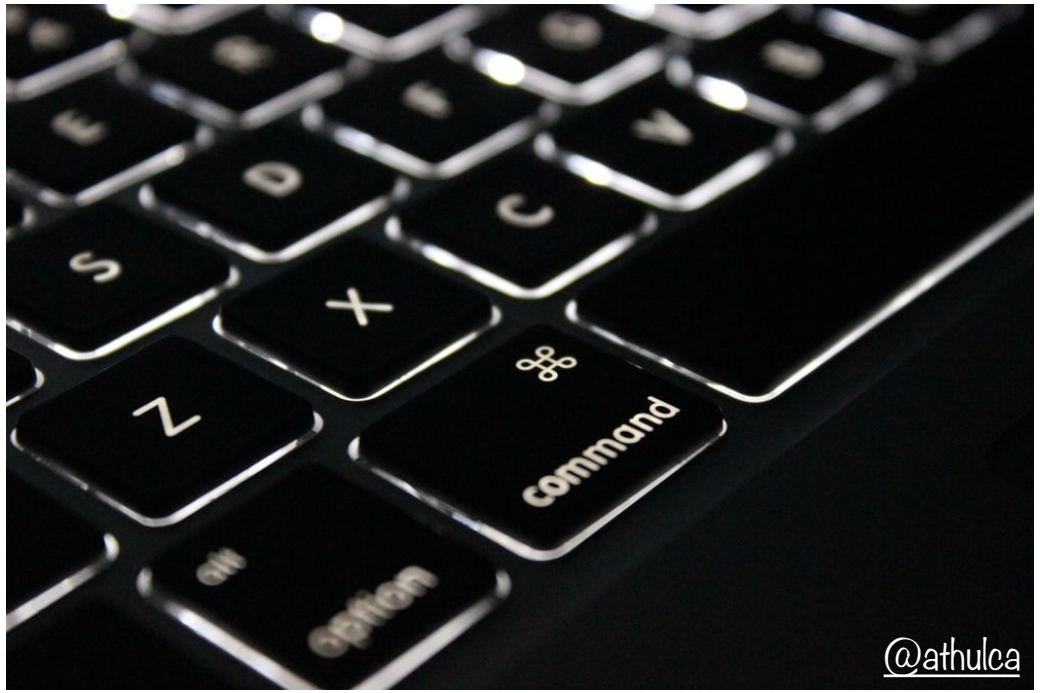
# COS 217: Introduction to Programming Systems

Command Line Arguments,
Structures,
Dynamic Memory

PRINCETON UNIVERSITY




# COMMAND LINE ARGUMENTS

# What's my name?

- String[] args was COS 126 day 1


- How to get the equivalent in C?

# With `sed s/s/v/ ,` natch.

```
int main(int argc, char *argv[])
{
   int i;


   /* Write the command-line argument count to stdout. */
   printf("argc:  %d\n", argc);

   /* Write the command-line arguments to stdout. */
   for (i = 0; i < argc; i++)
      printf("argv[%d]:  %s\n", i, argv[i]);


   return 0;
}
```

As parameters, these are identical:

`char a[]` and `char *a`

So it follows that, as parameters, these are, too:

`char *argv[]` and `char **argv`

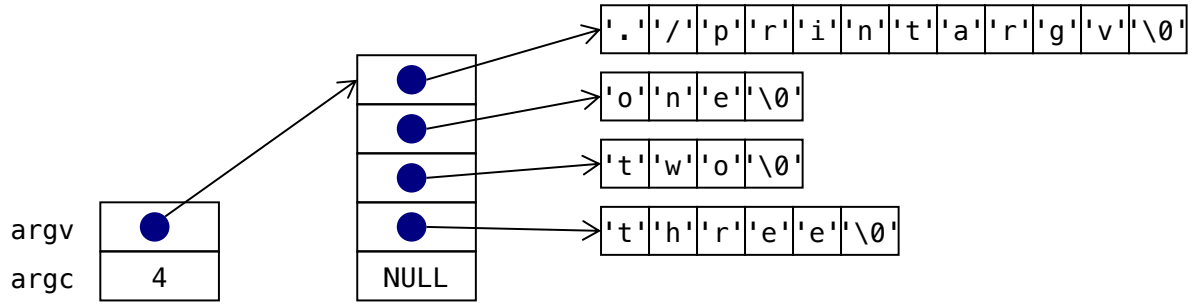
Note: array indices should be `size_t`, but `argc` is an `int`, so index with `int` here to avoid warning about comparison signedness or needing to have a bunch of casts.

# Elucidating Example: Explanatory echo

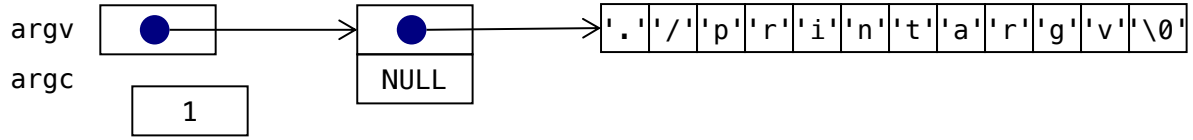


```
int main(int argc, char *argv[])
{
  int i;
  printf("argc:  %d\n", argc);

  for (i = 0; i < argc; i++)
    printf("argv[%d]:  %s\n",
                      i, argv[i]);
  return 0;
}
```

```
$ ./printargv one two three
```




```
$ ./printargv
```



# What's argc?

```
./printargv one "two  three" four
```

A. 3

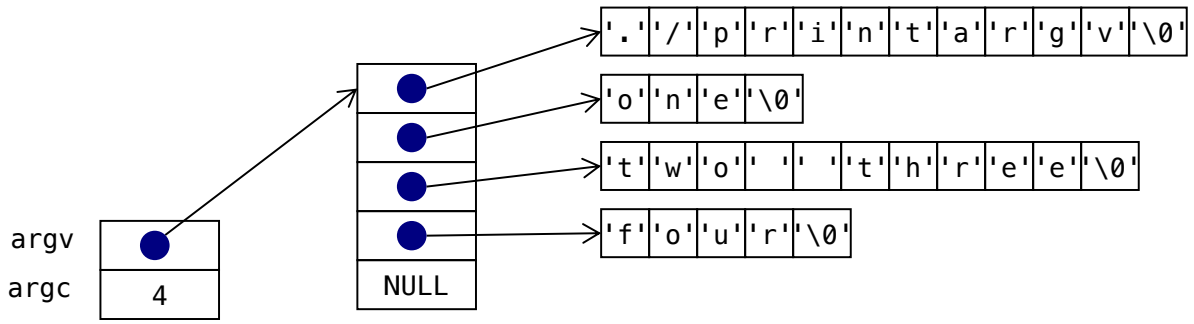
B. 4

C. 5

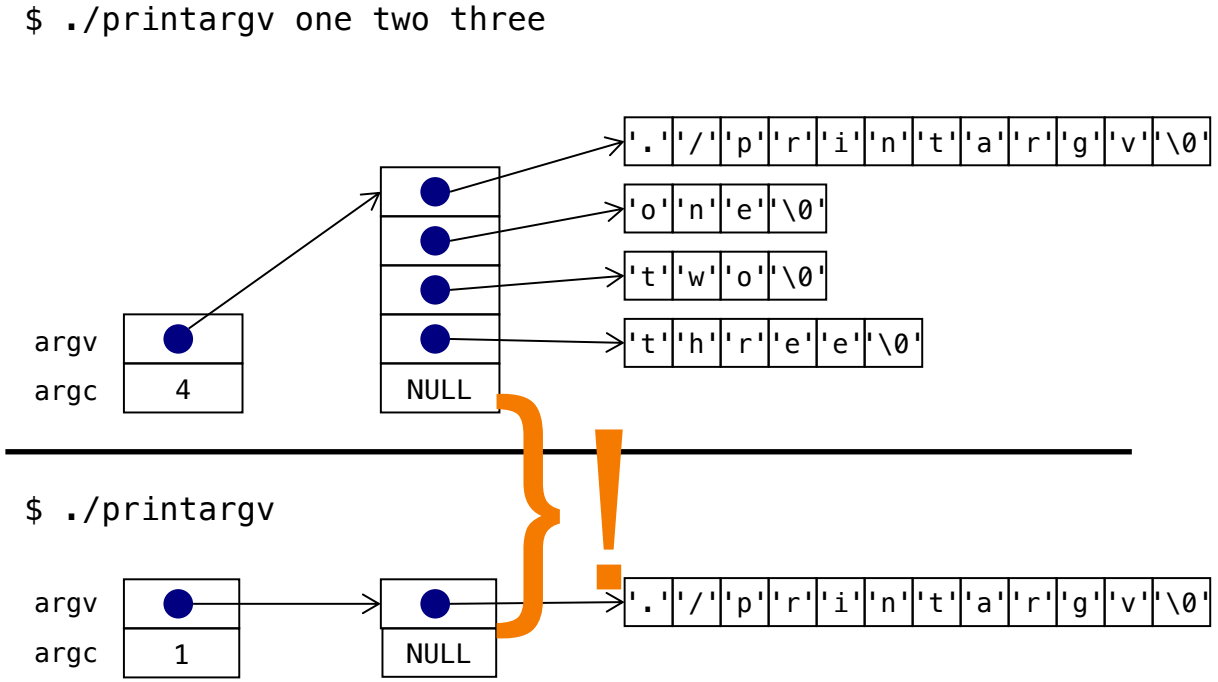
D. Syntax error at runtime

B:

```
$ ./printargv one "two  three" four
```



# A2-inspired: rewrite everything in arrays to use pointers




```
int main(int argc, char *argv[])
{
  char **ppc = argv;
  printf("argc:  %d\n", argc);

  while (*ppc != NULL)
    printf("argv[%d]:  %s\n",
           ppc-argv, *ppc++);
  return 0;
}
```

Post-increment with pointers is just like we saw with integer types: emits the **old** value of `ppc`

The dereference then happens on value emitted, so this could be parenthesized as: `*(ppc++)`

# Kicking the extra point?

```
int main(int argc, char *argv[])
{
  char **ppc = argv;
  int i = 0;
  printf("argc:  %d\n", argc);

  while(*ppc != NULL)
    printf("argv[%d]:  %s\n",
                  i++, *ppc++);
  return 0;
}
```

?

```
int main(int argc, char *argv[])
{
  char *pc = *argv;
  int i = 0;
  printf("argc:  %d\n", argc);

  while(pc != NULL)
    printf("argv[%d]:  %s\n", i++,
                          pc++);
  return 0;
}
```

A. Yes! This works and is clearer.

B. Maybe. This works but is less clear.

C. No! This is incorrect!

D. No! This doesn't even compile!

C: When run with no arguments:

```
argc: 1
argv[0]: ./pcla-wrong
argv[1]: /pcla-wrong
argv[2]: pcla-wrong
argv[3]: cla-wrong
...
```

# Challenge for the bored: `main`ly nonsense

```
int main(int argc, char **argv) {
int retVal;
if (argc == 0) {
  return 0;
} else {
  retVal = main(argc-1, argv+1);
  printf("%d: %s\t", argc-1, argv[0]);
  return retVal;
}
}
```

## What does this program do?

A. prints arguments

B. prints arguments in reverse order

C. recurs infinitely: `argc` is always ≥ 1

D. prints only the last argument:
`return` from `main` exits the program

The correct answer is B:

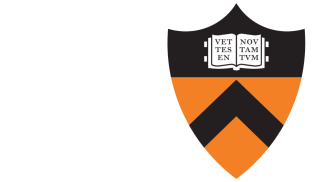
```
armlab01$ ./recur-r a b c; echo
0: c 1: b 2: a 3: ./recur-r
```

C is only the case at the start of execution,
and does not hold if the program changes `argc`.

D would be the behavior with `exit(retVal);` instead of `return retVal;`


# C STRUCTURES

# {new state, updated line number} would've worked



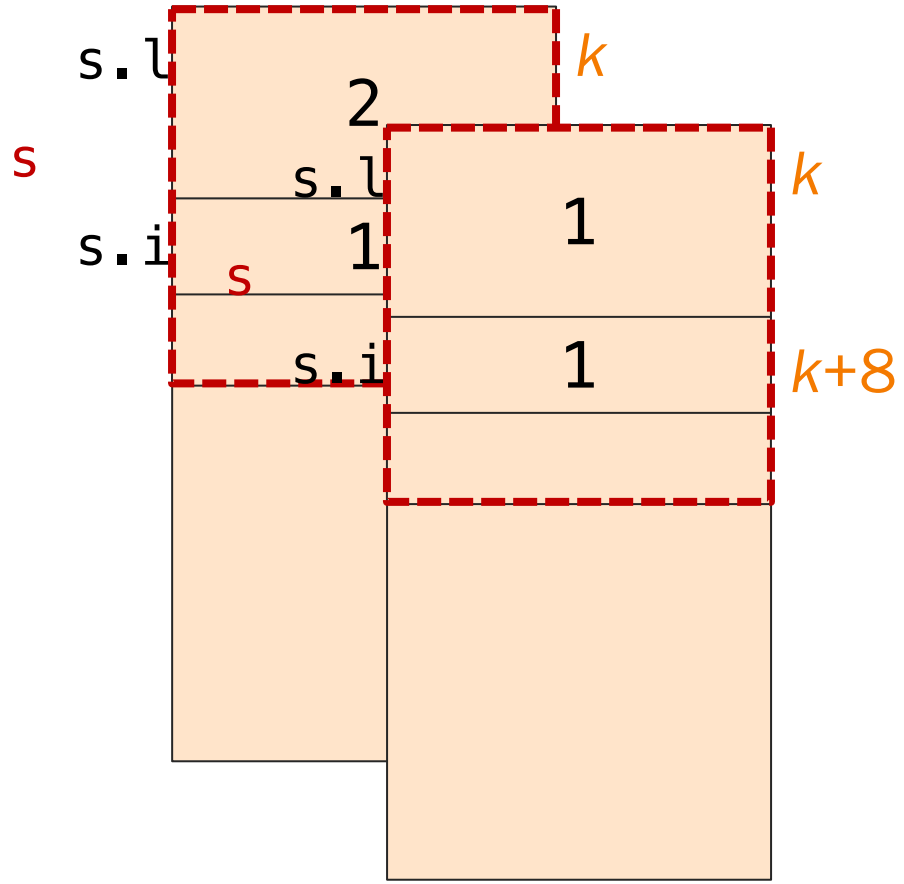
- Java classes can have many fields



- How to get the equivalent in C?

# Add some structure to your program

```
struct S {
  long l;
  int i;
};

struct S s = {2L, 1};


s.l = s.i;
```

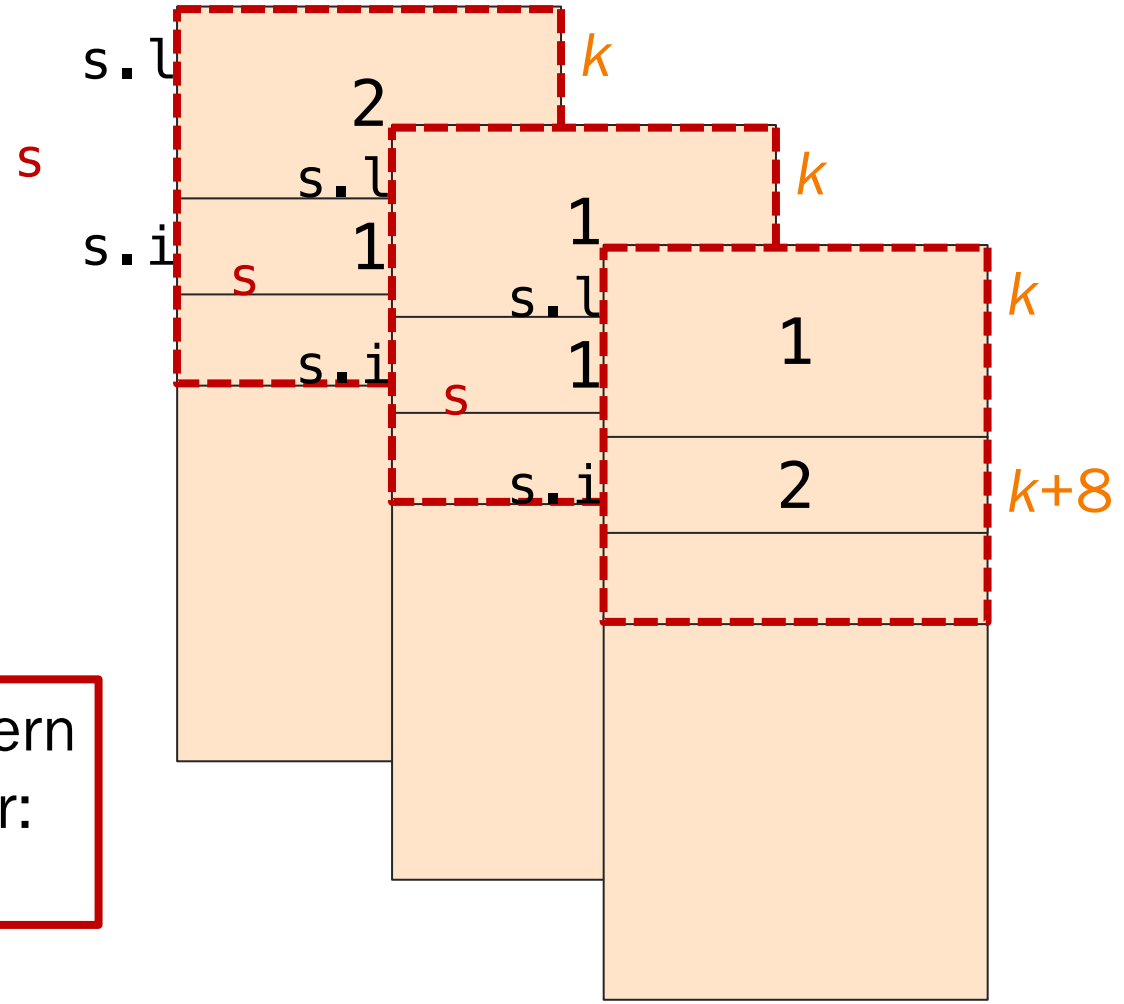


# Add some structure to your program

```
struct S {
  long l;
  int i;
};

struct S s = {2L, 1};

struct S *ps = &s;

s.l = s.i;

(*ps).i *= 2;
```

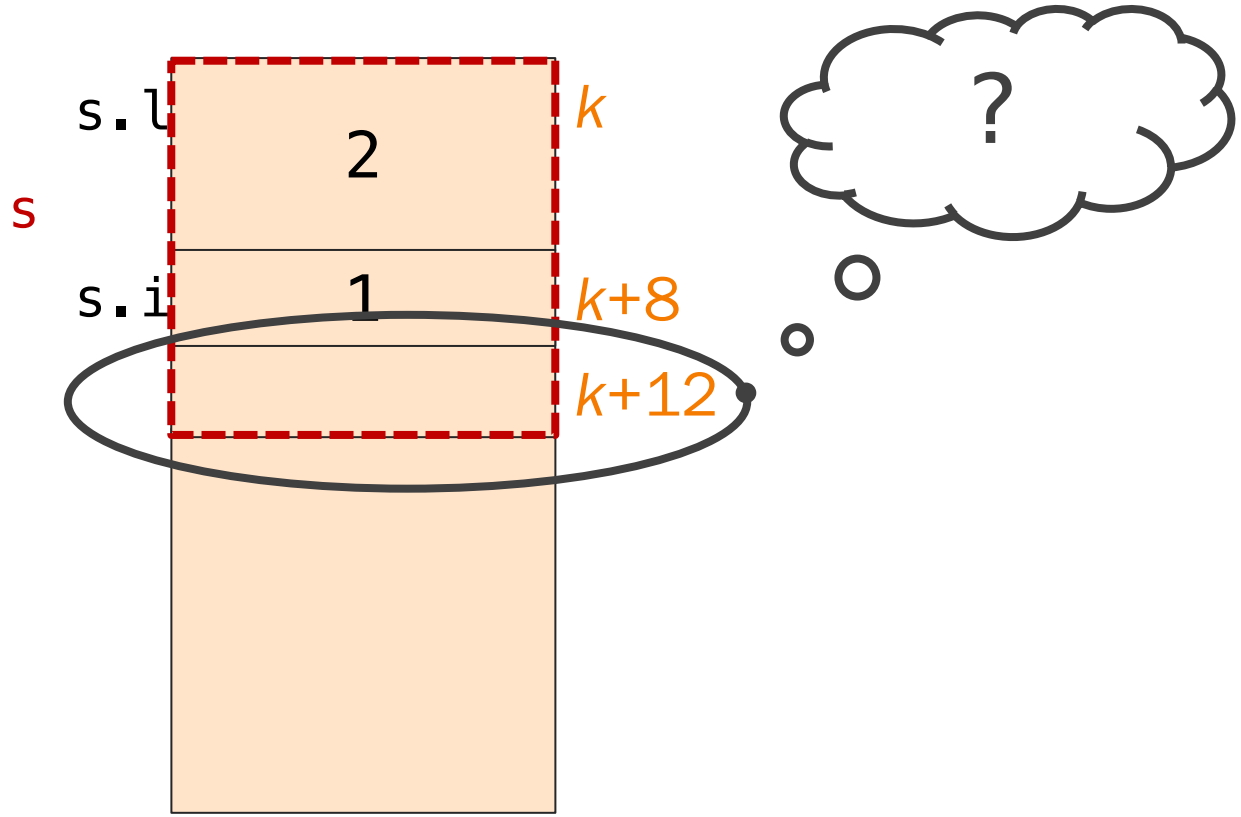
This is such a common pattern that it has its own operator:

`ps->i`



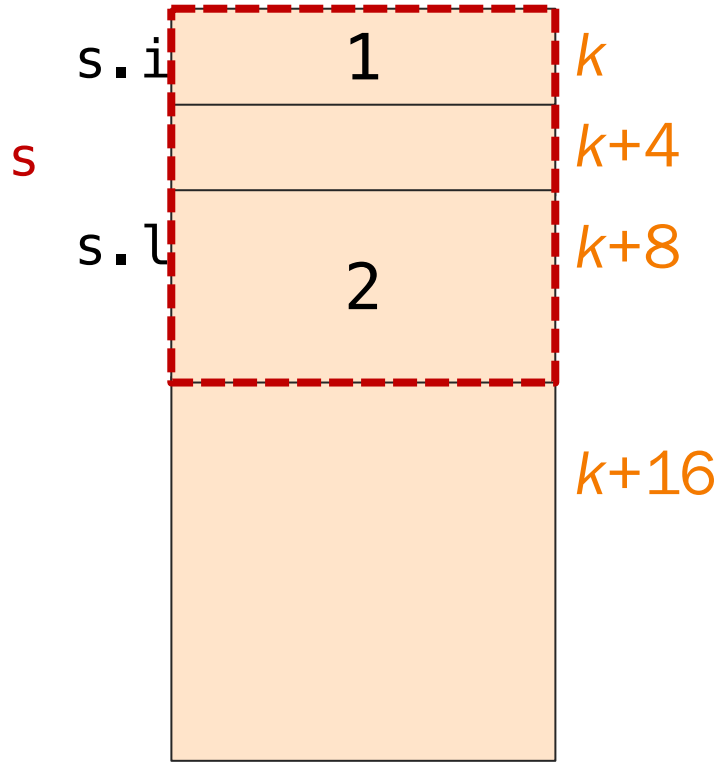
# struct instruction

```
struct S {
  long l;
  int i;
};

struct S s = {2L, 1};
```



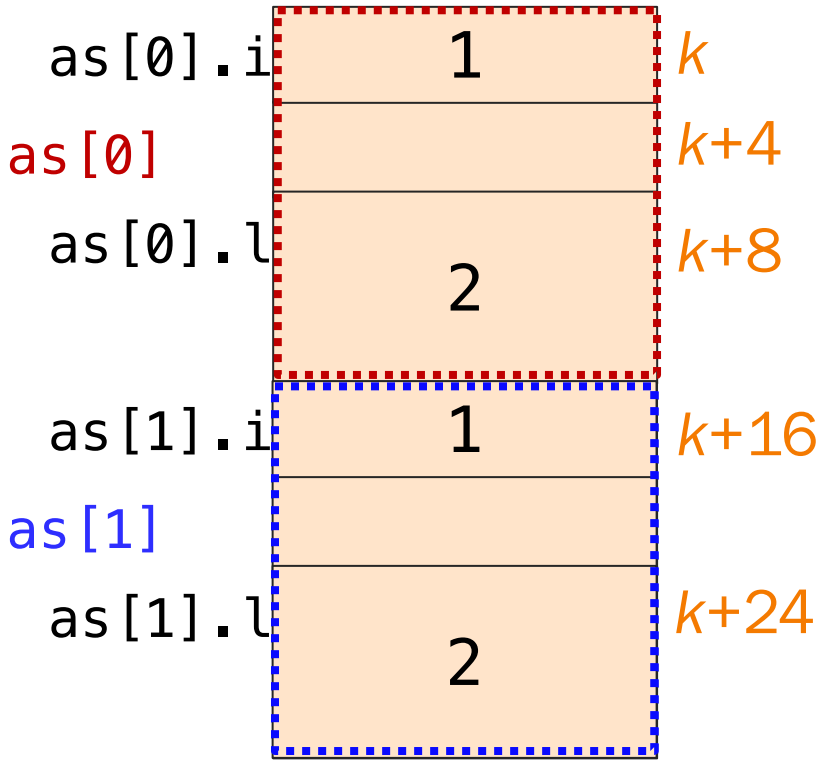
# Internal Padding

```
struct S {
   int i;
   long l;
};

struct S s = {1, 2L};
```

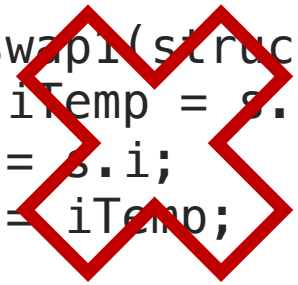



# ~~structstructstructstructstructstruct~~>

```
struct S {
  int i;
  long l;
};

struct S as[2] =
  { {1, 2L}, {3, 4L} };


as[1] = as[0];
```



# struct construction, what's your function?



```
void printS(struct S s) {
  printf("%d %ld\n", s.i, s.l);
}
void swap1(struct S s) {
  int iTemp = s.l;
  s.l = s.i;
  s.i = iTemp;
}
struct S swap2(struct S s) {
  int iTemp = s.l;
  s.l = s.i;
  s.i = iTemp;
  return s;
}
void swap3(struct S *ps) {
  int iTemp = ps->l;
  ps->l = ps->i;
  ps->i = iTemp;
}
```

```
int main(void) {
   struct S s = {1, 2L};
   printS(s);

   swap1(s);
   printS(s);

   s = swap2(s);
   printS(s);

   swap3(&s);
   printS(s);
   return 0;
}
```

```
armlab01:~/Test$ ./sswap
1 2
1 2
2 1
1 2
```

# Whose Rules Rule?

```
struct S {
  int aiSomeInts[10];
};

void printS(struct S s) {
  int i;
  for (i = 0; i < 10; i++)
    printf("%d ", s.aiSomeInts[i]);
  printf("\n");
}
```

```
int main(void) {
  struct S s = { {0,1,2,3,4,5} };
  struct S s2 = s;
  printS(s2);
  return 0;
}
```

```
armlab01:~/Test$ ./sa
0 1 2 3 4 5 0 0 0 0
```

How many int arrays are stored in memory?

A. 0: arrays in a struct aren't really arrays
B. 1: arrays are copied/passed as a pointer
C. 2: structs are copied on assignment
D. 3: C, plus structs are passed by value
E. Arrays can't be fields of a structure.

The correct answer is D.

Passing, returning, or assigning a structure with an array field copies the array by value (a deep copy)!

# DYNAMIC MEMORY

# Why, though?

- Thus far, all memory that we have used has had to be known at compile time.
- This is not feasible for realistic workloads; many times memory needs are dependent on runtime state
  - User input
  - Reading from a resource (file, network, etc.)
  - …

```
How many records are being entered?
```

# Memory Allocation at Runtime

Thus far we have seen 3 memory sections:

RODATA

- Read-only data, e.g. string literals

Stack

- Activation records (aka "stackframes"):
  a function call's params and local variables

Text

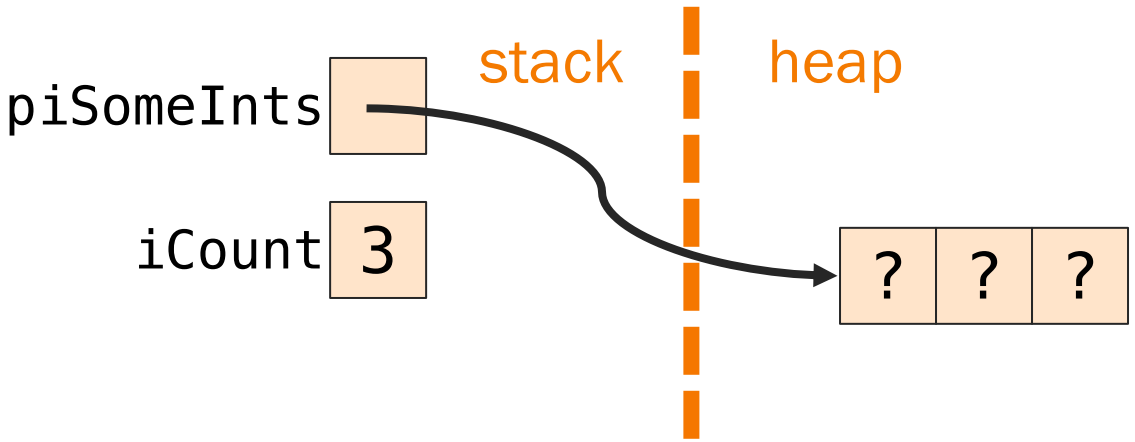
- Program machine language code

Now, a 4th: the “Heap”:
dynamically allocated storage

# Your New Friends: malloc

```
int iCount;
int *piSomeInts;
printf("How many ints?");
scanf("%d", &iCount);
piSomeInts =
   malloc(iCount *
          sizeof(int));
```

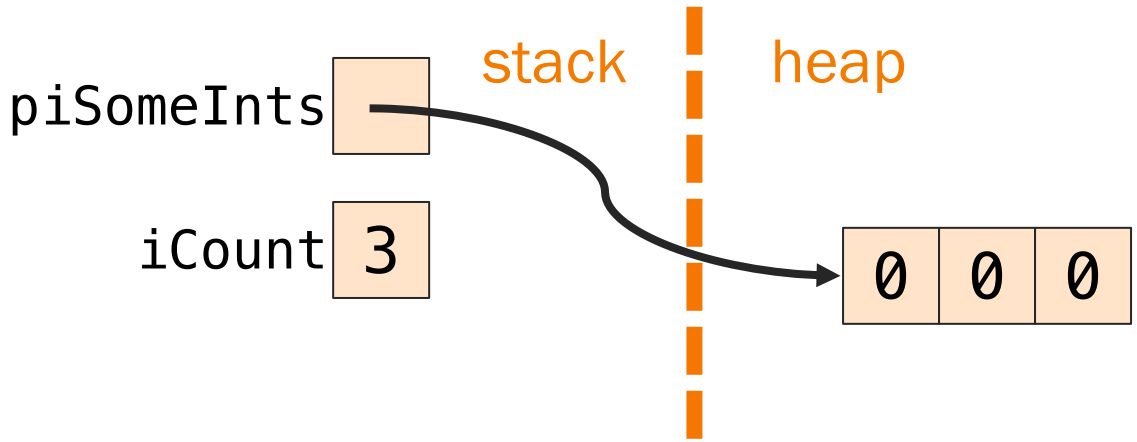
```
int iCount;
int *piSomeInts;
printf("How many ints?");
scanf("%d", &iCount);
piSomeInts =
   calloc(iCount,
          sizeof(int));
```



# Your New Friends: calloc

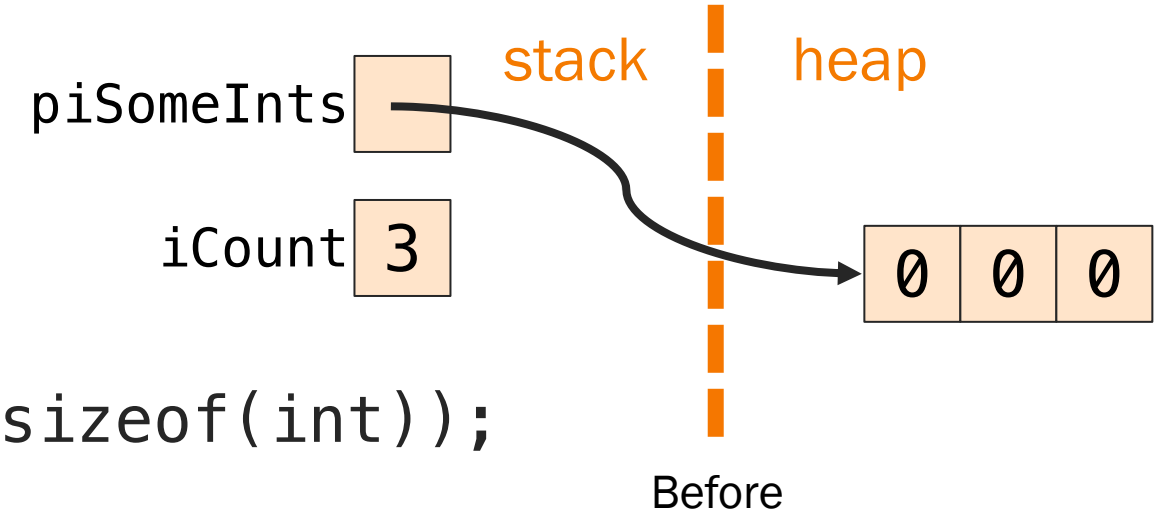
```
int iCount;
int *piSomeInts;
printf("How many ints?");
scanf("%d", &iCount);
piSomeInts =
   malloc(iCount *
          sizeof(int));
```

```
int iCount;
int *piSomeInts;
printf("How many ints?");
scanf("%d", &iCount);
piSomeInts =
   calloc(iCount,
          sizeof(int));
```



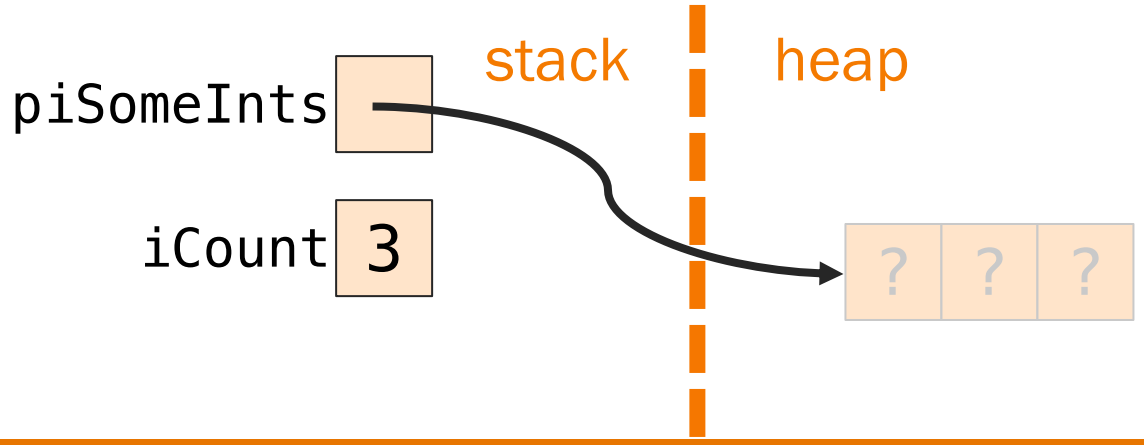
# Your New Friends: free

```
int iCount;
int *piSomeInts;
printf("How many ints?");
scanf("%d", &iCount);
piSomeInts = calloc(iCount, sizeof(int));
```



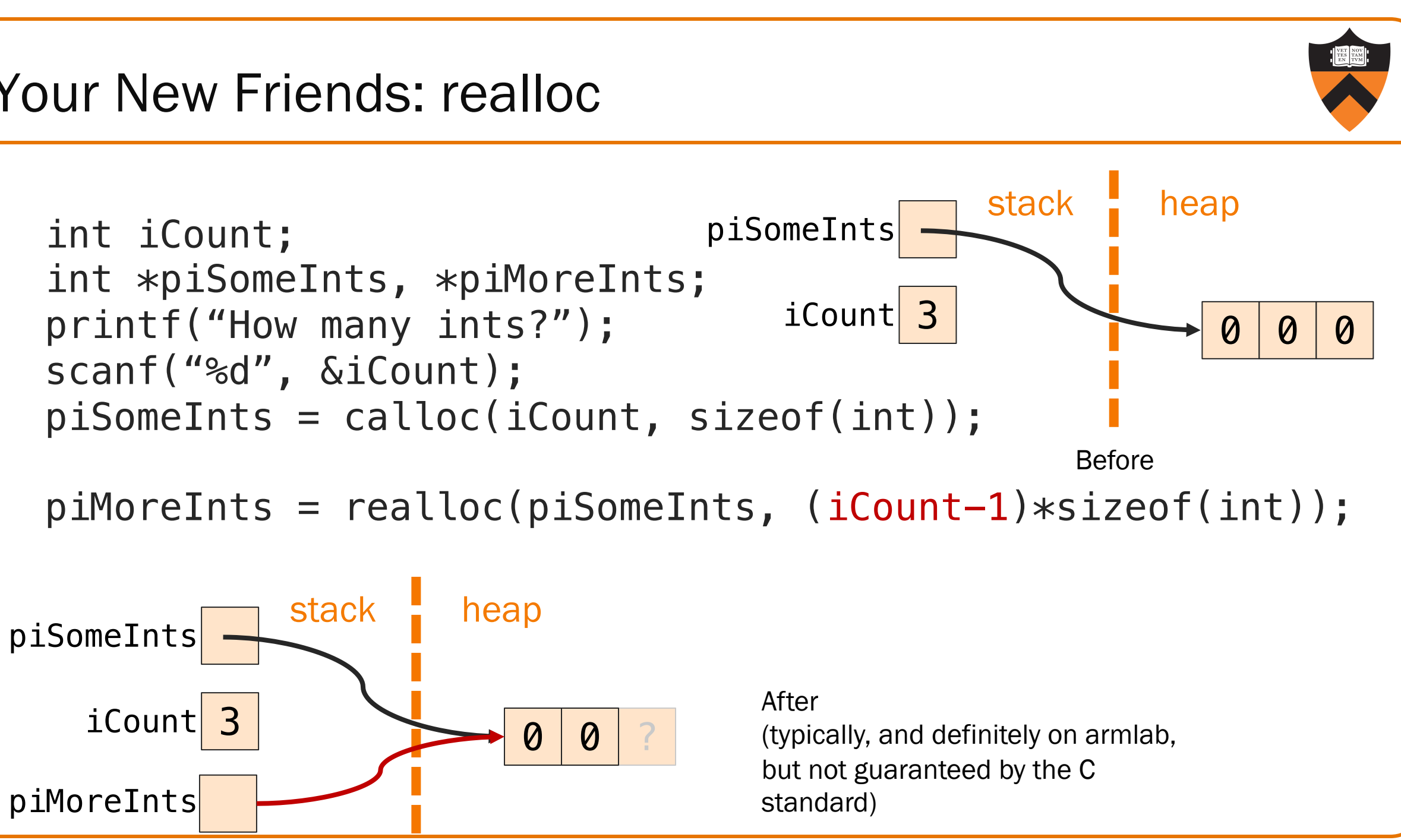

Before

```
free(piSomeInts);
```




After

# Your New Friends: realloc



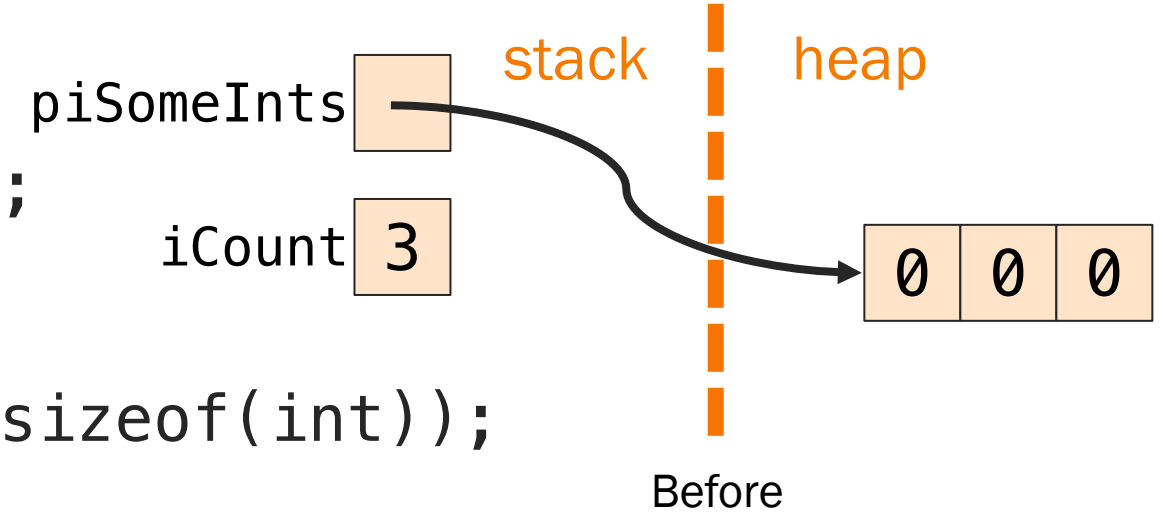
```
int iCount;
int *piSomeInts, *piMoreInts;
printf("How many ints?");
scanf("%d", &iCount);
piSomeInts = calloc(iCount, sizeof(int));

piMoreInts = realloc(piSomeInts, (iCount-1)*sizeof(int));
```



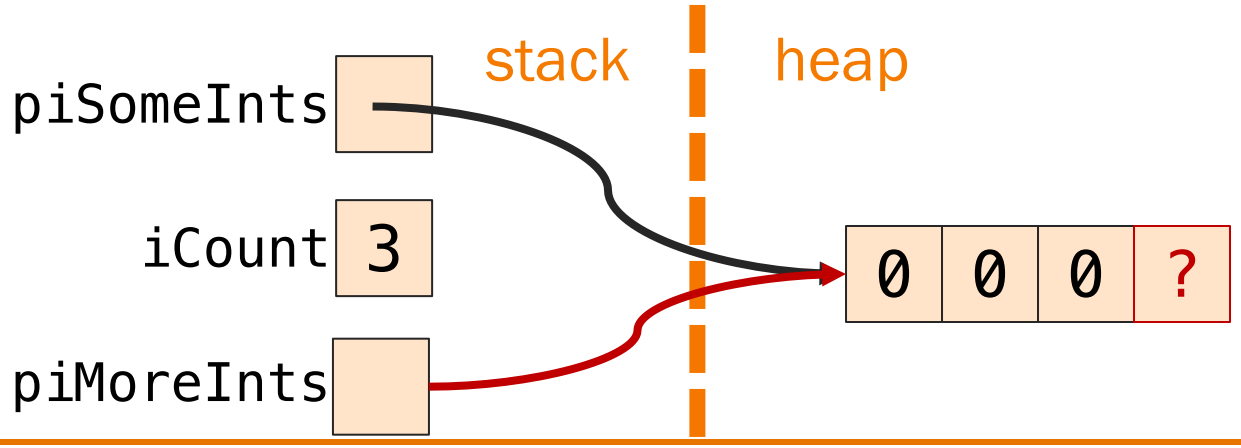
After
(typically, and definitely on armlab, but not guaranteed by the C standard)

# Your New Friends: realloc

```
int iCount;
int *piSomeInts, *piMoreInts;
printf("How many ints?");
scanf("%d", &iCount);
piSomeInts = calloc(iCount, sizeof(int));

piMoreInts = realloc(piSomeInts, (iCount+1)*sizeof(int));
```



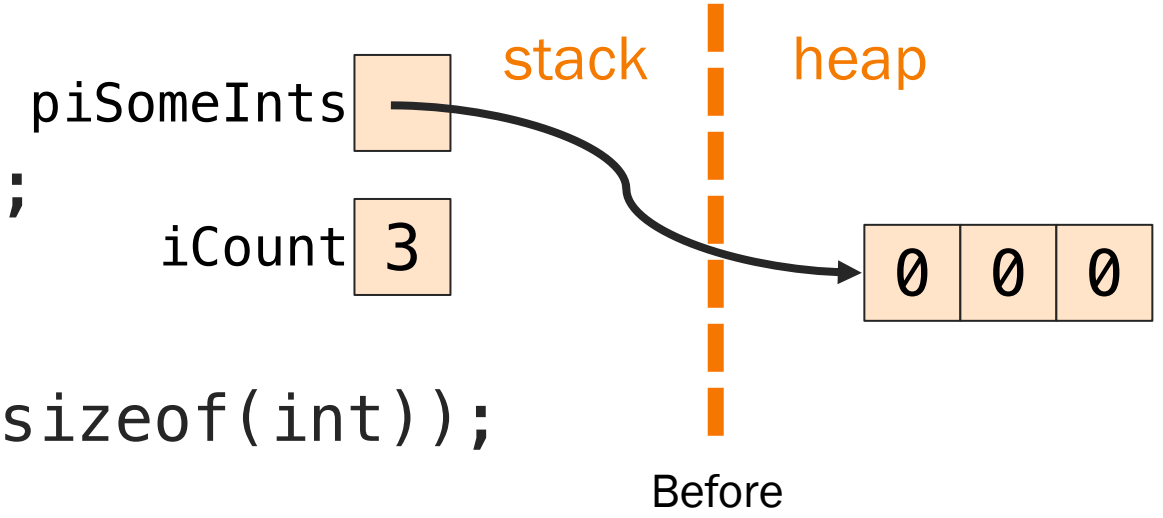

Before



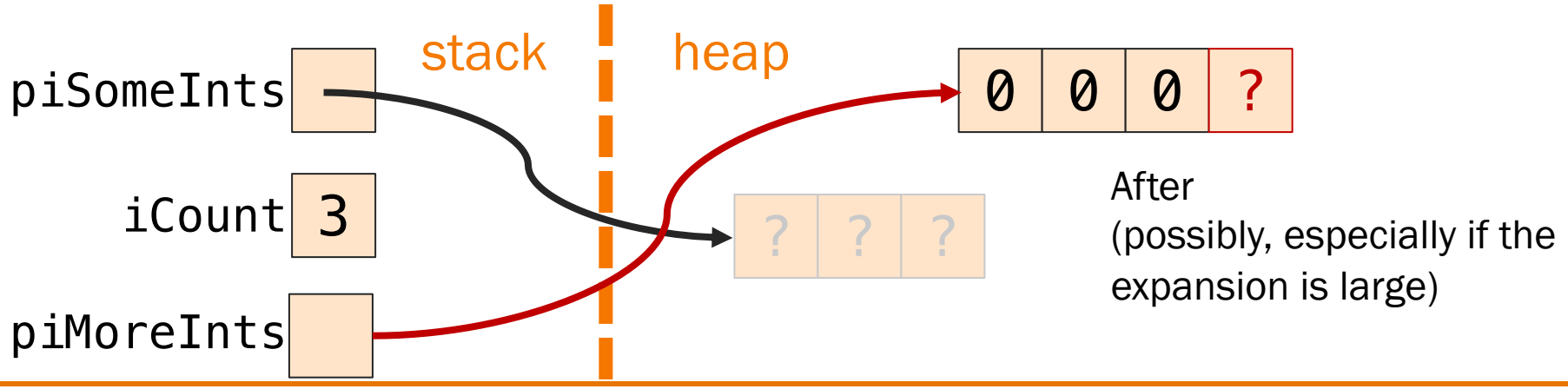

After
(typically, but not guaranteed,
especially if instead of (iCount+1)
you want, say, $2^{iCount}$)

# Your New Friends: realloc

```
int iCount;
int *piSomeInts, *piMoreInts;
printf("How many ints?");
scanf("%d", &iCount);
piSomeInts = calloc(iCount, sizeof(int));

piMoreInts = realloc(piSomeInts, (iCount+1)*sizeof(int));
```




Before

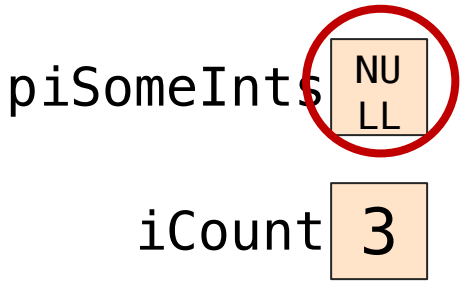



After
(possibly, especially if the expansion is large)

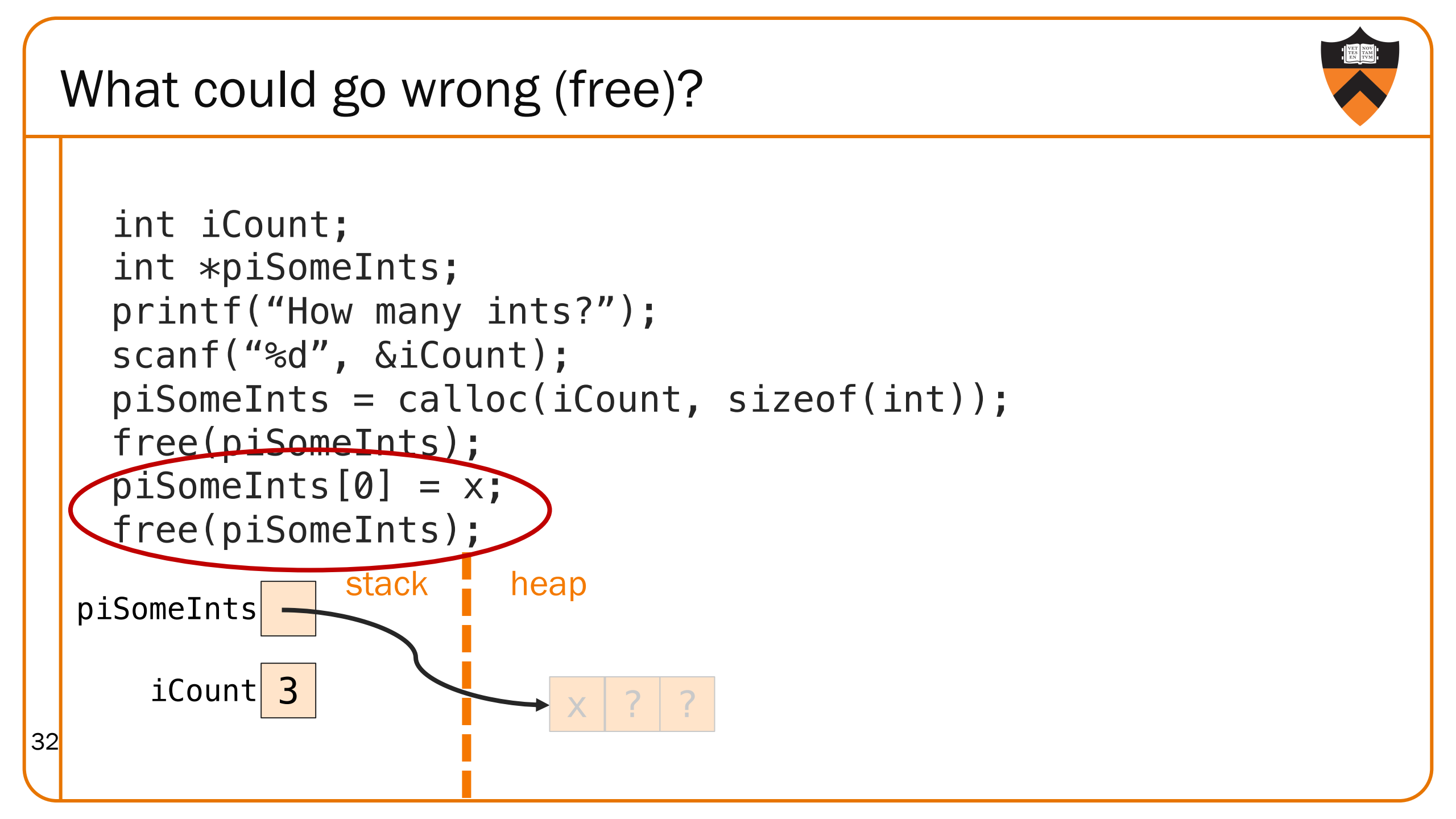

# DYNAMIC MEMORY DISASTERS

# What could go wrong (malloc, calloc)?

```
int iCount;
int *piSomeInts;
printf("How many ints?");
scanf("%d", &iCount);
piSomeInts = calloc(iCount, sizeof(int));
if(piSomeInts == NULL)...
piSomeInts[0] = ...
```



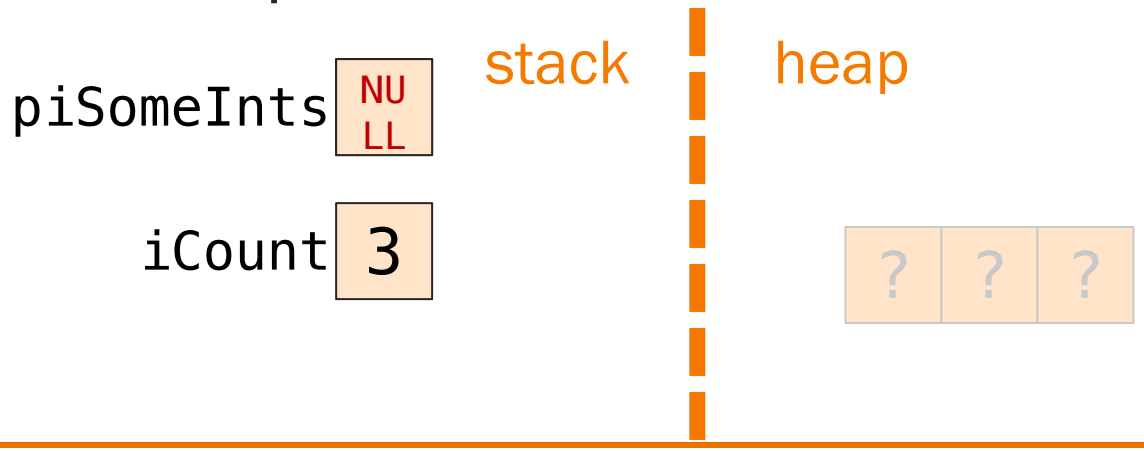

# What could go wrong (free)?



```
int iCount;
int *piSomeInts;
printf("How many ints?");
scanf("%d", &iCount);
piSomeInts = calloc(iCount, sizeof(int));
free(piSomeInts);
piSomeInts[0] = x;
free(piSomeInts);
```

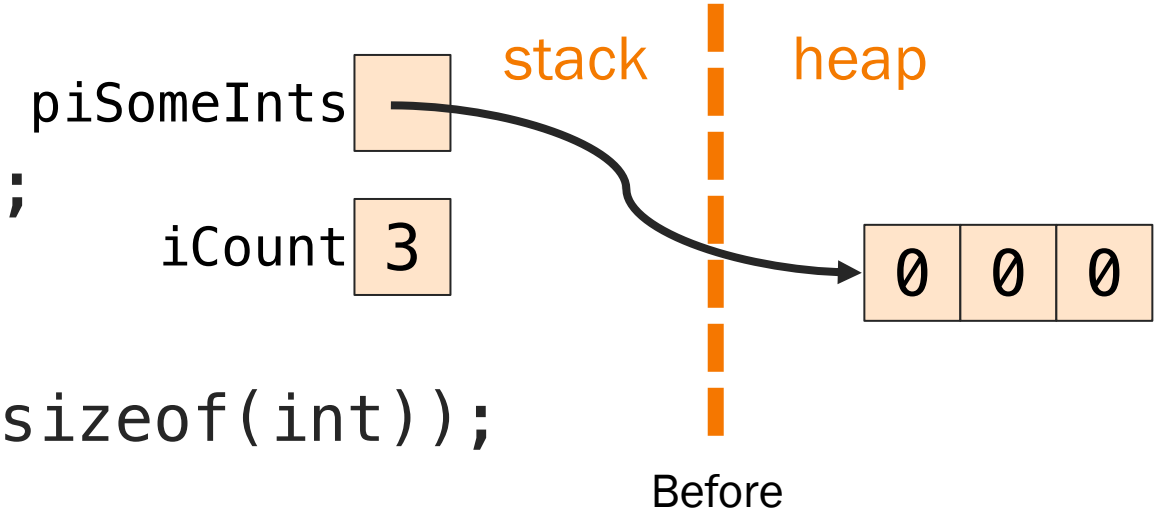
# It’s still a bug! (But now you’ll find it "easily"!)

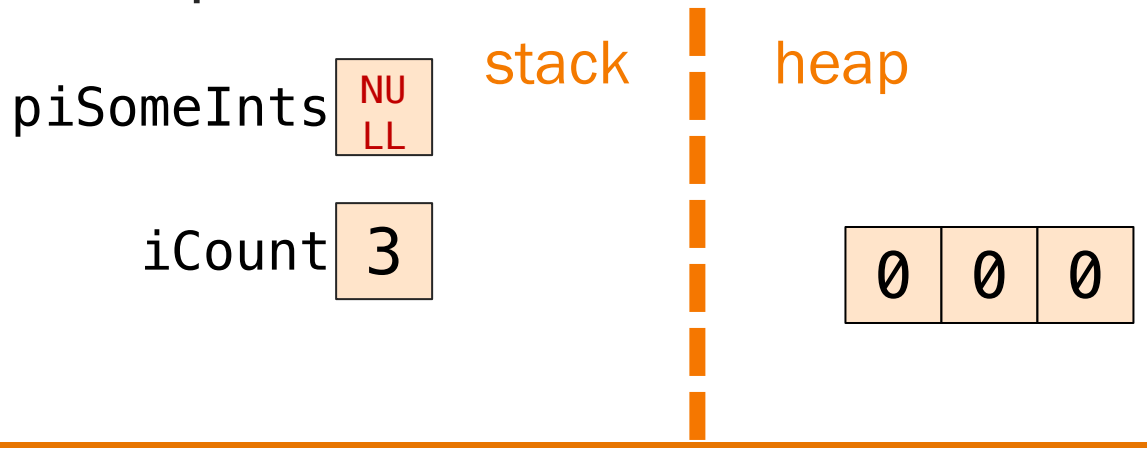
```
int iCount;
int *piSomeInts;
printf(“How many ints?”);
scanf(“%d”, &iCount);
piSomeInts = calloc(iCount, sizeof(int));
free(piSomeInts); piSomeInts = NULL;
piSomeInts[0] = x;
free(piSomeInts);
```



# What could go wrong: realloc

```
int iCount;
int *piSomeInts, *piMoreInts;
printf("How many ints?");
scanf("%d", &iCount);
piSomeInts = calloc(iCount, sizeof(int));
piSomeInts =
   realloc(piSomeInts, (iCount+1)*sizeof(int));
if(piSomeInts == NULL)...
```

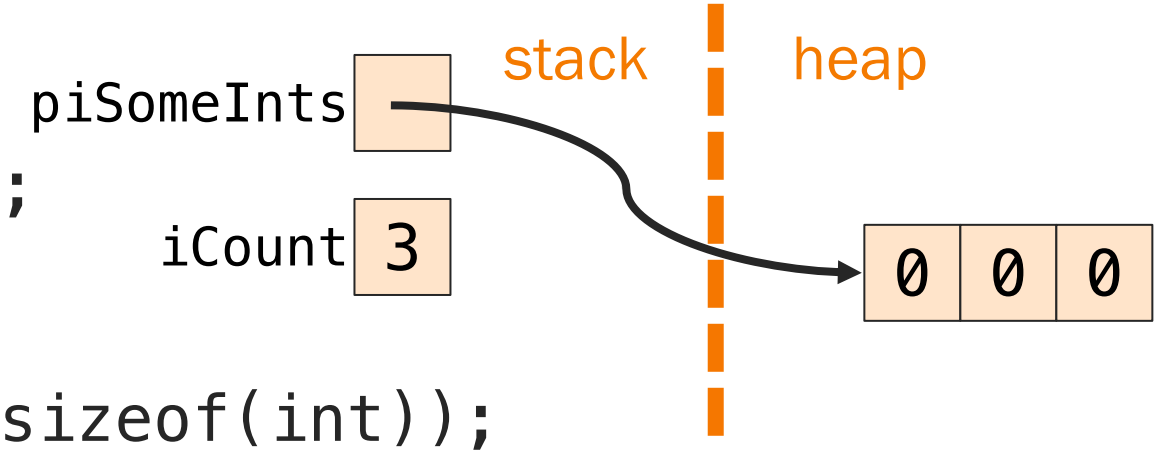


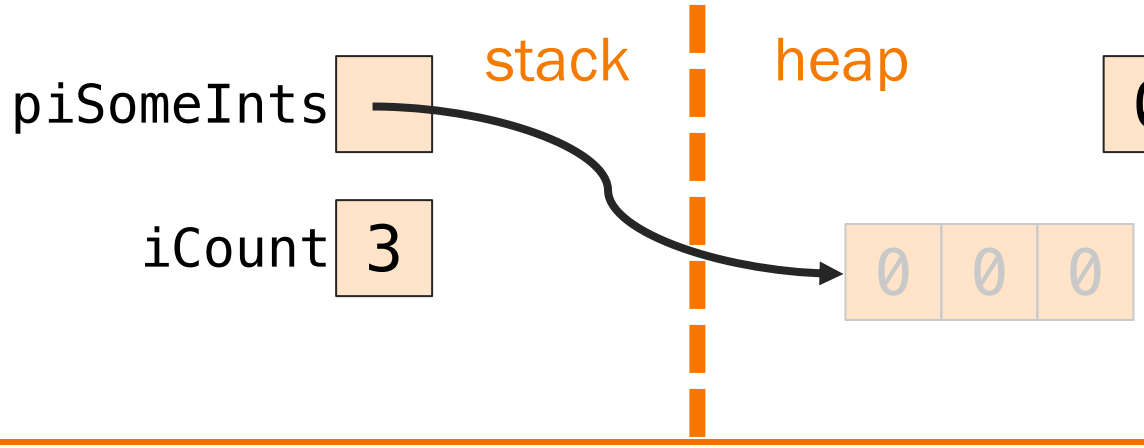

After:
If `realloc` returns NULL,
Memory Leak
NULL pointer dereference if not checked

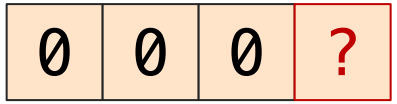
# What could go *really* wrong: realloc

```
int iCount;
int *piSomeInts, *piMoreInts;
printf("How many ints?");
scanf("%d", &iCount);
piSomeInts = calloc(iCount, sizeof(int));
realloc(piSomeInts, (iCount+1)*sizeof(int));
if(piSomeInts == NULL)...
```




Before




After:
Memory Leak,
Dangling Pointer,
Likely eventual double free.

# Catch the Most Common Bug

```
newCopy = malloc(strlen(oldCopy));
strcpy(newCopy, oldCopy);
```

## Does this work?

A. Totally! (Wait, what's the title of this slide again?)

B. Nope! The bug is …

B:

This allocates 1 too few bytes for `newCopy`, because `strlen` doesn't count the trailing `'\0'`.

# Save a line?

```
newCopy = strcpy(malloc(strlen(oldCopy)+1), oldCopy);
```

## Does this work?

A. So *that's* why `strcpy` returns the destination! Sure!

B. Eh, okay, but this is less clear.

C. Nope!

C:

If `malloc` returns NULL, this fails the precondition for `strcpy`

(This was also an issue on the previous slide.)

# Don't get ahead of yourself!

Assignment 2 does **NOT** use dynamic memory!

Assignments 3 and 4 will use it extensively.
The topic **is** fair game for the midterm.

But DO NOT use `{m,c,re}alloc` + `free` on A2!

# Sample Exam Problem (Fall 2020 – 14 points / 80)

For the statements in each part of this question, indicate one or more appropriate statuses from this list:

ML - Memory Leak: aka garbage creation
BD - Bad Dereference: derefs NULL or a pointer to memory that was never allocated or has already been freed
IF - Improper Free: frees a pointer to memory that was never allocated or has already been freed
OK - Okay: exhibits no dynamic memory problem

If different statuses could result depending on the result of a call to malloc, calloc, or realloc, then list all possible statuses. You do NOT have to delineate the cases in which each would result.

Each part of this question is independent from the others, but you should assume for each that:

1. p is a char pointer pointing to k bytes that have been allocated in the heap, at least one of which is '\0'.
2. q is a char pointer

a) `strcpy(calloc(strlen(p)+1, sizeof(char)), p);`

b) `for(i=0; i<k; i++) free(p+i);`

c) `free(p); printf("%ul\n", p);`

d) `free(p++);`

e) `q = p; free(q); printf("%s", p);`

f) `free(p); p=NULL; free(p);`

g) `p = realloc(p, 2*k);`

# Sample Exam Problem (Fall 2020 – 22 points /80)

Consider the following program that contains 9 numbered location (0 through 8) :

```
#include <stdlib.h>
#include <stdio.h>
#include <string.h>
int main(⓪ int argc, ① char** argv) {
② int a[10] = {-1, 0, 1};
③ double x = 10.75;
④ double* px = &x;
⑤ char* s;
⑥ char* f = ⑦ "¥"%s¥"¥n";
s = ⑧ calloc(*px, sizeof(*s));
printf(f, s);
return strlen(s);
}
```

a. how many bytes are allocated, and in which section of memory, for the expression immediately following each callout. Assume this is using `gcc217` on armlab, and that the `calloc` call does not return `NULL`.

b. What does this program print to standard output?

c. How would this program's return value change if callout 8 were replaced with `malloc(x*sizeof(*s));` (Assume that, like `calloc`, `malloc` does not return `NULL`.)