Ch9-Virtual Memory

9.9 Dynamic Memory Allocation

Malloc-Related Interfaces

```
#include <stdlib>
void *malloc(size_t size);
```

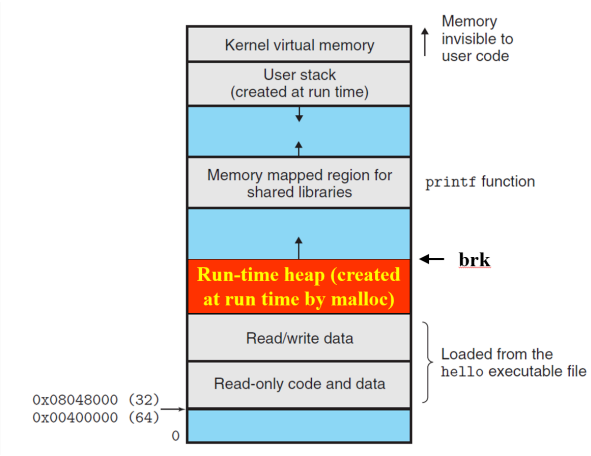
分配成功时返回8字节对齐的内存块；当size==0时返回NULL；分配失败则返回NULL的同时，设置errno为ENOMEM

```
#include <stdlib>
void free(void *p);
```

释放对应的内存块，但指针p必须是由malloc,calloc,realloc分配的

```
#include <unistd.h>
void *sbrk(int incr);
```

sbrk函数通过修改堆顶指针brk来扩展和收缩堆。成功，则返回brk的旧值；失败，则返回-1；当incr==0时，返回当前值；incr可为负数，此时收缩堆



Allocator Requirements

- 能处理任意请求序列：不能提前假设
- 立刻响应请求：不能缓冲
- 只使用堆
- 8字节对齐块
- 不修改已经分配的块

优化目标：

- **throughput(最大化吞吐率)**：每个单位时间完成的请求数
- **peak memory utilization(峰值利用率)**：认为有效载荷(payload)p为请求的块大小，聚合有效载荷(aggregate payload)P_k为已分配块的有效载荷之和，堆的当前大小为H_k，则$U_k = (max_{i<=k}P_i)/H_k$

Fragmentation

碎片导致低利用率，分为内部碎片和外部碎片

- **Internal Fragmentation**:当已分配块大于有效载荷时产生，如维护堆时产生的开销，对齐时产生的填充，显式规则等，这是很好衡量的
- **External Fragmentation**:当堆的剩余空间足够，但没有单独的空闲块足够时发生，难以衡量

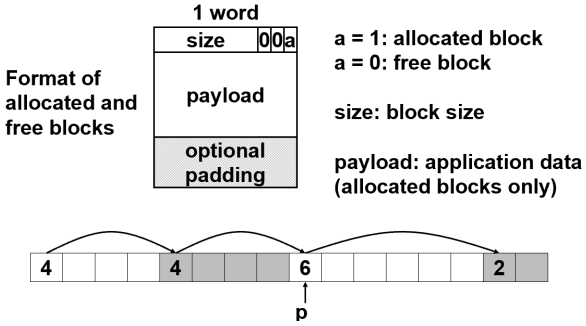
Implementation Issues and Solutions

Knowing how Much to Free(How do we know how much memory to free just given a pointer?)

每个块都使用头部维护块的大小，注意此时的size是要加上这个4字节的头部的，而非有效载荷，同时应当是有效载荷对齐8字节，而非头部，且指针指向的也是有效载荷

Implicit List(How do we keep track of the free blocks?)

使用额外的比特维护块是否空闲，需要3个比特，这样size就会被乘以8，这样就产生了隐式空闲链表



Finding a Free Block(How do we pick a block to use for allocation?)

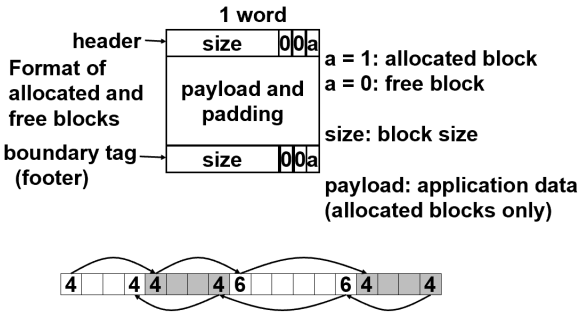
- **First fit(首次适配)**：从头开始搜索合适的空闲块，使得大的空闲块集中在链表后面，但会使链表起始处产生小的空闲块碎片
- **Next fit(下一次适配)**：从上一次查询结束的位置开始检查，但内存利用率比首次适配低很多
- **Best fit(最佳适配)**：遍历整个链表，选择所有空闲块中最适合的，碎片少但用时多

Allocating in a free block(How to deal with the extra space?)

将空闲块分割成分配块和新的空闲块

Freeing a block(How do we reinsert freed block?)

- **Coalescing(合并)**：释放的空闲块需要与前后的空闲块合并，但在合并前面的空闲块时，难以判断哪个字才是头部
- **Bidirectional Coalescing(双向合并)**：需要使用边界标记(boundary tags)，在块的尾部也需要维护块大小和是否空闲，形成双向链表，头部尾部连续使得可以确定前后块的确切位置



接下来合并分为四种情况，处理如图：

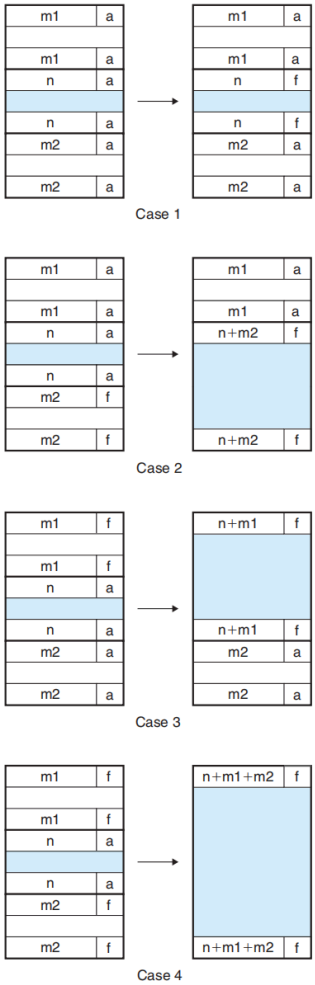
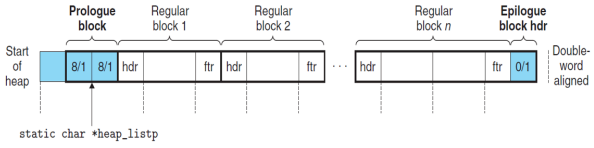


Figure 9.40 **Coalescing with boundary tags.** Case 1: prev and next allocated. Case 2: prev allocated, next free. Case 3: prev free, next allocated. Case 4: next and prev free.

A Basic Implementation

接下来需要实现一个简单的分配器，提供三个接口：

```
int mm_init(void);
void *mm_malloc(size_t size);
void mm_free(void *bp);
```



宏定义：

```
/* Basic constants and macros */
#define WSIZE 4 /* word 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)))
```

```
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*WIZE);

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

这里传给内置函数extent_heap的参数为字的数目，故需要先检查是否能8对齐（也就是参数是否为偶数），mem_sbrk返回的值为旧的brk，也就是旧堆的结尾，即新堆的有效载荷的起始位置

```
static void *extend_heap(size_t words)
{
    char *bp;
    size_t size;

    /* Allocate an even number of words to maintain alignment */
    size = (words % 2) ? (words+1) * WSIZE : words * WSIZE;
    if ((long)(bp = mem_sbrk(size))  == -1)
        return NULL;

    /* Initialize free block header/footer and the epilogue header */
    PUT(HDRP(bp), PACK(size, 0));                /* free block header */
    PUT(FTRP(bp), PACK(size, 0));                /* free block footer */
    PUT(HDRP(NEXT_BLKP(bp)), PACK(0, 1));       /* new epilogue header */

    /* Coalesce if the previous block was free */
    return coalesce(bp);
}
```

```
void mm_free(void *bp)
{
    size_t size = GET_SIZE(HDRP(bp));

    PUT(HDRP(bp), PACK(size, 0));
    PUT(FTRP(bp), PACK(size, 0));
    coalesce(bp);
}


static void *coalesce(void *bp)
{
    size_t prev_alloc = GET_ALLOC(FTRP(PREV_BLKP(bp)));
    size_t next_alloc = GET_ALLOC(HDRP(NEXT_BLKP(bp)));
    size_t size = GET_SIZE(HDRP(bp));

    if (prev_alloc && next_alloc) {         /* Case 1 */
        return bp;
    }

    else if (prev_alloc && !next_alloc) {   /* Case 2 */
        size += GET_SIZE(HDRP(NEXT_BLKP(bp)));
        PUT(HDRP(bp), PACK(size, 0));
        PUT(FTRP(bp), PACK(size,0));
        return(bp);
    }
    else if (!prev_alloc && next_alloc) {   /* Case 3 */
        size += GET_SIZE(HDRP(PREV_BLKP(bp)));
        PUT(FTRP(bp), PACK(size, 0));
        PUT(HDRP(PREV_BLKP(bp)), PACK(size, 0));
        return(PREV_BLKP(bp));
    }

    else {                                  /* Case 4 */
        size += GET_SIZE(HDRP(PREV_BLKP(bp))) + GET_SIZE(FTRP(NEXT_BLKP(bp)));
        PUT(HDRP(PREV_BLKP(bp)), PACK(size, 0));
        PUT(FTRP(NEXT_BLKP(bp)), PACK(size, 0));
        return(PREV_BLKP(bp));
    }
}
```

malloc时，需要为块分配4字节的头部和4字节的尾部，并对齐8字节，这就使得块的下限为4+8+4=16字节，同时块的大小应为8的倍数；当找不到合适的空闲块时，就需要扩充整个堆

```
void *mm_malloc (size_t size)
{
    size_t asize; /* adjusted block size */
    size_t extendsize; /* amount to extend heap if no fit */
    char *bp;

    /* Ignore spurious requests */
    if (size <= 0)
        return NULL;

    /* Adjust block size to include overhead and alignment reqs. */
    if (size <= DSIZE)
        asize = DSIZE + DSIZE;
    else
        asize = DSIZE * ((size + DSIZE + (DSIZE-1)) / DSIZE);

    /* Search the free list for a fit */
    if ((bp = find_fit(asize)) != NULL) {
        place (bp, asize);
        return bp;
    }

    /* No fit found. Get more memory and place the block */
    extendsize = MAX (asize, CHUNKSIZE) ;
    if ((bp = extend_heap (extendsize/WSIZE)) == NULL)
        return NULL;
    place (bp, asize);
    return bp;
}
```

这里使用首次分配搜索合适的空闲块

```
static void *find_fit(size_t asize)
{
    void *bp ;

    /* first fit search */
    for (bp = heap_listp; GET_SIZE(HDRP(bp)) > 0 ; bp = NEXT_BLKP(bp) ) {
        if (!GET_ALLOC(HDRP(bp)) && (asize<=GET_SIZE(HDRP(bp)))) {
            return bp;
        }
    }
    return NULL;  /*no fit */
 }
```

分配块时，需要检查是否需要分割空闲块，如果剩余的块太小，为了对齐8，直接认为是padding就可以了

```
static void place(void *bp, size_t asize)
{
    size_t csize = GET_SIZE(HDRP(bp)) ;

    if ( (csize -asize) >= (2*DSIZE) ) {
        PUT(HDRP(bp), PACK(asize, 1)) ;
        PUT(FTRP(bp), PACK(asize, 1)) ;
        bp = NEXT_BLKP(bp) ;
        PUT(HDRP(bp), PACK(csize-asize, 0) ;
        PUT(FTRP(bp), PACK(csize-asize, 0) ;
    } else {
        PUT(HDRP(bp), PACK(csize, 1) ;
        PUT(FTRP(bp), PACK(csize, 1) ;
    }
}
```