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

Decimal	Hex	Char	Decimal	Hex	Char	Decimal	Hex	Char	Decimal	Hex	Char
0	0	*[NULL]*	32	20	*[SPACE]*	64	40	@	96	60	`
1	1	*[START OF HEADING]*	33	21	!	65	41	A	97	61	a
2	2	*[START OF TEXT]*	34	22	"	66	42	B	98	62	b
3	3	*[END OF TEXT]*	35	23	#	67	43	C	99	63	c
4	4	*[END OF TRANSMISSION]*	36	24	$	68	44	D	100	64	d
5	5	*[ENQUIRY]*	37	25	%	69	45	E	101	65	e
6	6	*[ACKNOWLEDGE]*	38	26	&	70	46	F	102	66	f
7	7	*[BELL]*	39	27	'	71	47	G	103	67	g
8	8	*[BACKSPACE]*	40	28	(	72	48	H	104	68	h
9	9	*[HORIZONTAL TAB]*	41	29	)	73	49	I	105	69	i
10	A	*[LINE FEED]*	42	2A	*	74	4A	J	106	6A	j
11	B	*[VERTICAL TAB]*	43	2B	+	75	4B	K	107	6B	k
12	C	*[FORM FEED]*	44	2C	,	76	4C	L	108	6C	l
13	D	*[CARRIAGE RETURN]*	45	2D	-	77	4D	M	109	6D	m
14	E	*[SHIFT OUT]*	46	2E	.	78	4E	N	110	6E	n
15	F	*[SHIFT IN]*	47	2F	/	79	4F	O	111	6F	o
16	10	*[DATA LINK ESCAPE]*	48	30	0	80	50	P	112	70	p
17	11	*[DEVICE CONTROL 1]*	49	31	1	81	51	Q	113	71	q
18	12	*[DEVICE CONTROL 2]*	50	32	2	82	52	R	114	72	r
19	13	*[DEVICE CONTROL 3]*	51	33	3	83	53	S	115	73	s
20	14	*[DEVICE CONTROL 4]*	52	34	4	84	54	T	116	74	t
21	15	*[NEGATIVE ACKNOWLEDGE]*	53	35	5	85	55	U	117	75	u
22	16	*[SYNCHRONOUS IDLE]*	54	36	6	86	56	V	118	76	v
23	17	*[ENG OF TRANS. BLOCK]*	55	37	7	87	57	W	119	77	w
24	18	*[CANCEL]*	56	38	8	88	58	X	120	78	x
25	19	*[END OF MEDIUM]*	57	39	9	89	59	Y	121	79	y
26	1A	*[SUBSTITUTE]*	58	3A	:	90	5A	Z	122	7A	z
27	1B	*[ESCAPE]*	59	3B	;	91	5B	[	123	7B	{
28	1C	*[FILE SEPARATOR]*	60	3C	<	92	5C	\	124	7C	|
29	1D	*[GROUP SEPARATOR]*	61	3D	=	93	5D	]	125	7D	}
30	1E	*[RECORD SEPARATOR]*	62	3E	>	94	5E	^	126	7E	~
31	1F	*[UNIT SEPARATOR]*	63	3F	?	95	5F	_	127	7F	*[DEL]*

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

U+1F600		grinning face
U+1F601		beaming face with smiling eyes
U+1F602		face with tears of joy
U+1F923		rolling on the floor laughing
U+1F603		grinning face with big eyes

UTF-8, UTF-16, UTF-32

- UTF-32 is a fixed length (32-bit) encoding
- UTF-8 and UTF-16 are variable length
  - UTF-8 (use 1, 2 or 4 byte)
    - UTF-8 one byte character is the same as ASCII
  - UTF-16 (use 2 or 4 byte)
- C character is ASCII (no built-in support for UTF)
- Java character is UTF-16

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

```
// 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)

```
void tolower_string(char *s) {


}
```

Strings

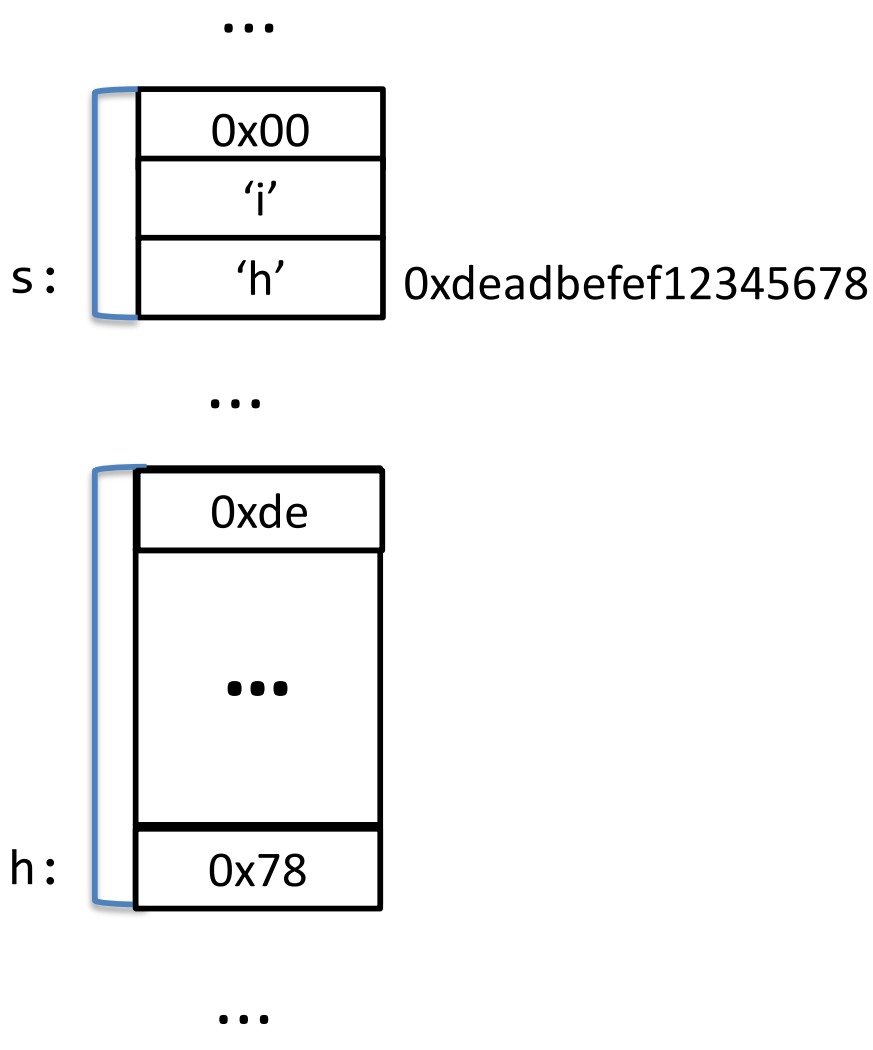
- String is represented as an array of chars.
  - Array has no space to encode its length.
- How to determine string length?
  - explicitly pass around an integer representing length
  - C string stores a NULL character to mark the end (by convention)

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

Copying string?

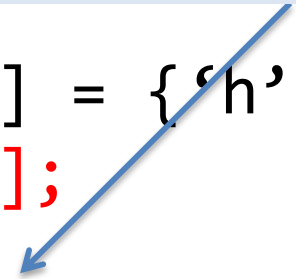
does this make a copy of "hi"?

```
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"?



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

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

Copying string

```
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);
}
```

Copying string

```
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);
}
```

strcpy is included in C std library.

Copying string

```
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

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

strncpy is included in C std library.

```
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);
}
```

A different way of initializing string …

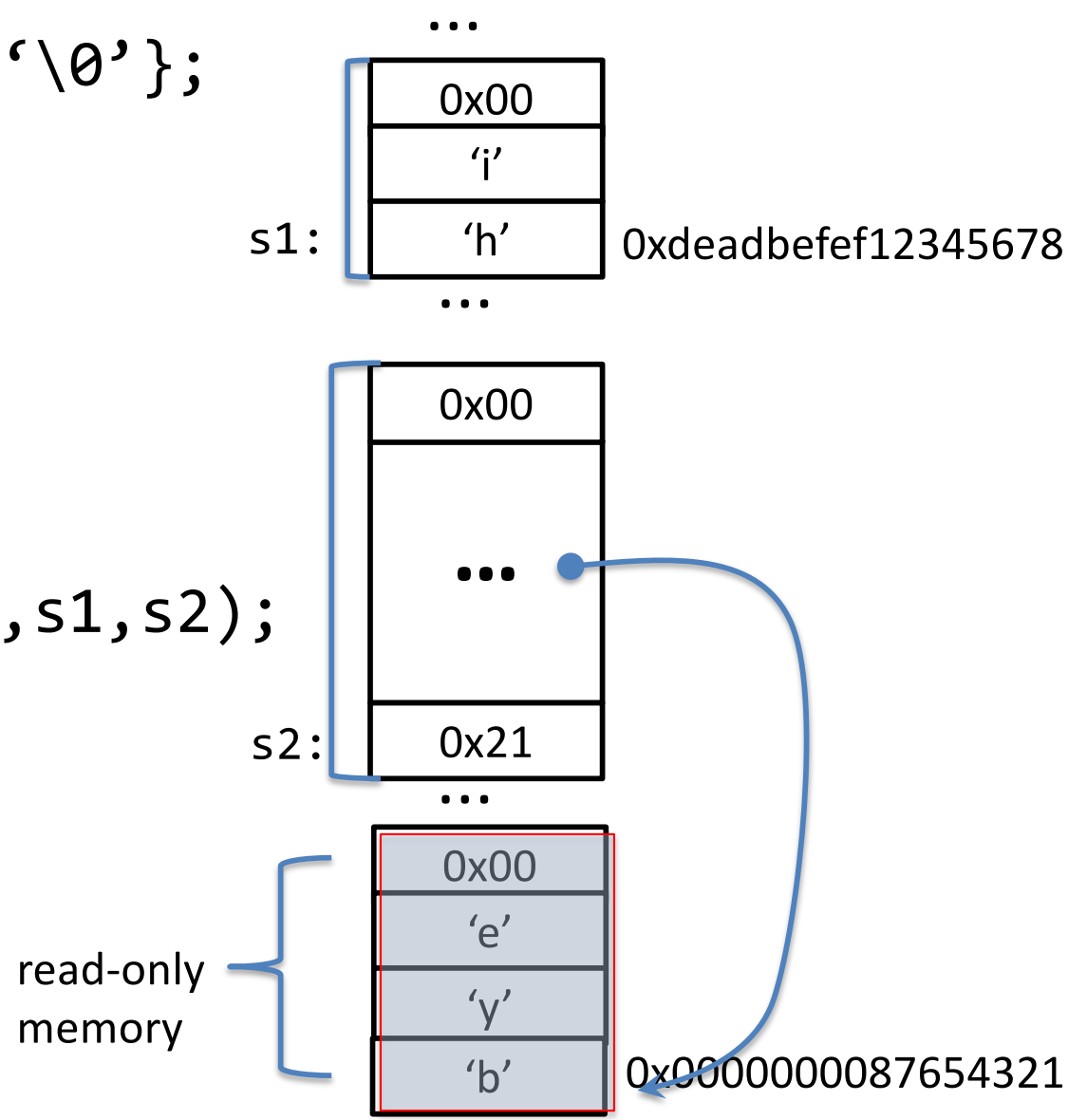
```
char s1[3] = {‘h’,‘i’,‘\0’};
//equivalent to
//char s1[3] = “hi”;
char *s2 = “bye”;
s1[0] = ‘H’;
s2[0] = ‘B’;

printf(“s1=%s s2=%s\n”,s1,s2);
```

OK

Segmentation fault (bus error)

A different way of initializing string

```
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);
```

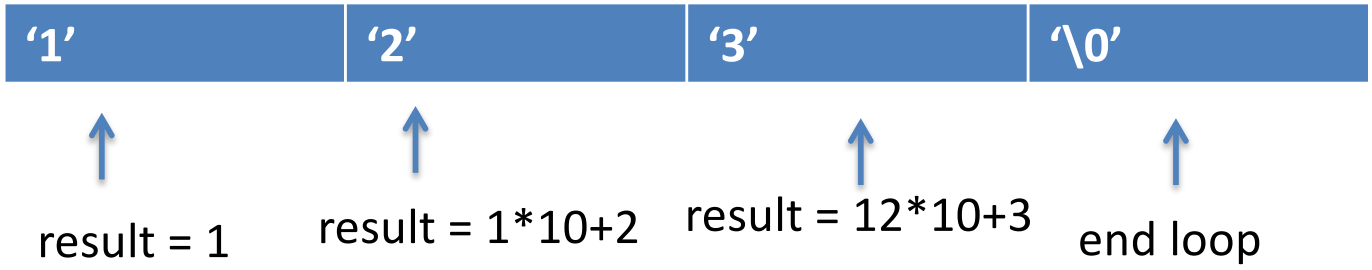


The Atoi function

```
// 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));
}
```

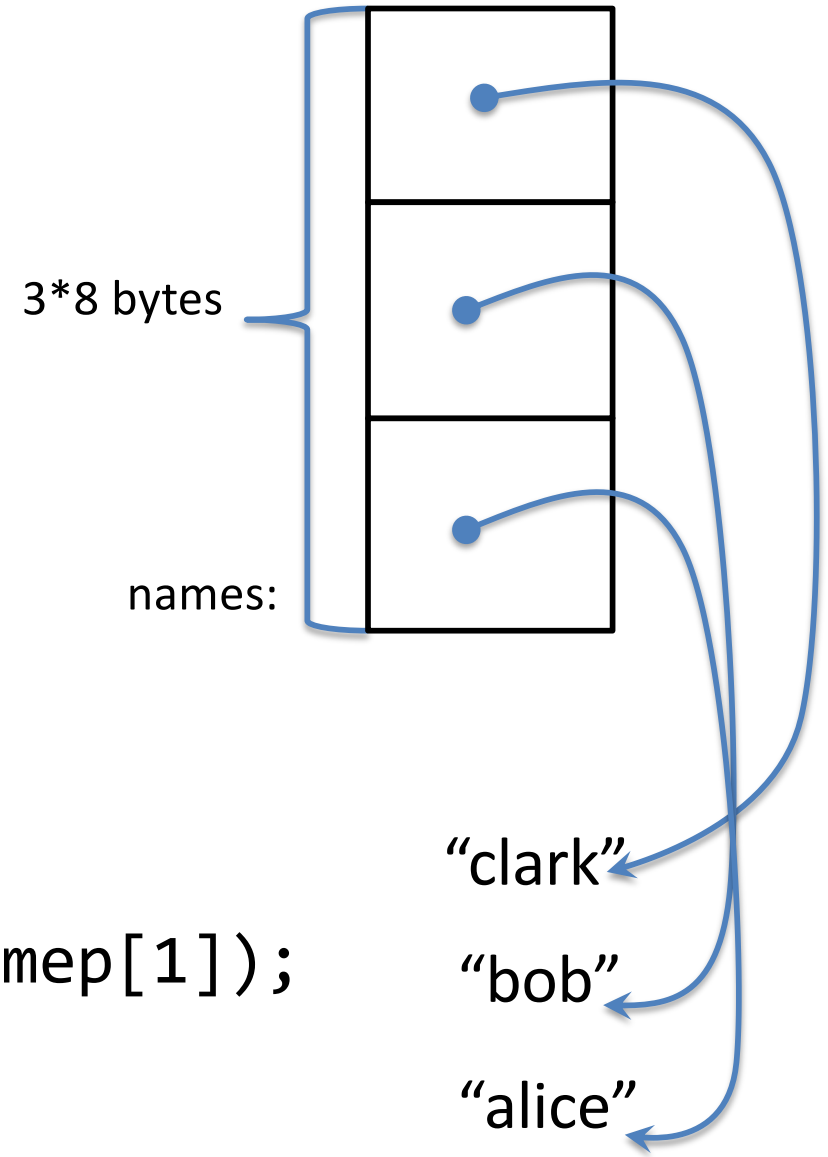
The Atoi function

```
// 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;
}
```



Array of pointers

```
char* names[3] = {
    “alice”,
    “bob”,
    “clark”
};
```




```
char **namep;
namep = names;

printf(“name is %s”, namep[1]);
```

The most commonly used array of pointers: argv

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

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

argv[0] is the name of the executable

What we've learnt so far

- Pointers and arrays
  - Pointers are addresses

```
*(p+i) ↔ a[i]
```

- ASCII characters

```
assert('0' != 0)
assert('\0' == 0)
```

- C string
  - an array of characters terminated by '\0'
  - Programmers are responsible for storing '\0' at the end

```
char s[10] = "hello";
s[1] = '\0';
printf("s=%s", s);
```

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 diffferent types.

Structure

```
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

```
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;
t.name = “alice”;
```

Access the fields of this struct

Typedef

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

~~struct~~ student t;
```

Pointer to struct

```
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

```
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.

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

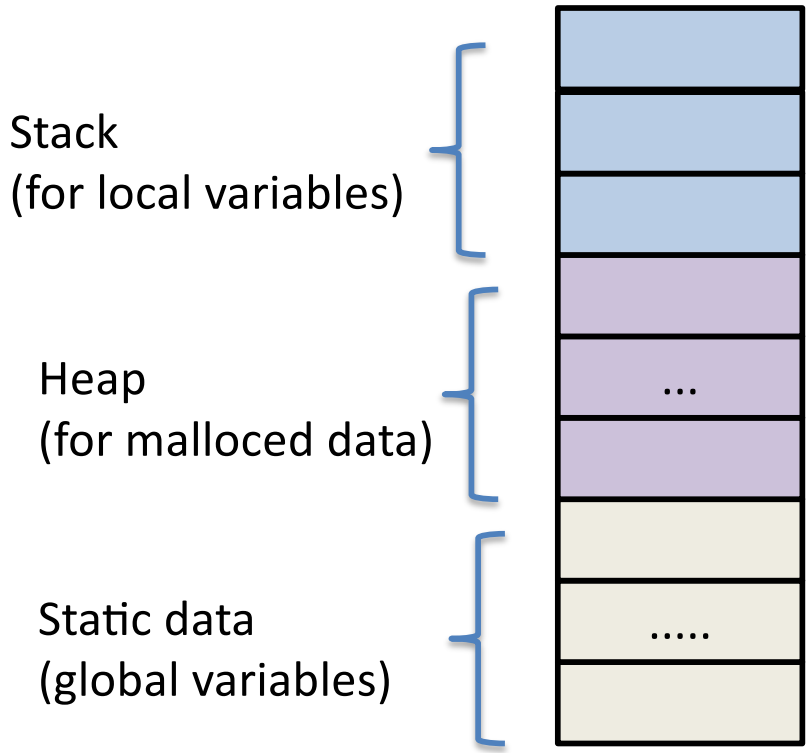
Malloc

Malloc is implemented as a C library

```
#include <stdlib.h>

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

Conceptual view of a C program's memory at runtime

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



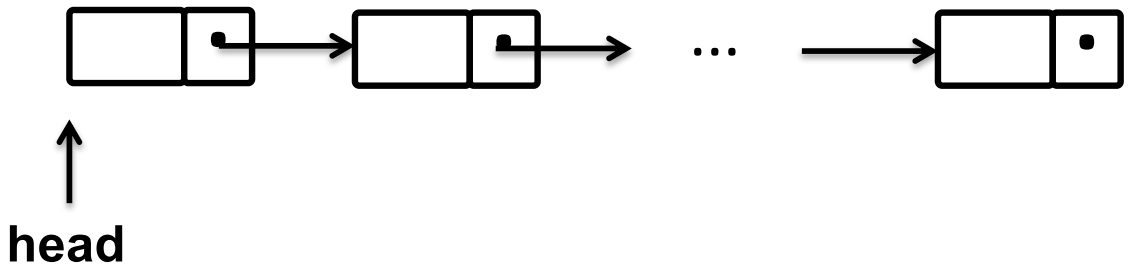
We will refine this simple view in later lectures

Linked list in C: insertion

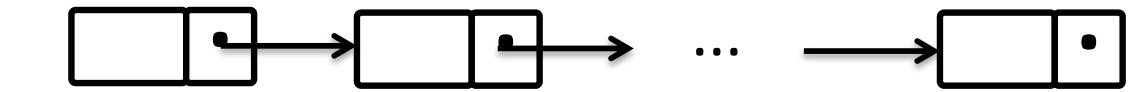
```
typedef struct {
      int val;
      struct node *next;
 }node;

// 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);
}
```

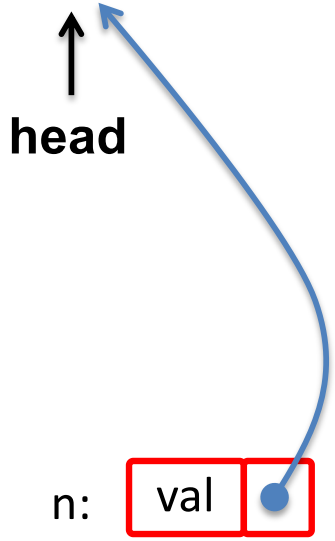
⚠ This linked list implementation is different from Lab1

Inserting into a linked list

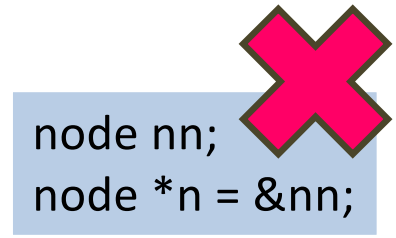


Inserting into a linked list

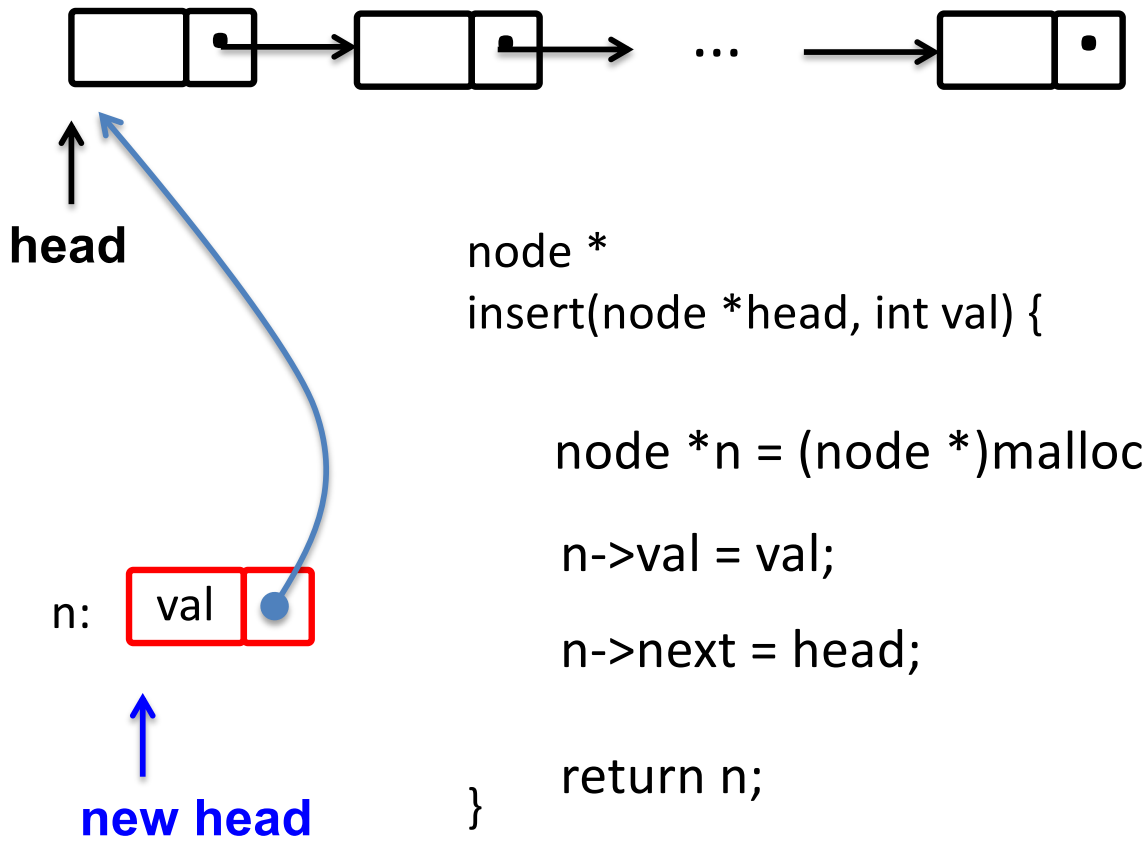





```
node *
insert(node *head, int val) {
    node *n = (node *)malloc(sizeof(node));
    n->val = val;
    n->next = head;

}
```



Inserting into a linked list

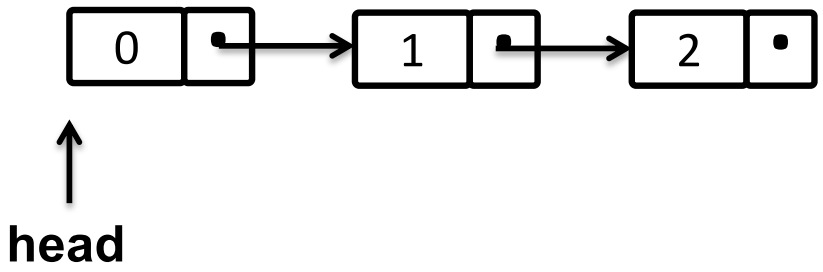



```
node *
insert(node *head, int val) {

    node *n = (node *)malloc(sizeof(node));

    n->val = val;

    n->next = head;

    return n;
}
```

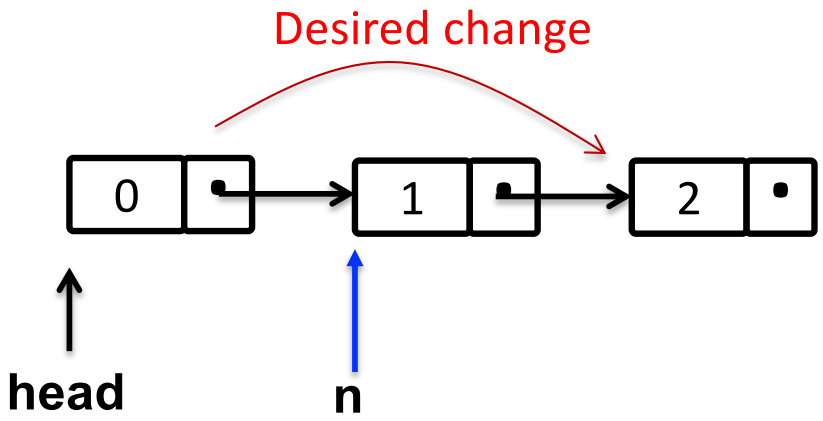
Linked list in C: removal

```
// remove node with val from linked list, return the new
// head of the list.
node*
remove(node *head, int val) {

}

int main() {
    node *head = NULL;
    for (int i = 0; i < 3; i++)
       head = insert(head, i);
    head = remove(head, 1);
    head = remove(head, 0);
}
```

Removing from a linked list



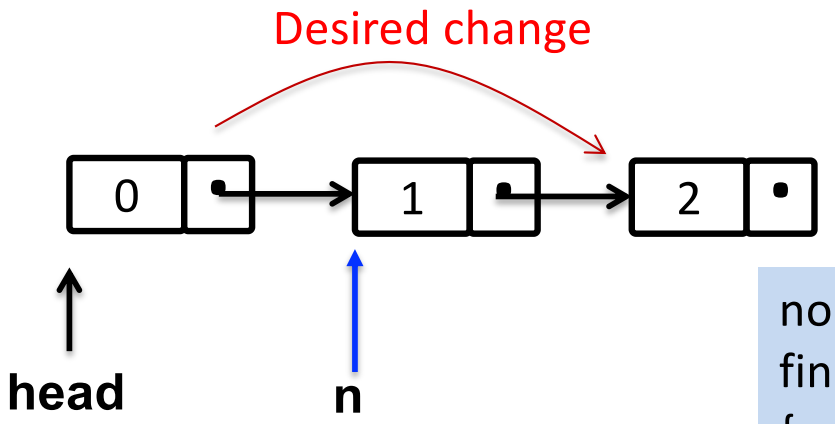
Removing from a linked list




```
node *
remove(node *head, int val) {
    node *n;
    n = find_node(head, val);
    // ???? How to get to n's predecessor?
}
```

```
node *
find(node *head, int val) {
    node *n = head;
    while (n) {
        if (n->val == val)
            return n;
        n = n->next;
    }
    return NULL;
}
```

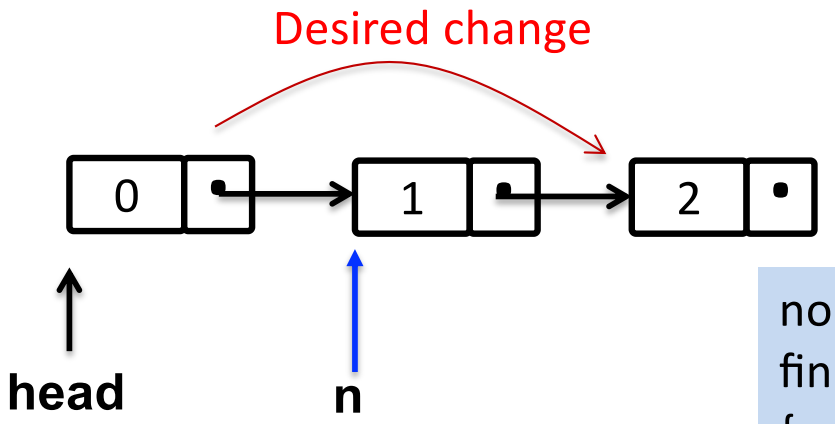
Removing from a linked list




```
node *
remove(node *head, int val) {
    node *n;
    node *pred;
    n = find_node(head, val, &pred);

}
```

```
node *
find(node *head, int val, node **predp)
{
    node *n = head;
    *predp = NULL;
    while (n) {
      if (n->val == val)
            return n;
      *predp = n;
      n = n->next;
    }
    return NULL;
}
```

Removing from a linked list




```
node *
remove(node *head, int val) {
    node *n;
    node *pred;
    n = find_node(head, val, &pred);
    if (!predp && n)
      head = n->next;
    else if (!n)
    else
       predp->next = n->next;
     free(n);
     return head;
}
```

```
node *
find(node *head, int val, node **predp)
{
    node *n = head;
    *predp = NULL;
    while (n) {
      if (n->val == val)
            return n;
      *predp = n;
      n = n->next;
    }
    return NULL;
}
```