15-213 Recitation
Malloc Part II

Your TAs

Monday, March 18th

Agenda

- Logistics
- Debugging Malloc Lab
  - Activity 1
- Checkpoint/Final Review

Logistics

- Malloc Lab Checkpoint is due **March 19th** at **11:59 pm**
- Malloc Lab Final is due **March 26th** at **11:59 pm**
- 7% of final grade (+4% for checkpoint)
- Style matters! Don't let all of your hard work get wasted.
  - There are many different implementations and TAs will need to know the details behind your implementation.
  - **Code Review** Signups for **Checkpoint** due **March 21st** at **11:59 pm**
- Post-checkpoint Malloc Bootcamp was yesterday!
  - Resources on piazza post.

Submitting Malloc

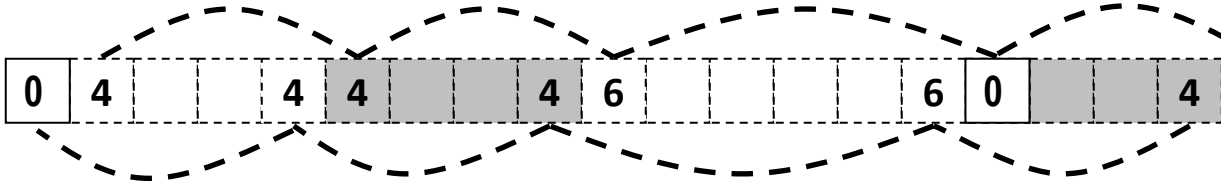
- Make sure to submit to AutoLab!
- Run `make submit`
- Upload `mm.c` to Autolab

Understanding Your Code

- Sketch out the heap
- Add Instrumentation
- Use tools

Sketch out the Heap

- Start with a heap, in this case implicit list



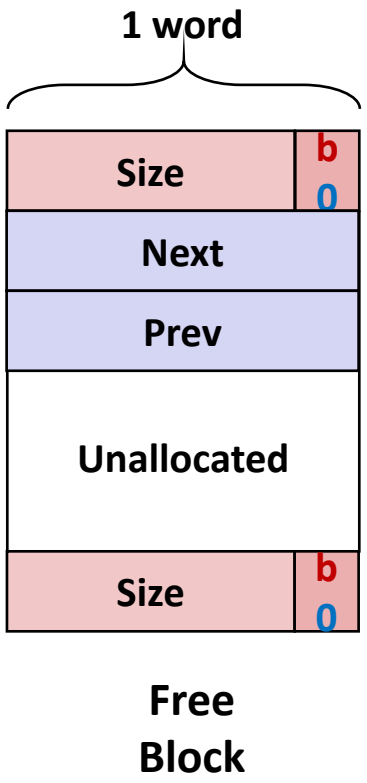
- Now try something, in this case, extend_heap

```
block_t *block = payload_to_header(bp);
write_block(block, size, false);
// Create new epilogue header
block_t *block_next = find_next(block);
write_epilogue(block_next);
```

Sketch out the Heap

- **Here is a free block based on lectures 13 and 14**
  - Explicit pointers (will be well-defined see writeup and Piazza)
    - **This applies to ALL new fields you want inside your struct**
  - Optional boundary tags

- **If you make changes to your design beyond this**
  - Draw it out.
  - If you have bugs, pictures can help the staff help you
  - Put a picture of your data structure into your file header
    (optional, but we will be impressed)



Common Problems

- **Throughput is very low**
  - Which operation is likely the most throughput intensive?
  - Hint: It uses loops!
  - Solution: ??

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Add Instrumentation

- **Remember that measurements inform insights.**
  - Add temporary code to understand aspects of malloc
  - Code can violate style rules or 128 byte limits, because it is temporary

- **Particularly important to develop insights into performance before making changes**
  - What is expensive throughput-wise?
  - How much might a change improve utilization?

Add Instrumentation example

- Searching in `find_fit` is often the slowest step

- How efficient is your code? How might you know?
  - Compute the ratio of blocks viewed to calls

```
static block_t *find_fit(size_t asize)
{
    block_t *block; call_count++;
    for (block = heap_listp; get_size(block) > 0;
                             block = find_next(block))
    {   block_count++;
        if (!(get_alloc(block)) && (asize <= get_size(block)))
        {
            return block;
        }
    }
    return NULL; // no fit found
}
```

Add Instrumentation cont.

- **What size of requests?**
  - How many 8 bytes or less?
  - How many 16 bytes or less?
  - What other sizes?

- **What else could you measure? Why?**

- **Remember that although the system's performance varies**
  - The traces are deterministic
  - Measured utilization should not change between runs
  - Measured throughput, however, may vary

Use tools

- **Use mm_checkheap()**
  - Write it if you haven't done so already
  - Add new invariants when you add new features
  - Know how to use the heap checker.
    - Why do you need a heap checker? 2 reasons.

- **Use gdb**
  - You can call print or mm_checkheap whenever you want in gdb. No need to add a whole lot of printf's.
  - Offers useful information whenever you crash, like backtrace.
  - Write helper functions to print out free lists that are ONLY called from GDB

Write your own traces!

- Write short traces that test simple sequences of malloc and free
- Read the README file in the traces directory and the writeup from the traces assignment to see how trace files need to be written

mdriver-emulate

- **Testing for 64-bit address space**

- **Use correctly sized masks, constants, and other variables**
- **Be careful about subtraction between size types (may result in underflow/overflow)**
  - Note: there are many other issues besides this.
- **Reinitialize your pointers in mm_init**

Garbled Bytes

- **Malloc library returns a block**
  - mdriver writes bytes into payload (using memcpy)
  - mdriver will check that those bytes are still present
  - If malloc library has overwritten any bytes, then report garbled bytes
    - Also checks for other kinds of bugs
- **Now what?**
- **The mm_checkheap call is catching it right?**
- **If not, we want to find the garbled address and watch it**

Garbled Bytes GDB and Contracts

- Get out a laptop

- Login to shark machine
- wget http://www.cs.cmu.edu/~213/activities/rec9.tar
- tar -xvf rec9.tar
- cd rec9

- mm.c is a fake implicit list implementation.
  - Source code is based on mm.c starter code

GDB and Contracts Exercise

- First, let us run without contracts and gdb
- ./mdriver -c ./traces/syn-struct-short.rep

(example output)

```
ERROR [trace ./traces/syn-struct-short.rep, line 16]: block 1
(at 0x8000000a0) has 8 garbled bytes, starting at byte 16
ERROR [trace ./traces/syn-struct-short.rep, line 21]: block 4
(at 0x800000180) has 8 garbled bytes, starting at byte 16



correctness check finished, by running tracefile
"traces/syn-struct-short.rep".
 => incorrect.

Terminated with 2 errors
```

Using watchpoints in GDB

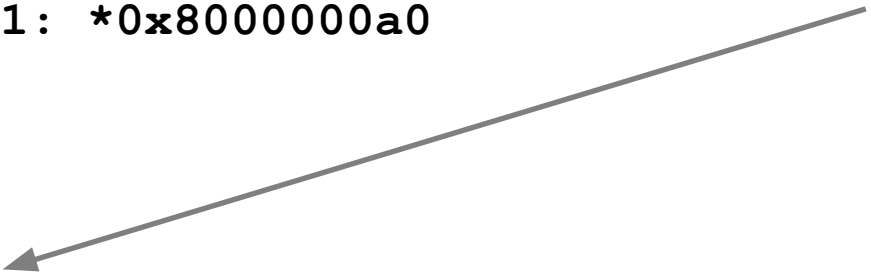
- gdb --args ./mdriver-dbg1 -c ./traces/syn-struct-short.rep
- What is the first address that was garbled?
  - Use gdb watch to find out when / what garbled it.

```
(gdb) watch *0x8000000a0
(gdb) run

// Keep continuing through the breaks:
// write_block()
// 4 x memcpy
Hardware watchpoint 1: *0x8000000a0

Old value = 129
New value = 32
write_block() at mm.c:333
```

We just broke in after overwriting



- Tells us to take a closer look at write_block()

Contracts Exercise cont.

- Now let us see what happens, when we use the file with contracts
  - ./mdriver-dbg2 -c ./traces/syn-struct-short.rep

```
mdriver-dbg: mm.c:331: void write_block(block_t *, size_t, _Bool): Assertion
`(unsigned long)footerp < ((long)block + size)' failed.
Aborted (core dumped)
```

- Contract failed on line 331, which gives us a better idea of the source of the issue
- Open mm.c and try to find what is causing the contract to fail
- Writing effective contracts can save a lot of debugging time!

Tips for using our tools

- Run mdriver with the –D option to detect garbled bytes as early as possible. Run it with –V to find out which trace caused the error.
- Note that sometimes, you get the error within the first few allocations. If so, you could set a breakpoint for mm_malloc / mm_free and step through every line.
- Print out local variables and convince yourself that they have the right values.
- For mdriver-emulate, you can still read memory from the simulated 64-bit address space using `mem_read(address, 8)` instead of `x /gx`.

Style

- **Well organized code is easier to debug and easier to grade!**
  - Modularity: Helper functions to respect the list interface.
  - Documentation:
    - File Header: Describes all implementation details, including block structures.
  - Code Structure:
    - Minimal-to-no pointer arithmetic.
    - Loops instead of conditionals, where appropriate.
  - Use git!
    - Make sure you ***commit and push*** often and write descriptive commit messages

Malloc Lab

- **Checkpoint due Tuesday, March 19th**
- **7% of final grade (+4% for checkpoint)**
  - Style matters! Don't let all of your hard work get wasted.
  - There are many different implementations and TAs will need to know the details behind your implementation.
- **Read the write-up. It even has a list of tips on how to improve memory utilization.**
- **Rubber duck method**
  - If you explain to a rubber duck what your function does step-by-step, while occasionally stopping to explain why you need each of those steps, you may very well find the bug in the middle of your explanation.
  - Remember the "debug thought process" slide from last recitation?

Checkpoint/Final Review

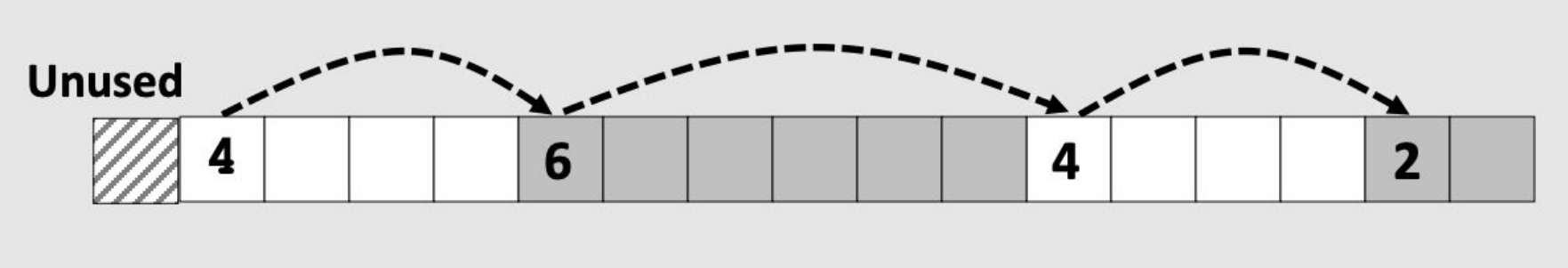
Checkpoint Review

Overview

- Implicit lists: coalescing
- Implicit lists to explicit lists
- Explicit lists to seglists

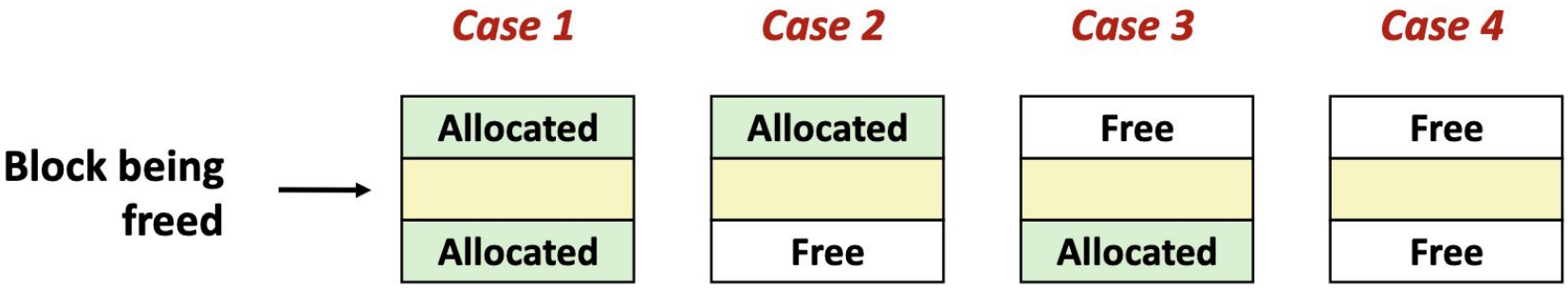
Step 1: Coalescing

- Recall: implicit list is just the entire heap.
  - Sizes stored in headers allow you to step between blocks.



Step 1: Coalescing

- *Coalescing* allows you to combine adjacent free blocks.
- Reduces fragmentation and allows you to more easily satisfy large requests.
- Review *Dynamic Memory Allocation: Basic* lecture for the details.



Step 2: Explicit Lists

- Explicit list: Free blocks explicitly point to other blocks, like in a linked list.
- Can maintain a global free list "head".
  - Make sure to initialize this in `mm_init()`!
- Use free payload space to store pointers.

Step 2: Explicit Lists

- *Write helper functions* for inserting/removing.
- Where do you need to insert? Where do you need to remove?
- Update `find_fit` to scan your new list!
- Expected throughput: 1000-2500kops.

Step 3: Seglists!

- Seglists: now store multiple lists, one for each size class.
- Can maintain a global array of free list heads.
  - Make sure to initialize these in `mm_init()`!
- Update insert/remove functions to insert to the correct bucket.
- Update `find_fit()` to scan the appropriate buckets.
- Common bug: can you leave blocks in the same list if their size changes?

Final Review

What are we trying to do?

- **Improve the utilization of `malloc`**

Optimization	Utilization	Throughput
Implicit List (Starter Code)	59%	10-100
Explicit Free List	-[3]	2000-5000
Segregated Free Lists	-	11000
Better Fit Algorithm	59%	Variable
Eliminating Footers in Allocated Blocks	+9%	-
Decreasing Block Size/Mini Blocks	+6%	-20%
Compressing Headers	+2%	-

source: writeup

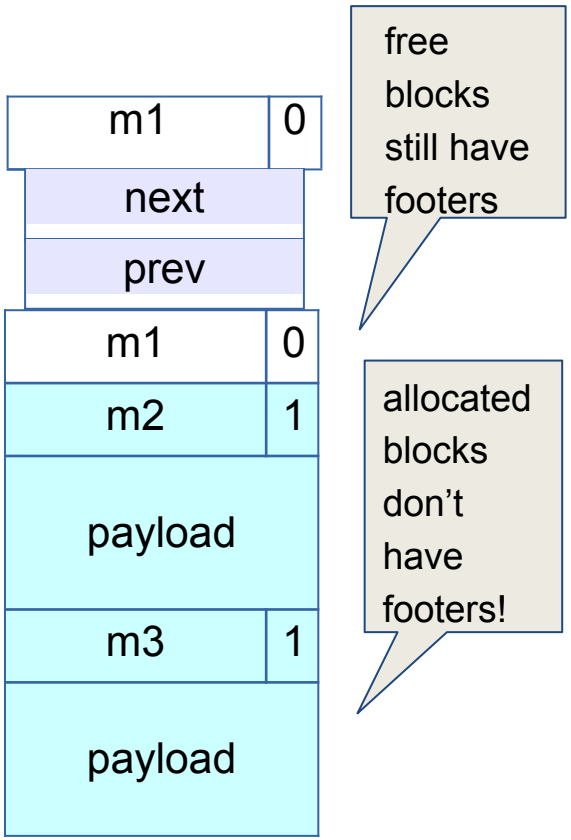
You probably don't want to do this one

Eliminating Footers

- What do we use footers for?
- For finding the prev_block when coalescing
- What kind of blocks do we want to coalesce?
- Do we need to know the size or position of the block if we are not going to coalesce it?
- We only need to know one piece of information about the previous block if it is free.

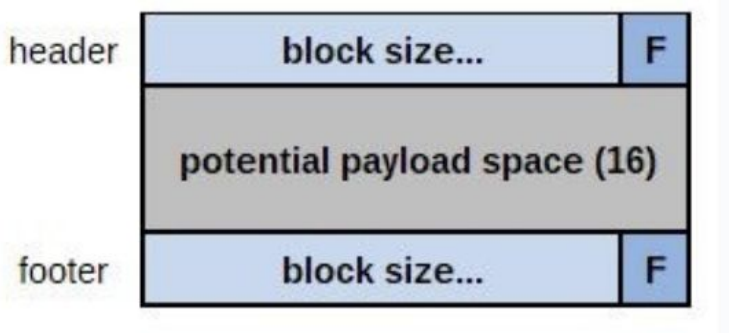
Eliminating Footers

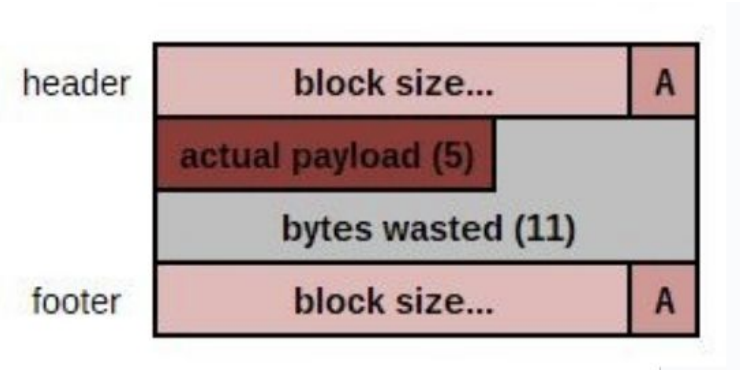
- **Where can we store an extra *bit* of information in the header?**



Decreasing The Minimum Block Size

- Currently the minimum block size is 32
- 8 byte header, 16 byte payload (min), and 8 byte footer.
- If we `malloc(5)`, we waste 11 bytes.
- How can we get this down to 8 bytes?
- Can we remove the need for some of the elements?





Good luck on Malloc Lab!