

Dynamic Memory Allocation

ITSC 2181: Introduction to Computer Systems
UNC Charlotte
College of Computing and Informatics

Why Dynamic Memory Allocation?

- Don't know how much data will need to be stored until runtime; choices?

Choice 1: Declare **static array** of maximum size that could possibly occur

```
#define MAXCLASSSIZE 500
struct student { ...definition here... };
struct student students[MAXCLASSSIZE];

int i = 0;
while (more_students && (i < MAXCLASSSIZE))
    readstudents (students[i++]);
```

Why Dynamic ... (cont'd)

Choice 2: Declare **dynamic (auto) array** of specific size needed, at run time

```
int main (void) {  
    int maxnum;  
    printf("Number of students in class? \n");  
    scanf("%d", &maxnum);  
    struct student students[maxnum];  
  
    int i = 0;  
    while (more_students && (i < maxnum))  
        readstudents (students[i++]);  
}
```

Why Dynamic... (cont'd)

Choice 3: Allocate memory **dynamically** using a standard library function (**malloc** or **calloc**)

```
#include <stdio.h>
#include <stdlib.h>
...
int main(void) {
    struct student *sp;
    while (more_students) {
        sp = (struct student *)
            calloc (num, sizeof(struct student));
        if (sp != NULL)
            readstudents (sp);
    }
}
```

Dynamic Storage Allocation

- Dynamic storage allocation is used most often for strings, arrays, and structures.
- Dynamically allocated structures can be linked together to form lists, trees, and other data structures.
- Dynamic storage allocation is done by calling a memory allocation function.

Memory Allocation Functions

- The `<stdlib.h>` header declares three memory allocation functions:

`malloc` — Allocates a block of memory but doesn't initialize it.

`calloc` — Allocates a block of memory and clears it.

`realloc` — Resizes a previously allocated block of memory.

- These functions return a value of type `void *` (a “generic” pointer).

Null Pointers

- If a memory allocation function can't locate a memory block of the requested size, it returns a ***null pointer*** (***NULL***).
- A null pointer is a special value that can be distinguished from all valid pointers.
- After we have stored the function's return value in a pointer variable, we must test to see if it is a null pointer.

Null Pointers

- An example of testing **malloc**'s return value:

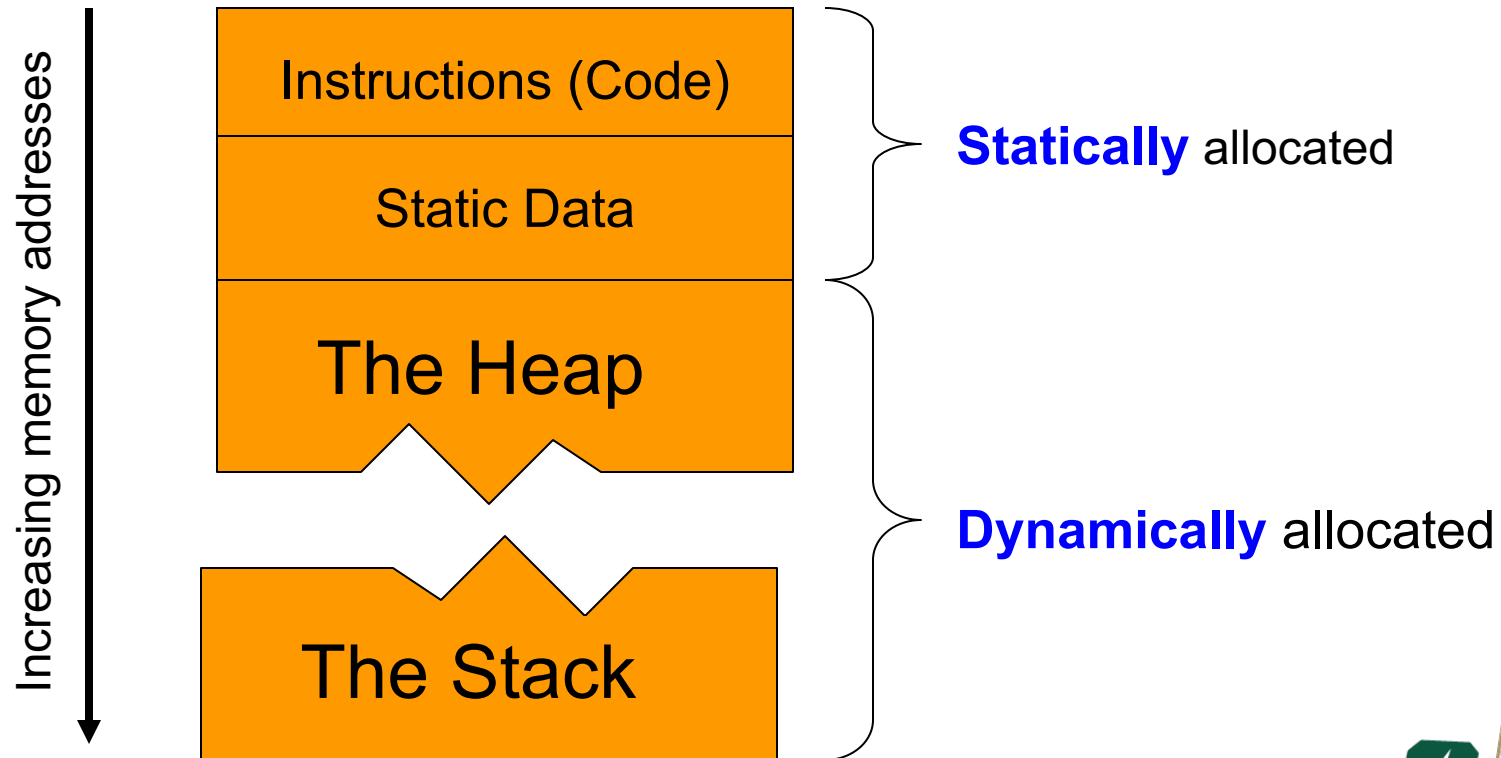
```
p = malloc(10000);  
if (p == NULL) {  
    /* allocation failed; take appropriate action */  
}
```

- **NULL** is a macro (defined in various library headers) that represents the null pointer.
- Some programmers combine the call of **malloc** with the **NULL** test:

```
if ((p = malloc(10000)) == NULL) {  
    /* allocation failed; take appropriate action */  
}
```


Memory Layout of a Program

- The **heap** is an area of *virtual memory* available for dynamic (runtime) memory allocation



C vs. Other Languages

- **C** requires you to **manually allocate and reclaim** memory.
- Other languages (e.g., Java, Python, C#) automatically allocate and reclaim memory for you.

The **sizeof** Operator

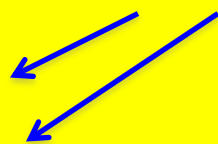
- Not a function call; a **C operator**
 - returns **number of bytes** required by a data type
- Return value is of predefined type **size_t**

(see `sizeof_example.c` in
Code samples and
Demonstrations in Canvas)

```
#include <stdlib.h>
size_t tsz1, tsz2, tsz3;
int a;
float b[100];
struct student { ...definition here... } st;
```

```
tsz1 = sizeof (a);    /* 4 */
tsz2 = sizeof (b);    /* ? */
tsz3 = sizeof (st);   /* ? */
```

what are these sizes?



The `malloc()` Std. Lib. Function

- Syntax: `void * malloc (size_t sz)`
- OS allocates `sz` bytes of contiguous storage
 - Uninitialized
- Returns starting address of storage
 - If size is 0, returns NULL or unique pointer that can be freed

💀 common source of bugs 💀
malloc() does not initialize memory

```
students = (struct student *)  
           malloc ( num * sizeof(struct student));  
ip = (int *) malloc (sizeof (int));  
cp = (char *) malloc ( 1000 * sizeof (char));
```

(see `examples.c` in *Code samples and Demonstrations in Canvas*)

The `calloc()` Standard Library Function

Syntax: `void *``calloc (size_t num, size_t sz)`

Generic pointer, must be cast to type of result

OS allocates (`num * sz`) **bytes** of contiguous storage (all bytes **initialized** to zeros)

```
struct student * students;  
students = (struct student *)  
           calloc (num, sizeof(struct student));  
int * ip;  
ip = (int *) calloc (1, sizeof (int));  
char *cp;  
cp = (char *) calloc (1000, sizeof (char));
```



calloc() (cont'd)

- Return value is starting address of the storage allocated
- If not enough memory available, returns **NULL**
 - Could also be a unique pointer that could be passed to free()
 - **ALWAYS** check for this error

💀 common source of bugs 💀
failure to check
return value

```
cp = (char *) calloc (1000, sizeof (char));  
if (cp == NULL) {  
    printf("Cannot allocate memory; exiting\n");  
    exit (-1);  
}
```

The `free()` Standard Library Function

- Syntax: `void free (void * ptr)`
 - no way to check for errors!
 - `ptr` **must** have been previously allocated by `malloc()` or `calloc()`
 - no need to specify **amount** of memory to be freed.
 - Frees (for other uses) memory previously allocated

```
free(students) ;  
free (ip) ;  
free (cp) ;
```

💀 *common source of bugs* 💀
*failure to free
unused memory*

Dynamic Memory Allocation

Common Mistakes

- These bugs can **really** be hard to find and fix
 - May run for hours before the bug pops up, and in a place that appears to have no relationship to the actual cause of the error

Mistake **M1**: Invalid Pointers

- Problems?

💀 *common source of bugs* 💀

```
int i, j, result;  
result = scanf ("%d %d", i, &j);
```

```
char *ptr;  
...  
ptr = 'A';  
...  
*ptr = 'B';
```

(see [invalid1.c](#) and [invalid2.c](#) in Code samples and Demonstrations in Canvas)

Invalid Pointers (cont'd)

- Problems?

💀 *common source of bugs* 💀

```
int * f( void )  
{  
    int val;  
    ...  
    return &val;  
}
```

(see `invalid3.c` in Code samples and Demonstrations in Canvas)

why is this a problem?

Invalid Pointers (cont'd)

- Problems? Fix?

💀 *common source of bugs* 💀

```
...dynamically allocate and construct a linked list...
```

```
...
```

```
/* now list is no longer needed,  
 * free memory  
 */
```

```
for (p = head; p != NULL; p = p->next)  
    free(p);
```

why is this a problem?

M2: Not Initializing Memory

- Problems?

💀 *common source of bugs* 💀

```
int * sumptr;  
int ival[100] = { ...initial values here... };  
int i;  
  
sumptr = (int *) malloc ( sizeof(int) );  
  
for (i = 0; i < 10; i++)  
    *sumptr += ival[i];
```

(see `no_initialization.c` in Code
samples and Demonstrations in Canvas)

M3: Stack Buffer Overflows

```
void bufoverflow (void)
{
    char buf[64];

    (void) gets(buf);
    return;
}
```

💀 *common source of bugs* 💀

- Problems?
- One of the biggest sources of **security** problems

Are you sure the input will be no more than 64 characters long?

M4: Writing Past End of Dynamically Allocated Memory

```
int i, sz;  
int *ip, *jp;  
  
(void) scanf ("%d", &sz);  
ip = (int *) calloc (sz, sizeof(int));  
...check for errors here...  
  
jp = ip;  
for (i = 0; i <= sz; i++)  
    (void) scanf ("%d", jp++);
```

💀 common source of bugs 💀

why is this a problem?

M5: Freeing Unallocated Memory

Problems?

```
int i;  
int *ip;  
  
ip = &i;  
...  
free(ip);
```

💀 *common source of bugs* 💀

why is this a problem?

(see `allocate.c` in Code samples and Demonstrations in Canvas)

Freeing Unallocated ...(cont'd)

- Problems?

```
int *ip;  
  
ip = (int *) calloc (1000, sizeof(int));  
...  
free(ip);  
...  
free(ip);
```

💀 *common source of bugs* 💀

(see `double_free.c` in Code samples and Demonstrations in Canvas)

M6: Memory Leaks

💀 *common source of bugs* 💀

- Allocated memory is referenced using pointer returned by allocation
- If you lose pointers (free them, change to another address), you can no longer reference or free allocated memory
- Common problem in large, long-running programs (think: servers)
 - over time, memory footprint of program gets bigger, bigger, ...

M6: Memory Leaks

```
void leak (int n)
{
    int * xp;
    xp = (int *) malloc (n * sizeof(int));
    ...memory is used and then no longer needed...
    return;
}
```

💀 common source of bugs 💀

why is this a problem?

No use of `free` to release memory.

Automatic Garbage Collection?

C requires you to **manually** allocate and reclaim memory,
e.g...

```
void addFirst (Object obj) {
    Node * newNode =
        (Node *) malloc (sizeof(Node));
    assert( newNode != NULL );
    newNode->data = ...;
    newNode->next = first;
    first = newNode;
}

Object removeFirst() {
    assert (first != NULL);
    Node * old = first;
    Object obj = first->data;
    first = first->next;
    free (old);
    return obj;
}
```

Programmer explicitly
indicates there are no
more references to
the removed object



References

- S. J. Matthews, T. Newhall and K. C. Webb, *Dive into Systems*, Version 1.2. Free online textbook, available at:
<https://diveintosystems.org/book/>
- K. N. King, *C Programming: A Modern Approach*, 2nd Edition. W. W. Norton & Company. 2008.
- D.S. Malik, *C++ Programming: From Problem Analysis to Program Design*, Seventh Edition. Cengage Learning. 2014.