C Programming Language:
Memory Management: malloc/free, first/next/best fit

Math 230

Assembly Language Programming
(Computer Organization)

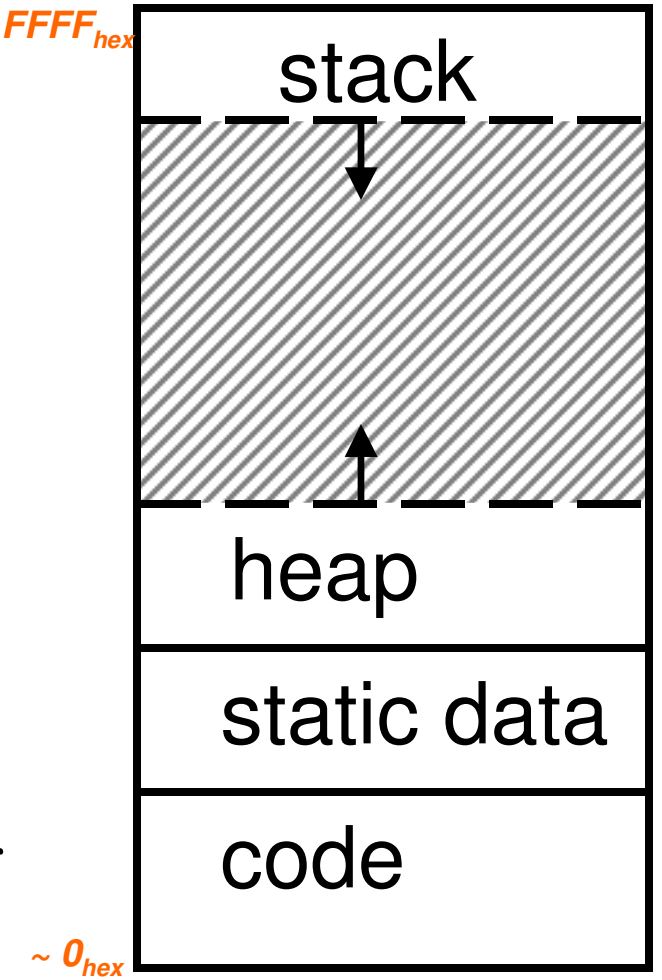
Thu. Feb 7, 2008

Overview

- malloc
  - under the hood
  - first-fit, best-fit, next-fit, buddy system

Recall: Normal C Memory Management

- A program's *address space* contains 4 regions:
  - stack: local variables, grows downward
  - heap: space requested for pointers via `malloc()`; resizes dynamically, grows upward
  - static data: variables declared outside main, does not grow or shrink
  - code: loaded when program starts, does not change



For now, OS somehow prevents accesses between stack and heap (gray hash lines). Wait for virtual memory

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Recall: Memory Management

- How do we manage memory?
- Code, Static storage are easy:
  they never grow or shrink
- Stack space is also easy:
  stack frames are created and destroyed in last-in, first-out (LIFO) order
- Managing the heap is tricky:
  memory can be allocated / deallocated at any time

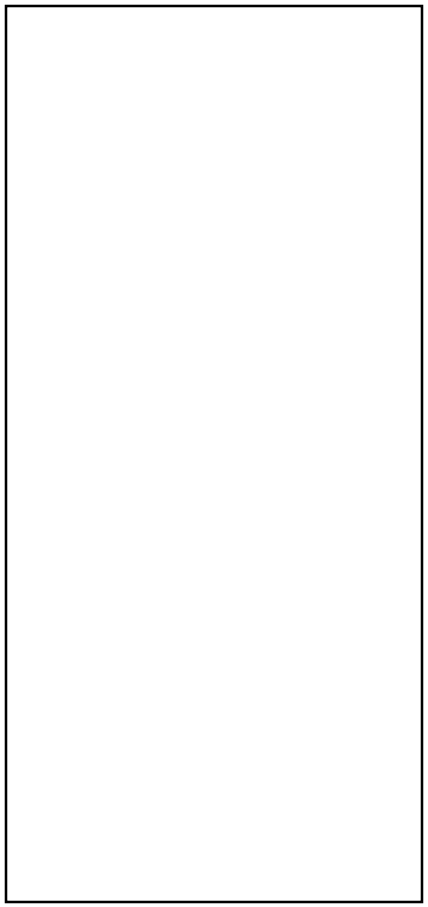
Heap Management Requirements

- Want `malloc()` and `free()` to run quickly.
- Want minimal memory overhead
- Want to avoid *fragmentation** – when most of our free memory is in many small chunks
  - In this case, we might have many free bytes but not be able to satisfy a large request since the free bytes are not contiguous in memory.

* This is technically called *external fragmention*

Heap Management

- An example
  - Request R1 for 100 bytes
  - Request R2 for 1 byte
  - Memory from R1 is freed
  - Request R3 for 50 bytes



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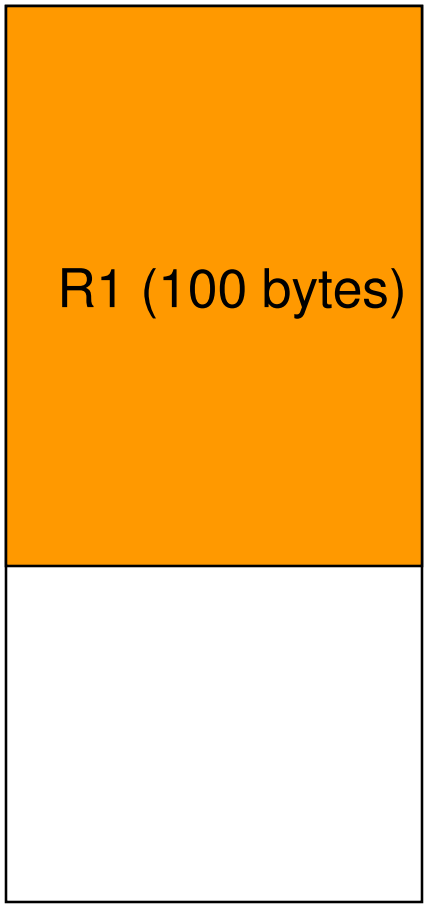

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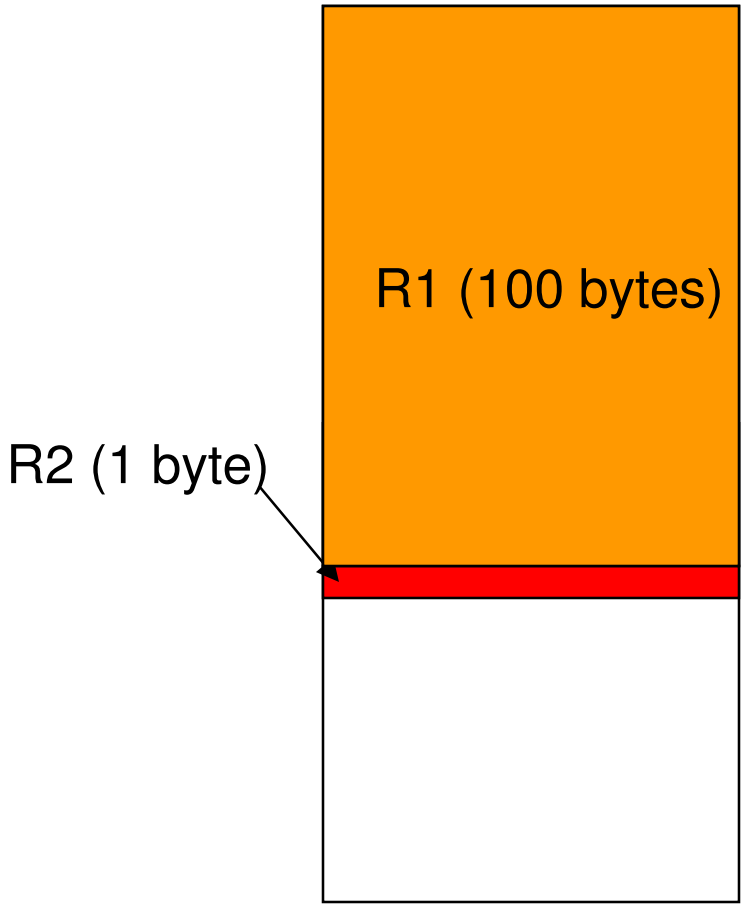

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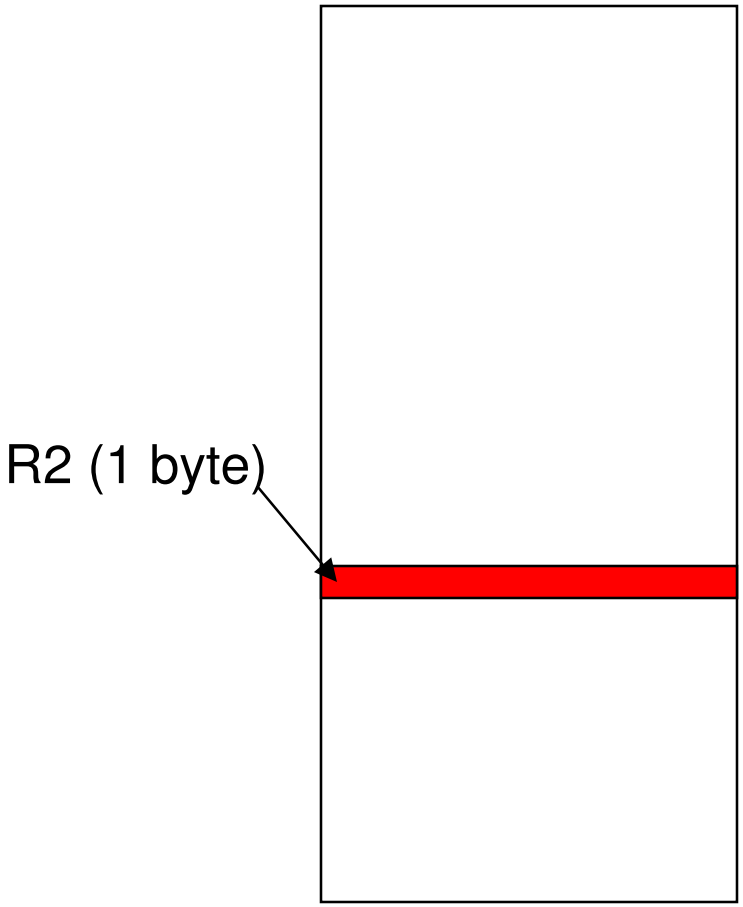

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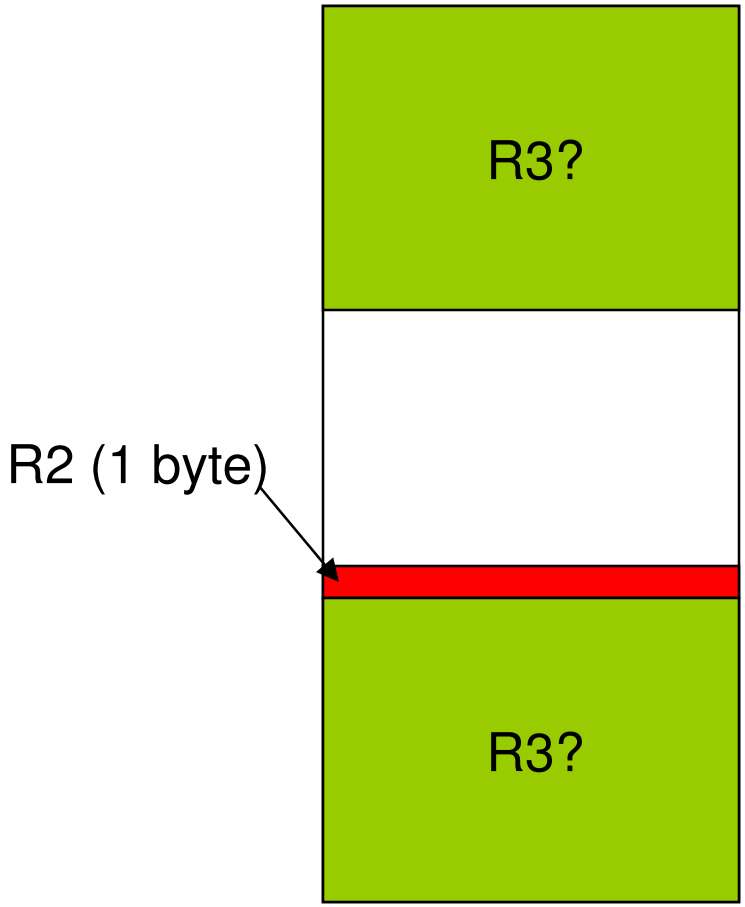

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K&R Malloc/Free Implementation

- From Section 8.7 of K&R
  - Code in the book uses some C language features we haven't discussed and is written in a very terse style, don't worry if you can't decipher the code
- Each block of memory is preceded by a header that has two fields:
  size of the block and
  a pointer to the next block
- All free blocks are kept in a linked list, the pointer field is unused in an allocated block

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K&R Implementation

- `malloc()` searches the free list for a block that is big enough. If none is found, more memory is requested from the operating system. If what it gets can't satisfy the request, it fails.
- `free()` checks if the blocks adjacent to the freed block are also free
  - If so, adjacent free blocks are merged (coalesced) into a single, larger free block
  - Otherwise, the freed block is just added to the free list

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Choosing a block in `malloc()`

- If there are multiple free blocks of memory that are big enough for some request, how do we choose which one to use?
  - best-fit: choose the smallest block that is big enough for the request
  - first-fit: choose the first block we see that is big enough
  - next-fit: like first-fit but remember where we finished searching and resume searching from there

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Tradeoffs of allocation policies

- Best-fit: Tries to limit fragmentation but at the cost of time (must examine all free blocks for each malloc). Leaves lots of small blocks (why?)
- First-fit: Quicker than best-fit (why?) but potentially more fragmentation. Tends to concentrate small blocks at the beginning of the free list (why?)
- Next-fit: Does not concentrate small blocks at front like first-fit, should be faster as a result.

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And in conclusion…

- C has 3 pools of memory
  - Static storage: global variable storage, basically permanent, entire program run
  - The Stack: local variable storage, parameters, return address
  - The Heap (dynamic storage): `malloc()` grabs space from here, `free()` returns it.
- `malloc()` handles free space with freelist. Three different ways to find free space when given a request:
  - First fit (find first one that's free)
  - Next fit (same as first, but remembers where left off)
  - Best fit (finds most "snug" free space)

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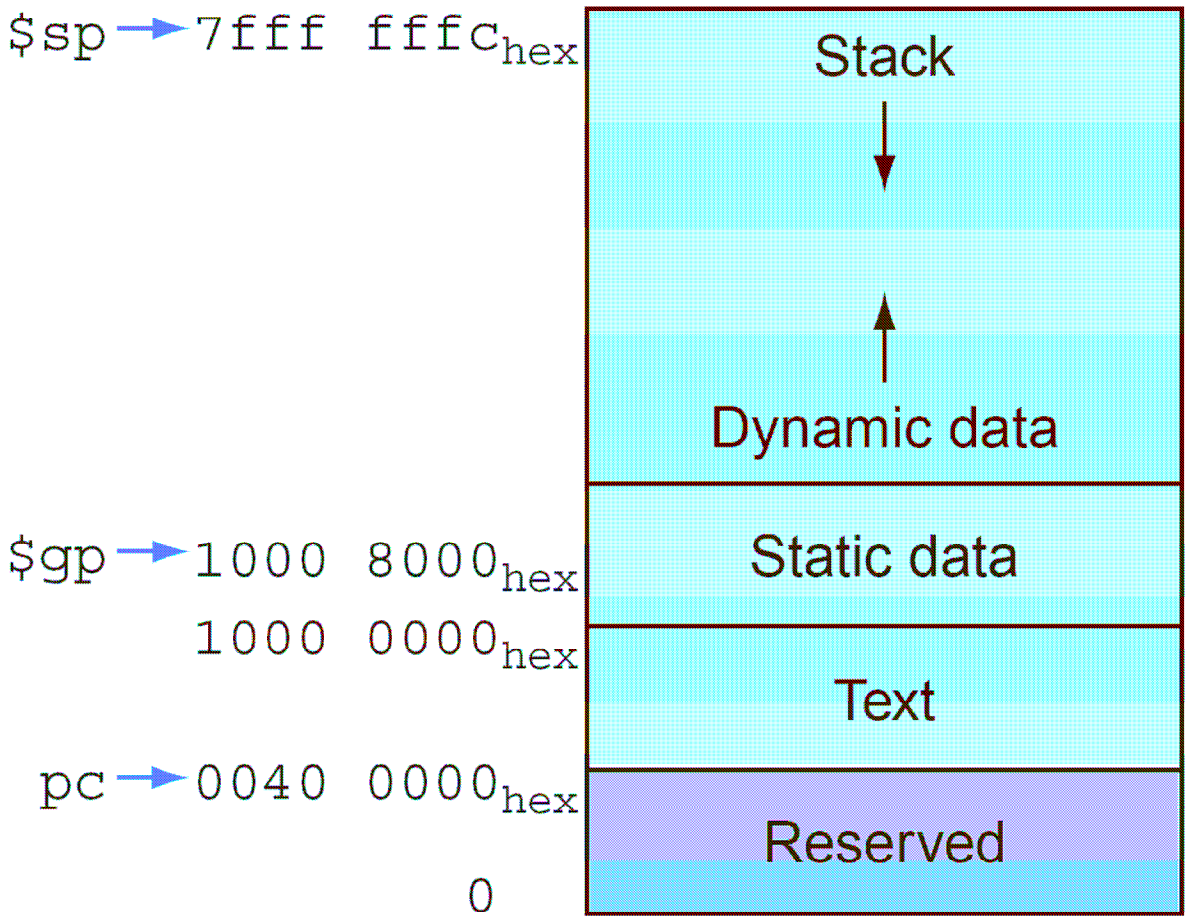
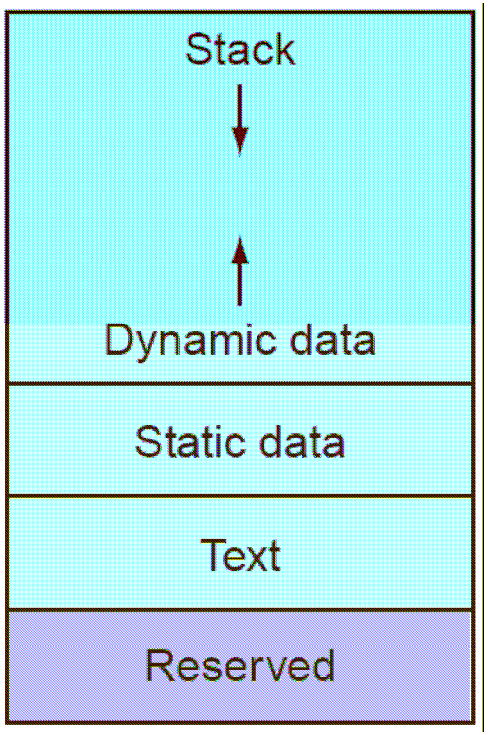
Memory Model



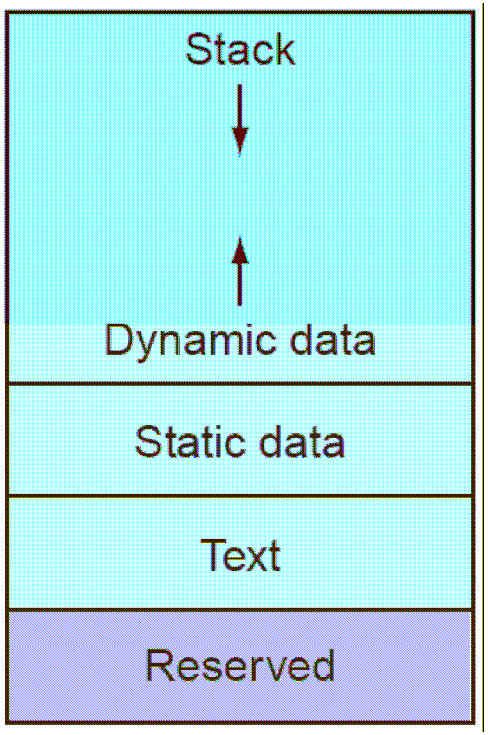
Memory Model

- Needed memory space
  - automatic variables local to procedures
    - automatically allocated upon function entry
  - Static variables
    - exists independent of any function; generally global in scope
  - dynamically allocated
    - requested and delivered as needed



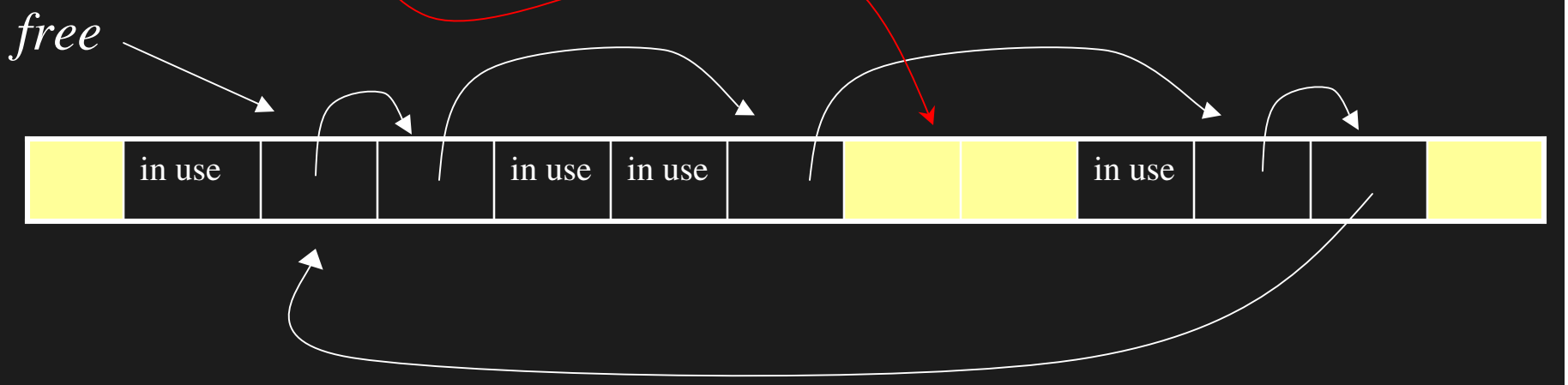
MIPS memory conventions

- stack
  - memory used from the top down
- heap
  - memory used from lower to higher, bottom up
- machine code
  - resides in memory even lower than the heap
  - traditionally called the “text” segment



Memory Mgmt Via malloc

- malloc manages memory requested by malloc
- other programs may have also requested their ***own space***, not managed by malloc
  - malloc may not have contiguous blocks
- malloc keeps track via linked lists



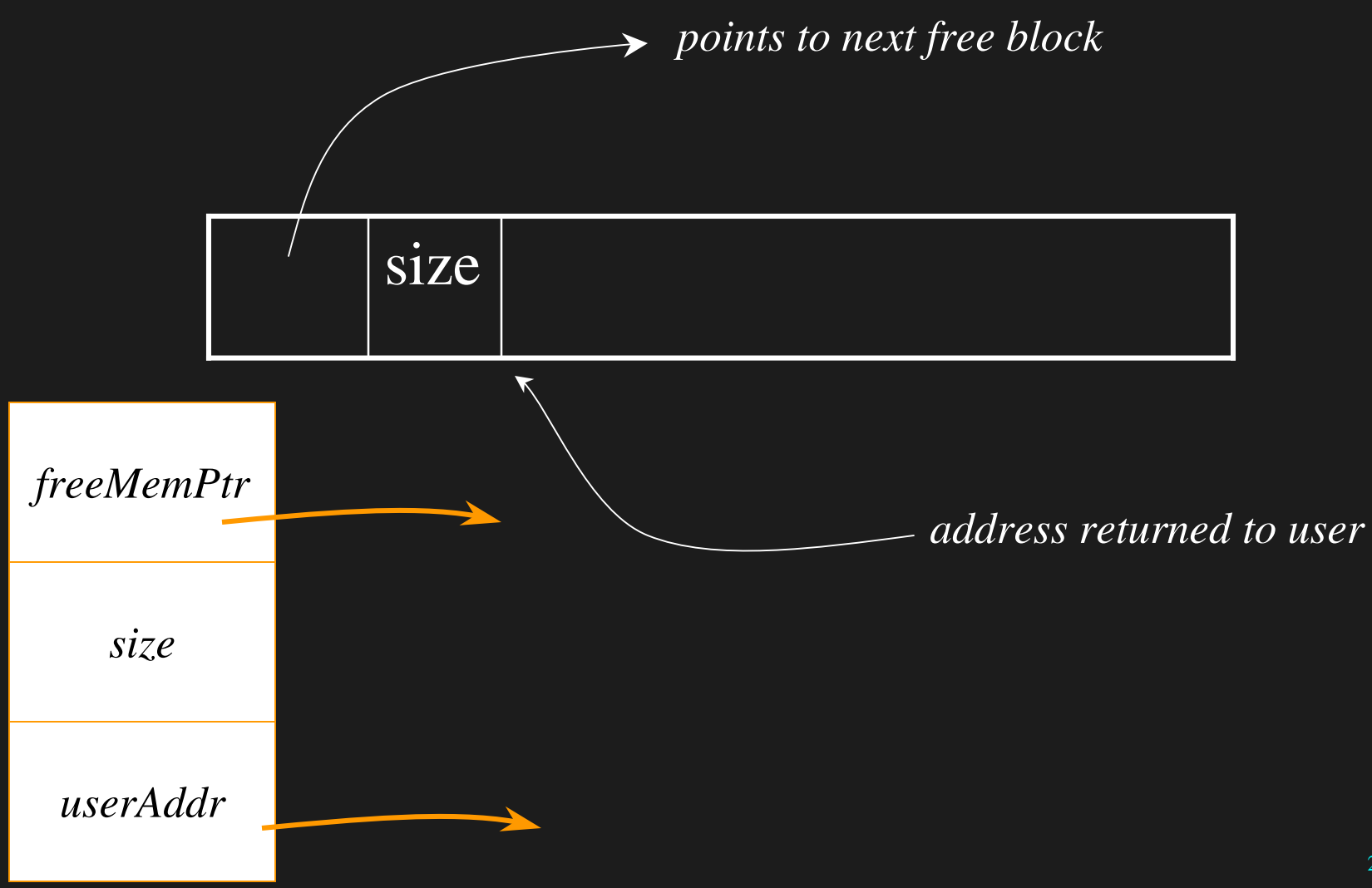
malloc

- memory mgmt algorithms
  - first fit
    - free list scanned/walked until big-enough block is found
  - best fit
    - looks for smallest block of memory to meet request
    - exact sized blocks are unlinked from the list and given to (claimed for) the user
    - big blocks are split and proper amount returned to user
      - rest remains on free list
    - if necessary, malloc will link in additional memory from the OS

freeing memory

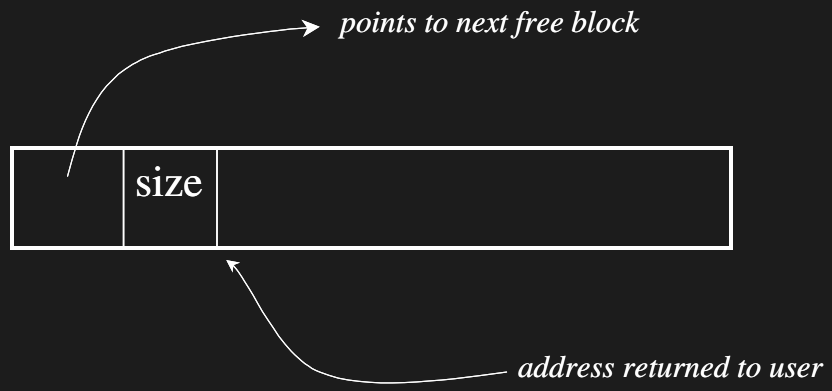
- when memory is freed, the list allocated must be returned to malloc's working list
- returned block may be "merged" (coalesced) with block next to it
  - helps with fragmentation

malloc blocks



malloc blocks II

- free blocks
  - pointer to next block in chain
  - size of block
  - available space follows
    - malloc'ed memory items are "tagged"



malloc blocks III

```
union header {
  struct {
     unsigned size;
     union header *ptr;
  } s;
};
typedef union header Header;
```

Summary