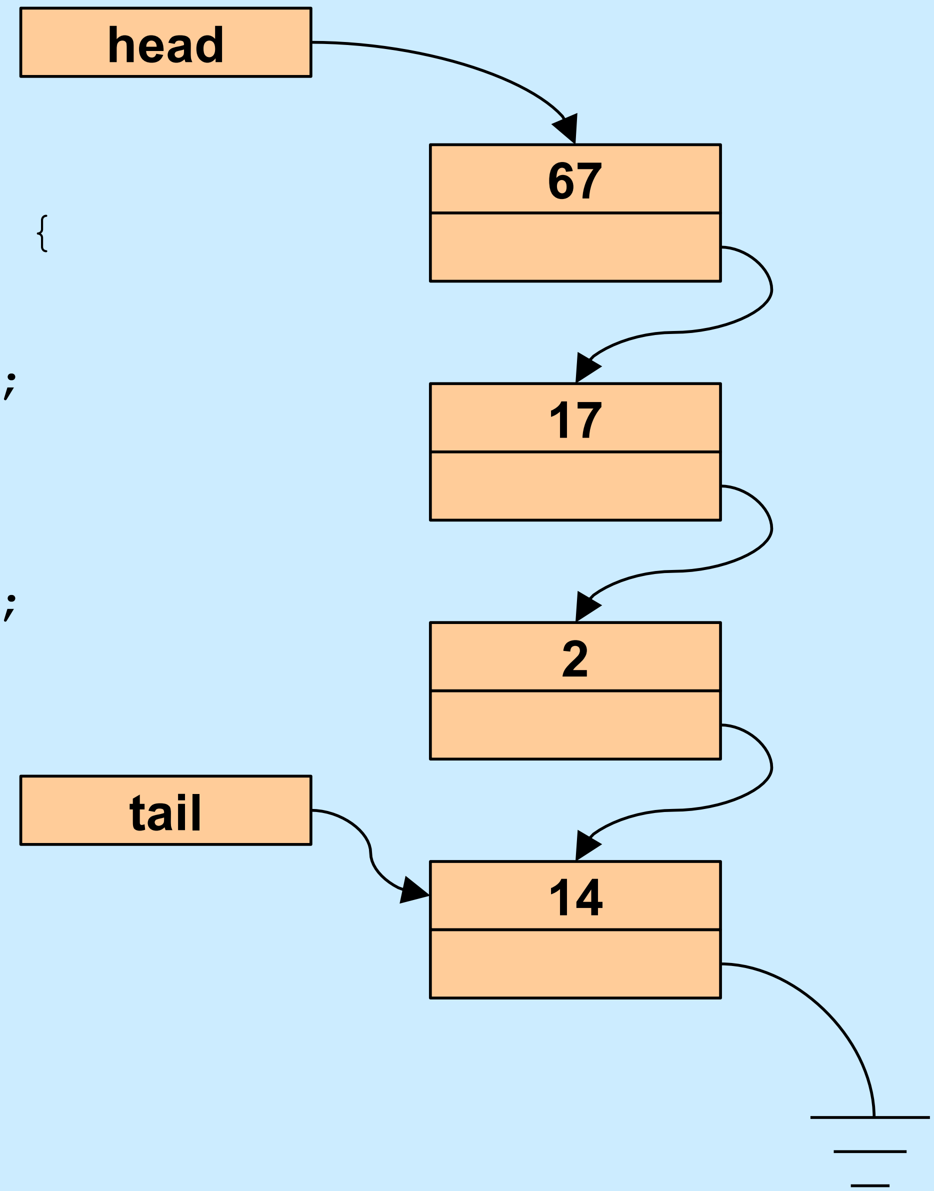
CS 33

Intro to Storage Allocation

A Queue

```
typedef struct list_element {
  int value;
  struct list_element *next;
} list_element_t;

list_element_t *head, *tail;
```



Enqueue

```
int enqueue(int value) {
  list_element_t *newle
      = (list_element_t *)malloc(sizeof(list_element_t));
  if (newle == 0)
    return 0; // can't do it: out of memory
  newle->value = value;
  newle->next = 0;
  if (head == 0) {
    // list was empty
    assert(tail == 0);
    head = newle;
  } else {
    tail->next = newle;
  }
  tail = newle;
  return 1;
}
```

Dequeue

```
int dequeue(int *value) {
  list_element_t *first;
  if (head == 0) {
    // list is empty
    return 0;
  }
  *value = head->value;
  first = head;
  head = head->next;
  if (tail == first) {
    assert(head == 0);
    tail = 0;
  }
  return 1;
}
```

What’s wrong with this code???

Storage Leaks

```
int main() {
  while(1)
    if (malloc(sizeof(list_element_t)) == 0)
      break;
  return 1;
}
```

For how long will this program run before terminating?

Dequeue, Fixed

```
int dequeue(int *value) {
  list_element_t *first;
  if (head == 0) {
    // list is empty
    return 0;
  }
  *value = head->value;
  first = head;
  head = head->next;
  if (tail == first)
    assert(head == 0);
    tail = 0;
  }
  free(first);
  return 1;
}
```


Quiz 1

```
int enqueue(int value) {
  list_element_t *newle
      = (list_element_t *)malloc(sizeof(list_element_t));
  if (newle == 0)
    return 0;
  newle->value = value;
  newle->next = 0;
  if (head == 0) {
    // list was empty
    assert(tail == 0);
    head = newle;
  } else {
    tail->next = newle;
  }
  tail = newle;
  free(newle); // saves us the bother of freeing it later
  return 1;
}
```

This version of enqueue makes unnecessary the call to free in dequeue.

a) **It works well.**
b) **It fails occasionally.**
c) **It hardly ever works.**
d) **It never works.**

malloc and free

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

– allocate *size* bytes of storage and return a pointer to it

– returns 0 (NULL) if the requested storage isn't available

```
void free(void *ptr)
```

– free the storage pointed to by *ptr*

– *ptr* must have previously been returned by *malloc* (or other storage-allocation functions — *calloc* and *realloc*)

realloc

```
void *realloc(void *ptr, size_t size)
```

- change the size of the storage pointed to by *ptr*
- the contents, up to the minimum of the old size and new size, will not be changed
- *ptr* must have been returned by a previous call to *malloc*, *realloc*, or *calloc*
- it may be necessary to allocate a completely new area and copy from the old to the new
  - » thus the return value may be different from *ptr*
  - » if copying is done the old area is freed
- returns 0 if the operation cannot be done

Get (contiguous) Input (1)

```
char *getinput() {
  int alloc_size = 4;  // start small
  int read_size = 4;   // max number of bytes to read
  int next_read = 0;   // index in buf of next read
  int bytes_read;      // number of bytes read
  char *buf = (char *)malloc(alloc_size);
  char *newbuf;

  if (buf == 0) {
    // no memory
    return 0;
  }
```

Get (contiguous) Input (2)

```
while (1) {
  if ((bytes_read
        = read(0, buf+next_read, read_size)) == -1) {
    perror("getinput");
    return 0;
  }
  if (bytes_read == 0) {
    // eof
    break;
  }
  if ((buf+next_read)[bytes_read-1] == '\n') {
    // end of line
    break;
  }
```

Get (contiguous) Input (3)

```
    next_read += read_size;
    read_size = alloc_size;
    alloc_size *= 2;
    newbuf = (char *)realloc(buf, alloc_size);
    if (newbuf == 0) {
      // realloc failed: not enough memory.
      // Free the storage allocated previously and report
      // failure.
      free(buf);
      return 0;
    }
    buf = newbuf;
  }
```

Get (contiguous) Input (4)

```
  // reduce buffer size to the minimum necessary
  newbuf = (char *)realloc(buf,
      alloc_size - (read_size - bytes_read));
  if (newbuf == 0) {
    // couldn't allocate smaller buf
    return buf;
  }
  return newbuf;
}
```


Some Common Memory-Related Errors

Dereferencing Bad Pointers

- **The classic `scanf` bug**

```
int val;

...

scanf("%d", val);
```

Reading Uninitialized Memory

- **Assuming that dynamically allocated data is initialized to zero**

```
/* return y = Ax */
int *matvec(int A[][N], int x[]) {
   int *y = (int *)malloc(N*sizeof(int));
   int i, j;

   for (i=0; i<N; i++)
      for (j=0; j<N; j++)
         y[i] += A[i][j]*x[j];
   return y;
}
```

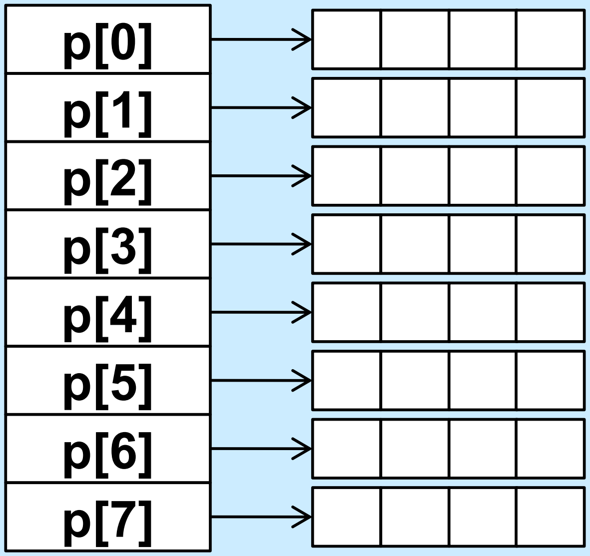
Overwriting Memory

- **Allocating the (possibly) wrong-sized object**

```
// set up p so it is an array of
// int *'s, allocated dynamically
int **p;

p = (int **)malloc(N*sizeof(int));

for (i=0; i<N; i++) {
  p[i] = (int *)malloc(M*sizeof(int));
}
```



Overwriting Memory

- **Not checking the max string size**

```
char s[8];
int i;

gets(s);  /* reads "123456789" from stdin */
```

- **Basis for classic buffer overflow attacks**

Going Too Far

- **Misunderstanding pointer arithmetic**

```
int *search(int p[], int val) {

   while (*p && *p != val)
      p += sizeof(int);

   return p;
}
```

Referencing Nonexistent Variables

- **Forgetting that local variables disappear when a function returns**

```
int *foo () {
   int val;

   return &val;
}
```

Freeing Blocks Multiple Times

```
x = (int *)malloc(N*sizeof(int));
        <manipulate x>
free(x);

y = (int *)malloc(M*sizeof(int));
        <manipulate y>
free(x);
```

Referencing Freed Blocks

```
x = (int *)malloc(N*sizeof(int));
  <manipulate x>
free(x);
   ...
y = (int *)malloc(M*sizeof(int));
for (i=0; i<M; i++)
   y[i] = x[i]++;
```

Failing to Free Blocks (Memory Leaks)

```
foo() {
   int *x = (int *)malloc(N*sizeof(int));
   Use(x, N);
   return;
}
```

Failing to Free Blocks (Memory Leaks)

- **Freeing only part of a data structure**

```
struct list {
   int val;
   struct list *next;
};

foo() {
   struct list *head = malloc(sizeof(struct list));
   head->val = 0;
   head->next = NULL;
   <allocate and manipulate the rest of the list>
    ...
   free(head);
   return;
}
```

Total Confusion

```
foo() {
    char *str;
    str = (char *)malloc(1024);
    ...
    str = "";
    ...
    strcat(str, "c");
    ...
    return;
}
```

It Works, But ...

- **Using a hammer where a feather would do ...**

```
hammer() {
   int *x = (int *)malloc(1024*sizeof(int));
   Use(x, 1024);
   free(x);
   return;
}
```

```
feather() {
   int x[1024];
   Use(x, 1024);
   return;
}
```

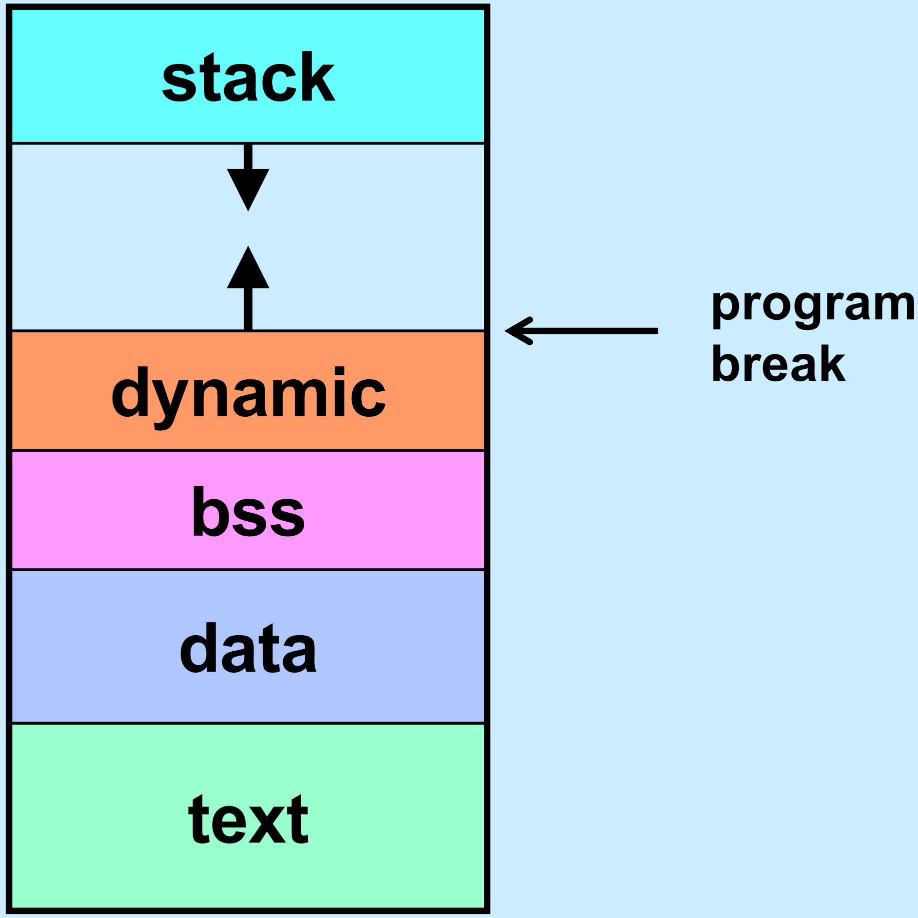

Quiz 2

- **Will this work?**
  a) always
  b) usually
  c) never

```
typedef struct
TwoParts {
    int part1[120];
    float part2[200];
} TwoParts_t;
```

```
void func() {
  TwoParts_t *X;
  X = malloc(sizeof(TwoParts_t));
  UseX1(X->part1);
  free(&X->part1);
  UseX2(X->part2);
  free(&X->part2);
}
```

The Unix Address Space



sbrk System Call

```
void *sbrk(intptr_t increment)
```

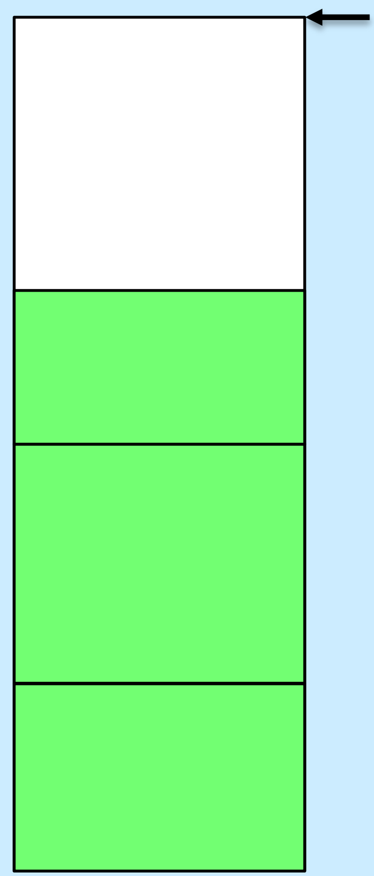
- moves the program break by an amount equal to *increment*
- returns the previous program break
- *intptr_t* is typedef'd to be a *long*

Managing Dynamic Storage

- **Strategy**
  - **get a "chunk" of memory from the OS using *sbrk***
    - **create pool of available storage, aka the "heap"**
  - ***malloc*, *calloc*, *realloc*, and *free* use this storage if possible**
    - **they manage the heap**
  - **if not possible, get more storage from OS**
    - **heap is made larger (by calling *sbrk*)**
- **Important note:**
  - **when process terminates, all storage is given back to the system**
    - **all memory-related sins are forgotten!**

Malloc and Free

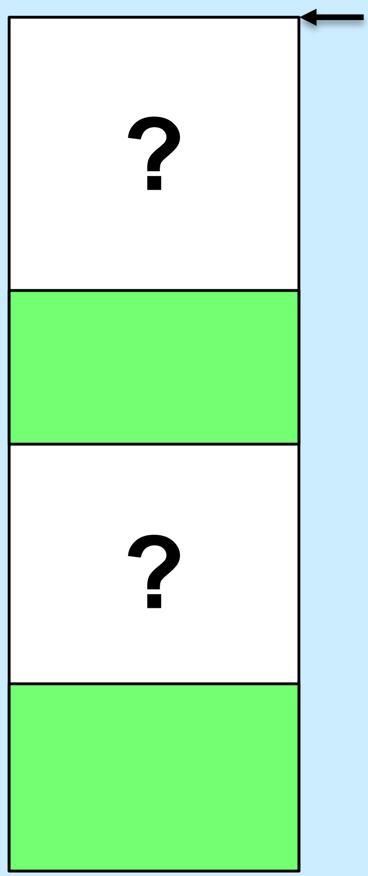
```
x = malloc(40);
y = malloc(60);
z = malloc(30);
free(y);
```



Malloc and Free

```
x = malloc(40);
y = malloc(60);
z = malloc(30);
free(y);

w = malloc(60);
```

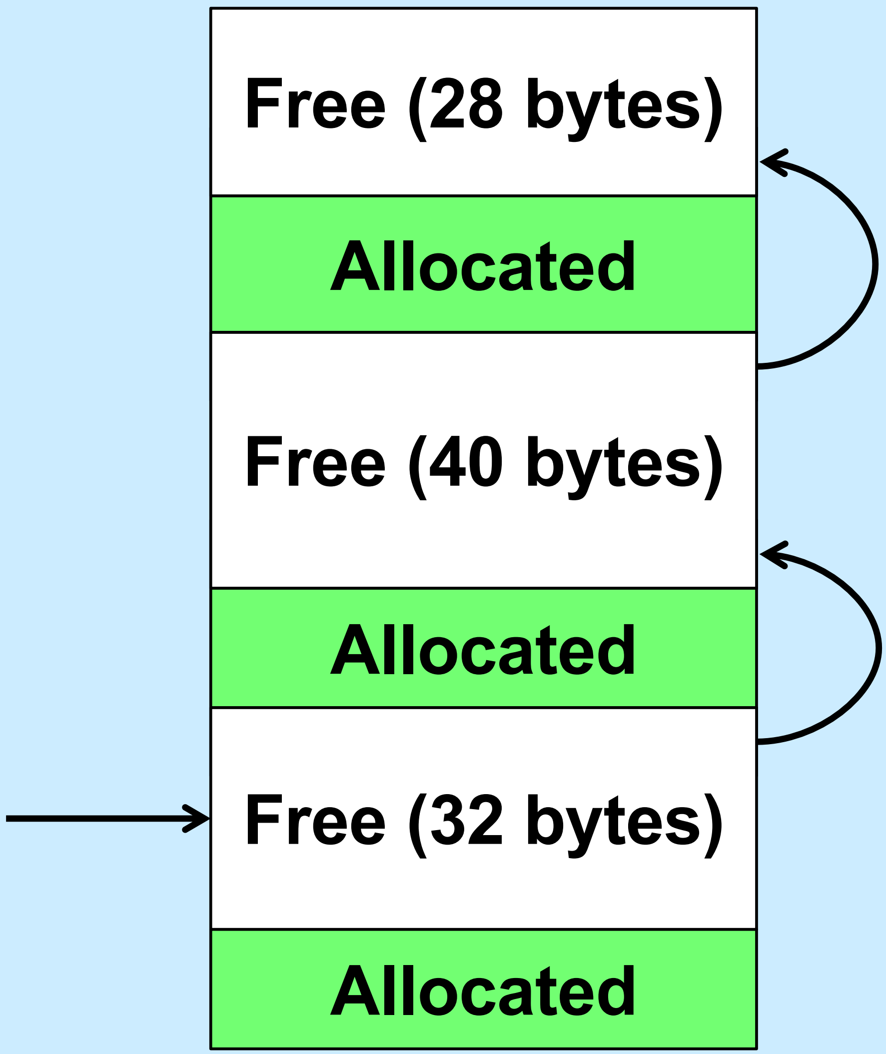


- How do we keep track of where free space is?
- How do we choose which to use?

Managing Free Space

- **Two possibilities**
  1) **don't worry about it: memory is cheap and plentiful — simply call *sbrk* when a new block is needed**
  2) **link together the free blocks**

Finding the Right Free Block



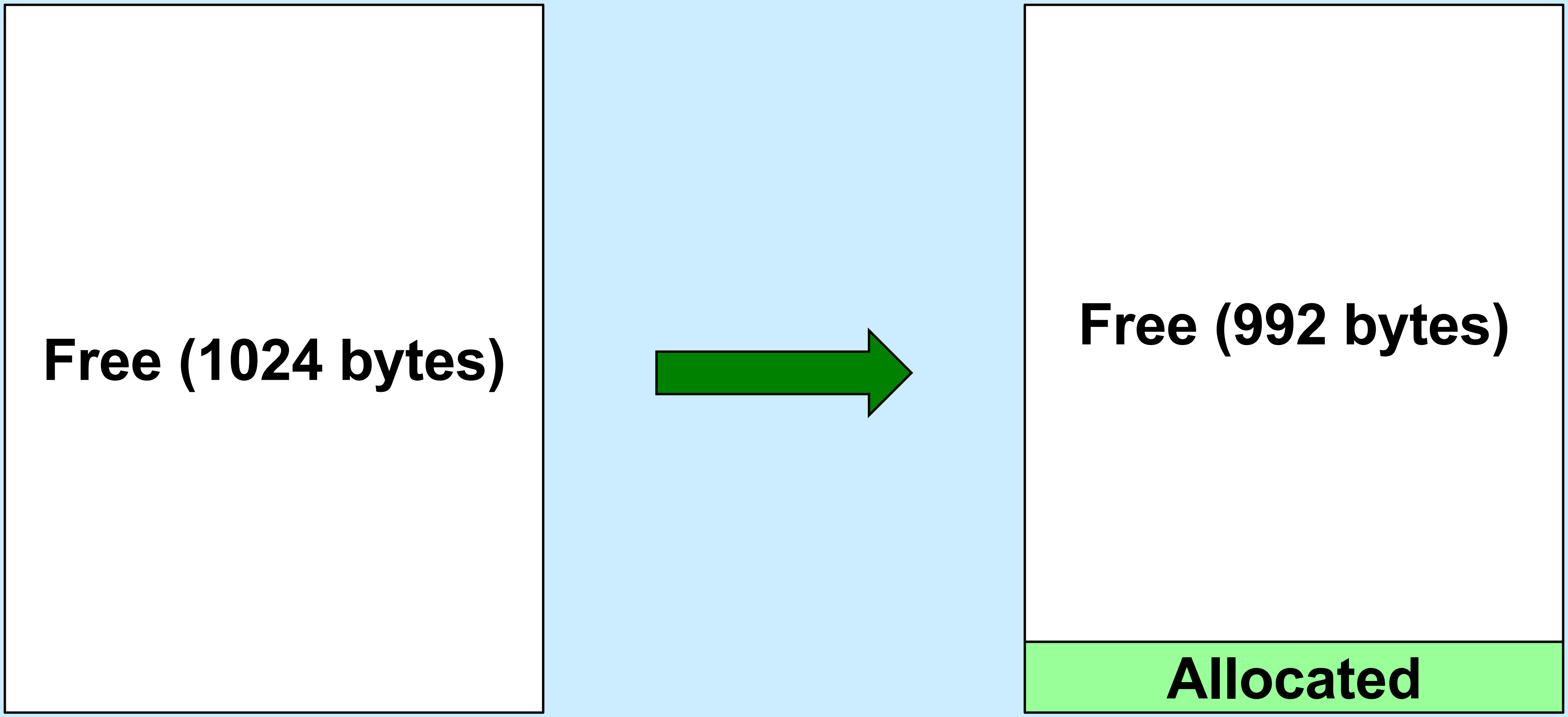
`malloc(24)`

- Search strategies
  - first fit
  - best fit

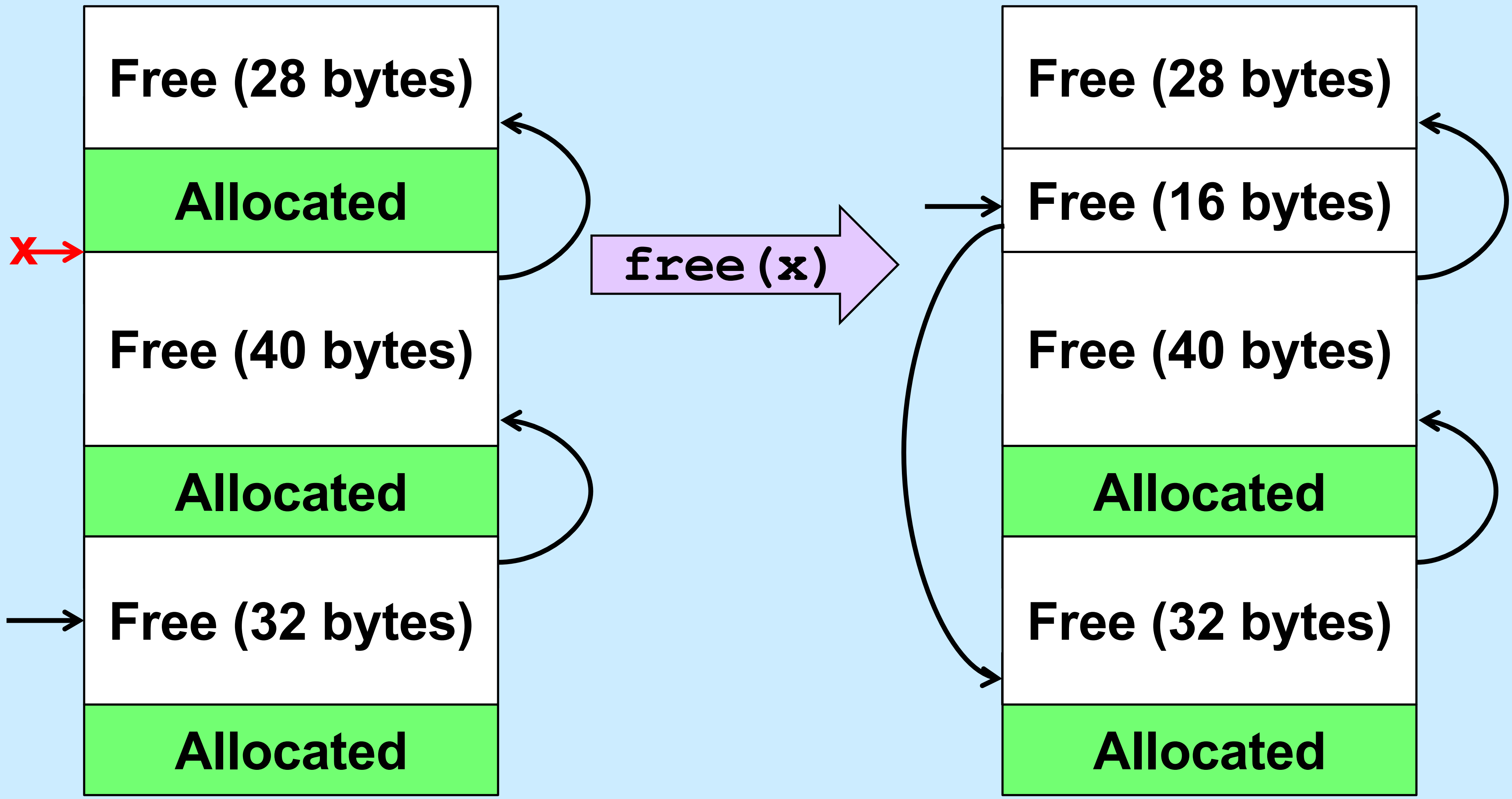
A Problem

- A malloc request is for a block of 32 bytes
- The block found on the free list is 1024 bytes long
- Should malloc return a pointer to the entire 1024-byte block?

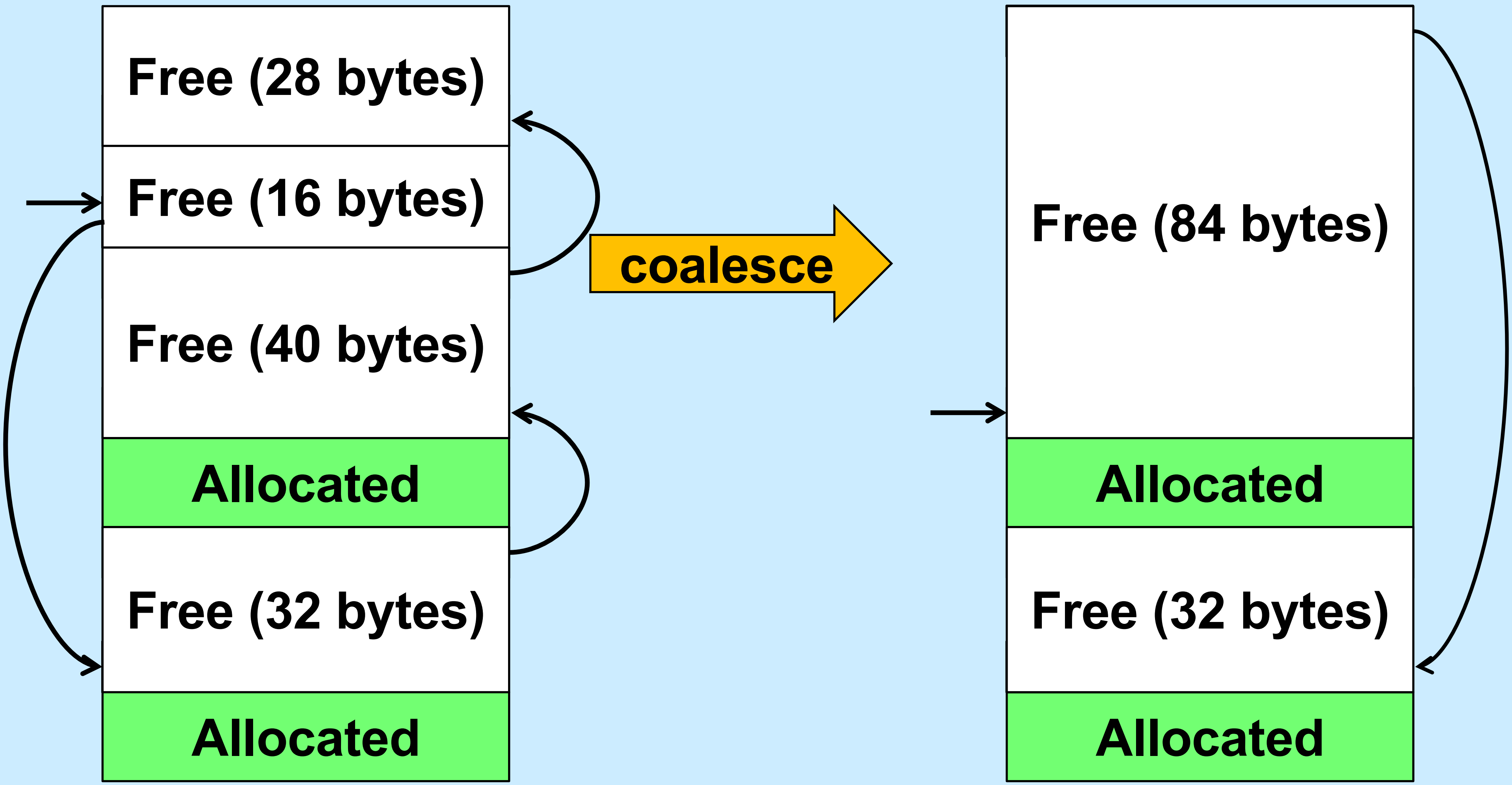
Splitting



Another Problem



Coalescing



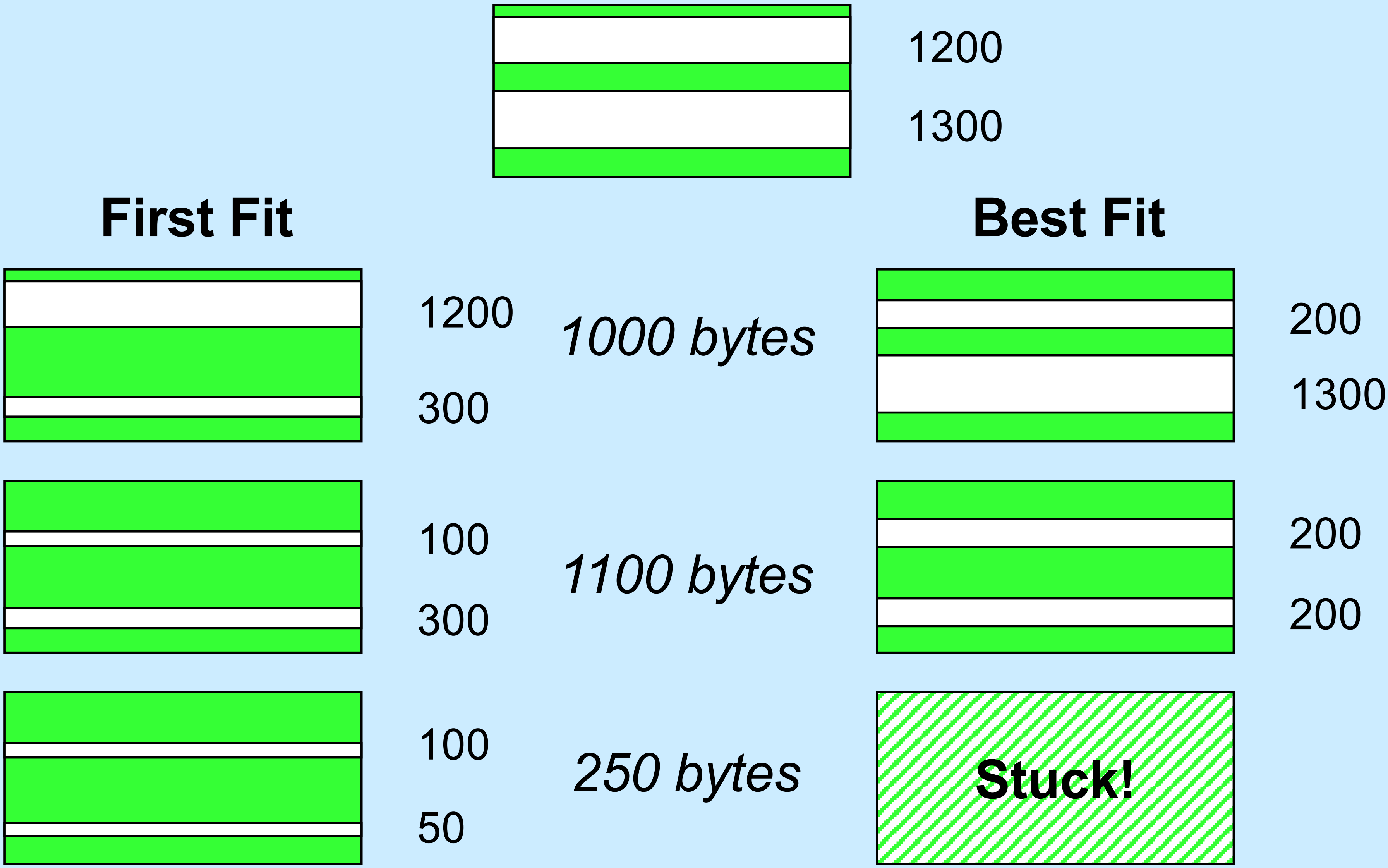
Free (28 bytes)
Free (16 bytes)
Free (40 bytes)
Allocated
Free (32 bytes)
Allocated
coalesce
Free (84 bytes)
Allocated
Free (32 bytes)
Allocated

Quiz 3

We have two free blocks of memory, of sizes 1300 and 1200 (appearing in that order). There are three successive requests to *malloc* for allocations of 1000, 1100, and 250 bytes. Which approach does best? (Hint: one of the two fails the last request.)

a) first fit
b) best fit

Allocation


1200
1300
First Fit
Best Fit
1200
300
1000 bytes
200
1300
100
300
1100 bytes
200
200
100
50
250 bytes
Stuck!

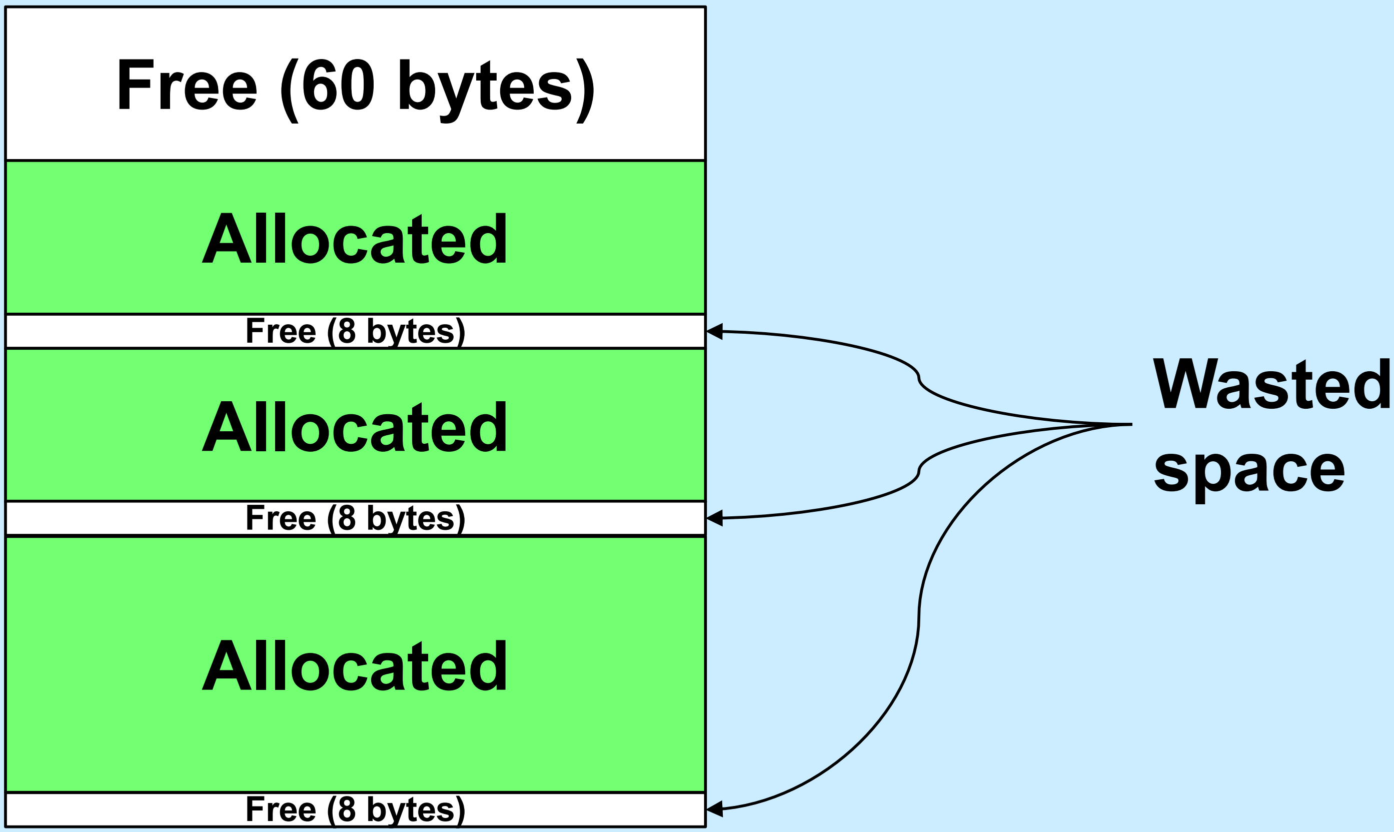
Some Observations

- **Best fit**
  - perhaps leaves behind chunks that are too small to be of use
  - requires linear time (in size of free list) for malloc
- **First fit**
  - small chunks congregate at beginning of free list
  - upper bound of linear time for malloc, but often much less

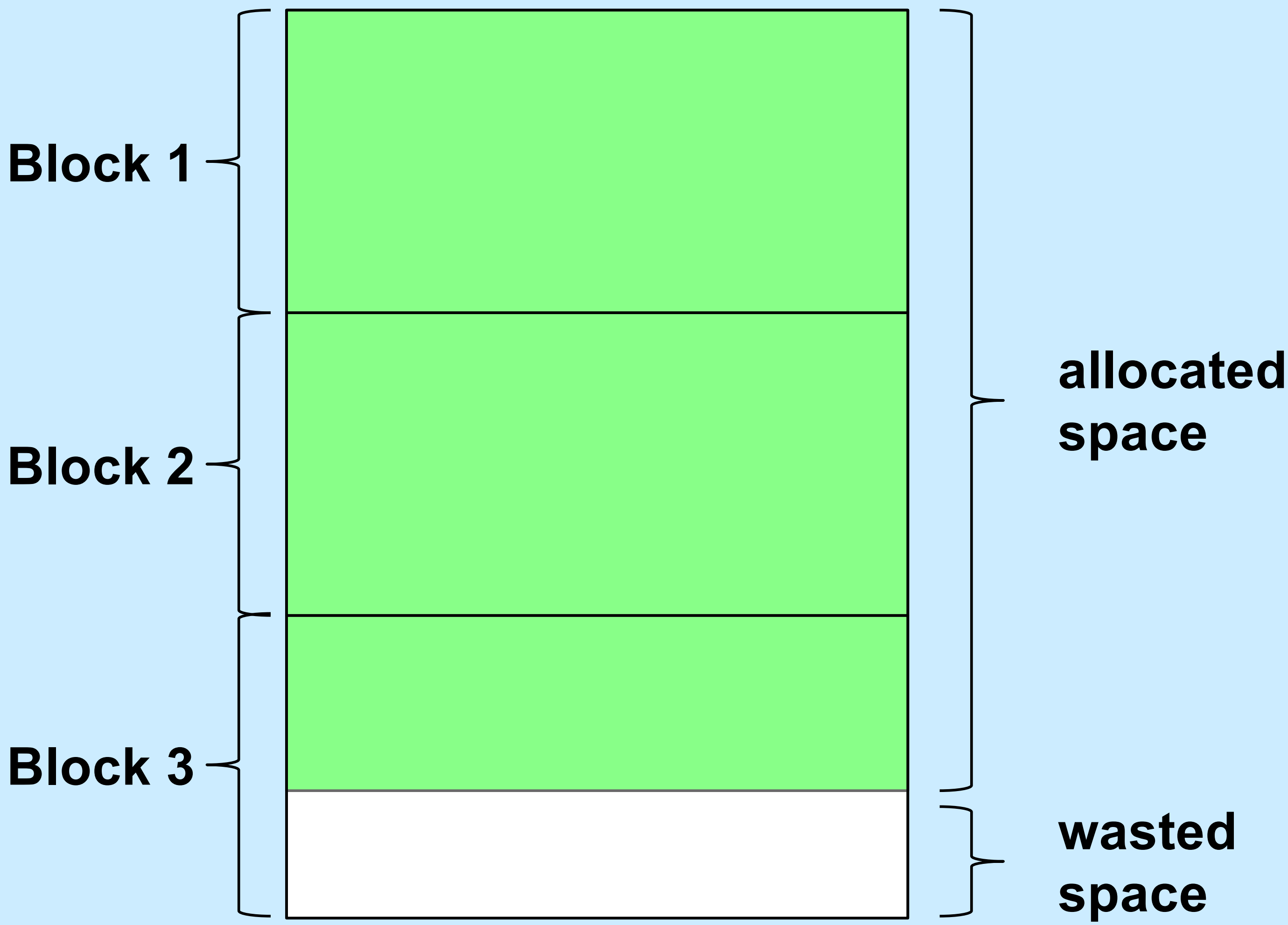
Fragmentation

- Fragmentation refers to the wastage of memory due to our allocation policy
- Two sorts
  - external fragmentation
  - internal fragmentation

External Fragmentation



Internal Fragmentation



Variations

- **Next fit**
  - like first fit, but the next search starts where the previous ended
- **Worst fit**
  - always allocate from largest free block
    - » perhaps reduces the number of “too small” blocks
- **Free-list insertion**
  - LIFO
    - » easy to do
    - » O(1)
  - ordered insertion
    - » O(n)

Quiz 4

Assume that best-fit results in less external fragmentation than first-fit.

We are running an application with modest memory demands. Which allocation strategy is likely to result in better performance (in terms of time) for the application:

a) first-fit with LIFO insertion

b) first-fit with ordered insertion

c) best-fit