C Preprocessor (CPP)

- Processes files before the compiler
- Lines that begin with #
- Preprocessor doesn't "know" C
- To see CPP output: **`gcc -E my_file.c`**
- Useful for
  - File inclusion
  - Constants
  - Macros
  - Conditional compilation

File Inclusion

- CPP replaces #include with the entire contents of the included file
- System headers
  - `#include <stdio.h>`
  - On UNIX, looks in **`/usr/include`**
  - You should not use **`<>`** to include user-defined header files
- User-defined headers
  - `#include "my_pow.h"`
  - Searches current (source) directory first
- Include files can be nested
- **`-I`** switch used to specify additional include directories

Constants

- Simple textual replacement

```
#define  name               replacement text
```

Examples:

```
#define PI                  3.14
#define MAX                 1000
#define TRUE                1
#define SECS_PER_DAY        (60 * 60 * 24)
#define READ_ACCESS         0x01
#define WRITE_ACCESS        0x02
#define RW_ACCESS           (READ_ACCESS | WRITE_ACCESS)
#undef PI /* un-defines a constant/macro */
```

Macros

```
#define max(A, B)      ((A) > (B) ? (A) : (B))
```

```
x = max(p+q, r+s);
```

becomes

```
x = ((p+q) > (r+s) ? (p+q) : (r+s));
```

Notice, expressions are evaluated twice!

- **`stdio.h`** defines the following macros:

```
#define getchar()      getc(stdin)
#define putchar(c)     putc((c), stdout)
```

Don't put a space between macro name and '('

Don’t end with semicolon

Stringification

- **`#parameter_name`** quotes **`parameter_name`**

```
#define PRINT_STR_VAR(S) printf(#S " = %s\n", S)

char szDrink[] = "Okocim";
PRINT_STR_VAR(szDrink);
```

- becomes

```
printf("szDrink" " = %s\n", szDrink);
```

which, after string concatenation, becomes

```
printf("szDrink = %s\n", szDrink);
```

finally, the output is

```
szDrink = Okocim
```

Stringify Constants

```
typedef enum { red, green, blue, white, black } EColor;

#define COLOR_CASE(x) case x: return "The color is " #x

const char* Color2Name(EColor clr) {
    switch (clr) {
        COLOR_CASE(red);
        COLOR_CASE(green);
        COLOR_CASE(blue);
        COLOR_CASE(white);
        COLOR_CASE(black);
        default: return "INVALID COLOR!";
    }
}
```

Stringification

- If you want to stringify the result of expansion of a macro argument, you have to use two levels of macros.

```
#define XSTR(S) STR(S)
#define STR(S) #S
#define FOO 4
STR (FOO)
   ==> "FOO"
XSTR (FOO)
   ==> XSTR (4)
   ==> STR (4)
   ==> "4"

#define FIELDSIZE 4
char* str="long string";
printf("%" XSTR(FIELDSIZE) "s",str);
```

Concatenation

- To concatenate two macro arguments, use the **##** operator:

```
#define DOUBLE(A,B) A##B
printf("%f\n",DOUBLE(3,e6));
   ==> printf("%f\n",3e6);

#define DOUBLE(A,B) AB
printf("%f\n",DOUBLE(3,e6));
   ==> printf("%f\n",AB); /* invalid */

#define DOUBLE(A,B) A B
printf("%f\n",DOUBLE(3,e6));
   ==> printf("%f\n",3 e6); /* invalid */
```

Pre-defined Names

- `__LINE__` Current source line number
- `__FILE__` Name of file being compiled
- Useful for error handling, debugging and logging

```
#define DEBUG_STR(S)\
      printf(#S " = %s [File: %s, Line: %d]\n",\
      S, __FILE__, __LINE__);

DEBUG_STR(szDrink)
```

- the output is

```
szDrink = Okocim [File: debug_str.c, Line: 16]
```

Conditional Compilation

- `#if, #ifdef, #ifndef, #else, #endif`
- Useful for separating debug-only code from release code
- `assert()`, debug_alloc, etc.

```
#ifdef MY_DEBUG
#define DEBUG_STR(S)\
  printf(#S " = %s [File: %s, Line: %d]\n",\
  S, __FILE__, __LINE__);
#else
#define DEBUG_STR(S)
        /* do nothing in release builds */
#endif /* MY_DEBUG */
```

- Use the `-Dmacro=value` compiler switch:
- `$ gcc -DMY_DEBUG=1 debug_str.c -o debug_str && ./debug_str`
- `szDrink = Okocim [File: debug_str.c, Line: 16]`

Macros for Portability

- Portability: Compiler-, Processor-, OS- or API- specific code

```
#ifdef _WIN32
OutputDebugString(szOutMessage);
#else  /* _WIN32 */
_CrtOutputDebugString(szOutMessage);
#endif  /* _WIN32 */
```

Almost a Function

- To define a macro which can be used as a function in all contexts use the following form

```
#define fun(x) do { printf(#x "=%d\n",x); x++;} while (0)
```

- It will work in the following example requiring the semicolon after the function/macro call

```
if (condition)
  fun(t);
else
  fun(z);
```

- A simpler construct below will not work

```
#define fun(x) { printf(#x "=%d\n",x); x++;}
```

Problems in Large Programs

- Small programs $\rightarrow$ single file
- “Not so small” programs:
  - Many lines of code
  - Multiple components
  - More than one programmer
- Problems:
  - Long files are harder to manage (for both programmers and machines)
  - Every change requires long compilation
  - Many programmers cannot modify the same file simultaneously
  - Division to components is desired

Multiple Modules

- Divide project to multiple files
  - Good division to components
  - Minimum compilation when something is changed
  - Easy maintenance of project structure, dependencies and creation
- Programming language constructs used to refer to external files (**`extern`**)
- Compilation can link several files together to create single application from several files
- Can compile several source files, link to pre-compiled object files or combination of these options

Multiple Modules

```
/* greetings.h */
void greetings(void);
```

```
/* main.c */
#include <stdio.h>
#include "greetings.h"

int main()
{
  greetings();
  return 0;
}
```

```
/* greetings.c */
#include <stdio.h>
#include "greetings.h"

void greetings(void)
{
  printf ("Hello user !\n");
}
```

```
gcc -g -Wall -pedantic -c main.c -o main.o
gcc -g -Wall -pedantic -c greetings.c -o greetings.o
gcc -g main.o greetings.o -o hello
```

compilation (first two commands)

linking (last command)

Multiple Modules - Change in `greetings.c`

```c
/* greetings.h */
void greetings(void);
```

```c
/* main.c */
#include <stdio.h>
#include "greetings.h"

int main()
{
  greetings();
  return 0;
}
```

```c
/* greetings.c */
#include <stdio.h>
#include <stdlib.h>
#include "greetings.h"

void greetings(void)
{
  printf ("Hello %s!\n",
   getenv("LOGNAME"));
}
```

```
gcc -g -Wall -pedantic -c greetings.c -o greetings.o
gcc -g main.o greetings.o -o hello
```

Multiple Modules - More Changes

```c
/* greetings.h */
int greetings(void);
```

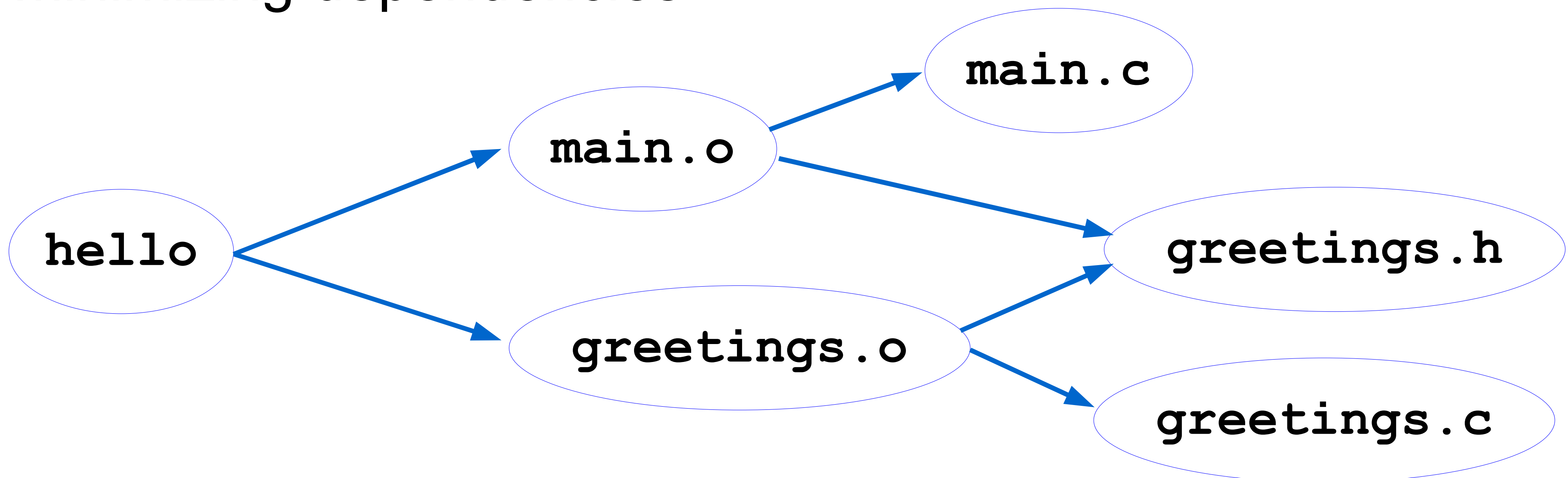
```c
/* main.c */
#include <stdio.h>
#include "greetings.h"

int main()
{
  greetings();
  return 0;
}
```

```c
/* greetings.c */
#include <stdio.h>
#include <stdlib.h>
#include "greetings.h"

int greetings(void)
{
  return printf ("Hello %s!\n",
   getenv("LOGNAME"));
}
```

```
gcc -g -Wall -pedantic -c main.c -o main.o
gcc -g -Wall -pedantic -c greetings.c -o greetings.o
gcc -g main.o greetings.o -o hello
```

Module Dependencies

- Module A has a compile-time dependency on Module B if **`A.c`** requires **`B.h`** to compile
- Program A has a link-time dependency on Module B if A requires **`B.o`** to link
- Avoid cyclic dependencies (A $\rightarrow$ B and B $\rightarrow$ A)
- Managing software complexity in a large part requires minimizing dependencies



Makefiles and `make`

- Its easy to change a header file but forget to re-compile all the source files that depend on it
- Makefiles help you manage dependencies
- **`make`** is a utility typically used for building software packages that are comprised of many source files
  - determines automatically which pieces need to be rebuilt
  - uses an input file (usually called **`makefile`** or **`Makefile`**) which specifies rules and dependencies for building each piece
- you can use any name for the makefile and specify it on the command line:

```
bash# make

bash# make -f myfile.mk
```

- first way (above) uses default (**`makefile`** or **`Makefile`**) as input file
- second way uses **`myfile.mk`** as input file

Simple makefile

```
hello: main.o greetings.o
        gcc -g main.o greetings.o -o hello
main.o: main.c greetings.h
        gcc -g -Wall -pedantic -c main.c -o main.o
greetings.o: greetings.c greetings.h
        gcc -g -Wall -pedantic -c greetings.c -o greetings.o
```

dependency line

action line

Dependency line + action line = rule

Dependency line **must** start in column 1

Action line **must** begin with a tab character

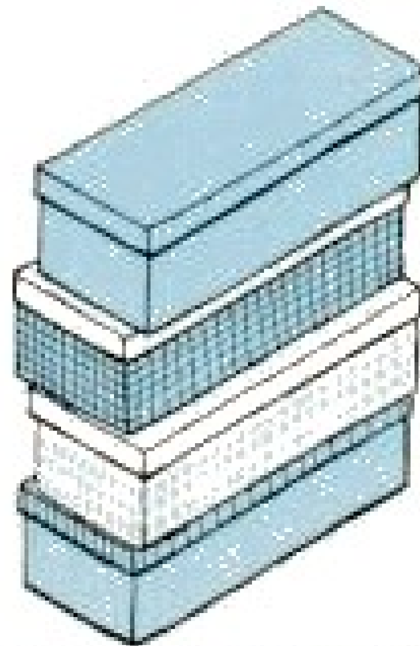
```
$ make
gcc -g -Wall -pedantic -c main.c -o main.o
gcc -g -Wall -pedantic -c greetings.c -o greetings.o
gcc -g main.o greetings.o -o hello
$ make
make: `hello' is up to date.
```

`#include` Guards

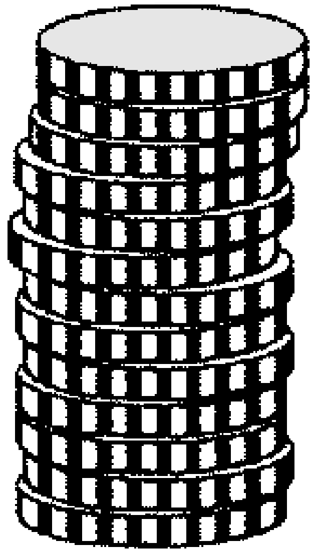
- When included header files include other files, some header files may be included multiple times
  - Sometimes harmless
    - e.g. multiple **`extern`** variable declaration
  - Sometimes harmful
    - e.g. you must not **`typedef`** the same type twice
  - always increases processing time
- To prevent such situations `#include` guards are used

```
/* header.h */
#ifndef _HEADER_H_
#define _HEADER_H_
/* header body */
typedef some_type some_name;
#endif /* _HEADER_H_ */
```

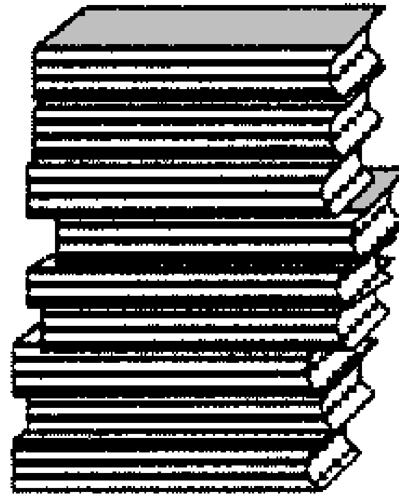
Stacks in Our Life



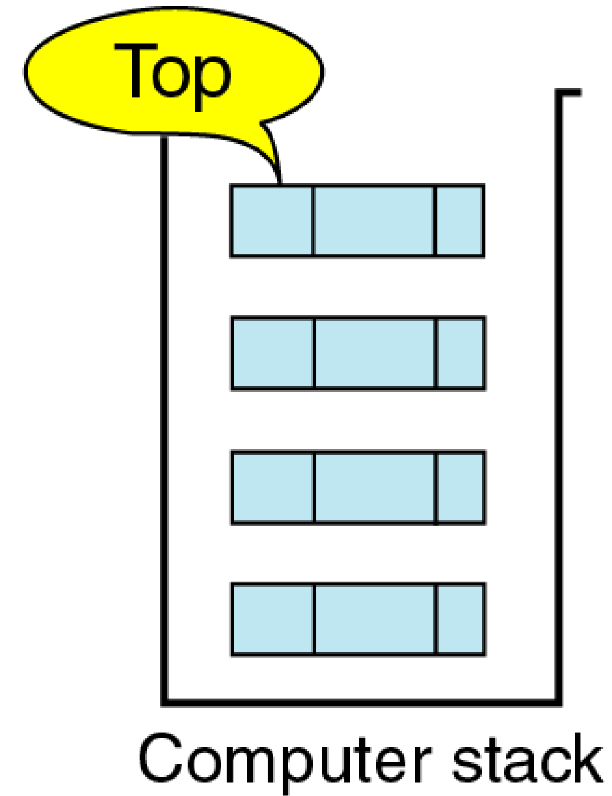
More Stacks



Stack of coins



Stack of books

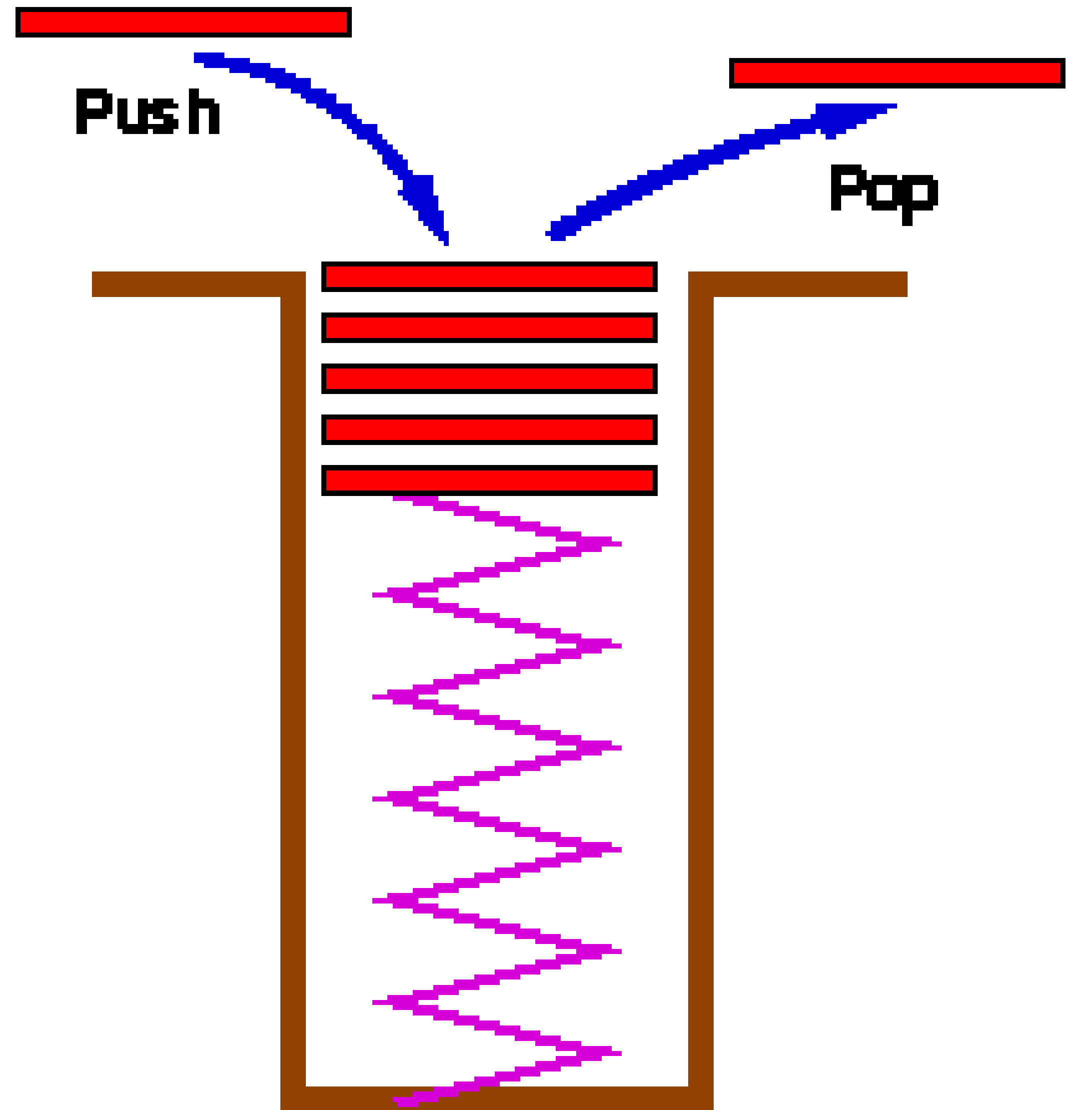


Computer stack

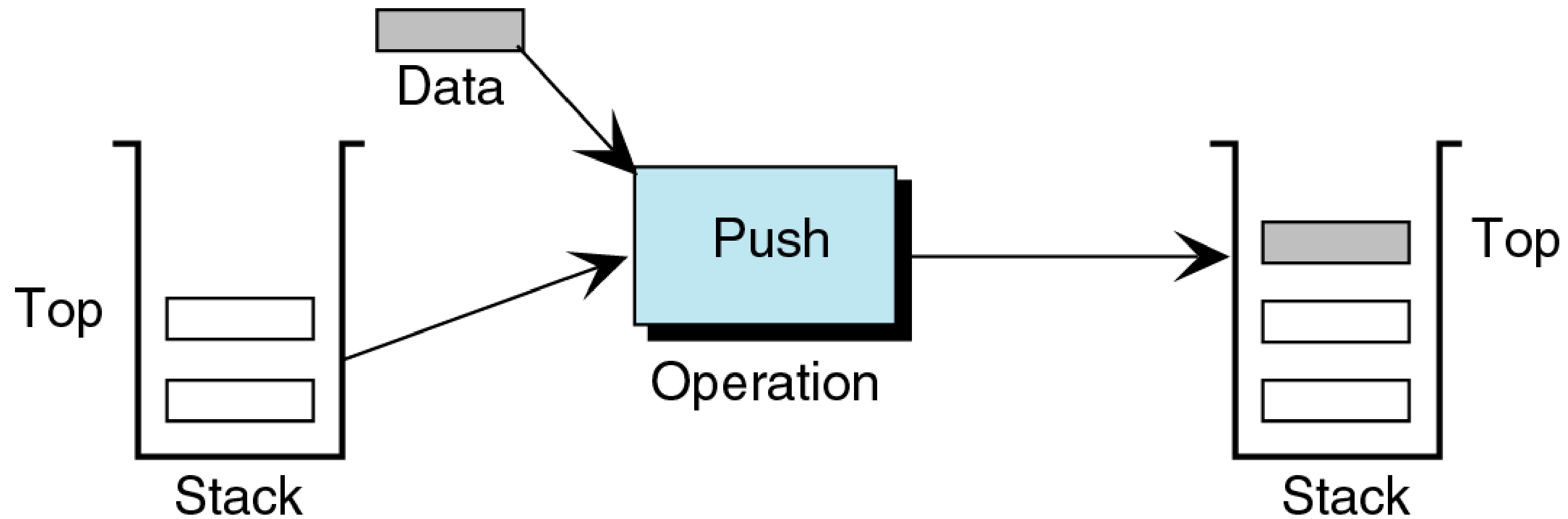
- A stack is a LIFO structure: Last In First Out

Basic Operations with Stack

- Push
  - Add and item
    - Overflow
- Pop
  - Remove an item
    - Underflow
- Stack Top
  - What's on the Top
    - Could be empty

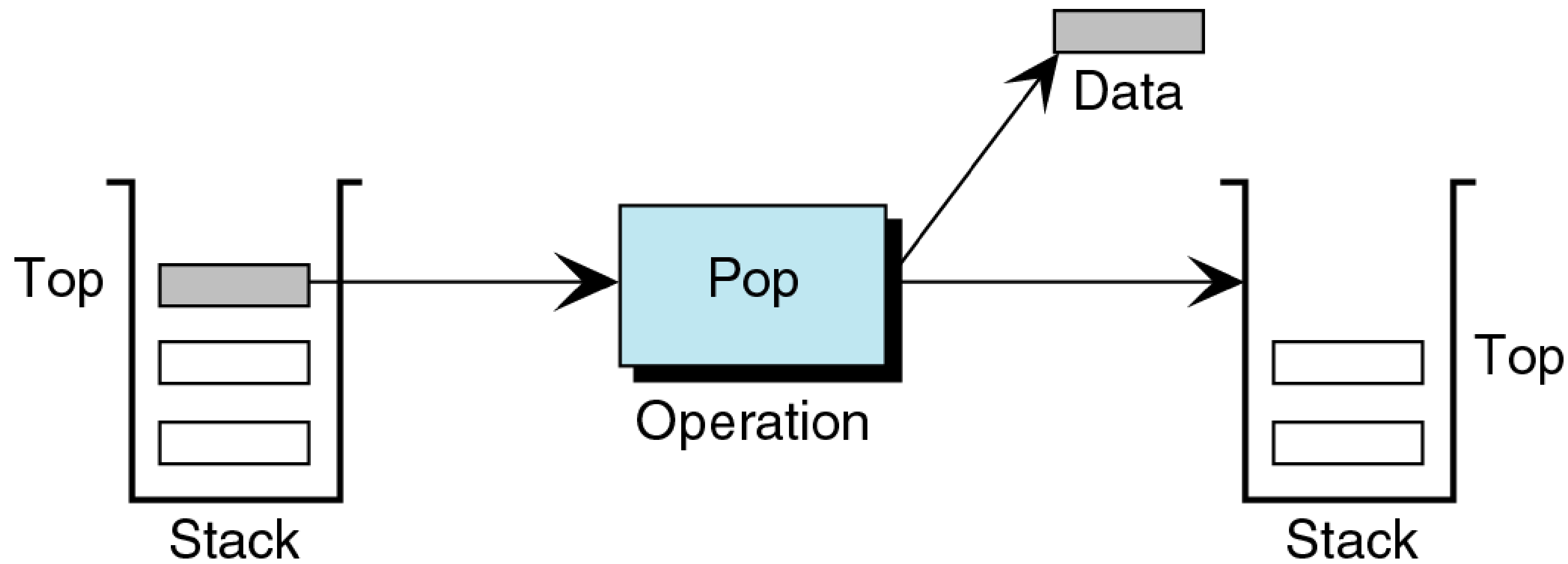


Push



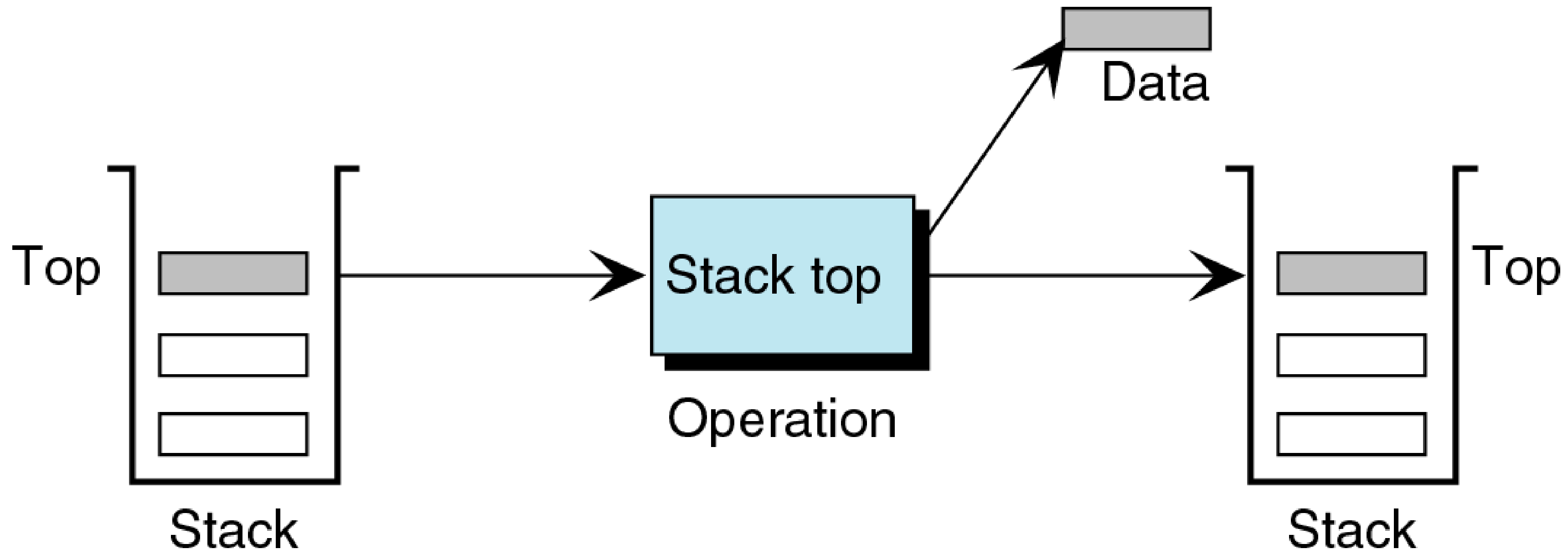
- Adds new data element to the top of the stack

Pop



- Removes a data element from the top of the stack

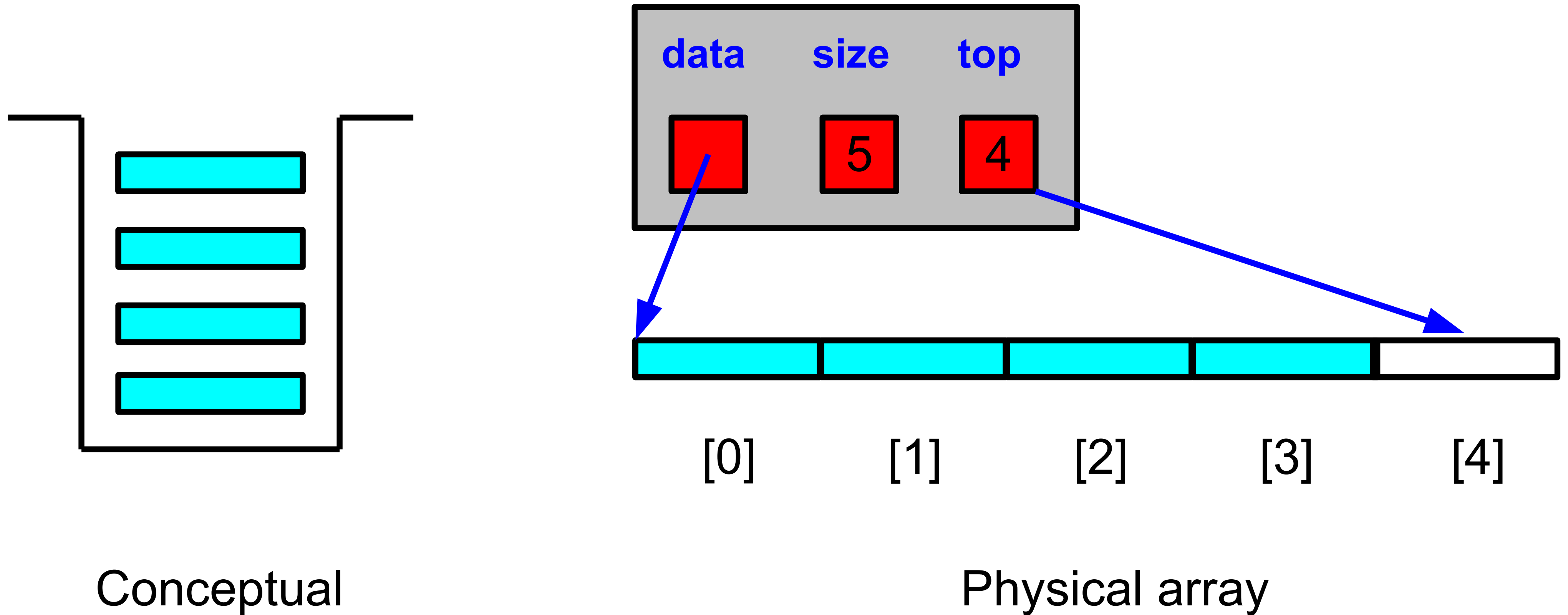
Stack Top



- Checks the top element. Stack is not changed

Implementing Stack with Array

- Stack is stored as an array
  - This implementation has fixed capacity

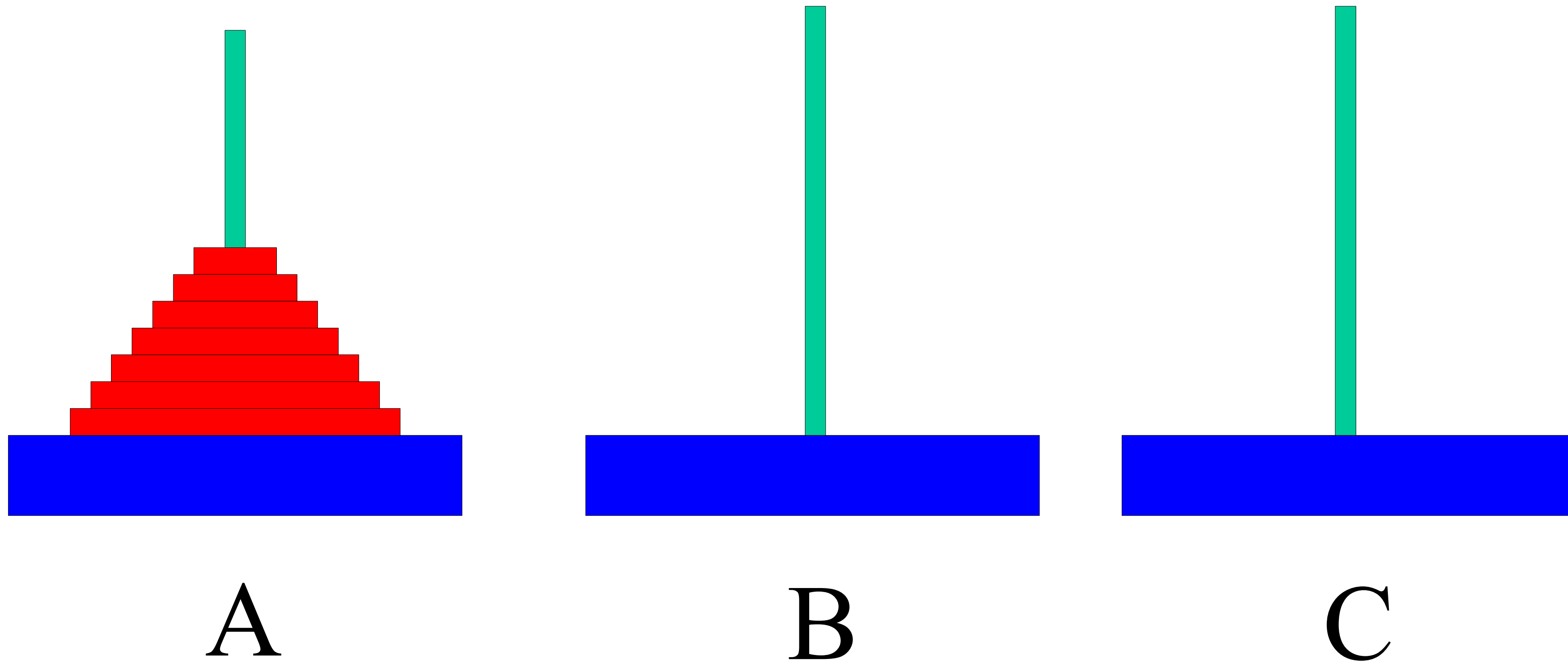


Stack Implementation

```c
/* stack.h */
void push(int a);
int pop(void);
int peek(void);
```

```c
/* stack.c */
#include <assert.h>
#include "stack.h"

#define STACKSIZE 20
static int top; /* first empty slot on the stack */
static int size=STACKSIZE;
static int data[STACKSIZE];

void push(int a)
{
        assert(top<size);
        data[top++]=a;
}

int pop(void)
{
        assert(top>0);
        return data[--top];
}

int peek(void)
{
        assert(top>0);
        return data[top-1];
}
```

Example: Towers of Hanoi



- Object of game is to move a set of disks, stacked in successively decreasing diameters, from tower A to tower C using tower B as an intermediate; we are not allowed to stack any disk on top of a smaller disk
- Stacks can be implemented as a two-dimensional array `towers[3][7]`

Debugging

- Frequently programs do not operate as intended
- You need some way to step through you logic other than just looking at your code
- Knowing the control flow and changes in variables as the program runs helps to find the errors
  - You can insert `printf`s in your code to print the values of variables in strategic places
  - Using a debugger is typically more convenient
- A debugger is a program that runs other programs, allowing the user to exercise control over these programs, and to examine variables when problems arise
- The most popular debugger for UNIX systems is GDB, the GNU debugger

Basic Features of a Debugger

- The debugger will let you find out
  - What statement or expression did the program crash on
  - If an error occurs while executing a function, what line of the program contains the call to that function, and what are the parameters
  - What are the values of program variables at a particular point during execution of the program
  - What is the result of a particular expression in a program

Using GDB

- Compile your program using **`-g`** option
  - **`gcc -Wall -pedantic -g -c hello.c`**
  - **`gcc -g hello.o -o hello`**
- Run the program under the control of a debugger
  - **`gdb hello`**
- Set the breakpoint at the **`main`** function
  - **`break main`**
- Run the program
  - **`run`**

GDB Commands

- ***run** command-line-arguments*
  - Starts your program as if you had typed

    hello command-line-arguments
  - You can type

```
run <file1 >file2
```

  to redirect files to the standard input and output of your program
- ***break** place*
  - Creates a breakpoint; the program will halt when it gets there. The most common breakpoints are at the beginnings of functions, as in
    - **break main**
  - You can also set breakpoints at a particular line in a source file
    - **break 20**
    - **break hello.c:10**

GDB Commands

- **`delete`** ***`N`***
  - Removes breakpoint number *N*. Leave off *N* to remove all breakpoints.
  - **`info break`** gives info about each breakpoint
- **`help`** ***`command`***
  - Provides a brief description of a GDB command or topic
  - Plain **`help`** lists the possible topics
- **`step`**
  - Executes the current line of the program and stops on the next statement to be executed
- **`next`**
  - Like **`step`**, however, if the current line of the program contains a function call, it executes the function and stops at the next line

GDB Commands

- **`finish`**
  - Continues execution until reaching the end of the current function
- **`continue`**
  - Continues regular execution of the program until a breakpoint is hit or the program stops
- **`where`**
  - Produces a backtrace - the chain of function calls that brought the program to its current place
  - The command **`backtrace`** is equivalent

GDB Commands

- **`print E`**
  - prints the value of E in the current frame in the program, where *E* is a C expression (usually just a variable)
  - **`display`** is similar, except every time you execute a next or step, it will print out the expression based on the new variable values
- **`quit`**
  - Leave GDB

Post-Mortem Debugging

- You can make the program *dump core* when the **`abort`** function is invoked
- It will create a **`core`** file in the program directory, which contains the image of the program memory when it crashed
- You can use it to find the cause of the crash
- To enable dumping core in bash shell, type at your shell prompt

```
ulimit -c unlimited
```

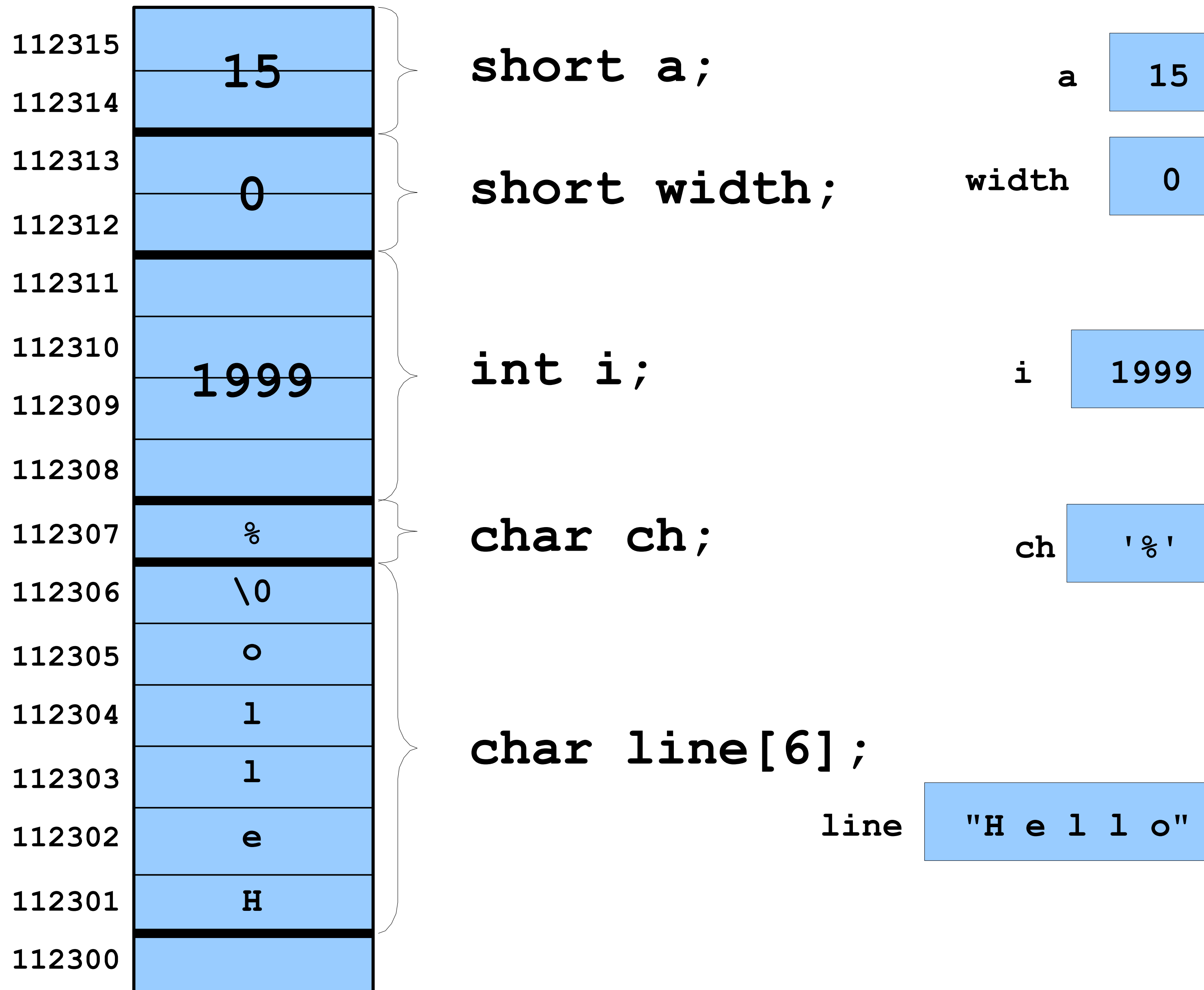
- To make GDB debug the program using the specific core file use the syntax

```
gdb progname corefilename
```

Computer Memory

- Computer memory is a huge array of consecutively numbered memory cells
- On most modern computers a cell can store one byte of data
- An address of a memory cell is its number in an array
- Data of different type occupies one of more contiguous cells (bytes)

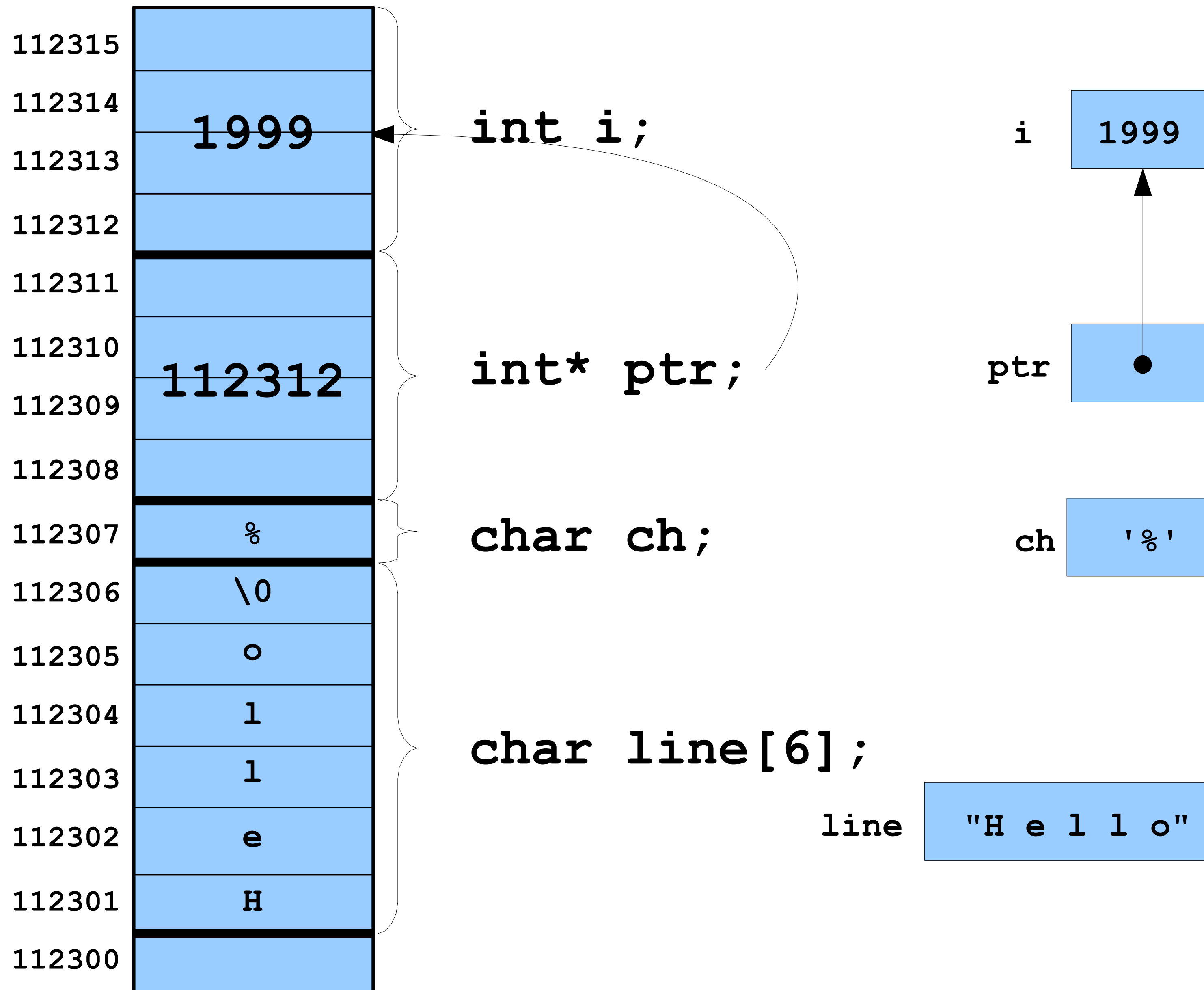
Computer Memory



Pointers

- A pointer is a variable that can store an address of a variable (i.e., 112300)
- We say that a pointer points to a variable that is stored at that address
- A pointer itself usually occupies 4 bytes of memory (then it can address cells from 0 to 2^{32}-1)

Computer Memory



Declaring Pointers

- In C you can specify the type of variable a pointer can point to:

```
int *ad; /* pointer to int */
char *s; /* pointer to char */
float *fp; /* pointer to float */
char **s; /* pointer to variable that is a
 pointer to char */
```

Operations with Pointers

- We can assign an address to a pointer

```
int *p1, *p2; int a, b;
p1 = &a;
```

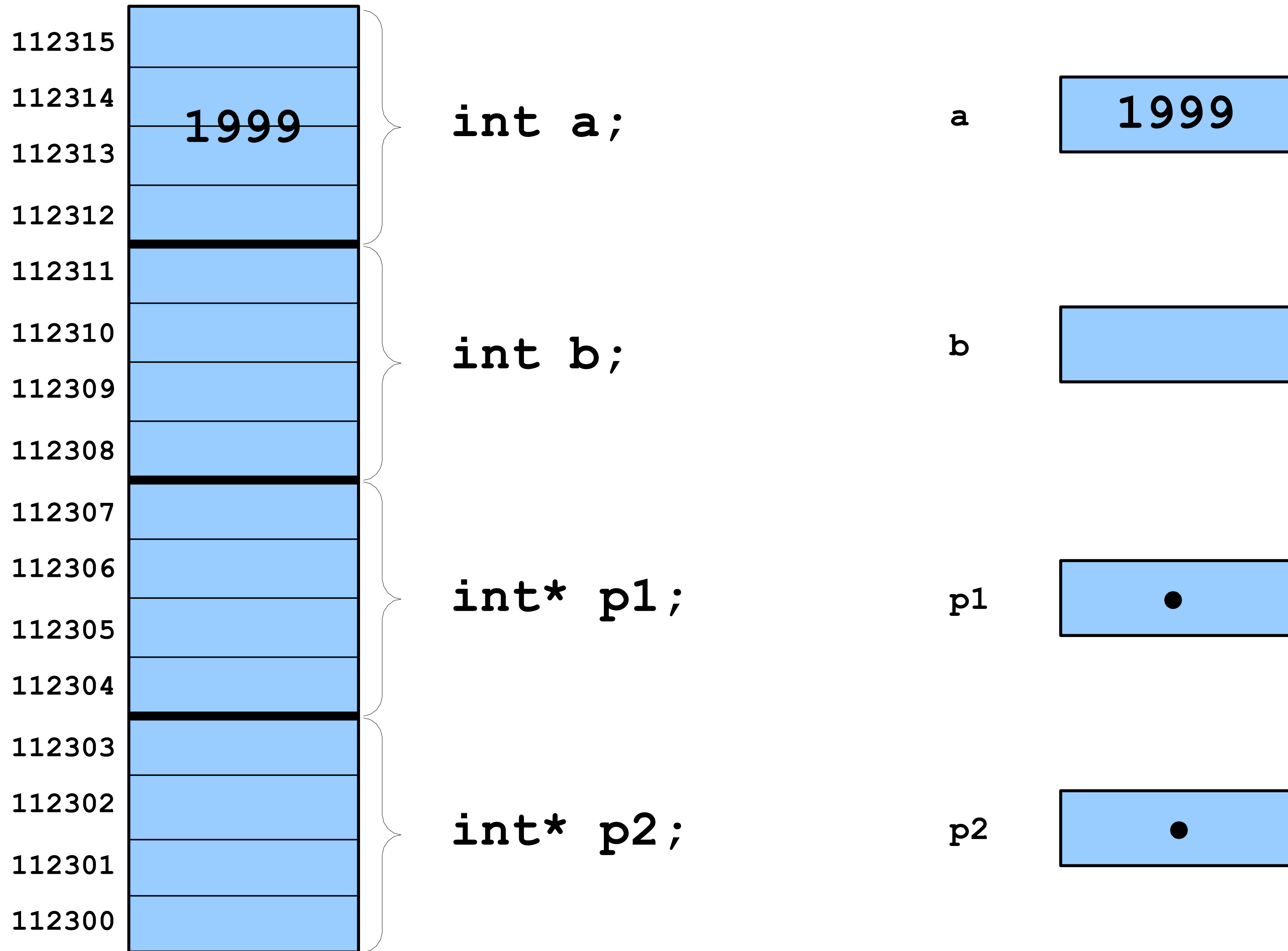
- We can assign pointers to each other

```
p2 = p1;
```

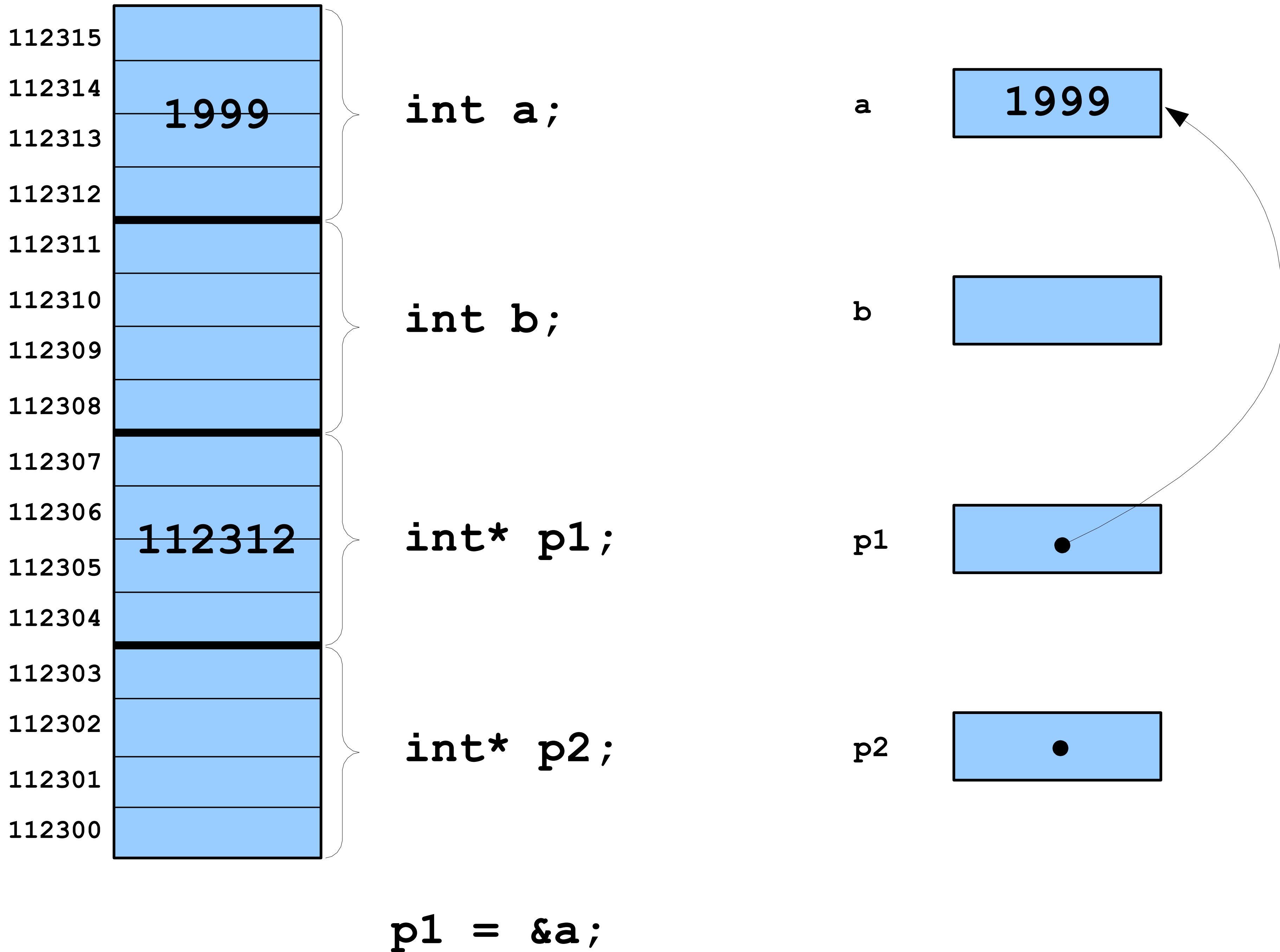
- We can dereference pointers

```
*p1 = 3; /* same as a = 3; */
b = *p1; /* same as b = a; */
```

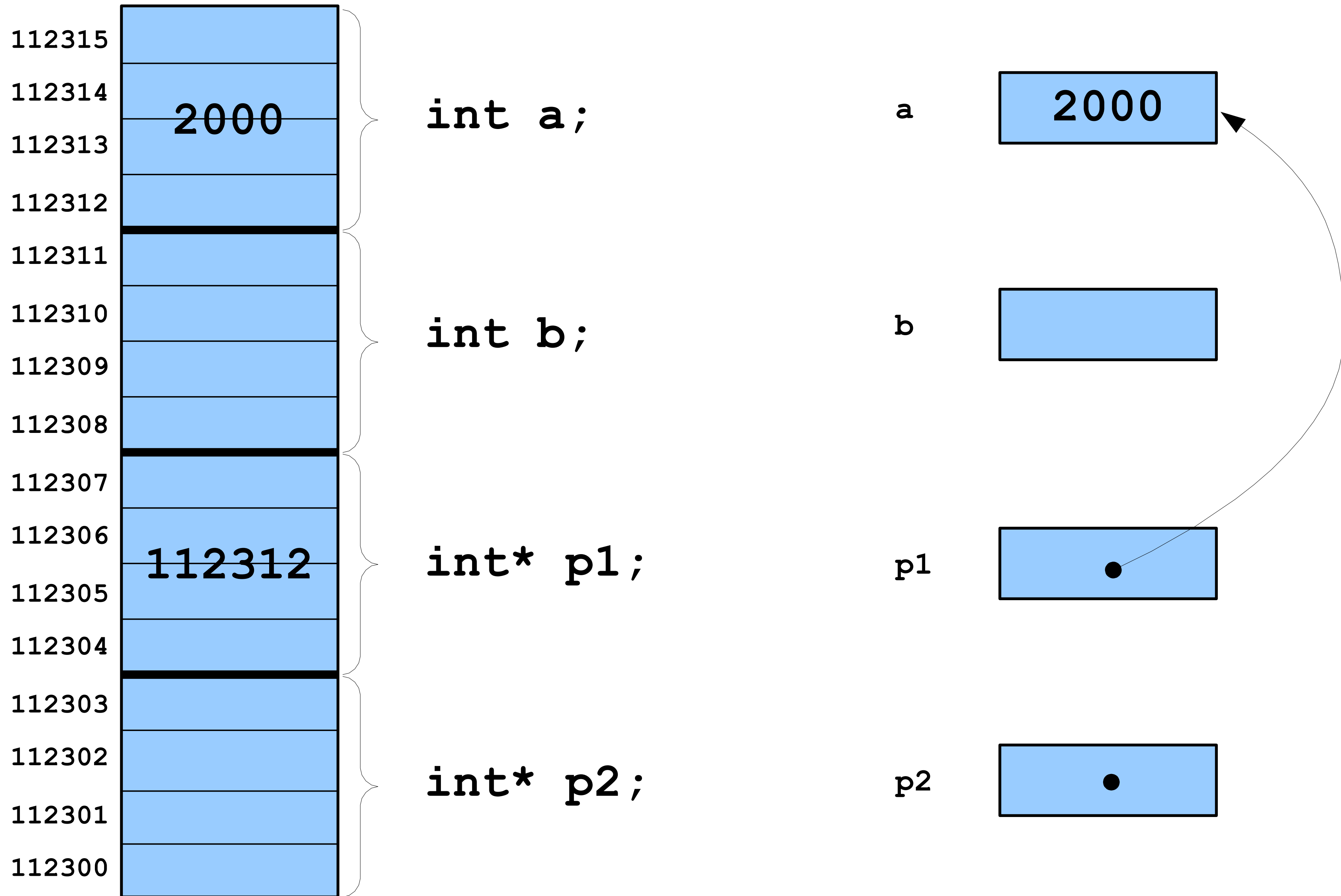
Operations & and *



Operations & and *

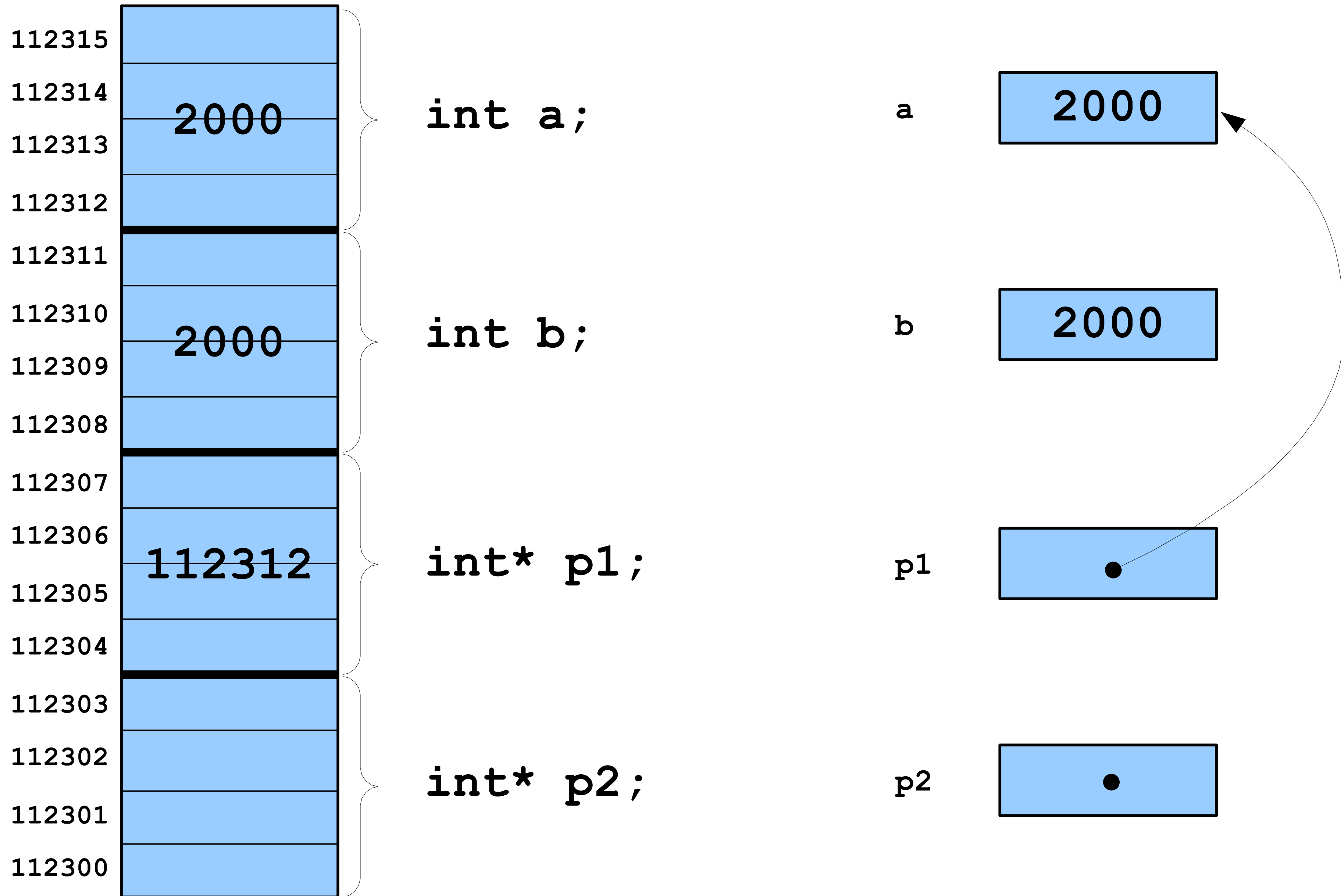


Operations & and *



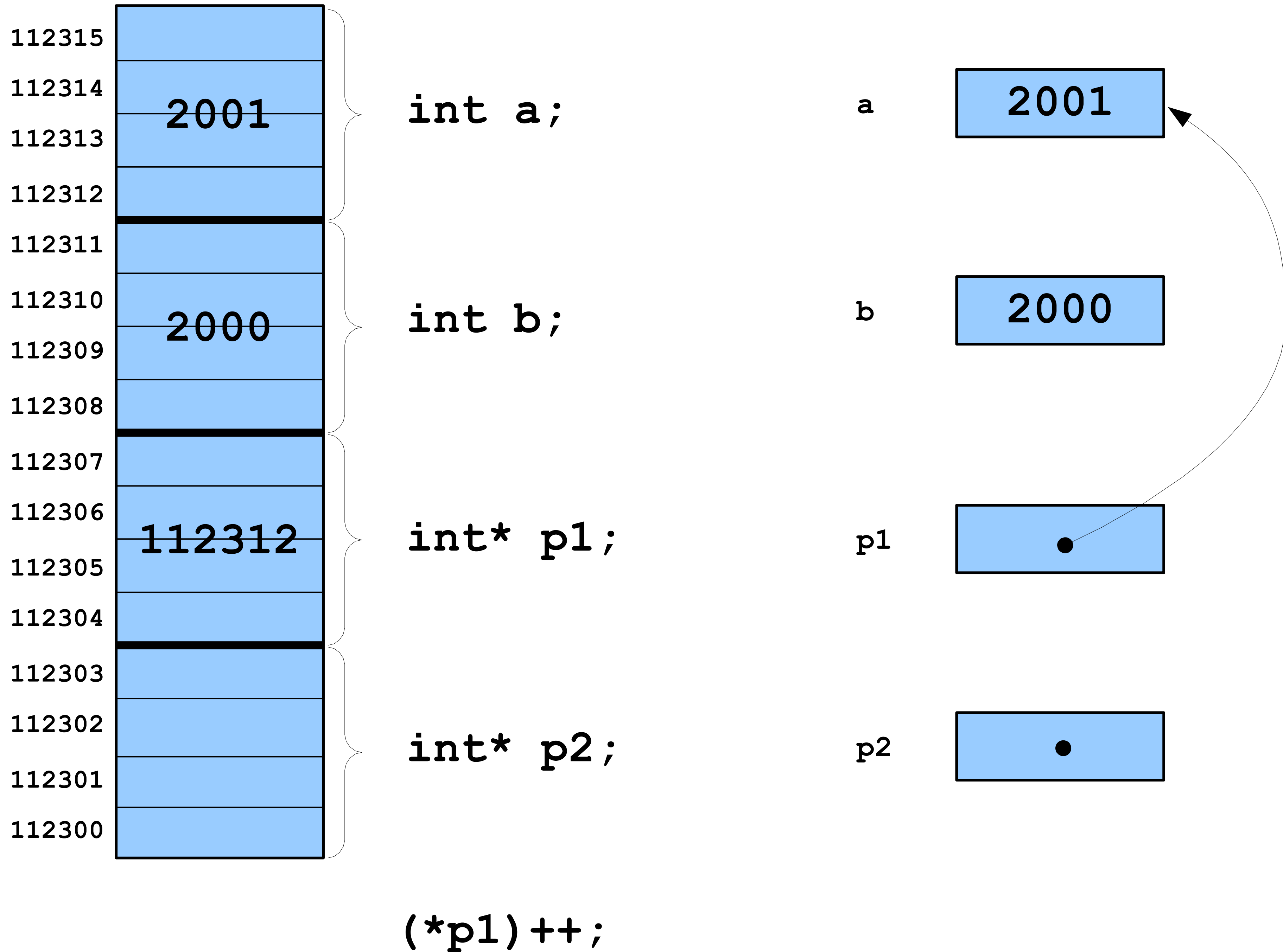

```
*p1 = 2000;
```

Operations & and *

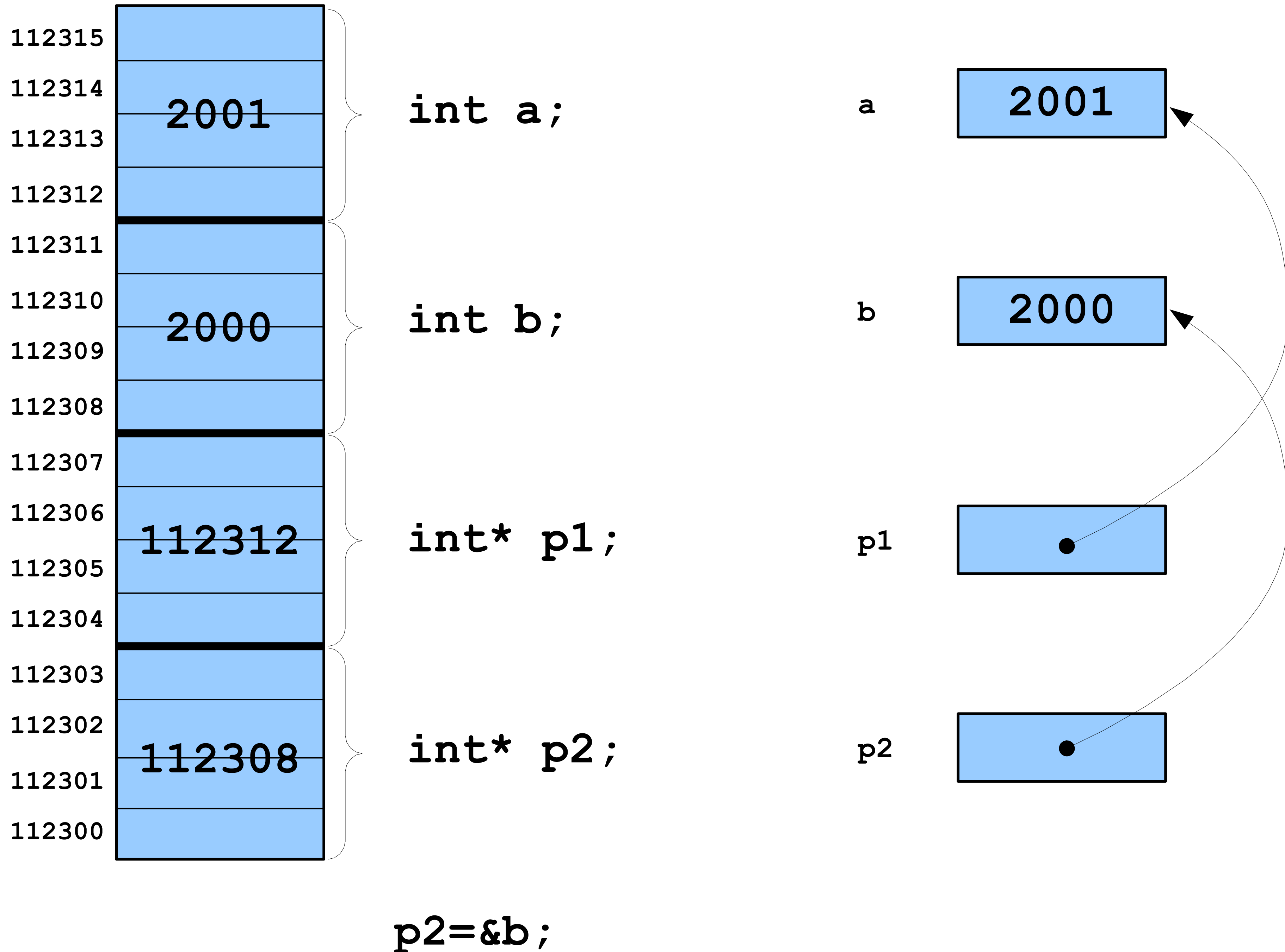


b=*p1;

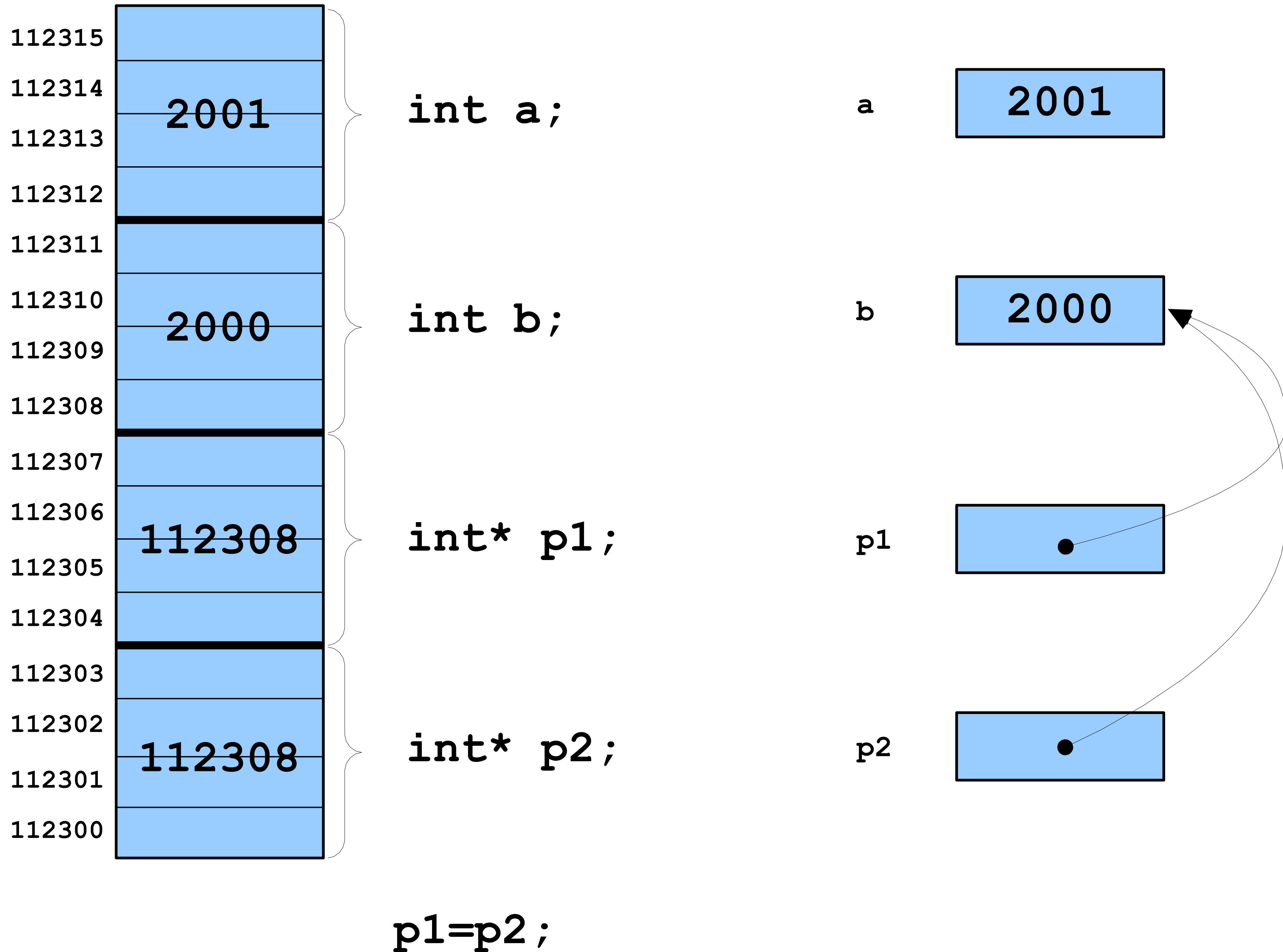
Operations & and *



Operations & and *

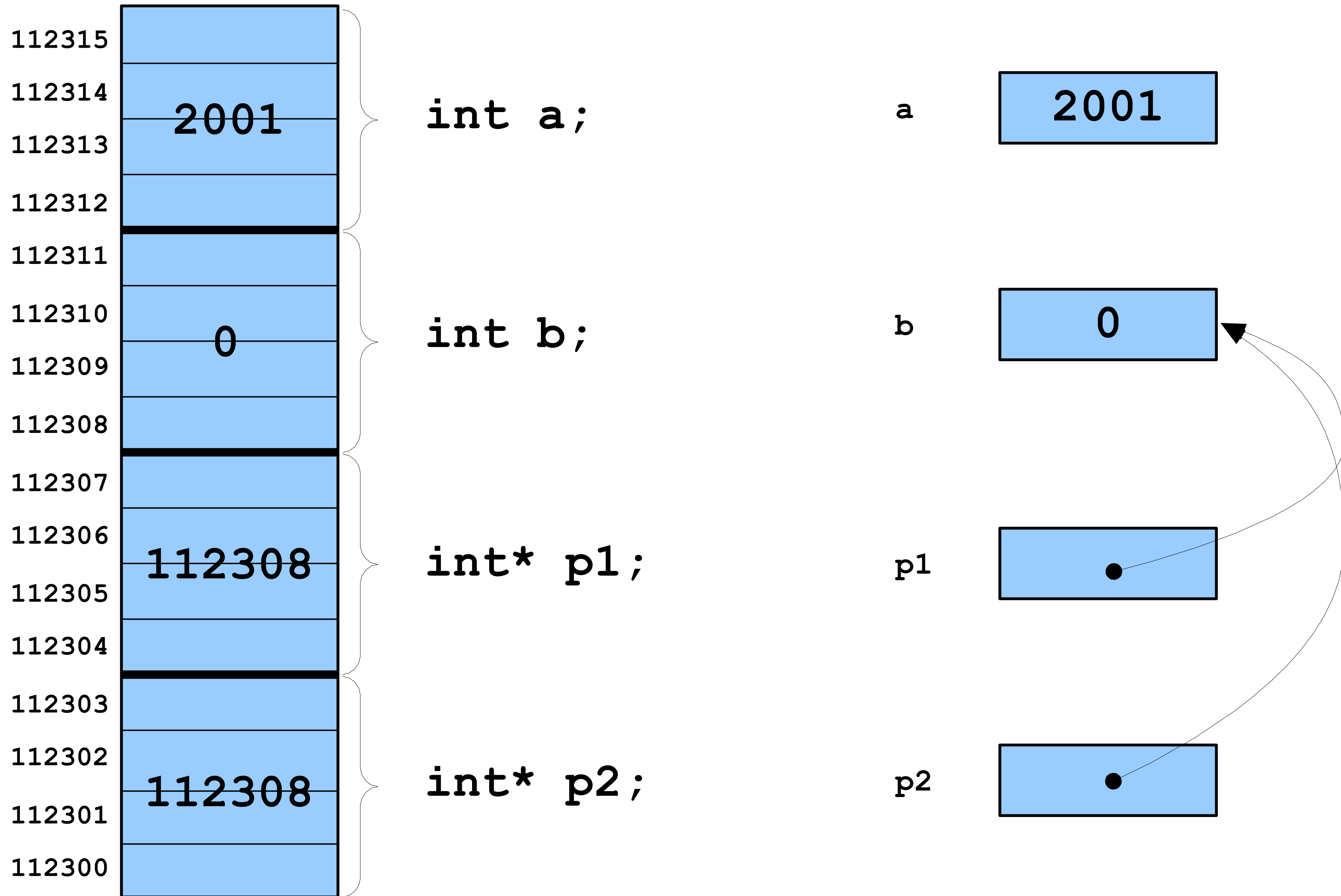


Operations & and *



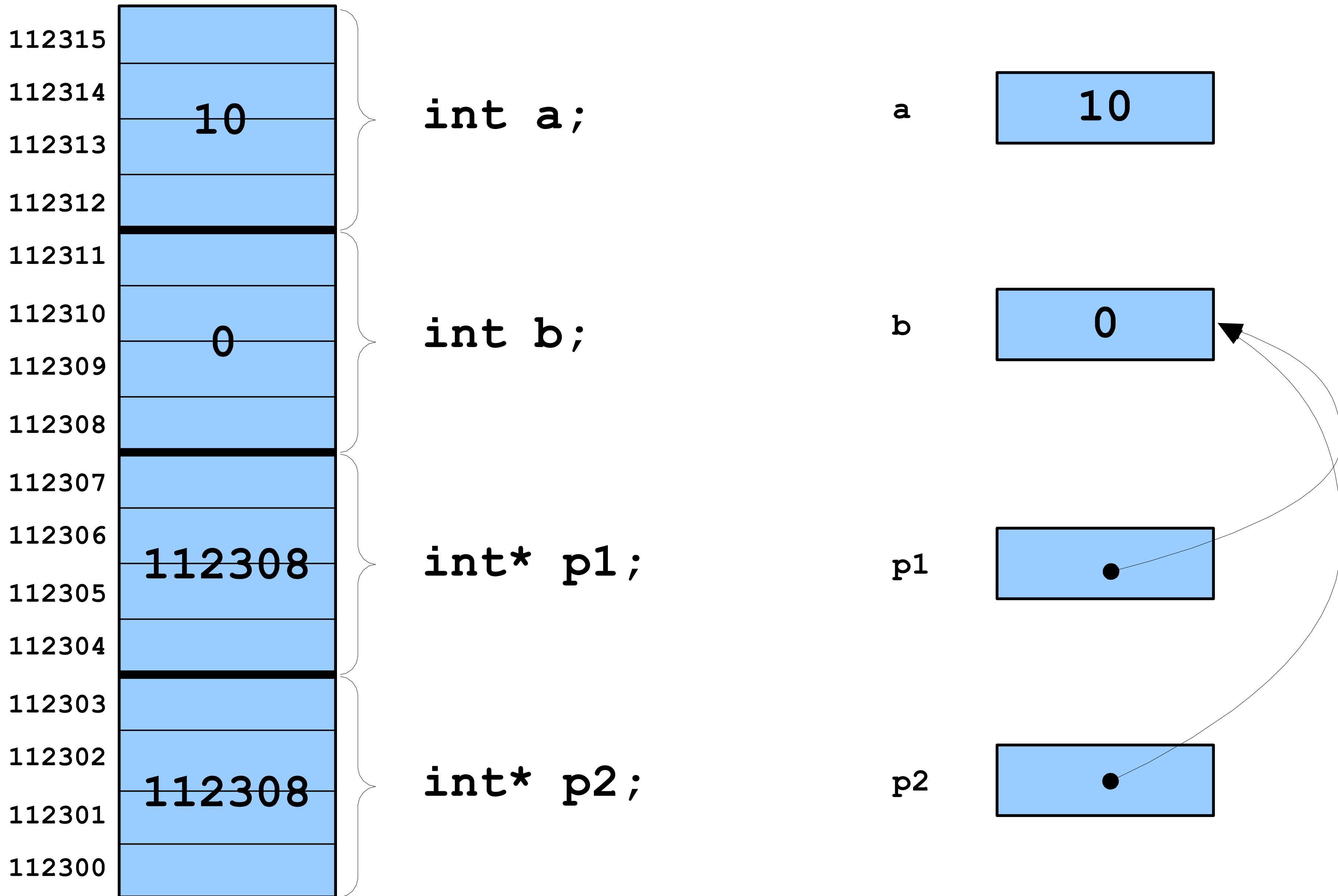
p1=p2;

Operations & and *




```
*p1=0;
```

Operations & and *




```
a=*p2+10;
```

Pointer Function Arguments

- Function arguments in C are strictly pass-by-value
- However, we can simulate pass-by-reference by passing a pointer
- This is very useful when you need to
  - Support in/out (bi-directional) parameters (e.g. swap, find-replace)
  - Return multiple outputs (one return value isn't enough)
  - Pass around large objects (arrays and structures)

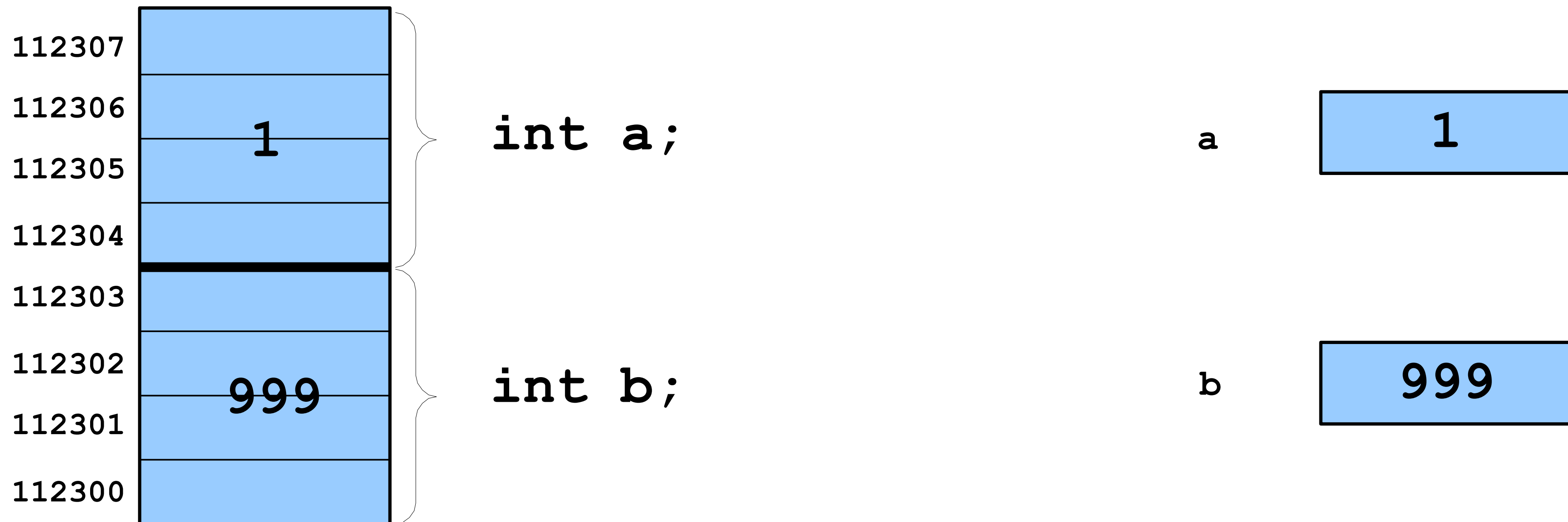
Pointers and Function Arguments

```
/* bad example of swapping
a function can't change parameters */
void bad_swap(int x, int y)
{
    int temp;

    temp = x;
    x = y;
    y = temp;
}

/* good example of swapping - a function can't change parameters,
   but if a parameter is a pointer it can change the value it points to */
void good_swap(int *px, int *py)
{
    int temp;

    temp = *px;
    *px = *py;
    *py = temp;
}
```

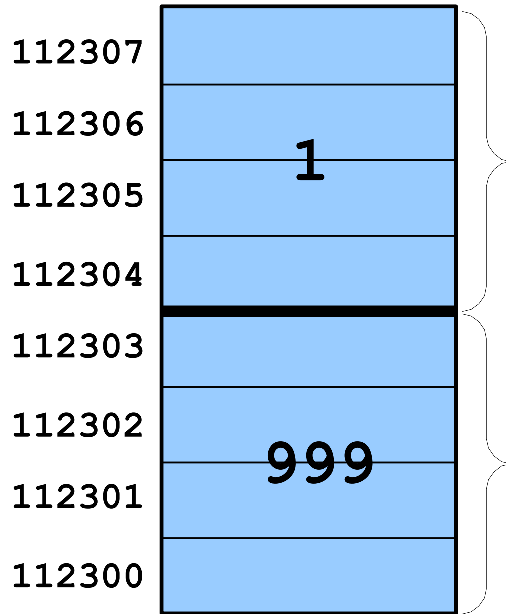
Pointers and Function Arguments

```
#include <stdio.h>
void bad_swap(int x, int y);
void good_swap(int *p1, int *p2);

main() {
    int a = 1, b = 999;

    printf("a = %d, b = %d\n", a, b);
    bad_swap(a, b);
    printf("a = %d, b = %d\n", a, b);
    good_swap(&a, &b);
    printf("a = %d, b = %d\n", a, b);
}
```

Inside Story



Inside Story



main

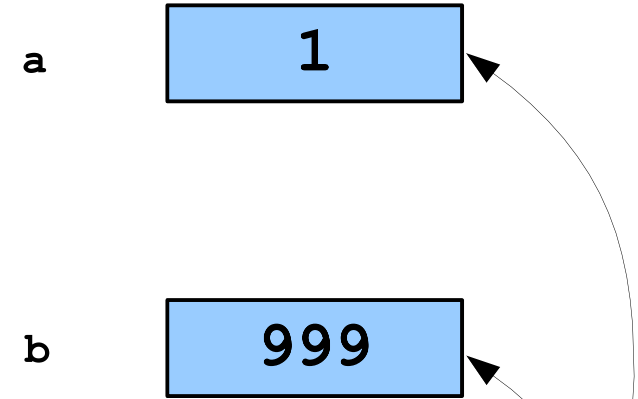
int a;

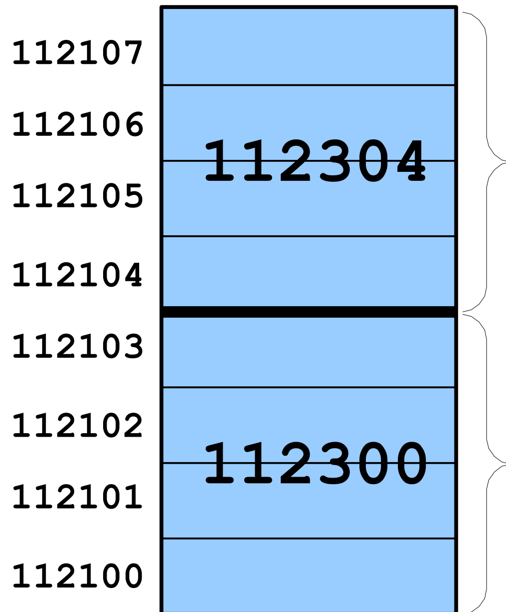
int b;

```
void swap(int *px,
          int *py)
{
    int temp;

    temp = *px;
    *px = *py;
    *py = temp;
}
```

a

b





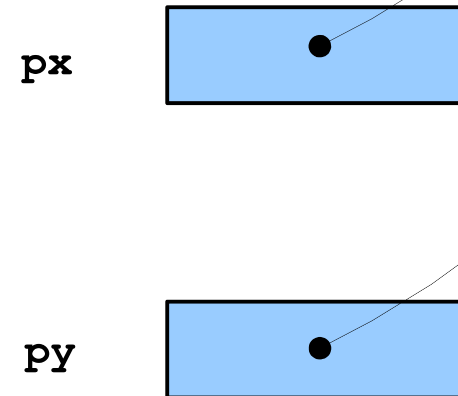
swap

int* px;

int* py;

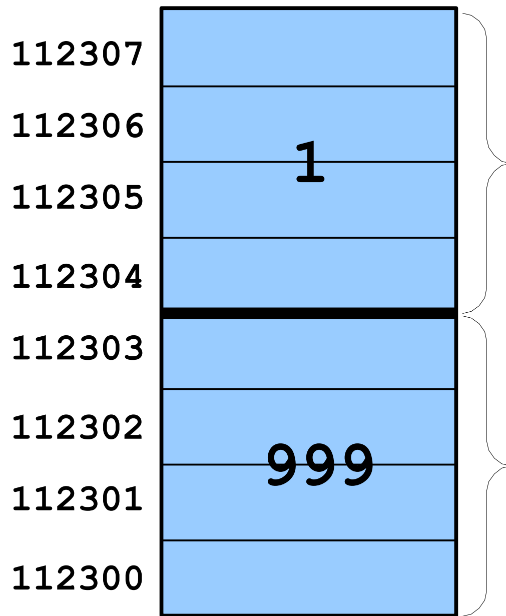
px

py



swap(&a, &b);

Inside Story

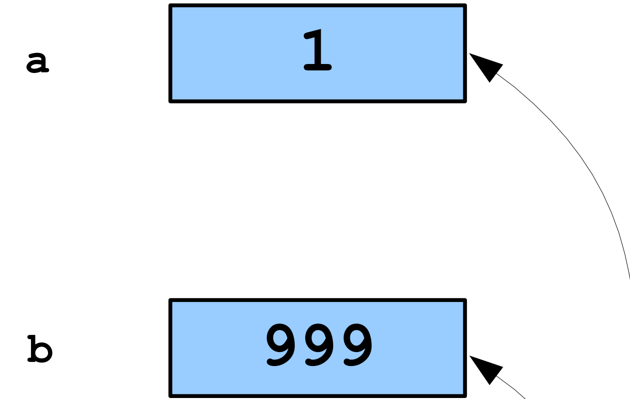


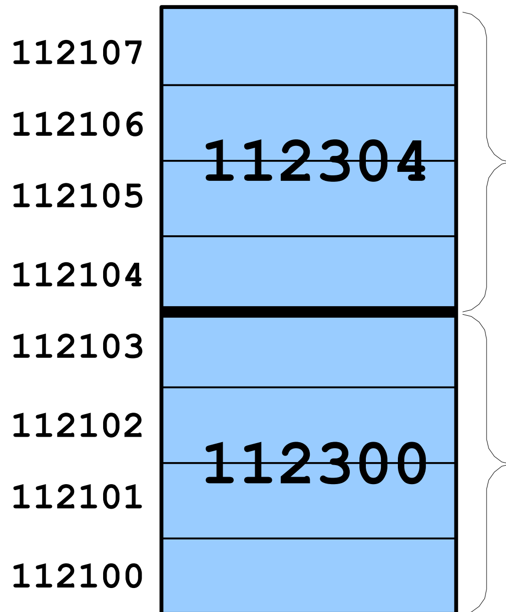
main

int a;

int b;

```
void swap(int *px,
          int *py)
{
     int temp;

     temp = *px;
     *px = *py;
     *py = temp;
}
```



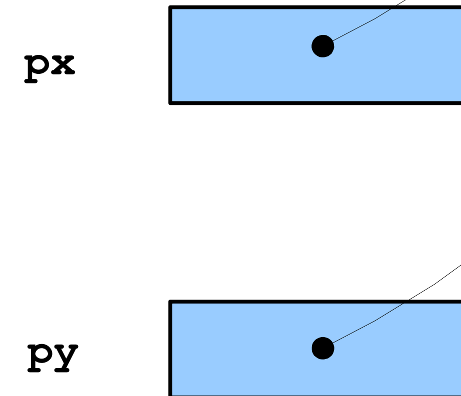


swap

int* px;

temp 1

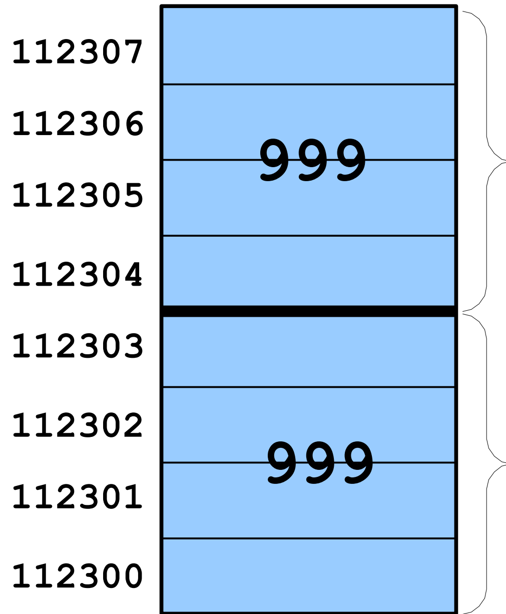
int* py;



temp=*px;

Inside Story

main

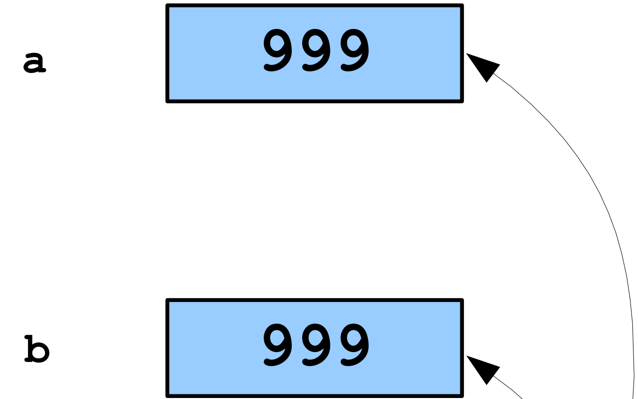


int a;

int b;

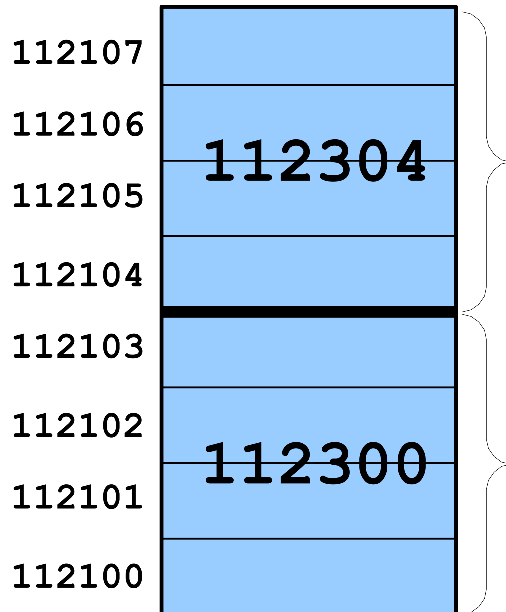
```
void swap(int *px,
          int *py)
{
     int temp;

     temp = *px;
     *px = *py;
     *py = temp;
}
```

a



b

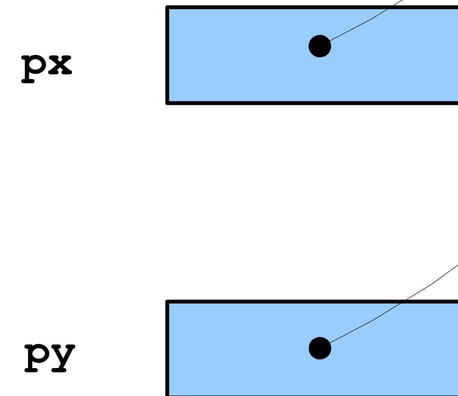
swap



int* px;

px

temp 1



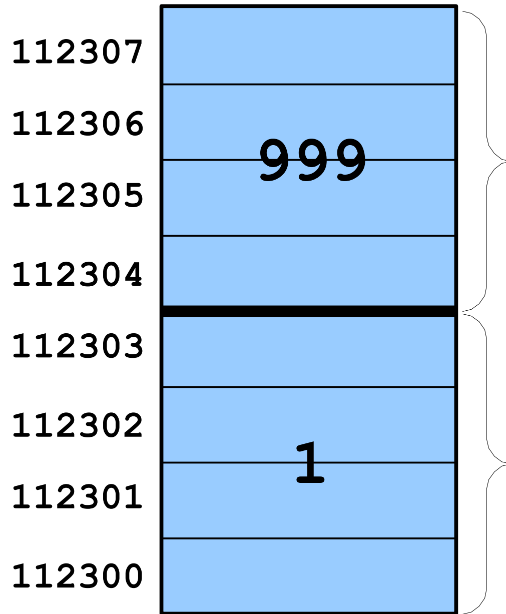
int* py;

py

*px=*py;

Inside Story

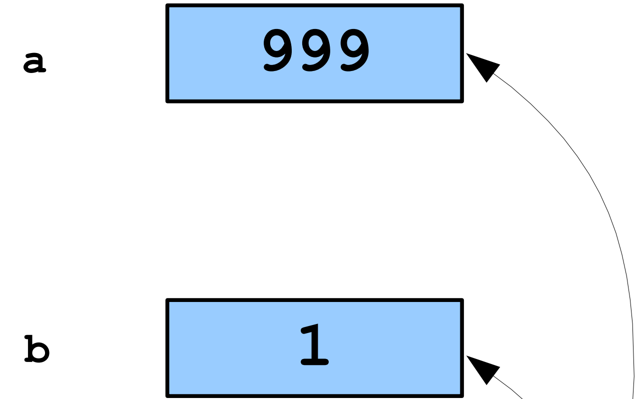
main



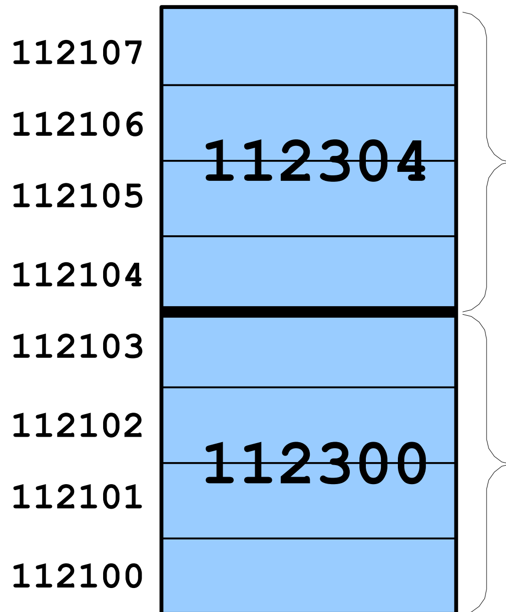
int a;

int b;

```
void swap(int *px,
          int *py)
{
    int temp;

    temp = *px;
    *px = *py;
    *py = temp;
}
```



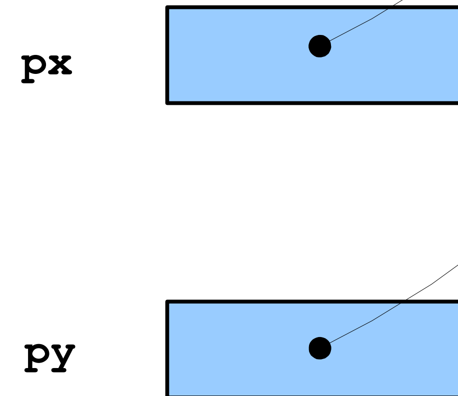
swap



int* px;

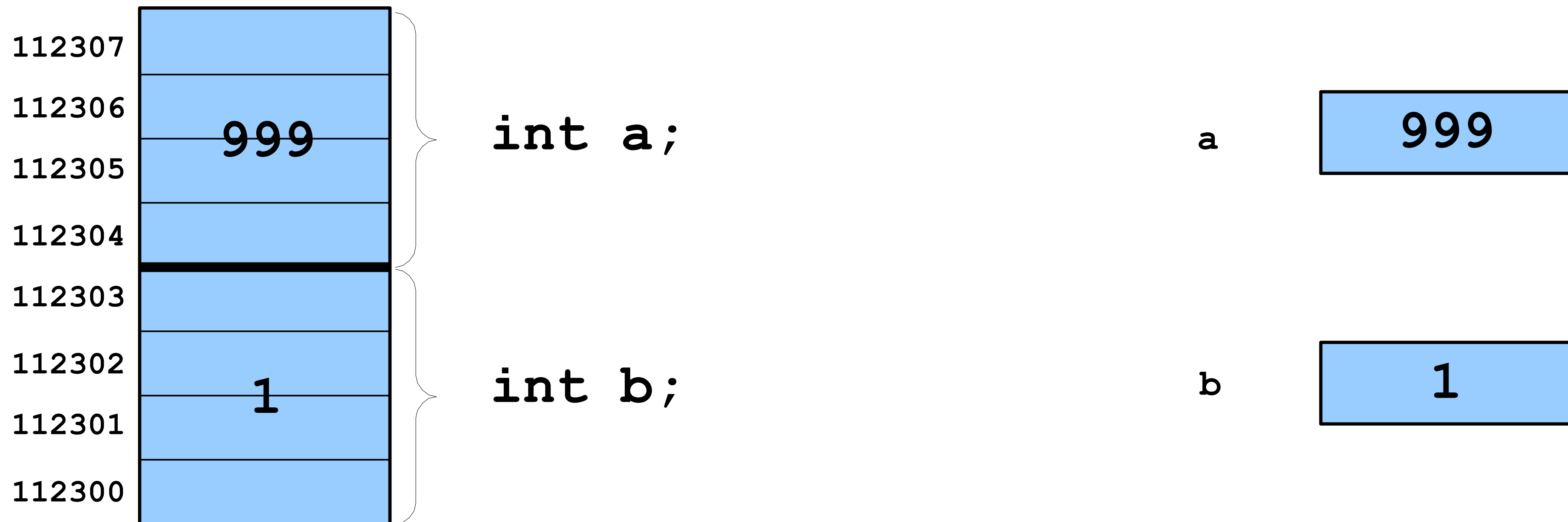
int* py;

temp 1



*py=temp;

Inside Story



Pointer Function Arguments

```
#include <stdio.h>    /* printf() */
#include <math.h>     /* pow() */

static void CalcAreaVol(double dRad, double* pdArea,
                        double* pdVol)
{
    *pdArea = 4.0 * M_PI * pow(dRad, 2.0);
    *pdVol  = 4.0/3.0 * M_PI * pow(dRad, 3.0);
}

int main()
{
   double area = 0.0, vol = 0.0;
   CalcAreaVol(3.5, &area, &vol);
   printf("Radius=%g Area=%g Vol=%g\n", 3.5,
     area, vol);
   return 0;
}
```

Reading Input - **`scanf`**

- If we need to read a value from the standard input into a variable we can use **`scanf`**
- **`scanf`** is able to put the input into a variable since we pass its address

```
int capital = 0;
scanf("%d", &capital);
```

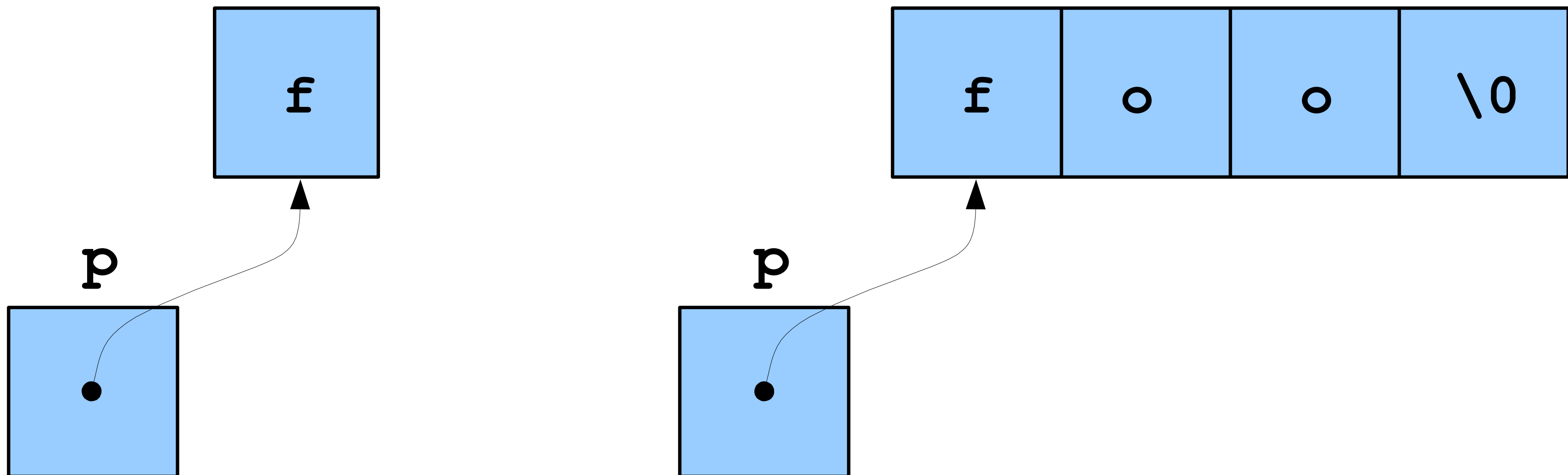
- What happens without &?

```
scanf("%d", capital);
```

- **`scanf`** thinks that the value of capital is an address where it has to place data!

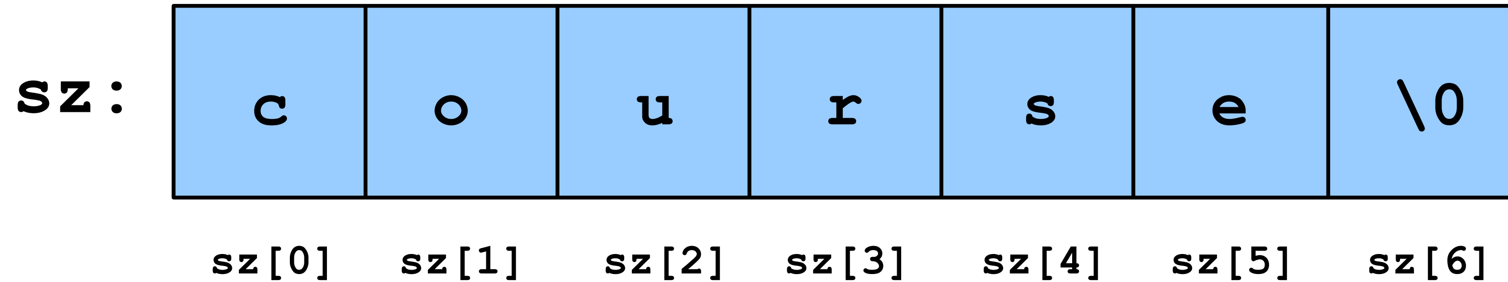
Pointers to Arrays

- A pointer can point to
  - a single value (**`int`**, **`char`**, **`float`**, **`double`**, **`struct`**, etc.)
  - an array of values
- Can be confusing
- Consider: **`char* p`**
- Need to know if its pointing to a single char or to the first element in an array of chars?

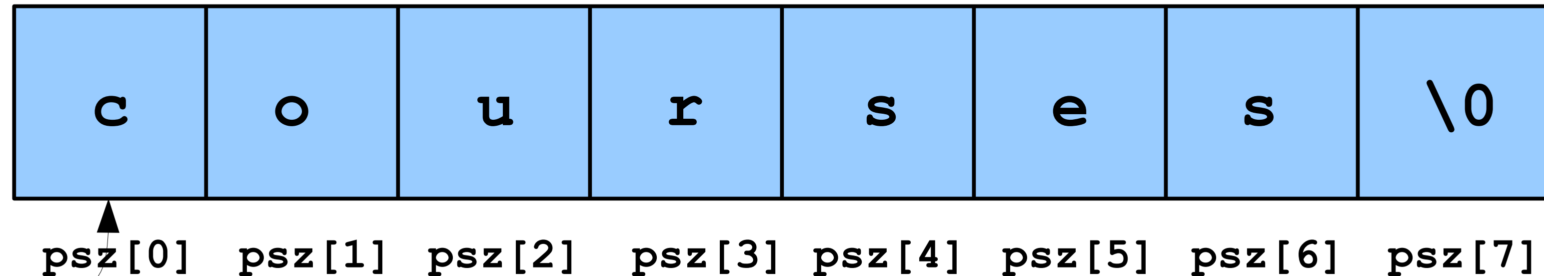


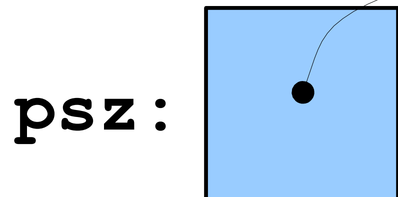
Strings Revisited

```
char sz[] = "course";
```




```
char* psz = "courses";
```

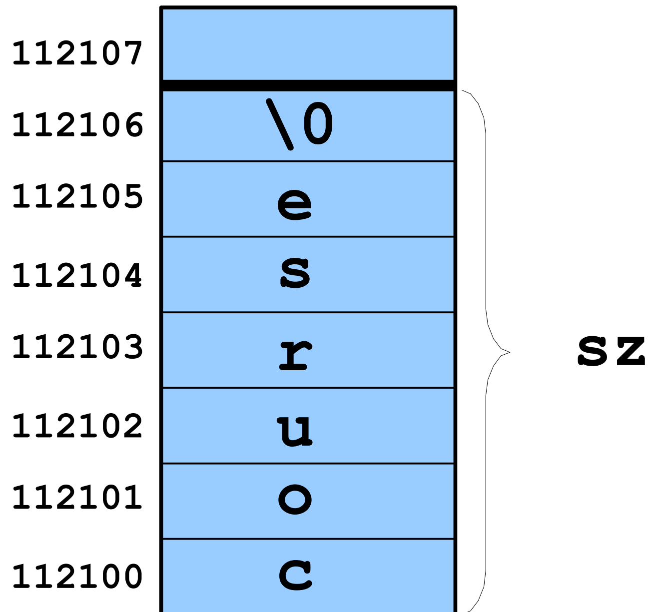


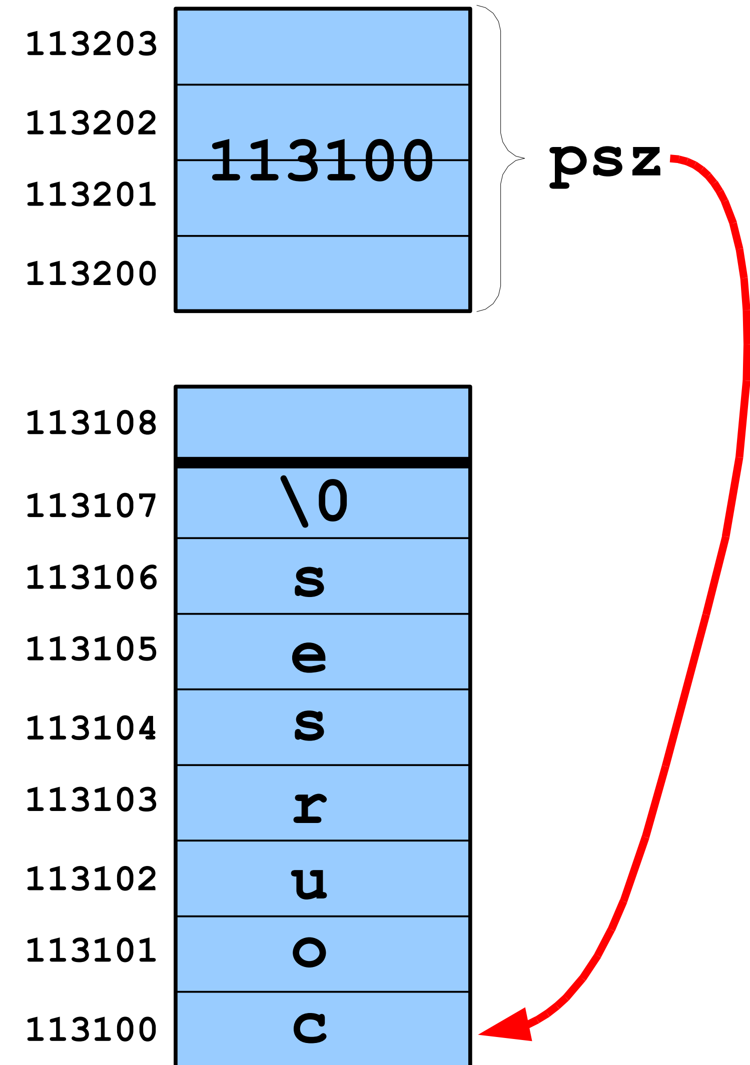


Strings Revisited

```
char sz[] = "course";
char* psz = "courses";
```

- **`sz`** is an array of characters
- **`psz`** is a pointer to an array of characters



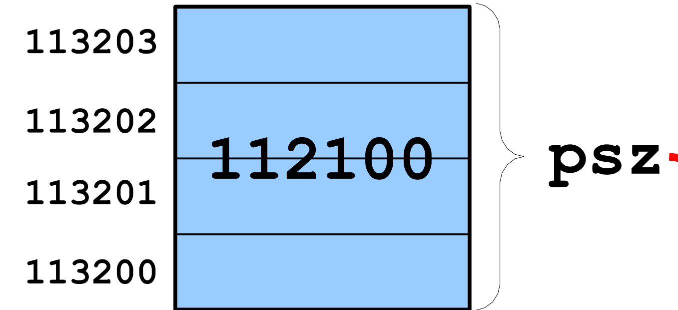


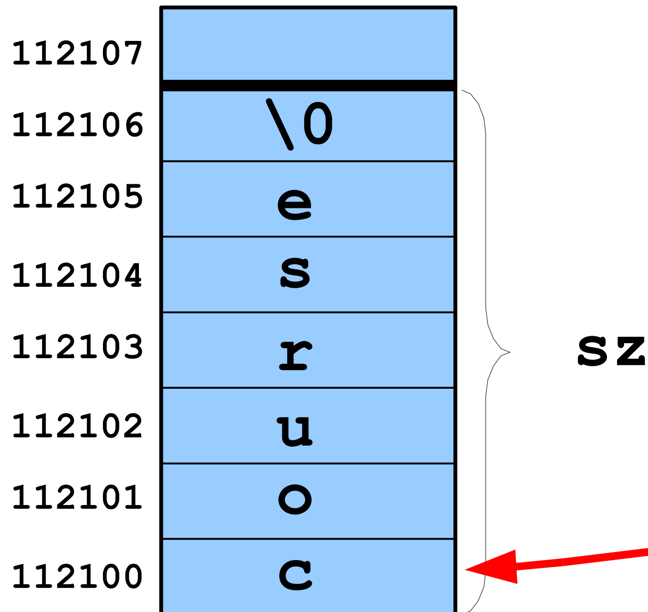
- **`sizeof(sz)`**? **`sizeof(psz)`** ?

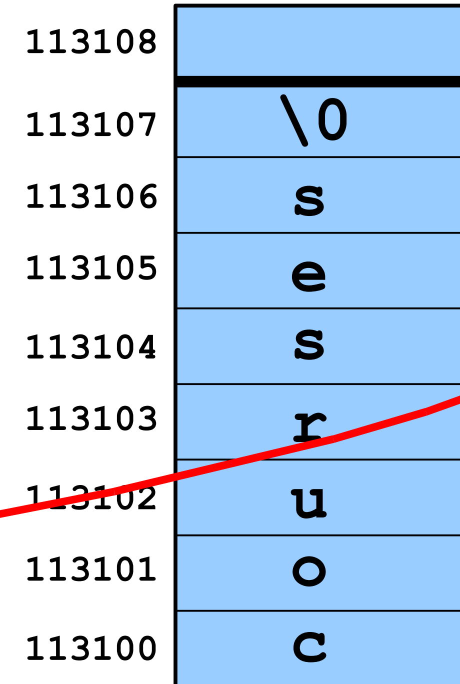
Strings Revisited

- You can change the pointer to point to something else

```
psz = sz;
```







Strings Revisited

- You can modify characters in **`sz`**

```
sz[0] = 'C'; /* Okay */
```

- You cannot modify characters in **`psz`**

```
psz[0] = 'C'; /* Danger, Will Robinson! */
```

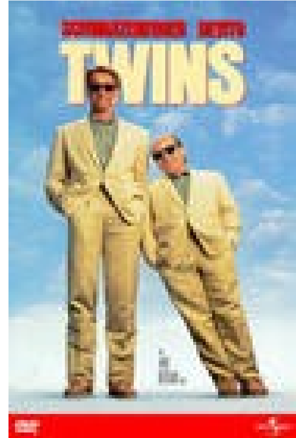
- **`psz`** is immutable (read-only). Why?
  - It points to a string literal ("courses") that usually resides in read-only memory
  - **`psz[0] = 'C'`** is undefined (implementation dependent)
  - On Linux, this causes a segmentation violation
  - **`const`** qualifier is used to prevent accidental modification

    ```
    const char* psz = "courses";
    ```

  - Also a good idea to use **`const`** for **`sz`**

    ```
    const char sz[] = "course";
    ```

[ ] and * Similarities



- From **stdio.h**:

```
size_t strlen(const char*);
```

- Can pass an array wherever a pointer is expected

```
strlen(sz);
strlen(psz);
strlen("Greetings!");
```

- Equivalent declaration:

```
size_t strlen(const char[]);
```

- Array names are implicitly converted to a pointer to their first element
  - `strlen(sz);` ⇒ `strlen(&sz[0]);`
  - `psz = sz;` ⇒ `psz = &sz[0];`

[ ] and * Similarities

- Only two things can be done to an array
  - Determine its size using **`sizeof()`**
  - Obtain a pointer to the first element
- All other array operations are actually done with pointers
- Subscripts are automatically converted to pointer operations

Pointer Arithmetic

- Can use subscript notation to access elements: **`p[i]`**

```
char sz[] = "course";
char* psz = sz;
sz[0]  = 'C';          ⇒ "Course"
psz[5] = 'E';          ⇒ "CoursE"
```

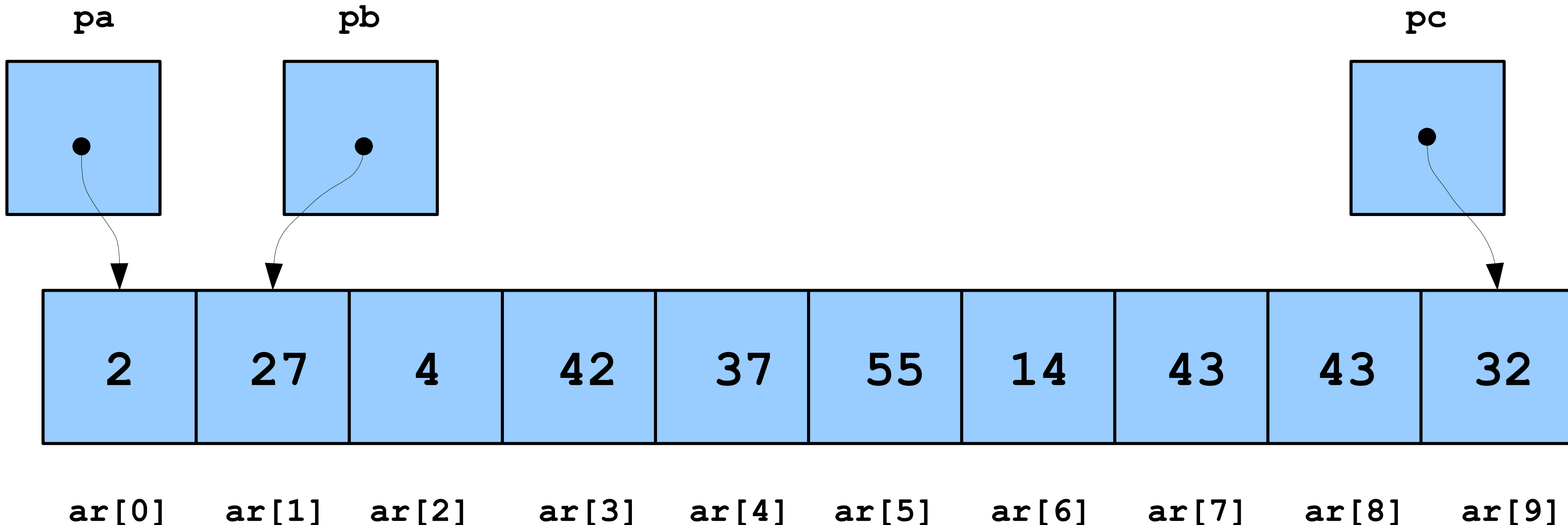
- Can also use pointer arithmetic: **`*(p + i)`**

```
*(sz + 0)  = 'C';
*(psz + 5) = 'E';
```

Pointer Arithmetic

- This works also with larger types

```
int ar[10];
int *pa, *pb, *pc;
pa = &ar[0] /* same as pa = ar */
pb = pa + 1; pc = pa + 9;
ar[3]=42; *(ar+4)=37; *pa=2; *pb=27; *pc=32;
```



Pointer Arithmetic

- We can add and subtract integers to/from pointers - the result is a pointer to another element of this type

  `int *pa; char *s;`

  `s-1` $\Rightarrow$ points to **`char`** before **`s`** (1 subtracted)

  `pa+1` $\Rightarrow$ points to next **`int`** (4 added!)

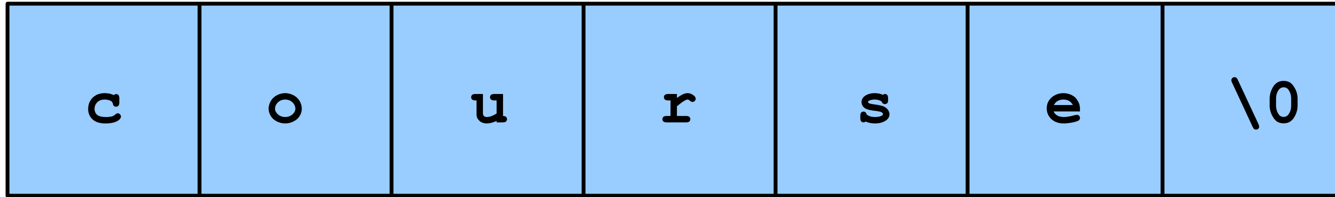
  `s+9` $\Rightarrow$ points to 9th **`char`** after **`s`** (9 added)

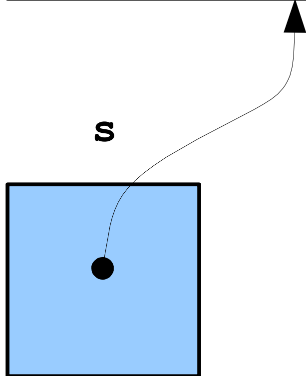
  `++pa` $\Rightarrow$ increments **`pa`** to point to next **`int`**

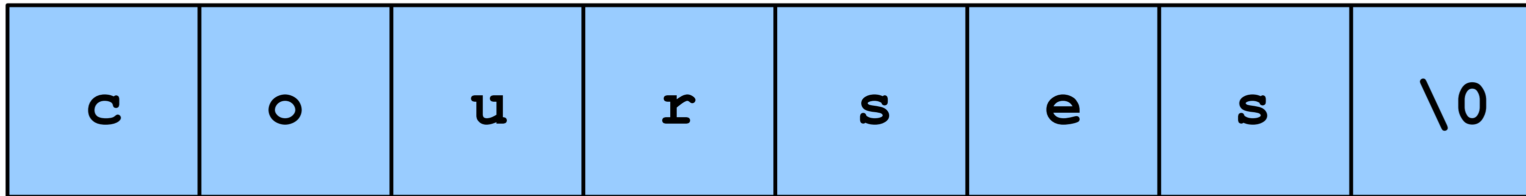
Example - String Comparison

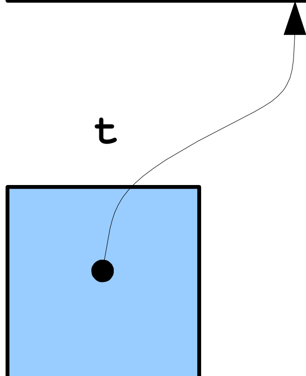
```
#define MAXLEN 100
int strcmp(char *p1, char *p2);
/*exactly the same as int strcmp(char p1[], char p2[]);*/
int getline(char *line, int max);
/*exactly the same as int getline(char line [], int max);*/

int main() {
    char a[MAXLEN], b[MAXLEN];
    int comp;
    getline(a, MAXLEN);
    getline(b, MAXLEN);
    comp = strcmp(a, b);
    if(comp > 0)
        printf("First line is greater than second\n");
    else if (comp < 0)
        printf("First line is less than second\n");
    else printf("These lines are equal!\n");
    return 0
}
```

Example - String Comparison

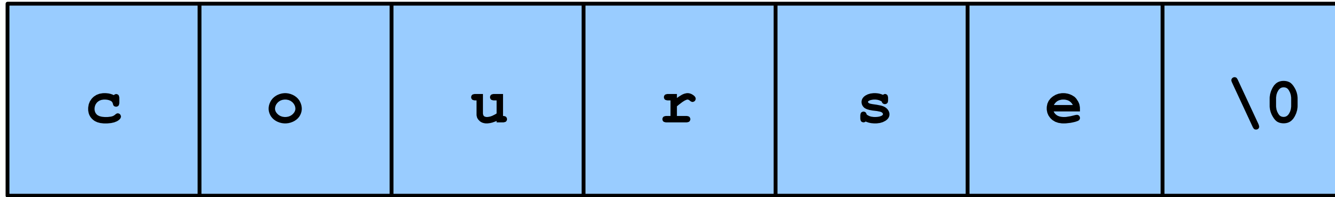




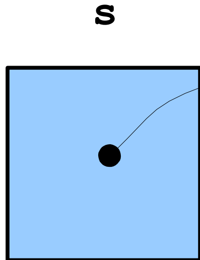


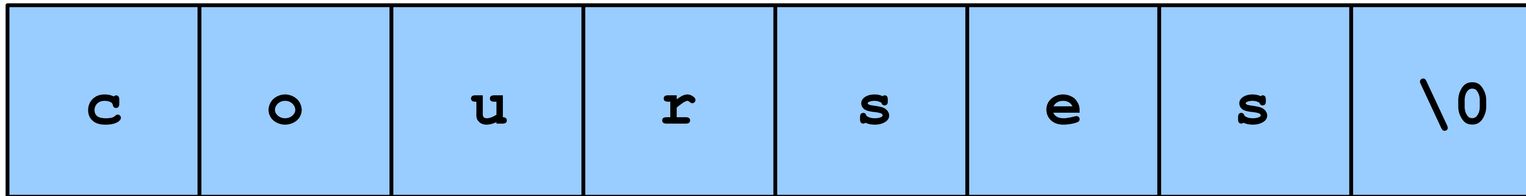


Example - String Comparison



s





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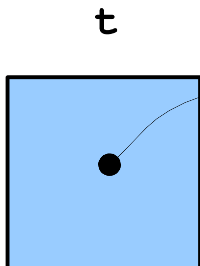


Compare String Comparisions

```c
/* pointer version */
/* strcmp: return <0 if s<t,
   0 if s==t, >0 if s>t */
int strcmp(char *s, char *t)
{
   for( ; *s == *t; s++, t++)
      if(*s == '\0')
         return 0;
   return *s - *t;
}
```

```c
/* array version */
/* strcmp: return <0 if s<t,
   0 if s==t, >0 if s>t */
int strcmp(char *s, char *t)
{
   int i;

   for(i = 0 ; s[i] == t[i]; i++)
      if(s[i] == '\0')
         return 0;
   return s[i] - t[i];
}
```

Pointer Subtraction

- Pointer subtraction is also valid

```
size_t strlen(const char* s)
{
        const char* p = s;
        while(*p != '\0')
             ++p;
        return p - s;
}
```

`NULL` Pointer

- 0 is a special value we can assign to a pointer which does not point to anything
  - most frequently, a symbolic constant **`NULL`** is used
- It is guaranteed, that no valid address is equal to 0
- The bit pattern of the NULL pointer does not have to contain all zeros
  - usually it does
  - depends on the processor architecture
- On many machines, dereferencing a NULL pointer causes a segmentation violation

Pointer Traps and Pitfalls

- NULL ptr is not the same as an EMPTY string

```
const char* psz1 = 0;
const char* psz2 = "";
assert(psz1 != psz2);
```

- Always check for NULL before dereferencing a pointer

```
if (psz1)
      /* use psz1 */
```

- **`sizeof(psz1)`** doesn't give you the number of elements in **`psz1`**. Need additional size variable.

Dangling Reference Bug

- Be careful not to return a pointer to a local variable
- Local variables are automatic, and are no longer valid after the function returns

```
#include <ctype.h> /* toupper */

const char* upcase(const char* s)
{
            char szBuf[100];
            char* p = szBuf;

            while(*p++ = toupper(*s++))
                    /* empty */ ;
            return szBuf;
}
```

Dangling Reference Bug - Poor Solution

- Static variable will be valid after the function returns
- Still problems with this solution

```
#include <ctype.h> /* toupper */
#include <stdio.h> /* printf */

const char* upcase(const char* s)
{
            static char szBuf[100];
            char* p = szBuf;

            while(*p++ = toupper(*s++))
                    /* empty */ ;
            return szBuf;
}

int main()
{
            printf("%s %s\n", upcase("ala"), upcase("ola"));
            return 0;
}
```

Function Pointers

- A function itself is not a variable
- However, you can take the address of a function
  - Store it in a variable
  - Store it in an array (e.g. C++ vtable emulation)
  - Pass it as a parameter to another function (e.g. **`bsearch`**, **`qsort`**). Aka, "callbacks"
  - Return it from a function (e.g. **`GetProcAddress()`** for Windows)
- Makes code independent of the actual function name and implementation

Function Pointer Variables

```
#include <stdio.h>
#include <math.h>

int main()
{
    float radians = 0, result = 0;
    char op = '\0';

    double (*pfn)(double) = 0; /* pfn is a function ptr variable */

    printf("Enter radians, a space, then s, c, or t: ");
    scanf("%g %c", &radians, &op);

    if (op == 's')      pfn = &sin;
    else if (op == 'c') pfn = &cos;
    else if (op == 't') pfn = &tan;

    result = (*pfn)(radians); /* Call function that pfn points to*/
    printf("Result=%g\n", result);
    return 0;
}
```

Function Pointer typedefs

```
#include <stdio.h>
#include <math.h>

typedef double (*PFN_OPER)(double);

int main()
{
    float radians = 0, result = 0;
    char op = '\0';

    PFN_OPER pfn = 0; /* pfn is a function ptr variable */

    printf("Enter radians, a space, then s, c, or t: ");
    scanf("%g %c", &radians, &op);

    if (op == 's')      pfn = &sin;
    else if (op == 'c') pfn = &cos;
    else if (op == 't') pfn = &tan;

    result = (*pfn)(radians); /* Call function that pfn points to*/
    printf("Result=%g\n", result);
    return 0;
}
```

Complicated Pointer Declarations

- `char** argv`
  - pointer to pointer to char
- `int *x[15]`
  - array of 15 pointers to integers
- `int (*x)[15]`
  - pointer to an array of 15 integers

Complicated Declarations

- `int *f()`
  - function returning pointer to an `int`
- `int (*f)()`
  - pointer to function returning an `int`
- `void *f()`
  - function returning a pointer to `void` (pointer to unknown type)
- `void (*f)()`
  - pointer to a function returning `void`
- `cdecl` program can help here

Command Line Arguments

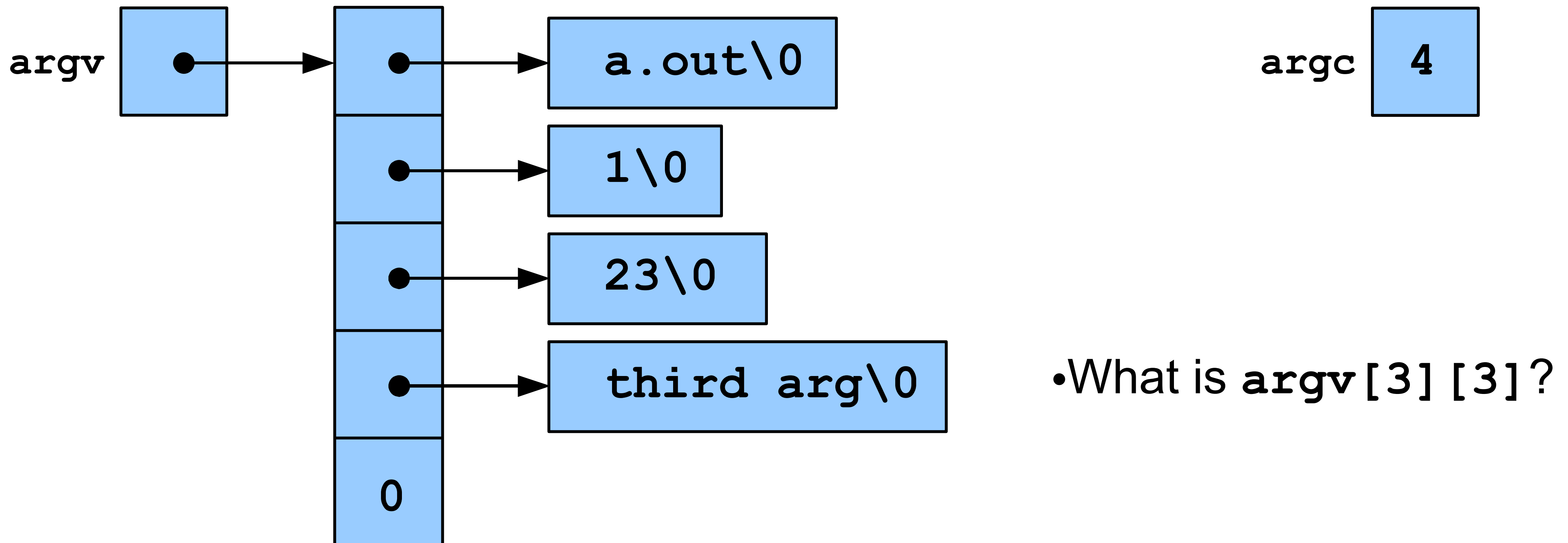
- Full declaration of **`main`** is as follows

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

- **`argv`** holds the command-line arguments, **`argc`** their number

```
$ a.out 1 23 "third arg"
```

- **`argv`** is a pointer to an array of strings



•What is **`argv[3][3]`**?

Command Line Arguments

- Print out the command-line arguments

```
#include <stdio.h>
int main(int argc, char* argv[])
{
        int i;
        for(i = 1; i < argc; ++i)
              printf("%d: %s\n", i, argv[i]);
        return 0;
}
```