Effiziente Programmierung in c

Dynamic Memory Allocation

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Agenda

- Introduction to Memory Management
- Basics of dynamic memory allocation
- Introduction to First-Fit, Next-Fit and Best-Fit
- Runtime comparison
- Summary

Introduction to Memory Management

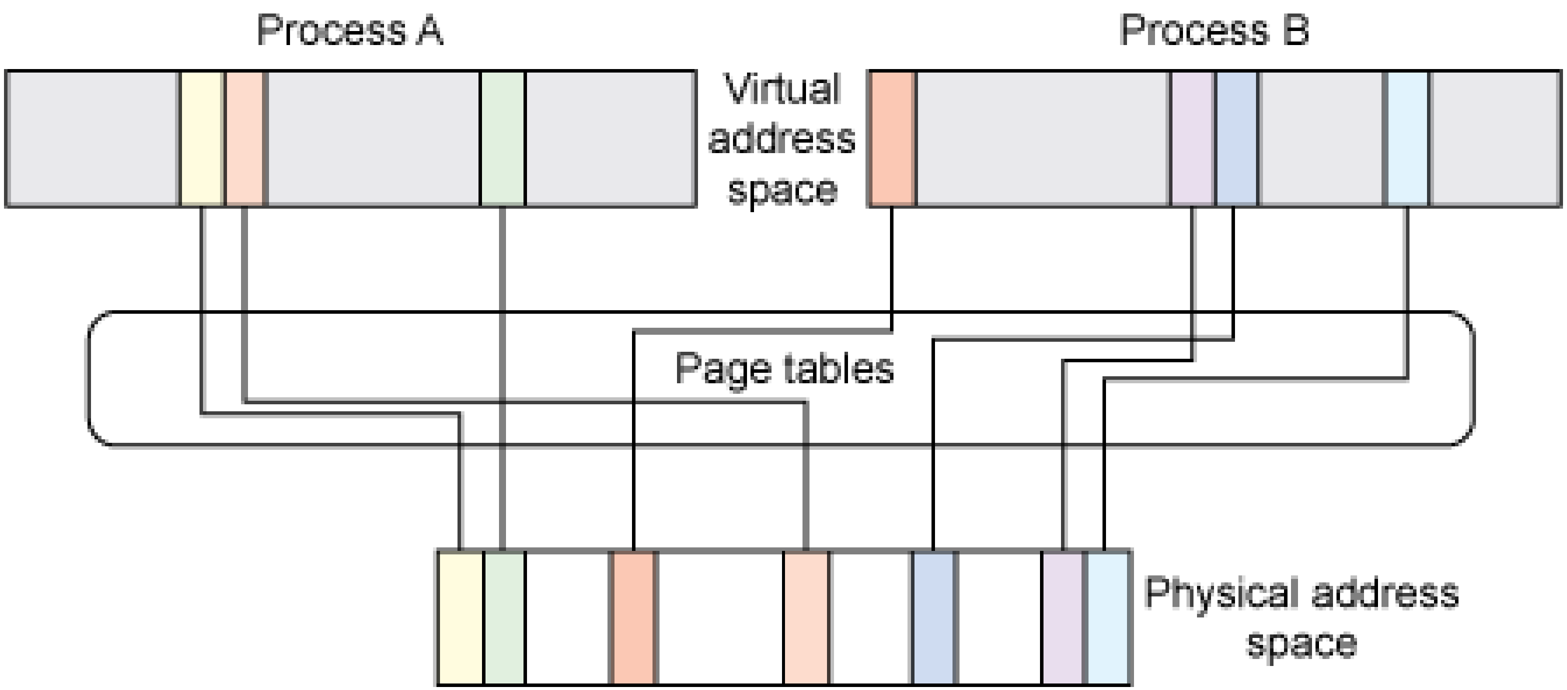
- Physical memory is described with pages
- Page size is architecture dependent
- X86 Architecture has 4KB Pages
- Often more than one page size is supported
- ARM supports 4KB, 8KB and 32KB Pages*

*http://www.makelinux.net/books/lkd2/ch19lev1sec6

Introduction to Memory Management

- Kernel has its own address space
- Each process has its own address space
- Processes run in a virtual address space
- Virtual addresses are mapped to physical addresses by pages

Introduction to Memory Management



From http://www.ibm.com/developerworks/linux/library/l-kernel-memory-access/index.html
Accessed on 09th January 2014

Introduction to Memory Management

- The full virtual address space is not mapped to physical memory right from the start
- On a system with 4KB Pages and 2GB Memory and a page size of 40 Byte the paging table would consume about 20MB.
- The process has to request mapping from its virtual address space to physical memory.
- Linux offers the brk/sbrk and mmap interface.

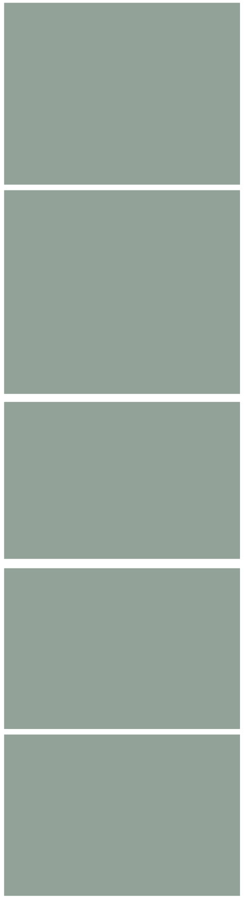
Introduction to Memory Management

- Each thread receives a default mapping of 8 MB at its highest available memory adress
- Space is the programm stack
- Stack pointer to the „top“ of the stack
- Grows from highest adress to lowest
- Only elements at the „top“ can be removed

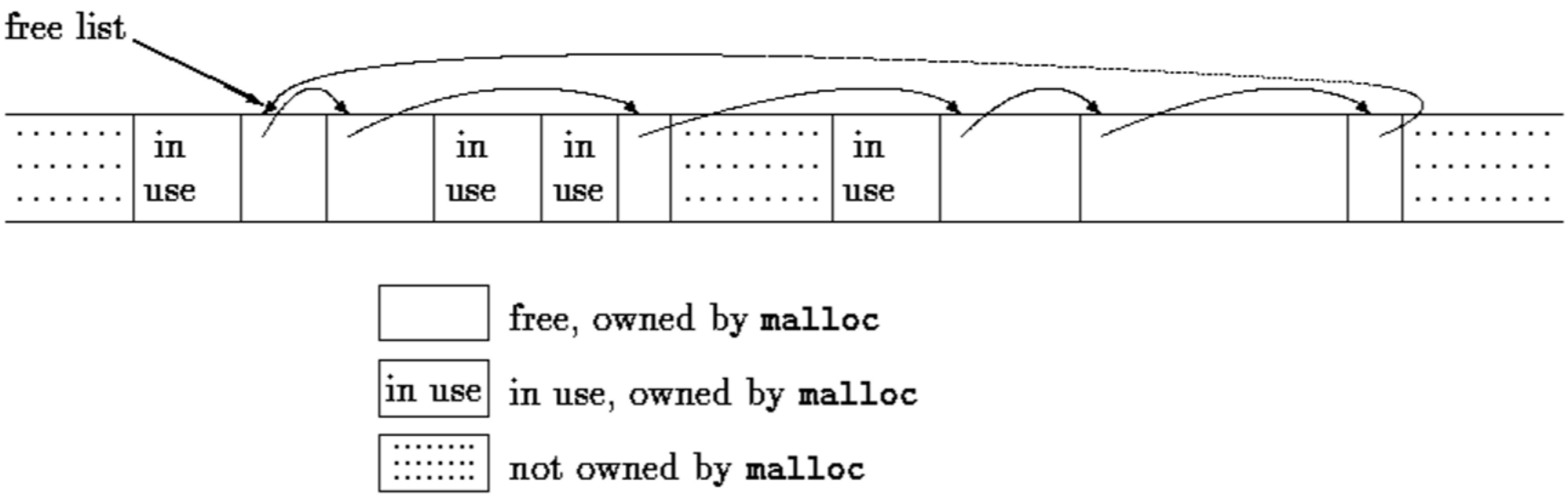
Basics of dynamic memory allocation

Basics of dynamic memory allocation

- If we free an allocated block we create wholes of free memory
- We do not want to waste that free memory
- Need to track free memory
- Need to handle our own memory space – can not use the heap



Basics of dynamic memory allocation



Source: The C programming Language; W. Kerningham & M. Ritchie; Pentice-Hall 1988

Basics of dynamic memory allocation

Requesting memory

- Usually the requested size is given in bytes
- Allocator has to select a free memory block from his free list
- Various approaches how to select the free memory block
- Allocator guarantees to return at least the requested block size
- Usually NULL is returned if no free memory is available

Basics of dynamic memory allocation

Requesting memory from OS

- Processes have nearly no virtual memory mapped by default
- **Program break** = the end of the process's data segment
- Increase that end with a call to the systems sbrk method
- System calls are slow
- Usually larger memory amounts are requested and than distributed to the process upon request.

Basics of dynamic memory allocation

Freeing memory

- The memory chunk has to be returned into the free list
- Free list is ordered by ascending memory address
- Memory block is inserted at its respective place within the order

Basics of dynamic memory allocation

- **External fragmentation:** A form of fragmentation that arises when memory is allocated in units of arbitrary size. When a large amount of memory is released, part of it may be used to meet a subsequent request, leaving an unused part that is too small to meet any further requests.*

*JOHN DAINTITH. "external fragmentation." A Dictionary of Computing. 2004.*Encyclopedia.com.* (January 15, 2014).

Basics of dynamic memory allocation
Coalescing

- To reduce external fragmentation blocks returned to the free list are coalesced with each other
- If block start at the end of a free block they’re merged
- If block ends at the start of a free block they’re merged

Basics of dynamic memory allocation

Miscellaneous

- Though the allocator has freed its memory, it's not guaranteed to be returned to the operating system
- OS can only reserve full memory pages for a process

Basics of dynamic memory allocation

Header structure

```
typedef long Align;

union Header
{
        struct
        {
                union Header *ptr;
                unsigned size;
        } s;
        Align x; /*Never used but forces alignment*/
};
```

- Header also used to align data
- Only multiples of the headers' size are allocated

Dynamic memory allocation methods

Dynamic memory allocation methods

First-Fit

- First fit searches the Free-List from the beginning
- Returns the first chunk big enough to hold at least the requested amount of bytes
- If the chunk is too big it's split and the remaining space is left in the Free-List.

Dynamic memory allocation methods
Next-Fit

- Similar to First-Fit
- Start searching from the block that pointed to the last allocated one
- Should drastically increase the performance
  - Average lookups should decrease
  - First-Fit tends to accumulate small block at its beginning but Next-Fit distributes the blocks uniformly.

Dynamic memory allocation methods
Best-Fit

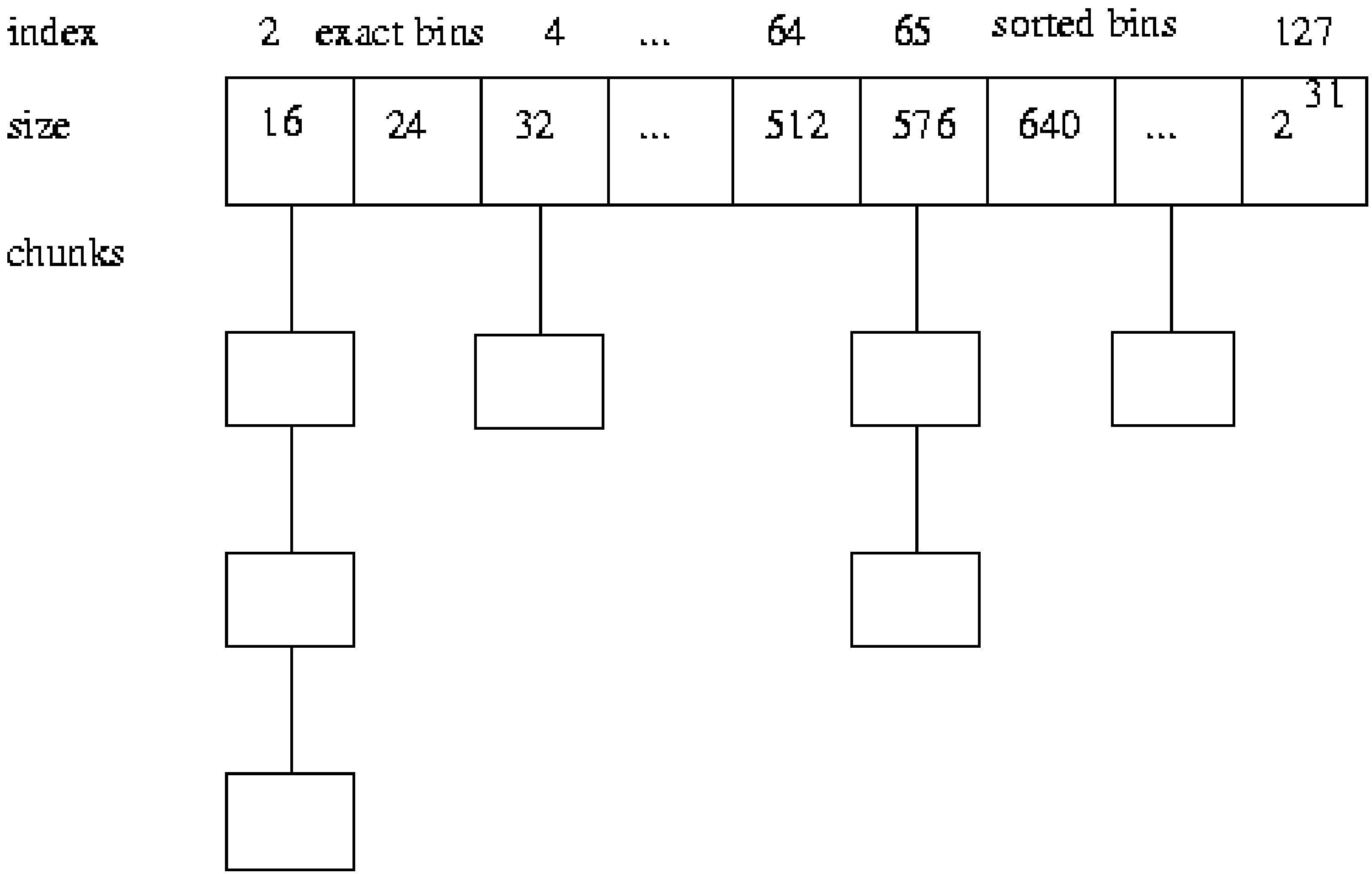
- Uses the free block that fits the best to the requested size.
- Has to search the whole list for a best match
- Tends to leave small unusable blocks
- Therefore produces external fragmentation

Dynamic memory allocation methods
Optimization

- To reduce external fragmentation usually a minimal block size is defined
- If *requested* < *available* and *requested* + *min* > *available* the whole block is returned and not split.
- Store available chunks in bins grouped by size

Dynamic memory allocation methods

Bins



http://gee.cs.oswego.edu/dl/html/malloc.html (15.01.2014)

Dynamic memory allocation methods
Bins

- 128 fixed-width bins
- Bins up to 512 bytes are each just spaced 8 bytes apart
- Only hold the exact size they're representing
- Bins over the 512 byte mark hold a range of chunks

Dynamic memory allocation methods
Bins

- Till 1995 the oldest-first rule has been applied
- Nowadays chunks are sorted within bins
- It is has been proven that *"the minor time investment was worth it to avoid observed bad cases"**.
- Best-Fit with the presented optimizations even reduces external fragmentation compared to other methods

*http://gee.cs.oswego.edu/dl/html/malloc.html

Dynamic memory allocation methods

Caching

- Caching refers to the fact that small blocks are not coalesced immediately
- Each split and each coalesce requires time
- Small blocks are kept up to a given number
- Very effective for many small allocations and frees i.e. when working with trees

Dynamic memory allocation methods

glib - malloc

*"This is not the fastest, most space-conserving, most portable, or most tunable malloc ever written. However it is among the fastest while also being among the most space-conserving, portable and tunable. Consistent balance across these factors results in a good general-purpose allocator for malloc-intensive programs."**

*http://code.woboq.org/userspace/glibc/malloc/malloc.c.html

Dynamic memory allocation methods
glib - malloc

- For Blocks with a size <= 64 bytes the algorithm uses a caching allocator
- Block with a size >= 512 bytes the algorithm uses a pure best-fit allocator
- In between “it does the best it can trying to meet both goals at once”*

*http://code.woboq.org/userspace/glibc/malloc/malloc.c.html

Runtime comparision

Runtime comparison

- We perform INS_MAX cycles
- Each cycles between 1 and 10 allocations are performed
- Each allocation allocates between 1 and 8 kb
- Each allocation lasts between 1 clock and 10 seconds
- All random values are distributed uniformly
- Comparison done for First-Fit, Next-Fit, glib’s malloc

Runtime comparison

- For 100.000 cycles
- First-Fit: 157 seconds
- Next-Fit: 168 seconds
- glib's malloc: 78 seconds

Runtime comparison
Evaluation

- Malloc outperforms each of the custom implementations
- Despite the fact that next-fit should be a huge improvement it's even slower
- Differences might be to flaws in own implementations and some missing or ineffective optimizations

Summary

- Virtual memory
- Sbrk, mmap
- External fragmentation
- Best-Fit, Next-Fit, First-Fit
- Free-List
- Binning
- Caching

Literature

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