CSE 374
Programming Concepts & Tools

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C: the heap and manual memory management

(Thanks to Hal Perkins)

Communicating between frames

-bash-4.2$ ./fgrep hello

```
int main(argc, char** argv) {
  …
  if (fgrep(argv[1]))…
}

int fgrep(char* pat) {
       …
       char buf[128];
       tolower(pat, buf);
       …
       c = *buf
}

void tolower(char* src, char* dest) {
  strcpy(dest, src);
…
}
```

Communicating between frames

```
int main(argc, char** argv) {
  …
  if (fgrep(argv[1]))…
}

int fgrep(char* s) {
      …
      char* buf = tolower(s);
      …
      c = *buf
}

char* tolower(char* src) {
  char dest[128];
  strcpy(dest, src);
…
  return dest;
}
```

-bash-4.2$ ./fgrep hello

tolower() dest[128]
fgrep () char* buf
main()
start() “hello”

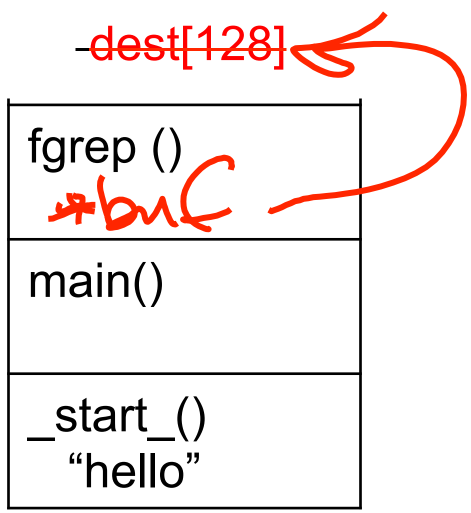
Communicating between frames

```
int main(argc, char** argv) {
  …
  if (fgrep(argv[1]))…
}

int fgrep(char* s) {
       …
       char* buf = tolower(s);
       …
       c = *buf
}

char* tolower(char* src) {
  char dest[128];
  strcpy(dest, src);
…
  return dest;
}
```

-bash-4.2$ ./fgrep hello



Heap allocation

- So far, all of our ints, pointers, and arrays, have been stack-allocated, which in C has a huge limitation:
  - The space is reclaimed when the allocating function returns
- Heap-allocation separates lifetime of data from that of a block or function call
- Comparison: new T(...) in Java does all this:
  - Allocate space for a T (exception if out-of-memory)
  - Initialize the fields to null or 0
  - Call the user-written constructor function
  - Return a reference (hey, a pointer!) to the new object
    - And the reference has a specific type: T
- In C, these steps are almost all separated

malloc, part 1

- malloc is "just" a library function: it takes a number, heap-allocates that many bytes and returns a pointer to the newly-allocated memory
  - Returns NULL on failure
  - Does not initialize the memory
  - You must cast the result to the pointer type you want
  - You do *not* know how much space different values need!
    - Do ***not*** do things like malloc(17) !
    - instead malloc(17 * sizeof(char))

malloc, part 2

- malloc is “always” used in a specific way:

  (T*)malloc(e * sizeof(T))
- Returns a pointer to memory large enough to hold an array of length e with elements of type T
- It is still not initialized (use a loop)!
  – Underused friend: calloc (takes e and sizeof(T) as separate arguments, initializes everything to 0)
- malloc returns an untyped pointer (void*); the cast (T*) tells C to treat it as a pointer to a block of type T

Half the battle

- We can now allocate memory of any size and have it “live” forever
- For example, we can allocate an array and use it indefinitely
- Unfortunately, computers do not have infinite memory so “living forever” could be a problem

Half the battle

- We can now allocate memory of any size and have it “live” forever
- For example, we can allocate an array and use it indefinitely
- Unfortunately, computers do not have infinite memory so “living forever” could be a problem
- Java solution: Conceptually objects live forever, but the system has a garbage collector that finds unreachable objects and reclaims their space
- C solution: You explicitly free an object’s space by passing a pointer to it to the library function free
- Freeing heap memory correctly is ***very*** *hard* in complex software and is the *disadvantage* of C-style heap-allocation

Everybody wants to be free(d once)

```
int * p = (int*)malloc(sizeof(int));
p = NULL; /* memory leak! */
int * q = (int*)malloc(sizeof(int));
free(q);
free(q); /* HYCSBWK */
int * r = (int*)malloc(sizeof(int));
free(r);
int * s = (int*)malloc(sizeof(int));
*s = 19;
*r = 17; /* HYCSBWK, but maybe *s==17 ?! */
```

- Problems much worse with functions:
  - f returns a pointer; (when) should f's caller free the pointed-to object?
  - g takes two pointers and frees one pointed-to object. Can the other pointer be dereferenced?

The Rules

1. For every run-time call to malloc there should be one run-time call to free
2. If you "lose all pointers" to an object, you can't ever call free (a leak)!
3. If you "use an object after it's freed" (or free it twice), you used a dangling pointer!

- Interesting side-note: The standard-library must "remember" how big the object returned by malloc is (but it won't tell you)
  - We will explore this further…

later ….

Valgrind

- Ideally there are no memory leaks, dangling pointers, or other bugs, but how do we check?
- valgrind *program program-arguments*
  - Runs *program* with *program-arguments*
  - Catches pointer errors during execution
  - At end, prints summary of heap usage, including details of any memory leaks at termination
- But it *really* slows down execution
  - But still a fantastic diagnostic, debugging tool
- Valgrind has other options/tools but memory check is the default and most commonly used

Processes and the heap

- Recall: a process (running program) has a single address space (code, static/global, heap, stack)
- When a program terminates the address space is released by the OS
  - So any allocated memory is “reclaimed” since it no longer exists
- Good practices
  - OK to rely on this if appropriate, but…
  - Any data structure package that allocates storage should normally provide routines to free it so client code can release the space if the client wants to