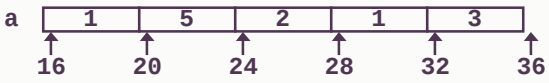
Pointers & Memory Allocation Wrap-Up

Topics

- Arrays
- Association between pointers and arrays
- Memory-related perils and pitfalls

Array Example

```
//Automatic allocation and init
int a[] = { 1, 5, 2, 1, 3 };
```



Notes

- Declaration above equivalent to:

  #define N 5

  `int a[N]; a[0] = 1; a[1] = 5; … a[4] = 3;`
- Code Does Not Do Any Bounds Checking !

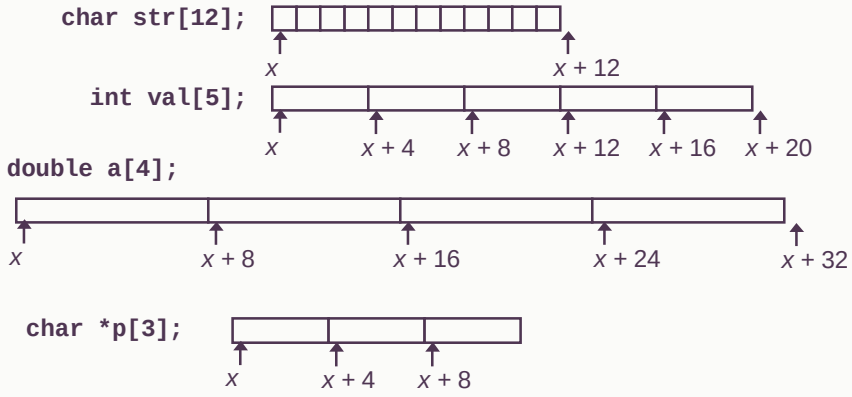
  Valid range 0 – (N –1)

Array Allocation

Basic Principle

T `A[`*L*`];`

- Array of data type *T* and length *L*
- Contiguously allocated region of *L* * `sizeof(`*T*`)` bytes

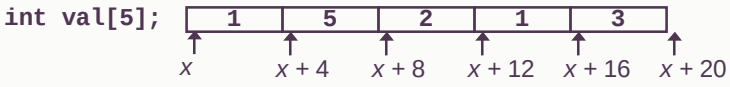


Array Access

Basic Principle

T `A[`*L*`];`

- Array of data type *T* and length *L*
- Identifier `A` can be used as a pointer to array element 0



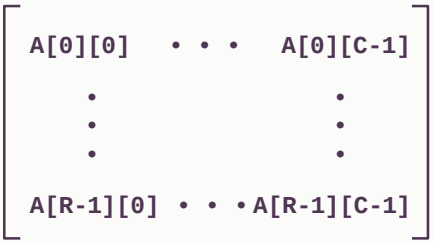
Reference	Type	Value
`val[4]`	`int`	3
`val`	`int *`	*x*
`val+1`	`int *`	*x* + 4 //!!! Adds sizeof(int)
`&val[2]`	`int *`	*x* + 8
`val[5]`	`int`	??
`*(val+1)`	`int`	5
`val + i`	`int *`	*x* + 4 *i*

Multi-Dimensional Array Allocation

Declaration

T `A[`*R*`][`*C*`];`

- Array of data type *T*
- *R* rows, *C* columns
- Type *T* element requires *K* bytes



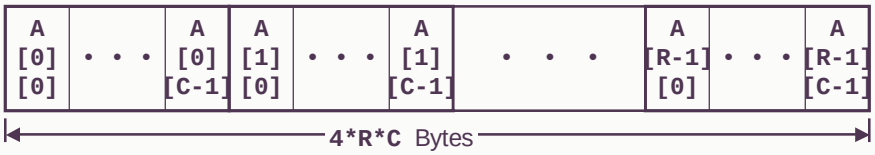
Array Size

- *R* * *C* * *K* bytes

Arrangement

- Row-Major Ordering

`int A[R][C];`

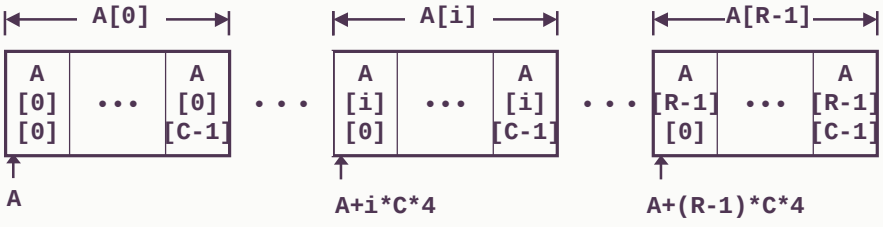


Nested Array Allocation

Row Vectors

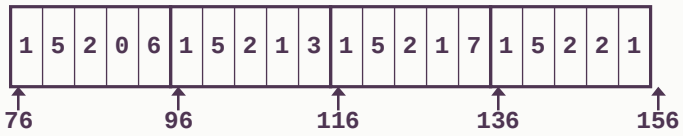
- `A[i]` is array of *C* elements
- Each element of type *T*

`int A[R][C];`



Array Init/Allocation Example

```
#define PCOUNT 4
int p[PCOUNT][5] =
  {{1, 5, 2, 0, 6},
   {1, 5, 2, 1, 3 },
   {1, 5, 2, 1, 7 },
   {1, 5, 2, 2, 1 }};
```



- Allocated contiguously
- Each element is an array of 5 `int`'s

Dynamic Allocation of Array

- int *a;
  (the same as a[N]
  except needs to be allocated dynamically)
- cin >> n;
- a = new int[n];

Feeing of Array Space

- int *a;
- cin >> n;
- a = new int[n];
- delete a[ ]; //Otherwise if say “delete a”
  //only first element is
  //freed

Array Loop Using Pointers

Computations

- zbegin = pointer to begin, zend = pointer to end
- z++ increments by 4

```
int A[10];
int i = 0;
int *zbegin = A;
int *zptr = zbegin;
int *zendptr = A + 10;
 while(zptr < zendptr) {
    i++;
    zptr++;
    cout << A[i] << *zptr;
  }
```

Dyn. Allocation of Multi-Dim Array

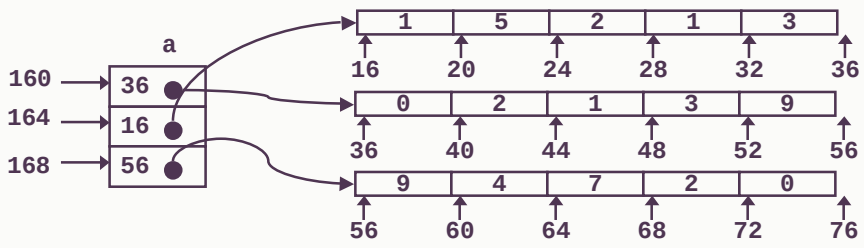
- int **a;
  (the same as a[N][M]
  except needs to be allocated dynamically)

```
cin >> n; cin >> m; //dimensions can be set at run-time

a = new int[n];
for each i
  a[i] = new int[m];
```

Dyn. Allocation of Multi-Dim Array

- int **a;
- Each pointer points to an array of `int`'s



Summary

Arrays in C++

- Contiguous allocation of memory
- Pointer to first element
- No bounds checking

Memory-Related Bugs

Dereferencing “dangling” or NULL pointers

Reading uninitialized memory

Overwriting memory

Referencing nonexistent variables

Freeing blocks multiple times

Referencing freed blocks

Failing to free blocks

Next – examples of each – BAD ! please AVOID !

Dereferencing NULL Pointers

The classic bug:

```
int i;
int *pi = NULL; //pointer pi contains a bad address
cout << *i; //this will likely result in a SEGFAULT
```

Dereferencing “dangling” Pointers

Another classic bug:

```
int i;
int *pi = new int; // pi contains a valid address  addr
…
delete pi;  //pi is now a “dangling” pointer
            //still contains addr, but the object at
            //                addr has just been freed
…
*pi = 5;    //dereferencing a dangling pointer can
            //cause arbitrary memory corruption
```

Reading Uninitialized Memory

Another classic bug (already shown):

```
/* return y = Ax */
int *matvec(int **A, int *x) {
   int *y = new int[N];
   int i, j;

   for (i=0; i<N; i++)
      for (j=0; j<N; j++)
         y[i] += A[i][j]*x[j];
   return y;
}
```

Overwriting Memory

Off-by-one error (all arrays start at 0, go to N-1)

```
int *p;

p = new int[N];

for (i=0; i<=N; i++) {
   p[i] = i;
}
```

```
int **p;

p = new int*[N];

for (i=0; i<=N; i++) {
   p[i] = new int[M];
}
```

Overwriting Memory

Not checking the max string size

```
char s[8];
int i;

cin >> s;  /* reads “123456789” from keyboard */
```

Basis for buffer overflow

Overwriting Memory

Misunderstanding pointer arithmetic

```
int *search(int *p, int val) {

   while (*p && *p != val)
      p += sizeof(int);

   return p;
}
```

Referencing Nonexistent Variables

Forgetting that local variables disappear when a function returns

```
int *foo () {
   int val;
   return &val;
}

int main () {

int *p = foo ();
cout << *p;
//p is a “dangling” pointer
//the variable it was pointing to
//has been freed.
```

Freeing Blocks Multiple Times

Nasty!

```
px = new int;
<manipulate x>
delete px;

py = new int;
<manipulate y>
delete px;
```

Referencing Freed Blocks

Evil!

```
px = new int[N};
<manipulate x>
delete px[];
...
py = new int[M];
for (i=0; i<M; i++)
   y[i] = x[i]++;
```

Failing to Free Blocks (Memory Leaks)

Slow, long-term killer!

```
void foo() {
   int *p = new int[128];
   return; /* p block is now garbage */
}
```

Failing to Free Blocks (Memory Leaks)

Freeing only part of a data structure

```
struct list {
   int val;
   struct list *next;
};

foo() {
   struct list *head =
               new struct list;
   head->val = 0;
   head->next = NULL;
   <create and manipulate the rest of the list>
   ...
   delete head;
   return;
}
```

Dealing With Memory Bugs

Conventional debugger (gdb)

- Good for finding bad pointer dereferences
- Hard to detect the other memory bugs
- Self-guards such as making pointers = NULL when uninitialized or “dangling” (after delete), may make bugs easier to track