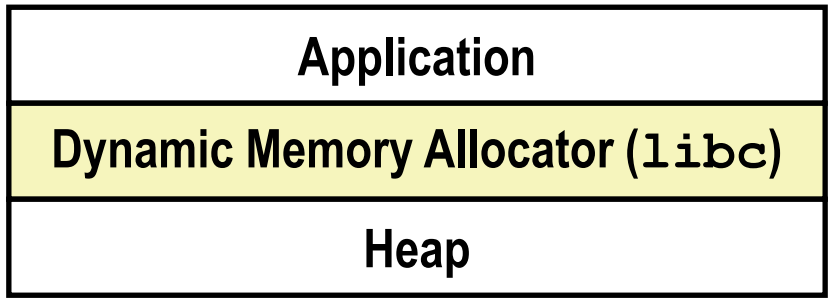
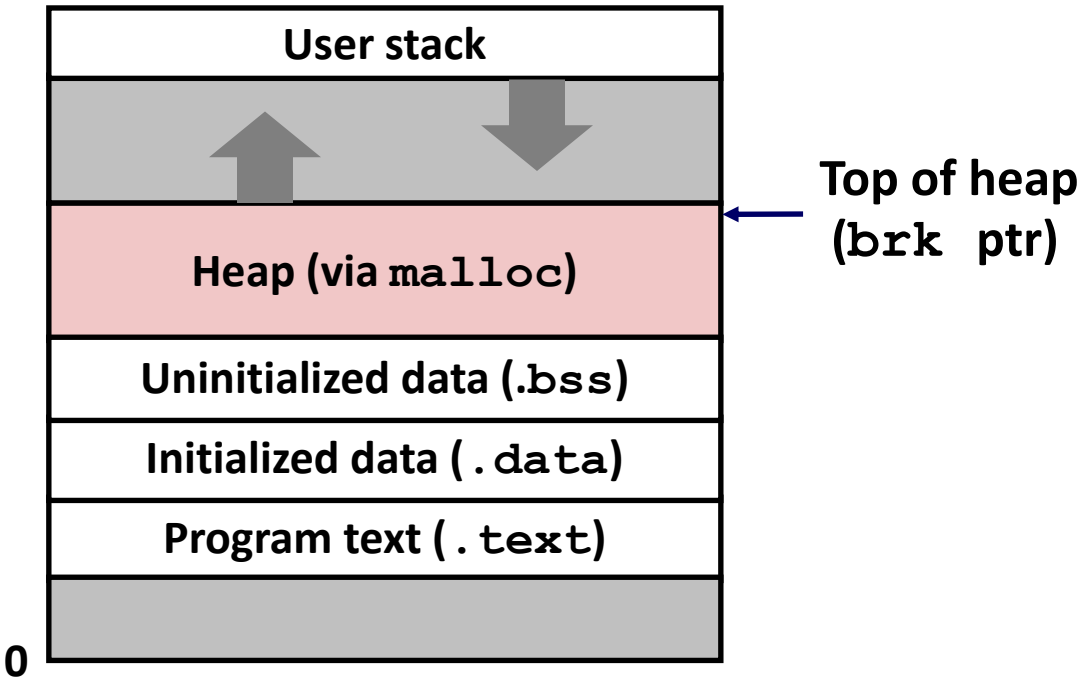
Virtual Memory:
malloc: Concepts

Dynamic Memory Allocation

- **Programmers use *dynamic memory allocators* (such as `malloc`) to acquire VM 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***
- **Types of allocators**
  - ***Explicit allocator*:** application allocates and frees space
    - E.g., `malloc` and `free` in C, `new` and `delete` in C++
  - ***Implicit allocator:*** application allocates, but does not free space
    - E.g. garbage collection in Java, ML, and Lisp

- **We focus on explicit memory allocation in this lecture**

The `malloc` Package (`stdlib.h`)

`void *malloc(size_t size)`

- Successful:
  - Returns a pointer to a memory block of at least **`size`** bytes aligned to an 8-byte (x86) or 16-byte (x86-64) boundary
  - If **`size == 0`**, returns NULL
- Unsuccessful: returns NULL (0) and sets **`errno`**

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- **`p`** must come from a previous call to **`malloc`** or **`realloc`**

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Other functions

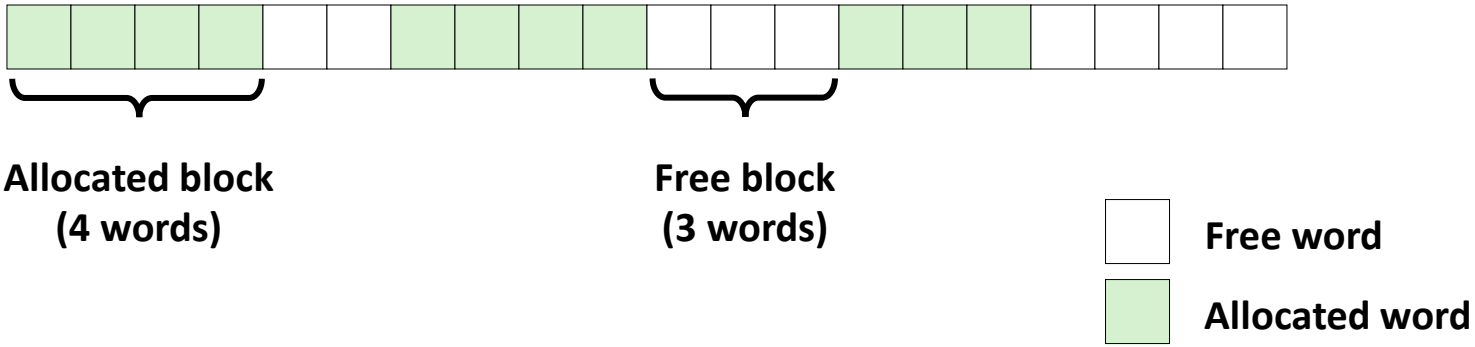
- **`calloc`:** Version of **`malloc`** that initializes allocated block to zero (`malloc` followed by `memset`)
- **`realloc`:** Changes the size of a previously allocated block
- **`sbrk`:** Used *internally* (syscall) by allocators to grow or shrink the heap

malloc Example

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

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

    /* Allocate a block of n ints */
    p = (int *) malloc(n * sizeof(int));
    if (p == NULL) {
        perror("malloc");
        exit(0);
    }

    /* Initialize allocated block */
    for (i=0; i<n; i++)
        p[i] = i;


    /* Return allocated block to the heap */
    free(p);
}
```

Assumptions Made

- Memory is word addressed.
- Words are int-sized.



Allocation Example

```
p1 = malloc(4)
```

```
p2 = malloc(5)
```

```
p3 = malloc(6)
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```
free(p2)
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p4 = malloc(2)
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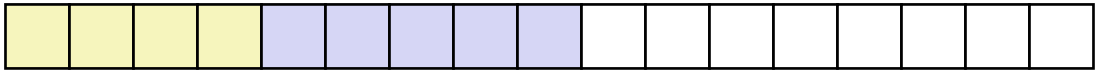

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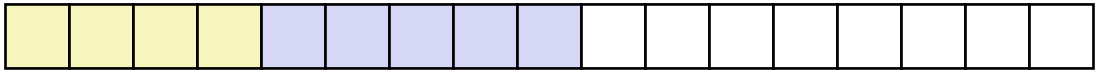

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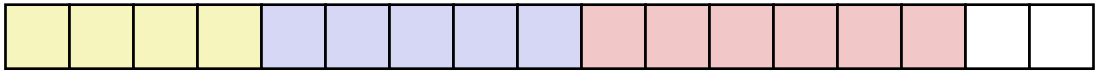

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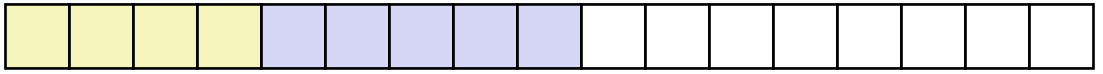

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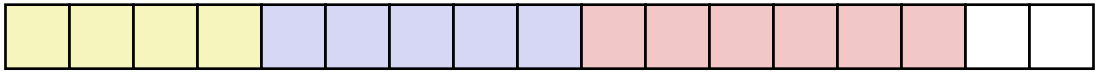

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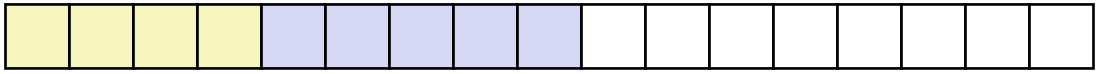

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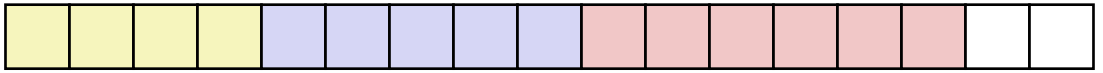

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Constraints

- **Applications**
  - Can issue arbitrary sequence of **`malloc`** and **`free`** requests
  - **`free`** request *must* be to a **`malloc`**'d block

- **Allocators**
  - Can't control number or size of allocated blocks
  - Must respond immediately to **`malloc`** requests
    - *i.e.*, can't reorder or buffer requests
  - Must allocate blocks from free memory
    - *i.e.*, can only place allocated blocks in free memory
  - Must align blocks so they satisfy all alignment requirements
    - 8-byte (x86) or 16-byte (x86-64) alignment on Linux boxes
  - Can manipulate and modify only free memory
  - Can't move the allocated blocks once they are **`malloc`**'d
    - *i.e.*, compaction/defragmentation is not allowed