Pointers and Arrays

Based on slides from K. N. King and Dianna Xu

Bryn Mawr College
CS246 Programming Paradigm

The NULL Pointer

- C guarantees that zero is never a valid address for data
- A pointer that contains the address zero known as the **NULL** pointer
- It is often used as a signal for abnormal or terminal event
- It is also used as an initialization value for pointers

Pass by Value

- All functions are pass-by-value in C
  - A copy is made of each parameter's value and then the copy is passed
- Variables supplied as parameters to a function call are protected against change
  - i.e. impossible to write a **swap(x, y)** function
- Only way to modify a variable through a function is to assign the return value to that variable

Pass by Value and Pointers

- All functions are pass-by-value in C
- Pass-by-value still holds even if the parameter is a pointer
  - A copy of the pointer's value is made – the address stored in the pointer variable
  - The copy is then a pointer pointing to the same object as the original parameter
  - Thus modifications via de-referencing the copy STAYS.

Function Arguments

- **x** and **y** are copies of the original, and thus **a** and **b** can not be altered.

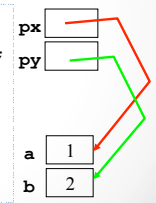
```
void swap(int x, int y) {
  int tmp;
  tmp = x; x = y; y = tmp;
}

int main() {
  int a = 1, b = 2;

  swap(a, b);
  return 0;
}
```

Wrong!

Pointers as Function Arguments

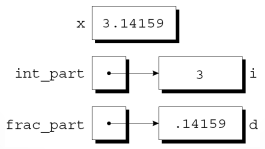
- Passing pointers – **a** and **b** are passed by reference (the pointers themselves **px** and **py** are still passed by value)

```
void swap(int *px, int *py) {
  int tmp;
  tmp = *px; *px = *py; *py = tmp;
}

int main() {
  int a = 1, b = 2;

  swap(&a, &b);
  return 0;
}
```



Pointers as Function Arguments

- Write a function that will decompose a `double` value into an integer part and a fractional part.
- As a result of the call, `int_part` points to `i` and `frac_part` points to `d`:



Pointers as Function Arguments

```
void decompose(double d, int *i, double *frac) {
  *i = (int) d;
  *frac = d - *i;
}

int main() {
  int int_part;
  double frac_part, input;

  scanf("%lf", &input);
  decompose(input, &int_part, &frac_part);
  printf("%f decomposes to %d and %f\n",
         *int_part, *frac_part);
  return 0;
}
```

Pass by Reference

- The pointer variables themselves are still passed by value
- In a function, if a pointer argument is de-referenced, then the modification indirectly through the pointer will stay

Pointers are Passed by Value

```
void f(int *px, int *py) {
  px = py;
}

int main() {
  int x = 1, y = 2, *px;
  px = &x;
  f(px, &y);
  printf("%d", *px);
}
```

Modification of a Pointer

```
void g(int **ppx, int *py) {
  *ppx = py;
}

int main() {
  int x = 1, y = 2, *px;
  px = &x;
  g(&px, &y);
  printf("%d", *px);
}
```

Pointer as Return Value

- We can also write functions that return a pointer
- Thus, the function is returning the memory address of where the value is stored instead of the value itself
- Be very careful not to return an address to a temporary variable in a function!!!

Example

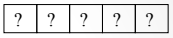
- **x** and **y** are copies of the original, and thus what is **&x** and **&y**?

```
int* max(int *x, int *y) {
  if (*x > *y)
    return x;
  return y;
}

int main() {
  int a = 1, b = 2, *p;

  p = max(&a, &b);
  return 0;
}
```

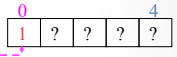
```
int* max(int x, int y) {
  if (x > y)
    return &x;
  return &y;
}

p = max(a, b);
```

Arrays

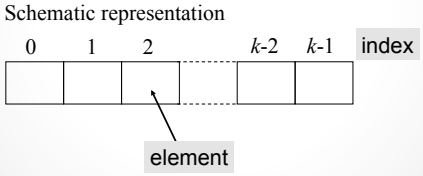
- Declaration – `int a[5]; a`



- Assignment – `a[0] = 1;`
- Reference – `y = a[0];`

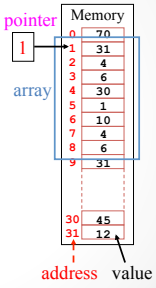


- Schematic representation



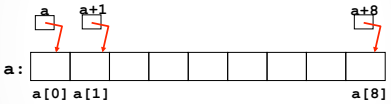
Pointers and Arrays

- Arrays are contiguous allocations of memory of the size:
  `sizeof(elementType) * numberOfElements`
- Given the address of the first byte, using the type (size) of the elements one can calculate addresses to access other elements



Name of an Array

- The variable name of an array is also a pointer to its first element.



- **`a == &a[0]`**
- **`a[0] == *a`**

Pointer Arithmetic

- One can add/subtract an integer to/from a pointer
- The pointer advances/retreats by that number of *elements (of the type being pointed to)*
  - **`a+i == &a[i]`**
  - **`a[i] == *(a+i)`**
- Subtracting two pointers yields the number of *elements* between them

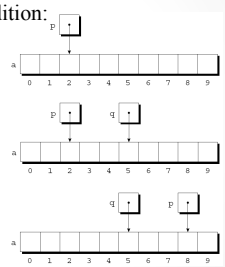
Adding an Integer to a Pointer

- Example of pointer addition:

```
p = &a[2];
```

```
q = p + 3;
```

```
p += 6;
```

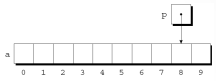


If `p` points to the array element `a[i]`, then `p + j` points to `a[i+j]`.

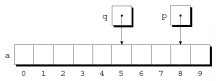
Subtracting an Integer from a Pointer

- If `p` points to `a[i]`, then `p - j` points to `a[i-j]`.
- Example:

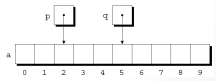
```
p = &a[8];
```



```
q = p - 3;
```



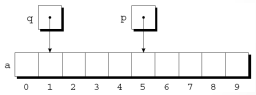
```
p -= 6;
```



Subtracting One Pointer from Another

- When one pointer is subtracted from another, the result is the distance (measured in array elements) between the pointers.
- If `p` points to `a[i]` and `q` points to `a[j]`, then `p - q` is equal to `i - j`.
- Example:

```
p = &a[5];
q = &a[1];
```



```
i = p - q;   /* i is 4 */
i = q - p;   /* i is -4 */
```

Using Pointers for Array Processing

- Pointer arithmetic allows us to visit the elements of an array by repeatedly incrementing a pointer variable.
- A loop that sums the elements of an array `a`:

```
#define N 10
…
int a[N], sum, *p;
…
sum = 0;
for (p = &a[0]; p < &a[N]; p++)
  sum += *p;
```

- `&a[N]` is legal since the loop doesn't attempt to examine its value.

Combining * and ++/--

- `++` and `--` has precedence over `*`
  - `a[i++] = j;`
  - `p=a; *p++ = j; <==> *(p++) = j;`
  - `*p++; value: *p, inc: p`
  - `(*p)++; value: *p, inc: *p`
  - `++(*p); value: (*p)+1, inc: *p`
  - `*++p; value: *(p+1), inc: p`

Combining * and ++/--

- The most common combination of `*` and `++` is `*p++`, which is handy in loops.
- Instead of writing

```
for (p = &a[0]; p < &a[N]; p++)
  sum += *p;
```

to sum the elements of the array `a`, we could write

```
p = &a[0];
while (p < &a[N])
  sum += *p++;
```

Using an Array Name as a Pointer

- *The name of an array can be used as a pointer to the first element in the array.*
- Suppose that `a` is declared as follows:

```
int a[10];
```

- Examples of using `a` as a pointer:

```
*a = 7;   /* stores 7 in a[0] */
*(a+1) = 12;   /* stores 12 in a[1] */
```

- In general, `a + i` is the same as `&a[i]`.
  - Both represent a pointer to element `i` of `a`.
- Also, `*(a+i)` is equivalent to `a[i]`.
  - Both represent element `i` itself.

Using an Array Name as a Pointer

- The fact that an array name can serve as a pointer makes it easier to write loops that step through an array.
- Original loop:

```
for (p = &a[0]; p < &a[N]; p++)
  sum += *p;
```

- Simplified version:

```
for (p = a; p < a + N; p++)
  sum += *p;
```

Using an Array Name as a Pointer

- Although an array name can be used as a pointer, it's not possible to assign it a new value.
- Attempting to make it point elsewhere is an error:

```
while (*a != 0)
  a++;            /*** WRONG ***/
```

- This is no great loss; we can always copy `a` into a pointer variable, then change the pointer variable:

```
p = a;
while (*p != 0)
  p++;
```

Arrays as Arguments

- Arrays are passed by reference
- Modifications stay

```
/* equivalent pointer alternative */
void init(int *a) {
  int i;

  for(i = 0;i<SIZE;i++){
    *(a+i) = 0;
  }
}
```

```
#define SIZE 10

void init(int a[]) {
  int i;

  for(i = 0;i<SIZE;i++){
    a[i] = 0;
  }
}

int main() {
  int a[SIZE];

  init(a);
  return 0;
}
```

Arrays as Arguments

- When passed to a function, an array name is treated as a pointer.
- Example:

```
int find_largest(int a[], int n)
{
  int i, max;

  max = a[0];
  for (i = 1; i < n; i++)
    if (a[i] > max)
      max = a[i];
  return max;
}
```

- A call of `find_largest`:

```
largest = find_largest(b, N);
```

This call causes a pointer to the first element of `b` to be assigned to `a`; the array itself is NOT copied.

Consequence of Array Arguments

- *Consequence 1:* When an ordinary variable is passed to a function, its value is copied; any changes to the corresponding parameter don't affect the variable. An array used as an argument is NOT protected against change.

```
void store_zeros(int a[], int n)
{
  int i;

  for (i = 0; i < n; i++)
    a[i] = 0;
}
```

Consequence of Array Arguments

- To indicate that an array parameter won't be changed, we can include the word `const` in its declaration:

```
int find_largest(const int a[], int n)
{
  …
}
```

- If `const` is present, the compiler will check that no assignment to an element of `a` appears in the body of `find_largest`.

Consequence of Array Arguments

- *Consequence 2:* The time required to pass an array to a function does not depend on the size of the array.
- *Consequence 3:* An array parameter can be declared as a pointer if desired.
- `find_largest` could be defined as follows:

```
int find_largest(int *a, int n)
{
  …
}
```

Consequence of Array Arguments

- Declaring a *parameter* to be an array is the same as declaring it to be a pointer.
- However, it is NOT same for a *variable*.

```
int a[10];
```

The compiler to set aside space for 10 integers

```
int *a;
```

The compiler to allocate space for a pointer variable.

`a` is not an array; attempting to use it as an array can have disastrous results.

Consequence of Array Arguments

- *Consequence 4:* A function with an array parameter can be passed an array "slice"—a sequence of consecutive elements.
- An example that applies `find_largest` to elements 5 through 14 of an array `b`:

```
largest = find_largest(&b[5], 10);
```

Using a Pointer as an Array Name

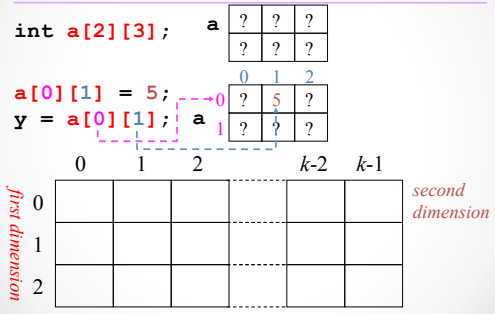
- C allows us to subscript a pointer as though it were an array name:

```
#define N 10
…
int a[N], i, sum = 0, *p = a;
…
for (i = 0; i < N; i++)
  sum += p[i];
```

The compiler treats `p[i]` as `*(p+i)`.

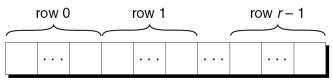
Multi-Dimensional Array

```
int a[2][3];
a[0][1] = 5;
y = a[0][1];
```



Multi-Dimensional Array

- Layout of an array with *r* rows:



- If `p` initially points to the element in row 0, column 0, we can visit every element in the array by incrementing `p` repeatedly.

Processing the Elements of a Multi-Dimensional Array

```
int a[NUM_ROWS][NUM_COLS];
```

- Use nested `for` loops:

```
int row, col;
…
for (row = 0; row < NUM_ROWS; row++)
  for (col = 0; col < NUM_COLS; col++)
    a[row][col] = 0;
```

- If we view `a` as a one-dimensional array of integers, a single loop is sufficient:

```
int *p;
…
for (p = &a[0][0];
     p <= &a[NUM_ROWS-1][NUM_COLS-1]; p++)
  *p = 0;
```

Processing the Rows of a Multi-Dimensional Array

- To visit the elements of row `i`, we'd initialize `p` to point to element 0 in row `i` in the array `a`:

```
p = &a[i][0];
```

or we could simply write

```
p = a[i]; //a pointer to the first element in row i
```

- Recall that `a[i]` is equivalent to `*(a + i)`
- Thus, `&a[i][0]` is the same as `&(*(a[i] + 0))`, which is equivalent to `&*a[i]`.
- This is the same as `a[i]`

Processing the Rows of a Multi-Dimensional Array

- A loop that clears row `i` of the array `a`:

```
int a[NUM_ROWS][NUM_COLS], *p, i;
…
for (p = a[i]; p < a[i] + NUM_COLS; p++)
  *p = 0;
```

- Use `find_largest` to determine the largest element in row `i` of the two-dimensional array `a`:

```
largest = find_largest(a[i], NUM_COLS);
```

Processing the Columns of a Multi-Dimensional Array

- A loop that clears column `i` of the array `a`:

```
int a[NUM_ROWS][NUM_COLS], (*p)
[NUM_COLS], i;
…
for (p = &a[0]; p < &a[NUM_ROWS]; p++)
  (*p)[i] = 0;
```

Using the Name of a Multidimensional Array as a Pointer

- The name of *any* array can be used as a pointer, regardless of how many dimensions it has, but some care is required.
- Example:

```
int a[NUM_ROWS][NUM_COLS];
```

`a` is *not* a pointer to `a[0][0]`; instead, it's a pointer to `a[0]`.

- C regards `a` as a one-dimensional array whose elements are one-dimensional arrays.
- When used as a pointer, `a` has type `int (*)[NUM_COLS]` (pointer to an integer array of length `NUM_COLS`).

Using the Name of a Multidimensional Array as a Pointer

- Since `a` points to `a[0]`, we can simplify loops that process the elements of a two-dimensional array.
- To clear column `i` of the array `a`:

```
for (p = &a[0]; p < &a[NUM_ROWS]; p++)
  (*p)[i] = 0;
```

- Now we can write

```
for (p = a; p < a + NUM_ROWS; p++)
  (*p)[i] = 0;
```

Using the Name of a Multidimensional Array as a Pointer

- We can "trick" a function into thinking that a multidimensional array is really one-dimensional.
- A first attempt at using using `find_largest` to find the largest element in `a`:

```
largest = find_largest(a, NUM_ROWS * NUM_COLS);
  /* WRONG */
```

- This an error, because the type of `a` is `int (*)[NUM_COLS]` but `find_largest` is expecting an argument of type `int *`.
- The correct call:

```
largest = find_largest(a[0], NUM_ROWS * NUM_COLS);
```

`a[0]` points to element 0 in row 0, and it has type `int *` (after conversion by the compiler).

Summary

- Understand the relationship between arrays and pointers
- Understand the relationship between two-dimensional arrays and pointer arrays
- Arrays are passed by reference to functions
- Pointer arithmetic is powerful but dangerous!

Exercise

- Suppose that the following declarations are in effect:
  int a[]={5, 15, 34, 54, 14, 2, 52, 72};
  int *p = &a[1], *q=&a[5];
- (a) what is the value of *(p+3)?
  (b) what is the value of *(q-3)?
  (c) what is the value of q-p?
  (d) Is p<q true or false?
  (e) Is *p<*q true or false?

Exercise

- What will be the contents of the array after the following statements are executed?
- #define N 10
  int a[N]={1,2,3,4,5,6,7,8,9,10};
  int *p=&a[0], *q=&a[N-1], temp;
  while(p<q){
  temp = *p;
  *p++ = *q;
  *q-- = temp;
  }