CS 354 - Machine Organization & Programming
Tuesday Oct 1st, and Thursday Oct 3rd, 2024

Midterm Exam - Thurs, Oct 3rd, 7:30 - 9:30 pm

You should have received email with your EXAM INFORMATION including:
DATE, TIME, ROOM, NAME, LECTURE NUMBER, and ID NUMBER,

- **UW ID required. Students without UW ID must wait until other students are checked in**
- **Hardcopy or photo of Exam info email, on phone is fine**
- **#2 pencils required**
- **closed book, no notes, no electronic devices (e.g., calculators, phones, watches)**
- **see "Midterm Exam 1" on course site Assignments for topics**

A05 submit copy of e1_cheatsheet.pdf to your activities directory

PM BYOL: Exam Review

Project p2B: Due on or before Sunday, Oct 6th

Homework hw2: Due on Monday 9/30 (solution available Wed morning)

This Week: Linux: Proceses and Address Spaces Posix `brk` & `unistd.h` C's Heap Allocator & `stdlib.h` Meet the Heap Allocator Design Simple View of Heap	Free Block Organization Implicit Free List Placement Policies **MIDTERM EXAM 1**
Next Week: Dynamic Memory Allocator options Read for next week: B&O 9.9.7 Placing Allocated Blocks 9.9.8 Splitting Free Blocks 9.9.9 Getting Additional Heap Memory 9.9.10 Coalescing Free Blocks	9.9.11 Coalescing with Boundary Tags 9.9.12 Putting It Together: Implementing a Simple Allocator 9.9.13 Explicit Free Lists 9.9.14 Segregated Free Lists

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Posix `brk` & `unistd.h`

What? `unistd.h` contains a collection of OS functions (system call wrappers) used to access functions in the Posix API

Posix API (Portable OS Interface) standard for maintaining compatibility among Unix OS's

DIY "Do It Yourself" Heap via Posix Calls

brk "program break" - pointer to end of program, at top of heap

```
int brk(void *addr)
```

Sets the top of heap to the specified address `addr`.
Returns 0 if successful, else -1 and sets `errno`.
OS initially clears new pages of heap memory for security

```
void *sbrk(intptr_t incr)  //intptr_t is sizeof long for ptr addr
```

Attempts to change the program's top of heap by `incr` bytes.
Returns the old **brk** if successful, else -1 and sets `errno`.

`errno`

set by OS functions to communicate a specific error

- *For most applications, it's best to use malloc/calloc/realloc/free*

- ***Caveat: Using both malloc/calloc/realloc and break functions above results in undefined program behavior.***

C's Heap Allocator & `stdlib.h`

What? **`stdlib.h`** contains a collection of ~25 commonly used C functions

-
-
-
-
-
-

C's Heap Allocator Functions

```
void *malloc(size_t size)//size_t is sizeof unsigned int
```

Allocates and returns generic ptr to block of heap memory of `size` bytes, or returns `NULL` if allocation fails.

```
void *calloc(size_t nItems, size_t size)
```

Allocates, clears to 0, and returns a block of heap memory of `nItems * size` bytes, or returns `NULL` if allocation fails.

```
void *realloc(void *ptr, size_t size)
```

Reallocates to `size` bytes a previously allocated block of heap memory pointed to by `ptr`, or returns `NULL` if reallocation fails.

```
void free(void *ptr)
```

Frees the heap memory pointed to by `ptr`. If `ptr` is `NULL` then does nothing.

❊ ***For CS 354, if malloc/calloc/realloc returns NULL***
just exit the program with an appropriate error message.

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Meet the Heap

What? The heap is

-

  dynamically allocated memory:

-

  block:

  payload:

  overhead:

  allocator:

Two Allocator Approaches

1. Implicit:
   -
   -
2. Explicit:
   -
   -

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Allocator Design

Two Goals

1. maximize *throughput*

2. maximize *memory utilization*

Trade Off:

Requirements

→ List the requirements of a heap allocator.

1.

2.

3.

4.

5.

Design Considerations

-
-
-
-

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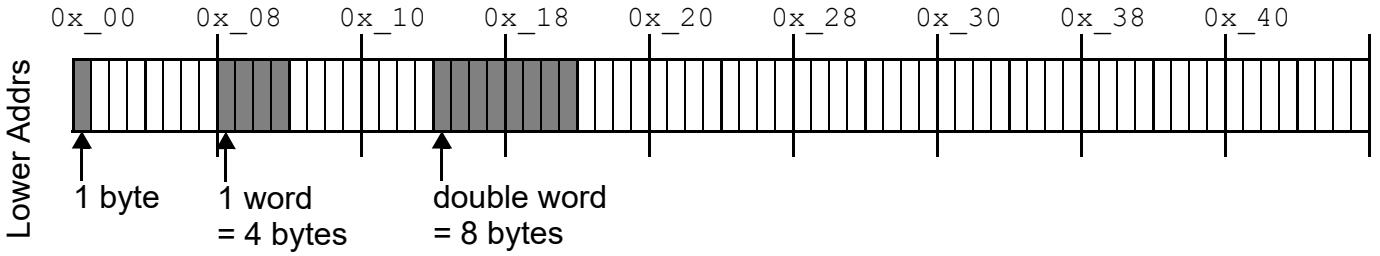
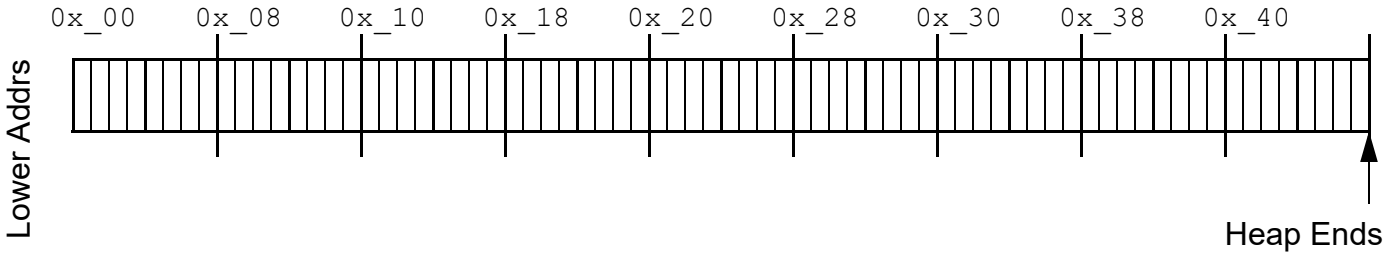
Simple View of Heap

Rotated Linear Memory Layout



double word alignment:

Run 1: Simple View of Heap Allocation



→ Update the diagram to show the following heap allocations:

```
1) p1 = malloc(2 * sizeof(int));
2) p2 = malloc(3 * sizeof(char));
3) p3 = malloc(4 * sizeof(int));
4) p4 = malloc(5 * sizeof(int));
```

→ What happens with the following heap operations:

```
5) free(p1); p1 = NULL;
6) free(p3); p3 = NULL;
7) p5 = malloc(6 * sizeof(int));
```

External Fragmentation:

Internal Fragmentation:

➢ Why does it make sense that Java doesn't allow primitives on the heap?

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Free Block Organization

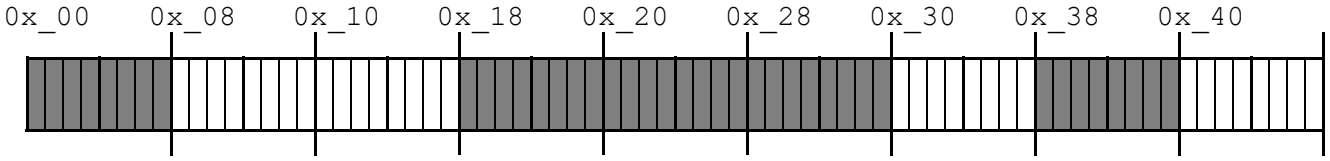
❋ *The simple view of the allocator has*

size

status

Explicit Free List

◆



code:

space:

time:

Implicit Free List

◆

code:

space:

time:

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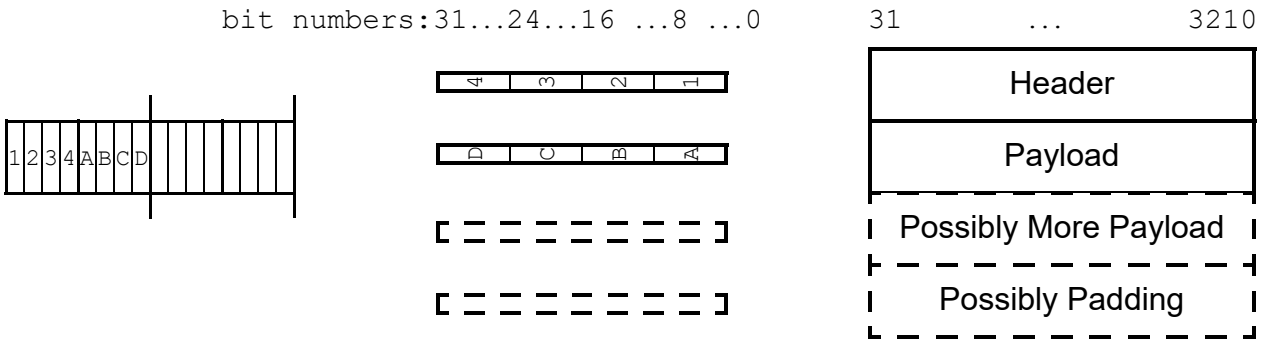
Implicit Free List

❋ *The first word of each block*

Layout 1: Basic Heap Block (3 different memory diagrams of same thing)



❋ *The header stores*

→ Since the block size is a multiple of 8, what value will the last three header bits always have?

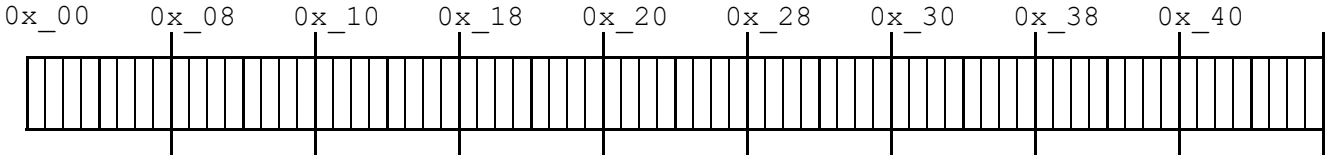
→ What integer value will the header have for a block that is:

allocated and 8 bytes in size?

free and 32 bytes in size?

allocated and 64 bytes in size?

Run 2: Heap Allocation with Block Headers



→ Update the diagram to show the following heap allocations:

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1) p1 = malloc(2 * sizeof(int));
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4) p4 = malloc(5 * sizeof(int));
```

→ Given a pointer to the first block in the heap, how is the next block found?

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Placement Policies

What? *Placement Policies* are

Assume the heap is pre-divided into various-sized free blocks ordered from smaller to larger.

- **First Fit** (FF): start from
  stop at
  fail if

  mem util:

  thruput:

- **Next Fit** (NF): start from
  stop at
  fail if

  mem util:

  thruput:

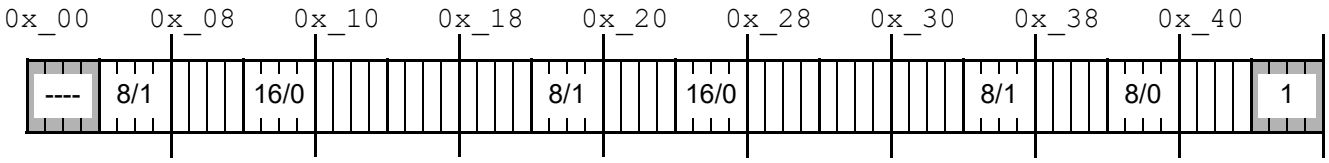
- **Best Fit** (BF): start from
  stop at
  or stop early
  fail if

→

mem util:

thruput:

Run 3: Heap Allocation using Placement Policies



→ Given the original heap above and the placement policy, what address is `ptr` assigned?

```
ptr = malloc(sizeof(int));            //FF?            BF?

ptr = malloc(10 * sizeof(char));      //FF?            BF?
```

→ Given the original heap above and the address of block most recently allocated, what address is `ptr` assigned using NF?

```
ptr = malloc(sizeof(char));         //0x_04?           0x_34?

ptr = malloc(3 * sizeof(int));      //0x_1C?           0x_34?
```

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