Roadmap

Memory & data
Integers & floats
Machine code & C
x86 assembly
Procedures & stacks
Arrays & structs
Memory & caches
Processes
Virtual memory
Memory allocation
Java vs. C

C:

```
car *c = malloc(sizeof(car));
c->miles = 100;
c->gals = 17;
float mpg = get_mpg(c);
free(c);
```

Java:

```
Car c = new Car();
c.setMiles(100);
c.setGals(17);
float mpg =
    c.getMPG();
```

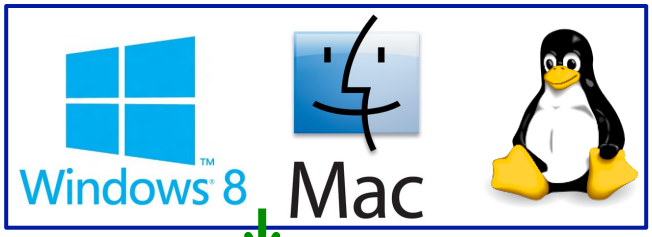
Assembly language:

```
get_mpg:
    pushq   %rbp
    movq    %rsp, %rbp
    ...
    popq    %rbp
    ret
```

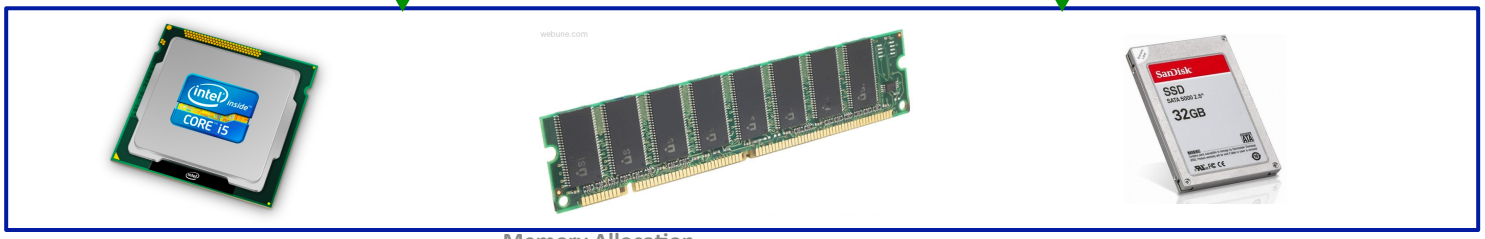
Machine code:

```
0111010000011000
10001101000010000000010
1000100111000010
11000001111110100011111
```

OS:



Computer system:

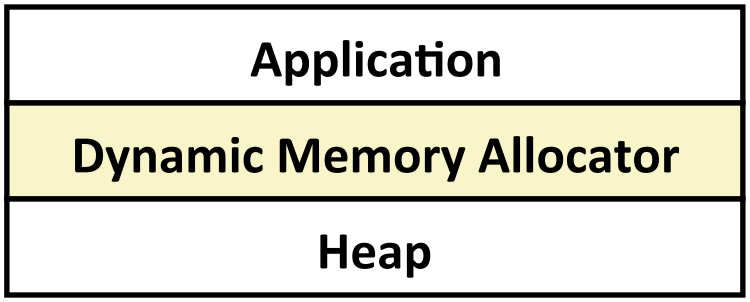


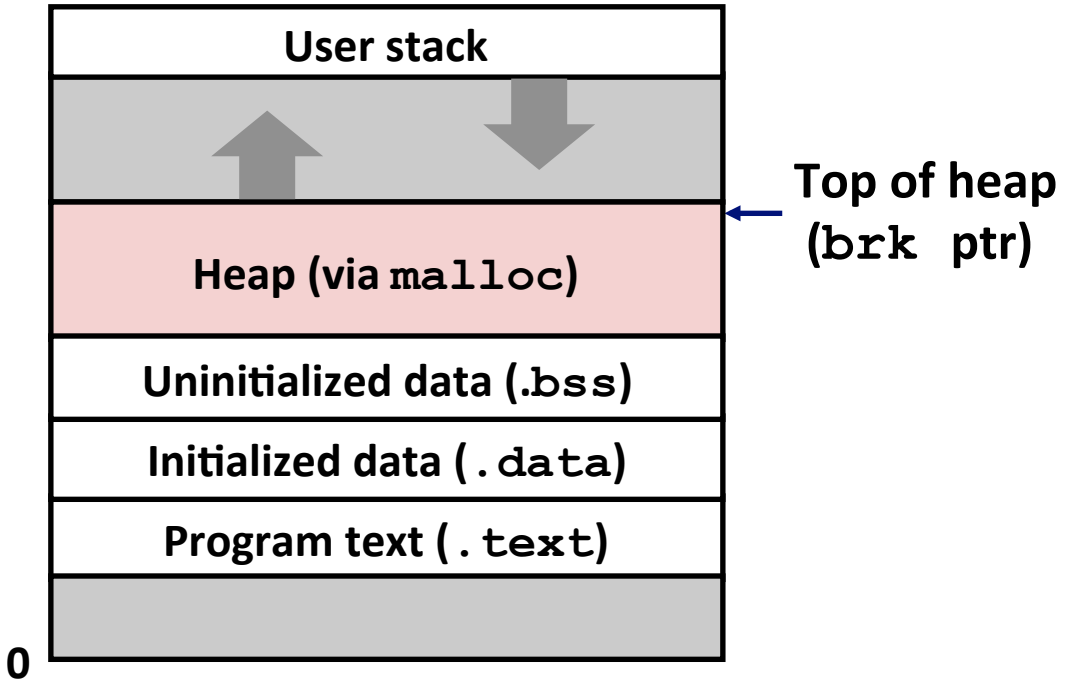
Section 10: Memory Allocation Topics

- **Dynamic memory allocation**
  - Size/number of data structures may only be known at run time
  - Need to allocate space on the heap
  - Need to de-allocate (free) unused memory so it can be re-allocated
- **Implementation**
  - Implicit free lists
  - Explicit free lists – subject of next programming assignment
  - Segregated free lists
- **Garbage collection**
- **Common memory-related bugs in C programs**

Dynamic Memory Allocation

- **Programmers use *dynamic memory allocators* (such as `malloc`) to acquire memory at run time.**
  - For data structures whose size is only known at runtime.
- **Dynamic memory allocators manage an area of process virtual memory known as the *heap*.**





Dynamic Memory Allocation

- **Allocator maintains heap as collection of variable sized *blocks*, which are either *allocated* or *free***
  - Allocator requests space in heap region; VM hardware and kernel allocate these pages to the process
  - Application objects are typically smaller than pages, so the allocator manages blocks *within* pages
- **Types of allocators**
  - ***Explicit allocator*:** application allocates and frees space
    - E.g. **`malloc`** and **`free`** in C
  - ***Implicit allocator:*** application allocates, but does not free space
    - E.g. garbage collection in Java, ML, and Lisp

The `malloc` Package

```
#include <stdlib.h>
```

```
void *malloc(size_t size)
```

- Successful:
  - Returns a pointer to a memory block of at least **`size`** bytes (typically) aligned to 8-byte boundary
  - If **`size == 0`**, returns NULL
- Unsuccessful: returns NULL and sets **`errno`**

```
void free(void *p)
```

- Returns the block pointed at by **`p`** to pool of available memory
- **`p`** must come from a previous call to **`malloc`** or **`realloc`**

Other functions

- **`calloc`:** Version of **`malloc`** that initializes allocated block to zero.
- **`realloc`:** Changes the size of a previously allocated block.
- **`sbrk`:** Used internally by allocators to grow or shrink the heap.

Malloc Example

```
void foo(int n, int m) {
  int i, *p;

  /* allocate a block of n ints */
  p = (int *)malloc(n * sizeof(int));
  if (p == NULL) {
    perror("malloc");
    exit(0);
  }
  for (i=0; i<n; i++) p[i] = i;

  /* add space for m ints to end of p block */
  if ((p = (int *)realloc(p, (n+m) * sizeof(int))) == NULL) {
    perror("realloc");
    exit(0);
  }
  for (i=n; i < n+m; i++) p[i] = i;

  /* print new array */
  for (i=0; i<n+m; i++)
    printf("%d\n", p[i]);

  free(p); /* return p to available memory pool */
}
```