CSE 374
Programming Concepts & Tools

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Lecture 10 – C: the heap and manual memory management
Pointer syntax

- A review (for completeness)
- Declare a variable to have a pointer type:
  \[ t * x; \text{ or } t^* x; \text{ or } t \times x; \text{ or } t^\times x; \]
  (where \( t \) is a type and \( x \) is a variable)
- An expression to dereference a pointer:
  \[ *x \] (or more generally \( *e \))
  where \( e \) is an expression.
- C’s designers used the same character on purpose, but declarations (create space) and expressions (compute a value) are totally different things.
Heap allocation

- So far, all of our ints, pointers, and arrays, have been stack-allocated, which in C has two huge limitations:
  - The space is reclaimed when the allocating function returns
  - The space required must be a constant (only an issue for arrays)
- Heap-allocation has neither limitation.
- 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)!
malloc, part 2

- malloc is “always” used in a specific way:
  \((t*)\text{malloc}(e \times \text{sizeof}(t))\)
- 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 \(\text{sizeof}(t)\) as separate arguments, initializes everything to 0)
- malloc returns an untyped pointer (\(\text{void}\*)\); 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.
• 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)

```c
int * p = (int*)malloc(sizeof(int));
p = NULL; /* 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

• For every run-time call to malloc there should be one run-time call to free.
• If you “lose all pointers” to an object, you can’t ever call free (a leak)!
• If you “use an object after it’s freed” (or free it twice), you used a dangling pointer!
• Note: It’s possible but rare to use up too much memory without creating “leaks via no more pointers to an object”.
• Interesting side-note: The standard-library must “remember” how big the object is (but it won’t tell you).
  – We will explore this further…
  
  later …. 