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Avoiding C/C++ Dynamic Memory Problems with Parasoft Inuse

Introduction

One of the most important features of modern computing languages is the ability to dynamically allocate memory blocks. This freedom allows algorithms to be created in much more flexible ways than is possible with static memory allocation. However, this freedom comes with a price. A program does not always use dynamic memory in the manner intended by the developer. As a result, memory leaks, bottlenecks and other problems arise unexpectedly. Traditionally, the only way to counter such problems has been to add a lot of extra code to your application to print out information about the memory blocks that get allocated and freed. Unfortunately, this process is at best tedious and at worst not very informative.

This paper will describe the types of dynamic memory problems which developers and end-users frequently encounter. A new tool which helps developers solve memory problems quickly and intuitively will also be described.

Use and Abuse of Dynamic Memory

Many modern algorithms make heavy use of dynamic memory, but few take any great precautions to insure they achieve the best possible use of the memory system. As a result, many applications can benefit from streamlining their memory usage or modifying the order of their allocation requests to reduce the fragmentation that takes place when memory is allocated and freed.

Many algorithms also contain subtle “memory leaks” in which the program consumes growing amounts of memory as it runs, until the resources of the host are finally exhausted and the program crashes--sometimes days or even weeks after starting.

As stated previously, the only solutions to these problems have involved print statements that were time-consuming to set up and not always helpful once added. Fortunately, a new solution is now available to aid developers in optimizing memory usage.

A New Solution to Overcoming Memory Problems

Parasoft Inuse, a graphical memory display/animation tool included in Parasoft Insure++, is designed to help developers avoid memory problems by displaying and animating in real time the memory allocations performed by an application. By watching your program allocate and free dynamic memory blocks, you gain a better understanding of the memory usage patterns of your algorithms and also an idea of how to optimize their behavior.

Inuse allows you to:

- Look for memory leaks.
- See how much memory your application uses in response to particular user events.
- Check on the overall memory usage of your application to see if it matches your expectations.
- Look for memory fragmentation to see if different allocation strategies might improve performance.
- Analyze memory usage by function, call stack, and block size.

Avoiding Memory Problems with Inuse

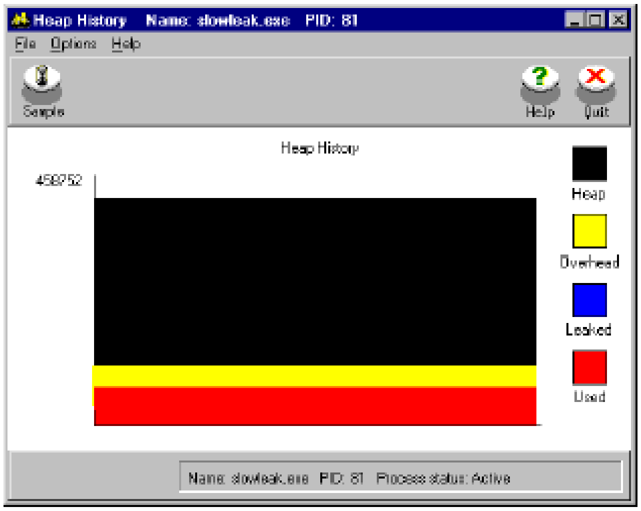
Inuse can help you detect and avoid more than just memory leaks. It can show you most common memory problems, including memory blowout, memory fragmentation, memory overuse, and memory bottlenecks.

Memory Blowout

Many programers are not aware of the danger which memory blowout poses for commercial and industrial applications.Memory blowout is very common in many programs because the operating system allocates pages of memory to the program and never releases them. Other programs running on this machine will then be starved for memory and crash.

How does memory blowout happen? A program allocates a large chunk of memory for use and after it is done with it, frees it. At that moment, the freed memory can be reused by the program, but it is not released to the operating system. The reason for this is that when memory was allocated by the program, the operating system allocated all the needed memory pages. The operating system then will not release the memory pages, even after they are freed by the program, until the program is exited. As a result, other programs running on the machine needing memory will ultimately crash.

Inuse can help you prevent memory blowouts. Figure 1 shows the Heap History report generated by Inuse for a program showing memory blowout. This problem can be easily identified by the large size of the heap and the small amount of allocated memory. This shows up on the Inuse display as a low ratio of allocated memory to heap space.Without Inuse, it would be difficult-- if not impossible-- for most developers to detect this impending “catastrophe.”



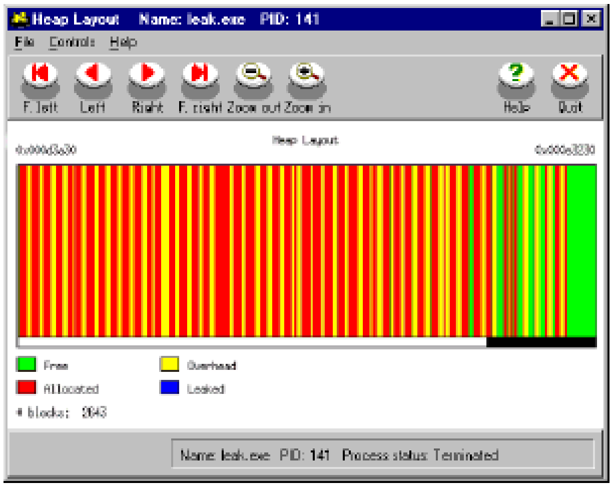
Heap History Name: slowleak.exe PID: 81

Name: slowleak.exe PID: 81 Process status: Active

Figure 1. Memory Blowout

Memory Fragmentation

Most programs which use a lot of dynamic memory are risking the danger of memory fragmentation. Memory fragmentation can be caused by overuse of memory. This slows down memory allocation. For example, when a program allocates and frees small and large memory blocks interchangeably, the programmer will expect the total amount of allocated memory to remain constant. However, memory allocation routines cannot fit blocks of memory in freed spaces that are the wrong size. This will lead the program to request new pages for memory from the operating system. This will cause the program to consume more memory and ultimately run out of dynamic memory without leaking a single byte. Developers can use Inuse’s Heap Layout report to monitor memory fragmentation in their program (See Figure 2). They can immediately see the layout of dynamically allocated blocks and the free spaces in between them. By simply clicking on a block, the status of the block, its memory address, its size, and the stack trace where it was allocated are displayed. Another way that memory fragmentation shows up on Inuse is by a large amount of Overhead in the Heap History graph.



blocks: 2043

Name: leak.exe PID: 141 Process status: Terminated

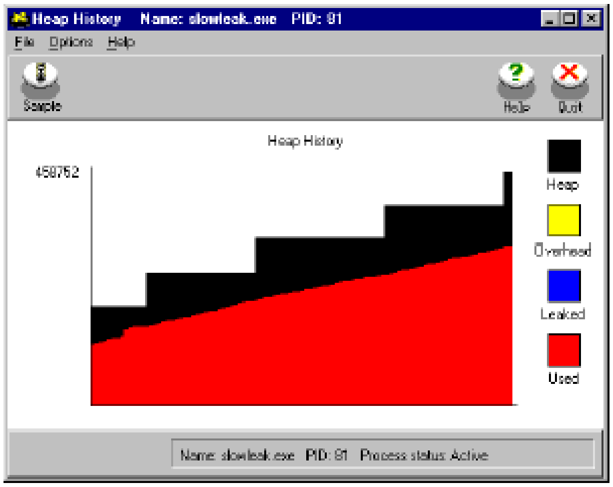
Figure 2. Monitoring Fragmented Memory

Inuse can help developers identify and overcome many additional memory problems, including Memory Overuse and Memory Bottlenecks.

Memory Overuse (Hogging)

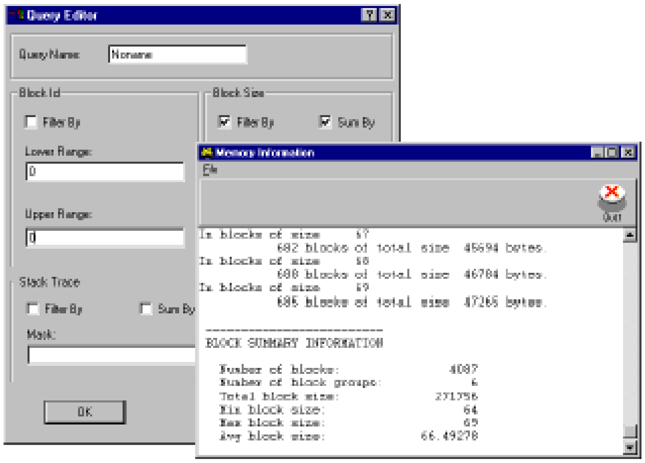
This is a common problem for many programs. Memory is allocated by a program and never freed. The memory is not leaked, because pointers still stay in the program and can be freed, but the program does not do it. As a result, the program uses more and more memory until it runs out and crashes.

Memory overuse can be viewed on the Heap History graph. If the amount of leaked memory is negligible and stays constant, or Insure++ does not report any leaks but Heap History exhibits a stairway pattern (as in Figure 3), the program is hogging memory and eventually will run out of memory. In this case, the programmer should use the Query report to look for totals of memory allocated for different stack traces. The stack trace for which the total amount of allocated memory continues growing likely points to the offending line of the source code (see Figure 4). At that moment, the programmer should analyze the code and verify that indeed, the program needs to allocate memory at that stage and needs to keep it. If it doesn't, this is an algorithmic problem and needs to be fixed.



Name: slowleak.exe PID: 81 Process status: Active

Figure 3. Memory Hogging



Query Name: Noname

Block Id: ☐ Filter By

Lower Range: 0

Upper Range: 0

Block Size: ☑ Filter By ☑ Sum By

Stack Trace: ☐ Filter By ☐ Sum By

Mask:

```
In blocks of size     67
           682 blocks of total size  45694 bytes.
In blocks of size     68
           688 blocks of total size  46784 bytes.
In blocks of size     69
           685 blocks of total size  47265 bytes.

 -------------------------
 BLOCK SUMMARY INFORMATION

   Number of blocks:                 4087
   Number of block groups:              6
   Total block size:               271756
   Min block size:                     64
   Max block size:                     69
   Avg block size:               66.49278
```

Figure 4. Analyzing Memory with Query

Memory Bottlenecks

Bottlenecks occur when an operating system spends more time paging memory than running the program. Memory bottlenecks frequently arise when a program uses large amounts of dynamic memory or calls large amounts from different parts of the program. They are particularly problematic because a program may perform well in-house but stop dead in the field.

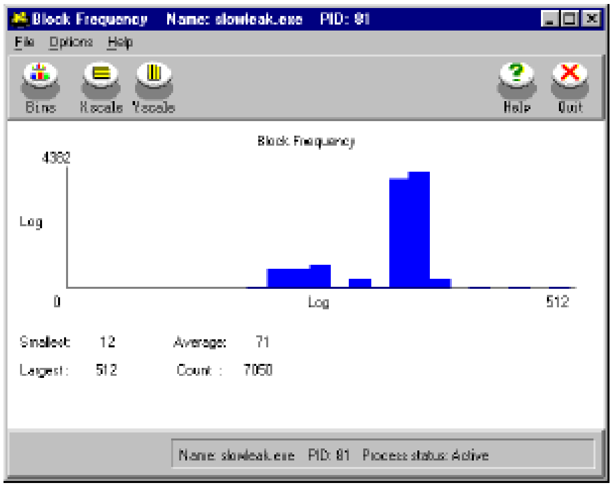
Paging can slow down execution of the program by a factor of 100, effectively stopping the program from running. A program may perform in-house without having to page, but this can change when different conditions are introduced. A customer might have less memory or be crunching much more data than the program was tested with. As a result, the program uses a larger portion of memory and forces the operating system to page. The problem is compounded if the program accesses a lot of memory from different locations.

To avoid this problem, the program should be analyzed in respect to how much memory different parts of the program need and if that need is warranted. The Query feature of Inuse enables developers to calculate how much memory is allocated by a specific path, routine, or block type. This type of analysis is critical for understanding algorithmic problems and can make it much easier to improve memory performance.

Inuse Gives You the “Truth” About Your Program’s Memory Use

When developers write their programs, they usually have some idea how memory should be allocated by the program. This idea is typically far from what the program is actually doing. Inuse lets developers see the “truth” about their programs by visualizing memory allocation at runtime.

Developers can single-step the program by setting breakpoints at calls to `malloc, free, new, delete, realloc` and then watch allocations in Inuse as they happen. This works as a confirmation of an algorithm's performance and it shows if the program works correctly or not. Single-stepping should be done just after a program is first built. By checking memory usage early, you can save a lot of headaches down the road. Also, you can spot significant algorithmic problems. It is particularly useful at this stage to look at the Block Frequency graph of Inuse (see Figure 5). This graph will show the distribution of memory blocks.



Block Frequency   Name: slowleak.exe   PID: 81

Smallest: 12   Average: 71

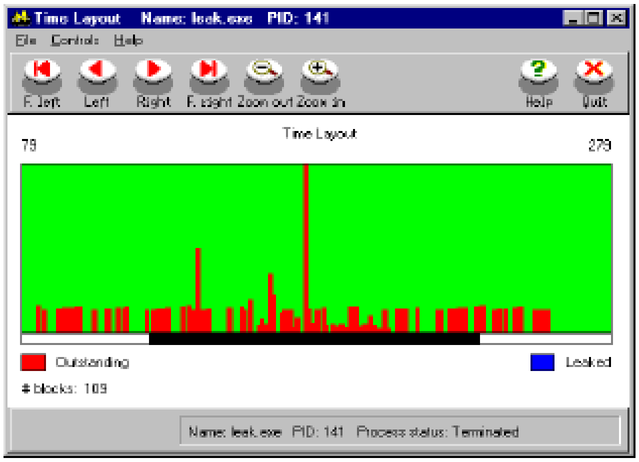
Largest: 512   Count : 7050

Name: slowleak.exe   PID: 81   Process status: Active

Figure 5. Viewing Block Frequency

Cleaning Up Leaks

Not all leaks in a program have to be cleaned. Leaks are only deadly if they reoccur constantly. Leaks which occur only at the beginning of a program can, in most cases, be ignored. However, leaks which occur during the execution of a program--especially ones in parts containing loops--are deadly and need to be fixed. The severity of a leak can be easily determined using the Time Layout display of Inuse (See Figure 6). This diagram shows blocks as they are allocated in time sequence. All leaks concentrated at the initial stage of program can be safely ignored. On the Time Layout display, clicking on a block will show its size, address, and stack trace where it was allocated.



blocks: 109

Name: leak.exe PID: 141 Process status: Terminated

Figure 5. Checking the Timing of a Leak

Using Inuse with Insure++: An Example

Running Inuse with Insure++ can be very effective in detecting different dynamic memory anomalies, as you are provided with the most thorough debugging information available combined with the unique visual perspective of Inuse. Consider the following program:

```
1: #include <stdlib.h>
2: #include <stdio.h>
3:
4: #define MAXSLOTS 16
5: main()
6: {
7: int i, which;
8: char **pp;
9:
10: while(1) {
11: pp = (char **)malloc(MAXSLOTS*sizeof(char *));
12: for(i=0; i<MAXSLOTS; i++) {
13: pp[i] = malloc(64+i);
14: }
15: sleep(1);
16: for(i=0; i<MAXSLOTS; i++) {
17: which = (rand() >> 4) % MAXSLOTS;
18: if(pp[which]) {
19: free(pp[which]);
20: pp[which] = 0;
21: }
22: }
23: free(pp);
24: }
25: exit(0);
26: }
```

The above program has a memory leak. One way to detect the leak is to compile the program with Insure++ and run it. Insure++ will report an error at line 23 and give you a complete diagnosis of the problem. The leak will also appear graphically in Inuse reports, letting you see exactly how it affects the program at runtime. By running Inuse and Insure++ together, you are getting the ultimate memory checking solution. You will be able to visually “see” the leak happen then get all the information you need to fix the problem. For more information on how Insure++ can automatically detect large classes of memory, compilation, and runtime errors, see the Insure++ white paper.

Conclusion

Dynamic memory is a powerful and convenient feature of modern computing languages. However, it can be difficult for a developer to fully understand the implications of dynamically allocating memory blocks in a program. Inuse was designed to automate this process and present memory usage data in an intuitive, informative format. With the introduction of Inuse, developers can finally understand just how their programs are using (and abusing) memory.

Learning More

Inuse is available with Insure++ at http://www.parasoft.com. To learn more about how Inuse, Insure++, and other Parasoft solutions can help your organization prevent errors, contact Parasoft today or visit http://www.parasoft.com.

In addition, Parasoft packages customizable solutions that provide a team-wide, full-lifecycle error prevention strategy. Based on the Parasoft AEP Methodology, these solutions ensure consistent and uniform behavior across development teams by providing infrastructure, technologies, configuration, and training to support full-team operation. For details on these solutions, contact Parasoft.

About Parasoft

Parasoft is the leading provider of innovative solutions for automated software test and analysis and the establishment of software error prevention practices as an integrated part of the software development lifecycle. Parasoft's product suite enables software development and IT organizations to significantly reduce costs and delivery delays, ensure application reliability and security and improve the quality of the software they develop and deploy through the practice of Automated Error Prevention (AEP). Parasoft has more than 10,000 clients worldwide including: Bank of America, Boeing, Cisco, Disney, Ericsson, IBM, Lehman Brothers, Lockheed, Lexis-Nexis, Sabre Holdings, SBC and Yahoo. Founded in 1987, Parasoft is headquartered in Monrovia, CA. For more information visit: http://www.parasoft.com.

Contacting Parasoft

USA

101 E. Huntington Drive, 2nd Floor
Monrovia, CA 91016
Toll Free: (888) 305-0041
Tel: (626) 305-0041
Fax: (626) 305-3036
Email: info@parasoft.com
URL: www.parasoft.com

Europe

France: Tel: +33 (1) 64 89 26 00
UK: Tel: + 44 (0)1923 858005
Germany: Tel: +49 7805 956 960
Email: info-europe@parasoft.com

Asia

Tel: +886 2 6636-8090
Email: info-psa@parasoft.com

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