Dynamic Memory Allocation: Explicit Free Lists

COMP 321

Dave Johnson

1

Why an Explicit Free List?

Problems with implicit free lists

- Allocation time can be linear in the number of blocks (the number of ***free*** and ***allocated*** blocks), not just in the number of ***free*** blocks
- No real way to improve on that with an ***implicit*** free list
  - Can't excluded allocated blocks from the list
  - Can't control the order or segregation of the free list
- ***The fundamental problem***
  - The heap is the free list is the heap ...
  - This includes all ***allocated*** blocks as well as all ***free*** blocks

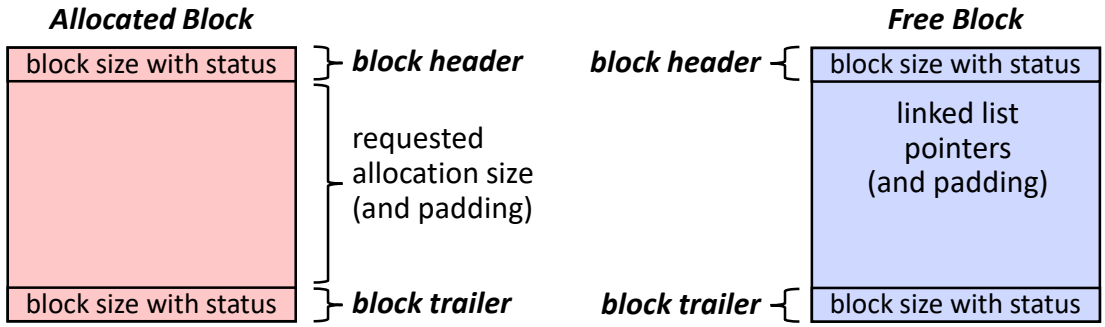
Creating and using an explicit free list lets us overcome this

2

Basic Idea of an Explicit Free List?

The free list should contain only free blocks

- All blocks still contain header and trailer with size and allocation status
- No change to the format of an allocated block
- Each free block now also needs to contain pointer(s) to place it in the free list

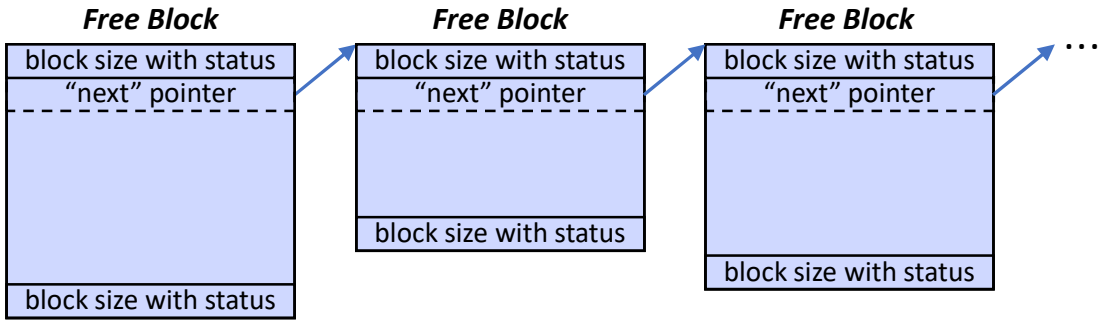


The Free Space in a Free Block Stores the Pointer(s)

The linked list pointer(s) take up no space to store

- A ***free*** block is by definition ***free*** – currently unused space
- Borrow some of that free space to store the pointer(s) for the free list

A simple example



The Minimum Size of a Block

An allocated block must be big enough to represent itself when it is a free block

- Meaning it must have room as a free block to hold the list pointer(s)
  - That extra room is not needed when it is an allocated block
- The minimum free block that can be represented contains
  - The free block's header
  - The free block's trailer
  - The free block's free list pointer(s)
- When allocating a block, must add extra padding inside the allocated block (in addition to padding for alignment) to make sure the allocated block is at least this minimum size
  - (May increase internal fragmentation)

The Order of the Free List

Many list ordering choices are possible, including

- FIFO – a freed block won't be reused until much later
- LIFO – a freed block will be reused on next allocation (depending on size)
- Ordered by addresses
- Ordered by size
  - ascending (increasing size) order
  - descending (decreasing size) order

The order of free blocks in the free list need not be the order in the heap

The Structure of the Free List

Many different list structures are possible for a "linked list"

- Singly linked or doubly linked
- Circular or not circular

Doubly linked circular is a good choice

- Can add or remove in constant time, regardless of the position in the list
- Example: for coalescing when freeing a block
  - May be able to merge yourself onto the previous block in place without removing it from the free list (depending on the ordering being used in the free list)
  - But may need to remove the following block from the free list, and you didn't find it by traversing the list

Segregated Free Lists

A remaining problem with our free list

- Allocation is still linear in the number of free blocks
  - Much better than linear in number of free or allocated blocks
  - But the search for a suitable free block can still be expensive

A solution: segregated free lists, with multiple explicit free lists

- A different free list for each different free block size (or range of block sizes), referred to as a ***size class*** (also called ***bins***)
- Makes finding a suitable block much faster (or even constant time)
  - First fit is now almost the same as best fit
- Small additional complexity (when splitting while allocating, or when coalescing while freeing) to move to correct new free list

Segregated Free Lists

Example: different size classes growing with powers of 2

- Size classes [1], [2], (2, 4], (4, 8], (8, 16], (16, 32], (32, 64], ..., (4096, ∞)
- All very large sizes are in the same (largest) size class

Example: different size classes for individual small sizes, then powers of 2

- Size classes [1], [2], [3], [4], [5], [6], ..., (1024, 2048], ..., (4096, ∞)
- All very large sizes are in the same (largest) size class

Some details

- What are the units here? Multiples of largest granularity or smallest block size
- What if the "correct" free list is empty? Can just look in the next larger class

Other Possibilities are Almost Endless

Once you have an explicit list, you can do other interesting forms of it

Example: a balanced binary tree free list rather than just a plain list

- Could, e.g., store in the space ***inside*** each ***free*** block

```
struct free_info {
        struct free_info *parent;    // pointer to parent in the tree
        struct free_info *left;      // subtree for smaller free blocks
        struct free_info *right;     // subtree for larger free blocks
        struct free_info *next;      // next free block of the same size
};
```

- Makes the minimum block size requirement be a bit larger
- With a flexible way to find the segregated list of the right size free blocks