Memory Allocation

CS 537 - Introduction to Operating Systems

Memory

- What is memory?
  - huge linear array of storage
- How is memory divided?
  - kernel space and user space
- Who manages memory?
  - OS assigns memory to processes
  - processes manage the memory they've been assigned

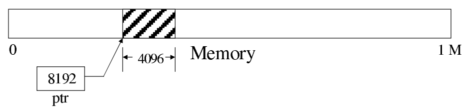
Allocating Memory

- Memory is requested and granted in contiguous blocks
  - think of memory as one huge array of bytes
  - *malloc* library call
    - used to allocate and free memory
    - finds sufficient contiguous memory
    - reserves that memory
    - returns the address of the first byte of the memory
  - *free* library call
    - give address of the first byte of memory to free
    - memory becomes available for reallocation
  - both *malloc* and *free* are implemented using the *brk* system call

Allocating Memory

- Example of allocation

```
char* ptr = malloc(4096);    // char* is address of a single byte
```



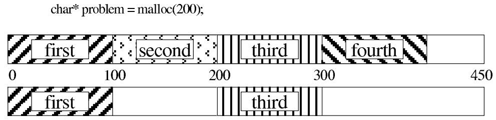
Fragmentation

- Segments of memory can become unusable
  - FRAGMENTATION
  - result of allocation scheme
- Two types of fragmentation
  - external fragmentation
    - memory remains unallocated
    - variable allocation sizes
  - internal fragmentation
    - memory is allocated but unused
    - fixed allocation sizes

External Fragmentation

- Imagine calling a series of *malloc* and *free*

```
char* first = malloc(100);
char* second = malloc(100);
char* third = malloc(100);
char* fourth = malloc(100);
free(second);
free(fourth);
char* problem = malloc(200);
```

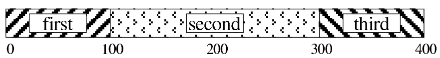


- 250 free bytes of memory, only 150 contiguous
  - unable to satisfy final malloc request

Internal Fragmentation

- Imagine calling a series of *malloc*
  - assume allocation unit is 100 bytes

```
char* first = malloc(90);
char* second = malloc(120);
char* third = malloc(10);
char* problem = malloc(50);
```



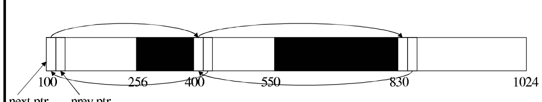
- All of memory has been allocated but only a fraction of it is used (220 bytes)
  - unable to handle final memory request

Internal vs. External Fragmentation

- Externally fragmented memory can be compacted
  - lots of issues with compaction
  - more on this later
- Fixed size allocation may lead to internal fragmentation, but less overhead
  - example
    - 8192 byte area of free memory
    - request for 8190 bytes
    - if exact size allocated - 2 bytes left to keep track of
    - if fixed size of 8192 used - 0 bytes to keep track of

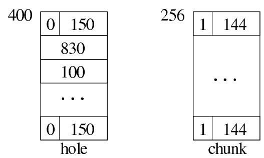
Tracking Memory

- Need to keep track of available memory
  - contiguous block of free mem is called a “hole”
  - contiguous block of allocated mem is a “chunk”
- Keep a doubly linked list of free space
  - build the pointers directly into the holes



Free List

- Info for each hole usually has 5 entries
  - next and previous pointers
  - size of hole (on both ends of hole)
  - a bit indicating if it is free or allocated (on both ends)
    - this bit is usually the highest order bit of the size
- A chunk also holds information
  - size and free/allocated bit (again, one on each end)
- Examples



Free List

- Prefer holes to be as large as possible
  - large hole can satisfy a small request
    - the opposite is not true
  - less overhead in tracking memory
  - fewer holes so faster search for available memory

Deallocating Memory

- When memory is returned to system
  - place memory back in list
    - set next and previous pointers and change allocation bit to 0 (not allocated)
  - now check allocation bit of memory directly above
    - if 0, merge the two
  - then check the allocation bit of memory directly beneath
    - if 0, merge the two

Allocation Algorithms

- Best Fit
  - pick smallest hole that will satisfy the request
- Comments
  - have to search entire list every time
  - tends to leave lots of small holes
    - external fragmentation

Allocation Algorithms

- Worst fit
  - pick the largest hole to satisfy request
- Comments
  - have to search entire list
  - still leads to fragmentation issues
  - usually worse than best fit

Allocation Algorithms

- First fit
  - pick the first hole large enough to satisfy the request
- Comments
  - much faster than best or worst fit
  - has fragmentation issues similar to best fit
- Next fit
  - exactly like first fit except start search from where last search left off
  - usually faster than first fit

Multiple Free Lists

- Problem with all previous methods is external fragmentation
- Allocate fixed size holes
  - keep multiple lists of different size holes for different size requests
  - take hole from a list that most closely matches size of request
  - leads to internal fragmentation
    - ~50% of memory in the common case

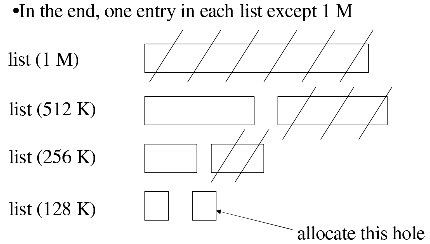
Multiple Free Lists

- Common solution
  - start out with single large hole
    - one entry in one list
    - hole size is usually a power of 2
  - upon a request for memory, keep dividing hole by 2 until appropriate size memory is reached
    - every time a division occurs, a new hole is added to a different free list

Multiple Free Lists

char* ptr = malloc(100 K)

•Initially, only one entry in first list (1 M)
•In the end, one entry in each list except 1 M



Buddy System

- Each hole in a free list has a *buddy*
  - if a hole and its buddy are combined, they create a new hole
    - new hole is twice as big
    - new hole is aligned on proper boundary
- Example
  - a hole is of size 4
    - starting location of each hole: 0, 4, 8, 12, 16, 20, …
  - buddies are the following: (0,4), (8, 12), …
  - if buddies are combined, get holes of size 8
    - starting location of these holes: 0, 8, 16, ...

Buddy System

- When allocating memory
  - if list is empty, go up one level, take a hole and break it in 2
    - these 2 new holes are buddies
  - now give one of these holes to the user
- When freeing memory
  - if chunk just returned and its buddy are in the free list, merge them and move the new hole up one level

Buddy System

- If all holes in a free list are powers of 2 in size, buddy system is very easy to implement
- A holes buddy is the exclusive OR of the hole size and starting address of hole
- Example

hole starting address		new hole address
0	$0 \oplus 4 = 4$	0
4	$4 \oplus 4 = 0$	
8	$8 \oplus 4 = 12$	8
12	$12 \oplus 4 = 8$	

Slab Allocation

- Yet one more method of allocating memory
  - used by Linux in conjunction with Buddy system
- Motivation
  - many allocations occur repeatedly!
    - user program requests a new node in linked list
    - OS requests a new process descriptor
  - instead of searching free list for new memory, keep a cache of recently deallocated memory
    - call these allocation, deallocation units objects
  - on a new request, see if there is memory in the cache to allocate
    - much faster than searching through a free list

Cache Descriptor

- Describes what is being cached
  - points to a *slab descriptor*
- Each cache only contains memory objects of a specific size
- All cache descriptors are stored in a linked list

Slab Descriptor

- Contains pointers to the actual memory objects
  - some of them will be free, some will be in use
  - always keeps a pointer to the next free object
- All slab descriptors for a specific object are stored in a linked list
  - cache descriptor points to the first element
  - each slab descriptor has a pointer to the next element

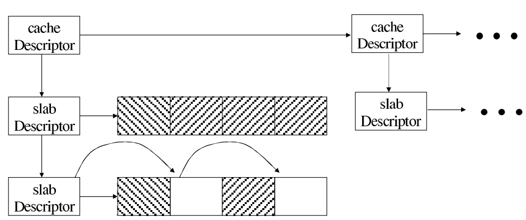
Object Descriptor

Contains one of two things

1. if the object is free
   - pointer to the next free element in the slab
2. if the object is allocated
   - the data stored in the object

- All of the object descriptors are stored in contiguous space in memory
  - similar to allocation scheme examined earlier
  - the cache and slab descriptors are probably not allocated contiguously in memory

Slab Allocator



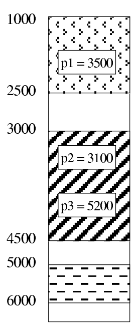
Compaction

- To deal with internal fragmentation
  - use paging or segmentation
  - more on this later
- To deal with external fragmentation
  - can do compaction

Compaction

- Simple concept
  - move all allocated memory locations to one end
  - combine all holes on the other end to form one large hole
- Major problems
  - tremendous overhead to copy all data
  - must find and change all pointer values
    - this can be very difficult

Compaction



1) Determine how far each chunk gets moved
   - chunk1 = 0
   - chunk2 = 500
   - chunk3 = 1000
2) Adjust pointers
   - p1 = 3500 - 0 = 3500
   - p2 = 3100 - 500 = 2600
   - p3 = 5200 - 1000 = 4200
3) Move Data