

Structures

Data aggregates

Like classes (in Java) except usually contain no func

Structure members are public (we'll learn this later)

```
struct student_data
{
    char    name[30];
    int     age;
    int     sid;
}; /* <== DO NOT FORGET the semicolon */
```

typedef

typedef <type definition> new_type_name;

```
struct student_data
{
    char    name[30];
    int     age;
    int     sid;
};

typedef struct student_data student;
```

typedef

typedef <type definition> new_type_name;

```
typedef struct student_data
{
    char    name[30];
    int     age;
    int     sid;
} student; //another way to write the typedef
```

Structures

```
#include <iostream>

typedef struct student_data
{
    char    name[30];
    ...
} student;

int main(int argc, char* argv[]) {
    student amza; //or struct student_data amza;
    cin >> amza.name;
    cin >> amza.age;
    cin >> amza.sid;
    cout << "name =" << amza.name << ", age =" << amza.age << endl;
    return 0;
}
```

Pointers

Topics

- Simple memory allocation and addressing
 - Pointers
 - Example Mechanisms
 - Operators for use with pointers
- Dynamic memory allocation

Harsh Reality

Memory Matters

Memory is not unbounded

- It must be allocated and managed

Memory referencing bugs especially pernicious

- Effects are distant in both time and space (e.g., accessing an uninitialized variable).

Memory Management

A variable lives in some memory location for some time

Memory is allocated to variables in two ways

- Automatic allocation: through variable declaration
 - e.g., `int i;` //allocates 4 bytes for i upon entering scope/function
- Dynamic allocation: using `new`
 - e.g., `new double;` //allocates 8 bytes upon calling `new`

Scope = Enclosing block for a variable - could be a func

or

artificially created by using `{int i;}` within func body

Memory Management

A variable lives in some memory location for some time

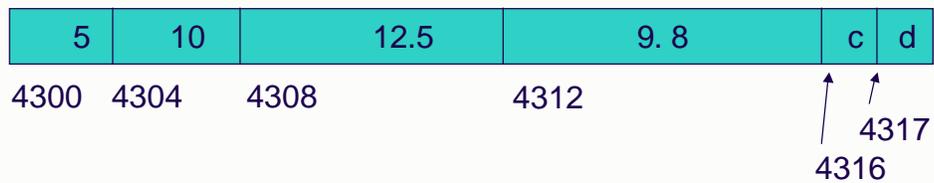
The variable lifetime is

- Automatic allocation: within scope
 - e.g., `int i;` //while enclosing function instantiation is active
- Dynamic allocation: until programmer explicitly frees block
 - e.g., `new double;` //until program calls `delete` (outlives scope)

Memory layout and addresses

Example using automatic allocation:

```
int x = 5, y = 10; //automatic vars
float f = 12.5, g = 9.8;
char c = 'c', d = 'd';
```



Pointers

Definitions:

“Pointers are variables that hold a memory address”

e.g., a pointer `p` contains an address `addr`

The memory address `addr` contains another variable `var`

We say that pointer `p` “points to” variable `var`

Pointers

Definitions:

“Pointers are variables that hold a memory address”

We say that pointer **p** “points to” variable **var**

Declarations:

```
float f; //variable of type float
```

```
float *p; //pointer to variable of type float
```

Pointer Initialization/Assignment

Q: How do we get the memory address of a variable ?

A: the “get address” operator: **&**

```
float f; //variable of type float
```

```
float *p; //pointer to variable of type float
```

```
p = &f;
```

Data Representations (revisited)

Sizes of C++ Objects (in Bytes)

■ Data Type	Compaq Alpha	Typical	Intel IA32
● int	4	4	4
● long int	8	4	4
● char	1	1	1
● short	2	2	2
● float	4	4	4
● double	8	8	8
● char *	8	4	4

» Or any other pointer

“Word Size” (Convention)

- Size of integer data (i.e., typically 4 bytes)

Pointer Dereferencing

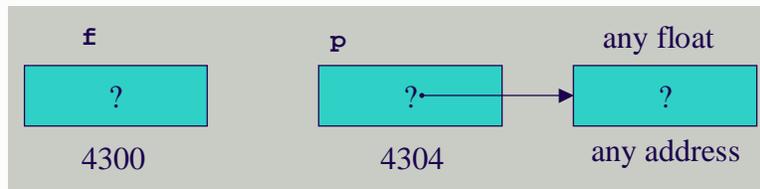
Q: Get the value of the variable “pointed-to” by pointer

A: the “indirection” operator: *

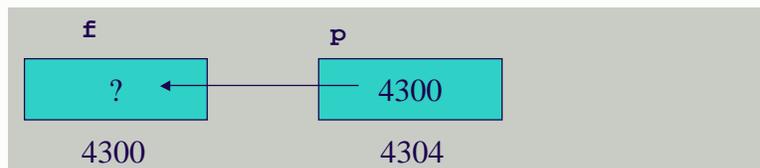
```
float f = 3.2;    //variable of type float
float *p;        //pointer to variable of type float
p = &f;
cout << *p;     //prints the var “pointed-to” by p
                // (i.e., var at address p)
```

Using Pointers (1)

```
float f;      /* data variable */  
float *p;    /* pointer variable */
```



```
p = &f;      /* & = address operator */
```



Pointer Dereferencing

Q: Get the value of the variable “pointed-to” by pointer

A: the “indirection” (a.k.a. “dereferencing”) operator: *

```
float f;      //variable of type float  
float *p;    //pointer to variable of type float  
*p = 3.2;    //WRONG !!  
             //Dereferencing an uninitialized pointer  
             //Typically results in SEGFAULT (bombing)
```

Pointer Dereferencing

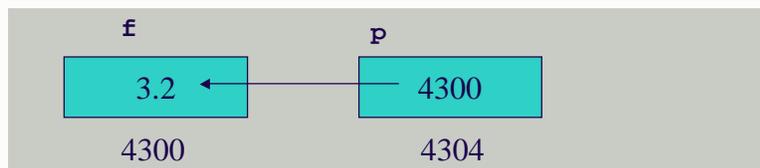
Q: Get the value of the variable “pointed-to” by pointer

A: the “indirection” operator: *

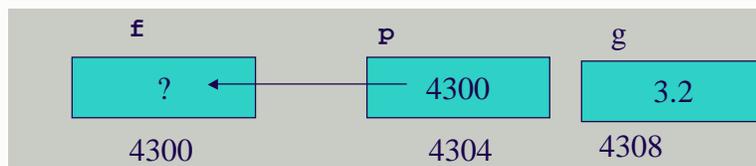
```
float f;          //variable of type float
float *p = &f;   //pointer to variable of type float
*p = 3.2;        //LHS is the var “pointed-to” by p
cout << f;      //prints the value of var
```

Pointers made easy (2)

```
float f;          /* data variable */
float *p = &f;    /* initializing pointer variable */
*p = 3.2;        /* use of indirection operator */
```

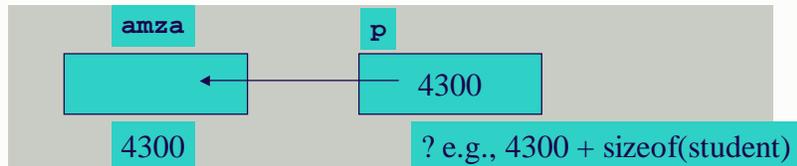


```
float g = *p;    /* indirection: g is now 3.2 */
*p = 1.3;        /* f becomes 1.3 but g is still 3.2 */
```

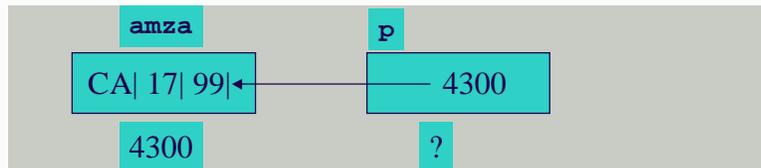


Pointers made easy (2)

```
student amza;      /* data variable */
student* p;        /* pointer variable */
p = &amza;         /* use of indirection operator */
```



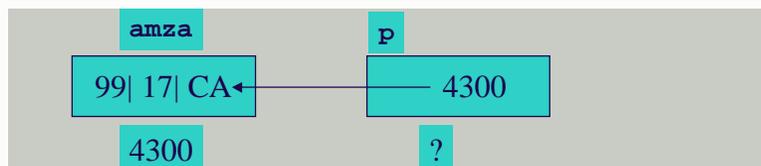
```
(*p).sid = 99;      /* indirection: amza.sid is now 999*/
(*p).age = 17;      /* amza.age is 17 */
cin >> (*p).name;  /* say we input "CA" */
```



The → Operator (instead of * and .)

```
student amza;      /* data variable */
student* p;        /* pointer variable */
p = &amza;         /* use of indirection operator */
```

```
p → sid = 99;      /* indirection: amza.sid is now 999*/
p → age = 17;      /* amza.age is 17 */
cin >> p → name;  /* say we input "CA" */
```



Dynamic Memory Allocation

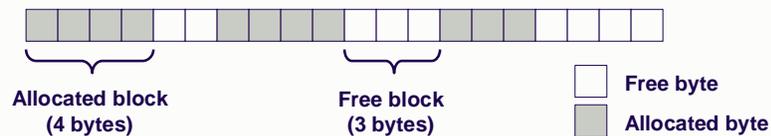
Java manages memory for you, C++ does not

- In Java programmer allocates with `new`, but does not free space (garbage collection in Java)
- C++ requires the programmer to *explicitly* allocate and deallocate memory
- Memory can be allocated dynamically during run-time with `new` and deallocated (freed) using `delete`

Memory

Memory allocated with `new`, de-allocated with `delete`

`new` returns address of (pointer to) allocated block



The memory allocator provides an abstraction of memory as a set of blocks

Use of New/Delete

`new double;`

- If successful:

- Returns a pointer to a memory block of at least `sizeof (double)` bytes, i.e. 8, (typically) aligned to 8-byte boundary.

`delete p;`

- Returns the block pointed to by `p` to pool of available memory
- `p` must come from a previous call to `new`.

new

Allocates memory in the heap

- Lives between function invocations

Examples

- Allocate an integer

- `int* iptr = new int;`

- Allocate a structure

- `struct student_data* amzaptr = new student;`
(same as: `student* amzaptr = new student;`)
(same as:
`student* amzaptr = new struct student_data;`)

delete

Deallocates memory in heap.

Pass in a pointer that was returned by new.

Examples

- Allocate an integer
 - `int* iptr = new int;`
 - `delete iptr;`
- Allocate a structure
 - `struct student_data* amzaptr = new student;`
 - `delete amzaptr;`

Caveat: don't free the same memory block twice!

Examples

```
typedef struct student_data
{
    char    name[30]; ...
} student;
```

```
typedef struct two_chars {
    char    first_char;
    char    second_char;
} two;
```

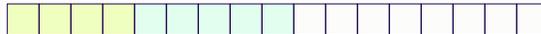
```
typedef struct five_chars {
    char    first_char;
    char    second_char; ...
    ... char    fifth_char;
} five;
```

Allocation/Dealloc. Examples

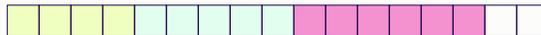
```
p1 = new int;
```



```
p2 = new struct five_chars;
```



```
p3 = new struct six_chars;
```



```
delete p2;
```



```
p4 = new struct two_chars;
```



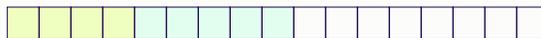
Allocation/Dealloc. Examples

```
p1 = new int;
```



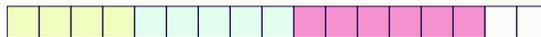
↑ p1

```
p2 = new five;
```



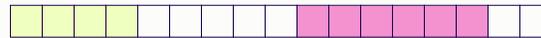
↑ p2

```
p3 = new six;
```



↑ p3

```
delete p2;
```



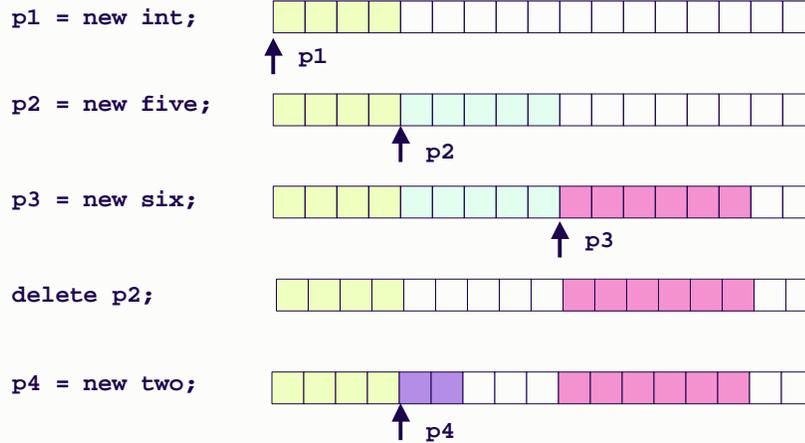
```
p4 = new two;
```



↑ p4

Pointer Declarations

```
int *p1; five *p2; six *p3; two *p4;
```



Dynamic Allocation Example

```
void foo(int n, int m) {
    int i, *p; //automatic allocation

    /* dynamically allocate a block of 4 bytes */
    if ((p = new int) == NULL) {
        cerr << "allocation failed";
        exit(0);
    }

    *p = 5;

    /* print the content of the newly allocated space */
    cout << *p << endl;

    i = *p;

    /* print the content of i */
    cout << i << endl;

    delete p; /* return 4 bytes to available memory */
              /* cannot access this space with *p anymore */

    /* print the content of i */
    cout << i << endl;
}
```

How about pointers inside structs ?

```
typedef struct four_chars {
    char    first_char;
    char    second_char; ...
    ... char    fourth_char;
} four;

typedef struct four_plus_two_chars {
    four    *first_four_chars;
    two     *last_two_chars;
} four_plus_two;
```

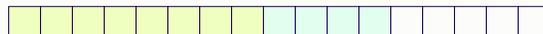
How about pointers inside structs ?

Need to allocate nested objects. Need to deallocate them correspondingly.

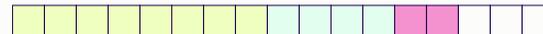
```
p1 = new four_plus_two;
```



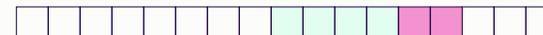
```
p2 = new four; p1->first_four_chars = p2;
```



```
p3 = new two; p1->last_two_chars = p3;
```



```
delete p1;
```



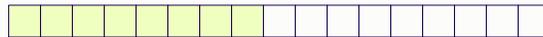
Oops !

Memory leak ! (garbage left around, need to delete all allocated blocks)

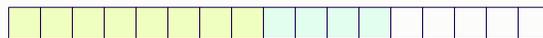
Easy fix because we kept p2 and p3

Need to allocate nested objects. Need to deallocate them correspondingly.

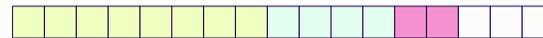
```
p1 = new four_plus_two;
```



```
p2 = new four; p1->first_four_chars = p2;
```



```
p3 = new two; p1->last_two_chars = p3;
```



```
delete p2;
```



```
delete p3;
```



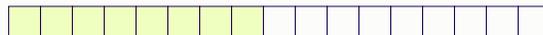
```
delete p1;
```



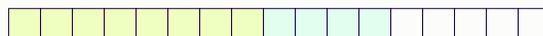
Usually only pointer to “top” is kept

Need to allocate nested objects. Need to deallocate them correspondingly.

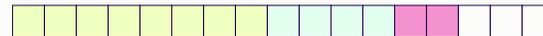
```
p1 = new four_plus_two_chars; (“top” pointer to object)
```



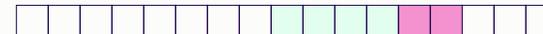
```
p1->first_four_chars = new four;
```



```
p1->last_two_chars = new two;
```



```
delete p1;
```



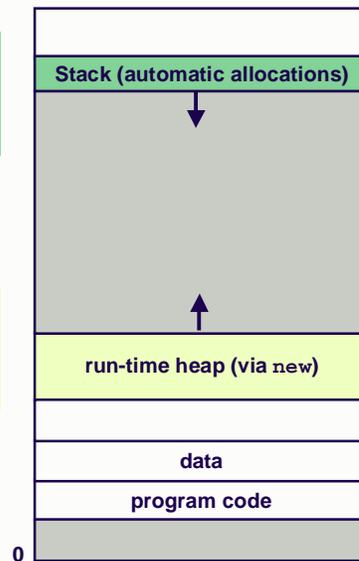
Oops !

Memory leak ! (garbage left around, cannot get to the remaining blocks !!)

Process Memory Image

Automatic variables are allocated memory on the stack. Stack grows downwards

Dynamic Memory Allocator requests memory from the heap. Heap grows upwards



Dynamic (Heap) Memory Allocator Summary: Not like Java

No garbage collection

Operator **new** is still a high-level request such as "I'd like an instance of class `String`"

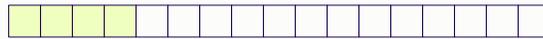
Try to think about it low level

- You ask for n bytes (the `sizeof` that type/class)
- You get a pointer (memory address) to the allocated object

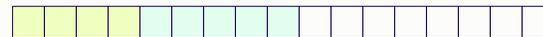
Heap Allocator Internals

Memory allocated in a **contiguous** block. **External Fragmentation**: when enough aggregate heap memory, but no single free block is large enough.

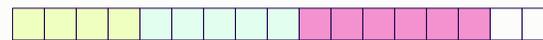
```
p1 = new four;
```



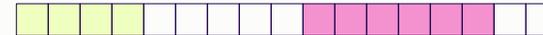
```
p2 = new five;
```



```
p3 = new six;
```



```
delete p2;
```



```
p4 = new six; //cannot allocate a block of 6 bytes  
             //this allocation fails due to  
             //"no more heap space"
```

Automatic Allocator Internals

Automatic allocation of variables occurs on the stack
We'll learn how the stack works next