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CS61C : Machine Structures

Lecture #4 –C Strings, Arrays, & Malloc

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Instructor

Review: C Strings

- A string in C is just an array of characters.

```
char string[] = "abc";
```

- Strings are ended by 0 byte (null terminator
  - Value as int, 0
  - Value as char, '\0'
- Programmer manually manages memory for strings.

Review: Arrays vs. Pointers

- Arrays are (almost) identical to pointers
  - `char *str_ptr` and `char str_array[]` are nearly identical
  - They differ in very subtle ways:
    - Incrementing
      `str_array++;` // ILLEGAL
    - declaration of filled arrays
      `int *int_array = {1,2,3};` // ILLEGAL
- Key Difference: An array variable is a constant "pointer" to the first element.

Review: Arrays vs. Pointers

- An array parameter can be declared as an array or a pointer; an array argument can be passed as a pointer.

```
int strlen(char s[])
{
    int n = 0;
    while (s[n] != 0)
        n++;
    return n;
}
```

```
int strlen(char *s)
{
    int n = 0;
    while (s[n] != 0)
        n++;
    return n;
}
```

Could be written:
`while (s[n])`

Review: Pointer Arithmetic

- Since a pointer is just a mem address, we can add to it to traverse an array.
- `p+1` returns a ptr to the next array elt.
- `*p++` vs `(*p)++` ?
  - `x = *p++` ⇒ `x = *p ; p = p + 1;`
  - `x = (*p)++` ⇒ `x = *p ; *p = *p + 1;`
- What if we have an array of large structs (objects)?
  - C takes care of it: In reality, `p+1` doesn't add `1` to the memory address, it adds the size of the (type of) array element.

Pointer Arithmetic Summary

- `x = *(p+1)` ?
  ⇒ `x = *(p+1) ;`
- `x = *p+1` ?
  ⇒ `x = (*p) + 1 ;`
- `x = (*p)++` ?
  ⇒ `x = *p ; *p = *p + 1;`
- `x = *p++` ? `(*p++)` ? `*(p)++` ? `*(p++)` ?
  ⇒ `x = *p ; p = p + 1;`
- `x = *++p` ?
  ⇒ `p = p + 1 ; x = *p ;`
- Lesson?
  - Using anything but the standard `*p++`, `(*p)++` causes more problems than it solves!
  - P. 53 is a precedence table if you ever have to deal with this

C String Standard Functions

- `int strlen(char *string);`
  - compute the length of `string`
- `int strcmp(char *str1, char *str2);`
  - return 0 if `str1` and `str2` are identical (how is this different from `str1 == str2`?)
- `char *strcpy(char *dst, char *src);`
  - copy the contents of string `src` to the memory at `dst`. The caller must ensure that `dst` has enough memory to hold the data to be copied.

Pointers to pointers (1/4) …review…

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

```
void AddOne(int  x)            y = 5
{     x =  x + 1;   }

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


Pointers to pointers (2/4) …review…

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

```
void AddOne(int *p)            y = 6
{    *p = *p + 1;   }

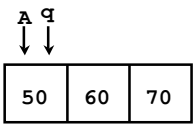
int y = 5;
AddOne(&y);
printf("y = %d\n", y);
```


Pointers to pointers (3/4)

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

```
void IncrementPtr(int  *p)     *q = 50
{    p =  p + 1;   }

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

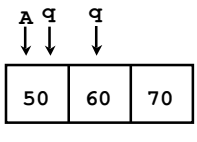


Pointers to pointers (4/4)

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

```
void IncrementPtr(int **h)     *q = 60
{   *h = *h + 1;   }

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



Dynamic Memory Allocation (1/3)

- Recall that we can make ptrs point to…
  - something that already exists
  - Newly allocated memory
- C has operator `sizeof()` which gives size in bytes (of type or variable)
- Assume size of objects can be misleading & is bad style, so use `sizeof(type)`
  - Many years ago an `int` was 16 bits, and programs assumed it was 2 bytes

Dynamic Memory Allocation (2/3)

- 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.

Dynamic Memory Allocation (3/3)

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

```
free(ptr);
```

- Use this command to clean up.

Peer Instruction 1

What will `y` contain?

```
int main(int argc, char** argv)
{
  int y, *z;
  y = 4;
  z = &y;
  y = *z + 9;
  return 0;
}
```


Peer Instruction 2

What is in foo and bar at the end of this program?

```
int main(int argc, char** argv)
{
  int foo, *bar, **baz, quux;
  bar = &quux;
  foo = 4;
  baz = &bar;
  **baz = 13;
  bar = &foo;
  **baz = 9;
  return 0;
}
```


Administrivia

- Homework submission
  - Guide on website, as well as within hw spec
  - You can submit as many times as you like, we will only grade the latest one.
- Upcoming due dates
  - HW0 out by tomorrow (sorry for delay)
    - Due 7/1 in lab or to my office
    - Picture + signed agreement to academic honesty policy
  - Quiz 1 due Friday 6/27
  - HW1 due Monday 6/30
    - Start today!
  - Quiz 2 due Tuesday 7/1
  - HW2 due Saturday 7/5, should be out by end of this week

Administrivia

- No Office Hours today (but I'll be in and out of lab)
- Waitlist should be resolved
- Newsgroup (details on website)

Binky Pointer Video (thanks to NP @ SU)

C structures : Overview

- A `struct` is a data structure composed for simpler data types.
  - Like a class in Java/C++ but without methods or inheritance.

```
struct point {
    int x;
    int y;
};
void PrintPoint(struct point p)
{
    printf("(%d,%d)", p.x, p.y);
}
```


C structures: Pointers to them

- The C arrow operator (`->`) dereferences and extracts a structure field with a single operator.
- The following are equivalent:

```
struct point *p;

printf("x is %d\n", (*p).x);
printf("x is %d\n", p->x);
```


How big are structs?

- Recall C operator `sizeof()` which gives size in bytes (of type or variable)
- How big is `sizeof(p)`?

```
struct p {
   char x;
   int y;
};
```

  - 5 bytes? 8 bytes?
  - Compiler may word align integer `y`

Linked List Example

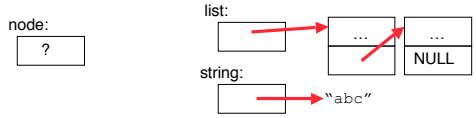
- Let's look at an example of using structures, pointers, `malloc()`, and `free()` to implement a linked list of strings.

```
struct Node {
    char *value;
    struct Node *next;
};
typedef struct Node *List;

/* Create a new (empty) list */
List ListNew(void)
{ return NULL; }
```


Linked List Example

```
/* add a string to an existing list */
List list_add(List list, char *string)
{
  struct Node *node =
    (struct Node*) malloc(sizeof(struct Node));
  node->value =
    (char*) malloc(strlen(string) + 1);
  strcpy(node->value, string);
  node->next = list;
  return node;
}
```



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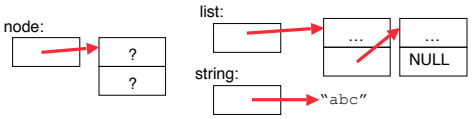
  return node;
}
```



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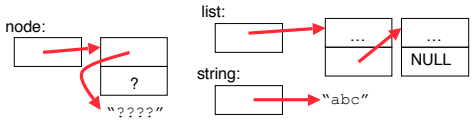
  strcpy(node->value, string);
  node->next = list;
  return node;
}
```



Linked List Example

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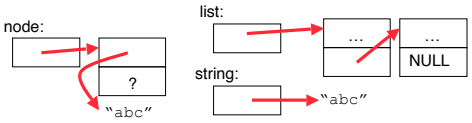
    (struct Node*) malloc(sizeof(struct Node));
  node->value =
    (char*) malloc(strlen(string) + 1);
  strcpy(node->value, string);
  node->next = list;
  return node;
}
```



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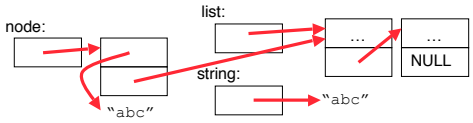
  node->value =
    (char*) malloc(strlen(string) + 1);
  strcpy(node->value, string);
  node->next = list;
  return node;
}
```



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List list_add(List list, char *string)
{
  struct Node *node =
    (struct Node*) malloc(sizeof(struct Node));
  node->value =
    (char*) malloc(strlen(string) + 1);
  strcpy(node->value, string);
  node->next = list;
  return node;
}
```

Peer Instruction

Which are guaranteed to print out 5?

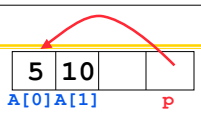
```
I:   main() {
       int *a-ptr; *a-ptr = 5; printf("%d", *a-ptr); }

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

III: main() {
       int *ptr;
       ptr = (int *) malloc (sizeof(int));
       *ptr = 5;
       printf("%d", *ptr); }
```

	I	II	III
1:	–	–	–
2:	–	–	YES
3:	–	YES	–
4:	–	YES	YES
5:	YES	–	–
6:	YES	–	YES
7:	YES	YES	–
8:	YES	YES	YES

Peer Instruction




```
int main(void){
  int A[] = {5,10};
  int *p = A;

  printf("%u %d %d %d\n",p,*p,A[0],A[1]);
   p =  p + 1;
  printf("%u %d %d %d\n",p,*p,A[0],A[1]);
  *p = *p + 1;
  printf("%u %d %d %d\n",p,*p,A[0],A[1]);
  }
```

If the first `printf` outputs <u>`100 5 5 10`</u>, what will the other two `printf` output?

```
1: 101 10 5 10        then 101 11 5 11
2: 104 10 5 10        then 104 11 5 11
3: 101 <other> 5 10   then 101 <3-others>
4: 104 <other> 5 10   then 104 <3-others>
5: One of the two printfs causes an ERROR
6: I surrender!
```


Summary

- Use handles to change pointers
- Create abstractions with structures
- Dynamically allocated heap memory must be manually deallocated in C.
  - Use `malloc()` and `free()` to allocate and deallocate memory from heap.