System Programming
Lab #3

2023-04-18

SP-TAs

Lab Assignment #3 : Malloc Lab

- Download skeleton code & pdf from eTL
  - malloclab-handout.tar, malloclab-handout.pdf
- Hand In
  - Upload your files eTL
    - 압축파일 양식 : [학번]_[이름]_malloclab.zip
    - Ex) 2023-12345_홍길동_malloclab.tar
  - A zip file should include
  - (1)mm.c (2) Report
    - mm.c 양식 : mm-[학번].c eg) mm-2023-12345.c (제출할 때만 바꿔서)
    - Report 양식 : [학번]_[이름]_malloclab_report.pdf (or .hwp, .docx etc)
- Please, READ the Hand-out thoroughly!
- Assigned : 4/18
- Deadline : 5/1 , 23:59:59
- Delay policy : Same as before
- Next week's Lab
  - Malloc LAB Q&A session

Before we start

- We need to know…
  - 1. Macros
  - 2. Pointer Arithmetic

Macros

- Why macros?
  - 1. Faster than function calls
  - 2. Encapsulate pointer arithmetic code lines
    - pointer arithmetic is error-prone & confusing
- Differences (with `__inline` functions)
  - Macros are done with preprocessor (before compile time)
  - No call, return overheads
- Drawbacks
  - Less expressive than functions
  - Arguments are not type-checked
  - Unintended side effects
    - Ex) #define xsquared(x) (x*x)
    - What happens when xsquared(x++) is called?

In the textbook

code/vm/malloc/mm.c

```
/* Basic constants and macros */
#define WSIZE       4       /* Word and header/footer size (bytes) */
#define DSIZE       8       /* Double word size (bytes) */
#define CHUNKSIZE   (1<<12) /* Extend heap by this amount (bytes) */

#define MAX(x, y) ((x) > (y)? (x) : (y))

/* Pack a size and allocated bit into a word */
#define PACK(size, alloc)  ((size) | (alloc))

/* Read and write a word at address p */
#define GET(p)       (*(unsigned int *)(p))
#define PUT(p, val)  (*(unsigned int *)(p) = (val))

/* Read the size and allocated fields from address p */
#define GET_SIZE(p)  (GET(p) & ~0x7)
#define GET_ALLOC(p) (GET(p) & 0x1)

/* Given block ptr bp, compute address of its header and footer */
#define HDRP(bp)       ((char *)(bp) - WSIZE)
#define FTRP(bp)       ((char *)(bp) + GET_SIZE(HDRP(bp)) - DSIZE)

/* Given block ptr bp, compute address of next and previous blocks */
#define NEXT_BLKP(bp)  ((char *)(bp) + GET_SIZE(((char *)(bp) - WSIZE)))
#define PREV_BLKP(bp)  ((char *)(bp) - GET_SIZE(((char *)(bp) - DSIZE)))
```

code/vm/malloc/mm.c

Figure 9.43 Basic constants and macros for manipulating the free list.

Pointer Arithmetic

- Pointers are 4-byte numbers
  - Use unsigned int / int to get 4-byte numbers

- Read, write address as below

```
/* Read and write a word at address p */
#define GET(p)        (*(unsigned int *)(p))
#define PUT(p, val)   (*(unsigned int *)(p) = (val))
```

Pointer Arithmetic

- What does ptr + a mean?
  - `(type_1) *ptr1 = some_val;`
  - `(type_1) *ptr2 = ptr + n;`
- This is really computing :
  - **`ptr2 = ptr1 + (n * sizeof(type_a));`**
  - **`lea  (ptr1, n, sizeof(type_a)), ptr2;`**
- Practice
  - `int *ptr = (int *)0x12341230;`
  - `int *ptr2 = ptr + 1;`

  - `char *ptr = (char *)0x12341230;`
  - `char *ptr2 = ptr + 1;`

Pointer Arithmetic

- What does ptr + a mean?
  - (type_1)* ptr1 = some value;
  - (type_1)* ptr2 = ptr + a;
- This is really computing :
  - **ptr2 = ptr1 + (a * sizeof(type_a));**
  - **lea (ptr1, a, sizeof(type_a)) , ptr2;**
- Practice
  - int * ptr = (int *) 0x12341230;
  - int * ptr2 = ptr + 1; //ptr2 = 0x12341234

  - char *ptr = (char *) 0x12341230;
  - char * ptr2 = ptr + 1; //ptr2 = 0x12341231

Pointer Arithmetic

- What does below mean?

```
/* Given block ptr bp, compute address of next and previous blocks */
#define NEXT_BLKP(bp)  ((char *)(bp) + GET_SIZE(((char *)(bp) - WSIZE)))
#define PREV_BLKP(bp)  ((char *)(bp) - GET_SIZE(((char *)(bp) - DSIZE)))
```

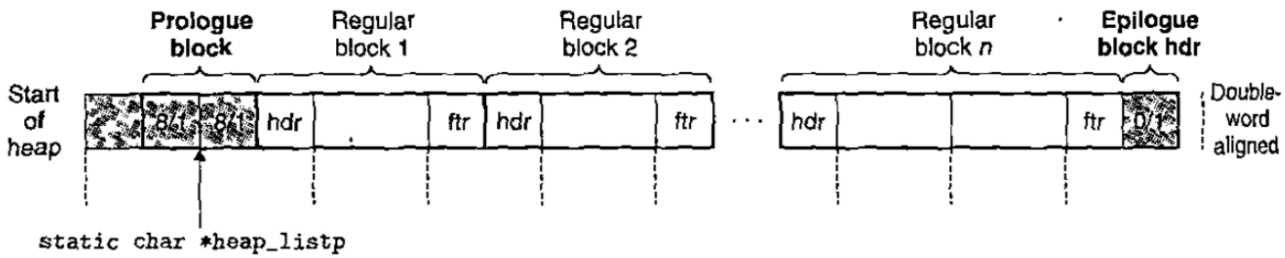
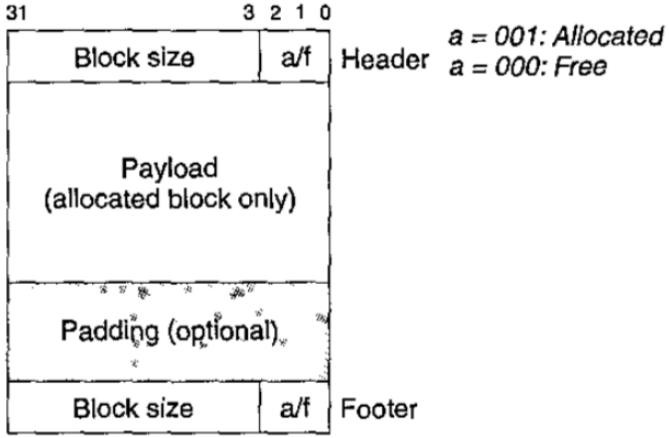


Figure 9.42 Invariant form of the implicit free list.

Figure 9.39
Format of heap block that uses a boundary tag.



Malloc Lab Preview

- Implementing your own dynamic storage allocator
  : mm_init, mm_malloc, mm_free, mm_realloc

- Ways to keep track of free, allocated blocks of memory
  - Implicit linked list of blocks
  - Explicit linked list of free blocks
  - Segregated lists of different size free blocks
- Other design decisions :
  - How to look for free blocks? (First fit, next fit, best fit, …)
  - Should the linked lists be doubly linked?
  - When to coalesce blocks?

Support Routines

Functions you can use (implemented in memlib.c)

- `void *mem_sbrk(int incr)`: Expands the heap by `incr` bytes, where `incr` is a positive non-zero integer and returns a generic pointer to the first byte of the newly allocated heap area. The semantics are identical to the Unix `sbrk` function, except that `mem_sbrk` accepts only a positive non-zero integer argument.
- `void *mem_heap_lo(void)`: Returns a generic pointer to the first byte in the heap.
- `void *mem_heap_hi(void)`: Returns a generic pointer to the last byte in the heap.
- `size_t mem_heapsize(void)`: Returns the current size of the heap in bytes.
- `size_t mem_pagesize(void)`: Returns the system's page size in bytes (4K on Linux systems).

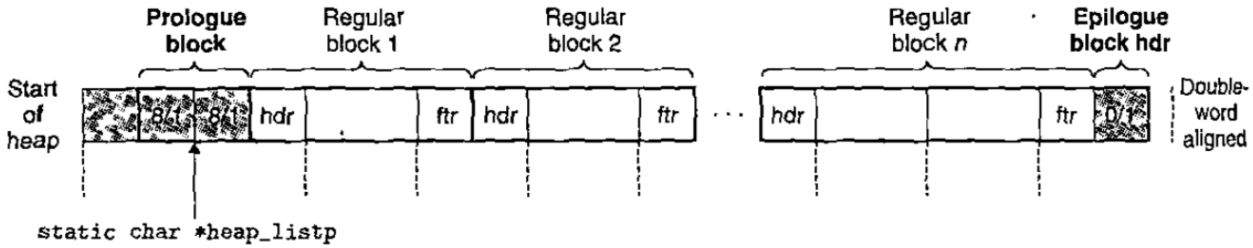


Figure 9.42 Invariant form of the implicit free list.

Watch Out!

7 Programming Rules

- You should not change any of the interfaces in `mm.c`.
- You should not invoke any memory-management related library calls or system calls. This excludes the use of `malloc`, `calloc`, `free`, `realloc`, `sbrk`, `brk` or any variants of these calls in your code.
- You are not allowed to define any global or `static` compound data structures such as arrays, structs, trees, or lists in your `mm.c` program. However, you *are* allowed to declare global scalar variables such as integers, floats, and pointers in `mm.c`.
- For consistency with the `libc malloc` package, which returns blocks aligned on 8-byte boundaries, your allocator must always return pointers that are aligned to 8-byte boundaries. The driver will enforce this requirement for you.

Do not change any sources except `mm.c`.

Testing with trace files

- `-t <tracedir>`: Look for the default trace files in directory `tracedir` instead of the default directory defined in `config.h`.
- `-f <tracefile>`: Use one particular `tracefile` for testing instead of the default set of trace-files.
- `-h`: Print a summary of the command line arguments.
- `-l`: Run and measure `libc` malloc in addition to the student's malloc package.
- `-v`: Verbose output. Print a performance breakdown for each tracefile in a compact table.
- `-V`: More verbose output. Prints additional diagnostic information as each trace file is processed. Useful during debugging for determining which trace file is causing your malloc package to fail.

```
ta@sp3:~/yschoi/testing/malloclab-handout/src$ ./mdriver -f ./traces/short1.rep  -V
Team Name:implicit first fit
Member 1 :Dave OHallaron:droh
Measuring performance with gettimeofday().

Testing mm malloc
Reading tracefile: ./traces/short1.rep
Checking mm_malloc for correctness, efficiency, and performance.

Results for mm malloc:
trace  valid  util     ops      secs  Kops
 0       yes   66%      12  0.000001 20000
Total          66%      12  0.000001 20000

Perf index = 40 (util) + 40 (thru) = 80/100
```

Testing with trace files

- Heap size(unused)
- Ids
- Ops
- Weight(unused)

- Op id size
- …

- A – alloc
- F – free
- R – realloc

test@SystemProgramming: ~/lab3/malloclab-...

```
20000
6
12
1
a 0 2040
a 1 2040
f 1
a 2 48
a 3 4072
f 3
a 4 4072
f 0
f 2
a 5 4072
f 4
f 5
                    17,0-1        All
```

Short1.rep

Testing with trace files

```
test@SystemProgramming: ~/lab3/malloclab-handout/src
test@SystemProgramming:~/lab3/malloclab-handout/src$ ./mdriver -V
Using default tracefiles in ./traces/
Measuring performance with gettimeofday().

Testing mm malloc
Reading tracefile: amptjp-bal.rep
Checking mm_malloc for correctness, efficiency, and performance.
Reading tracefile: cccp-bal.rep
Checking mm_malloc for correctness, efficiency, and performance.
Reading tracefile: cp-decl-bal.rep
Checking mm_malloc for correctness, efficiency, and performance.
Reading tracefile: expr-bal.rep
Checking mm_malloc for correctness, efficiency, and performance.
Reading tracefile: coalescing-bal.rep
ERROR: mem_sbrk failed. Ran out of memory...
Checking mm_malloc for correctness, ERROR [trace 4, line 7673]: mm_malloc failed.
Reading tracefile: random-bal.rep
ERROR: mem_sbrk failed. Ran out of memory...
Checking mm_malloc for correctness, ERROR [trace 5, line 1662]: mm_malloc failed.
Reading tracefile: random2-bal.rep
ERROR: mem_sbrk failed. Ran out of memory...
Checking mm_malloc for correctness, ERROR [trace 6, line 1780]: mm_malloc failed.
Reading tracefile: binary-bal.rep
Checking mm_malloc for correctness, efficiency, and performance.
Reading tracefile: binary2-bal.rep
Checking mm_malloc for correctness, efficiency, and performance.
Reading tracefile: realloc-bal.rep
ERROR: mem_sbrk failed. Ran out of memory...
Checking mm_malloc for correctness, ERROR [trace 9, line 1705]: mm_realloc failed.
Reading tracefile: realloc2-bal.rep
ERROR: mem_sbrk failed. Ran out of memory...
Checking mm_malloc for correctness, ERROR [trace 10, line 6562]: mm_realloc failed.

Results for mm malloc:
trace  valid  util     ops      secs  Kops
 0       yes   23%    5694  0.000068 83246
 1       yes   19%    5848  0.000070 83782
 2       yes   30%    6648  0.000083 79712
 3       yes   40%    5380  0.000063 85942
 4        no    -       -         -     -
 5        no    -       -         -     -
 6        no    -       -         -     -
 7       yes   55%   12000  0.000152 79051
 8       yes   51%   24000  0.000154155945
 9        no    -       -         -     -
10        no    -       -         -     -
Total          -       -         -     -

Terminated with 5 errors
test@SystemProgramming:~/lab3/malloclab-handout/src$
```

```
./mdriver -V
```

Evaluation

- Our evaluation
  - Correctness(20 points)
  - Performance(100 points)
    : Space utilization + Throughput
  - Style(10 points)
  - Report(10 points)

Last year's Questions

- Trace file의 경로 변경은 어떻게 하나요?
  => src/config.h

- mm_malloc의 input이 0인 경우의 return값?
  => NULL

- Global/Static으로 array 선언하면 안되나요?
  => 안됩니다

- libc-header-start.h 헤더파일 오류
  => $sudo apt install gcc-multilib 명령어로 설치

- 고친 부분이 없는데 Trace file을 돌릴 때 가끔 점수가 다르게 나옵니다.
  ⇒서버의 CPU 사용량에 따라 점수가 다르게 나올 수 있습니다.

How to begin

From handout.pdf, 10.hint

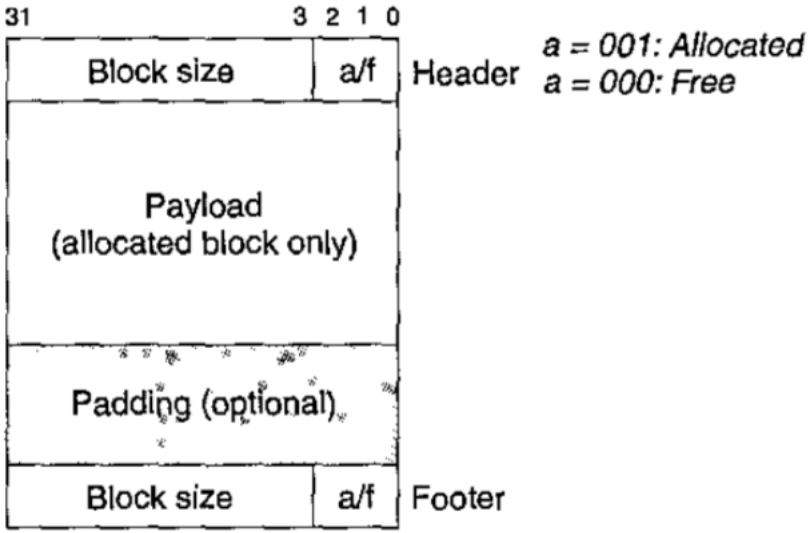
- *Understand every line of the malloc implementation in the textbook.* The textbook has a detailed example of a simple allocator based on an implicit free list. Use this is a point of departure. Don't start working on your allocator until you understand everything about the simple implicit list allocator.

Workflow

1. Understand textbook
2. Implement mm.c with implicit list
3. modify your implementation (to explicit, segregated)
4. use diff. policies (Next-fit, First-fit, … / When to coalesce / etc)
5. use diff. data structures

Understanding Textbook

Figure 9.39
Format of heap block that uses a boundary tag.



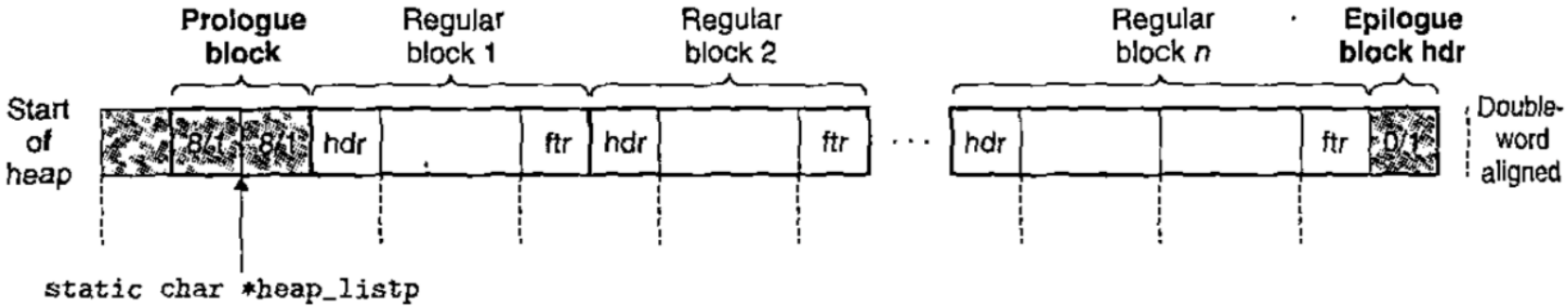


Figure 9.42 Invariant form of the implicit free list.

Understanding Textbook

code/vm/malloc/mm.c

```
int mm_init(void)
{
    /* Create the initial empty heap */
    if ((heap_listp = mem_sbrk(4*WSIZE)) == (void *)-1)
        return -1;
    PUT(heap_listp, 0);                          /* Alignment padding */
    PUT(heap_listp + (1*WSIZE), PACK(DSIZE, 1)); /* Prologue header */
    PUT(heap_listp + (2*WSIZE), PACK(DSIZE, 1)); /* Prologue footer */
    PUT(heap_listp + (3*WSIZE), PACK(0, 1));     /* Epilogue header */
    heap_listp += (2*WSIZE);

    /* Extend the empty heap with a free block of CHUNKSIZE bytes */
    if (extend_heap(CHUNKSIZE/WSIZE) == NULL)
        return -1;
    return 0;
}
```

code/vm/malloc/mm.c

Figure 9.44 `mm_init` **creates a heap with an initial free block.**

End

- Due: 5/1 23:59:59

- Questions
  - eTL Q&A Board
  - eMail: sp-ta@googlegroups.com
- Start early