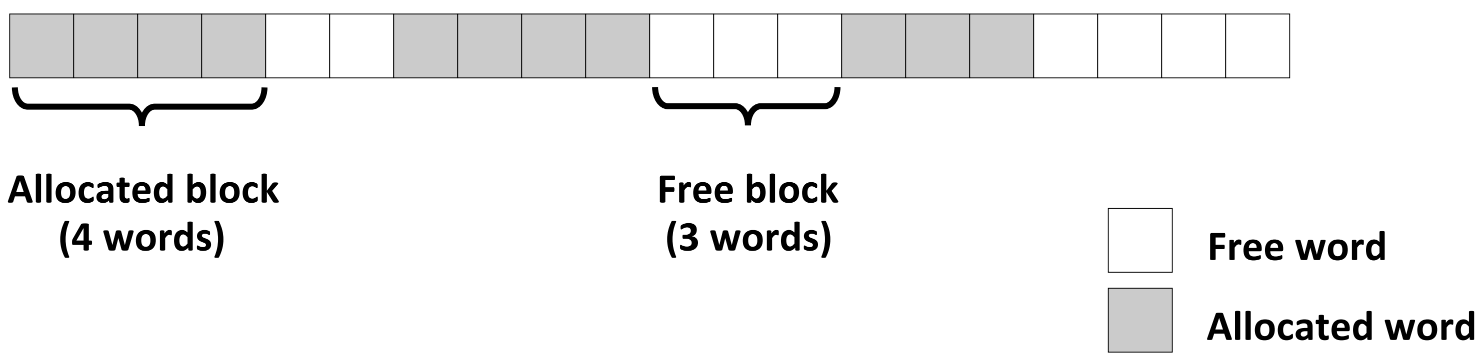
Section 10: Memory Allocation Topics

- **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**

Assumptions Made in This Section

- **Memory is word addressed (each word can hold a pointer)**
  - block size is a multiple of words



Allocation Example

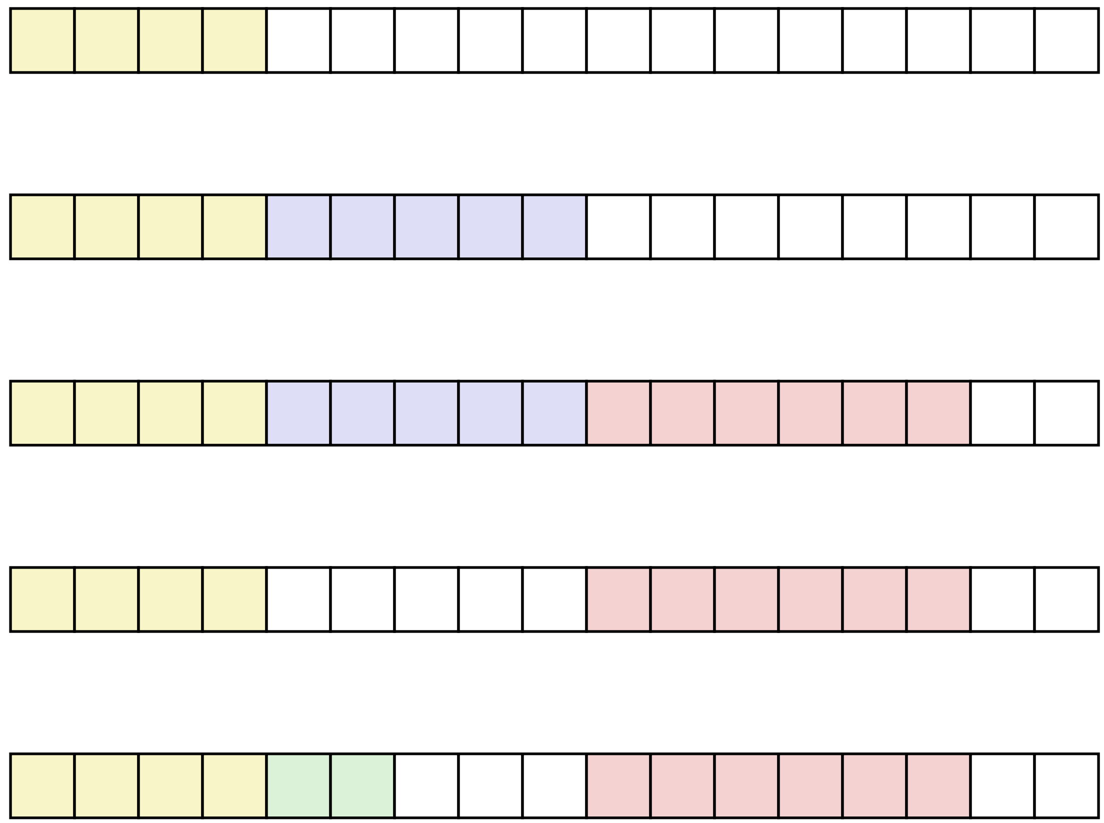
`p1 = malloc(4)`

`p2 = malloc(5)`

`p3 = malloc(6)`

`free(p2)`

`p4 = malloc(2)`



What information does the allocator need to keep track of?

Constraints

- **Applications**
  - Can issue arbitrary sequence of malloc() and free() requests
  - free() requests must be made only for a previously 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.*, blocks can't overlap
  - Must align blocks so they satisfy all alignment requirements
    - 8 byte alignment for GNU malloc (**`libc`** malloc) on Linux boxes
  - Can't move the allocated blocks once they are malloc()'d
    - *i.e.*, compaction is not allowed. *Why not?*

Performance Goal: Throughput

- **Given some sequence of `malloc` and `free` requests:**
  - $R_0, R_1, ..., R_k, ... , R_{n-1}$

- **Goals: maximize throughput and peak memory utilization**
  - These goals are often conflicting

- **Throughput:**
  - Number of completed requests per unit time
  - Example:
    - 5,000 **`malloc()`** calls and 5,000 **`free()`** calls in 10 seconds
    - Throughput is 1,000 operations/second

Performance Goal: Peak Memory Utilization

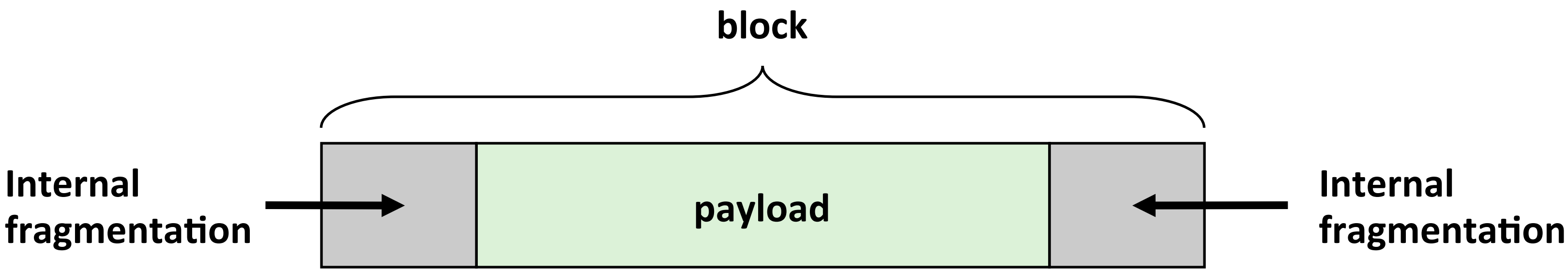
- **Given some sequence of `malloc` and `free` requests:**
  - $R_0, R_1, \ldots, R_k, \ldots, R_{n-1}$
- ***Def: Aggregate payload*** P_k
  - `malloc(p)` results in a block with a ***payload*** of `p` bytes
  - After request R_k has completed, the ***aggregate payload*** P_k is the sum of currently allocated payloads
- ***Def: Current heap size =*** H_k
  - Assume H_k is monotonically nondecreasing
    - Allocator can increase size of heap using `sbrk()`
- ***Def: Peak memory utilization after k requests***
  - $U_k = (\max_{i<k} P_i) \;/\; H_k$
  - Goal: maximize utilization for a sequence of requests.
  - *Why is this hard? And what happens to throughput?*

Fragmentation

- **Poor memory utilization is caused by *fragmentation***
  - ***internal*** fragmentation
  - ***external*** fragmentation

Internal Fragmentation

- **For a given block, *internal fragmentation* occurs if payload is smaller than block size**



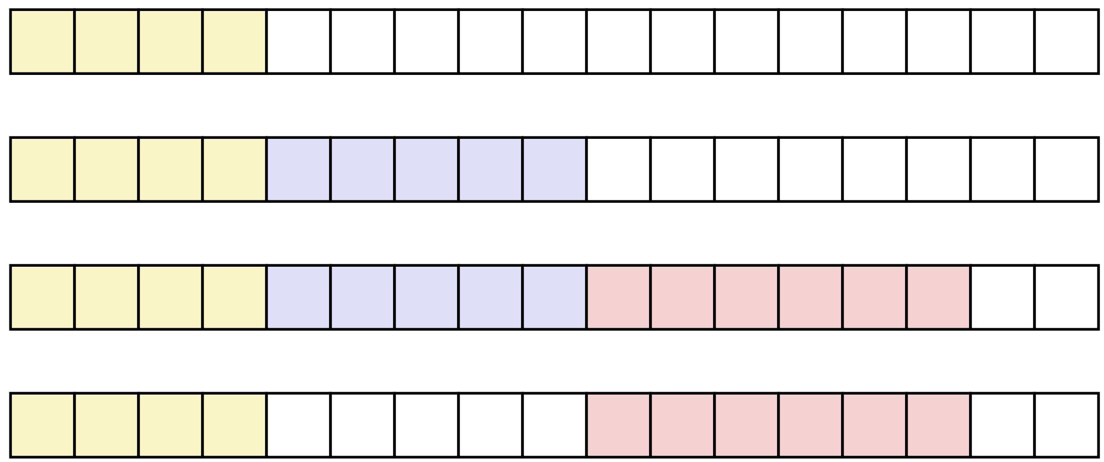
- **Caused by**
  - overhead of maintaining heap data structures (inside block, outside payload)
  - padding for alignment purposes
  - explicit policy decisions (e.g., to return a big block to satisfy a small request)
    why would anyone do that?

- **Depends only on the pattern of *previous* requests**
  - thus, easy to measure

External Fragmentation

- **Occurs when there is enough aggregate heap memory, but no single free block is large enough**

```
p1 = malloc(4)
p2 = malloc(5)
p3 = malloc(6)
free(p2)
p4 = malloc(6)
```



Oops! (what would happen now?)

- **Depends on the pattern of future requests**
  - Thus, difficult to measure