Pointers and Arrays

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In this lecture

- Types: data + operations
- Pointers and arrays
- Pointer arithmetic
- Arrays as arguments

- Multi-dimensional arrays (pointers)

Extras:

- Variable-length arrays (pointers)

Types

Name	int
Set of data	… -2, -1, 0, 1, … max_int
Operations	10 / 3 = 3 (vs. 10.0 / 3.0 = 3.333…)
Memory representation	00000000 00000000 00000000 00000000

Introduction

- In C, pointers, as a type, have their own operations.
- In particular, we will look at arithmetic on pointers – addition and subtraction – for pointers to array elements.

- This leads to an alternative way of processing arrays, in which pointers take the place of array indexes.
- The relationship between pointers and arrays in C is a close one, understanding which is critical for mastering C.

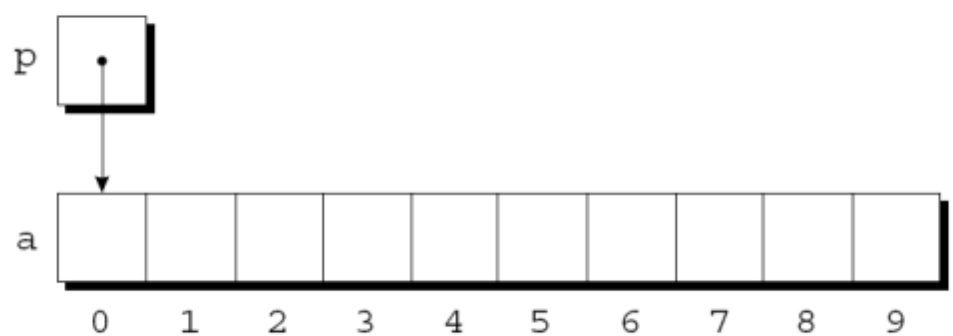
- This also gives you an idea of a *"memory-aware"* way of programming

Pointer Arithmetic

- We know that pointers can point to array elements:

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

- A graphical representation:

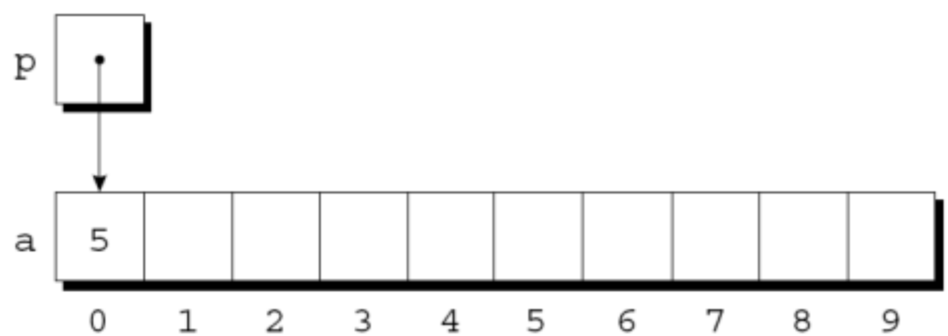


Pointer Arithmetic

- 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

- If `p` points to an element of an array `a`, what could be the meaning of `p+1`?

Pointer Arithmetic

- If `p` points to an element of an array `a`, what could be the meaning of `p+1`?

- 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:
  1. Adding an integer to a pointer
  2. Subtracting an integer from a pointer
  3. Subtracting one pointer from another

1. Adding an Integer to a Pointer

- Assume that the following declarations are in effect:

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

- 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]`,

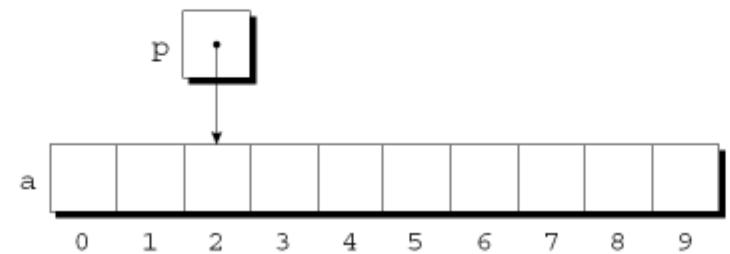
  then `p + j` points to

  `a[i+j]`.

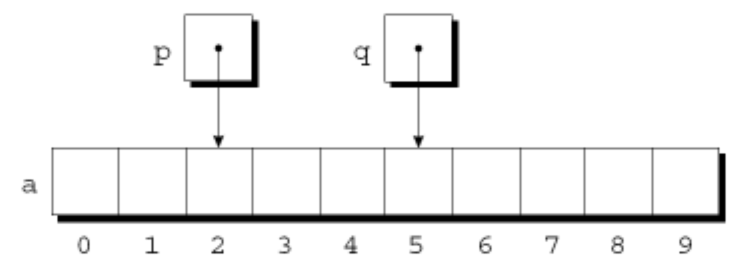
1. Adding an Integer to a Pointer

- Example of pointer addition:

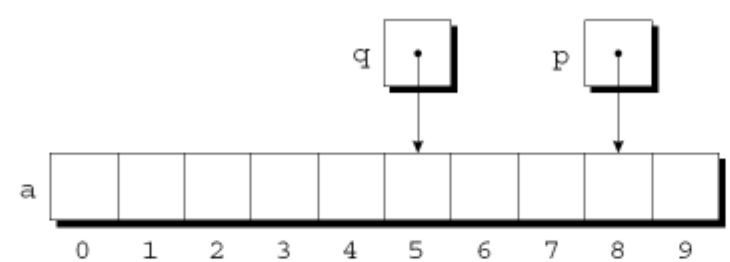
```
p = &a[2];
```




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



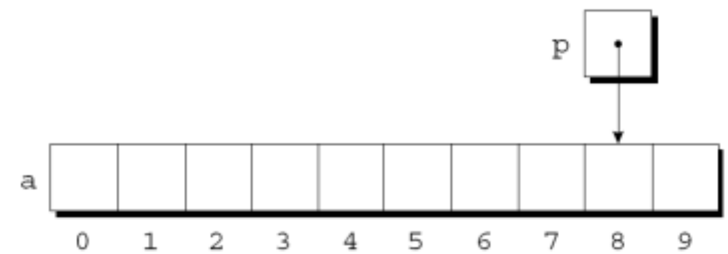

```
p += 6;
```



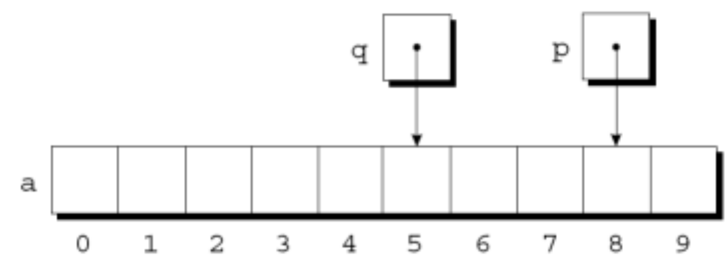
2. Subtracting an Integer from a Pointer

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

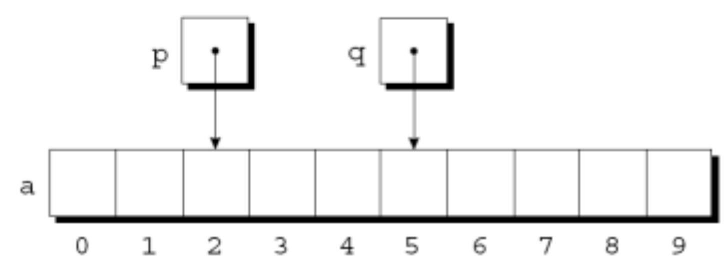
```
p = &a[8];
```




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




```
p -= 6;
```

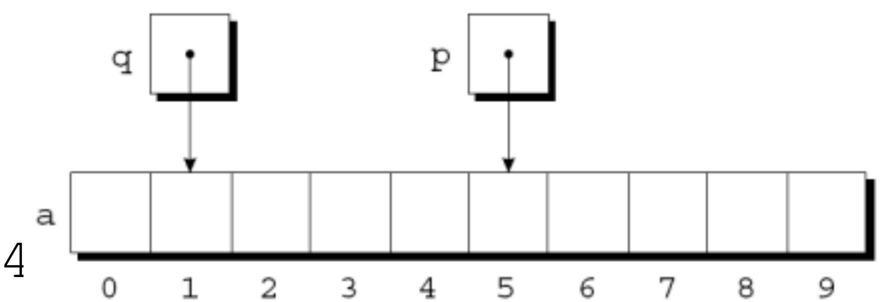


3. Subtracting One Pointer from Another

- 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
```



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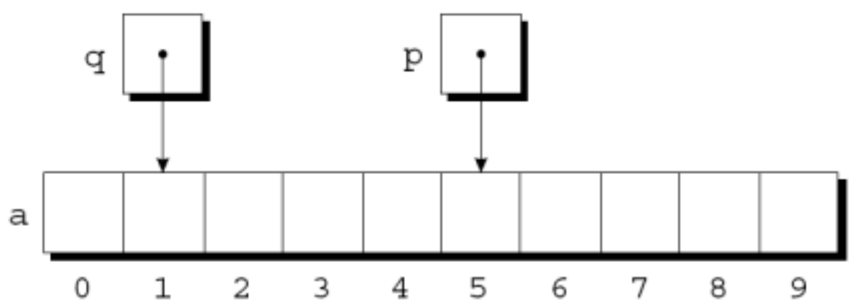


Subtracting One Pointer from Another

Careful !

- 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 (false) and

the value of `p >= q` is 1 (true).

Pointers to Compound Literals (C99)

- It's legal for a pointer to point to an element within an array created by a compound literal (i.e., an object that has no name):

```
int *p = (int []){3, 0, 3, 4, 1};
```

- Using a compound literal saves us the trouble of first declaring an array variable and then making `p` point to the first element of that array:

```
int a[] = {3, 0, 3, 4, 1};
int *p = &a[0];
```

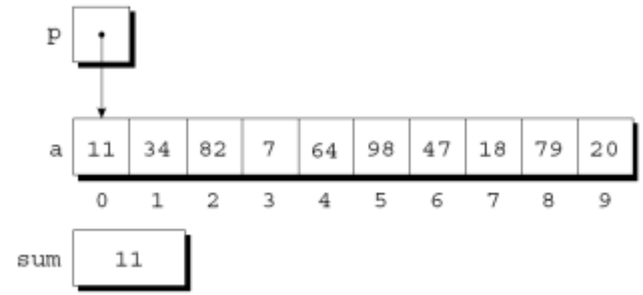
Using Pointers for Array Processing

- 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`:

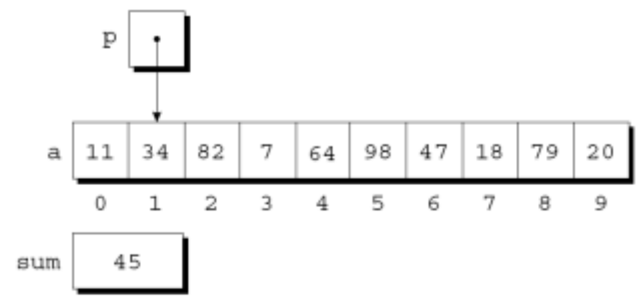
```
#define N 10
…
int a[N], sum, *p;
…
sum = 0;
for (p = &a[0]; p < &a[N]; p++)
   sum += *p;
```

Using Pointers for Array Processing

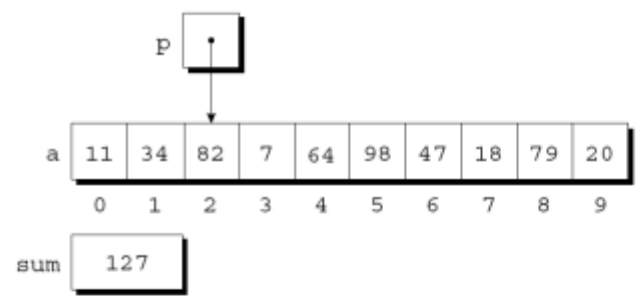
At the end of the first iteration:



At the end of the second iteration:



At the end of the third iteration:



Using Pointers for Array Processing

- The condition `p < &a[N]` in the `for` statement deserves special mention.
- It's legal to apply the address operator to `a[N]`, even though this element doesn't exist.

- Pointer arithmetic may save execution time.

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. E.g. with `int a[10];`

```
*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++;
```

Program: Reversing a Series of Numbers

- The `reverse.c` program reads 10 numbers, then writes the numbers in reverse order.
- A 'naïve' approach is to store 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.

reverse3.c

```
/* Reverses a series of numbers (pointer version) */

#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); /* Recall: p is a ptr, so no & req'd */

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

  return 0;
}
```

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- Multi-dimensional arrays (pointers)

Extras:

- Variable-length arrays (pointers)

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)

- 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)

- For example, the following 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;
}
```

Array Arguments (Revisited)

- 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)

- **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)

- **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)

- 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 100 integers:

```
int a[100];
```

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

```
int *a;
```

Array Arguments (Revisited)

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

  ```
  *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.

Array Arguments (Revisited)

- **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)`.

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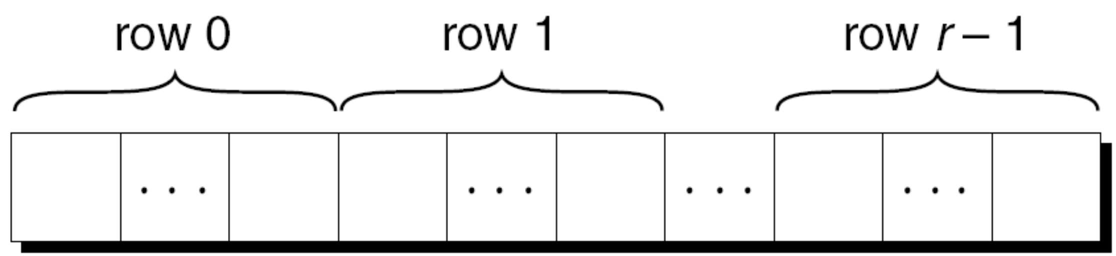
Pointers and Multidimensional Arrays

- 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

- Recall 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

- 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;
```

- 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 Elements of a Multidimensional Array

- 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

- 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

- 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, in this case.

Processing the Rows of a Multidimensional 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;
```

Processing the Rows of a Multidimensional Array

- 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, i.e. a function expecting a one-dimensional array will also work with a row belonging to a two-dimensional array.
- Consider `find_largest`, it finds the largest element of a one-dimensional array. It can be used 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`).

Using the Name of a Multidimensional Array as a Pointer

- 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

Careful about types, always! E.g.:

- 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).

Pointers and Variable-Length Arrays (C99)

- Pointers are allowed to point to elements of variable-length arrays (VLAs).
- An ordinary pointer variable would be used to point to an element of a one-dimensional VLA:

```
void f(int n)
{
  int a[n], *p;
  p = a;
  …
}
```

Pointers and Variable-Length Arrays (C99)

- When the VLA has more than one dimension, the type of the pointer depends on the length of each dimension except for the first.
- A two-dimensional example:

```
void f(int m, int n)
{
  int a[m][n], (*p)[n];
  p = a;
  …
}
```

Since the type of `p` depends on `n`, which isn't constant, `p` is said to have a **variably modified type.**

Pointers and Variable-Length Arrays (C99)

- The validity of an assignment such as `p = a` can't always be determined by the compiler.
- The following code will compile but is correct only if `m` and `n` are equal:

```
int a[m][n], (*p)[m];
p = a;
```

- If `m` is not equal to `n`, any subsequent use of `p` will cause undefined behavior.

Pointers and Variable-Length Arrays (C99)

- Variably modified types are subject to certain restrictions.
- The most important restriction: the declaration of a variably modified type must be inside the body of a function or in a function prototype.

Pointers and Variable-Length Arrays (C99)

- Pointer arithmetic works with VLAs.
- A two-dimensional VLA:

```
int a[m][n];
```

- A pointer capable of pointing to a row of `a`:

```
int (*p)[n];
```

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

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