Pointers

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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:

0	1	0	1	0	0	1	1

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

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Pointer Variables

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

Address	Contents
0	01010011
1	01110101
2	01110011
3	01100001
4	01101110
	⋮
n-1	01000011

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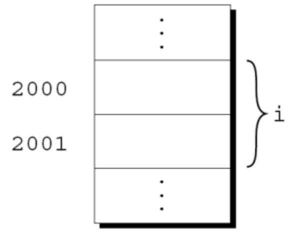
Pointer Variables

- 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:



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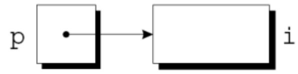
Pointer Variables

- 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:



Declaring Pointer Variables

- To declare a pointer variable, the 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.

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***):

```
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.

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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.

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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.

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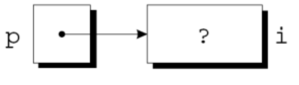
The Address Operator

- 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`:



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The Address Operator

- 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:

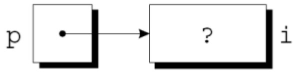
```
j = *&i;    /* same as j = i; */
```

The Indirection Operator

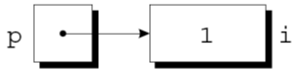
- As long as `p` points to `i`, `*p` is an ***alias*** for `i`.
  - `*p` has the same value as `i`.
  - Changing the value of `*p` changes the value of `i`.
- The example on the next slide illustrates the equivalence of `*p` and `i`.

The Indirection Operator

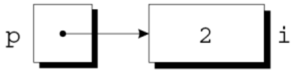
```
p = &i;
```




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

- Example of pointer assignment:

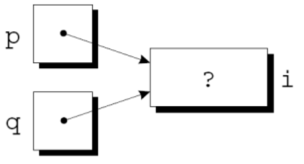
```
p = &i;
```

Pointer Assignment

- Another example of pointer assignment:

  `q = p;`

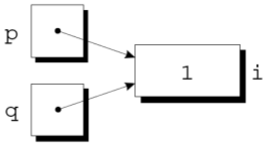
  `q` now points to the same place as `p`:



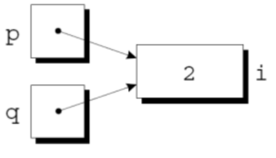
Pointer Assignment

- 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.

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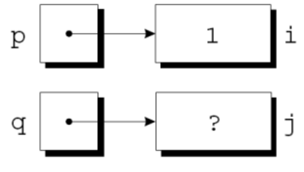
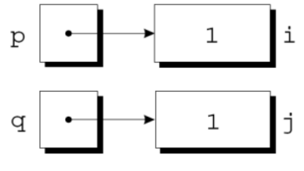
Pointer Assignment

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




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



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Pointers as Arguments

- Recall, we tried—and failed—to write a `decompose` function that could modify its arguments:

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

- By passing a *pointer* to a variable instead of the *value* of the variable, `decompose` can be fixed.

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

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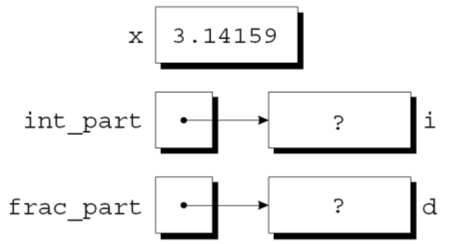
Pointers as Arguments

- A call of `decompose`:

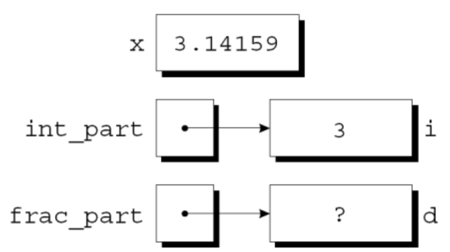
  `decompose(3.14159, &i, &d);`

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



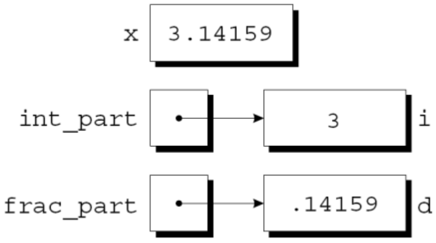
Pointers as Arguments

- 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`:



Pointers as Arguments

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



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's not always true that every argument needs the `&` operator:

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

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

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

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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'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.

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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]);
```

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```
  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];
  }
}
```

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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, 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 won't 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`.

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Pointers as Return Values

- Although `max` returns one of the pointers passed to it as an argument, that's 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;
} /*** WRONG ***/
```

The variable `i` won't exist after `f` returns.

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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's 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];
}
```