Characters, strings, structs, malloc

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This lecture

• Characters
• Strings
• Structs
• Dynamic Memory Allocation
Characters
How to represent text characters?

• How to associate bit patterns to integers?
  – base 2
  – 2’s complement

• How to associate bit patterns to floats?
  – IEEE floating point representation (based on normalized scientific notation)

• How to associate bit patterns to characters?
  – by convention
  – ASCII, UTF
ASCII: American Standard Code for Information Exchange

• Developed in 60s, based on the English alphabet
• use one byte (with MSB=0) to represent each character
• How many unique characters can be represented?

128
## ASCII TABLE

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<th>Hex</th>
<th>Char</th>
<th>Decimal</th>
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</table>
C exercise 1: tolower

// tolower returns the corresponding
// lowercase character for c if c is an
// uppercase letter. Otherwise, it returns c.
char tolower(char c) {
}

int main() {
    char c = ‘A’;
    c = tolower(c);
    ...
}

C exercise 1: tolower

// tolower returns the corresponding
// lowercase character for c if c is an
// uppercase letter. Otherwise, it returns c.
char tolower(char c) {

    // test if c is an uppercase letter
    if (c < 'A' || c > 'Z') {
        return c;
    }

}
C exercise 1: tolower

// tolower returns the corresponding lowercase character for c if c is an uppercase letter. Otherwise, it returns c.
char tolower(char c) {

    // test if c is an uppercase letter
    if (c < 'A' || c > 'Z') {
        return c;
    }

    return c + ('a' - 'A');
}

C’s standard library includes tolower, toupper
C exercise 2: toDigit

// toDigit returns the corresponding integer for c
// if c is a valid digit character, e.g ‘1’, ‘2’,
// Otherwise, it returns -1.
int toDigit(char c) {

}

int main() {
    int d = toDigit('8');
    printf("int is %d, multiply-by-2 %d\n", d, 2*d);
}
C exercise 2: toDigit

// toDigit returns the corresponding integer for c
// if c is a valid digit character, e.g ‘1’, ‘2’,
// Otherwise, it returns -1.
int toDigit(char c) {
    // test if c is a valid character
    if (c < ‘0’ || c > ‘9’) {
        return -1;
    }
}

int main() {
    int d = toDigit(‘8’);
    printf(“int is %d, multiply-by-2 %d\n”, d, 2*d);
}
C exercise 2: toDigit

// toDigit returns the corresponding integer for c
// if c is a valid digit character, e.g ‘1’, ‘2’,
// Otherwise, it returns -1.

int toDigit(char c) {
    // test if c is a valid character
    if (c < ‘0’ || c > ‘9’) {
        return -1;
    }
    return c – ‘0’;
}

int main() {
    int d = toDigit(‘8’);
    printf(“int is %d, multiply-by-2 %d\n”, d, 2*d);
}
The Modern Standard: UniCode

• ASCII can only represent 128 characters
  – How about Chinese, Korean, all of the worlds languages? Symbols? Emojis?

• Unicode standard represents >135,000 characters

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>U+1F600</td>
<td>grinning face</td>
</tr>
<tr>
<td>U+1F601</td>
<td>beaming face with smiling eyes</td>
</tr>
<tr>
<td>U+1F602</td>
<td>face with tears of joy</td>
</tr>
<tr>
<td>U+1F923</td>
<td>rolling on the floor laughing</td>
</tr>
<tr>
<td>U+1F603</td>
<td>grinning face with big eyes</td>
</tr>
</tbody>
</table>
UTF-8

• UTF-8 is one encoding form for Unicode
  – use 1, 2, or 4 byte to represent a character
  – Unicode for ASCII characters have the same ASCII value → UTF-8 one byte code is the same as ASCII
• C has no primitive support for Unicode
C Strings
Strings

• String is represented as an array of chars.
  – Array has no space to encode its length.

• How to determine string length?
  – explicitly pass around an integer representing length

```c
// tolower_string turns every character in character array s
// into lower case
void tolower_string(char *s, int len) {
    for (int i = 0; i < len; i++) {
        s[i] = tolower(s[i]);
    }
}
```
Strings

• String is represented as an array of chars.
  – Array has no space to encode its length.

• How to determine string length?
  – explicitly pass around an integer representing length
  – C string stores a NULL character to mark the end (by convention)

```c
void tolower_string(char *s) {
}
```
Strings

• String is represented as an array of chars.
  – Array has no space to encode its length.
• How to determine string length?
  – explicitly pass around an integer representing length
  – C string stores a NULL character to mark the end (by convention)

```c
void tolower_string(char *s) {
    int i = 0;
    while (s[i] != '\0') {
        s[i] = tolower(s[i]);
        i++;
    }
}
```
Copying string?

does this make a copy of “hi”?

```c
char s[3] = {'h','i','\0'};
char *h;
h = s;
h[0] = 'H';

printf("s=%s h=%s\n",s,h);
```

Copying string?

does this make a copy of “hi”?

```c
char s[3] = {'h', 'i', '\0'};
char h[3];
h = s;
h[0] = 'H';

printf("s=%s h=%s\n", s, h);
```
void strcpy(char *dst, char *src) {

}

int main() {
    char s[3] = {'h','i','\0'};
    char h[3];
    strcpy(h, s);
    h[0] = 'H';

    printf("s=%s h=%s\n",s,h);
}
void strcpy(char *dst, char *src) {
    int i = 0;
    while (src[i] != '\0') {
        dst[i] = src[i];
        i++;
    }
}

int main() {
    char s[3] = {'h', 'i', '\0'};
    char h[3];
    strcpy(h, s);
    h[0] = 'H';

    printf("s=%s h=%s\n", s, h);
}
Copying string

```c
void strcpy(char *dst, char *src) {
    int i = 0;
    while (src[i] != '\0') {
        dst[i] = src[i];
        i++;
    }
}

int main() {
    char s[3] = {'h','i','\0'};
    char h[2];
    strcpy(h, s);
    h[0] = 'H';

    printf("s=%s h=%s\n", s, h);
}
```

Results in out-of-bound write!
Buffer overflow!
Copying string

```c
void strncpy(char *dst, char *src, int n) {
    int i = 0;
    while (src[i] != '\0' && i < n) {
        dst[i] = src[i];
        i++;
    }
}

int main() {
    char s[3] = {'h', 'i', '\0'};
    char h[2];
    strncpy(h, s, 2);
    h[0] = 'H';

    printf("s=%s h=%s\n", s, h);
}
```

strncpy is included in C std library.
A different way of initializing string...

```c
char s1[3] = {'h','i','\0'};
//equivalent to
//char s1[3] = "hi";
char *s2 = "bye";
s1[0] = 'H';
s2[0] = 'B';
printf("s1=%s s2=%s\n",s1,s2);
```

OK  Segmentation fault (bus error)
char s1[3] = {'h','i','\0'};
// equivalent to
// char s1[3] = “hi”;
char *s2 = “bye”;
s1[0] = ‘H’;
s2[0] = ‘B’;

printf(“s1=%s s2=%s\n”, s1, s2);
The Atoi function

// atoi returns the integer
// corresponding to the string of digits
int atoi(char *s)
{

}

int main()
{
    char *s = "123";
    printf("integer is %d\n", atoi(s));
}
The Atoi function

// atoi returns the integer
// corresponding to the string of digits
int atoi(char *s) {
    int result = 0;
    int i = 0;
    while (s[i] >= '0' && s[i] <= '9') {
        result = result * 10 + (s[i] - '0');
        i++;
    }
    return result;
}
char* names[3] = {
    "alice",
    "bob",
    "clark"
};

char **namep;
namep = names;

printf("name is %s", namep[1]);
The most commonly used array of pointers: argv

```c
int main(int argc, char **argv)
{
    for (int i = 0; i < argc; i++) {
        printf("%s\n", argv[i]);
    }
}
```

argv[0] is the name of the executable

```bash
$ ./a.out 1 2 3
./a.out 1 2 3
```
Structs

Struct stores fields of different types contiguously in memory
Structure

• Array: a block of $n$ consecutive elements of the same type.

• Struct: a collection of elements of different types.
struct student {
  int id;
  char *name;
};

Fields of a struct are allocated next to each other, but there may be gaps (padding) between them.
Structure

```c
struct student {
    int id;
    char *name;
};

struct student t; // define variable t with type "struct student"
```
Structure

struct student {
  int id;
  char *name;
};

struct student t;

  t.id = 1024;  \hspace{1cm} \text{Access the fields of this struct}
  t.name = "alice";
typedef struct {
    int id;
    char *name;
} student;

struct student t;
typedef struct {
    int id;
    char *name;
} student;

student t = {1023, "alice"};
student *p = &t;

p->id = 1023;
p->name = "bob";
printf("%d %s\n", t.id, t.name\n");
Mallocs

Allocates a chunk of memory dynamically
Recall memory allocation for global and local variables

- **Global** variables are allocated space before program execution.
- **Local** variables are allocated when entering a function and de-allocated upon its exit.
Malloc

Allocate space dynamically and flexibly:
- `malloc`: allocate storage of a given size
- `free`: de-allocate previously malloc-ed storage

```c
void *malloc(size_t size);
```

A void pointer is a pointer that has no associated data type with it. A void pointer can hold address of any type and can be casted to any type.

```c
void free(void *ptr);
```
Malloc

#include <stdlib.h>

int *newArray(int n) {
  int *p;
  p = (int*)malloc(sizeof(int) * n);
  return p;
}

Malloc is implemented as a C library
Conceptual view of a C program’s memory at runtime

• Separate memory regions for global, local, and malloc-ed.

Stack
(for local variables)

Heap
(for malloced data)

Static data
(global variables)

We will refine this simple view in later lectures
Linked list in C: insertion

typedef struct {
    int val;
    struct node *next;
} node;

// insert val into linked list to the head
// of the linked list and return the new
// head of the list.
node*
insert(node *head, int val) {
}

int main() {
    node *head = NULL;
    for (int i = 0; i < 3; i++)
        head = insert(head, i);
}

* this linked list implementation is different from Lab1
Inserting into a linked list

head
Inserting into a linked list

```c
node *insert(node *head, int val) {
    node nn;
    node *n = &nn;
    node *n = (node *)malloc(sizeof(node));
    n->val = val;
    n->next = head;
}
```
Inserting into a linked list

```c
node *insert(node *head, int val) {
    node *n = (node *)malloc(sizeof(node));
    n->val = val;
    n->next = head;
    return n;
}
```