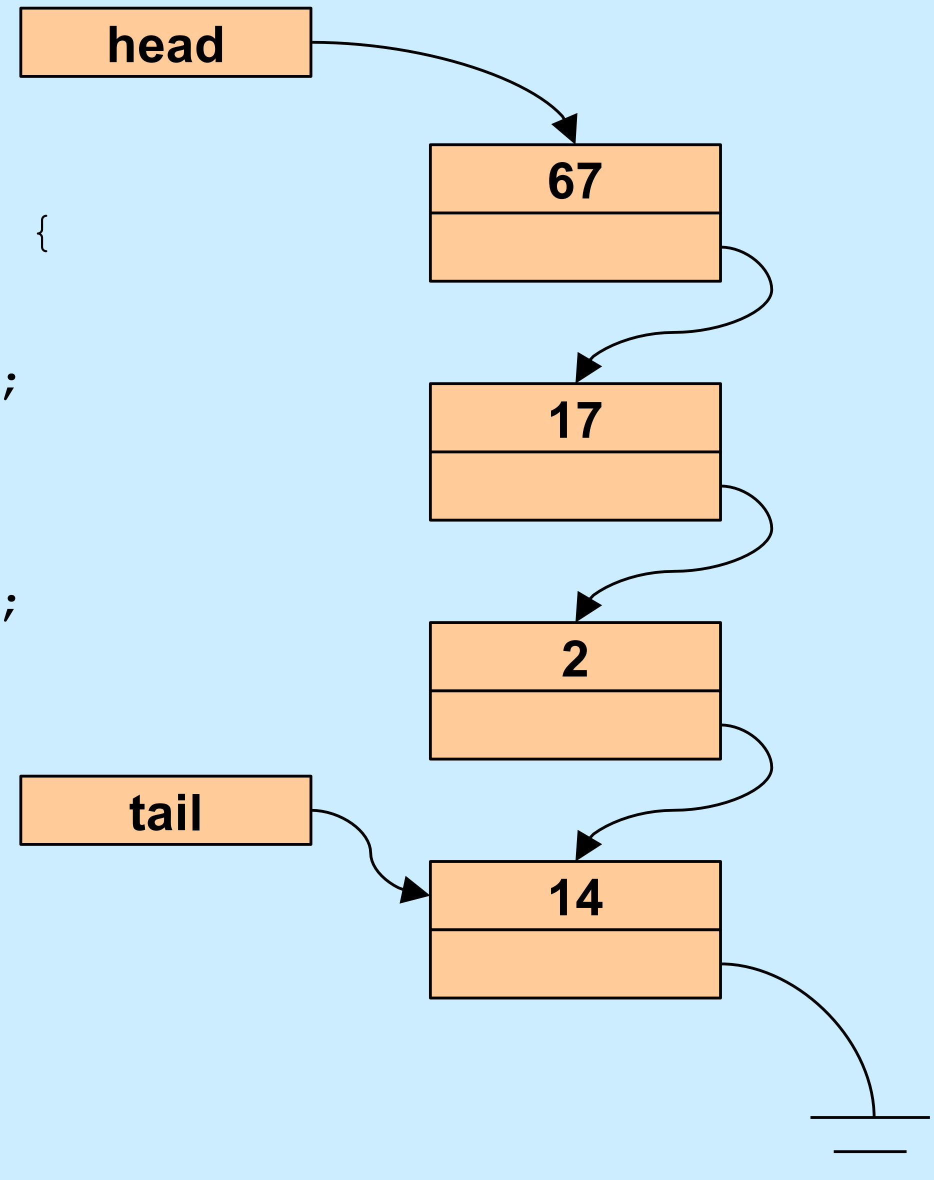
# CS 33

## 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;
}
```

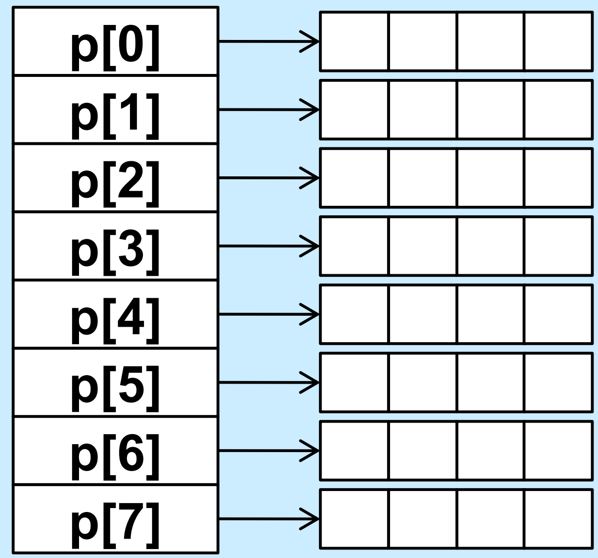
# Overwriting Memory

- **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;
}
```

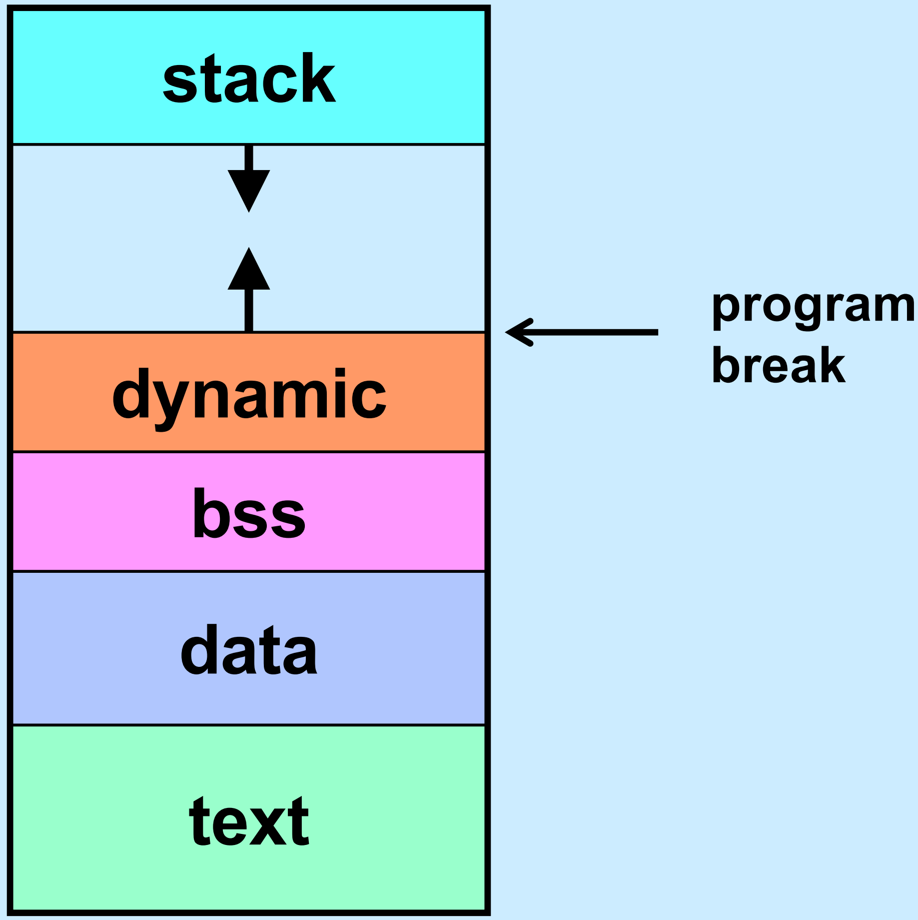
# Quiz 2

- **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)
```

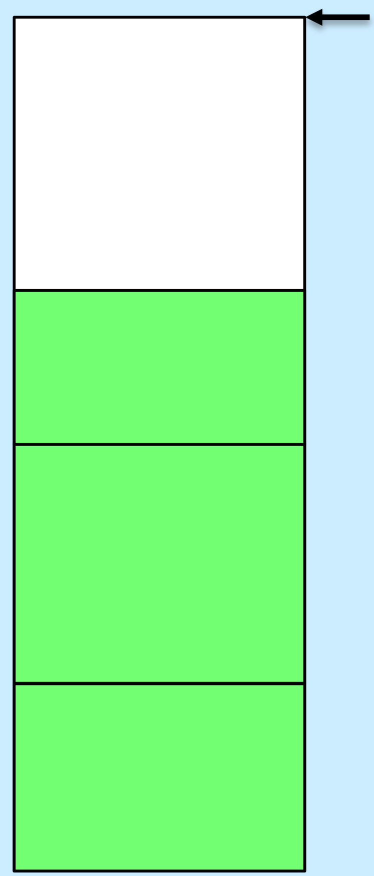
- moves the program break by an amount equal to *increment*
- returns the previous program break
- *intptr_t* is typedef'd to be a *long*

# 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

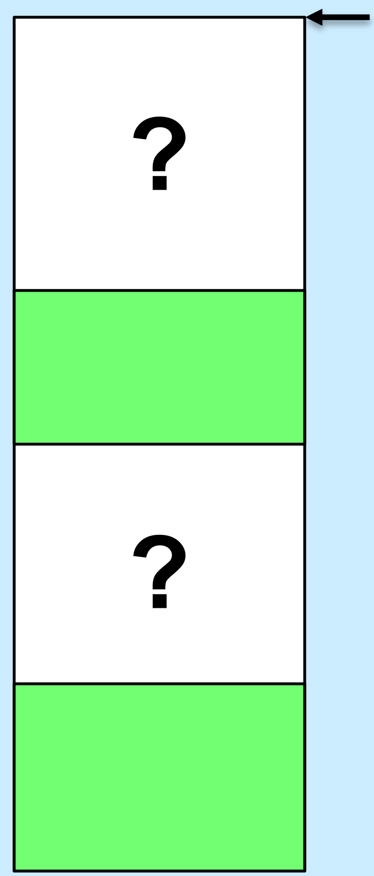
```
x = malloc(40);
y = malloc(60);
z = malloc(30);
free(y);
```



# Malloc and Free

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

w = malloc(60);
```



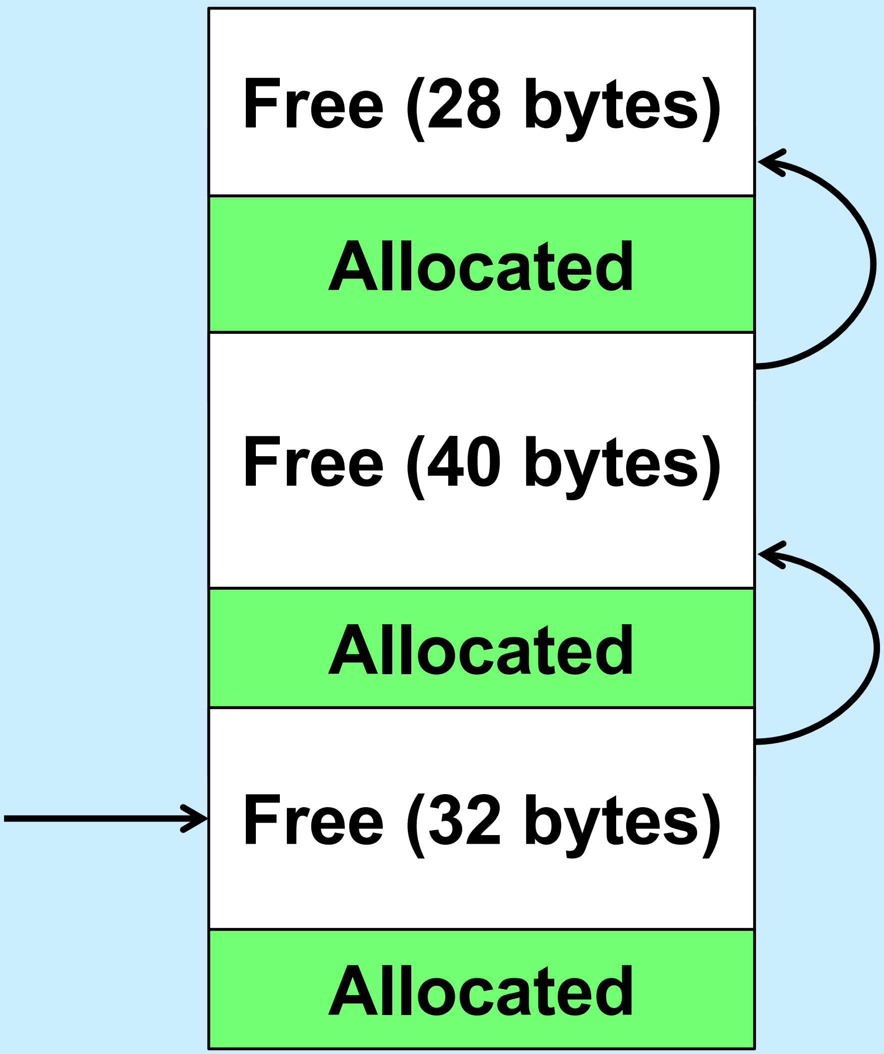

- How do we keep track of where free space is?
- How do we choose which to use?

# 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)`

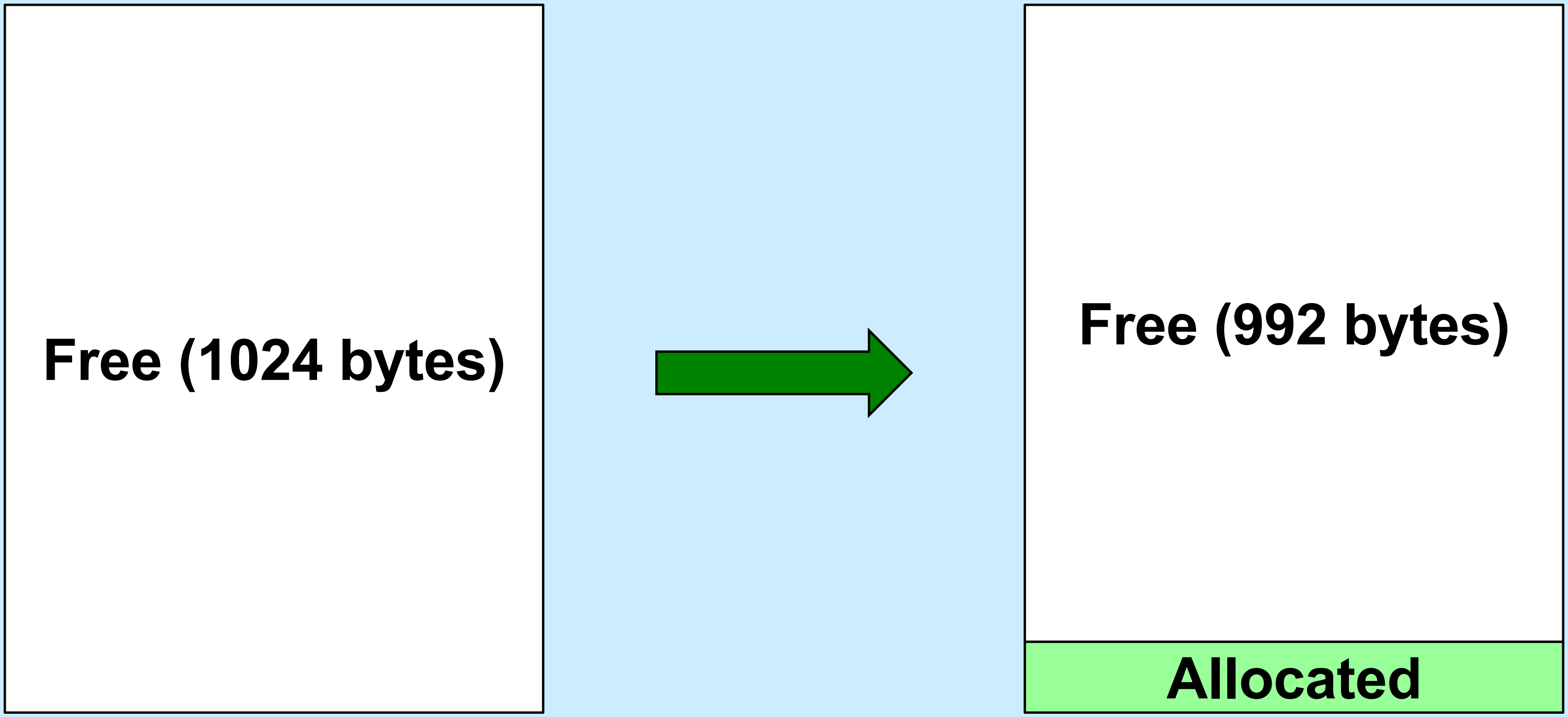
- Search strategies
  - first fit
  - best fit

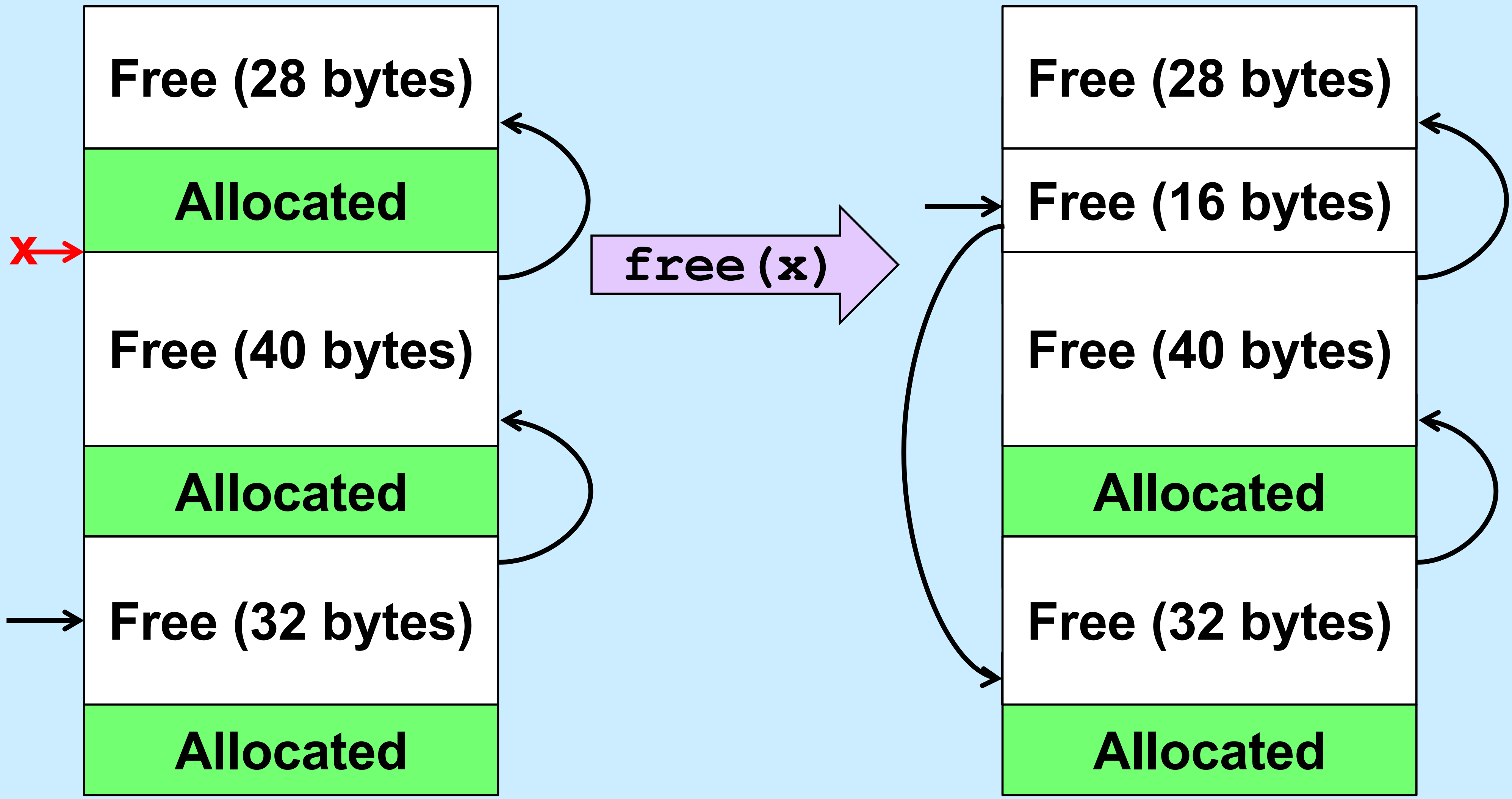
# A Problem

- 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

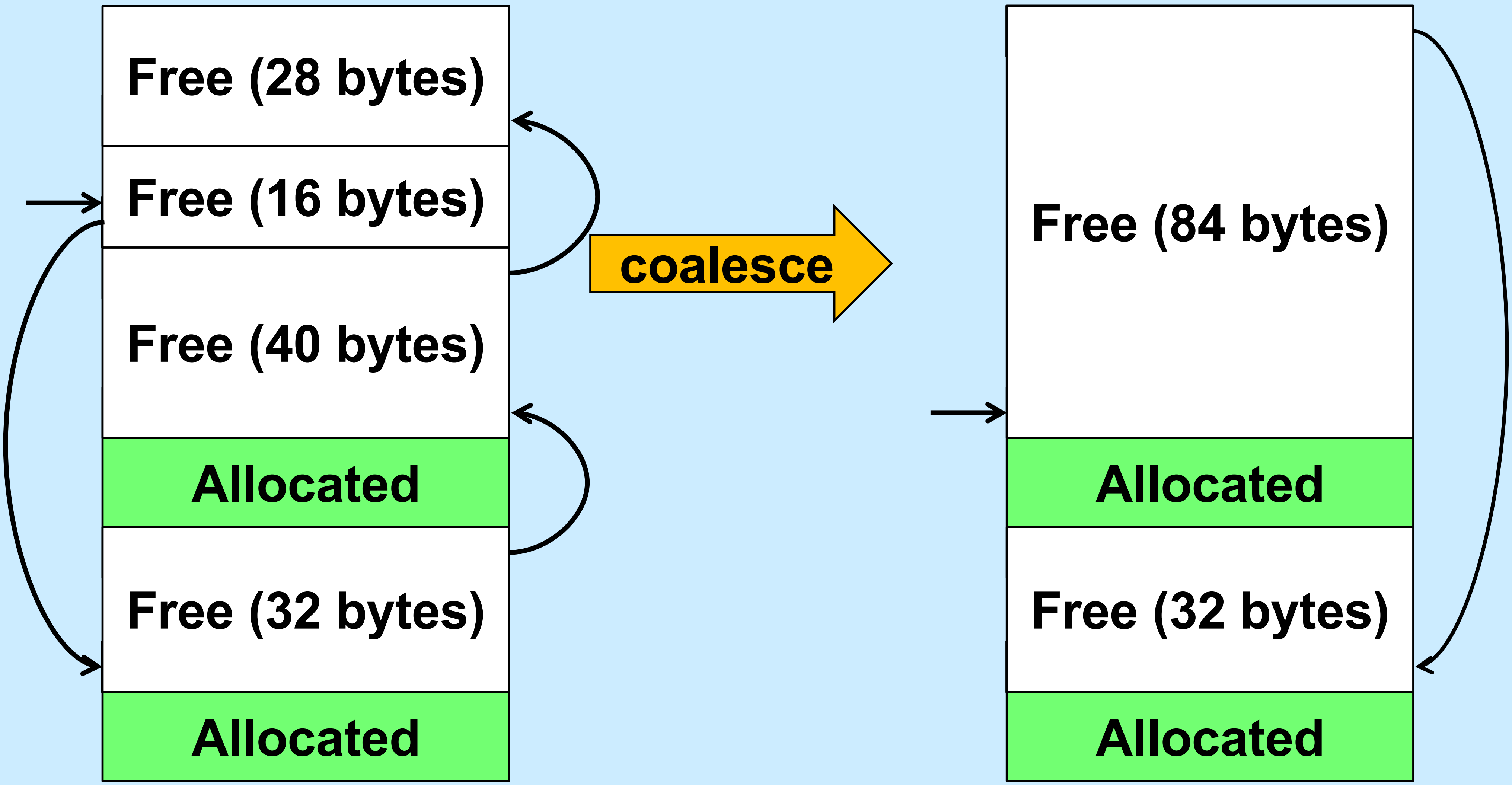


# Another Problem



# Coalescing



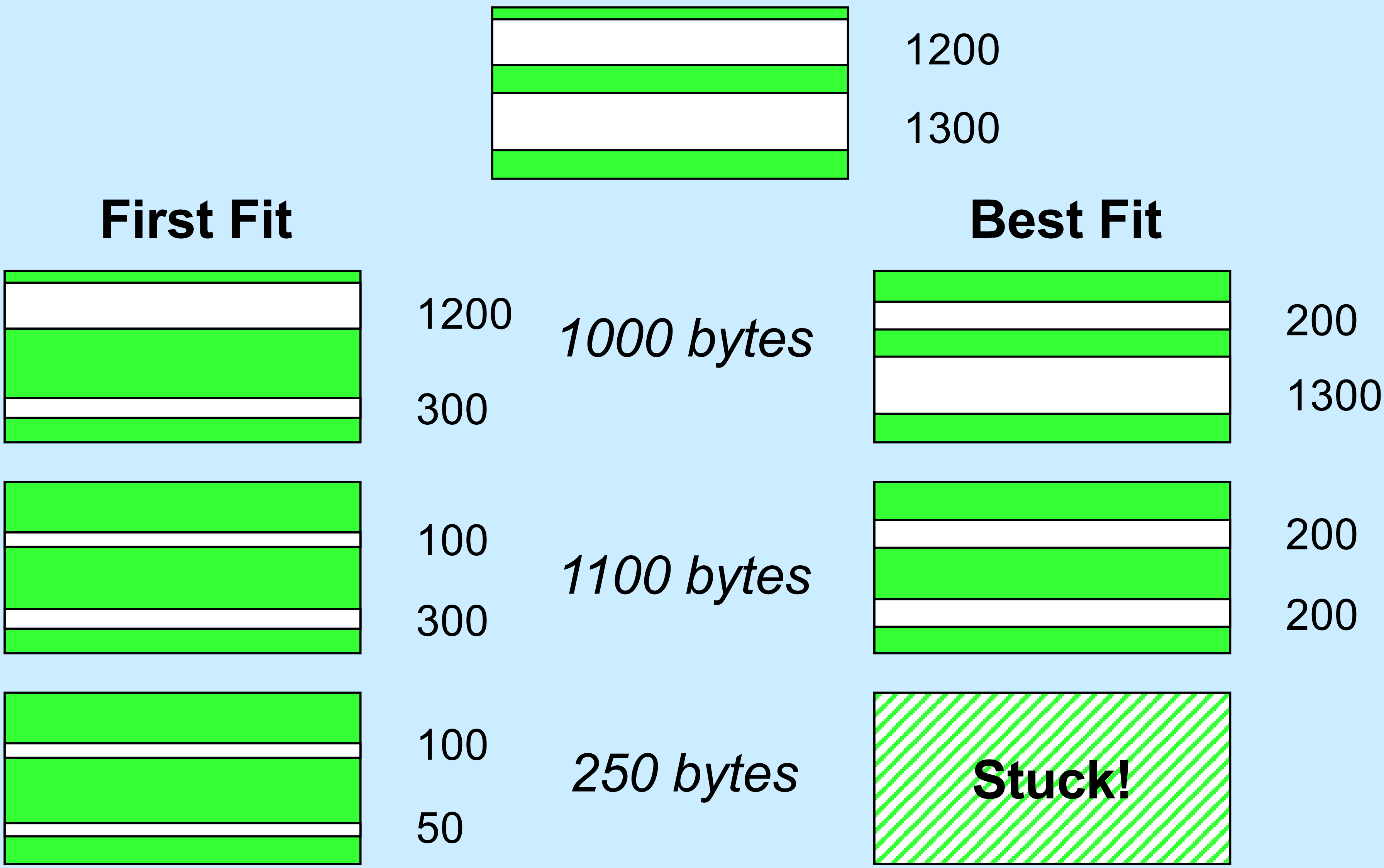
Free (28 bytes)
Free (16 bytes)
Free (40 bytes)
Allocated
Free (32 bytes)
Allocated
coalesce
Free (84 bytes)
Allocated
Free (32 bytes)
Allocated

# 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!

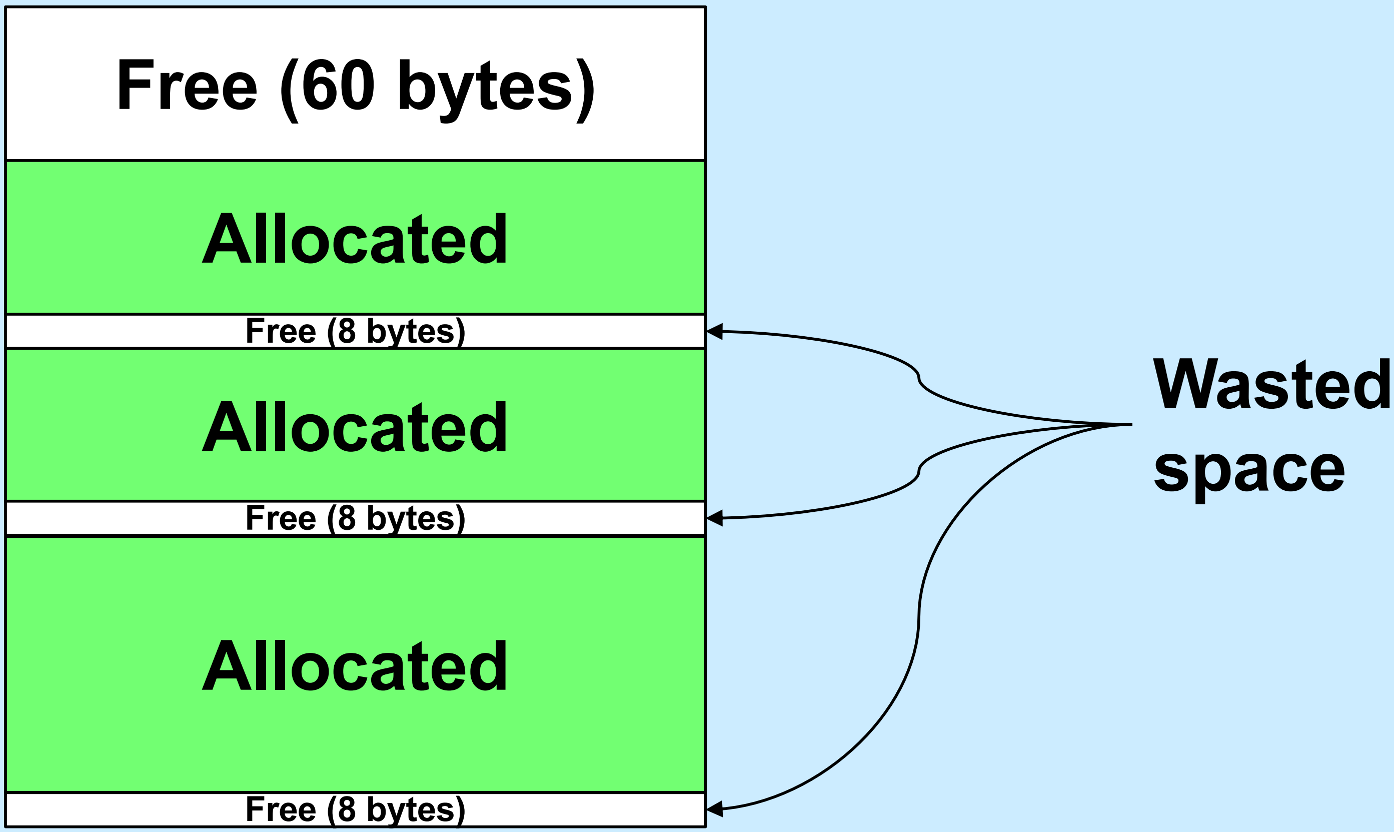
# Some Observations

- **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

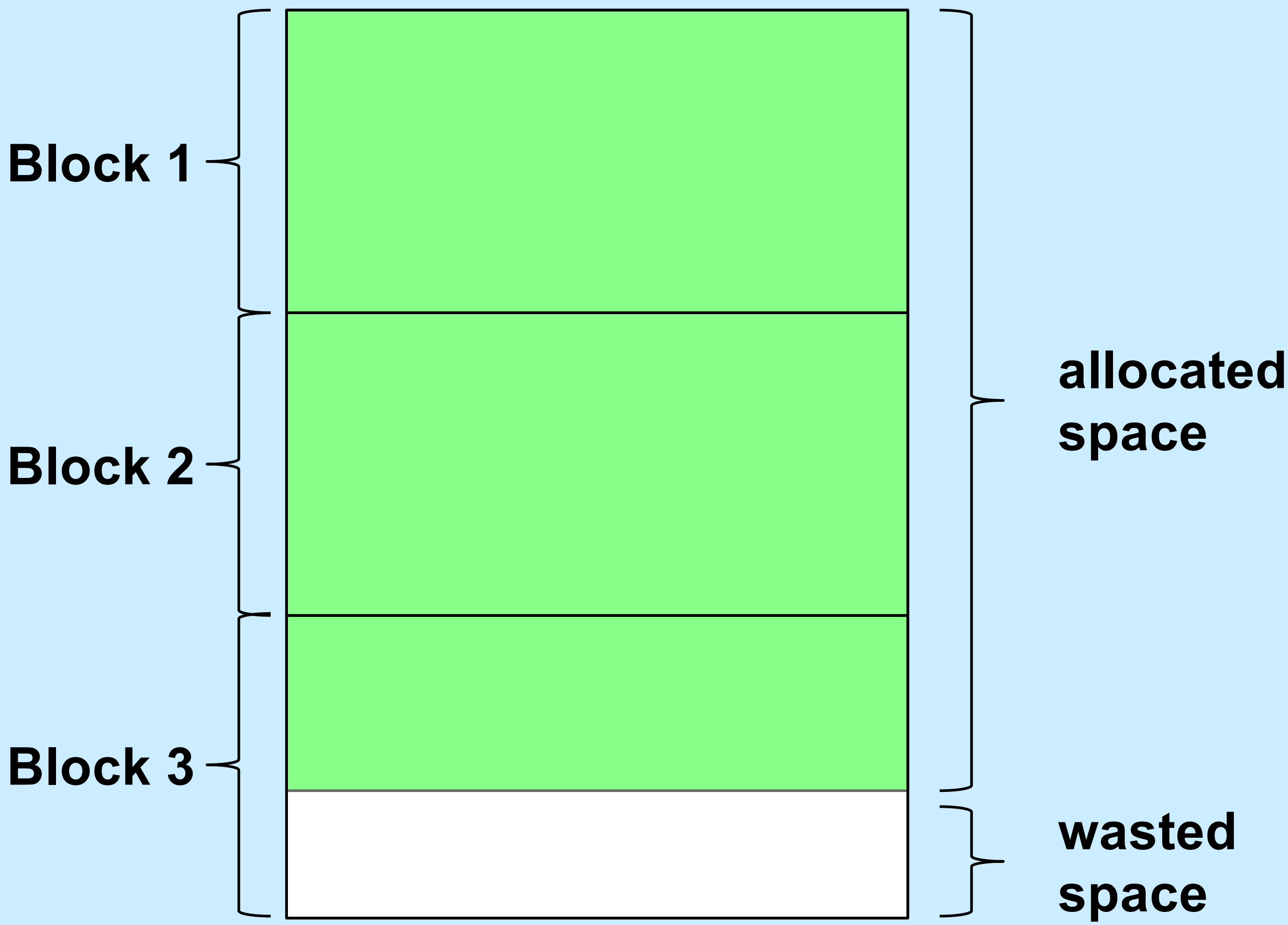
# Fragmentation

- 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