# Lecture 12 - Pointers and Arrays

Meng-Hsun Tsai
CSIE, NCKU

# Introduction

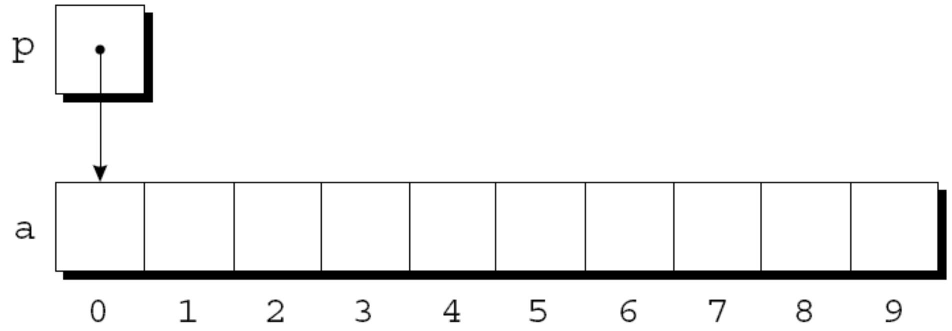
- C allows us to perform arithmetic—addition and subtraction—on pointers to array elements.
- This leads to an alternative way of processing arrays in which pointers take the place of array subscripts.
- The relationship between pointers and arrays in C is a close one.
- Understanding this relationship is critical for mastering C.

# Pointer Arithmetic

- Lecture 11 showed that pointers can point to array elements:

```
int a[10], *p;
p = &a[0];
```

- A graphical representation:

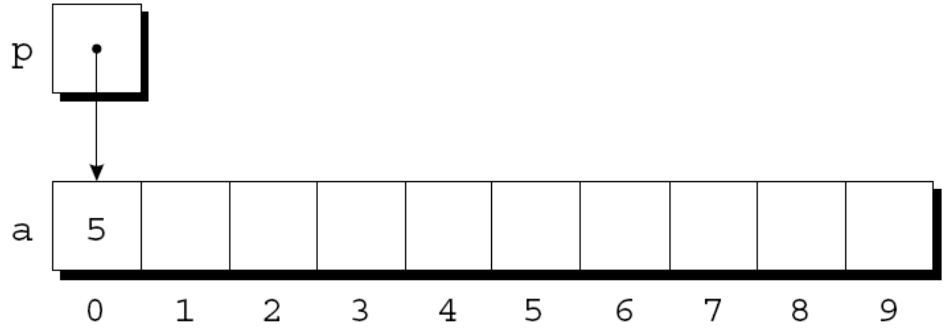


# Pointer Arithmetic (cont.)

- We can now access `a[0]` through `p`; for example, we can store the value 5 in `a[0]` by writing

```
*p = 5;
```

- An updated picture:



# Pointer Arithmetic (cont.)

- If `p` points to an element of an array `a`, the other elements of `a` can be accessed by performing ***pointer arithmetic*** (or ***address arithmetic***) on `p`.
- C supports three (and only three) forms of pointer arithmetic:
  - Adding an integer to a pointer
  - Subtracting an integer from a pointer
  - Subtracting one pointer from another

# Adding an Integer to a Pointer

- Adding an integer `j` to a pointer `p` yields a pointer to the element `j` places after the one that `p` points to.
- More precisely, if `p` points to the array element `a[i]`, then `p + j` points to `a[i+j]`.

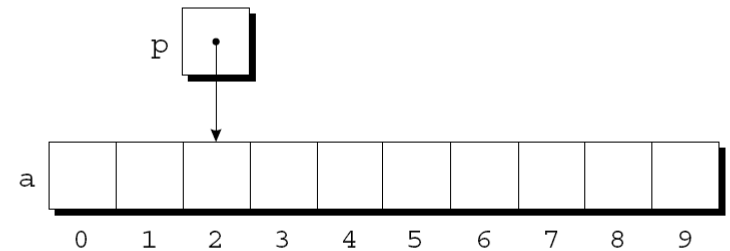
# Adding an Integer to a Pointer (cont.)

- Assume that the following declarations are in effect:

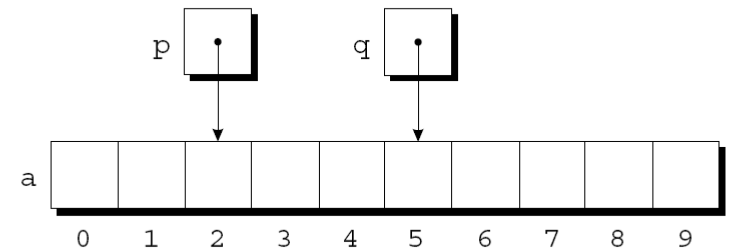
```
int a[10], *p, *q, i;
```

- Example of pointer addition:

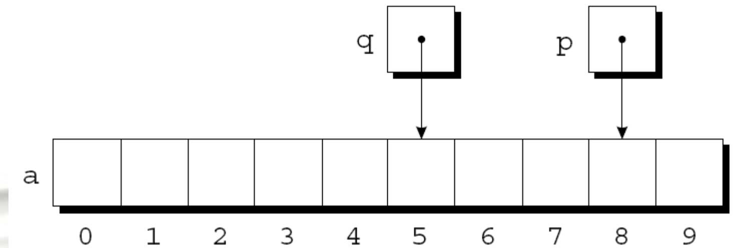
```
p = &a[2];
```




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



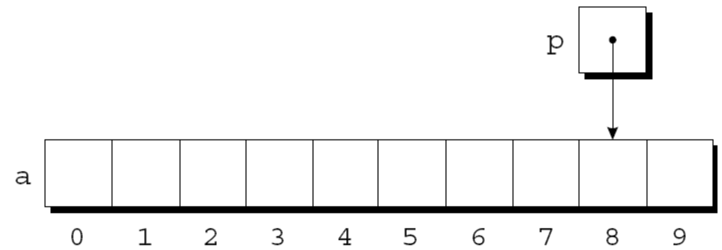

```
p += 6;
```



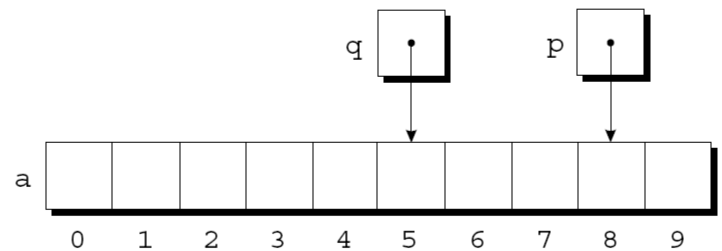
# Subtracting an Integer from a Pointer

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

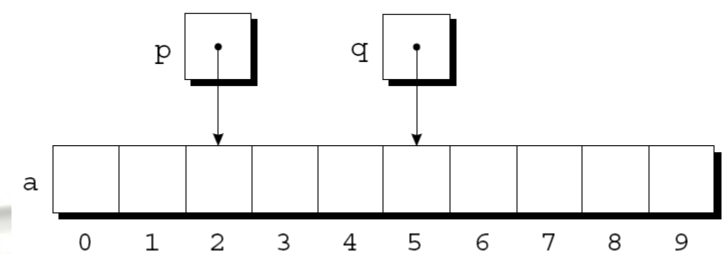
```
p = &a[8];
```




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



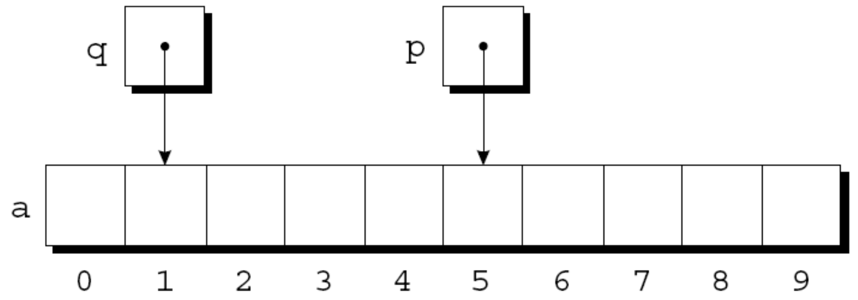

```
p -= 6;
```



# 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 */
```

# Subtracting One Pointer from Another (cont.)

- Operations that cause undefined behavior:
  - Performing arithmetic on a pointer that doesn’t point to an array element
- Subtracting pointers unless both point to elements of the same array

# Comparing Pointers

- Pointers can be compared using the relational operators (<, <=, >, >=) and the equality operators (== and !=).
  - Using relational operators is meaningful only for pointers to elements of the same array.
- The outcome of the comparison depends on the relative positions of the two elements in the array.
- After the assignments

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

the value of `p <= q` is 0 and the value of `p >= q` is 1.

# Using Pointers for Array Processing

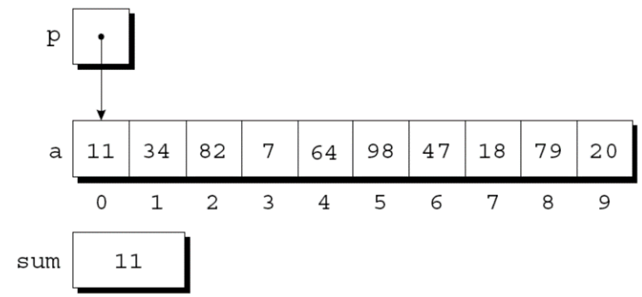
- Pointer arithmetic allows us to visit the elements of an array by repeatedly incrementing a pointer variable.
- A loop that sums the elements of an array `a`:

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

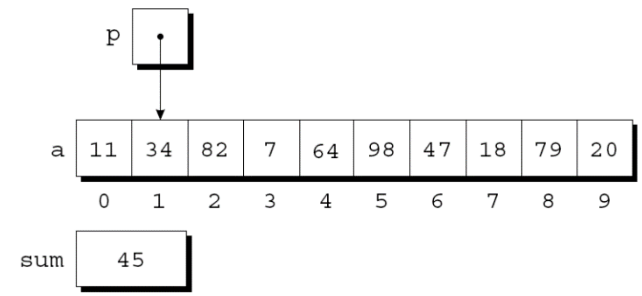
# Using Pointers for Array Processing (cont.)

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

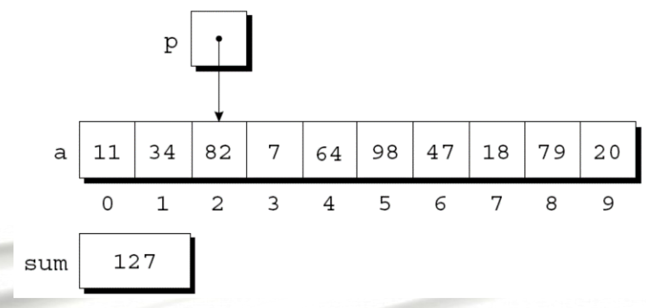
At the end of the first iteration:




At the end of the second iteration:




At the end of the third iteration:



# Using Pointers for Array Processing (cont.)

- It's legal to apply the address operator to `a[N]`, even though this element doesn't exist.
- Pointer arithmetic may save execution time.

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

# Combining the * and ++ Operators

- C programmers often combine the `*` (indirection) and `++` operators.
- A statement that modifies an array element and then advances to the next element:

```
a[i++] = j;
```

- The corresponding pointer version:

```
*p++ = j;
```

- Because the postfix version of `++` takes precedence over `*`, the compiler sees this as

```
*(p++) = j;
```

# Combining the * and ++ Operators (cont.)

- Possible combinations of `*` and `++`:

| *Expression* | *Meaning* |
|---|---|
| `*p++` or `*(p++)` | Value of expression is `*p` before increment; increment `p` later |
| `(*p)++` | Value of expression is `*p` before increment; increment `*p` later |
| `*++p` or `*(++p)` | Increment `p` first; value of expression is `*p` after increment |
| `++*p` or `++(*p)` | Increment `*p` first; value of expression is `*p` after increment |

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# Combining the * and ++ Operators (cont.)

- 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

- Pointer arithmetic is one way in which arrays and pointers are related.
- Another key relationship:

  *The name of an array can be used as a pointer to the first element in the array.*

- This relationship simplifies pointer arithmetic and makes both arrays and pointers more versatile.

# Using an Array Name as a Pointer (cont.)

- 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.

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# Using an Array Name as a Pointer (cont.)

- 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 (cont.)

- 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++;
```

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# Program: Reversing a Series of Numbers (Revisited)

- The `reverse.c` program of Lecture 8 reads 10 numbers, then writes the numbers in reverse order.
- The original program stores the numbers in an array, with subscripting used to access elements of the array.
- `reverse3.c` is a new version of the program in which subscripting has been replaced with pointer arithmetic.

# Program: Reversing a Series of Numbers (Revisited) (cont.)

**reverse3.c**

```
#include <stdio.h>
#define N 10

int main(void)
{
  int a[N], *p;

  printf("Enter %d numbers: ", N);
  for (p = a; p < a + N; p++)
    scanf("%d", p);

  printf("In reverse order:");
  for (p = a + N - 1; p >= a; p--)
    printf(" %d", *p);
  printf("\n");

  return 0;
}
```

```
for (i = 0; i < n; i++)
   scanf("%d", &a[i]);
```

```
for (i = n - 1; i >= 0; i--)
   printf(" %d", a[i]);
```

# Array Arguments (Revisited)

- 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 isn't copied.

# Array Arguments (Revisited) (cont.)

- The fact that an array argument is treated as a pointer has some important consequences.
- *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.
  - In contrast, an array used as an argument isn't protected against change.

# Array Arguments (Revisited) (cont.)

- For example, the `store_zeros()` function modifies an array by storing zero into each of its elements.

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

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

- 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`.

# Array Arguments (Revisited) (cont.)

- *Consequence 2*:
  - The time required to pass an array to a function doesn't depend on the size of the array.
  - There's no penalty for passing a large array, since no copy of the array is made.

# Array Arguments (Revisited) (cont.)

- *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)
    ```

  - Declaring `a` to be a pointer is equivalent to declaring it to be an array; the compiler treats the declarations as though they were identical.

# Array Arguments (Revisited) (cont.)

- Although declaring a *parameter* to be an array is the same as declaring it to be a pointer, the same isn't true for a *variable*.
- The following declaration causes the compiler to set aside space for 10 integers:

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

- The following declaration causes the compiler to allocate space for a pointer variable:

```
int *a;
```

# Array Arguments (Revisited) (cont.)

- In the latter case, `a` is not an array; attempting to use it as an array can have disastrous results.
- For example, the assignment

```
int *a;
```

```
*a = 0;    /*** WRONG ***/
```

will store 0 where `a` is pointing.

- Since we don't know where `a` is pointing, the effect on the program is undefined.

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# Array Arguments (Revisited) (cont.)

- *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];
```

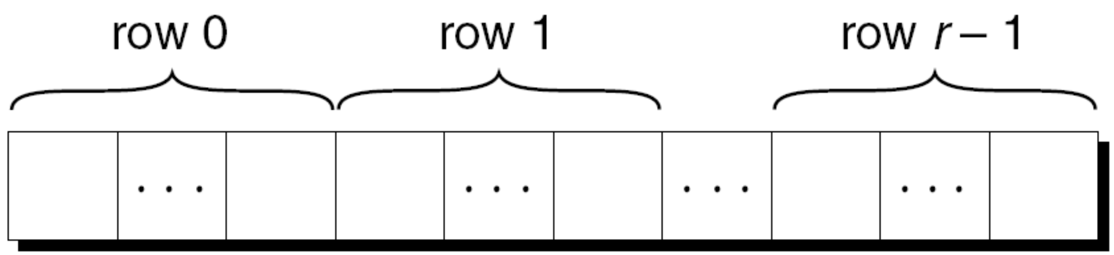
The compiler treats `p[i]` as `*(p+i)`.

# Pointers and Multidimensional Arrays

- Just as pointers can point to elements of one-dimensional arrays, they can also point to elements of multidimensional arrays.
- This section explores common techniques for using pointers to process the elements of multidimensional arrays.

# Processing the Elements of a Multidimensional Array

- Lecture 8 showed that C stores two-dimensional arrays in row-major order.
- 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 Multidimensional Array (cont.)

- Consider the problem of initializing all elements of the following array to zero:

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

- The obvious technique would be to 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;
```

# Processing the Elements of a Multidimensional Array (cont.)

- 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;
```

- Although treating a two-dimensional array as one-dimensional may seem like cheating, it works with most C compilers.
- Techniques like this one definitely hurt program readability, but—at least with some older compilers—produce a compensating increase in efficiency.
- With many modern compilers, though, there's often little or no speed advantage.

# Processing the Rows of a Multidimensional Array (cont.)

- A pointer variable `p` can also be used for processing the elements in just one *row* of a two-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];
  ```

# Processing the Rows of a Multidimensional Array (cont.)

- For any two-dimensional array `a`, the expression `a[i]` is a pointer to the first element in row `i`.
- To see why this works, 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]`, since the `&` and `*` operators cancel.

# Processing the Rows of a Multidimensional Array (cont.)

- 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;
```

- Since `a[i]` is a pointer to row `i` of the array `a`, we can pass `a[i]` to a function that's expecting a one-dimensional array as its argument.
- In other words, a function that's designed to work with one-dimensional arrays will also work with a row belonging to a two-dimensional array.

# Processing the Rows of a Multidimensional Array (cont.)

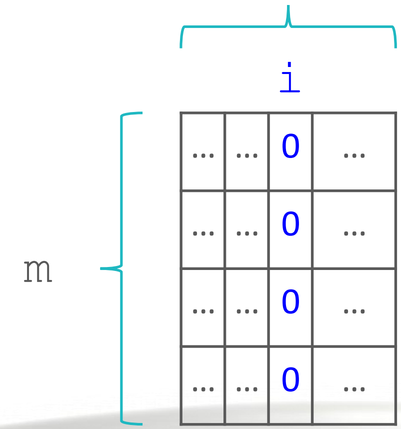
- Consider `find_largest`, which was originally designed to find the largest element of a one-dimensional array.
- We can just as easily use `find_largest` to determine the largest element in row `i` of the two-dimensional array `a`:

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

# Processing the Columns of a Multidimensional Array

- Processing the elements in a *column* of a two-dimensional array isn't as easy, because arrays are stored by row, not by column.
- 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`).

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# Using the Name of a Multidimensional Array as a Pointer (cont.)

- Knowing that `a` points to `a[0]` is useful for simplifying loops that process the elements of a two-dimensional array.
- Instead of writing

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

to clear column `i` of the array `a`, we can write

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

# Using the Name of a Multidimensional Array as a Pointer (cont.)

- 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).

# A Quick Review to This Lecture

- Arithmetic on pointers can take place of array subscripts.
- Three supported pointer arithmetic:
  - Adding an integer to a pointer
  - Subtracting an integer from a pointer
  - Subtracting one pointer from another
- Pointers can be compared using `<, <=, >, >=, ==` a and `!=`

```
int a[10], *p, *q, k;
p = &a[0];
q = &a[5];
*p = 5;    //a[0]=5
*p++ = 3; //a[0]=3;
*p-- = 4; //a[1]=4;
k = q - p; // k = 5;
```

# A Quick Review to This Lecture (cont.)

- Name of an array can be used as pointer to the first element., but it's not possible to assign a new value.
- Summing elements of an array

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

- Array name as an argument is treated as a pointer

```
int fun(int a[], const int *b)
{ *a = 3; }
int main()
{
  int c[10];
  fun(c, c);
}
```