`valgrind`: a tool for tracking memory usage

- `valgrind` is an easy-to-use tool for finding memory usage mistakes
  - invalid memory accesses: e.g. array index out of bounds
  - memory leaks: failure to `free` dynamically-allocated memory

`valgrind`: a tool for tracking memory usage

- To use:
  - As when using `gdb` to debug, compile program with `-g`
  - Run program using valgrind:

```
valgrind --leak-check=full ./myFile <arg1> <arg2> ...
```

- See also `http://valgrind.org/docs/manual/QuickStart.html`

Example using valgrind

example.c:

```c
#include <stdio.h>

int main() {
    printf(" *** My program's output ***\n");
    return 0;
}
```

```
$ gcc -std=c99 -Wall -Wextra -pedantic example.c -o example -g
```

Running our example code using `valgrind`: no issues reported

```
$ valgrind --leak-check=full ./example
 *** My program's output ***
==25901== Memcheck, a memory error detector
==25901== Copyright (C) 2002-2017, and GNU GPLd, by Julian Seward et al.
==25901== Using Valgrind-3.13.0 and LibVEX; rerun with -h for copyright info
==25901== Command: ./example
==25901==
==25901==
==25901== HEAP SUMMARY:
==25901==     in use at exit: 0 bytes in 0 blocks
==25901==   total heap usage: 1 allocs, 1 frees, 4,096 bytes allocated
==25901==
==25901== All heap blocks were freed -- no leaks are possible
==25901==
==25901== For counts of detected and suppressed errors, rerun with: -v
==25901== ERROR SUMMARY: 0 errors from 0 contexts (suppressed: 0 from 0)
```

Running code using `valgrind`

- Your program's output is interleaved with `valgrind` messages
- Kinds of issues that get flagged:
  - Invalid reads or writes: attempts to dereference pointers to memory that is not yours
  - Memory leaks: failing to deallocate a block of memory that you allocated. (See `valgrind`'s HEAP SUMMARY section)

Example with memory usage issues

stringCopy.c:

```c
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <assert.h>
char * string_copy(const char *orig) {
    char *fresh = malloc(strlen(orig));
    assert(fresh != NULL); //check that malloc succeeded
    strcpy(fresh, orig);
    return fresh;
}
int main() {
    char *hello_copy = string_copy("hello");
    assert(hello_copy != NULL);
    printf("%s\n", hello_copy);
    return 0;
}
```

```
$ gcc -std=c99 -Wall -Wextra -pedantic stringCopy.c -o stringCopy -g
```

valgrind output

```
$ valgrind --leak-check=full ./stringCopy
hello
==21672== Memcheck, a memory error detector
==21672== Copyright (C) 2002-2017, and GNU GPLd, by Julian Seward et al.
==21672== Using Valgrind-3.13.0 and LibVEX; rerun with -h for copyright info
==21672== Command: ./stringCopy
==21672==
==21672== Invalid write of size 1
==21672==    at 0x4C2FC9D: strcpy (vg_replace_strmem.c:510)
==21672==    by 0x40065D: string_copy (stringCopy.c:8)
==21672==    by 0x400675: main (stringCopy.c:12)
==21672==  Address 0x51ef045 is 0 bytes after a block of size 5 allocd
==21672==    at 0x4C2CB6B: malloc (vg_replace_malloc.c:299)
==21672==    by 0x400626: string_copy (stringCopy.c:6)
==21672==    by 0x400675: main (stringCopy.c:12)
==21672==
```

valgrind output, continued

```
==21672== Invalid read of size 1
==21672==    at 0x4C2FBD4: __strlen_sse2 (vg_replace_strmem.c:460)
==21672==    by 0x4EA7D81: puts (in /usr/lib64/libc-2.26.so)
==21672==    by 0x4006A5: main (stringCopy.c:14)
==21672==  Address 0x51ef045 is 0 bytes after a block of size 5 allocd
==21672==    at 0x4C2CB6B: malloc (vg_replace_malloc.c:299)
==21672==    by 0x400626: string_copy (stringCopy.c:6)
==21672==    by 0x400675: main (stringCopy.c:12)
==21672==
```

valgrind output, continued once more

```
==21672== HEAP SUMMARY:
==21672==     in use at exit: 5 bytes in 1 blocks
==21672==   total heap usage: 2 allocs, 1 frees, 4,101 bytes allocated
==21672==
==21672== 5 bytes in 1 blocks are definitely lost in loss record 1 of 1
==21672==    at 0x4C2CB6B: malloc (vg_replace_malloc.c:299)
==21672==    by 0x400626: string_copy (stringCopy.c:6)
==21672==    by 0x400675: main (stringCopy.c:12)
==21672==
==21672== LEAK SUMMARY:
==21672==    definitely lost: 5 bytes in 1 blocks
==21672==    indirectly lost: 0 bytes in 0 blocks
==21672==      possibly lost: 0 bytes in 0 blocks
==21672==    still reachable: 0 bytes in 0 blocks
==21672==         suppressed: 0 bytes in 0 blocks
==21672==
==21672== For counts of detected and suppressed errors, rerun with: -v
==21672== ERROR SUMMARY: 3 errors from 3 contexts (suppressed: 0 from 0)
```

Example with memory usage issues

- So what was wrong?
  - An invalid write
  - An invalid read
  - A block of memory that wasn't freed
- But when run on ugradx, this program didn't crash! In fact, it seemed to work!
  - `valgrind` is really useful for finding problematic code!

Fixing those memory usage issues

stringCopyFixed.c:

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <assert.h>
char * string_copy(const char *orig) {
   char *fresh = malloc(strlen(orig) + 1);  //FIX 1: make space for \0
   assert(fresh != NULL);
   strcpy(fresh, orig);
   return fresh;
}
int main() {
   char *hello_copy = string_copy("hello");
   assert(hello_copy != NULL);
   printf("%s\n", hello_copy);
   free(hello_copy);                        //FIX 2: free the memory that function malloc-ed
   return 0;
}
```

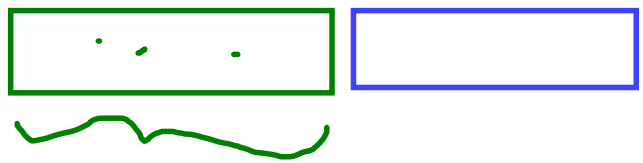
```
$ gcc -std=c99 -Wall -Wextra -pedantic stringCopyFixed.c -o stringCopyFixed -g
```

valgrind output for fixed version

```
$ valgrind --leak-check=full ./stringCopyFixed
hello
==33155== Memcheck, a memory error detector
==33155== Copyright (C) 2002-2017, and GNU GPLd, by Julian Seward et al.
==33155== Using Valgrind-3.13.0 and LibVEX; rerun with -h for copyright info
==33155== Command: ./stringCopyFixed
==33155==
==33155==
==33155== HEAP SUMMARY:
==33155==     in use at exit: 0 bytes in 0 blocks
==33155==   total heap usage: 2 allocs, 2 frees, 4,102 bytes allocated
==33155==
==33155== All heap blocks were freed -- no leaks are possible
==33155==
==33155== For counts of detected and suppressed errors, rerun with: -v
==33155== ERROR SUMMARY: 0 errors from 0 contexts (suppressed: 0 from 0)
```

realloc

- Reallocates the given area of memory
- Can be used for both expanding and contracting
- The area must have been previously (dynamically) allocated
- The reallocation is done either by:
  - expanding or contracting the existing area, if possible
  - allocating a new memory block of new size bytes
- On success:
  - returns the pointer to the beginning of newly allocated memory
- On failure:
  - returns a null pointer



realloc example

realloc_example.c:

```c
#include <stdio.h>
#include <stdlib.h>

int main()
{
  int *ptr = malloc(sizeof(int)*100);
  int i = 0;
  for (; i < 100; ++i) {
    ptr[i] = i;
  }

  ptr = realloc(ptr, sizeof(int) * 10000); // reallocate to expand

  return 0;
}
```

```
$ gcc -std=c99 -Wall -Wextra -pedantic realloc_example.c
```

calloc

- Similar to `malloc`, but initializes all bits to 0

```
#include <stdio.h>
#include <stdlib.h>

int main () {
  int *pData =  calloc (10, sizeof(int));
  for (int i = 0; i < 10; i++) {
      printf("%d ", pData[i]);
  }
}

$ gcc -std=c99 -Wall -Wextra -pedantic calloc_example.c
$ ./a.out
0 0 0 0 0 0 0 0 0 0
```

Exercise 2-3

- Work on Exercise 2-3