Arrays and Strings

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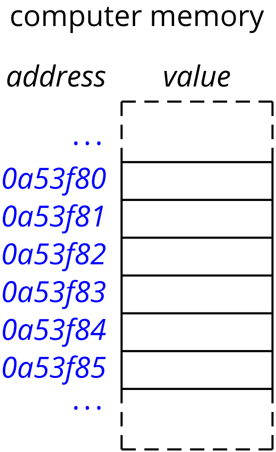
Outline

- General memory model
- Definition and use of pointers
- Invalid pointers and common errors
- Arrays and pointers
- Strings
- The `main` function

computer memory

Memory Model



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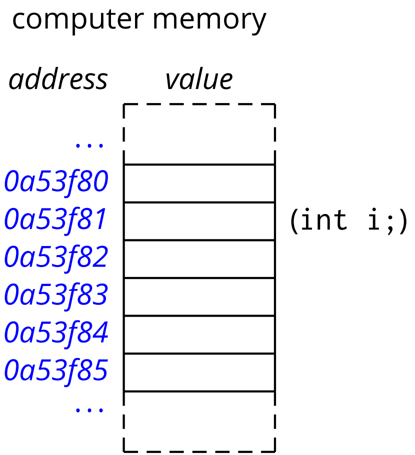


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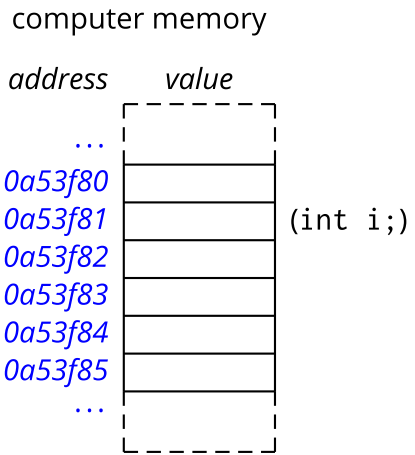
/* an int variable */
int i;
```

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/* an int variable */
int i;
i = 5;
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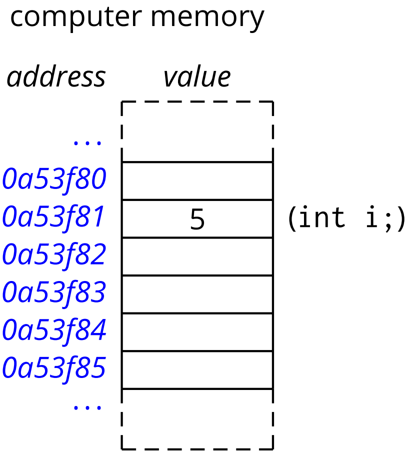


```c
/* an int variable */
int i;
i = 5;
```

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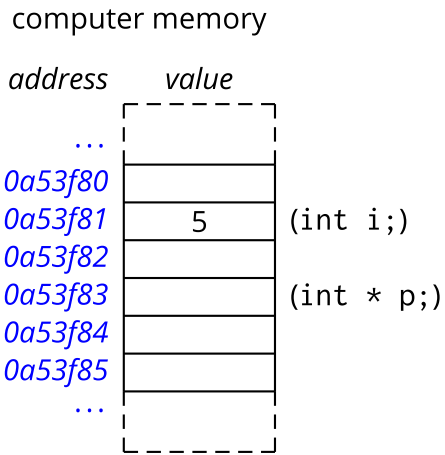


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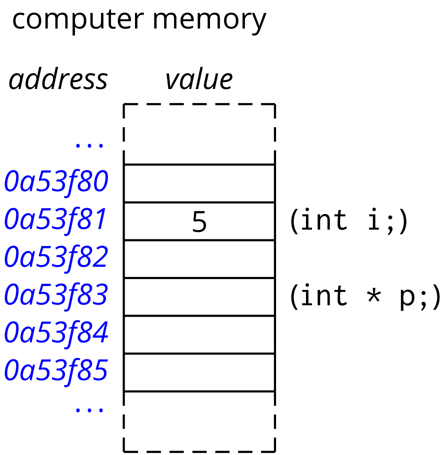


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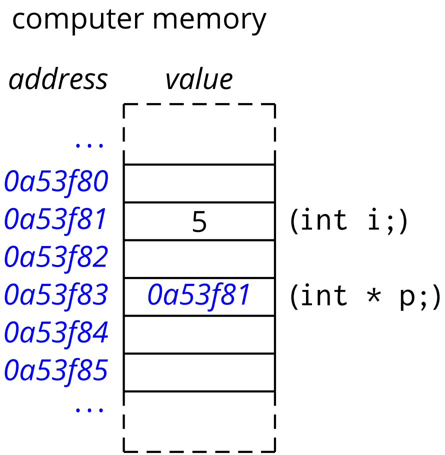


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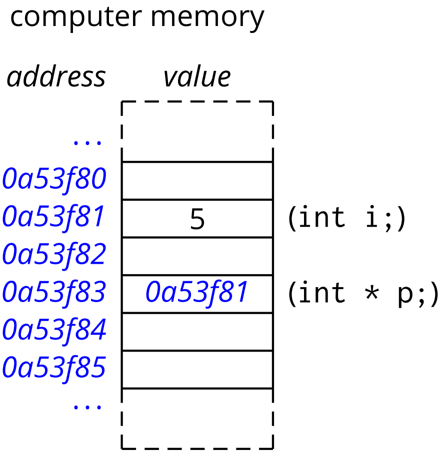


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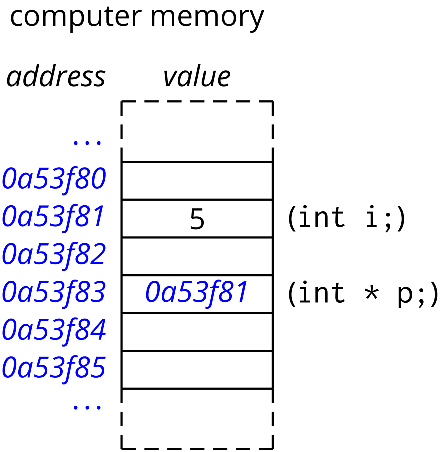


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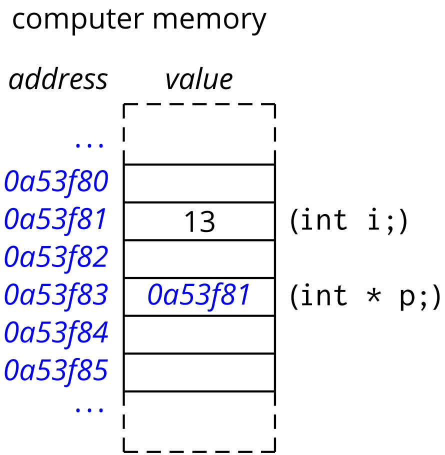
```

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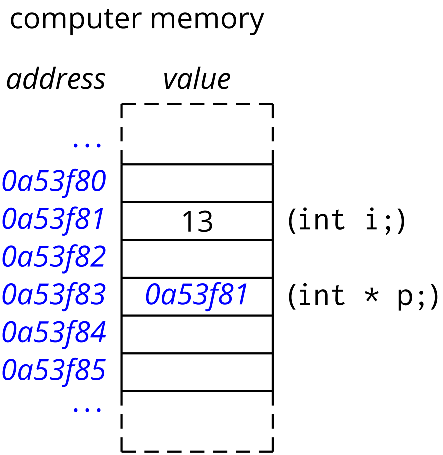

address-of operator

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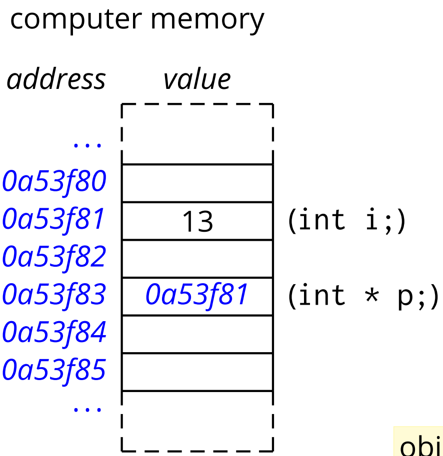


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address-of operator

object *pointed-to* by p

Pointers

- A *pointer* is an ***object*** whose value is the ***memory address of another object***

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  Example:

```
int * p;    /* pointer to an int */
int ** pp;  /* pointer to a pointer to an int */
char c;     /* a char variable */
int i;      /* an int variable */

p = &c;     /* type mismatch! */
p = &i;     /* okay */
pp = &i;    /* type mismatch! */
pp = &p;    /* okay */
```

Pointers (2)

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- **Example:**

```
int main() {
    int i = 123;
    int * p;     /* pointer declaration */
    p = &i;      /* address-of operator */
    *p = 345;    /* dereference operator */
    printf("i=%d\n", i);
    printf("*p=%d\n", *p);
}
```

Uses of Pointers

Uses of Pointers

- Pointers cause ***side-effects***
  - they should be used with special care
  - at the same time they are *indispensable*

…but first we need to talk about parameters passing

Pop quiz: What is the output of this program?

```c
#include <stdio.h>

void sign(int x) {
    if (x > 0)
        x = 1;
    else if (x < 0)
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}
```

Answer: `i = 7`

in C ***parameters are always passed by value***

Parameters, Arguments, and their Semantics

```
/* a function definition (and declaration) */
int maximum(int a, int b) {
    if (a > b)
        return a;
    else
        return b;
}

int set_temp(int t) {
    int new_t = maximum(t, 36);
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A function call ***initializes*** the ***parameters*** with the ***value of the arguments***

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So, how do we get information *out* of a function, other than through its return value?

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- **Example:**

```
int main() {
    int i;
    printf("How old are you? ");
    scanf("%d", &i);
    printf("You look a little older than %d\n", i);
}
```

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- Example

```
void swap(int * p1, int * p2) {
    *p1 ^= *p2;
    *p2 ^= *p1;
    *p1 ^= *p2;
}
int main() {
    int i = 7;
    int j = 13;
    swap(&i,&j);
    printf("i=%d j=%d\n", i, j);
}
```

Invalid Pointers

- Pointers are “dangerous” because they can take a ***restricted set of valid values***
  - values set by the platform
  - values themselves are *meaningless to the application*
  - in general, you can not check whether a pointer is valid

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- Dereferencing an invalid pointer causes ***undefined behavior***

- In fact, using an invalid pointer may be an error even without dereferencing it (e.g., comparing pointers)

Pointer to void

- Special ***pointer type*** compatible with any other pointer type
  - i.e., can be converted to/from any pointer type

```
#include <stdio.h>

int main() {
    int i;
    void * ptr = &i;
    int * i_ptr = ptr;
    int * i_ptr_2 = &i;

    if (i_ptr != i_ptr_2) {
        /* should never be the case */
        printf("Your system is broken!\n");
    }
}
```

```
int i;
char c;

void * int_or_char(int type) {
    if (type == 0)
        return &i;            /* (void *) <-- (int *) */
    else
        return &c;            /* (void *) <-- (char *) */
}

int main() {
    int t;
    scanf("%d", &t);
    if (t == 0) {
        int * p = int_or_char(t); /* (int *) <-- (void *) */
        *p = 123;
    } else {
        char * p = int_or_char(t); /* (char *) <-- (void *) */
        *p = 'a';
    }
}
```

Null Pointer

- The special "null" ***pointer value***

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  - integer constant expression with value `0`
  - or integer constant expression with value `0` cast to `void *`
  - or the NULL macro defined in <`stddef.h`>
  - usable with any pointer type
    - `0` and NULL convert to any pointer type
    - a null pointer of any type compares *equal* to `0` or NULL
  - guaranteed to *never compare equal to any valid pointer*
  - in C++, also `nullptr` pointer literal value (preferred)

- Use of invalid pointers
  - uninitialized pointer value
  - pointer to an object that no longer exists
  - pointer incremented beyond properly allocated boundaries
  - “uninitialized” ≠ `NULL`

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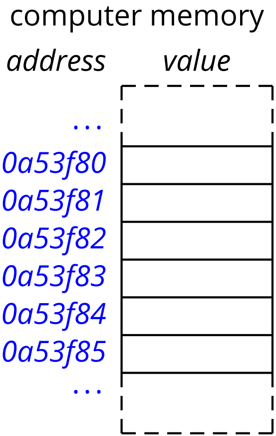
```
int * new_intp(int i) {
    int result = i;
    return &result;
}

int main() {
    int * p = new_intp(100);
    *p = 345;    /* what is p pointing to?! */
}
```

Uninitialized Pointers



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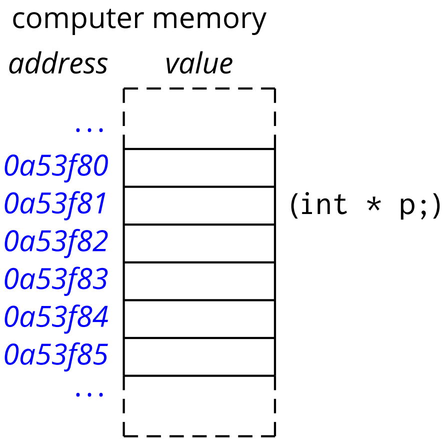


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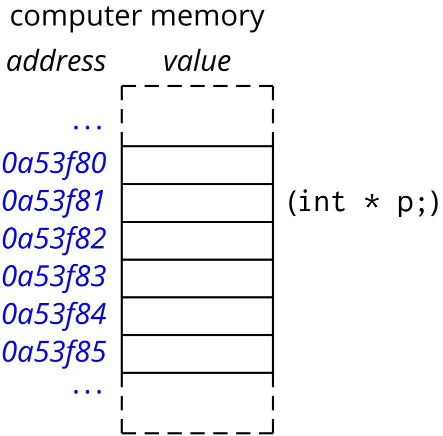


```
/* pointer to an int */
int * p;

*p = 13;
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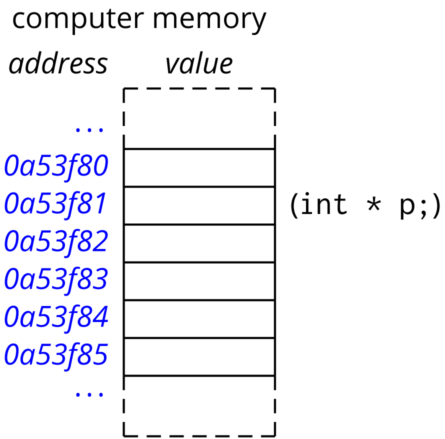


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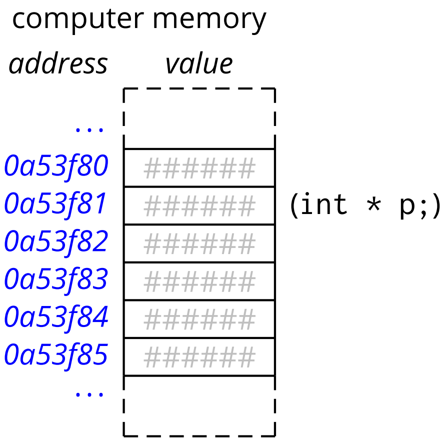


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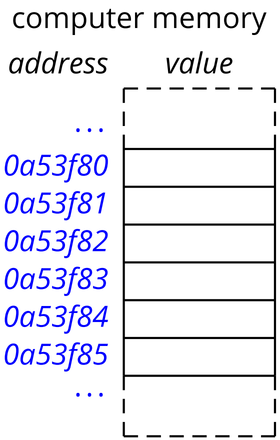
Pointer to a Dead Object



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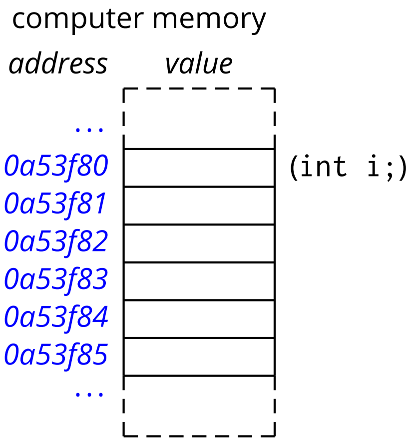


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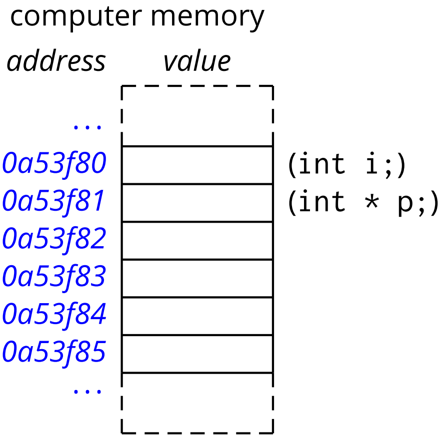


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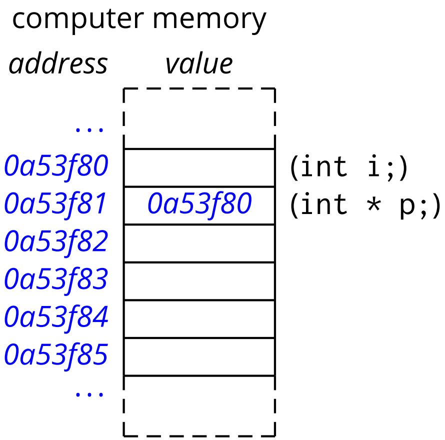


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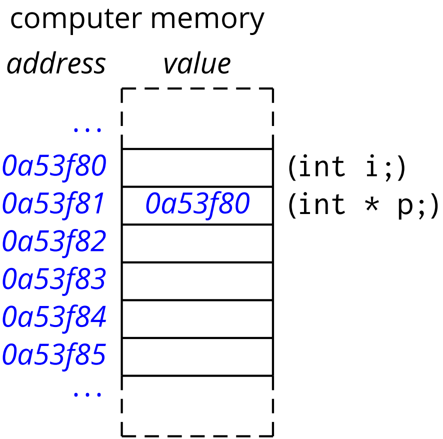


```
int i = 5;
int * p;
p = &i;

if (i > 0) {
```

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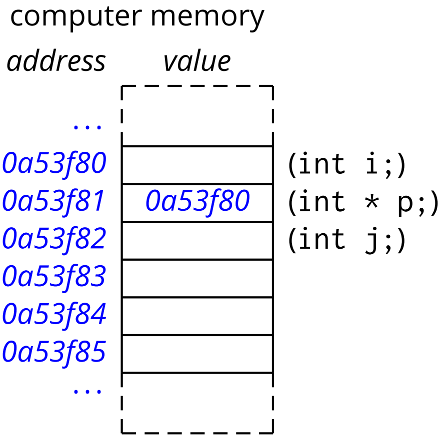


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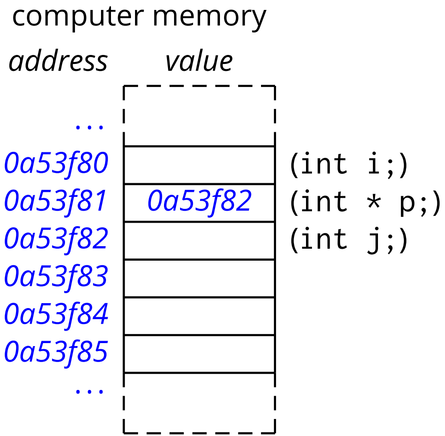


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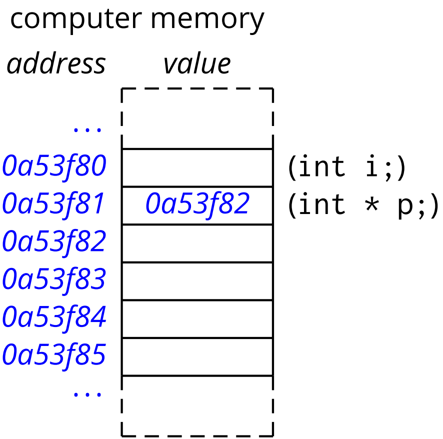


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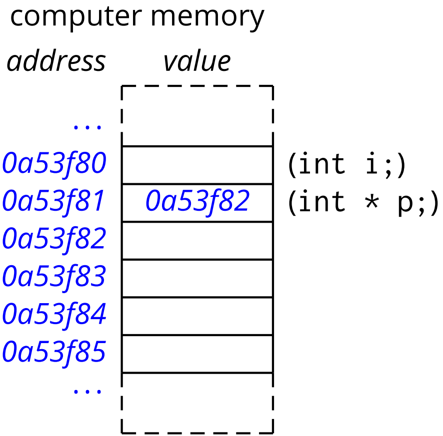


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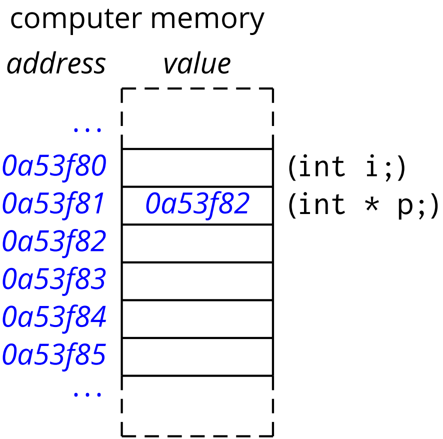


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- Example

```
int main() {
    int v[100];
    int i;
    for (i = 0; i < 100; ++i) {
        v[i] = getchar();
        if (v[i] == EOF) break;
    }
    while (i >= 0) {
        putchar(v[i]);
        --i;
    }
}
```

Strings

- A *string* in C is a *zero-terminated* array of chars

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- Example

```
int main() {
    char s[100];
    int i;
    for (i = 0; i < 99; ++i) {
        s[i] = getchar();
        if (s[i] == EOF || s[i] == '\n') break;
    }
    s[i] = 0;

    printf("Ciao %s\n", s);
}
```

- A *string* in C is a *zero-terminated* array of chars

- Example

```
int main() {
    char s[100];
    int i;
    for (i = 0; i < 99; ++i) {
        s[i] = getchar();
        if (s[i] == EOF || s[i] == '\n') break;
    }
    s[i] = 0;

    printf("Ciao %s\n", s);
}
```

- A string is represented by the pointer to its first character

Strings Literals

- We have already seen many string literals in this course.

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```
#include <stdio.h>

int main() {
    printf("Ciao!\n");
}
```

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```
#include <stdio.h>

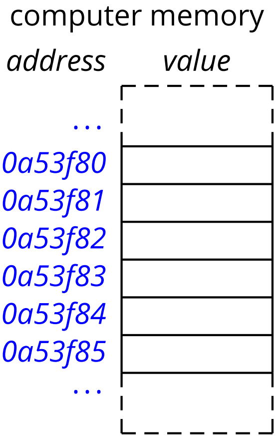
int main() {
    printf("Ciao!\n");
}
```

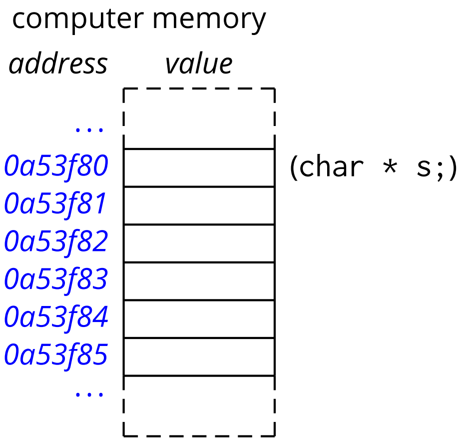
- A slightly more explicit example

```
#include <stdio.h>

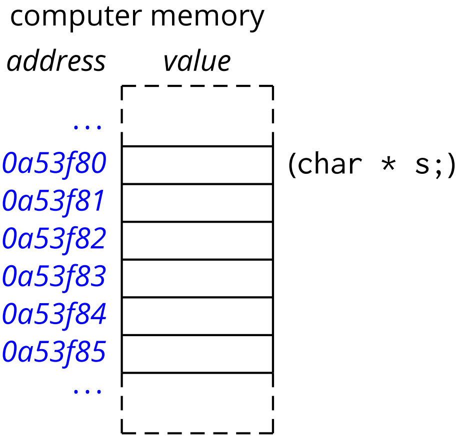
int main() {
    char * format;
    char * name;
    name = "James Bond";
    format = "My name is Bond--%s.\n";
    printf(format, name);
}
```

Strings in Memory





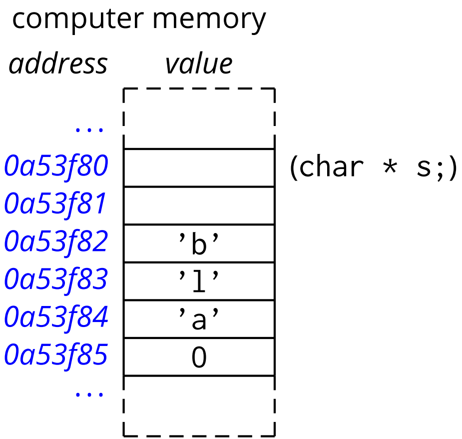

```
/* a pointer to char */
char * s;
```




```
/* a pointer to char */
char * s;

s = "bla";
```

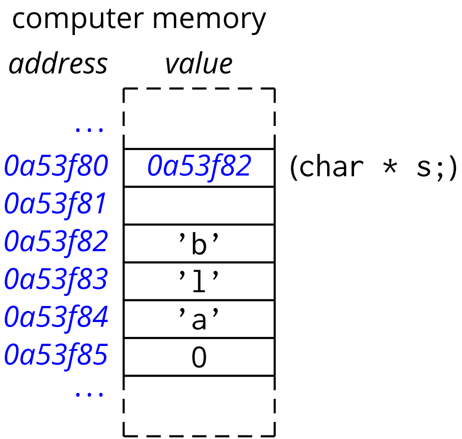
Strings in Memory




```
/* a pointer to char */
char * s;

s = "bla";
```

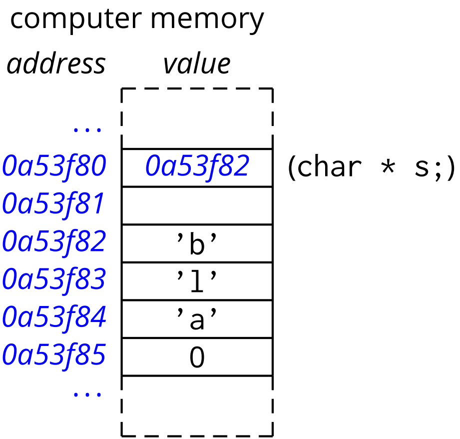
Strings in Memory




```
/* a pointer to char */
char * s;

s = "bla";
```

Strings in Memory




```
/* a pointer to char */
char * s;

s = "bla";

while (*s != 0) {
  putchar(*s);
  ++s;
}
```

Exercise (1)

- Implement a string comparison function `stringequal`
- `stringequal` takes two strings as pointers to characters and returns true if and only if the two strings are equal

  ```
  int stringequal(char * s1, char * s2);
  ```

A Bit More Standard I/O

- Input/Output of array of bytes and strings

A Bit More Standard I/O

- Input/Output of array of bytes and strings
  (what’s the difference?)

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  (what's the difference?)

- Reading an array of bytes with `fgets`

```
#include <stdio.h>

int main() {
    char buffer[100];
    while(fgets(buffer, 100, stdin))
        printf("I just read this: %s\n", buffer);
}
```

A Bit More Standard I/O

- Input/Output of array of bytes and strings
  (what's the difference?)

- Reading an array of bytes with `fgets`

```
#include <stdio.h>

int main() {
    char buffer[100];
    while(fgets(buffer, 100, stdin))
        printf("I just read this: %s\n", buffer);
}
```

- `stdin` is the predefined input stream

- `fgets` produces a C string (i.e., terminated by 0)

- `fgets` reads the input up to EOF, end of line, or the given number of characters (e.g., 100), whichever comes first

A Bit More Standard I/O (2)

- Reading an array of bytes with `fread`

```
#include <stdio.h>

int main() {
    char buffer[100];
    size_t size; /* size_t is an integer type */
    size = fread(buffer, 1, 100, stdin);
    if (size == 0) {
        fprintf(stderr, "Error or end of input\n");
    } else {
        fprintf(stdout, "%zu bytes read\n", size);
    }
}
```

A Bit More Standard I/O (2)

- Reading an array of bytes with `fread`

```
size = fread(buffer, 1, 100, stdin);
```

- `fread` reads end of line bytes as every other byte
- `fread` reads up to 100 elements of size 1 (byte)
- `fread` does not append a 0 (byte) at the end
- `stdout` and `stderr` are the predefined output and error streams

A Bit More Standard I/O (3)

- Reading numbers and other elements with scanf

```
#include <stdio.h>

int main() {
    unsigned int x, y;
    char battlefield[20][20];
    /* ... */
    puts("coordinates? ");
    if (scanf("%ud%ud", &x, &y)==2 && x < 20 && y < 20) {
        switch(battlefield[x][y]) {
        case 'S': /* ship ... */
        case 'w': /* water ... */
        }
    } else {
        puts("bad input!\n");
    }
}
```

- scanf reads a number of fields according to the given format
- scanf returns the number of successfully read fields

- Arrays are made of ***contiguous elements in memory***
  - given the address of the first element, we can point to all other elements

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  - given the address of the first element, we can point to all other elements

- **Example:**

```
int main() {
      int v[100];
      int * p;
      for(p = &(v[0]); p != &(v[100]); ++p)
          if ((*p = getchar()) == EOF) {
              --p;
              break;
          }
      while (p != v)
          putchar(*--p);
}
```

- Another example

- Another example

```
void printchar_string(const char * s) {
    for (;*s != '\0'; ++s)
        putchar(*s);
}

int main(int argc, char *argv[]) {
    int i;
    for (i = 0; i < argc; ++i) {
        printchar_string("Argument: ");
        printchar_string(argv[i]);
        printchar_string("\n");
    }
    return 0;
}
```

Arrays and Pointers (3)

- The *name* of an array can be used (in an expression) as a pointer to the array
  - i.e., a pointer to the first element

Arrays and Pointers (3)

- The *name* of an array can be used (in an expression) as a pointer to the array
  - i.e., a pointer to the first element

- Given a declaration

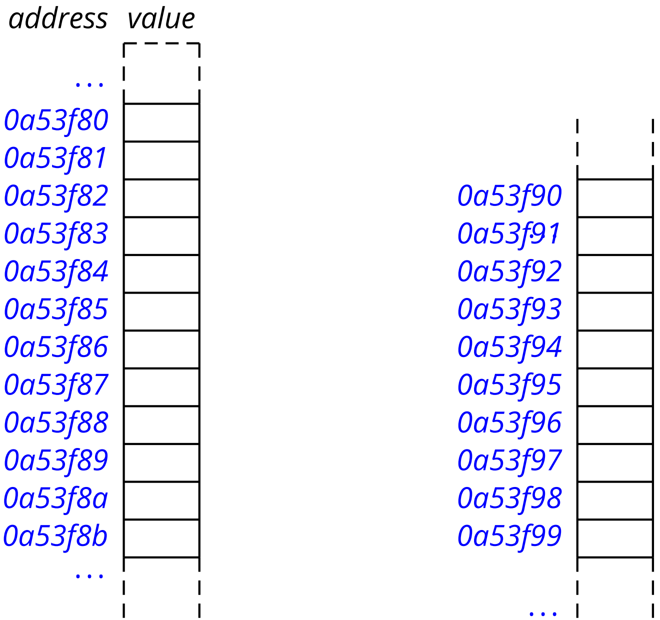
```
int A[100];
```

The following expressions are equivalent

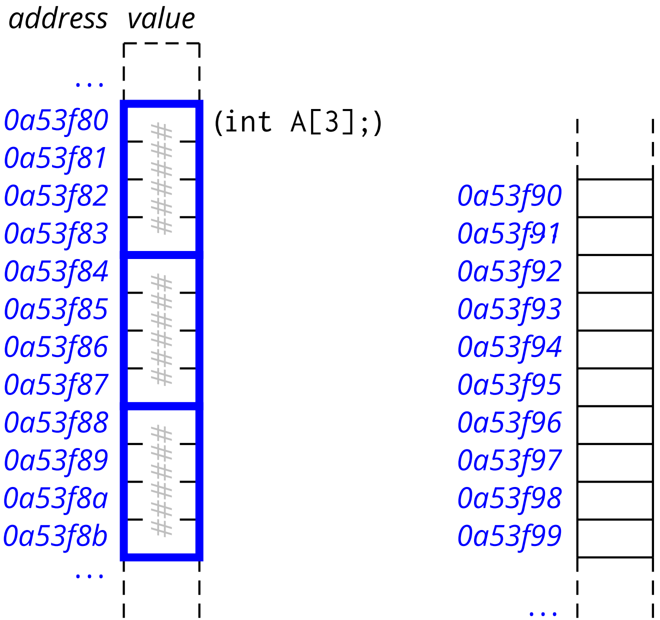
```
int * p = A;
```

```
int * p = &(A[0]);
```

Pointer Arithmetic

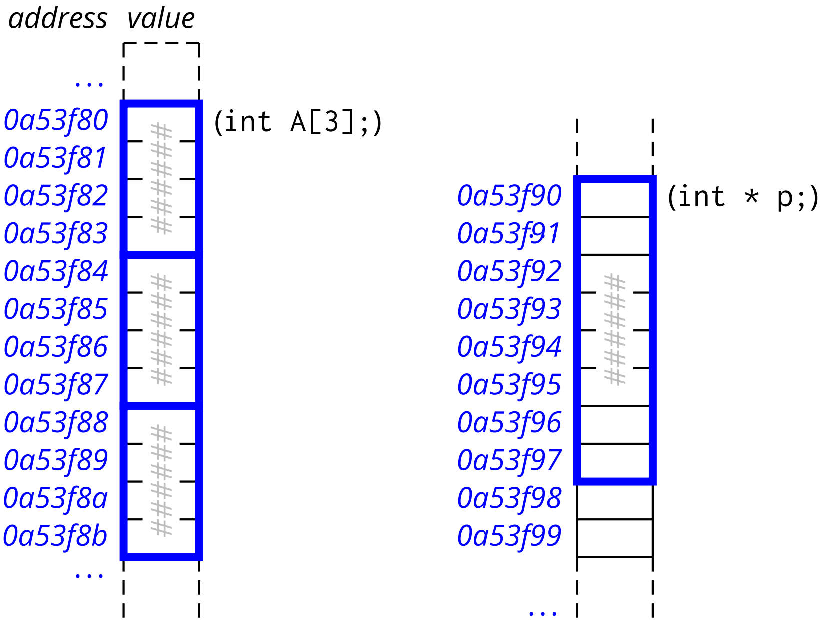


Pointer Arithmetic



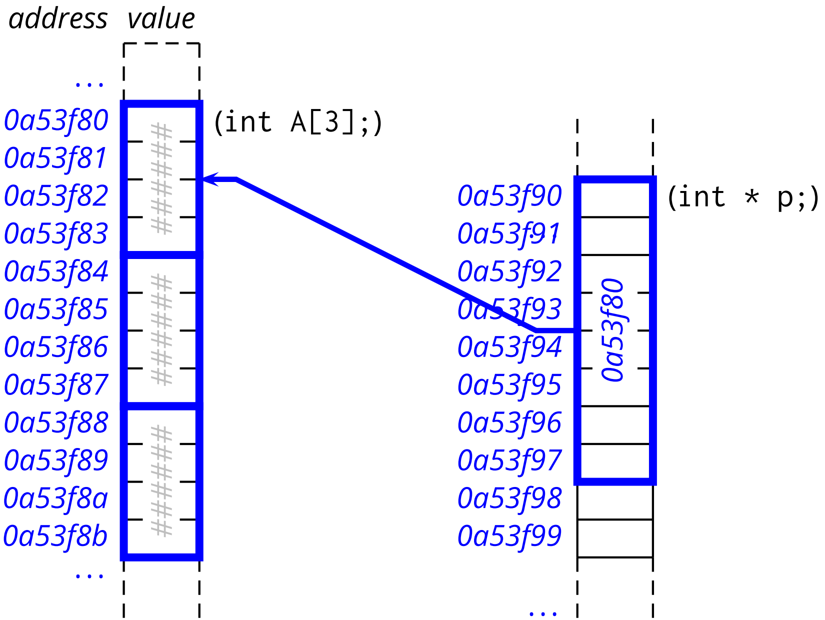

```
int A[3];
```

Pointer Arithmetic



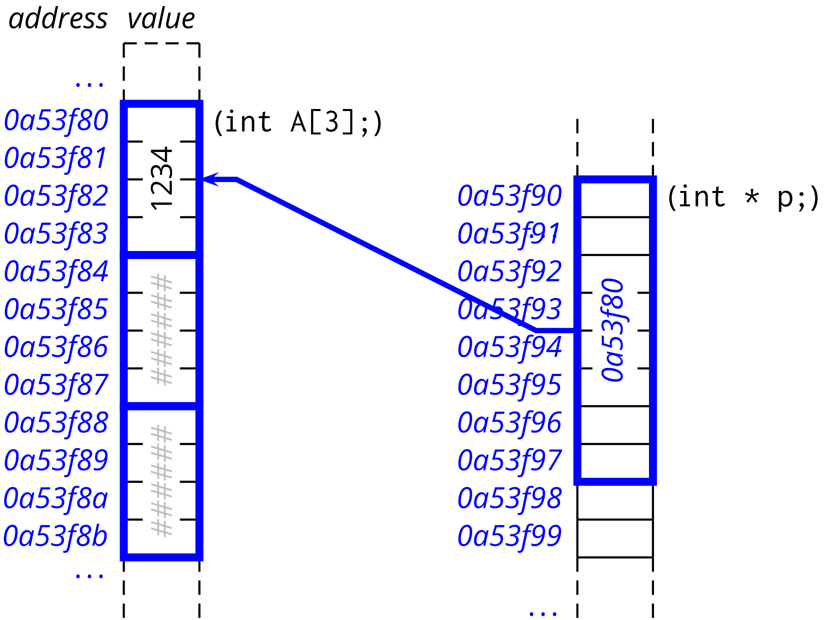

```
int A[3];
int * p;
```

Pointer Arithmetic



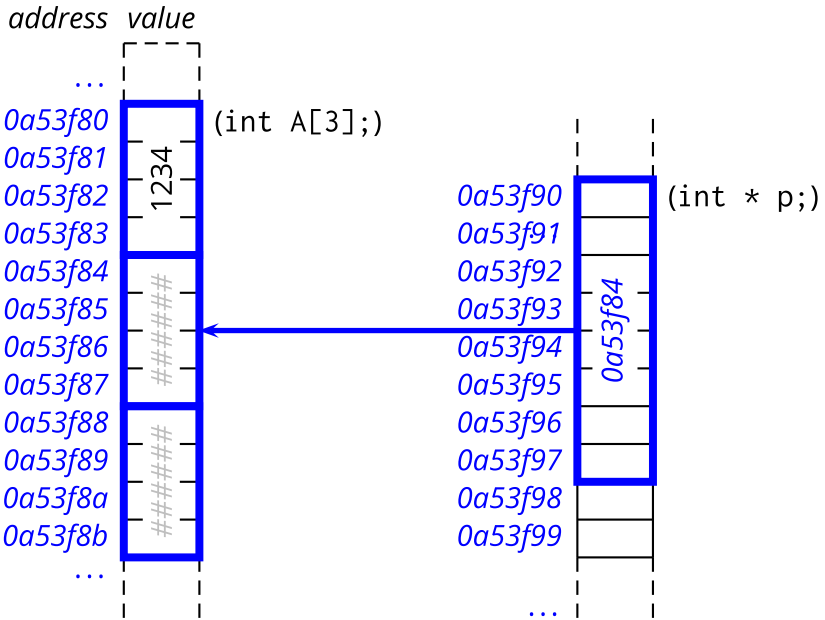

```
int A[3];
int * p;
p = A;
```

Pointer Arithmetic



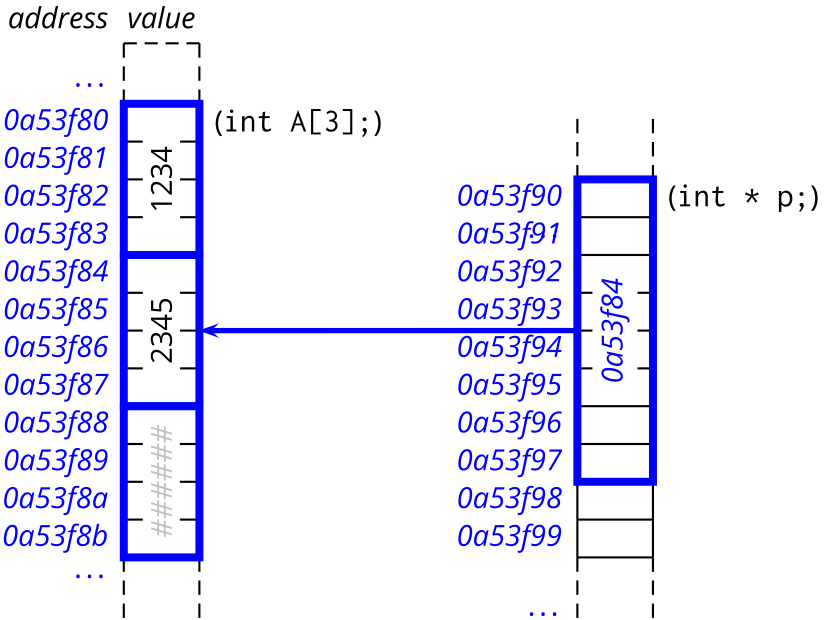

```
int A[3];
int * p;
p = A;
*p = 1234;
```

Pointer Arithmetic



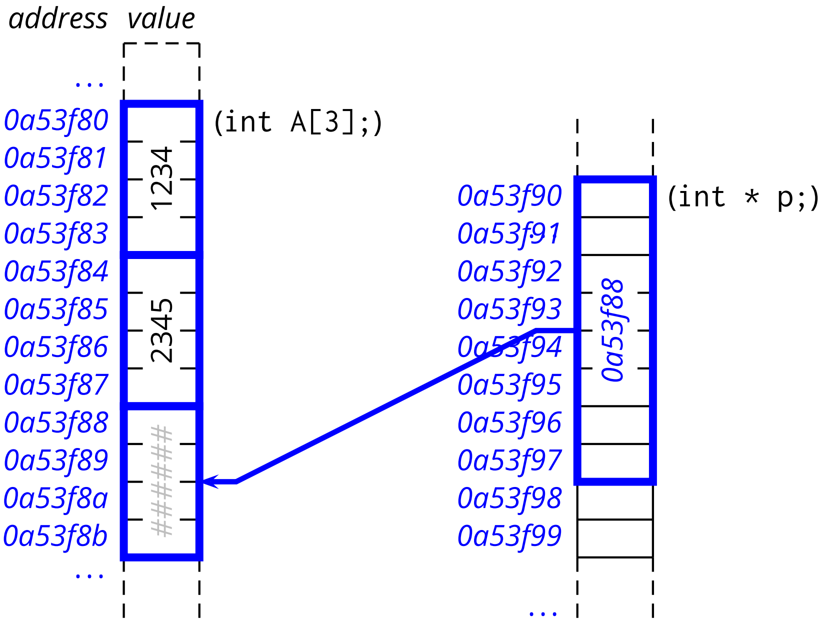

```
int A[3];
int * p;
p = A;
*p = 1234;
p = p + 1;
```

Pointer Arithmetic



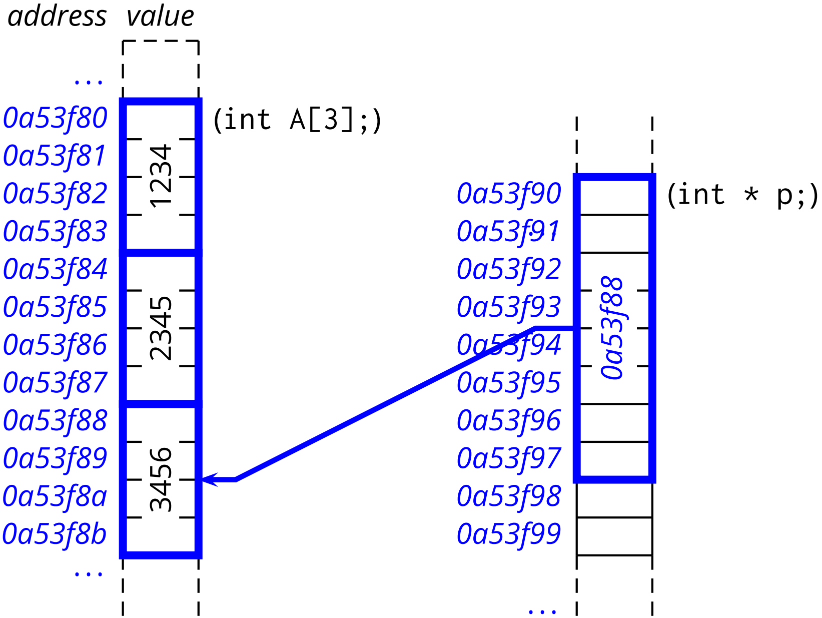

```
int A[3];
int * p;
p = A;
*p = 1234;
p = p + 1;
*p = 2345;
```

Pointer Arithmetic



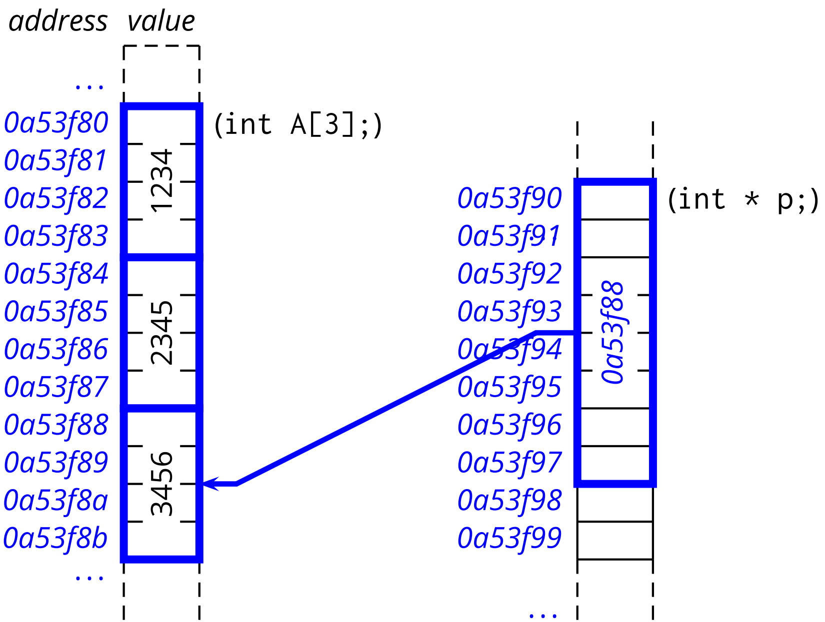

```
int A[3];
int * p;
p = A;
*p = 1234;
p = p + 1;
*p = 2345;
p = p + 1;
```

Pointer Arithmetic




```
int A[3];
int * p;
p = A;
*p = 1234;
p = p + 1;
*p = 2345;
p = p + 1;
*p = 3456;
```

Pointer Arithmetic




```
int A[3];
int * p;
p = A;
*p = 1234;
p = p + 1;
*p = 2345;
p = p + 1;
*p = 3456;
```

Exercise (2)

- Write a program that reads a text file from standard input in which lines are at most 1000 characters long, and outputs each line in reverse. A *line* is terminated by the newline character or by the end of file. Use the tests available on-line here:
http://www.inf.usi.ch/carzaniga/edu/sysprog_exercises/flipline_tests.tgz

`const` Pointers

- The `const` keyword means that the value can not be modified

- The const keyword means that the value can not be modified
  - which value?

```
void printchar_string(const char * s) {
    while (*s != '\0') {
        putchar(*s); /* no modifications here? */
        ++s;         /* definitely a modification. */
    }
}
```

- The const keyword means that the value can not be modified
  - which value?

```
void printchar_string(const char * s) {
    while (*s != '\0') {
        putchar(*s); /* no modifications here? */
        ++s;         /* definitely a modification. */
    }
}
```

What about this example?

```
void clear_string(const char * s) {
    while (*s != '\0') {
        *s = ' ';
        ++s;
    }
}
```

- Anatomy of a function definition

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```
int http_request(const char * method,
                 int pcount,
                 const char *args[]) {
    /* ... */
}
```

- Anatomy of a function definition

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- Anatomy of a function definition

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                 int pcount,
                 const char *args[]) {
    /* ... */
}
```

  - return type
  - function name

- Anatomy of a function definition

```
int http_request(const char * method,
                 int pcount,
                 const char *args[]) {
    /* ... */
}
```

  - return type
  - function name
  - formal parameters

- Anatomy of a function definition

```
int http_request(const char * method,
                 int pcount,
                 const char *args[]) {
    /* ... */
}
```

  - return type
  - function name
  - formal parameters
  - body

Declaring Functions

- A function must be at least *declared* before it is used

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```
int http_request(const char * method,
                 int pcount,
                 const char *args[]); /* no body */

int main() {
    /* ... */
    http_request("GET", 0, NULL);
    /* ... */
}

int http_request(const char * method,
                 int pcount,
                 const char *args[]) {
    /* function definition is here! */
}
```

Exercise (3)

- Implement a function `twotimes` that reads a word of up to 1000 characters from the standard input and returns *true* if the given string consists of the concatenation of two identical substrings

- Test this function by writing a little program that reads a word of up to 1000 characters from the standard input and outputs “YES” or “NO” according to the result of the `twotimes` function applied to the input word

Exercise (4)

- What is the output of the following program?

```
void f(char * s) {
    char p;
    unsigned int c;
    while(*s != 0) {
        c = 1;
        p = *s;
        for(++s; *s == p; ++s) {
            ++c;
        }
        printf(" %d", c);
    }
    putchar('\n');
}
int main() {
    f("mamma, ciaaaaao!");
    /* ... */
}
```

The `main` Function

The `main` Function

- The main function takes two parameters

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```
int main(int argc, char *argv[]) {
    int i;
    printf("You gave me %d parameters:\n", argc);
    for (i = 0; i < argc; ++i)
        printf("argv[%d] = %s\n", i, argv[i]);
    return 0;
}
```

The `main` Function

- The main function takes two parameters

```
int main(int argc, char *argv[]) {
    int i;
    printf("You gave me %d parameters:\n", argc);
    for (i = 0; i < argc; ++i)
        printf("argv[%d] = %s\n", i, argv[i]);
    return 0;
}
```

- argv is an array of strings
- argc is the length of the array
- main returns an integer value
  - in general a 0 return value means “completed successfully”

Exercise (5)

- Write a program called `sortlines` that reads one line at a time from the standard input, and outputs the sequence of words in each line sorted in lexicographical order. A *word* is a (maximal) contiguous sequence of alphabetic characters as defined by the `isalpha` library function. The output sequence for each line should be printed on a single line with each word separated by one space. An input line is guaranteed to be at most 1000 characters.

Homework Assignment

- Implement a program that takes a string as a command-line parameter, reads the standard input, and returns 0 if the given string is found in the input stream.

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- Implement a program that takes a string as a command-line parameter, reads the standard input, and returns 0 if the given string is found in the input stream.

- **More interesting variant:** Implement a program that takes one or more strings as a command-line parameters, reads the standard input, and returns 0 if all the given strings are found in the input stream.