1. How many calls to malloc happen, with what sizes, in the program labelled Review: DoubleList?

2. (skip)

3. Draw the picture showing the "24 bytes in 2 blocks lost"

1. How many calls to malloc happen, with what sizes, in the program labelled Review: DoubleList?

2. (skip)

3. Draw the picture showing the "24 bytes in 2 blocks lost"

REFER TO HANDOUT!

Review: DoubleList

```
1  #include <stdio.h>
2  #include <stdlib.h>
3  #include <string.h>
4
5  typedef struct {
6    double *data;
7    int size;
8  } DoubleList;
9
10 void list_append(DoubleList *list, double val);
11 void list_print(DoubleList *list);

13 int main() {
14   DoubleList temps = { NULL, 0 };
15
16   list_append(&temps, 68.5);
17   list_append(&temps, 72.0);
18   list_append(&temps, 65.3);
19
20   list_print(&temps);
21
22   free(temps.data);
23 }
```

each list_append calls malloc

8 = ((0 + 1) * sizeof(double))

16 = ((1 + 1) * sizeof(double))

24 = ((2 + 1) * sizeof(double))

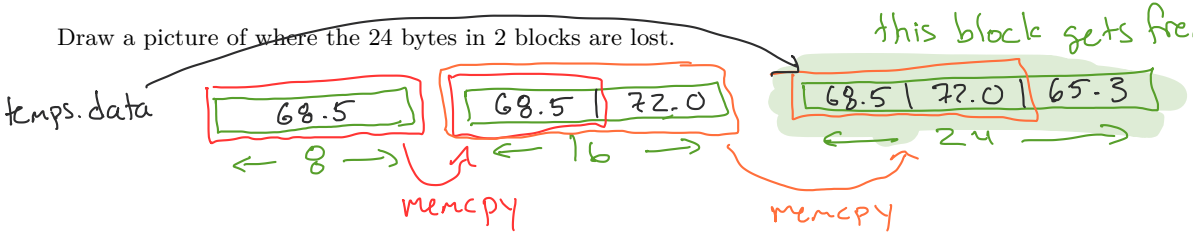
---

list_append — version 0 (has a bug!)

```
25 void list_append(DoubleList *list, double val) {
26   double *new_data = malloc((list->size + 1) * sizeof(double));
27   memcpy(new_data, list->data, list->size * sizeof(double));
28   list->data = new_data;
29   list->data[list->size] = val;
30   list->size++;
31 }
```

```
$ valgrind ./list-leak
[68.5, 72.0, 65.3]
==2303169== HEAP SUMMARY:
==2303169==     in use at exit: 24 bytes in 2 blocks
==2303169==   total heap usage: 4 allocs, 2 frees, 1,072 bytes
    allocated
==2303169== LEAK SUMMARY:
==2303169==    definitely lost: 24 bytes in 2 blocks
```

Draw a picture of where the 24 bytes in 2 blocks are lost.



list_append — version 1, using malloc and free

```
void list_append(DoubleList *list, double val) {
    double* newd = malloc((list->size + 1) * sizeof(double));
    memcpy(newd, list->data, list->size * sizeof(double));
    free(list->data);
    list->data = newd;
    list->data[list->size] = val;
    list->size += 1;
}
```

note we are still using the "old" list->data here - after this line we lose that reference!

list_append — version 2, using realloc

```
void list_append(DoubleList *list, double val) {
    double* newd = realloc(list->data,
                           ((list->size+1) * sizeof(double)));
    list->data = newd;
    list->data[list->size] = val;
    list->size += 1;
}
```

realloc does malloc + memcpy + free

realloc wraps malloc + memcpy + free into one call:

```
void *realloc(void *ptr, size_t new_size);
```

- May extend in place or allocate + copy + free
- `realloc(NULL, n)` acts like `malloc(n)`

Filtering a DoubleList - describe what these 3 do in English!

```
16 int is_less_70(double val) { return val < 70.0; }
17 DoubleList filter_less_70(DoubleList *list) {
18   DoubleList result = { NULL, 0 };
19   for (int i = 0; i < list->size; i++) {
20     if (is_less_70(list->data[i])) {
21       list_append(&result, list->data[i]);
22     }
23   }
24   return result;
25 }
```

Takes a DoubleList, returns a new DL with all elements less than 70

```
27 int is_integer(double val) { return val == (int)val; }
28 DoubleList filter_is_integer(DoubleList *list) {
29   DoubleList result = { NULL, 0 };
30   for (int i = 0; i < list->size; i++) {
31     if (is_integer(list->data[i])) {
32       list_append(&result, list->data[i]);
33     }
34   }
35   return result;
36 }
```

Takes a DoubleList returns a new DL with all elements that are exact integers.

```
38 int is_unit(double val) { return val >= 0.0 && val <= 1.0; }
39 DoubleList filter_unit(DoubleList *list) {
40   DoubleList result = { NULL, 0 };
41   for (int i = 0; i < list->size; i++) {
42     if (is_unit(list->data[i])) {
43       list_append(&result, list->data[i]);
44     }
45   }
46   return result;
47 }
```

Takes a DoubleList returns a new DL with all elements between 0 and 1 (inclusive)

What's the same across all three functions?

What's different?

Factoring out the pattern: `list_filter`

```
typedef int (*Predicate)(double);

DoubleList list_filter(DoubleList *list, Predicate pred) {
    DoubleList result = {NULL, 0};
    for(int i=0; i< list->size; i+=1) {
        if( (*pred) (list->data[i])) {
            list_append(&result, list->data[i]);
        }
    }
    return result;
}
```

Examples: hardcoded filters

```
void list_examples() {
  DoubleList d = { NULL, 0 };
  list_append(&d, 68.5);
  list_append(&d, 72.0);
  list_append(&d, 0.5);
  list_append(&d, 99.0);
  // How to call each filter function? What's the expected result
      for each?



}
```

Examples: using `list_filter`

```
void list_examples_pred() {
  DoubleList d = { NULL, 0 };
  list_append(&d, 68.5);
  list_append(&d, 72.0);
  list_append(&d, 0.5);
  list_append(&d, 99.0);
  // How to call list_filter for each? What's the expected result?
  DoubleList less70 = list_filter(&d, &is_less_70);
  DoubleList units = list_filter(&d, &is_unit);
}
```

Passing a function as a value

Review: DoubleList

```
1  #include <stdio.h>
2  #include <stdlib.h>
3  #include <string.h>
4
5  typedef struct {
6    double *data;
7    int size;
8  } DoubleList;
9
10 void list_append(DoubleList *list, double val);
11 void list_print(DoubleList *list);

13 int main() {
14   DoubleList temps = { NULL, 0 };
15
16   list_append(&temps, 68.5);
17   list_append(&temps, 72.0);
18   list_append(&temps, 65.3);
19
20   list_print(&temps);
21
22   free(temps.data);
23 }
```

8 = ((0 + 1) * sizeof(double))
16 = ((1 + 1) * sizeof(double))
24 = ((2 + 1) * sizeof(double))

---

list_append — version 0 (has a bug!)

```
25 void list_append(DoubleList *list, double val) {
26   double *new_data = malloc((list->size + 1) * sizeof(double));
27   memcpy(new_data, list->data, list->size * sizeof(double));
28   list->data = new_data;
29   list->data[list->size] = val;
30   list->size++;
31 }
```

changes temp.data

```
$ valgrind ./list-leak
[68.5, 72.0, 65.3]
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==2303169==   total heap usage: 4 allocs, 2 frees, 1,072 bytes
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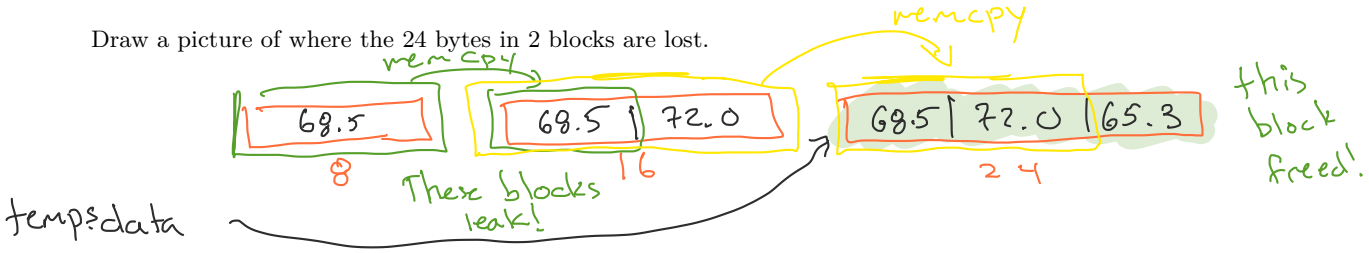
Draw a picture of where the 24 bytes in 2 blocks are lost.



list_append — version 1, using malloc and free

```
void list_append(DoubleList *list, double val) {
  double* newd = malloc(....);
  memcpy(newd, list->data, list->size * sizeof(double));
  free(list->data);
  list->data = newd;
  list->data[list->size] = val;
  list->size += 1;
}
```

still using list->data

losing the reference to list->data

list_append — version 2, using realloc

```
void list_append(DoubleList *list, double val) {
  double* newd = realloc(list->data,
                         ((list->size + 1) * sizeof(double)));
  list->data = newd;
  list->data[list->size] = val;
  list->size += 1;
}
```

uses header/malloc metadata to decide how much to memcpy

`realloc` wraps malloc + memcpy + free into one call:

```
void *realloc(void *ptr, size_t new_size);
```

- May extend in place or allocate + copy + free
- `realloc(NULL, n)` acts like `malloc(n)`

Filtering a `DoubleList` 1-sentence English description of each

```
16 int is_less_70(double val) { return val < 70.0; }
17 DoubleList filter_less_70(DoubleList *list) {
18   DoubleList result = { NULL, 0 };
19   for (int i = 0; i < list->size; i++) {
20     if (is_less_70(list->data[i])) {
21       list_append(&result, list->data[i]);
22     }
23   }
24   return result;
25 }
```

Takes a DoubleList, returns a new DL containing all the elements less than 70

```
27 int is_integer(double val) { return val == (int)val; }
28 DoubleList filter_is_integer(DoubleList *list) {
29   DoubleList result = { NULL, 0 };
30   for (int i = 0; i < list->size; i++) {
31     if (is_integer(list->data[i])) {
32       list_append(&result, list->data[i]);
33     }
34   }
35   return result;
36 }
```

Takes a DoubleList returns a new DL containg all the elements that are exact integers

```
38 int is_unit(double val) { return val >= 0.0 && val <= 1.0; }
39 DoubleList filter_unit(DoubleList *list) {
40   DoubleList result = { NULL, 0 };
41   for (int i = 0; i < list->size; i++) {
42     if (is_unit(list->data[i])) {
43       list_append(&result, list->data[i]);
44     }
45   }
46   return result;
47 }
```

Takes a DoubleList returns a new DL containg all the elements that are between 0 and 1 (inclusive)

What's the same across all three functions?

What's different?

The function (predicate) that is called

Factoring out the pattern: `list_filter`

```
typedef int (*Predicate)(double);
```

"a pointer to/addr of a function takes double returns int"

```
DoubleList list_filter(DoubleList *list, Predicate pred) {
    DoubleList result = { NULL, 0 };
    for (int i = 0; i < list->size; i += 1) {
        if ( (*pred) (list->data[i]) ) {
            list_append(&result, list->data[i]);
        }
    }
    return result;
}
```

Examples: hardcoded filters

```
void list_examples() {
  DoubleList d = { NULL, 0 };
  list_append(&d, 68.5);
  list_append(&d, 72.0);
  list_append(&d, 0.5);
  list_append(&d, 99.0);
  // How to call each filter function? What's the expected result
      for each?



}
```

Examples: using `list_filter`

```
void list_examples_pred() {
  DoubleList d = { NULL, 0 };
  list_append(&d, 68.5);
  list_append(&d, 72.0);
  list_append(&d, 0.5);
  list_append(&d, 99.0);
  // How to call list_filter for each? What's the expected result?
  DoubleList less70s = list_filter(&d, &is_less_70);
  DoubleList units = list_filter(&d, &is_unit);
}
```

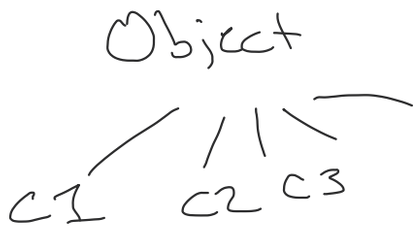
Passing functions as values!

"Higher-order functions"

"Dynamic Dispatch"

```
void doStrngStuff(Object[] objs) {
    ...
        obj[i].toStrng()
    ...
}
```

← this calls toString of whatever actual class obj[i] is



"lambda"

λ

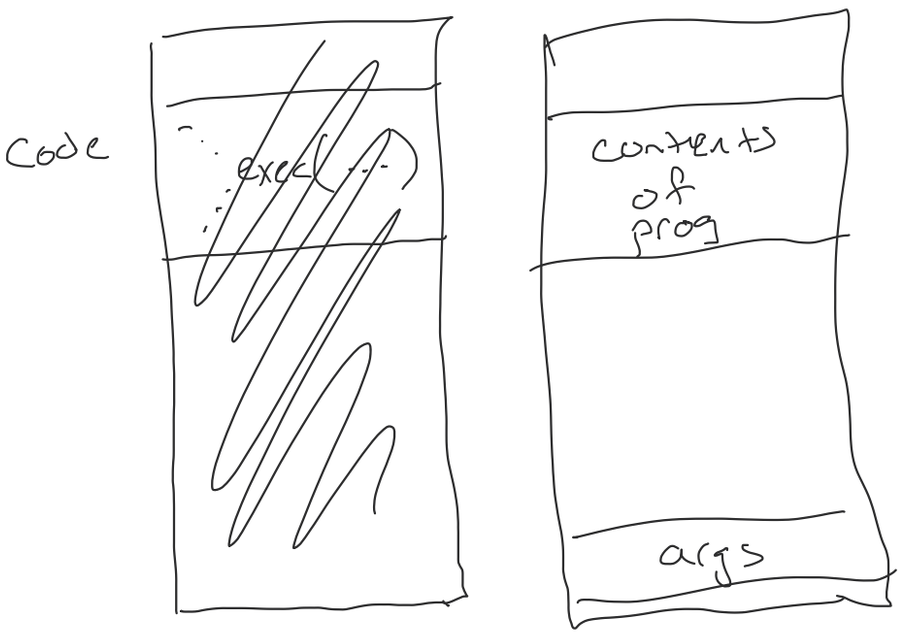
"anonymous functions"

```
def less70(n): return n < 70
filter(lst, less70)
```

```
filter(lst, lambda n: n < 70)
```

execvp(prog, args)

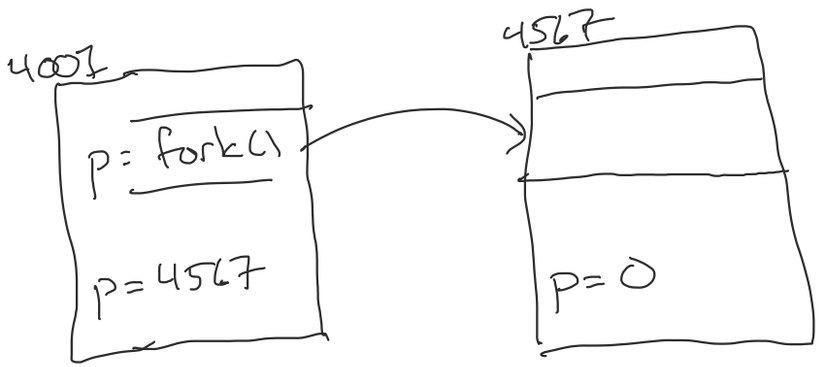
replaces current process address space by starting given prog with args



overwrite the whole process with a new one

int fork()

copies current process address space and runs both processes, returns 0 in child, pid in parent



wait(int* status)

- returns when any child process finishes

waitpid(int pid, int* status)

- returns when pid finishes

typedef - makes an "alias" or a "abbreviation" for a type

int n; typedef int n; n is an alias for int

void (*handle)(int port, char* request) declares handle as a function ptr

typedef void (*handle)(int port, char* request) declares handle as a type of functions that take ... and return ...

"Runtime environment"