Pointers

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

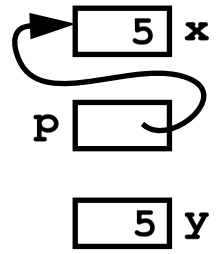
  "address of" (reference)

  "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);`



- 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++);`

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Pointer References

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

```
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);

2 1
```

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 there 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) {
        s++;
        t++;
    }
}
```

```
while ((*s = *t) != 0)
```

- ***Idiomatic*** version:

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

```
while ((*s++ = *t++) != 0)
```

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

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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 char (strings); declaration mimics use:

  `*line[i]`

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

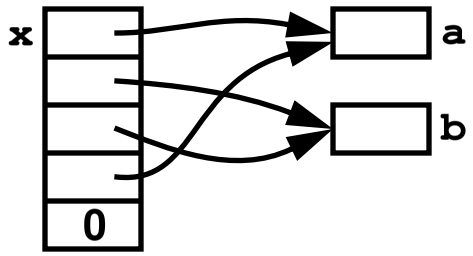
- Arrays of pointers can be ***initialized***

`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"

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Command-Line Arguments

- By convention, **`main`** is called with 2 arguments (actually 3!)

  `int main(int argc, char *argv[])`

  `argc` ("***arg***ument ***c***ount") is the number of command-line arguments

  `argv` ("***arg***ument ***v***ector") is an array of pointers to the arguments

- For the command ***`echo hello, world`***

```
argc = 3
argv[0] = "echo"
argv[1] = "hello,"
argv[2] = "world"
argv[3] = NULL
```

- **`NULL`** is the ***null pointer***, which points to nothing; defined to be 0

- Implementation of **`echo`**:

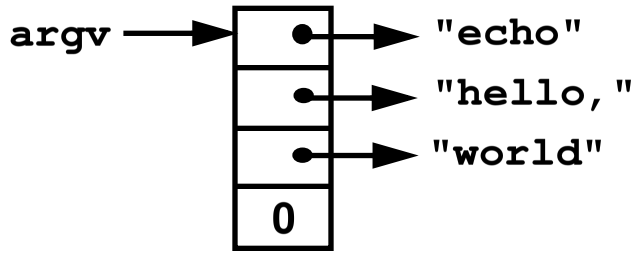
```
int main(int argc, char *argv[]) {
    int i;
    for(i = 1; i < argc; i++)
        printf("%s%c", argv[i], (i < argc-1) ? ' ' : '\n');
    return 0;
}
```

More on argc and argv

- Another (less clear) implementation of **`echo`**:

```
int main(int argc, char **argv) {
    while (--argc > 0)
        printf("%s%c", *++argv, argc > 1 ? ' ' : '\n');
    return 0;
}
```

initially, **`argv`** points to the program name:



`*++argv` increments **`argv`** to point the cell that points to **`"hello,"`**, and indirection fetches that pointer (a **`char *`**)

- Example

```
void f(int *a[10]);        is the same as      void f(int **a);
void g(int a[][10]);                           void g(int (*a)[10]);
```

`**a = 1;` is legal in ***both*** **`f`** and **`g`**; what gets changed in each?

- See H&S for more

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's 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

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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);`