Malloc Recitation

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Agenda

- Macros in C
- Pointer declarations
- Casting and Pointer Arithmetic
- Malloc

Macros

Macros

- Runtime, compile-time, or pre-compile time?
- Constant:
  - `#define NUM_ENTRIES 100`
  - OK
- Macro
  - `#define twice(x) 2*x`
    - Not OK
    - twice(x+1) becomes 2*x+1
  - `#define twice(x) (2*(x))`
    - OK
  - Use lots of parenthesis, it's a naïve search-and-replace!

Macros

- Why macros?
  - "Faster" than function calls
    - Why?
  - For malloc
    - Quick access to header information (payload size, valid)

- What's the keyword `inline` do?
  - At **compile-time** replaces "function calls" with code

Pointer declarations

C operators (K&R p. 53)

<table>
<tr><th>Operators</th><th>Associativity</th></tr>
<tr><td>() [] -> .</td><td>left to right</td></tr>
<tr><td>! ~ ++ -- + - * & (type) sizeof</td><td>right to left</td></tr>
<tr><td>* / %</td><td>left to right</td></tr>
<tr><td>+ -</td><td>left to right</td></tr>
<tr><td><< >></td><td>left to right</td></tr>
<tr><td>< <= > >=</td><td>left to right</td></tr>
<tr><td>== !=</td><td>left to right</td></tr>
<tr><td>&</td><td>left to right</td></tr>
<tr><td>^</td><td>left to right</td></tr>
<tr><td>|</td><td>left to right</td></tr>
<tr><td>&&</td><td>left to right</td></tr>
<tr><td>||</td><td>left to right</td></tr>
<tr><td>?:</td><td>right to left</td></tr>
<tr><td>= += -= *= /= %= &= ^= != <<= >>=</td><td>right to left</td></tr>
<tr><td>,</td><td>left to right</td></tr>
</table>

Note: Unary +, −, and * have higher precedence than binary forms

Review of C Pointer Declarations (K&R section 5.12)

`int *p`	p is a pointer to int
`int *p[13]`	p is an array[13] of pointer to int
`int *(p[13])`	p is an array[13] of pointer to int
`int **p`	p is a pointer to a pointer to an int
`int (*p)[13]`	p is a pointer to an array[13] of int
`int *f()`	f is a function returning a pointer to int
`int (*f)()`	f is a pointer to a function returning int
`int (*(*f())[13])()`	f is a function returning ptr to an array[13] of pointers to functions returning int
`int (*(*x[3])())[5]`	x is an array[3] of pointers to functions returning pointers to array[5] of ints

Pointer casting, arithmetic, and dereferencing

Pointer casting

- Separate from non-pointer casting
  - float to int, int to float
  - <struct_a> to <struct_b>
    - No! gcc error.
- Cast from
  - <type_a> * to <type_b> *
  - <type_a> * to integer/ unsigned int
  - integer/ unsigned int to <type_a> *

Pointer casting

- What actually happens in a pointer cast?
  - Nothing! It's just an assignment. Remember all pointers are the same size.
  - The magic happens in dereferencing and arithmetic

Pointer arithmetic

- The expression `ptr + a` doesn't always evaluate into the arithmetic sum of the two
- Consider:

```
<type_a> * pointer = …;
(void *) pointer2 = (void *) (pointer + a);
```

- Think about it as
  - `leal (pointer, a, sizeof(type_a)), pointer2;`

Pointer arithmetic

- ```
  int * ptr = (int *)0x12341234;
  int * ptr2 = ptr + 1;
  ```
- ```
  char * ptr = (char *)0x12341234;
  char * ptr2 = ptr + 1;
  ```
- ```
  int * ptr = (int *)0x12341234;
  int * ptr2 = ((int *) (((char *) ptr) + 1));
  ```
- ```
  void * ptr = (char *)0x12341234;
  void * ptr2 = ptr + 1;
  ```
- ```
  void * ptr = (int *)0x12341234;
  void * ptr2 = ptr + 1;
  ```
  ```

Pointer arithmetic

- ```
  int * ptr = (int *)0x12341234;
  int * ptr2 = ptr + 1; //ptr2 is 0x12341238
  ```

- ```
  char * ptr = (char *)0x12341234;
  char * ptr2 = ptr + 1; //ptr2 is 0x12341235
  ```

- ```
  int * ptr = (int *)0x12341234;
  int * ptr2 = ((int *) (((char *) ptr) + 1));
  //ptr2 is 0x12341235
  ```

- ```
  void * ptr = (char *)0x12341234;
  void * ptr2 = ptr + 1; //ptr2 is 0x12341235
  ```

- ```
  void * ptr = (int *)0x12341234;
  void * ptr2 = ptr + 1; //ptr2 is still 0x12341235
  ```
  ```

More pointer arithmetic

- ```
  int ** ptr = (int **)0x12341234;
  int * ptr2 = (int *) (ptr + 1);
  ```

- ```
  char ** ptr = (char **)0x12341234;
  short * ptr2 = (short *) (ptr + 1);
  ```

- ```
  int * ptr = (int *)0x12341234;
  void * ptr2 = &ptr + 1;
  ```

- ```
  int * ptr = (int *)0x12341234;
  void * ptr2 = ((void *) (*ptr + 1));
  ```

- <u>**This is on a 64-bit machine!**</u>

More pointer arithmetic

- ```
  int ** ptr = (int **)0x12341234;
  int * ptr2 = (int *) (ptr + 1); //ptr2 = 0x1234123c
  ```

- ```
  char ** ptr = (char **)0x12341234;
  short * ptr2 = (short *) (ptr + 1);
  //ptr2 = 0x1234123c
  ```

- ```
  int * ptr = (int *)0x12341234;
  void * ptr2 = &ptr + 1; //ptr2 = ??
  //ptr2 is actually 8 bytes higher than the address
  of the variable ptr
  ```

- ```
  int * ptr = (int *)0x12341234;
  void * ptr2 = ((void *) (*ptr + 1)); //ptr2 = ??
  //ptr2 is just one higher than the value at
  0x12341234 (so probably segfault)
  ```

Pointer dereferencing

- Basics
  - It must be a POINTER type (or cast to one) at the time of dereference
  - Cannot dereference (void *)
  - The result must get assigned into the right datatype (or cast into it)

Pointer dereferencing

- What gets “returned?”

```
int * ptr1 = malloc(100);
*ptr1 = 0xdeadbeef;

int val1 = *ptr1;
int val2 = (int) *((char *) ptr1);
```

What are val1 and val2?

Pointer dereferencing

- What gets “returned?”

```
int * ptr1 = malloc(sizeof(int));
*ptr1 = 0xdeadbeef;

int val1 = *ptr1;
int val2 = (int) *((char *) ptr1);
```

```
//  val1 = 0xdeadbeef;
//  val2 = 0xffffffef;
```

What happened??

Malloc

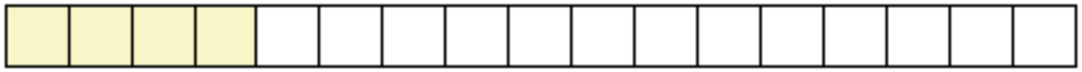
Malloc basics

- What is dynamic memory allocation?

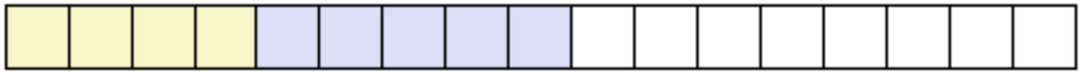
- Terms you will need to know
  - malloc / calloc / realloc
  - free
  - sbrk
  - payload
  - fragmentation (internal vs. external)
  - coalescing
    - Bi-directional
    - Immediate vs. Deferred

Allocation Example

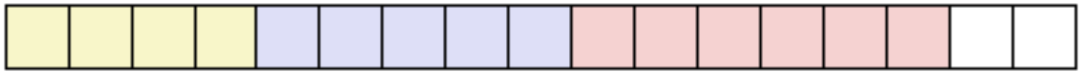
`p1 = malloc(4)`



`p2 = malloc(5)`



`p3 = malloc(6)`



`free(p2)`

`p4 = malloc(2)`

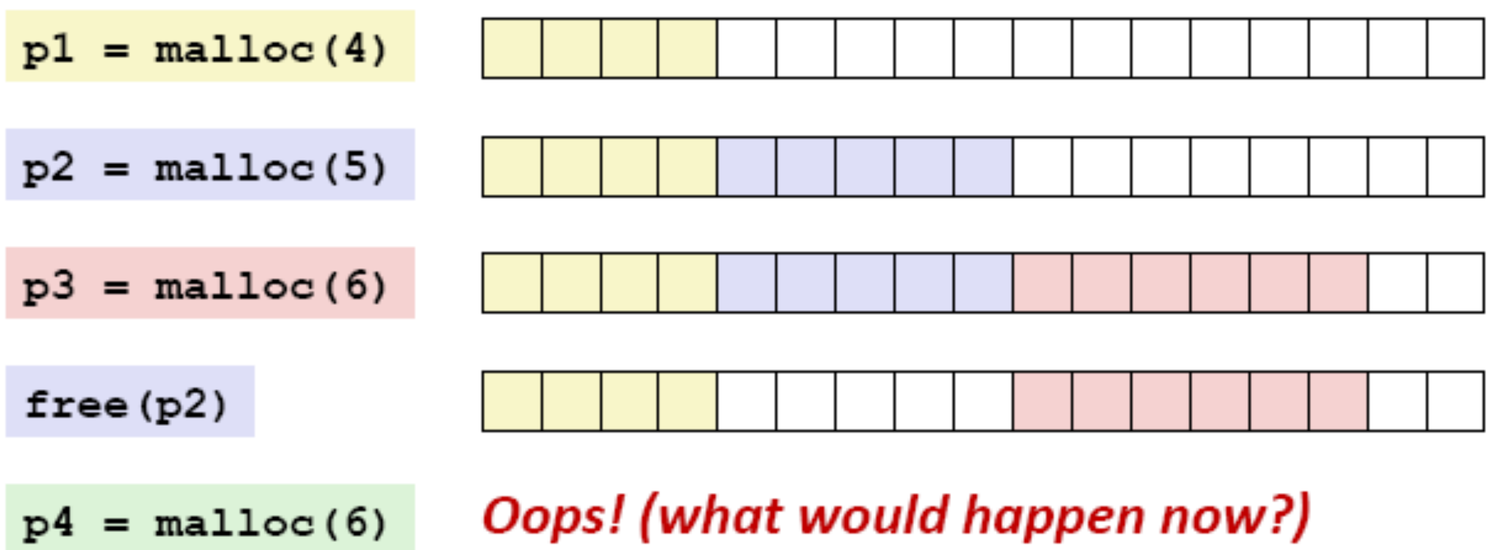
Fragmentation

- Internal fragmentation
  - Result of **payload** being smaller than block size.
  - `void * m1 = malloc(3); void * m1 = malloc(3);`
  - `m1,m2` both have to be aligned to 8 bytes…

- External fragmentation

External Fragmentation

- **Occurs when there is enough aggregate heap memory, but no single free block is large enough**



- **Depends on the pattern of future requests**
  - Thus, difficult to measure

Implementation Hurdles

- How do we know where the chunks are?
- How do we know how big the chunks are?
- How do we know which chunks are free?
- Remember: can't buffer calls to malloc and free... must deal with them real-time.
- Remember: calls to `free` only takes a pointer, not a pointer and a size.
- Solution: **Need a data structure to store information on the "chunks"**
  - Where do I keep this data structure?

The data structure

- Requirements:
  - The data structure needs to tell us where the chunks are, how big they are, and whether they're free
  - We need to be able to CHANGE the data structure during calls to malloc and free
  - We need to be able to find the **next free chunk** that is "a good fit for" a given payload
  - We need to be able to quickly mark a chunk as free/allocated
  - We need to be able to detect when we're out of chunks.
    - What do we do when we're out of chunks?

The data structure

- It would be convenient if it worked like:

```
malloc_struct malloc_data_structure;
…
ptr = malloc(100, &malloc_data_structure);
…
free(ptr, &malloc_data_structure);
…
```

- Instead all we have is the memory we're giving out.
  - All of it doesn't have to be payload! We can use some of that for our data structure.

The data structure

- The data structure IS your memory!
- A start:
  - <h1> <pl1> <h2> <pl2> <h3> <pl3>
  - What goes in the header?
    - That’s your job!
  - Lets say somebody calls free(p2), how can I coalesce?
    - Maybe you need a **footer**? Maybe not?

The data structure

- Common types
  - Implicit List
    - Root -> chunk1 -> chunk2 -> chunk3 -> …
  - Explicit List
    - Root -> free chunk 1 -> free chunk 2 -> free chunk 3 -> …
  - Segregated List
    - Small-malloc root -> free small chunk 1 -> free small chunk 2 -> …
    - Medium-malloc root -> free medium chunk 1 -> …
    - Large-malloc root -> free large chunk1 -> …

Design considerations

- I found a chunk that fits the necessary payload… should I look for a better fit or not?
- Splitting a free block:

```
void* ptr = malloc(200);
free(ptr);
ptr = malloc(50); //use same space, then "mark" remaining bytes
                    as free

void* ptr = malloc(200);
free(ptr);
ptr = malloc(192);//use same space, then "mark" remaining bytes
                    as free??
```

Design Considerations

- Free blocks: address-ordered or LIFO
  - What's the difference?
  - Pros and cons?
- Implicit / Explicit / or Seg?
  - Implicit won't get you very far… too slow.
  - Explicit is a good place to start, and can be turned into a seg-list.
  - Seg-list: what are the thresholds?