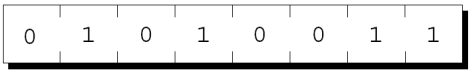
Chapter 11

Pointers

Pointer Variables

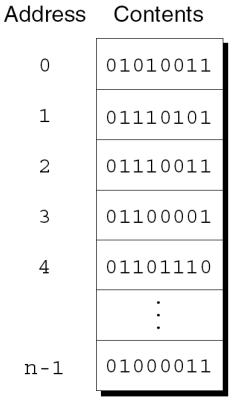
- The first step in understanding pointers is visualizing what they represent at the machine level
- In most modern computers, main memory is divided into ***bytes***, with each byte capable of storing eight bits of information



- Each byte has a unique ***address***

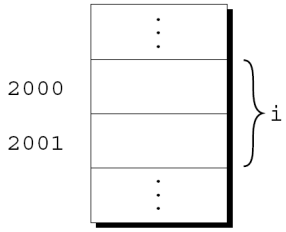
Pointer Variables

- If there are *n* bytes in memory, we can think of addresses as numbers that range from 0 to *n* – 1



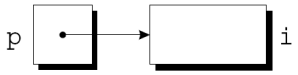
Pointer Variables

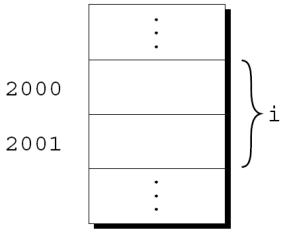
- Each variable in a program occupies one or more bytes of memory
- The address of the first byte is said to be the address of the variable
- In the following figure, the address of the variable `i` is 2000



Pointer Variables

- Addresses can be stored in special ***pointer variables***
- When we store the address of a variable `i` in the pointer variable `p`, we say that `p` "points to" `i`
- A graphical representation





- What is the value of `p`?

Declaring Pointer Variables

- When a pointer variable is declared, its name must be preceded by an asterisk

```
int *p;
```

  where `p` is a pointer variable capable of pointing to ***object(s)*** of type `int`
- We use the term *object* instead of *variable* since `p` might point to an area of memory that does not belong to a variable

Declaring Pointer Variables

- Pointer variables can appear in declarations along with other variables

```
int i, j, a[10], b[20], *p, *q;
```

- C requires that every pointer variable point only to objects of a particular type (the ***referenced type***); ***why?***

```
int *p;     /* points only to integers   */
double *q;  /* points only to doubles    */
char *r;    /* points only to characters */
```

- There are no restrictions on what the referenced type may be

The Address and Indirection Operators

- C provides a pair of operators designed specifically for use with pointers
  - To find the address of a variable
    - we use the `&` (***address***) operator
  - To gain access to the object that a pointer points to
    - we use the `*` (***indirection***) operator

The Address Operator

- Declaring a pointer variable sets aside space for a pointer but ***does not*** make it point to an object

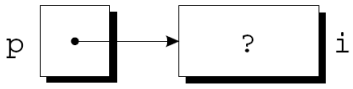
```
int *p;  /* points NoWhere in particular */
```

- It is crucial to ***initialize*** `p` before we use it

The Address Operator

- One way to initialize a pointer variable is to assign it the address of a variable

```
int i, *p;
…
…
p = &i;
```



- Assigning the address of `i` to the variable `p` makes `p` point to `i`

The Address Operator

- It is also possible to initialize a pointer variable at the time it is declared

```
int i;
int *p = &i;
```

- The declaration of `i` can even be combined with the declaration of `p`

```
int i, *p = &i;
```


The Indirection Operator

- Once a pointer variable points to an object, we can use the `*` (***indirection***) operator to access what is stored in the object
- If `p` points to `i`, we can print the value of `i` as follows

```
printf("%d\n", *p);
```

- Applying `&` to ***a variable***
  - produces a pointer to the variable
- Applying `*` to ***a pointer***
  - takes us back to the original variable

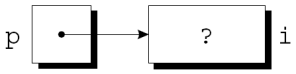
```
j = *&i;
/* same as j = i; */
```

The Indirection Operator

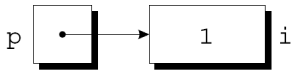
- As long as `p` points to `i`, `*p` is an ***alias*** for `i`
  - `*p` has the same value as `i`
  - Changing the value of `*p` changes the value of `i`
  - Changing the value of `i` changes the value of `*p`
- The example on the next slide illustrates the equivalence of `*p` and `i`

The Indirection Operator

```
p = &i;
```

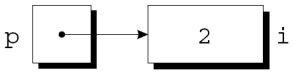



```
i = 1;
```




```
printf("%d\n", i);     /* prints 1 */
printf("%d\n", *p);    /* prints 1 */
```

```
*p = 2;
```




```
printf("%d\n", i);     /* prints 2 */
printf("%d\n", *p);    /* prints 2 */
```

The Indirection Operator

- Applying the indirection operator to an uninitialized pointer variable causes undefined behavior

```
int *p;
printf("%d", *p);   /*** WRONG ***/
```

- Assigning a value to `*p` is particularly dangerous

```
int *p;
*p = 1;   /*** WRONG ***/
```


Pointer Assignment

- `C` allows the use of the assignment operator to copy pointers ***of the same type***
- Assume that the following declaration is in effect

```
int i, *p, *q;
```

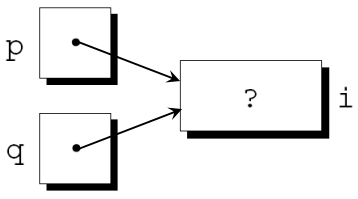
- Example of pointer assignment

```
p = &i;
```

- Another example of pointer assignment

```
q = p;
```

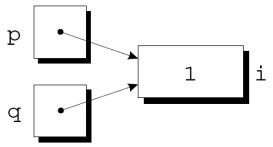
`q` now points to the same place as `p`



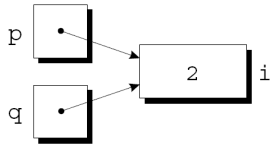
Pointer Assignment

- If `p` and `q` both point to `i`, we can change `i` by assigning a new value to either `*p` or `*q`

```
*p = 1;
```




```
*q = 2;
```



- Any number of pointer variables may point to the same object

Pointer Assignment

- Be careful not to confuse

```
q = p;
```

with

```
*q = *p;
```

- The first statement is a pointer assignment, but the second is not
- The example on the next slide shows the effect of the second statement

Assume that the following declaration is in effect

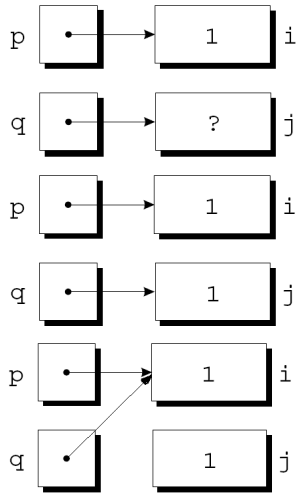
```
int i, j, *p, *q;
```

Pointer Assignment

```
p = &i;
q = &j;
i = 1;

*q = *p;

q = p;
```



Pointers as Arguments

- In Chapter 9, we tried—and failed—to write a `decompose` function that could modify its arguments
- By passing a *pointer to a variable* instead of the *value of the variable*, `decompose` can be fixed

Pointers as Arguments

- New definition of `decompose`

```
void decompose(double x,
               long *int_part,
               double *frac_part)
{ *int_part = (long) x;
  *frac_part = x - *int_part;
}
```

- Possible prototypes for `decompose`

```
void decompose(double x,
               long   *int_part,
               double *frac_part);
```

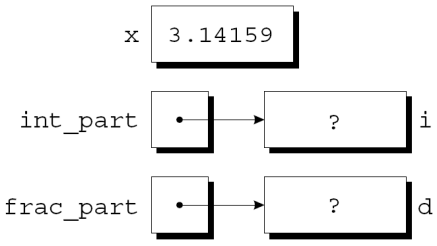
or simply

```
void decompose(double, long *, double *);
```


Pointers as Arguments

- New definition of `decompose`

```
void decompose(double x,
               long *int_part,
               double *frac_part)
{ *int_part = (long) x;
  *frac_part = x - *int_part;
}
```



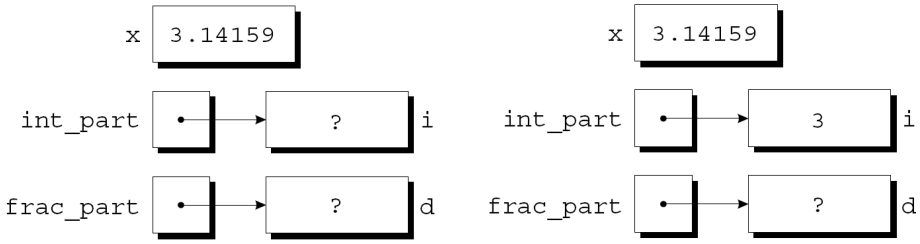
- A call of `decompose` can be

```
decompose(3.14159,
          &i, &d);
```

- As a result of the call, `int_part` points to `i` and `frac_part` points to `d`

Pointers as Arguments

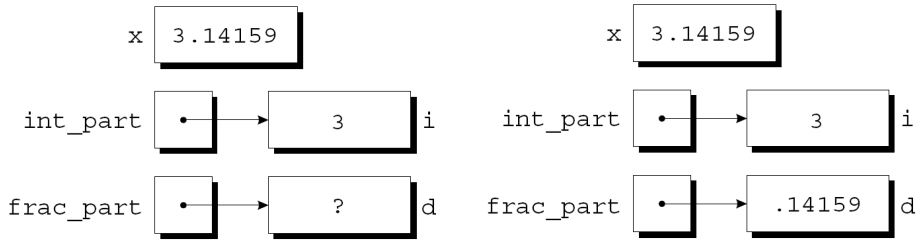
- The first assignment in the body of `decompose`
  `*int_part = (long) x;`
  converts the value of `x` to type `long` and stores it in the object pointed to by `int_part`



Before *After*

Pointers as Arguments

- The second assignment
  `*frac_part = x - *int_part;`
  stores `x - *int_part` into the object that `frac_part` points to



Before *After*

Pointers as Arguments

- Arguments in calls of `scanf` are pointers

```
int i;
…
scanf("%d", &i);
```

Without the `&`, `scanf` would be supplied with the *value* of `i`

Pointers as Arguments

- Although `scanf`'s arguments must be pointers, it is not always true that every argument needs the `&` operator

```
int i, *p;
…
p = &i;
scanf("%d", p);
```

- In this situation, using the `&` operator before `p` in this `scanf` call would be wrong

```
scanf("%d", &p);    /*** WRONG ***/
```

Pointers as Arguments

- Failing to pass a pointer to a function when one is expected can have disastrous results
- A call of `decompose` in which the `&` operator is missing

```
decompose(3.14159, i, d);
```

  - When `decompose` stores values in `*int_part` and `*frac_part`, it will attempt to change unknown memory locations instead of modifying `i` and `d`
- If we have provided a prototype for `decompose`, the compiler will detect the error
- In the case of `scanf`, however, failing to pass pointers may go undetected

Program: Finding the Largest and Smallest Elements in an Array

- The `max_min.c` program uses a function named `max_min` to find the largest and smallest elements in an array
- Prototype for `max_min`

```
void max_min(int a[], int n, int *max, int *min);
```

- Example call of `max_min`

```
max_min(b, N, &big, &small);
```

- When `max_min` finds the largest element in `b`, it stores the value in `big` by assigning it to `*max`
- `max_min` stores the smallest element of `b` in `small` by assigning it to `*min`

Program: Finding the Largest and Smallest Elements in an Array

- `max_min.c` will read 10 numbers into an array, pass it to the `max_min` function, and print the results

```
Enter 10 numbers: 34 82 49 102 7 94 23 11 50 31
Largest: 102
Smallest: 7
```


maxmin.c

```
/* Finds the largest and smallest elements in an array */

#include <stdio.h>

#define N 10

void max_min(int a[], int n, int *max, int *min);

int main(void)
{
  int b[N], i, big, small;

  printf("Enter %d numbers: ", N);
  for (i = 0; i < N; i++)
    scanf("%d", &b[i]);
```

```
  max_min(b, N, &big, &small);

  printf("Largest: %d\n", big);
  printf("Smallest: %d\n", small);

  return 0;
}

void max_min(int a[], int n, int *max, int *min)
{
  int i;

  *max = *min = a[0];
  for(i = 1; i < n; i++)
  { if(a[i] > *max)
      *max = a[i];
    else
      if(a[i] < *min)
        *min = a[i];
  }
}
```


Using `const` to Protect Arguments

- When an argument is a pointer to a variable `x`, it means that `x` can be modified inside the function

  ```
  f(&x);
  ```

- It is possible, though, that `f` merely needs to examine the value of `x`, not change it
- The reason for the pointer might be efficiency
  - passing the value of a variable can waste time and space if the variable requires a large amount of storage

Using `const` to Protect Arguments

- We can use `const` to document that a function will not change an object whose address is passed to the function
- `const` goes in the parameter's declaration, just before the specification of its type

```
void f(const int *p)
{
  *p = 0;    /*** WRONG ***/
}
```

Attempting to modify `*p` is an error that the compiler will detect

Pointers as Return Values

- Functions are allowed to return pointers

```
int *max(int *a, int *b)
{
  if (*a > *b)
    return a;
  else
    return b;
}
```

- A call of the `max` function

```
int *p, i, j;
…
p = max(&i, &j);
```

After the call, `p` points to either `i` or `j`

Pointers as Return Values

- Although `max` returns one of the pointers passed to it as an argument, that is not the only possibility
- A function could also return a pointer
  - to an ***external*** variable or
  - to a ***static local*** variable
- Never return a pointer to an *automatic* local variable

```
int *f(void)
{
  int i;
  …
  return &i; // ** Never do that **
}
```

The variable `i` ***will not*** be exist after `f` returns

Pointers as Return Values

- Pointers can point to array elements
- If `a` is an array, then `&a[i]` is a pointer to element `i` of `a`
- It is sometimes useful for a function to return a pointer to one of the elements in an array
- A function that returns a pointer to the middle element of `a`, assuming that `a` has `n` elements

```
int *find_middle(int a[], int n)
{ return &a[n/2];
}
```