Lecture 8 - Pointers

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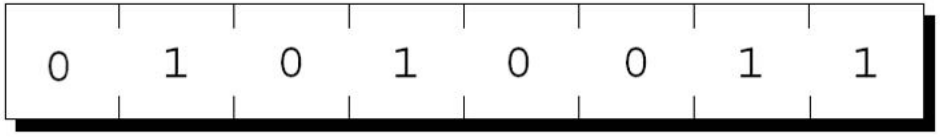
8.1 Pointer Variables

Pointer Variables

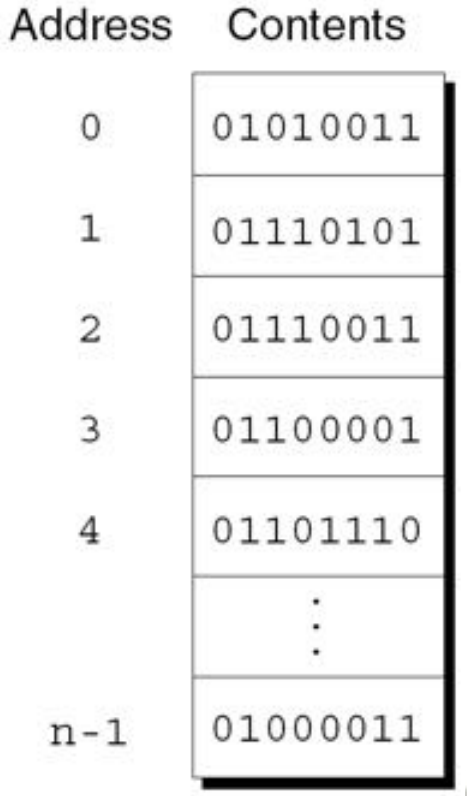
- The first step in understanding pointers is visualizing what they represent at the machine level.
- In most modern computers, main memory is divided into ***bytes***, with each byte capable of storing eight bits of information:



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

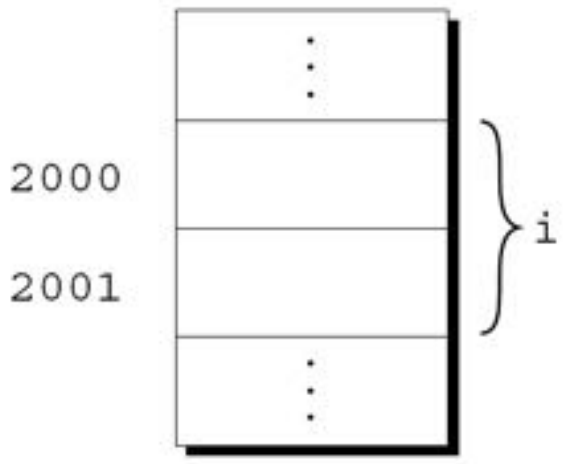
Pointer Variables (cont.)

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



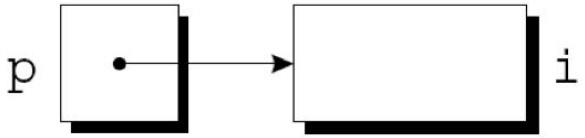
Pointer Variables (cont.)

- 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 (cont.)

- 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:



Declaring Pointer Variables

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

```
int *p;
```

- `p` is a pointer variable capable of pointing to ***objects*** of type `int`.
- We use the term *object* instead of *variable* since `p` might point to an area of memory that doesn't belong to a variable.

```
int *p;
p = 2001;
```

Declaring Pointer Variables (cont.)

- 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***):

```
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 doesn't make it point to an object:

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

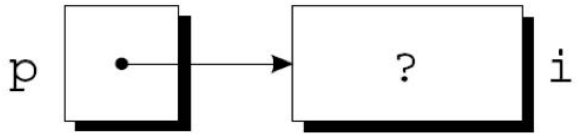
- It's crucial to initialize `p` before we use it.

The Address Operator (cont.)

- 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 (cont.)

- It's also possible to initialize a pointer variable at the time it's 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's 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 the pointer takes us back to the original variable:

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

The Indirection Operator (cont.)

- 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`.
- The example on the next slide illustrates the equivalence of `*p` and `i`.

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

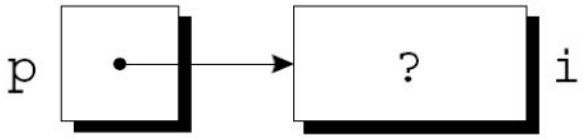
```
printf("%d\n", i);
```

```
*p = 5;
```

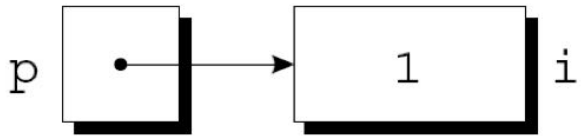
```
i = 5;
```

The Indirection Operator (cont.)

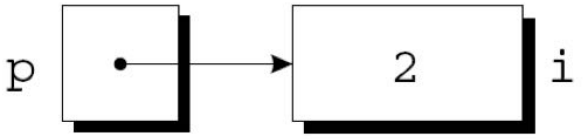
```
p = &i;
```




```
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 (cont.)

- 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, j, *p, *q;
```

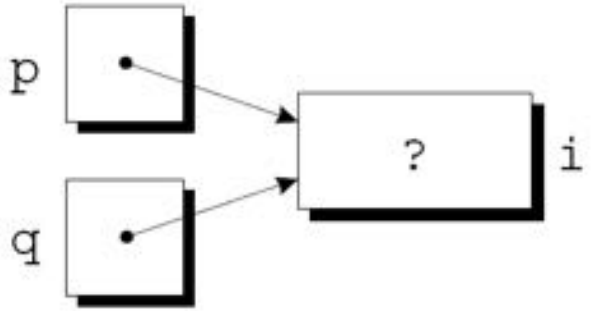
- Example of pointer assignment:

```
p = &i;
```

- Another example of pointer assignment:

```
q = p;
```

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

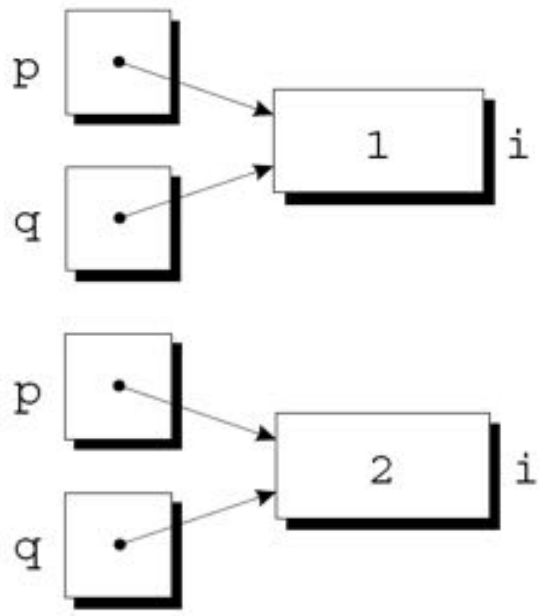


Pointer Assignment (cont.)

- 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 (cont.)

- Be careful not to confuse

```
q = p;
```

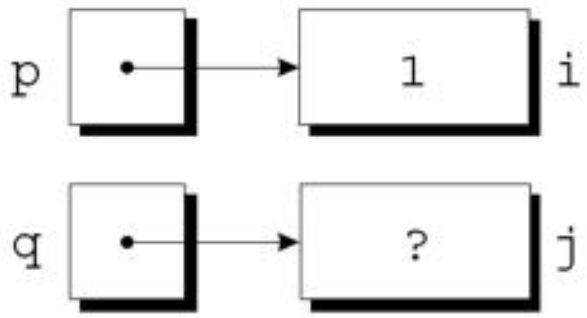
with

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

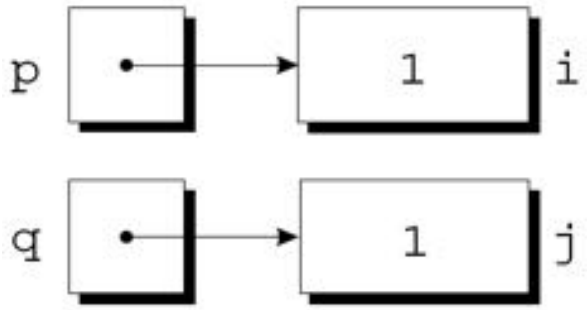
- The first statement is a pointer assignment, but the second is not.
- The example on the next slide shows the effect of the second statement.

Pointer Assignment (cont.)

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




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



8.2 Pointers as Arguments and Return Values

Pointers as Arguments

- By passing a *pointer* to a variable instead of the *value* of the variable, `decompose` (in Lecture 6) can be fixed.
- New definition of `decompose`:

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

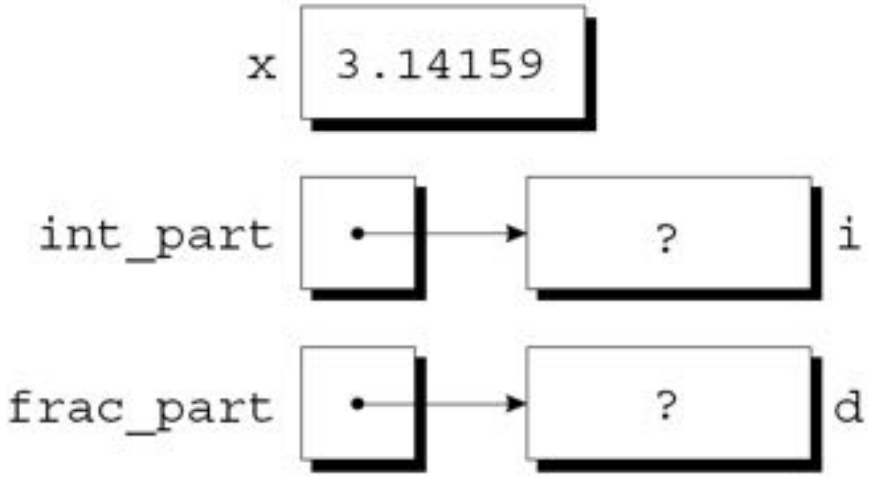
```
void decompose(double x, long int_part, double frac_part)
{
   int_part = (long) x;
   frac_part = x - int_part;
}
```

Pointers as Arguments (cont.)

- A call of `decompose`:

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

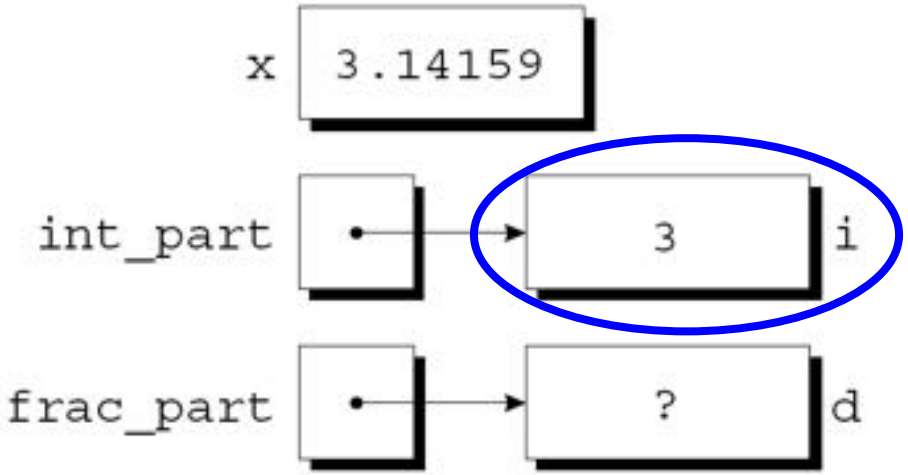
- As a result of the call, `int_part` points to `i` and `frac_part` points to `d`:



Pointers as Arguments (cont.)

- The first assignment in the body of `decompose` converts the value of `x` to type `long` and stores it in the object pointed to by `int_part`:

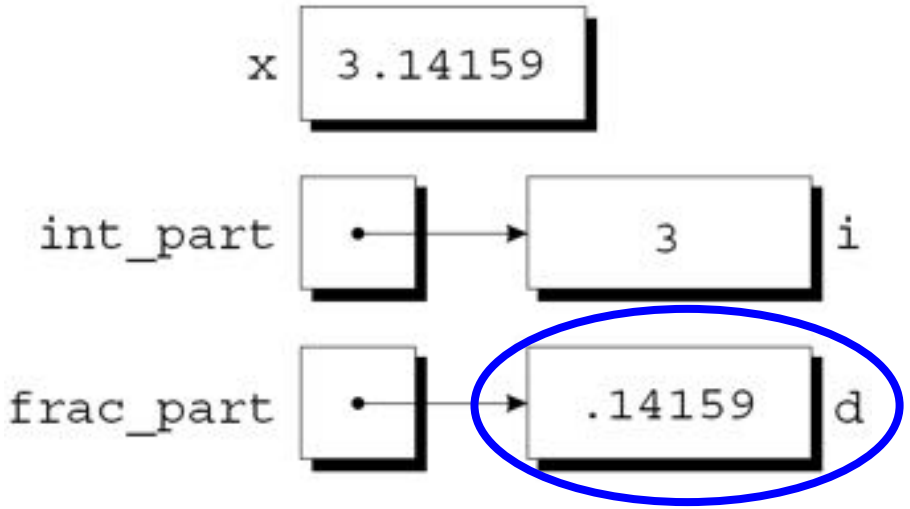
```
*int_part = (long) x;
```



Pointers as Arguments (cont.)

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

```
*frac_part = x - *int_part;
```



Pointers as Arguments (cont.)

- Arguments in calls of `scanf` are pointers:

```
int i;
scanf("%d", &i);
```

Without the `&`, `scanf` would obtain the *value* of `i`, not the address of `i`, which may crash the program execution .

- You can also directly pass a pointer instead:

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

- Using the `&` operator in the call would be wrong:

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

Pointers as Arguments (cont.)

- 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've 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 (cont.)

- `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
```

Program: Finding the Largest and Smallest Elements in an Array (cont.)

maxmin.c

```
#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

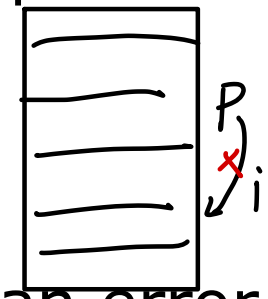
- When an argument is a pointer to a variable `x`, we normally assume that `x` will be modified:

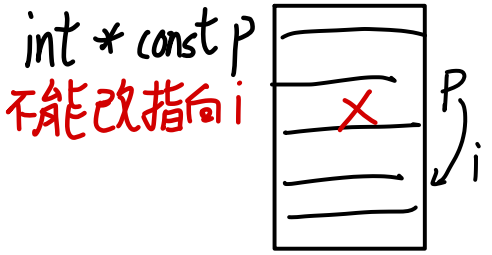
```
f(&x);
```

- It's possible, for efficiency reason, that `f` merely needs to examine the value of `x`, not change it.
- We can use `const` to ensure that a function won't change an object whose address is passed to the function:

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

不能改指向的i的value





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;
}
int main()
{
  int *p, i, j;
  p = max(&i, &j);   /* After the call, p points to either i or j. */
  return 0;
}
```

Pointers as Return Values (cont.)

- Never return a pointer to an *automatic* local variable.

```
int *f(void)
{
    int i;
    return &i;   /* i won't exist after f returns. */
}
```

- A function could also return a pointer to an external variable or to a static local variable.

```
int i;
int *max(int *a)
{
    static int j;
    return (j>*a)?&j:a;
}
int main()
{
    int *p;
    p = max(&i);
}
```

Pointers as Return Values (cont.)

- Pointers can point to array elements.
- If `a` is an array, then `&a[i]` is a pointer to element `i` of `a`.
- A function that returns a pointer to the middle element of `a`, assuming that `a` has `n` elements:

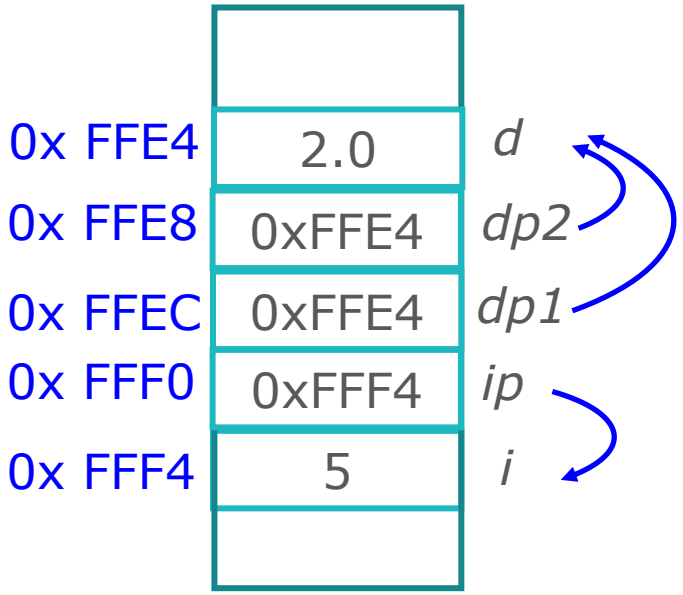
```
int *find_middle(int a[], int n) {
  return &a[n/2];
}
```

A Quick Review to This Lecture

- Each byte has a unique address.
- Each variable occupies one or more bytes, where the first byte is the address of the variable.
- Addresses can be stored in pointer variables.
- Address (&) and Indirection (*) Operators

```
int i=5, *ip = &i;
double *dp1, *dp2, d;
dp1 = dp2 = &d;
*dp1 = 2.0;
*ip = *&i;    /* garbage code */
```

- Remember to initialize a pointer before using indirection operator.



A Quick Review to This Lecture (cont.)

- Pointer as arguments (can use `const` to protect from modification) and return values

```
int x;
int * fun(int *ip1, const int *ip2)
{
    *ip1 = 3;
    *ip2 = 5;    /* compilation error */
    return &x;
}
int main(){
    int i, *ip3;
    ip3 = fun(&i, &i);
}
```