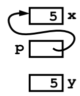
Pointers

- Pointers are variables whose ***values*** are the ***addresses*** of other variables
- Basic operations

  "address of" (reference)

  "indirection" (dereference)
- Suppose **`x`** and **`y`** are integers, **`p`** is a pointer to an integer:



`p = &x;`	**`p`** gets the address of **`x`**
`y = *p;`	**`y`** gets the value pointed to by **`p`**
`y = *(&x);`	same as **`y = x`**

- Declaration syntax mimics use of variables in expressions

`int *p;`	**`*p`** is an **`int`**, so **`p`** is a pointer to an **`int`**

- Unary **`*`** and **`&`** bind more tightly than most other operators

`y = *p + 1;`	**`y = (*p) + 1;`**
`y = *p++;`	**`y = *(p++);`**

Pointer References

- Pointer references (e.g. **`*p`**) are ***lvalues.***

  `int x, y, *px, *py;`

`px = &x;`	**`px`** is the address of **`x`**
`*px = 0;`	sets **`x`** to 0
`py = px;`	**`py`** also points to **`x`**
`*py += 1;`	increments **`x`** to 1
`y = (*px)++;`	sets **`y`** to 1, **`x`** to ***2***

- Passing pointers to functions ***simulates*** passing arguments "by reference"

```
void swap(int x, int y) {
    int t;

    t = x;
    x = y;
    y = t;
}

int a = 1, b = 2;
swap(a, b);
printf("%d %d\n", a, b);
```

```
void swap(int *x, int *y) {
    int t;

    t = *x;
    *x = *y;
    *y = t;
}

int a = 1, b = 2;
swap(&a, &b);
printf("%d %d\n", a, b);
```


Pointers & Arrays

- Pointers can "walk along" arrays

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

`p = &a[0];`	**`p`** is the address of the 1st element of **`a`**
`x = *p;`	**`x`** gets **`a[0]`**
`x = *(p + 1);`	**`x`** gets **`a[1]`**
`p = p + 1;`	**`p`** points to **`a[1]`**, ***by definition***
`p++;`	**`p`** points to **`a[2]`**

- Array names are ***constant*** pointers

`p = a;`	**`p`** points to **`a[0]`**
`a++;`	illegal; can't change a constant
`p++;`	legal; **`p`** is a variable

- Subscripting, for any type, is defined in terms of pointers

`a[i]`		**`*(a + i)`**		**`i[a]`** is legal, too!		
`&a[i]`		**`a + i`**				
`p = &a[0]`	⇒	**`&*(a + 0)`**	⇒	**`&*a`**	⇒	**`a`**

- Pointers can walk along arrays efficiently

```
p = a;
for (i = 0; i < 10; i++)
    printf("%d\n", *p++);
```


Pointer Arithmetic

- Pointer arithmetic takes into account the ***stride*** (size of) the value pointed to

  T **`*p;`**

`p += i`	increment **`p`** by **`i`** elements
`p -= i`	decrement **`p`** by **`i`** elements
`p++`	increment **`p`** by **`1`** element
`p--`	decrement **`p`** by **`1`** element

- If **`p`** and **`q`** are pointers to the same type ***T***

`p - q`	number of elements between **`p`** and **`q`**

- Does it make sense to add two pointers?
- Other operations: **`p < q`**; **`<= == != >= >`**

  `p` and **`q`** ***must*** point to the ***same*** array; ***no runtime checks*** to insure this
- Example

```
int strlen(char *s) {
    char *p;
    for (p = s; *p; p++)
        ;
    return p - s;
}
```

Pointers & Array Parameters

- Array parameters:

  array formal parameters are not constants, they are ***variables***

  passing an array passes a ***pointer*** to the ***first element***

  arrays (and ***only*** arrays) are automatically passed "by reference"

  `void f(`*T*` a[]) {...}` is equivalent to **`void f(`*T*` *a) {...}`**

- String constants denote constant pointers to the actual characters

```
char *msg = "now is the time";        char amsg[] = "now is the time";
                                       char *msg = amsg;
```

  `msg` points to the first character of **`"now is ..."`**

- Strings can be used wherever arrays of characters are used

```
putchar("0123456789"[i]);        static char digits[] = "0123456789";
                                  putchar(digits[i]);
```

- Is any difference between

  `extern char x[];` **`extern char *x;`**

Pointers & Array Parameters, cont'd

- Copying strings: **`void scopy(char *s, char *t)`** copies **`t`** to **`s`**
- ***Array*** version:

```
void scopy(char s[], char t[]) {
    int i = 0;
    while ((s[i] = t[i]) != '\0')
        i++;
}
```

- ***Pointer*** version:

```
void scopy(char *s, char *t) {
    while (*s = *t) {                    while ((*s = *t) != 0)
        s++;
        t++;
    }
}
```

- ***Idiomatic*** version:

```
void scopy(char *s, char *t) {
    while (*s++ = *t++)                  while ((*s++ = *t++) != 0)
        ;
}
```

- **Which one is better and why?**

Arrays of Pointers

- Arrays of pointers help build tabular structures
- Indirection (`*`) has ***lower*** precedence than **`[]`**

  `char *line[100];` same as **`char *(line[100]);`**

  declares an array of pointers to strings; declaration mimics use:

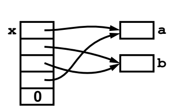
  `*line[i]`

  refers to the 0th character in the **`i`**th string

- Arrays of pointers can be ***initialized***

  `name` **is visible only within** **`month`**;
  allocated & initialized at *compile time*

```
char *month(int n) {
    static char *name[] = {
        "January",
        "February",
        ...,
        "December"
    };
    assert(n >= 1 && n <= 12);
    return name[n-1];
}
int a, b;
int *x[] = { &a, &b, &b, &a, NULL };
```



Arrays of Pointers, cont'd

- Arrays of pointers are ***similar*** to multi-dimensional arrays, but different

```
int a[10][10];      both     a[i][j]
int *b[10];                  b[i][j]
                    are legal references to ints
```

- Array **`a`**:

  2-dimensional 10x10 array

  storage for 100 elements allocated at compile time

  `a[6]` is a ***constant***; **`a[i]`** ***cannot*** change during execution

  each row of **`a`** has 10 elements

- Array **`b`**:

  an array of 10 pointers; each element ***could*** point to an array

  storage for 10 pointer elements allocated at compile time

  values of these pointers must be initialized during execution

  `b[6]` is a ***variable***; **`b[i]`** ***can*** change during execution

  each row of **`b`** can have a different length; "ragged array"

Pointers to Functions

- Pointers to functions help ***parameterize*** other functions

```
void sort(void *v[], int n, int (*compare)(void *, void *)) {
    ...
    if ((*compare)(v[i],v[j]) <= 0) {
        ...
    }
    ...
}
```

- **`sort`** does not depend the type of the objects it is sorting

  it can sort arrays of pointers to ***any*** type

  such functions are called ***generic*** or ***polymorphic*** functions

- Use an array of **`void *`** (generic pointers) to pass data

- **`void *`** is a ***placeholder***

  dereferencing a **`void *`** ***requires*** a cast to a specific type

Pointers to Functions, cont'd

- Declaration syntax can confuse:

  `int (*compare)(void *, void *)`

  declares **`compare`** to be "a ***pointer*** to a ***function*** that takes two **`void *`** arguments and returns an **`int`**"

  `int *compare(void *, void *)`

  declares **`compare`** to be "a ***function*** that takes two **`void *`** arguments and returns a ***pointer*** to an **`int`**"

- Invocation syntax can also confuse:

  `(*compare)(v[i], v[j])`

  calls the function ***pointed*** to by **`compare`** with the arguments **`v[i]`** and **`v[j]`**

  `*compare(v[i], v[j])`

  calls the function **`compare`** with the arguments **`v[i]`** and **`v[j]`**, then ***dereferences*** the pointer value returned

- Function call has higher precedence than dereferencing

Pointers to Functions, cont'd

- A function name itself is a ***constant pointer*** to a function (like array name)

```
#include <string.h>
```

  contains `extern int strcmp(char *, char *);`

```
main(int argc, char *argv[]) {
    char *v[VSIZE];
    ...
    sort(v, VSIZE, strcmp);
    ...
}
```

- Actually, both **`v`** and **`strcmp`** require a ***cast***:

```
sort((void **)v, VSIZE, (int (*)(void *, void *))strcmp);
```

- Arrays of pointers to functions:

```
extern int mul(int, int), add(int, int), sub(int, int), ...;
```

```
int (*operators[])(int, int) = {
    mul, add, sub, ...};
```

  to call the *i*th function: **`(*operators[i])(a, b);`**