COS 217: Introduction to Programming Systems

Structures,
Command Line Arguments,
Dynamic Memory

PRINCETON UNIVERSITY

C STRUCTURES

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

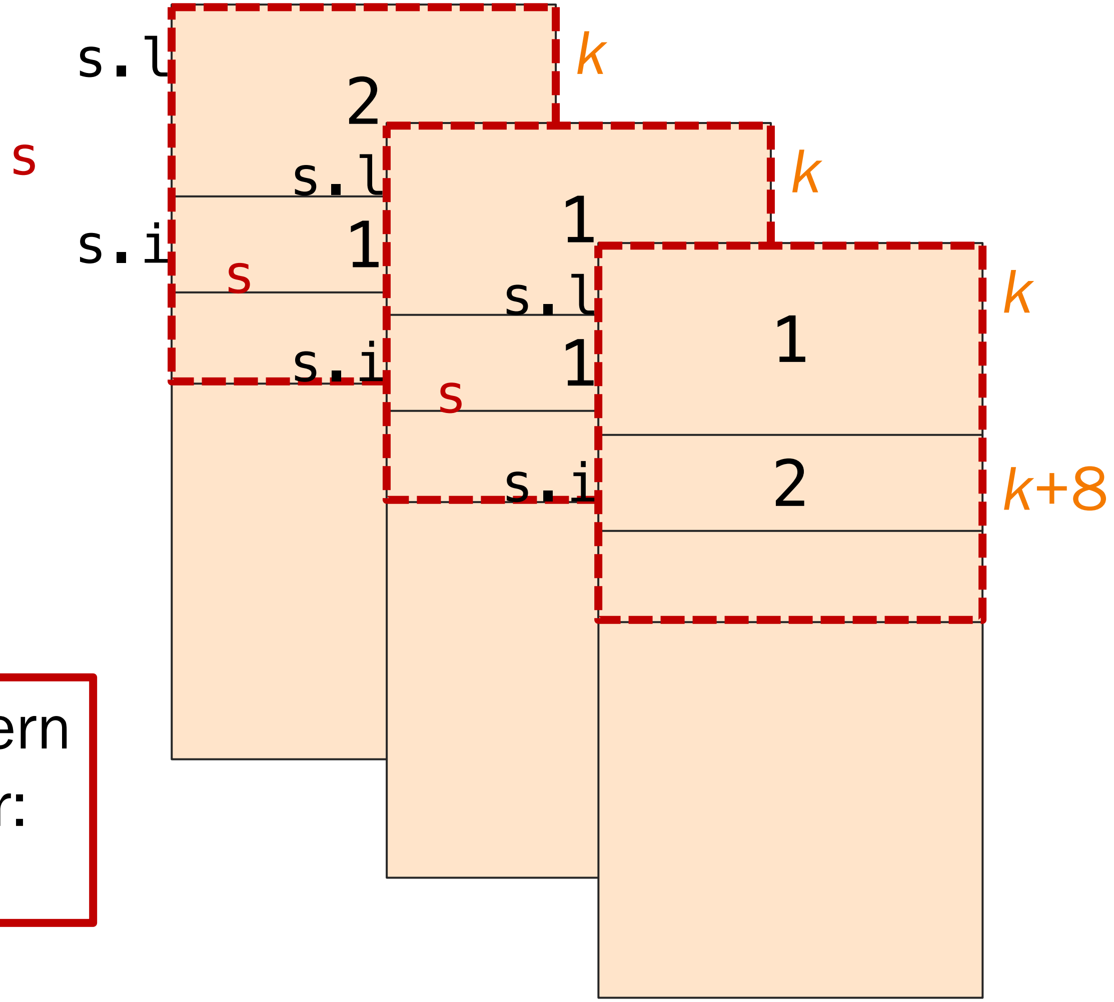
- Java classes can have many fields

- How to get the equivalent in C?

Add some structure to your program

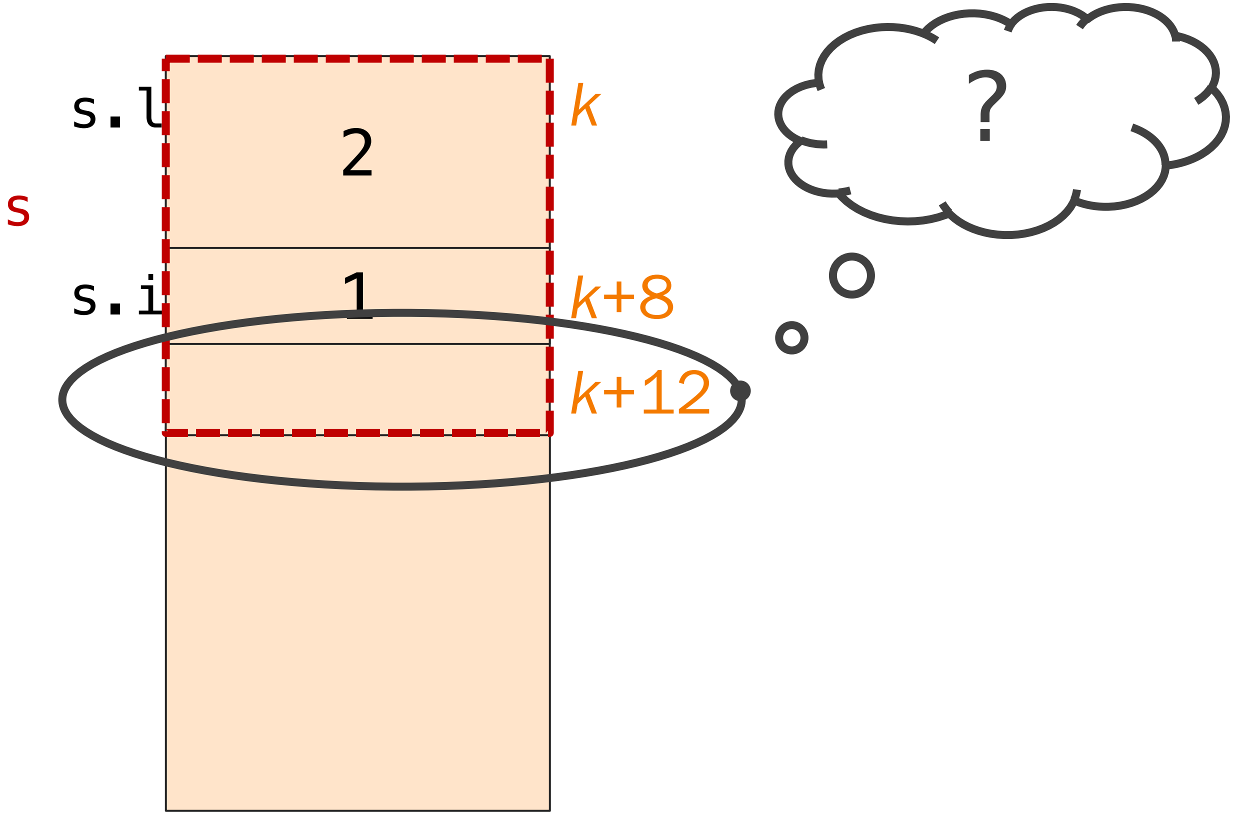
```
struct S {
  long l;
  int i;
};

struct S s = {2, 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`



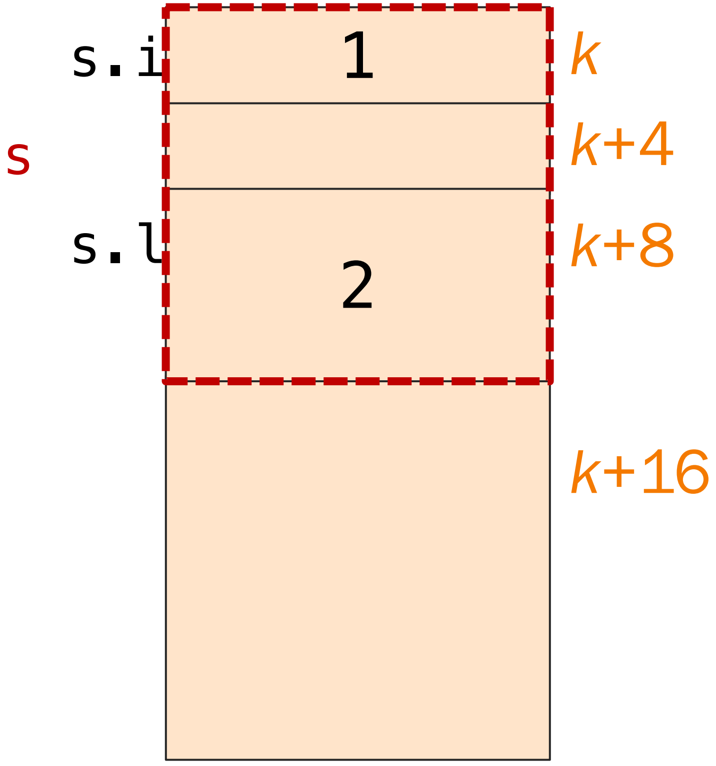
struct instruction

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

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



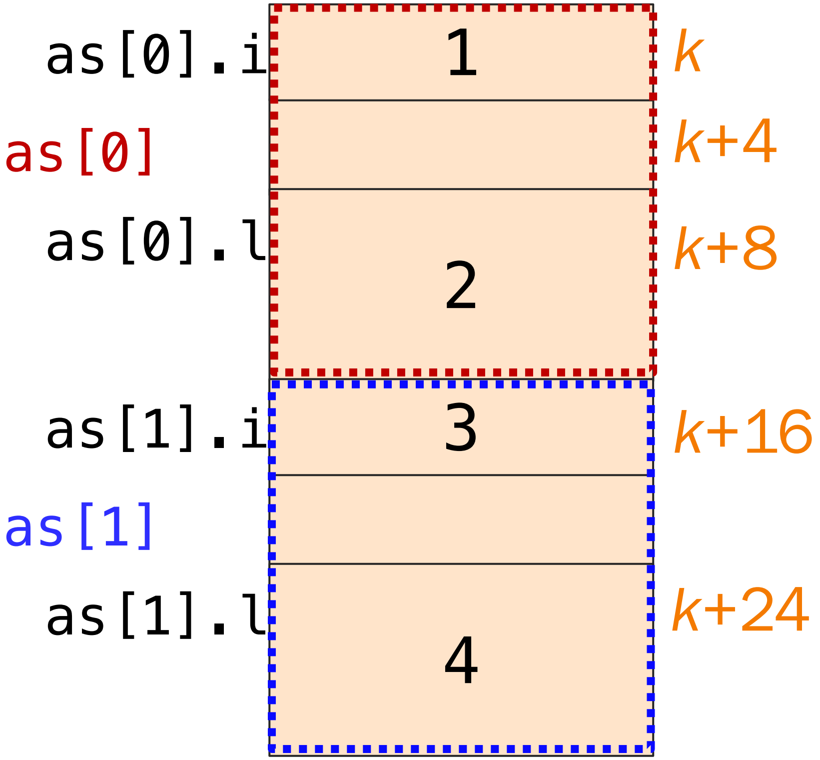
Internal Padding

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

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



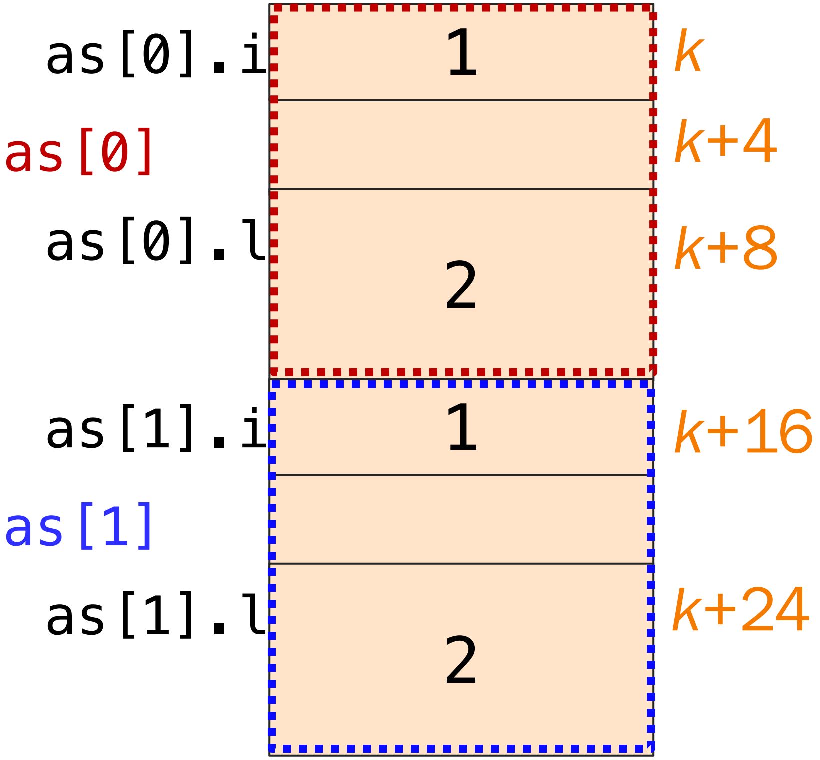
structstructstructstructstructstruct

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

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



structstructstructstructstructstruct

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

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

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 temp = s.l;
  s.l = s.i;
  s.i = temp;
}
struct S swap2(struct S s) {
  int temp = s.l;
  s.l = s.i;
  s.i = temp;
  return s;
}
void swap3(struct S *ps) {
  int temp = ps->l;
  ps->l = ps->i;
  ps->i = temp;
}
```

```
int main(void) {
    struct S s = {1, 2};
    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 arr[10];
};

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

How many int arrays are stored in memory?

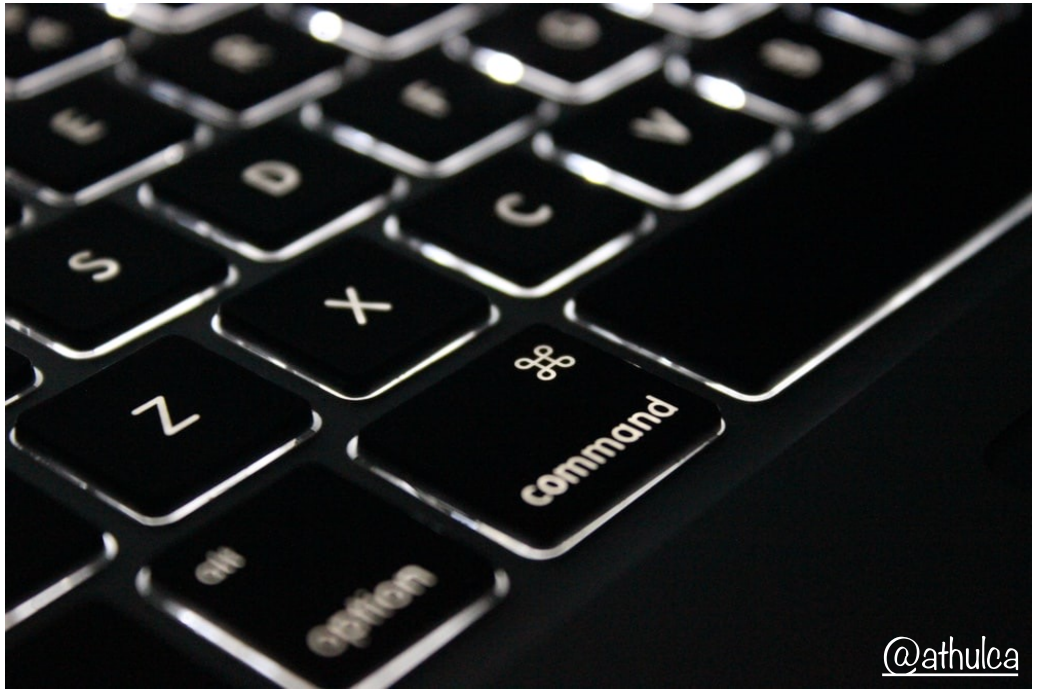
A. 0: arrays in a struct aren't really arrays
B. 1: arrays are copied/passed as a pointer
C. 2: structs are copied on assignment
D. 3: C + plus structs are passed by value
E. Arrays can't be fields of a structure.

```
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
```

The correct answer is D.

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



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.

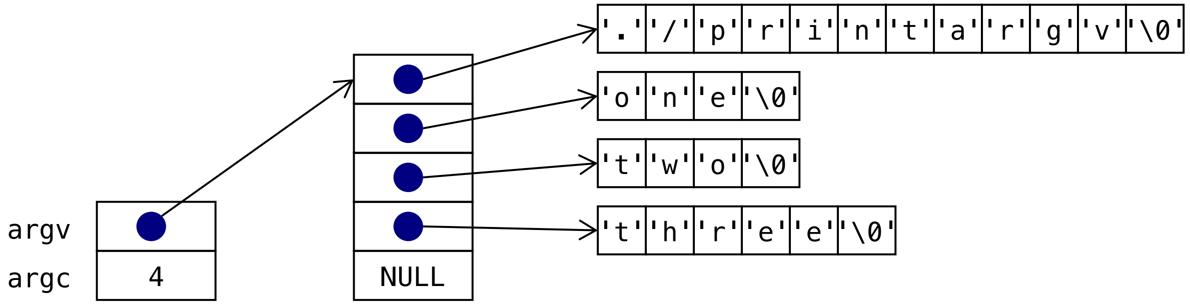
```
int main(int argc, char *argv[])
{
   int i;


   /* 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`

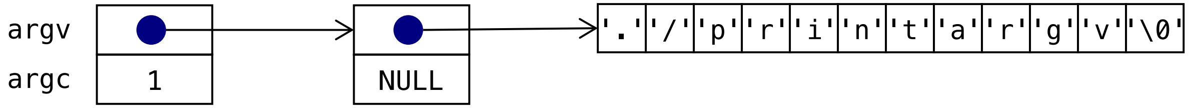
Elucidating Example: Explanatory Echo

```
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
```

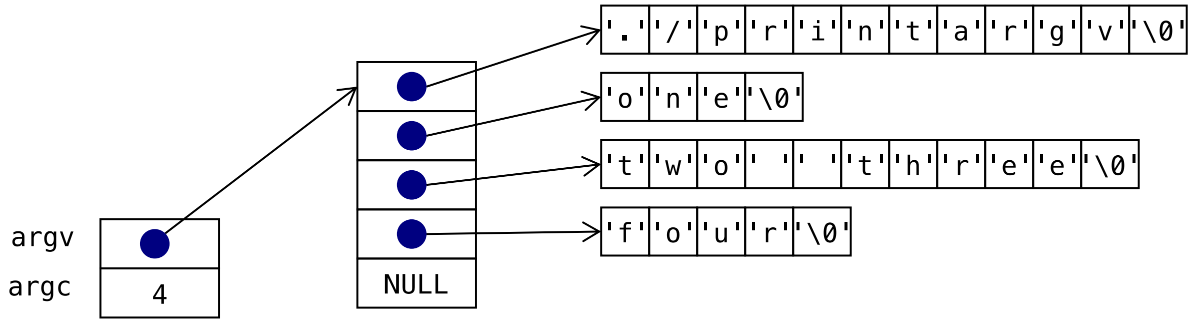


What’s argc?

```
./printargv one “two  three” four
```

B:

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



A. 3

B. 4

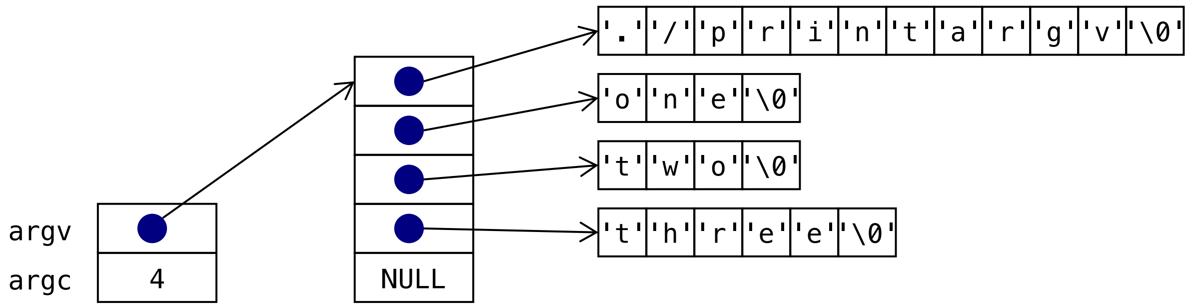
C. 5

D. Syntax error at runtime

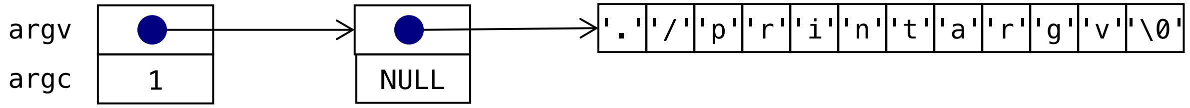
A2-inspired: rewrite everything in arrays to use pointers

```
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;
}
```

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




```
$ ./printargv
```



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:

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

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

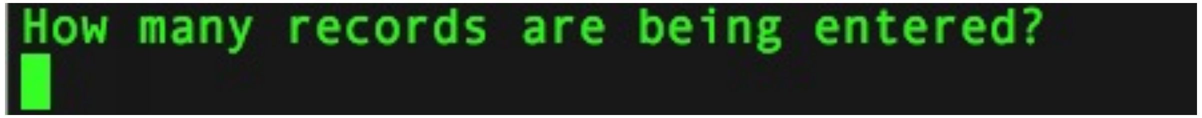
C is only the case at the start of execution, and does not hold if the program changes `argc`.

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

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.)
  - …



Memory Allocation at Runtime

Thus far we have seen 3 memory sections:

Stack

- Function parameters and local variables

Text

- Program machine language code

RODATA

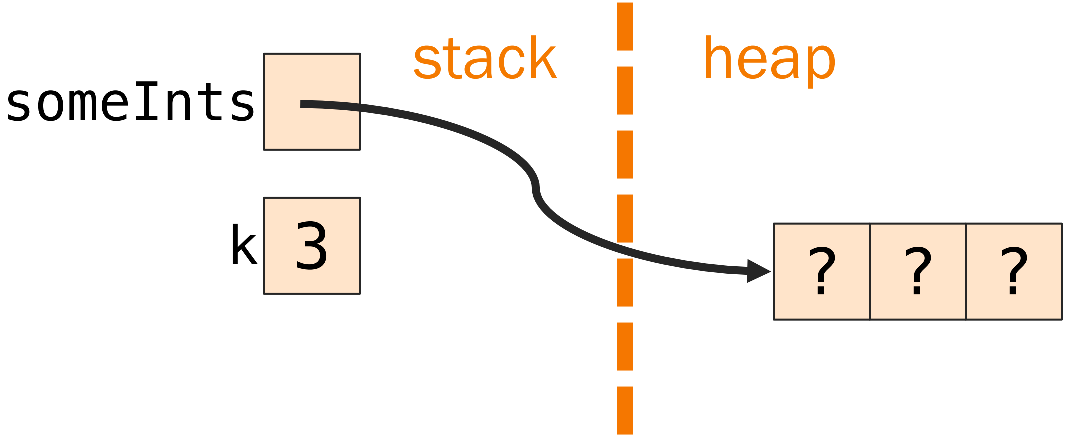
- Read-only data, e.g. string literals

Now: "Heap"

Your New Friends: malloc

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

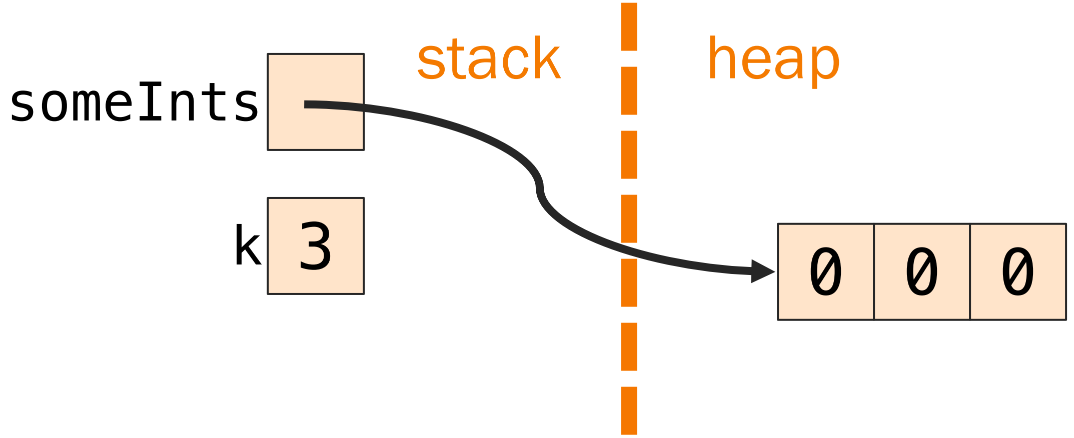
```
int k;
int *someInts;
printf("How many ints?");
scanf("%d", &k);
someInts =
   calloc(k, sizeof(int));
```



Your New Friends: calloc

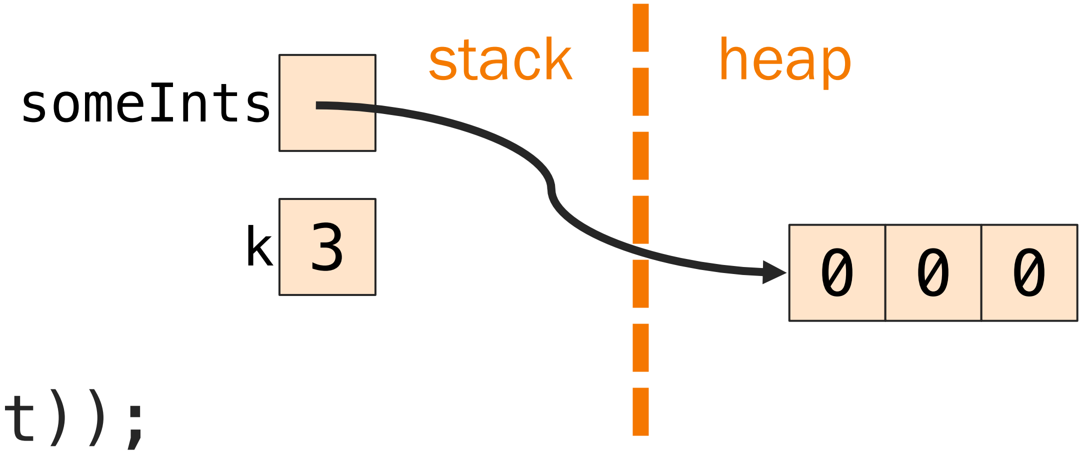
```
int k;
int *someInts;
printf("How many ints?");
scanf("%d", &k);
someInts =
   malloc(k * sizeof(int));
```

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

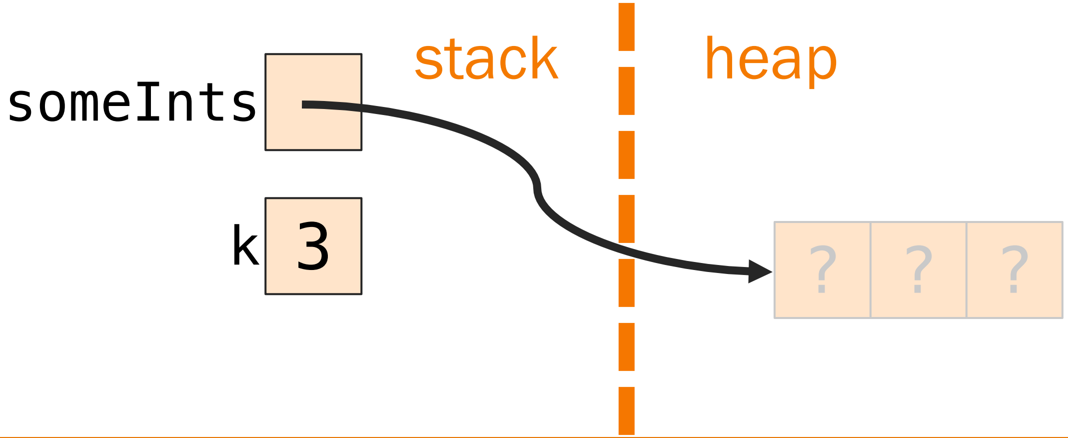


Your New Friends: free

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

free(someInts);
```



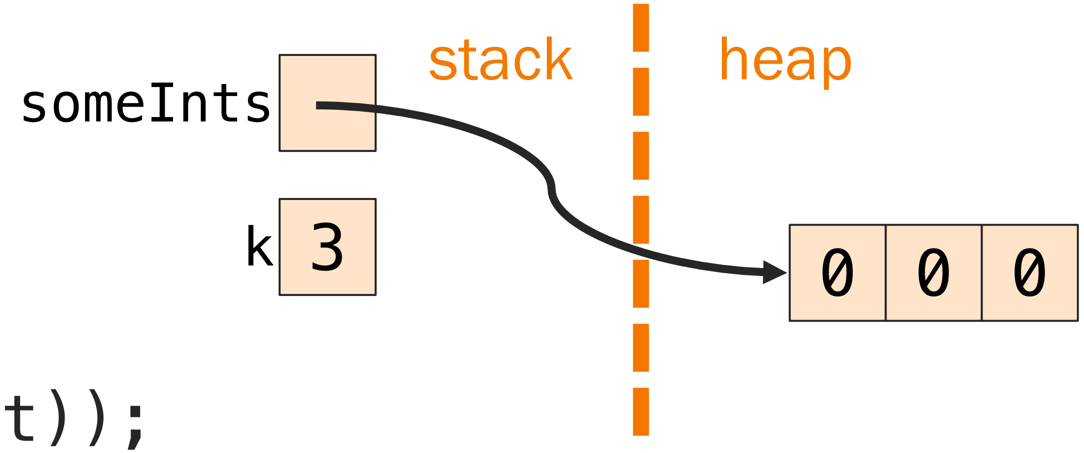
Before



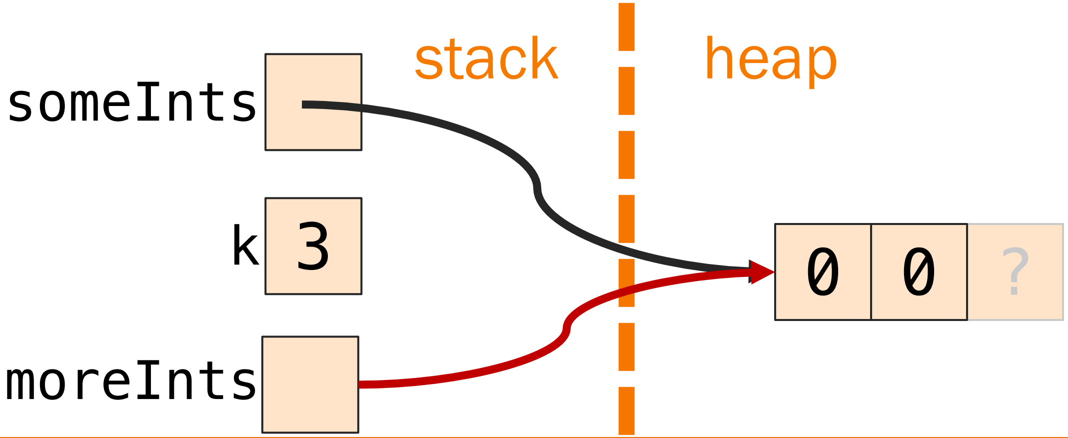
After

Your New Friends: realloc

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

moreInts = realloc(someInts, (k-1)*sizeof(int));
```



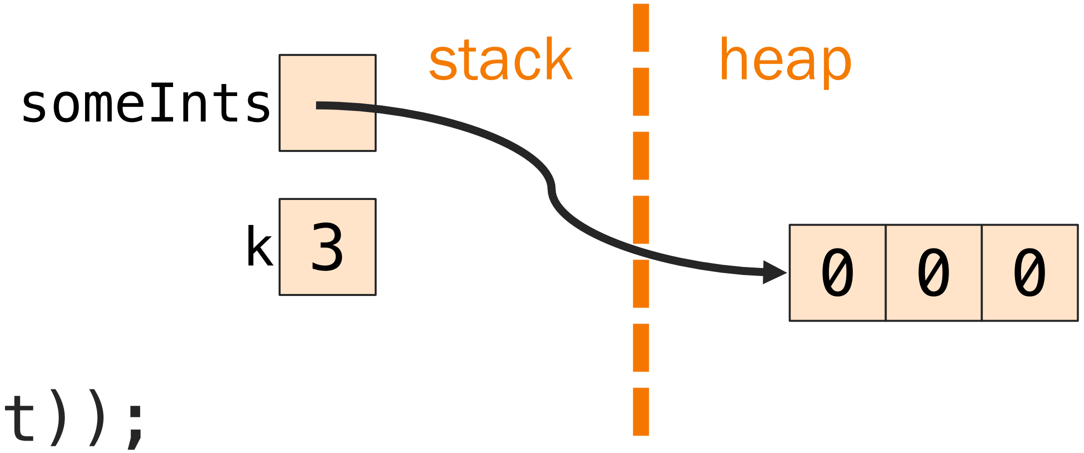
Before



After
(typically, but not guaranteed
by the C standard)

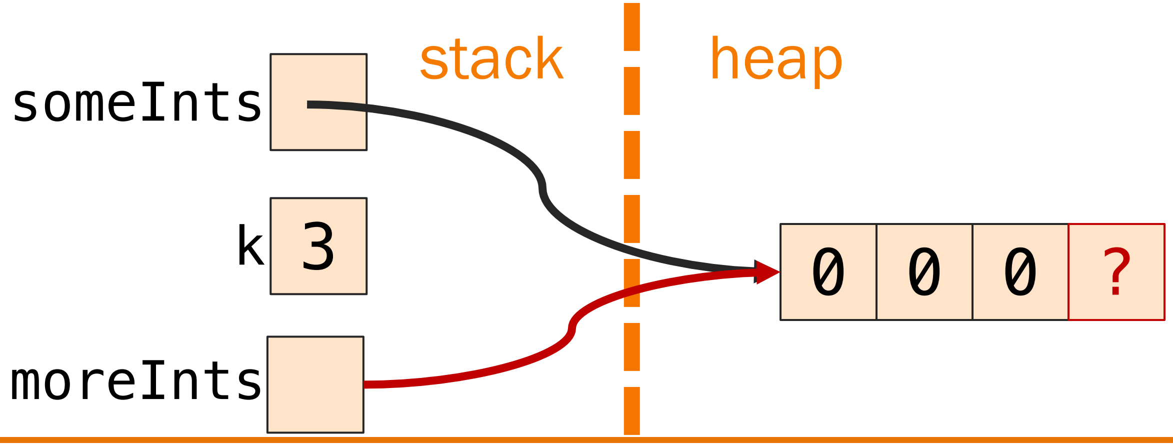
Your New Friends: realloc

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



Before

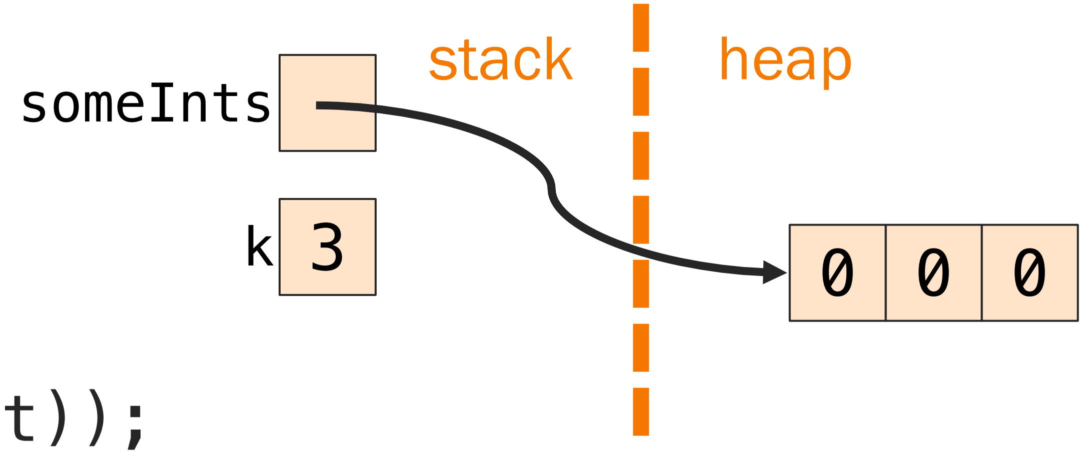
```
moreInts = realloc(someInts, (k+1)*sizeof(int));
```



After
(typically, but not guaranteed,
especially if instead of (k+1)
you want, say, 2^k)

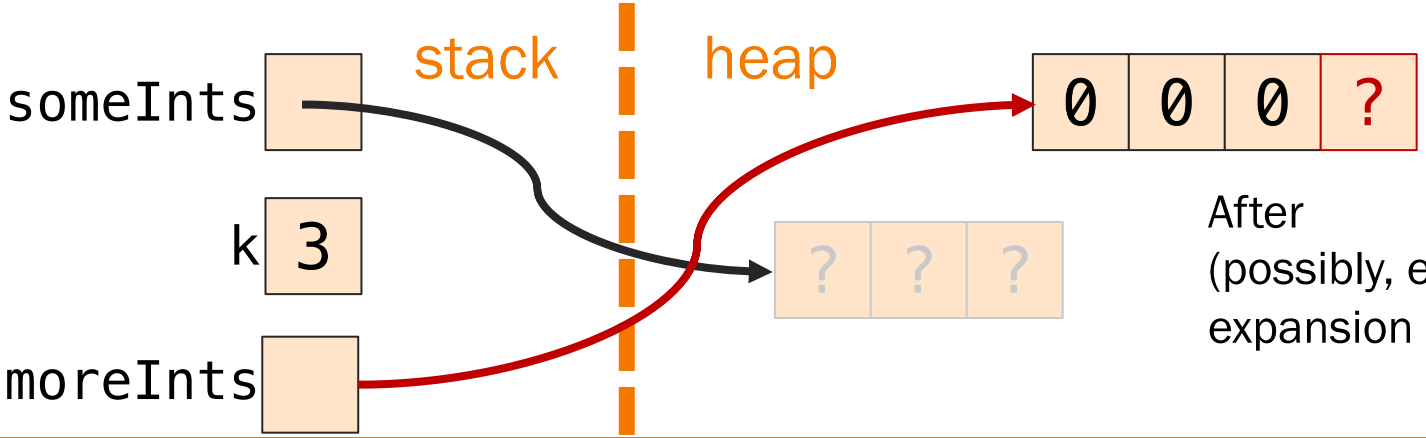
Your New Friends: realloc

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



Before

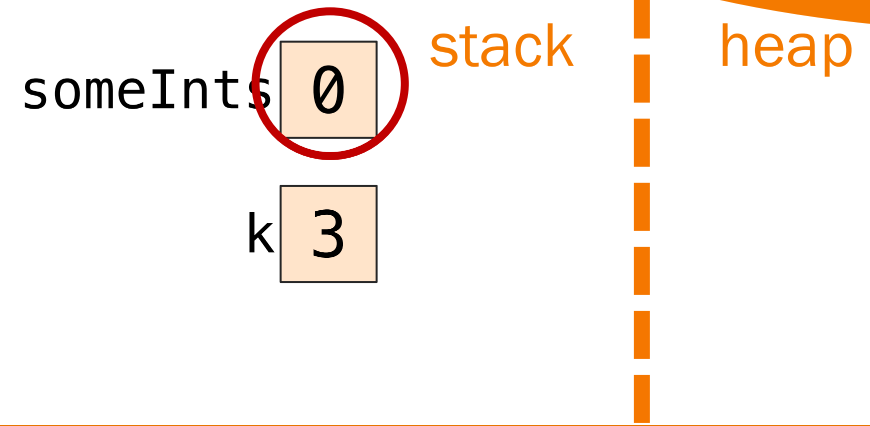
```
moreInts = realloc(someInts, (k+1)*sizeof(int));
```



After
(possibly, especially if the expansion is large)

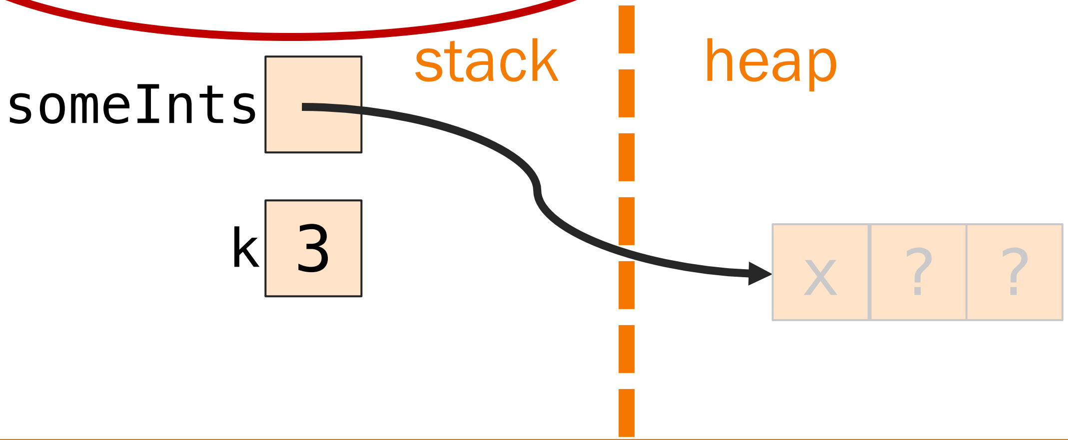
What could go wrong (malloc, calloc)?

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



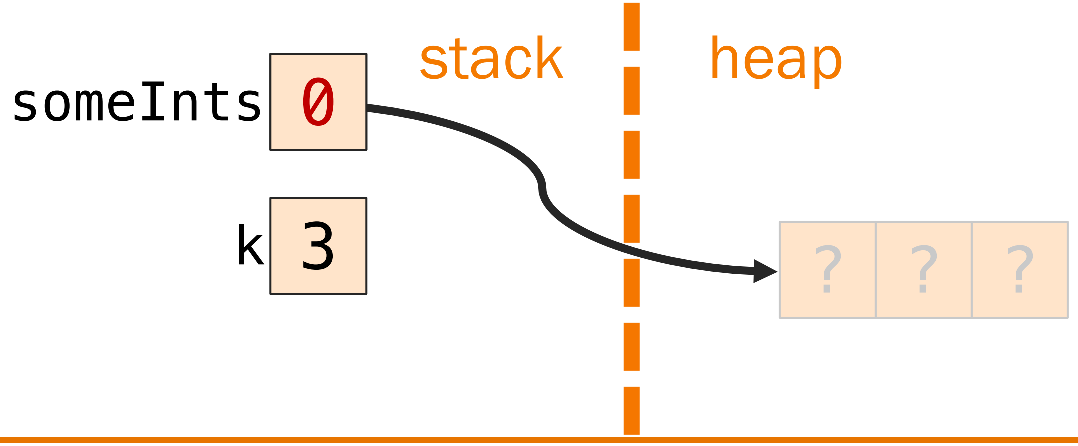
What could go wrong (free)?

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



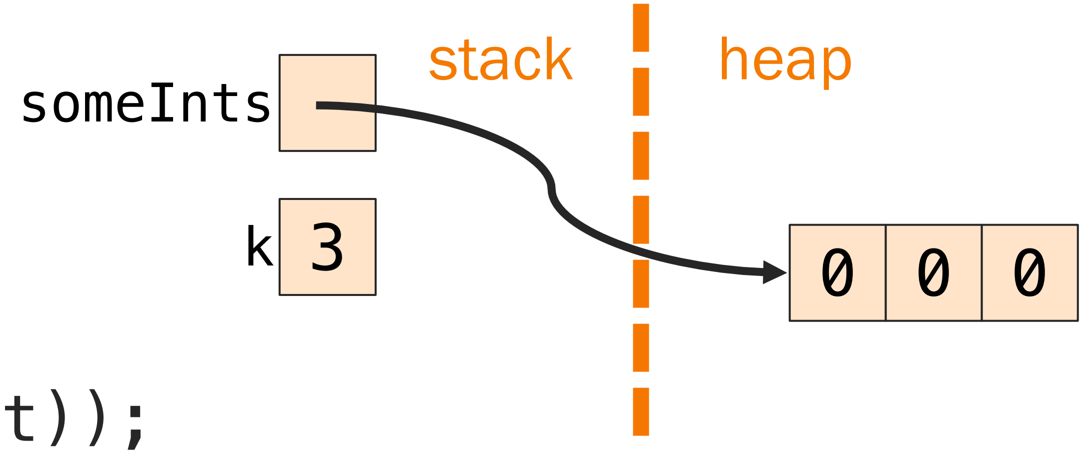
It's still a bug! (But now you'll find it!)

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

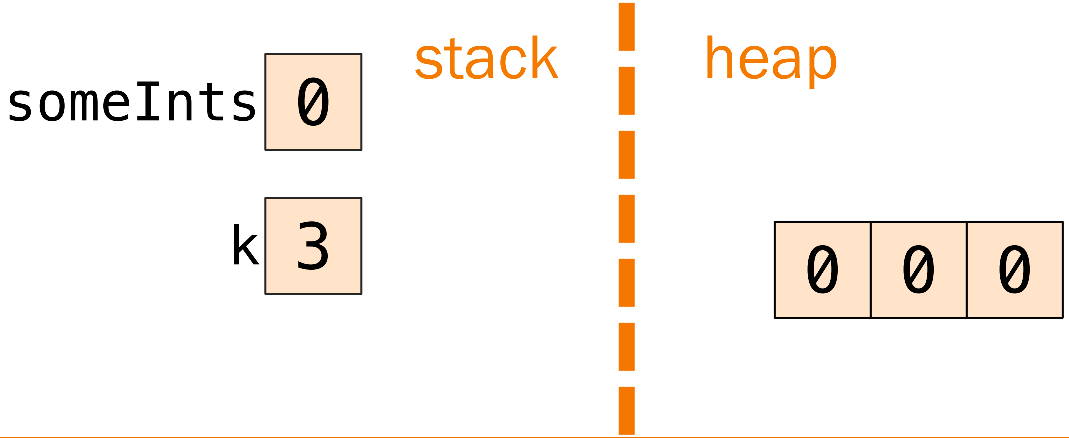


What could go wrong: realloc

```
int k;
int *someInts, *moreInts;
printf("How many ints?");
scanf("%d", &k);
someInts = calloc(k, sizeof(int));
someInts =
    realloc(someInts, (k+1)*sizeof(int));
```



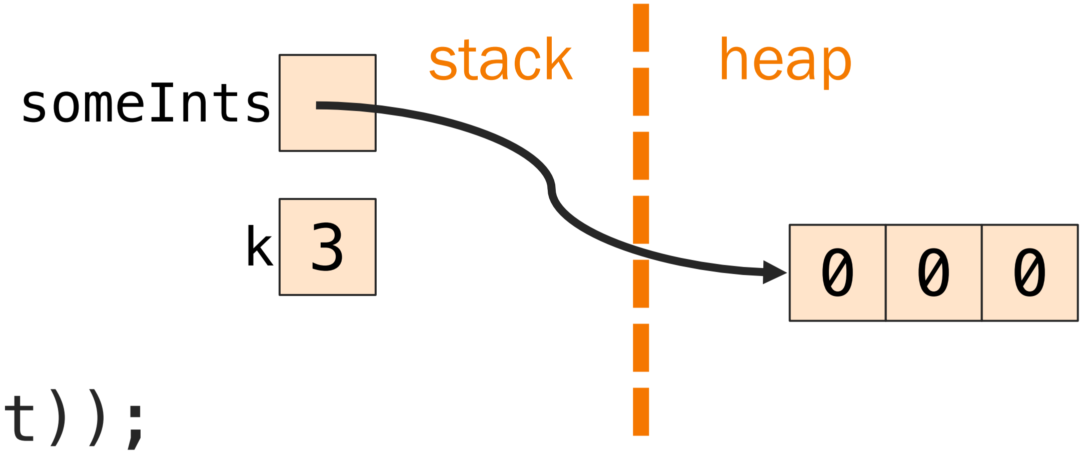
Before



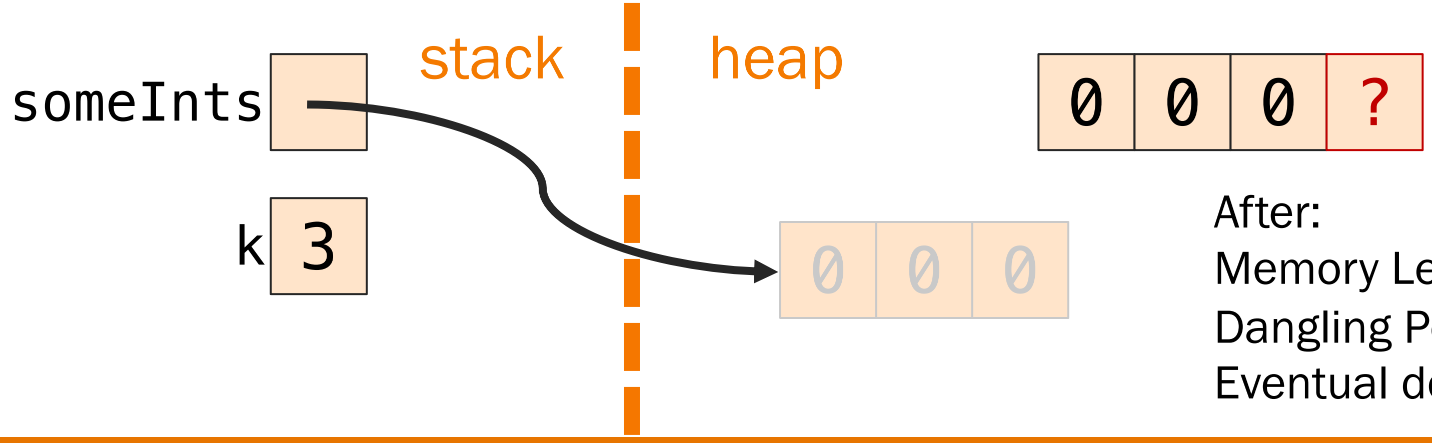
After:
If `realloc` returns NULL,
Memory Leak

What could go even worse: realloc

```
int k;
int *someInts, *moreInts;
printf("How many ints?");
scanf("%d", &k);
someInts = calloc(k, sizeof(int));
realloc(someInts, (k+1)*sizeof(int));
```

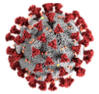


Before



After:
Memory Leak,
Dangling Pointer,
Eventual double free.

Catch the Most Common Bug

Yes, even more common than 

```
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`