transient overload that caused by excessive page fault handling. As transient overload state occurred, the QoS of multimedia application may be degraded because the deadline miss ratio is increased. In this paper, we suggest new methodology that supports soft real-time task efficiently. To improve real-time characteristics in memory management, we present efficient memory management techniques called Rate-based Page Fault Handling mechanism. With these mechanism, we can support soft real-time characteristics in memory constraint situation. A significant feature of the mechanism is resource reservation for kernel activity and page fault dispersion based on per process limit.

We implement the memory management mechanism on Linux kernel and present the experiment results with Berkeley MPEG-1 video decoder. Experiment result shows that our mechanism could achieve 10%-20% reduction in deadline miss ratio and 50%-60% reduction in average delay.

1. Introduction

Today's general-purpose operating systems are required to support a mix of conventional best effort, throughput-intensive and soft real-time applications. Especially, soft real-time applications have time-constrained data types such as digital audio and video. Audio and video streams periodically change the values of the media data over time, and they must be presented at a specific deadline. A key of designing a multimedia system is whether media data are handled properly in terms of time. Therefore, the importance of a scheduling algorithm is well recognized, and real-time scheduling techniques[1, 2, 3, 4, 5, 6, 7]

have been used. Although they are important for a multimedia system, the area of memory management has been totally ignored and is not supported any concept of Quality of Service. In this paper, we focus on transient overload state that caused by virtual memory architecture. In virtual memory system, whenever a new task is dynamically launched, virtual memory system suffers from extensive page fault that cause transient overload state. When a process attempts to access a page that is not resident in memory, the system generates page fault event and handles fault that causes unpredictable delay. So current virtual memory system is not appropriate for real-time system, because it can increase the deadline miss ratio of real-time task.

In this paper, we discuss about transient overload caused by excessive page fault handling. Furthermore, we suggest ideas that prevent transient overload. The contribution of this paper is as follows. First, we show how to control excessive page fault in current virtual memory system. Second, we consider several real-world applications and demonstrate that RAPHA(Rate-based Page Fault Handling) enable to provide benefits such as predictable resource management. For instance, we show that RAPHA enables a multimedia player to display MPEG-1 files at their real-time rates regardless of the transient overload state. Finally, we show that the implementation overheads of resource management techniques are small, making them a practical choice for general-purpose operating systems such as Solaris[21] and Linux [22].

The rest of this paper is structured as follows. Section 2 describes related works, and section 3 presents current virtual memory problems and discusses about transient overload state. Section 4 discusses the principles underlying the design of RAPHA and briefly describes each component employed by RAPHA. Section 5 presents the results of our experimental evaluation, and finally, Section 6 presents some concluding remarks.

2. Related Works

The growing popularity of the multimedia application has resulted in several research efforts that have focused on the design of predictable resource management mechanisms. The problem of ensuring that applications are guaranteed a required quality of service and do not violate certain restrictions on resource usage has recently attracted a lot of attention. Consequently, several resource management techniques have been proposed for the predictable allocation of memory [8, 9, 10, 11, 12, 13, 14, 15, 16].

One way to support predictable memory management is memory-wiring technique. In traditional Unix environment, the function *mlock(addr, len)* causes those whole pages containing any part of the address space of the process starting at address *addr* and continuing for *len* bytes to be memory resident until unlocked or until the process exits. While memory wiring prevent real-time task from being paged out, it could not prevent transient overload when a task is dynamically created environment. Furthermore, the excessive use of *mlock()* tends to lead overall process to starvation. Resource reservation model is widely used in various operating systems such as real-time Mach [1], Rialto [19] and Eclipse [20]. This scheme is implemented reservation-based resource scheduling that guarantees applications a predictable resource share over periodic time interval. Although resource reservation is widely used, however, resource reservation model has been focused on CPU and disk issues. Another mechanism to support predictable memory management is external pager such as Nemesis[10], V++[11], Exokernel[15], SPIN[17] and VINO[18]. External pager mechanism allows the use of one or more external pagers in order to provide application specific paging policy. With external pager mechanism, operating system can support QoS for multimedia task and provide flexibility and extensibility. But external pager is only interested in application specific paging policy and memory utilization.

3. Transient Overload Problem

Although the current general-purpose computer system is equipped with much more memory capacity than before, memory requirement for application is not sufficient. As there is much less physical memory than virtual memory, the operating system must be careful that it does not use the

physical memory inefficiently. One way to save physical memory is to only load virtual pages that are currently being used by the executing program. This technique of only loading virtual pages into memory as they are accessed is known as demand paging mechanism. Traditionally, general-purpose operating system uses demand paging to load executable images into a processes virtual memory. Whenever a command is executed, the file containing it is opened and its contents are mapped into the processes virtual memory. This is done by modifying the data structures describing this processes memory map and is known as memory mapping. However, only the first part of the image is actually brought into physical memory. The rest of the image is left on disk. As the image executes, it generates page faults and virtual memory system uses the processes memory map in order to determine which parts of the image to bring into memory for execution.

When a process attempts to access a virtual address that is not currently in memory, a page fault is generated. The instruction must be halted, and determine the cause of a page fault. The page fault handler gets control as a result of the machine raising a page fault exception. If the faulting virtual address is invalid this means that the process has attempted to access an invalid virtual address. In this case, currently running process is signaled by kernel, and terminated abnormally. If the faulting virtual address was valid but the page that it refers to is not currently in memory, the operating system must bring the appropriate page into memory from the image on disk. In this case, if there is no unused frame in memory, scan the physical memory for selecting a victim page. If necessary, allocate space on the backing store to receive the contents of the victim page and initiate I/O to write the contents of the victim page to the backing store. After this, adjust the page table for the process to which the victim page belongs to reflect the fact

that it is no longer resident in memory. The memory management module locates the page for which the fault was generated on the backing store and initiate I/O to load the page into the page frame. The fetched page is written into a free physical page frame and an entry for the virtual page frame number is added to the processes page table. The process is then restarted at the machine instruction where the memory fault occurred. In page fault handling, a disk access takes a long time, and so the process must wait quite a while until the page has been fetched. If there are other processes that could run then the operating system will select one of them to run. Because page fault handling is urgent kernel task and requires excessive CPU load and I/O load, operating system falls into transient overloading state.

We show transient overload state in general-purpose operating system while executing diverse real applications such as Netscape, gimp, gzip, find and mpeg_play. Table 1 shows application characteristics and figure 1 shows the required RSS(Resident set size) of each application. The RSS means resident memory frame of each application.

Table 1. Application characteristics (byte)

	gimp	netscape	gzip	find	mpeg_play
text	1683884	11616067	46829	72148	138363
data	138100	2013332	3072	592	8120
bss	347044	317412	329264	604	941636
total	2169028	13946811	379165	73344	1088119

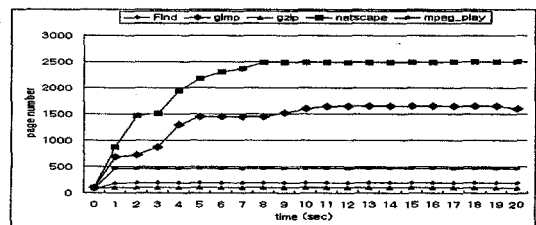


Figure 1. RSS of applications

Figure 2 shows the frequency of page fault when

Netscape web browser is launched. The x-axis is the elapsed time, and the y-axis is the number of page fault. In this figure, we can find that excessive page fault is occurred when task is launched. Excessive page fault lead the system to unstable state that causes temporal overload state.

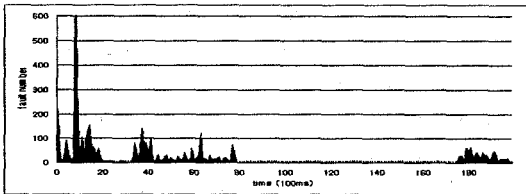


Figure 2. Frequency of page fault in Netscape web browser

When transient overload state occurs, real-time task such as multimedia task may miss deadline. Figure 3 represents the deadline miss in the decoding time. We measured the decoding time of a MPEG-1 movie clip with `mpeg_play` (`mpeg_play` is a Berkeley MPEG-1 decoder). The x-axis is the video sequence, and the y-axis is the deadline. If y-axis value is under 0, deadline miss occurred in `mpeg_play`. When `mpeg_play` is running, we launched Netscape web browser about 6 second after. In this figure, the result shows that excessive deadline miss occurred when there is newly launched task.

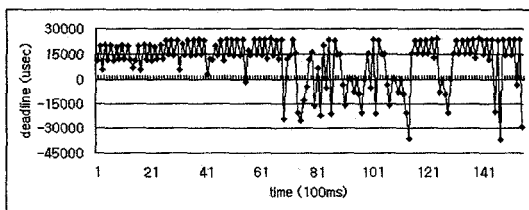


Figure 3. Deadline misses in `mpeg_play`

4. System Design

In section 3, It is obvious that an application that

fault repeatedly will still degrade the overall system performance. In particular, they will adversely affect the operation of other application. What is required is a system whereby applications benefit from the ability to reserve their execution and not affected by excessive page fault load. In this section, we describe about RAPHA mechanism. A significant feature of the RAPHA algorithm is page fault dispersion that keeps page fault ratio from exceeding available bound by monitoring current system resources. Figure 4 shows RAPHA layout.

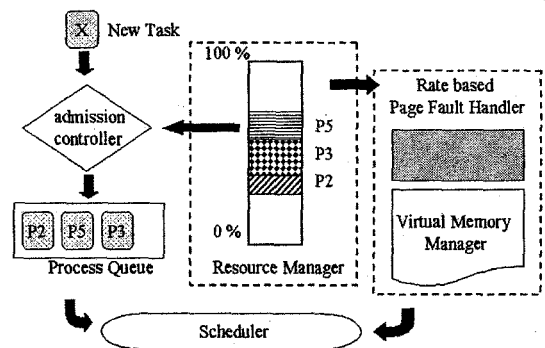


Figure 4. Rate based page fault handling layout

4.1 Resource allocation stage

Admission controller abstracts system resource and uses reserves as predictable resource management. In this paper, we used resource reservation mechanism in real-time Mach [1]. Reserves used in real-time Mach prevent applications from over-running their allowed resource usage and interfering with other reserved activities or starving unreserved activities. In real-time Mach, applications reserve capacity on the resources they need to carry out their computations. For example, applications can reserve 10% processor capacity (10ms of computation time on a processor for every 100ms). The application then binds to the reserve, and the processor scheduler uses the information associated with the reserve to control the scheduling of the application. In Real-time Mach, resource reservation algorithm reserves system resource only for

application itself and does not accurately count system resource. Because the page fault-handling load is not counted for each application reserve, unexpected virtual memory behavior makes system into unpredictable. In this paper, we try to reserve the kernel activity such as page fault handling. The key role of RAPHA is monitoring system resource and reserves required resource for page fault handling.

4.2 Page fault handling stage

In RAPHA, when page fault occurred, the number of page fault is counted. If the page fault-handling interval is expired, new fault period is inserted. If excessive page fault is occurred and page fault upper bound is reached, page fault handling is postponed. Figure 5 shows pseudo code of RAPHA.

```

FUNCTION : PAGE_FAULT_HANDLER
  if( system.fault_period is expired)
    system.fault_period= SYS_FAULT_PERIOD ;
    system.fault_count = 0 ;
  else
    system.fault_count++;
    if (system.fault_count > system.fault_limit)
      call swapper;
  if ( task(i).fault_period is expired)
    task(i).fault_period= TASK_FAULT_PERIOD ;
    task(i).fault_count = 0 ;
  else
    task(i).fault_count ++ ;
    if( task(i).fault_count > task(i).fault_limit)
      suspend task ;
  end PAGE_FAULT_HANDLER

```

Figure 5. Rate based page fault handler

The proposed algorithm uses the following notation:

- `fault_unit` : processor capacity for processing one page fault
- `task(i).pc` : processor capacity for task i.
- `task(i).fault_period` : fault processing interval for

task i

- `task(i).fault_count` : the number of page fault during fault processing interval for task i;
- `task(i).fault_limit` : upper limit fault count for task i;
- `system.pc` : sum of all task's processor capacity
- `system.fault_count` : the number of page fault during fault processing interval for system;
- `system.fault_period`: fault processing interval for system
- `system.fault_limit` : sum of all task's `fault_limit`
- `system.fault_pc` : processor capacity for system page fault

5. Evaluation

In this section, we experimentally evaluate the performance of RAPHA in modified Linux kernel, so called, LMX(Linux Multimedia Extension) that composed of admission control, resource manager and RAPHA mechanism. In particular, we examine the efficacy of the memory resource management mechanisms within RAPHA to (i) keep page fault ratio from exceeding available bound by monitoring current memory resources, (ii) allocate memory bandwidth in a predictable manner, and (iii) provide memory isolation. We use several real applications, benchmarks for our experimental evaluation. We first describe the test-bed for our experiments and then present the results of our experimental evaluation. The test-bed for our experiments consists of 500MHz Pentium II CPU and 64MB RAM and equipped with a 100Mb/s 3-Com Ethernet card. The Linux kernel version in our experiments is based on the 2.2.4. The workload for our experiments consists of combination of real-world applications, benchmarks, and sample applications that we wrote to demonstrate specific features.

A number of simple experiments have been carried out to illustrate the operation of the system so far

described. The purpose of these experiments is to show the behavior under same load and how efficiently multimedia task will be executed with RAPHA. We use mpeg_play for multimedia task and measured the performance. Our experimental environment stressed the system with constant CPU load, and measured the page fault frequency. Figure 6 shows excessive page fault occurred without RAPHA while figure 7 shows dispersed page fault frequency. In this experiment, we can conclude that RAPHA efficiently control page fault and get rid of transient overloading state.

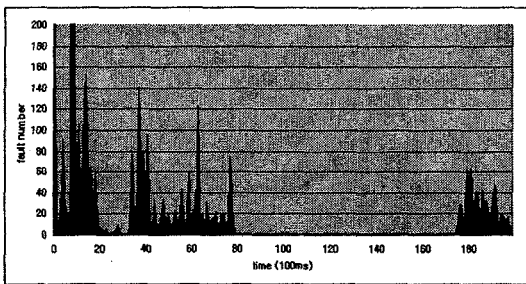


Figure 6. Frequency of Netscape page fault(Linux kernel)

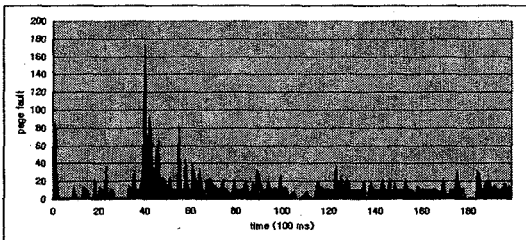


Figure 7. Frequency of Netscape page fault(LMX)

Figure 8 shows the resident set of physical page with RAPHA and without RAPHA. The growth of RSS with RAPHA is slowly increased, but the other shows sharp curve. The sharp curve means excessive memory requirements, so if there is not enough memory, paging overhead will be high. Figure 9 shows how multimedia application works. Experiment result shows mpeg_play works well with

RAPHA. In figure 9, deadline miss rate reduced to 10 % and average delay reduced to 50%. Average delay and miss rate is quite important for multimedia system, because it represents QoS of multimedia application.

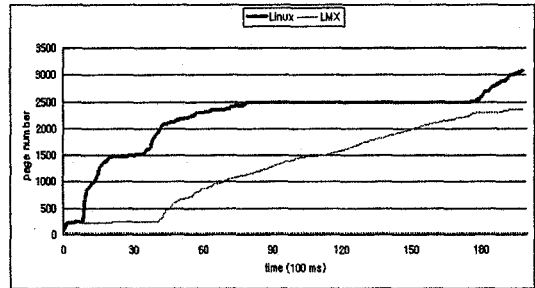


Figure 8. RSS of Netscape web browser

	frame number	deadline miss	miss rate(%)	average delay
LINUX	500	161	32.2	15054
LMX	500	110	22	6954

Figure 9. Deadline miss ratio analysis

6. Conclusion

Emerging multimedia and real applications require conventional operating systems to be enhanced along several dimensions. In this paper, we presented the problems of virtual memory when a task is dynamically launched and how multimedia task influenced. We have argued that the cost of page fault is too high to be hidden from the application, and excessive page fault makes real-time task from isolation. Without isolation, real-time task miss its deadline.

RAPHA employs two key components; the rate based page fault handling and resource reservation for kernel activity. Our experimental results showed that multimedia application could indeed benefit from predictable RAPHA mechanism and application isolation offered. As part of future work, we plan to

enhance soft real-time memory management along several dimensions. In particular, we are designing seamless cooperation mechanism among processor, memory and disk.

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