# Case study with atop: memory leakage

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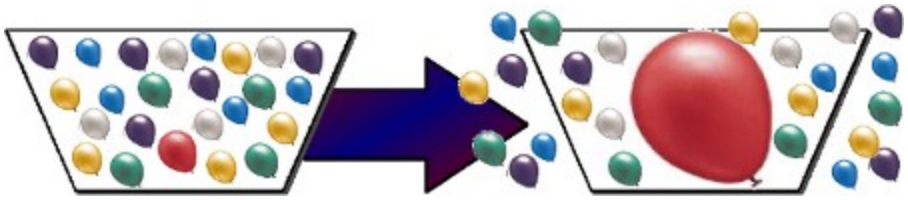
This document describes the analysis of a slow system suffering from a process with a memory leakage. Such process regularly requests for more dynamic memory with the subroutine `malloc`, while the programmer has “forgotten” to free the requested memory again. In this way the process grows virtually as well as physically. Mainly by the *physical* growth (the process' resident set size increases), the process inflates like a balloon and pushes other processes out of main memory. Instead of a healthy system where processes reach a proper balance in their memory consumption, the total system performance might degrade just by one process that leaks memory.



Notice that the Linux kernel does not limit the physical memory consumption of processes. Every process, either running under root identity or non-root identity, can grow unlimited. In the last section of this case study, some suggestions will be given to decrease the influence of leaking processes on your overall system performance.

In order to be able to interpret the figures produced by `atop`, basic knowledge of Linux memory management is required. The next sections describe the utilization of physical memory as well as the impact of virtual memory before focussing on the details of the case itself.

## Introduction to physical memory

The physical memory (RAM) of your system is subdivided in equally-sized portions, called *memory pages*. The size of a memory page depends on the CPU-architecture and the settings issued by the operating system. Let's assume for this article that the size of a memory page is 4 KiB.

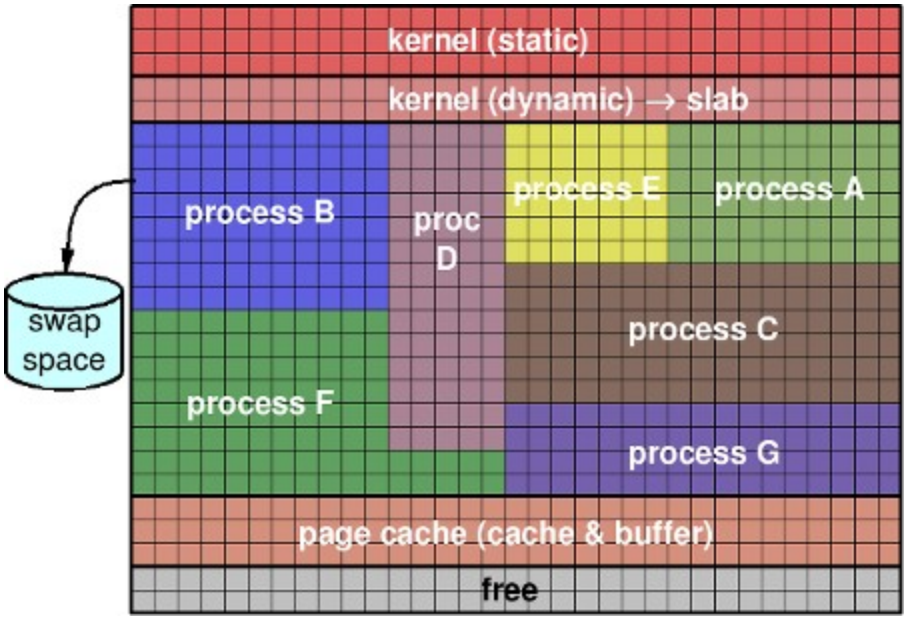
At the moment that the system is booted, the compressed kernel image – known as the file `/boot/vmlinuz-....` – is loaded and decompressed in memory. This static part of the kernel is loaded somewhere at the beginning of the RAM memory.

The running kernel requires however more space, e.g. for the administration of processes, open files, network sockets, ... but also to load dynamic loadable modules. Therefore, the kernel dynamically allocates memory using so-called “slab caches”, in short *slab*. When this dynamically allocated kernel memory is not needed any more (removal of process administration when a process exits, unloading a loaded module, ....), the kernel might free this memory. This means that the slab space will shrink again. Notice that all pages in use by the kernel are memory resident and will never be swapped.

Apart from the kernel, also processes require physical pages for their text (code), static data and stack. The physical space consumed by a process is called “Resident Set Size”, in short *RSS*. How a page becomes part of the RSS will be discussed in the next section.

The remaining part of the physical memory – after the kernel and processes have taken their share – is mainly used for the *page cache*. The page cache keeps as much data as possible from the disks (filesystems) in memory in order to improve the access speed to disk data. The page cache consists of two parts: the part where the data blocks of files are stored and the part where the metadata blocks (superblocks, inodes, bitmaps, ...) of filesystems are stored. The latter part is called the “buffer cache”. Most tools (like `free`, `top`, `atop`) show two separate values for these parts, resp. “cached” and “buffer”. The sum of these two values is the total size of the page cache.

The size of the page cache varies. If there is plenty free memory, the page cache will grow and if there is a lack of memory, the page cache will shrink again.




Finally, the kernel keeps a pool of free pages to be able to fullfill a request for a new page and deliver it from stock straight away. When the number of free pages drops below a particular threshold, pages that are currently occupied will be freed and added to the free page pool. Such page can be retrieved from a process (current page contents might have to be swapped to swap space first) or it can be stolen from the page cache (current page contents might have to be flushed to the filesystem first). In the first case, the RSS of the concerning process shrinks. In the second case, the size of the page cache shrinks.

Even the slab might shrink in case of a lack of free pages. Also the slab contains data that is just meant to speed up certain mechanisms, but can be shrunk in case of memory pressure. An example is the *incore inode cache* that contains inodes of files that are currently open, but also contains inodes of files that have recently been open but are currently closed. That last category is kept in memory, just in case such file will be opened again in the near future (saves another inode retrieval from disk). If needed however, the incore inodes of closed files can be removed. Another example is the *directory name cache* (dentry cache) that holds the names of recently accessed files and directories. The dentry cache is meant to speed up the pathname resolution by avoiding accesses to disk. In case of memory pressure, the least-recently accessed names might be removed to shrink the slab.

In the output of `atop`, the sizes of the memory components that have just been discussed can be found:

```
ATOP - sammy          2010/03/02  16:14:33          ----             10s elapsed
PRC | sys    0.45s | user   6.12s | #proc    220  | #zombie    0 | #exit      0 |
CPU | sys      4% | user    61% | irq       0%  | idle    134% | wait      0% |
CPL | avg1    0.31 | avg5    0.34 | avg15   0.62  | csw     8414 | intr   22038 |
MEM | tot     3.8G | free    2.3G | cache 322.7M  | buff  249.9M | slab  152.8M |
SWP | tot     8.0G | free    7.7G |               | vmcom   1.8G | vmlim   9.9G |
LVM |  vg00-lvhome | busy      1% | read       0  | write      5 | avio 11.0 ms |
LVM |   vg00-lvtmp | busy      0% | read       0  | write     31 | avio 1.42 ms |
DSK |          sda | busy      1% | read       0  | write     13 | avio 7.62 ms |
```

In the line labeled MEM, the size of the RAM memory is shown (`tot`), the memory that is currently free (`free`), the size of the page cache (`cache+buff`) and the size of the dynamically allocated kernel memory (`slab`).

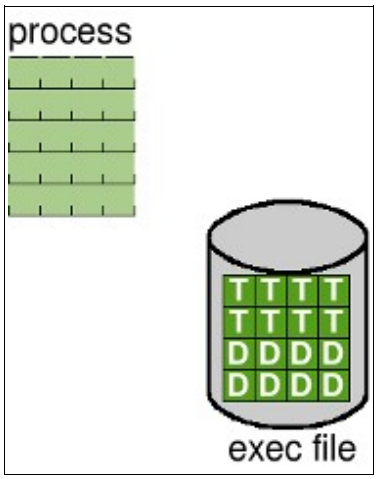
The RSS of the processes can be found in the process list (the lower part of screen):

```
  PID MINFLT  MAJFLT  VSTEXT   VSIZE  RSIZE   VGROW   RGROW   MEM CMD          1/2
31186      0        0      2K  259.7M 246.3M      0K      0K    6% upload
 3456    451        0      3K    1.2G 112.1M   1628K   1596K    3% simpress.bin
29272     60        0  34499K    1.0G 99396K      0K    240K    2% chrome
 4680      0        0     74K  749.4M 70140K   -272K   -272K    2% firefox
 1530    795        0   1778K  174.7M 23180K   6116K      0K    1% Xorg
```

The memory details (subcommand '**m**') show the current RSS per process in the column RSIZE and (as a percentage of the total memory installed) in the column MEM. The physical growth of the process during the last interval is shown in the column RGROW.

## Introduction to virtual memory

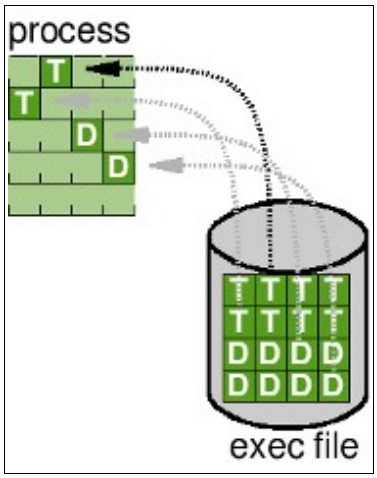
When a new program is activated, the kernel constructs a *virtual* address space for the new process. This virtual address space describes all memory that the process could possibly use. For a starting process, the size of the virtual space is mainly determined by the text (T) and data (D) pages in the executable file, with a few additional pages for the process' stack.



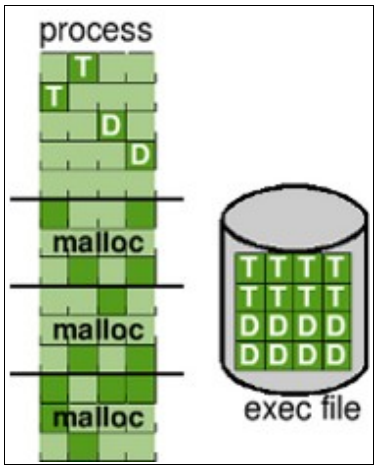

Notice that the process does not consume any physical memory yet during its early startup stage.

The illustration shows an executable file with 32KiB (8 pages) of text and 32KiB (8 pages) of static data. The kernel has just built a virtual address space for the pages of the executable file and 4 additional pages (e.g. for stack).

After the virtual address space has been built, the kernel fills the program counter register of the CPU with the address of the first instruction to be executed. The CPU tries to fetch this instruction, but notices that the concerning text page is not in memory. Therefore the CPU generates a fault (trap). The fault handling routine of the kernel will load the requested text page from the executable file and restarts the process at the some point. Now the CPU is able to fetch the first instruction and executes it. When a branch is made to an instruction that lies in another text page, that page will be loaded via fault handling as well. The kernel will load a data page as soon as a reference is made to a static variable. In this way, any page can be physically loaded into memory at its first reference. Pages that are not referenced at all, will not be loaded into memory.




The illustration shows that the process has a *virtual* size of 80KiB (20 pages) and a physical size (RSS) of 16KiB (4 pages). Obviously, the physical size is always a subset of the virtual size and can never be larger than that.




Suppose that the process allocates memory dynamically (with the subroutine `malloc`), the requested space will initially only extend the process' virtual address space. Only when the proces really refers to a page in the dynamic area, that page is physically created and filled with binary zeroes.

The illustration shows that the first malloc'ed area has a vrtual size of 48KiB (12 pages) while only 16KiB (4 pages) are physically created by a reference. Also the pages in the second and third malloc'ed space have not all been referenced.

In the process list shown by `atop`, information can be found about the virtual address space:

```
  PID MINFLT  MAJFLT  VSTEXT   VSIZE  RSIZE   VGROW   RGROW   MEM CMD         1/2
31186      0        0      2K  259.7M 246.3M      0K      0K    6% upload
 3456    451        0      3K    1.2G 112.1M   1628K   1596K    3% simpress.bin
29272     60        0  34499K    1.0G 99396K      0K    240K    2% chrome
 4680      0        0     74K  749.4M 70140K   -272K   -272K    2% firefox
 1530    795        0   1778K  174.7M 23180K   6116K      0K    1% Xorg
```

The memory details (subcommand '**m**') show the current virtual size per process in the column VSIZE. The virtual growth of a process during the last interval is shown in the column VGROW.

For process `simpress.bin` with pid 3456 a virtual growth of 1628KiB is shown (probably by issueing a `malloc`) while the resident growth is 1596KiB. Process `chrome` with pid 29272 has not been grown virtually (0KiB) but has referenced pages (60 pages of 4KiB) during the last interval that have been allocated virtually during earlier intervals. Process `Xorg` with pid 1530 has only been grown virtually (6116KiB) but has not referenced any of the new pages (yet).

Process `firefox` with pid 4680 has *freed* malloc'ed space with a virtual size of 272KiB. Apparently, this implies the release of 272KiB resident space.

**Case study: A quiet system**

The first `atop` snapshot was taken when a program that leaks memory has just been started, called `lekker` (Dutch for “leaker”). In this snapshot we see a system with net 3.8GiB of physical memory of which 186MiB is free and more than 1GiB in the page cache (MEM line: `cache + buff`). The kernel has dynamically allocated 273MiB slab. Thus, some 2.3GiB is in use by application processes. Swap space (8GiB) is almost unused (so far...). We can see that the `lekker` process has grown 156Mib (virtual) during the last interval which was also made resident by really referencing the allocated space. For now, there is no reason to be worried.

```
ATOP - sammy          2010/03/02  15:12:12          ----          20s elapsed
PRC | sys    2.46s | user   7.17s | #proc    229 | #zombie    0 | #exit      0 |
CPU | sys      12% | user     35% | irq       0% | idle    149% | wait      4% |
CPL | avg1    0.45 | avg5    0.45 | avg15   0.69 | csw    52480 | intr   40316 |
MEM | tot     3.8G | free  186.7M | cache 706.8M | buff  324.2M | slab  273.2M |
SWP | tot     8.0G | free    7.8G |              | vmcom   3.4G | vmlim   9.9G |
LVM |  vg00-lvhome | busy      2% | read       0 | write     10 | avio 42.5 ms |
LVM |   vg00-lvtmp | busy      0% | read       0 | write      5 | avio 12.6 ms |
LVM |   vg00-lvvar | busy      0% | read       0 | write      6 | avio 0.00 ms |
DSK |          sda | busy      2% | read       0 | write     21 | avio 23.2 ms |
NET | transport    | tcpi     36 | tcpo      45 | udpi       0 | udpo       0 |
NET | network      | ipi      41 | ipo       46 | ipfrw      0 | deliv     36 |
NET | wlan0   ---- | pcki     42 | pcko      47 | si    1 Kbps | so    4 Kbps |

  PID MINFLT  MAJFLT  VSTEXT  VSIZE   RSIZE   VGROW  RGROW   MEM  CMD       1/17
30457      0        0      2K 259.7M  256.3M      0K     0K    7%  upload
30926      0        0      2K 259.7M  256.3M      0K     0K    7%  upload
30925      0        0      2K 259.7M  256.3M      0K     0K    7%  upload
30456      0        0      2K 259.7M  256.3M      0K     0K    7%  upload
30425      0        0      2K 259.7M  256.0M      0K     0K    7%  upload
30455      0        0      2K 259.7M  252.3M      0K     0K    6%  upload
31048  40020        0      2K 175.7M  172.3M  156.3M 156.3M    4%  lekker
29272    143        0  34499K   1.0G  103.8M      0K  -108K    3%  chrome
 3456      0        0      3K   1.1G   91232K      0K     0K    2%  simpress.bin
 4680      0        0     74K 640.4M   69532K      0K     0K    2%  firefox
30574      0        0  34499K 958.3M   52416K      0K     0K    1%  chrome
30549     46        0  34499K 622.4M   44972K      0K     0K    1%  chrome
 3343      0        0    127K 51148K   38872K      0K     0K    1%  atop
29211      0        0  34499K   1.5G   30600K      0K     0K    1%  chrome
```

Please take notice of the six `upload` processes. They have allocated 256MiB each (virtual and resident). We can also see multiple `chrome` processes that may have a large virtual size, but only a small portion of that is resident: the cumulated virtual size is 4.1GiB (1+1+0.6+1.5 GiB) of which 229MiB (103+52+44+30 MiB) is resident. The process `simpress.bin` has made less than 10% of its virtual footprint (1.1GiB) resident (91MiB). Also `firefox` has a relatively small portion of its virtual footprint resident. A lot of these virtual sizes will be shared, not only for the same executable file (4 `chrome` processes share at least the same code), but also for shared library code used by all processes. Till now the system has “promised” 3.4GiB of virtual memory (MEM line, `vmcom`) of the total limit 9.9GiB (`vmlim`, which is the size of swap space plus half of the physical memory).

**Case study: It's getting a bit busy...**

One snapshot of twenty seconds later, `lekker` has grown another 150MiB (virtual and resident). For a large part that could be claimed from the free space, but not entirely. The number of free pages in stock is getting very low, so the kernel tries to free memory somewhere else. We can see that the first victims are the page cache and the slab. They both have to shrink.

```
ATOP - sammy          2010/03/02  15:12:32           ----           20s elapsed
PRC | sys    2.72s | user   6.99s | #proc    229 | #zombie    0 | #exit      0 |
CPU | sys      13% | user     34% | irq       0% | idle     151% | wait      2% |
CPL | avg1    0.48 | avg5    0.46 | avg15   0.69 | csw    48261 | intr   38102 |
MEM | tot     3.8G | free   56.5M | cache 697.7M | buff  315.1M | slab  272.0M |
SWP | tot     8.0G | free    7.8G |              | vmcom   3.5G | vmlim   9.9G |
PAG | scan    4180 | stall      0 |              | swin       0 | swout      0 |
LVM |  vg00-lvhome | busy       2% | read      15 | write    111 | avio 2.60 ms |
LVM |   vg00-lvtmp | busy       0% | read       0 | write      1 | avio 1.00 ms |
DSK |          sda | busy       2% | read      15 | write     54 | avio 4.74 ms |
NET | network      | ipi        3 | ipo        1 | ipfrw      0 | deliv      0 |
NET | wlan0   ---- | pcki       6 | pcko       2 | si    0 Kbps | so    0 Kbps |

  PID MINFLT  MAJFLT  VSTEXT  VSIZE   RSIZE   VGROW  RGROW   MEM  CMD       1/16
31048  38019        0      2K 324.2M  320.8M  148.5M 148.5M    8%  lekker
30457      0        0      2K 259.7M  256.3M      0K     0K    7%  upload
30926      0        0      2K 259.7M  256.3M      0K     0K    7%  upload
30925      0        0      2K 259.7M  256.3M      0K     0K    7%  upload
30456      0        0      2K 259.7M  256.3M      0K     0K    7%  upload
30425      0        0      2K 259.7M  256.0M      0K     0K    7%  upload
30455      0        0      2K 259.7M  252.3M      0K     0K    6%  upload
29272    137        0  34499K   1.0G  103.8M      0K   -24K    3%  chrome
 3456      0        0      3K   1.1G   91232K      0K     0K    2%  simpress.bin
 4680    331        0     74K 640.4M   70424K      0K   892K    2%  firefox
30574      0        0  34499K 958.3M   52416K      0K     0K    1%  chrome
30549     41        0  34499K 622.4M   44972K      0K     0K    1%  chrome
 3343      0        0    127K 51148K   38872K      0K     0K    1%  atop
29211      0        0  34499K   1.5G   30600K      0K     0K    1%  chrome
 1530   3181        0   1778K 157.7M   29240K      0K     0K    1%  Xorg
```

The MEM line is displayed in cyan because the amount of memory that can quickly be claimed is small (free plus the page cache). The processes are not yet in the danger zone because no pages are swapped out (PAG line, `swout`). Better yet, `firefox` has physically referenced another 892KiB (that is a small amount compared to the 156MiB that `lekker` got).

We can see that `chrome` has shrunk by 24KiB (6 pages). We later found out that this was caused by malloc'ed memory pages that were freed, followed by a new malloc of 6 pages without referencing the pages again. Hence the virtual and resident size at first shrunk by 6 pages, after which only the virtual size grew by 6 pages. After all, the resident size shrunk without a change of the virtual size.

**Case study: The kernel gets worried....**

Four snapshots of 20 seconds later, we see that `lekker` has an unsatisfiable hunger: it has grown more than 600MiB (virtual and resident) since the previous screen shot, which is about 150MiB per 20 seconds.

```
ATOP - sammy          2010/03/02  15:13:52           ----           20s elapsed
PRC | sys    2.49s | user   7.14s | #proc    229 | #zombie    0 | #exit      0 |
CPU | sys      12% | user     35% | irq       0% | idle     147% | wait      6% |
CPL | avg1    0.70 | avg5    0.52 | avg15   0.69 | csw    49194 | intr   38728 |
MEM | tot     3.8G | free   97.9M | cache 314.2M | buff   87.7M | slab  224.5M |
SWP | tot     8.0G | free    7.8G |              | vmcom   4.1G | vmlim   9.9G |
PAG | scan   30712 | stall      0 |              | swin      91 | swout    322 |
LVM |  vg00-lvswap | busy       1% | read      91 | write    322 | avio 0.59 ms |
LVM |   vg00-lvusr | busy       1% | read       9 | write      0 | avio 12.8 ms |
LVM |  vg00-lvhome | busy       1% | read       0 | write     25 | avio 4.32 ms |
DSK |          sda | busy       3% | read      41 | write     60 | avio 5.21 ms |
NET | network      | ipi        4 | ipo        0 | ipfrw      0 | deliv      0 |
NET | wlan0   ---- | pcki       4 | pcko       0 | si    0 Kbps | so    0 Kbps |

  PID MINFLT  MAJFLT  VSTEXT  VSIZE   RSIZE   VGROW  RGROW   MEM  CMD       1/17
31048  40020        0      2K 941.7M  938.3M  156.3M 156.3M   24%  lekker
30457      0        0      2K 259.7M  256.3M      0K     0K    7%  upload
30456      0        0      2K 259.7M  256.3M      0K     0K    7%  upload
30925      0        0      2K 259.7M  256.2M      0K   -76K    7%  upload
30425      0        1      2K 259.7M  256.0M      0K  -104K    7%  upload
30926      7        4      2K 259.7M  255.6M      0K  -688K    7%  upload
30455      0        0      2K 259.7M  252.3M      0K    -4K    6%  upload
29272    119        0  34499K   1.0G  104.0M      0K   224K    3%  chrome
 3456      0        0      3K   1.1G  90840K      0K  -352K    2%  simpress.bin
 4680    109        6     74K 640.4M  70188K      0K  -192K    2%  firefox
30574      0        2  34499K 958.3M  52404K      0K   -12K    1%  chrome
30549     42        0  34499K 622.4M  44964K      0K    -8K    1%  chrome
 3343      0        0    127K 51148K  38872K      0K     0K    1%  atop
29211      0        0  34499K   1.5G  30520K      0K   -80K    1%  chrome
```

The page cache has been shrunk as well as the slab (e.g. in-core inodes and directory entries). Processes weren't spared either. They didn't shrink virtually, but some of their resident pages were taken away by the kernel (negative `RGROW`). Because the worried (but not yet desparate) kernel is looking hard for memory to free, more and more pages are checked by the page scanner: 30712 pages were verified to see if they are candidate to be removed from memory (PAG line, `scan`). If a page has to be removed from memory that was modified, that page has to be saved to the swap space. In this snapshot, 322 pages were written to the swap disk (PAG line, `swout`). This resulted in 322 writes to the swap space logical volume (`vg00-lvswap`) that were combined to about 60 writes to the physical disk (`sda`). Because so many pages were swapped out in a short time, the PAG line is displayed in red.

However, processes don't sit still and some of the pages that were swapped out will be referenced again. These pages are read again which happened 91 times (PAG line, `swin`). Fortunately `atop` itself makes all its pages resident at startup and locks them in memory, thus preventing them to be swapped out and making the measurements unreliable.

**Case study: The kernel gets desparate as well as the users...**

The memory-leaking process `lekker` cannot be stopped. We fast-forward 5 minutes:

```
ATOP - sammy          2010/03/02  15:18:52           ----           20s elapsed
PRC | sys    2.54s | user   0.82s | #proc    229 | #zombie    1 | #exit      1 |
CPU | sys      12% | user     4% | irq       0% | idle      63% | wait    120% |
CPL | avg1   12.77 | avg5    6.18 | avg15   2.88 | csw    14932 | intr   30144 |
MEM | tot     3.8G | free   29.6M | cache  41.9M | buff    0.7M | slab   95.6M |
SWP | tot     8.0G | free    6.5G |              | vmcom   5.9G | vmlim   9.9G |
PAG | scan  121298 | stall      0 |              | swin    8440 | swout  32135 |
LVM |  vg00-lvswap | busy      98% | read    8432 | write  32135 | avio 0.49 ms |
LVM |  vg00-lvhome | busy      92% | read      44 | write     55 | avio  188 ms |
LVM |   vg00-lvusr | busy      75% | read     267 | write      0 | avio 57.2 ms |
DSK |          sda | busy      98% | read    3972 | write    428 | avio 4.55 ms |
NET | network      | ipi         3 | ipo         1 | ipfrw      0 | deliv      0 |
NET | wlan0   ---- | pcki        5 | pcko        3 | si    0 Kbps | so    0 Kbps |

  PID MINFLT  MAJFLT  VSTEXT  VSIZE   RSIZE   VGROW  RGROW   MEM  CMD        1/17
31048  32016       0      2K   2.8G    2.0G  125.1M 34212K   52%  lekker
30457     89      69      2K 259.7M  253.1M      0K    24K    6%  upload
30456    588     261      2K 259.7M  247.4M      0K  3180K    6%  upload
30455      0       0      2K 259.7M  243.8M      0K  -120K    6%  upload
30925    149     231      2K 259.7M  184.8M      0K -3744K    5%  upload
30425   1979     411      2K 259.7M  138.5M      0K  6980K    4%  upload
30926    224     254      2K 259.7M  90332K      0K -18.9M    2%  upload
29272    134       6  34499K   1.0G  86560K      0K  -656K    2%  chrome
 3343      0       0    127K 51148K  38872K      0K     0K    1%  atop
 4680     91     111     74K 640.4M  36500K      0K -2904K    1%  firefox
30574      0       0  34499K 960.7M  29576K      0K   -64K    1%  chrome
 3456     99     102      3K   1.1G  29252K      0K  -876K    1%  simpress.bin
30549     43       3  34499K 622.4M  18372K      0K   -44K    0%  chrome
29211    144      25  34499K   1.5G  16824K      0K   420K    0%  chrome
```

By now, `lekker` has grown to a virtual size of 2.8GiB of which 2GiB is resident (more than 50% of the physical memory of the system). In the past 20 seconds, `lekker` has tried to get hold of 128MiB more virtual memory but has only been able to make 34MiB resident. We know from the past that `lekker` tries to make all its virtual memory resident as soon as it can, so we can conclude that the kernel is very busy swapping out pages. The page cache has already been minimized, as well as the inode cache and directory entry cache (part of the slab). Obviously the processes will also have to "donate" physical memory. One of the `upload` processes (PID 30926) is even donating 19MiB. We can see for some of the `upload` processes that they had to give back quite a lot more physical memory (`RSIZE`). They had 6 times 256MiB, of which they now have only two thirds.

The system is swapping out heavily (32135 pages in the last 20 seconds) but is also swapping in (8440 pages). Because of this, the PAG line is displayed in red. The disk is very busy (the DSK as well as LVM lines are red). The average service times of requests for the logical volumes that are not related to swapping (`lvhome` and `lvusr`) are getting longer because the requests to those areas are swamped by requests to swap space (`lvswap`). Although a relatively small number of requests are related to `lvusr` and `lvhome`, these logical volumes are busy respectively 75% and 92% of the time. The system feels extremely slow now. Time to get rid of the leaking process.....

**Case study: Relief...**

Five minutes later, the big spender `lekker` has finished and thus not using memory any more:

```
ATOP - sammy          2010/03/02  15:23:52           ----           20s elapsed
PRC | sys    1.89s | user   2.53s | #proc    229 | #zombie    1 | #exit      1 |
CPU | sys      9% | user     12% | irq       1% | idle     68% | wait    110% |
CPL | avg1   11.35 | avg5    9.85 | avg15   5.39 | csw    21621 | intr   27397 |
MEM | tot     3.8G | free    1.8G | cache  45.1M | buff    0.9M | slab   93.2M |
SWP | tot     8.0G | free    7.2G |              | vmcom   3.4G | vmlim   9.9G |
PAG | scan     32 | stall      0 |              | swin    7384 | swout      0 |
LVM |  vg00-lvswap | busy     98% | read    7384 | write      0 | avio 2.71 ms |
LVM |  vg00-lvhome | busy     71% | read      85 | write     77 | avio 88.6 ms |
LVM |   vg00-lvtmp | busy     36% | read       0 | write     10 | avio  738 ms |
DSK |          sda | busy     98% | read    4119 | write     40 | avio 4.81 ms |
NET | transport    | tcpi      18 | tcpo      16 | udpi       0 | udpo       0 |
NET | network      | ipi       22 | ipo       18 | ipfrw      0 | deliv     18 |
NET | wlan0   ---- | pcki      23 | pcko      19 | si    0 Kbps | so    2 Kbps |

  PID MINFLT  MAJFLT  VSTEXT  VSIZE   RSIZE   VGROW  RGROW   MEM  CMD       1/18
30457      0       0      2K 259.7M  253.0M      0K     0K    6%  upload
30455    174     274      2K 259.7M  243.0M      0K  1788K    6%  upload
31071     44     100      2K 259.7M  241.7M      0K   576K    6%  upload
30456     15       8      2K 259.7M  238.0M      0K    92K    6%  upload
30925    313     360      2K 259.7M  179.4M      0K  2692K    5%  upload
30425    540     448      2K 259.7M  142.0M      0K  3952K    4%  upload
30926   1019     455      2K 259.7M  103.2M      0K  5896K    3%  upload
29272    126       3  34499K   1.0G  89364K      0K  -508K    2%  chrome
 3343      0       0    127K 51148K  38872K      0K     0K    1%  atop
 4680    286     323     74K 640.4M  33784K      0K  1804K    1%  firefox
30574     67      58  34499K 960.7M  29200K      0K   492K    1%  chrome
 3456    395     227      3K   1.1G  27504K      0K  1312K    1%  simpress.bin
30549     80      32  34499K 622.4M  18332K      0K   256K    0%  chrome
```

However, the effect of `lekker` as a memory hog can be noticed for a long time. We can see that the `upload` processes are slowly referencing their swapped-out pages resulting in a resident growth again. Because there is an ocean of free space (1.8 GiB), nothing is swapped out any more and hardly any scanning (PAG line, `scan`).

We see a lot of major page faults (MAJFLT) for processes: references to virtual pages that are retrieved from disk. Either they were swapped out and now have to be swapped in, or they are read from the executable file. The minor page faults (MINFLT) are references to virtual pages that can be made resident without loading the page from disk: pages that need to be filled with zeroes (e.g. for malloc's) or pages that were “accidentally” still available in the free page pool.

The disk is still very busy retrieving the virtual pages that are referenced again and need to be swapped in (`swin` is 7384 which corresponds to `read` for logical volume `lvswap`). Therefore the DSK and some LVM lines are shown in red. The physical disk `sda` is mainly busy due to the requests of logical volume `lvswap`. However this also slows down the requests issued for the other logical volumes. One request to `lvtmp` even takes 738ms!

**Case study: Life's almost good again...**

More than seven minutes later, we can see that the system is almost tranquil again:

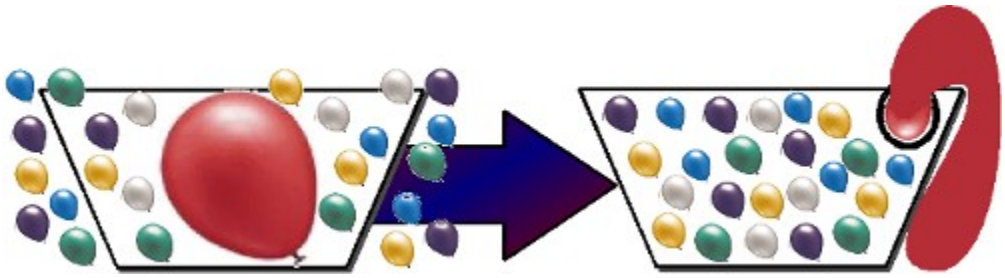
```
ATOP - sammy          2010/03/02  15:31:12           ----           20s elapsed
PRC | sys    4.66s | user   7.23s | #proc    228 | #zombie    0 | #exit      1 |
CPU | sys      23% | user     35% | irq       1% | idle    111% | wait     30% |
CPL | avg1    1.91 | avg5    4.49 | avg15   4.57 | csw    41583 | intr   48545 |
MEM | tot     3.8G | free  996.5M | cache 157.0M | buff  240.4M | slab  141.9M |
SWP | tot     8.0G | free    7.7G |              | vmcom   3.4G | vmlim   9.9G |
PAG | scan       0 | stall      0 |              | swin     664 | swout      0 |
LVM |   vg00-lvusr | busy     44% | read    2903 | write      0 | avio 3.10 ms |
LVM |  vg00-lvswap | busy      2% | read     664 | write      0 | avio 0.69 ms |
LVM |  vg00-lvhome | busy      1% | read       0 | write     49 | avio 3.92 ms |
DSK |          sda | busy     47% | read    3094 | write     40 | avio 3.06 ms |
NET | transport    | tcpi     235 | tcpo     172 | udpi       9 | udpo       9 |
NET | network      | ipi      249 | ipo      183 | ipfrw      0 | deliv    244 |
NET | wlan0   ---- | pcki     250 | pcko     184 | si  135 Kbps | so    8 Kbps |

  PID MINFLT  MAJFLT  VSTEXT  VSIZE   RSIZE   VGROW  RGROW   MEM  CMD       1/18
30457      0        0      2K 259.7M  256.3M      0K     0K    7%  upload
30456      0        0      2K 259.7M  255.9M      0K     0K    7%  upload
30925      0        0      2K 259.7M  255.1M      0K     0K    6%  upload
31071      0        0      2K 259.7M  255.0M      0K     0K    6%  upload
30926    483      188      2K 259.7M  252.2M      0K  2684K    6%  upload
30455      0        0      2K 259.7M  252.0M      0K     0K    6%  upload
30425      0        0      2K 259.7M  247.3M      0K     0K    6%  upload
29272    136        0  34499K   1.0G  95864K      0K  -200K    2%  chrome
 3456      0        0      3K   1.1G  80776K      0K     0K    2%  simpress.bin
 4680   3581        0     74K 767.4M  75628K   6144K  7152K    2%  firefox
 3343      0        0    127K 51148K  38872K      0K     0K    1%  atop
30574      0        0  34499K 960.7M  34448K      0K     0K    1%  chrome
29211      0        0  34499K   1.5G  27064K      0K     0K    1%  chrome
```

There is far less disk I/O and certainly not all disk I/O is related to swapping any more. Processes (like `upload`) still do not have all their resident memory back, because they simply haven't touched all of their virtual pages since the “storm” has passed. Probably many of these pages have been used during their initialization phase and will not even be referenced any more. As such a small brease might help to clean up a dusty memory, however a stormy leaker as `lekker` can better be avoided.....

## Possible solutions for memory leakage

From the case study, it is clear that only one misbehaving process can cause a heavy performance degradation for the entire system. The most obvious solution is to solve the memory leakage in the guilty program and take care that every malloc'ed area is sooner or later freed again. However, in practice this might not be a trivial task since the leaking program will often be part of a third-party application.

Suppose that a real solution is not possible (for the time being), it should be possible to avoid that the leaking process is bothering *other* processes. Preferably it should only harm its own performance by limiting the resident memory that the leaking process is allowed to consume. So not allowing the balloon to expand unlimited (pushing out the others), but putting a bowl around it redirecting the superfluous expansions outside the box....



The good news is: there is a standard ulimit value to limit the resident memory of a process.

```
$ ulimit -a
....
max memory size         (kbytes, -m) unlimited
```

The default value is “unlimited”. The command `ulimit` can be used to set a limit on the resident memory consumption of the shell and the processes started by this shell:

```
$ ulimit -m 409600
$ lekker &
```

The bad news however is: this method only works with kernel version 2.4, but not any more with kernel version 2.6 (dummy value).

But there is other good news (without related bad news this time):
In the current 2.6 kernels a new mechanism is introduced called *container groups* (cgroups). Via cgroups it is possible to partition a set of processes (threads) and specify certain resource limits for such partition (container). A cgroup can be created for all kind of resources, also for memory. It is beyond the scope of this document to go into detail about cgroups, but a small example can already illustrate the power of this mechanism.

Cgroups are implemented via a filesystem module, so first of all the virtual cgroup filesystem (with option “memory”) should be mounted to an arbitrary directory. This mount has to be done only once after boot, so it's better to specify it in your `/etc/fstab` file:

```
# mkdir /cgroups/memo
# mount -t cgroup -o memory none /cgroups/memo
```

To define a new memory cgroup for the leaking process(es):

1. Create a subdirectory below the mount point of the virtual cgroup filesystem:

   ```
   # mkdir /cgroups/memo/leakers
   ```

   At the moment that you create a subdirectory, it is magically filled with all kind of pseudo files and subdirectories that can be used to control the properties of this cgroup.

2. One of the “files” in the newly created subdirectory is called `memory.limit_in_bytes` and can be used to set the total memory limit for all processes that will run in this cgroup:

   ```
   # echo 420M > /cgroup/memo/leakers/memory.limit_in_bytes
   ```

3. Another “file” in the newly created directory is called `tasks` and can be used to specify the id's of the processes/threads that must be part of the cgroup. If you assign a process to a cgroup, also its descendents (started from then on) will be part of that cgroup. Suppose that the leaking process `lekker` runs with PID 2627, it can be assigned to the cgroup `leakers` as follows:

   ```
   # echo 2627 > /cgroup/memo/leakers/tasks
   ```

Now the leaking process can not use more resident memory than 420MiB. When it runs, `atop` might show the following output:

```
MEM | tot     3.8G | free    1.9G | cache 369.1M | buff  390.1M | slab  247.8M |
SWP | tot     8.0G | free    4.8G |              | vmcom   4.2G | vmlim   9.9G |
PAG | scan       0 | stall      0 |              | swin       0 | swout  40913 |
DSK |          sda | busy     20% | read      29 | write    708 | avio 5.47 ms |

  PID MINFLT  MAJFLT  VSTEXT  VSIZE   RSIZE   VGROW  RGROW   MEM  CMD        1/6
 2627  34017       0      2K   3.6G  374.7M  132.9M -26.8M   10%  lekker
 2532      0       0      3K   1.1G  119.2M      0K     0K    3%  simpress.bin
 1702      0       0   1779K 453.5M  100.9M      0K     0K    3%  Xorg
 1992      0       0   1764K   1.1G   23844K     0K     0K    1%  nautilus
```

The line labeled MEM shows that 1.9GiB memory is free. On the other hand, the line labeled PAG shows that a lot of pages have been swapped out.
The process `lekker` has already grown to 3.6GiB virtual memory (VSIZE), but it only uses 374MiB resident memory (RSIZE). During the last sample, the process has even grown 132MiB virtually (VGROW), but it has shrunk 26MiB physically (RGROW). And what's more important, the other processes are not harmed any more by the leaking process. Their resident growth is not negative. The leakage is not fixed, though under control...