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CS61C : Machine Structures

Lecture 4 – Introduction to C (pt 2)

2011-09-02

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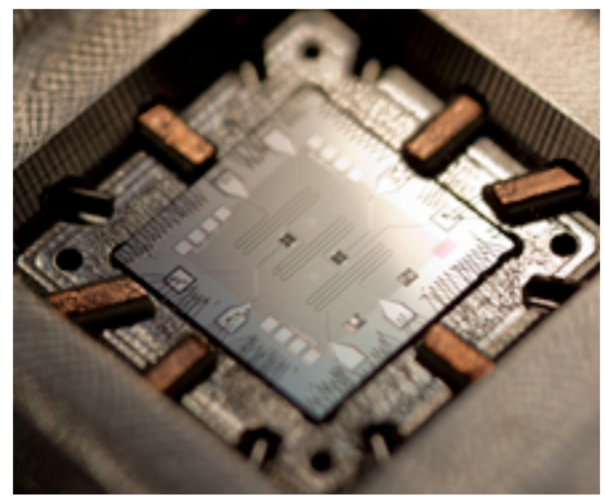
Quantum Processor ⇒

Researchers @ UCSB have produced the first Quantum processor with memory that can be used to store instructions and data! (ala what von Neumann did in 1940s)



www.technologyreview.com/computing/38495

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Review

- All declarations go at the beginning of each function except if you use C99.
- All data is in memory. Each memory location has an address to use to refer to it and a value stored in it.
- A pointer is a C version of the address.
  - `*` "follows" a pointer to its value
  - `&` gets the address of a value
- Only 0 (i.e., NULL) evaluate to FALSE.

More C Pointer Dangers

- Declaring a pointer just allocates space to hold the pointer – it does not allocate something to be pointed to!
- Local variables in C are not initialized, they may contain anything.
- What does the following code do?

```
void f()
{
    int *ptr;
    *ptr = 5;
}
```


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Arrays (1/5)

- **Declaration**:

```
int ar[2];
```

declares a 2-element integer array. *An array is really just a block of memory.*

```
int ar[] = {795, 635};
```

declares <u>and fills</u> a 2-elt integer array.

- **Accessing elements**:

```
ar[num]
```

returns the `num`th element.

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Arrays (2/5)

- Arrays are (almost) identical to pointers
  - `char *string` and `char string[]` are nearly identical declarations
  - They differ in very subtle ways: incrementing, declaration of filled arrays
- **Key Concept**: An array variable is a "pointer" to the first element.

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Arrays (3/5)

- **Consequences:**
  - `ar` is an array variable but looks like a pointer in many respects (though not all)
  - `ar[0]` is the same as `*ar`
  - `ar[2]` is the same as `*(ar+2)`
  - We can use pointer arithmetic to access arrays more conveniently.
- **Declared arrays are only allocated while the scope is valid**

```
char *foo() {
    char string[32]; ...;
    return string;
}
```

is incorrect

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Arrays (4/5)

- Array size `n`; want to access from `0` to `n-1`, so you should use counter AND utilize a variable for declaration & incr
  - Wrong

```
int i, ar[10];
for(i = 0; i < 10; i++){ ... }
```

  - Right

```
int ARRAY_SIZE = 10;
int i, a[ARRAY_SIZE];
for(i = 0; i < ARRAY_SIZE; i++){ ... }
```

- Why? SINGLE SOURCE OF TRUTH
  - You're utilizing indirection and avoiding maintaining two copies of the number 10

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Arrays (5/5)

- **Pitfall: An array in C does <u>not</u> know its own length, & bounds not checked!**
  - Consequence: We can accidentally access off the end of an array.
  - Consequence: We must pass the array <u>and its size</u> to a procedure which is going to traverse it.
- **Segmentation faults and bus errors:**
  - These are VERY difficult to find; be careful! (You'll learn how to debug these in lab…)

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Pointers (1/4) ...review...

- Sometimes you want to have a procedure increment a variable?
- What gets printed?

```
void AddOne(int  x)
{      x =  x + 1;    }

int y = 5;
AddOne( y);
printf("y = %d\n", y);
```

y = 5

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Pointers (2/4) ...review...

- Solved by passing in a pointer to our subroutine.
- Now what gets printed?

```
void AddOne(int *p)
{     *p = *p + 1;    }

int y = 5;
AddOne(&y);
printf("y = %d\n", y);
```

y = 6

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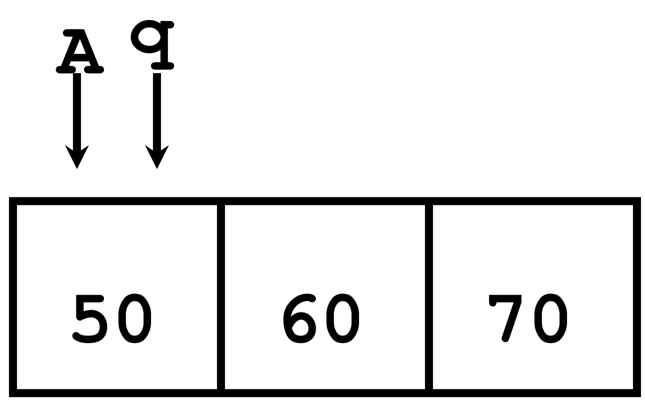
Pointers (3/4)

- But what if what you want changed is a pointer?
- What gets printed?

```
void IncrementPtr(int  *p)
{    p =  p + 1;    }

int A[3] = {50, 60, 70};
int *q = A;
IncrementPtr( q);
printf("*q = %d\n", *q);
```

*q = 50



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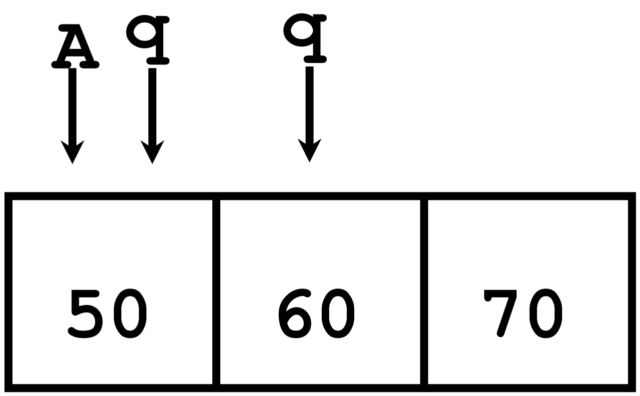
Pointers (4/4)

- Solution! Pass a pointer to a pointer, declared as `**h`
- Now what gets printed?

```
void IncrementPtr(int **h)
{    *h = *h + 1;    }

int A[3] = {50, 60, 70};
int *q = A;
IncrementPtr(&q);
printf("*q = %d\n", *q);
```

*q = 60



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Dynamic Memory Allocation (1/4)

- C has operator `sizeof()` which gives size in bytes (of type or variable)
- Assume size of objects can be misleading and is bad style, so use `sizeof(type)`
  - Many years ago an `int` was 16 bits, and programs were written with this assumption.
  - What is the size of integers now?
- "`sizeof`" knows the size of arrays:

```
int ar[3]; // Or:   int ar[] = {54, 47, 99}
sizeof(ar) ⇒ 12
```

  - …as well for arrays whose size is determined at run-time:

```
int n = 3;
int ar[n]; // Or: int ar[fun_that_returns_3()];
sizeof(ar) ⇒ 12
```


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Dynamic Memory Allocation (2/4)

- To allocate room for something new to point to, use `malloc()` (with the help of a typecast and `sizeof`):

```
ptr = (int *) malloc (sizeof(int));
```

  - Now, `ptr` points to a space somewhere in memory of size `(sizeof(int))` in bytes.
  - `(int *)` simply tells the compiler what will go into that space (called a typecast).

- `malloc` is almost never used for 1 var

```
ptr = (int *) malloc (n*sizeof(int));
```

  - This allocates an array of `n` integers.

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Dynamic Memory Allocation (3/4)

- Once `malloc()` is called, the memory location contains garbage, so don't use it until you've set its value.
- After dynamically allocating space, we must dynamically free it:

```
free(ptr);
```

- Use this command to clean up.
  - Even though the program `frees` all memory on `exit` (or when `main` returns), don't be lazy!
  - You never know when your `main` will get transformed into a subroutine!

Dynamic Memory Allocation (4/4)

- The following two things will cause your program to crash or behave strangely later on, and cause VERY VERY hard to figure out bugs:
  - `free()`ing the same piece of memory twice
  - calling `free()` on something you didn't get back from `malloc()`
- The runtime does not check for these mistakes
  - Memory allocation is so performance-critical that there just isn't time to do this
  - The usual result is that you corrupt the memory allocator's internal structure
  - You won't find out until much later on, in a totally unrelated part of your code!

Pointers in C

- **Why use pointers?**
  - If we want to pass a huge struct or array, it's easier / faster / etc to pass a pointer than the whole thing.
  - In general, pointers allow cleaner, more compact code.
- **So what are the drawbacks?**
  - Pointers are probably the single largest source of bugs in software, so be careful anytime you deal with them.
  - Dangling reference (use ptr before malloc)
  - Memory leaks (tardy free, lose the ptr)

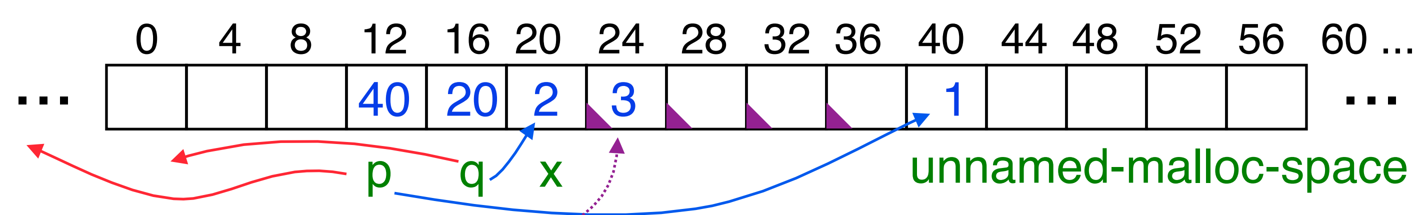
Arrays not implemented as you'd think

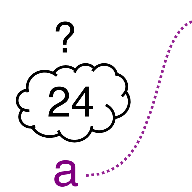
```
void foo() {
  int *p, *q, x;
  int a[4];
  p = (int *) malloc (sizeof(int));
  q = &x;

  *p = 1; // p[0] would also work here
  printf("*p:%u, p:%u, &p:%u\n", *p, p, &p);

  *q = 2; // q[0] would also work here
  printf("*q:%u, q:%u, &q:%u\n", *q, q, &q);

  *a = 3; // a[0] would also work here
  printf("*a:%u, a:%u, &a:%u\n", *a, a, &a);
}
```






```
*p:1, p:40, &p:12
*q:2, q:20, &q:16
*a:3, a:24, &a:24
```

K&R: "An array name is not a variable"

Peer Instruction

Which are guaranteed to print out 5?

```
I: main() {
      int *a-ptr = (int *)malloc(int);
      *a-ptr = 5;
      printf("%d", *a-ptr);
   }

II:main() {
      int *p, a = 5;
      p = &a; ...
      /* code; a,p NEVER on LEFT of = */
      printf("%d", a);
   }
```

	I	II
a)	-	-
b)	-	YES
c)	YES	-
d)	YES	YES
e)	No idea	

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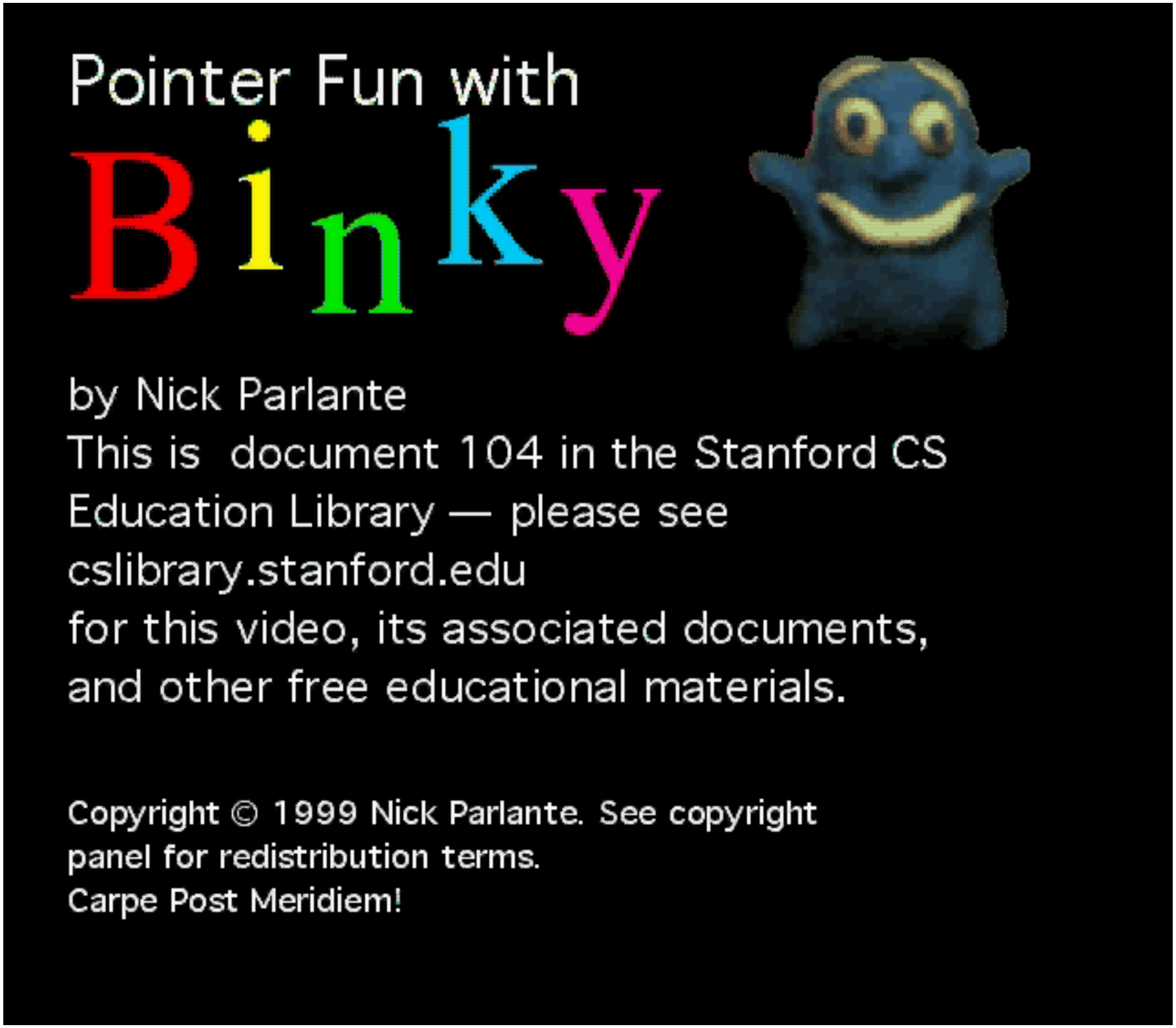
Binky Pointer Video (thanks to NP @ SU)



“And in Conclusion…”

- Pointers and arrays are virtually same
- C knows how to increment pointers
- C is an efficient language, with little protection
  - Array bounds not checked
  - Variables not automatically initialized
- Use handles to change pointers
- Dynamically allocated heap memory must be manually deallocated in C.
  - Use `malloc()` and `free()` to allocate and deallocate memory from heap.
- (Beware) The cost of efficiency is more overhead for the programmer.
  - “C gives you a lot of extra rope but be careful not to hang yourself with it!”

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