
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; or t* x; or t *x; or t*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
- 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*)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.
- 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; /* 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