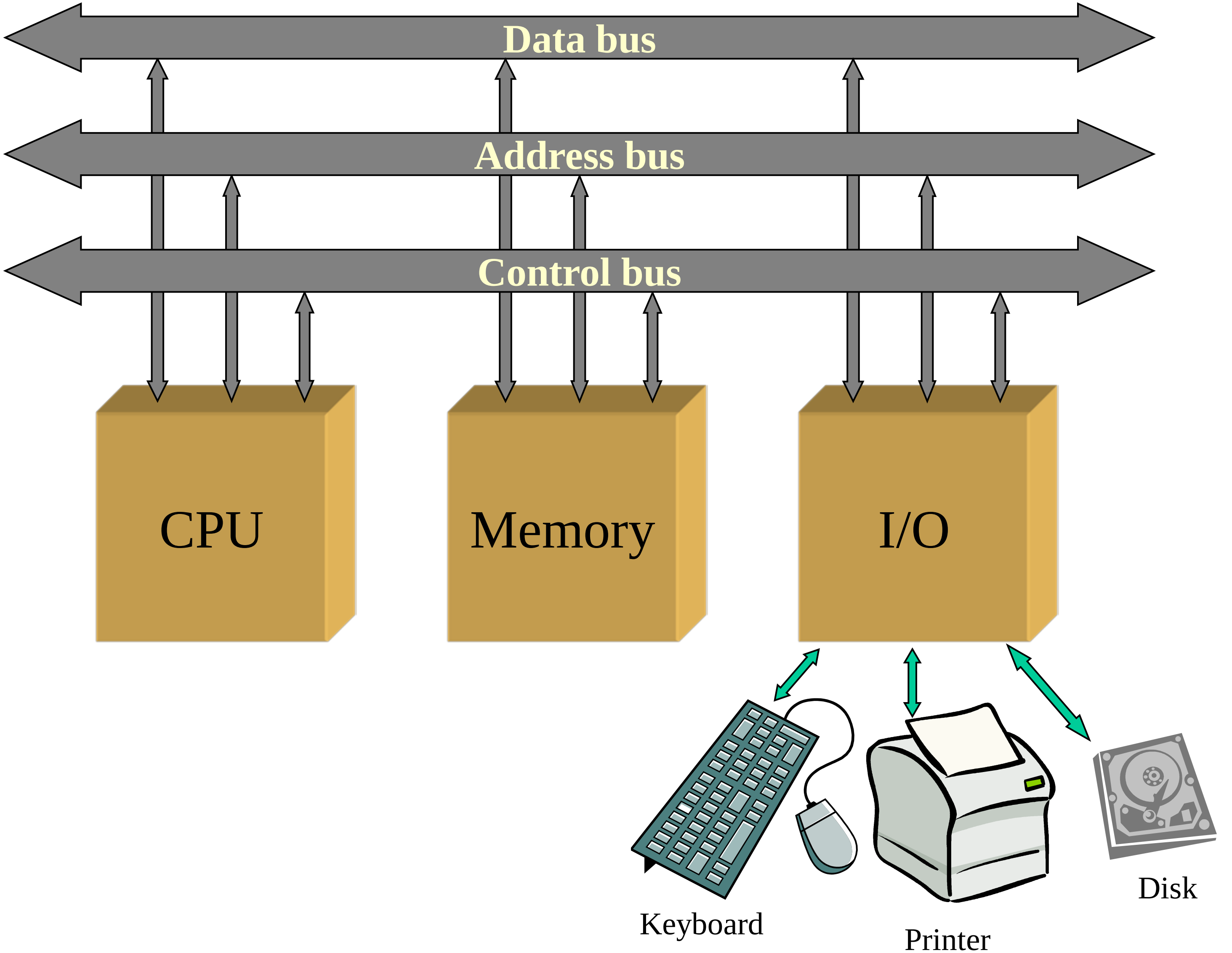
# Topic 2. System calls

1. Basic architecture
2. Input/Output routine mechanism
3. Resident routines
4. Accessing OS services: system calls

# *Von Neumann* architecture

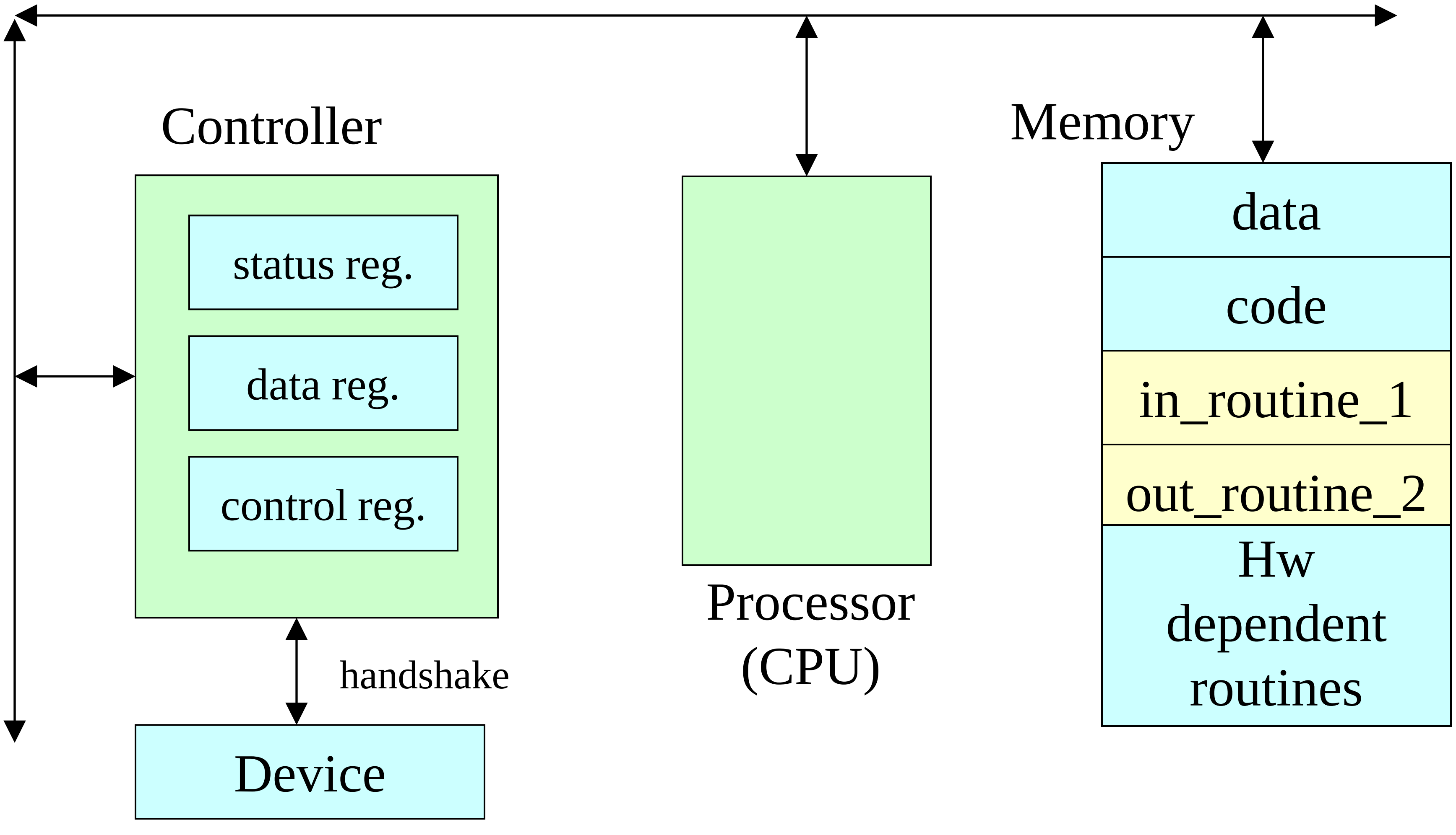


# Basic architecture

- If all components (CPU, memory, bus, devices) are efficient, the whole computer can also be efficient, but not necessarily…
  - The **tuned management** of all resources will be largely responsible for the success or failure

- In this regard, the **Operating Systems** is the set of routines in charge of the **efficient management** of all the resources of the computer
  - The way this management is carried out will be responsible of the good/poor performance of the computer

# Input/Output by busy waiting (spinning)



# Input/Output by busy waiting (spinning)

- Procedure for using the device:
  1. Check if the device (controller) is ready for reading/writing
  2. When the device is ready, read/write the data
  3. Indicate to the controller that the data has been read/written

- Checking if the device controller is ready is done by busy waiting on reading the status register

- It is the responsibility of the user program to check the status register and call the appropriate error handling routine when an error occurs

# Input/Output by busy waiting - Example

**Example:** read 80 characters from an input device *DEV1* and write them in an output device *DEV2*

Routine types:

Hardware dependent routines:
access the registers of the controllers (assumed to be coded)

Input/Output routines:
perform the input and output operations

*error* routine:
checks if there is an error, in which case it finishes the execution of the program (assumed to be coded)

⇨ Cooked/raw Input/Output: control-characters

Line feed (LF), Backspace (BS), End of file (EOF)…

# Input/Output by busy waiting - Example

**Input routine for device**

```
in_routine_1(char *vector, int count)
{
   int j, status;

   for (j = 0; j < count; j++)
   {
      do {
         status = read_status_register(DEV1);
      } while (status == BUSY);
      error(DEV1, status);
      vector[j] = read_data_register(DEV1);
      write_control_register(DEV1, READ);
   }
}
```

**Output routine for device 2**

```
out_routine_2(char *vector, int count)
{
   int j, status;

   for (j = 0; j < count; j++)
   {
      do {
         status = read_status_register(DEV2);
      } while (status == BUSY);
      error(DEV2, status);
      write_data_register(DEV2, vector[j]);
      write_control_register(DEV2, WRITTEN);
   }
}
```

**User program**

**(synchronous I/O)**

```
main()
{
   char buff[80];

   while (TRUE) {
      in_routine_1(buff, 80);
      out_routine_2(buff, 80);
   }
}
```

# Input/Output by busy waiting

- Issue:
  - During Input/Output operations the CPU is most of the time doing nothing else than just waiting…
  - Waiting times can be “extreeeeeeeeeemely” long
    - I/O devices are slow (compared to the CPU)

- Solution:
  - Interrupt driven Input/Output

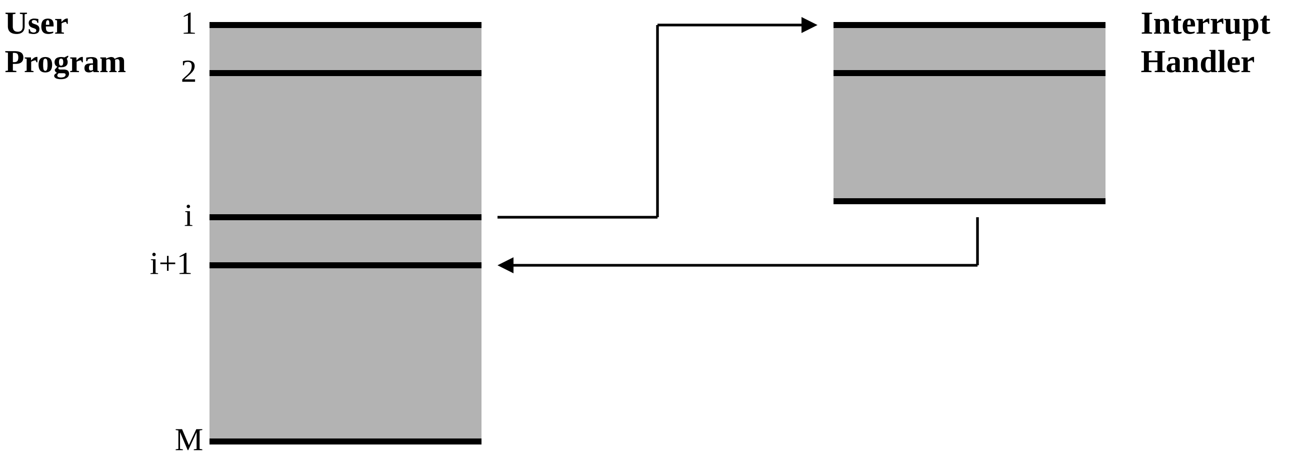
# Interrupts

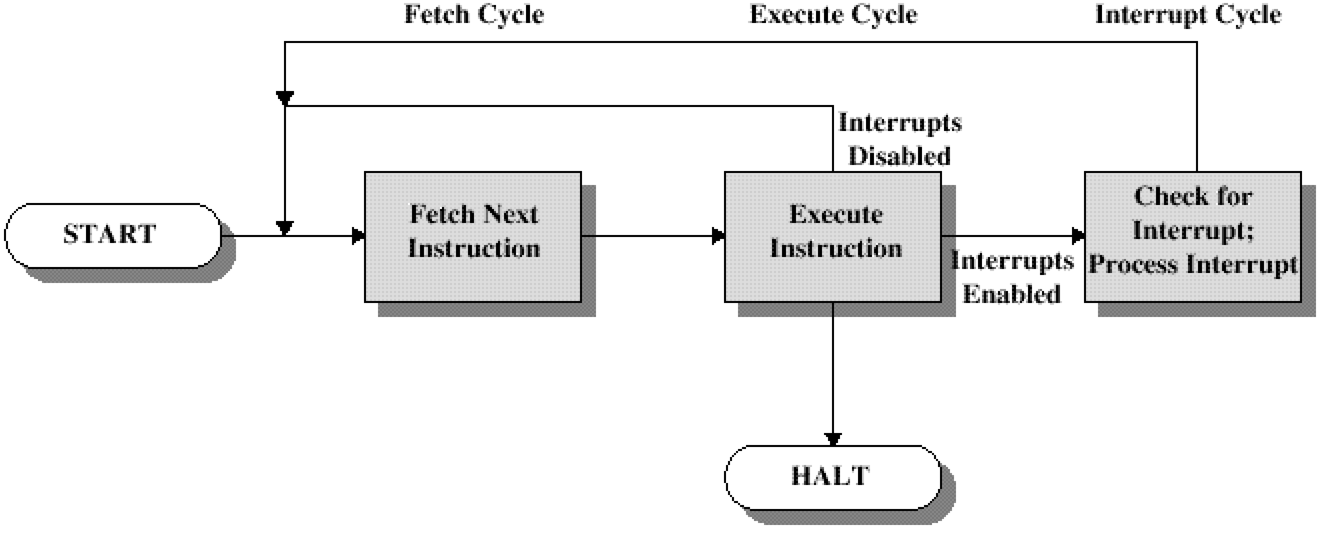
- Interrupt – event that occurs in a computing system, which affects the execution flow

- Types of interrupts:
  - Hardware interrupts
    - Clock interrupt (periodic)
    - I/O device interrupt (asynchronous)
    - Software error (arithmetic overflow, unknown instruction, wrong memory address…)
    - Hardware error (bus error)

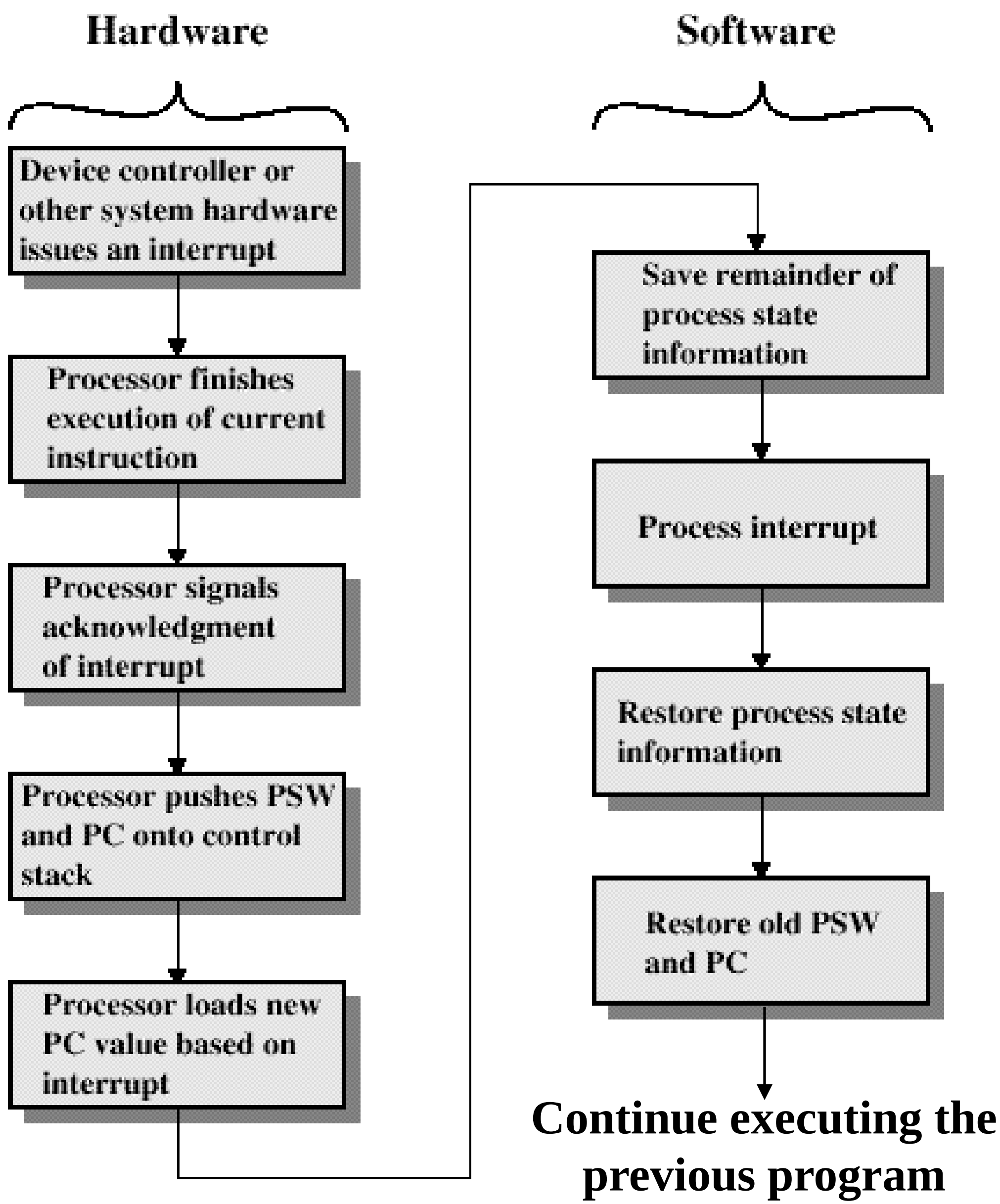
  - Software interrupt or *trap*
    - Special instruction of the processor
    - Synchronous with respect to the instruction sequence of the (calling) program

# Instruction Control Flow and Instruction Cycle with Interrupts

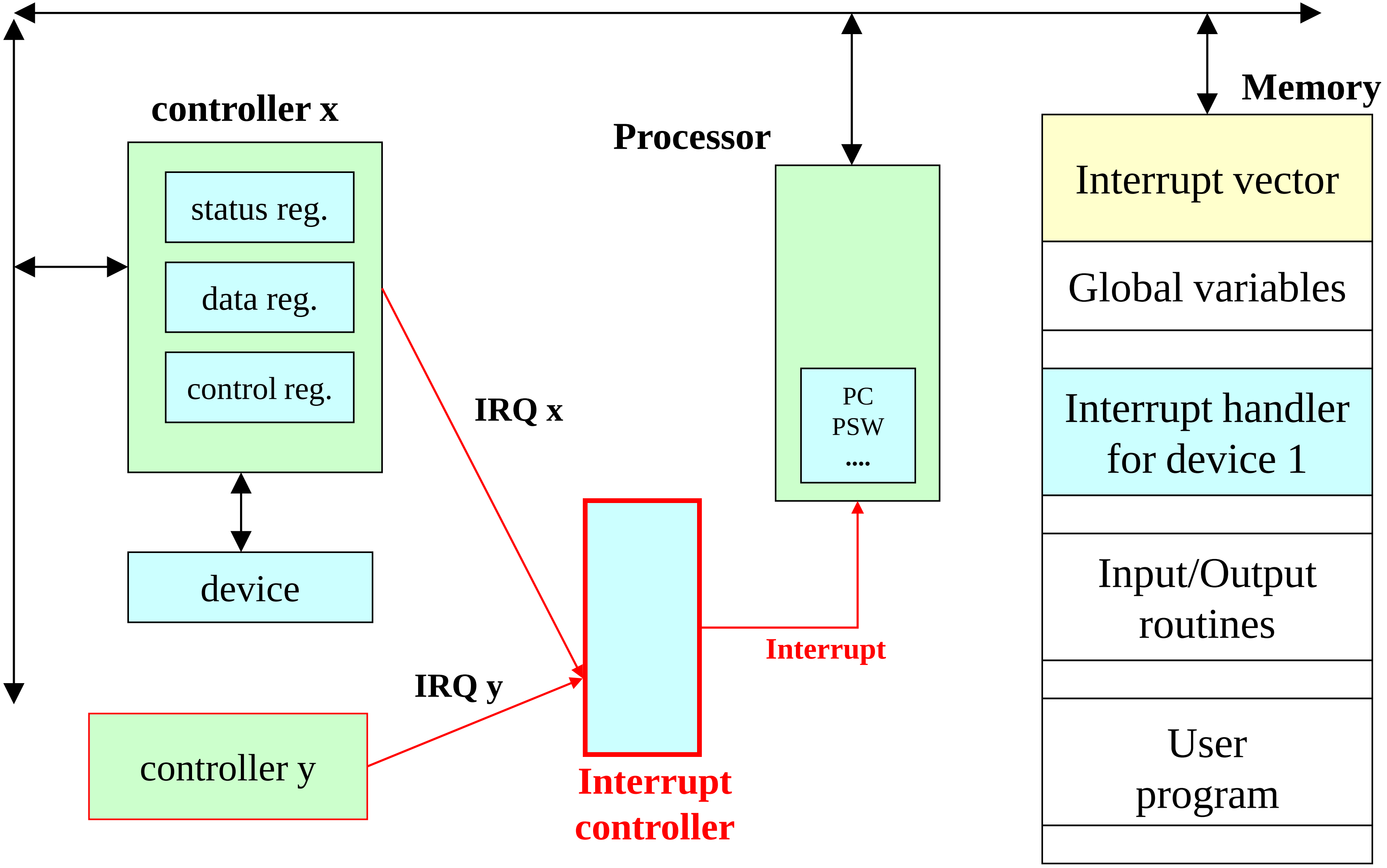


# Interrupt handling



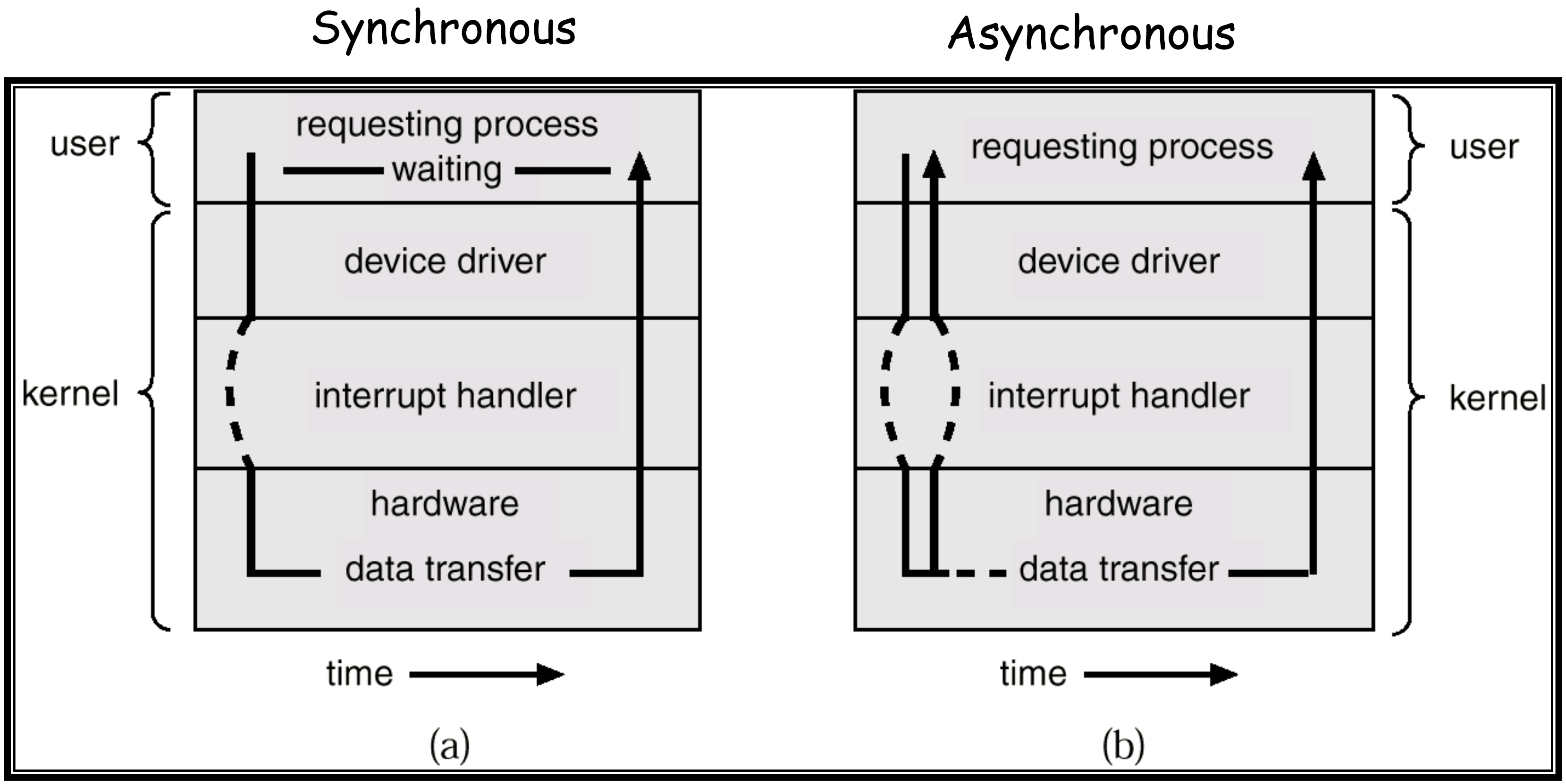
# Interrupt driven Input/Output



# Interrupt driven Input/Output

- Provides parallelism: operations can be synchronous or asynchronous
- The device generates an interrupt when a character/block is read/written
- Besides the input and output routines, the programmer must code the interrupt-handler, which is executed when an interrupt occurs
- The interrupt vector must be updated with the address of the interrupt-handler routine

# Types of I/O operations



# Interrupt driven Input/Output - Example

## User program (synchronous)

```
main()
{
  char buff[80];

  change_interrupt_vector(DEV1, interrupt_handler_1);
  change_interrupt_vector(DEV2, interrupt_handler_2);
  while (TRUE)
  {
    in_routine_1(buff, 80, SYNC);
    out_routine_2(buff, 80, SYNC);
  }
}
```

## Global variables

```
int end1 = TRUE, end2 = TRUE;
char *buff1, *buff2;
int count1 = 0, count2 = 0;
int index1, index2;
```

## Synchronization routine

```
void synchronize(int *end)
{
  while ((*end) == FALSE) NOP;
}
```

## Output routine for device 2

```
out_routine_2(char *vector, int count, int async_sync)
{
  int status;
  end2 = FALSE;
  /* first write by busy waiting */
  do {
    status = read_status_register(DEV2);
  } while (status == BUSY);
  error(DEV2, status);
  buff2 = vector;
  index2 = 1;
  count2 = count;
  write_data_register(DEV2, buff2[0]);
  write_control_register(DEV2, WRITTEN);
  if (async_sync == SYNC)
    synchronize(&end2);
}
```

## Input routine for device 1

```
in_routine_1(char *vector, int count, int async_sync)
{
  end1 = FALSE; buff1 = vector; index1 = 0;
  count1 = count;
  if (async_sync == SYNC)
    synchronize(&end1);
}
```

# Interrupt driven Input/Output - Example

**Interrupt handler for device 1**

```
interrupt_handler_1()
{
   int status;

   if (count1 != 0)
   {
      status = read_status_register(DEV1);
      error(DEV1, status);
      buff1[index1++] =
                   read_data_register(DEV1);
      count1--;
      if (count1 == 0) end1 = TRUE;
   }
   write_control_register(DEV1, READ);
   end_interrupt_handler();   /* EOI, IRET */
}
```

**Interrupt handler for device 2**

```
interrupt_handler_2()
{
   int status;

   status = read_status_register(DEV2);
   error(DEV2, status);
   count2--;
   if (count2 > 0)
   {
      write_data_register(DEV2,
                              buff2[index2++]);
      write_control_register(DEV2, WRITTEN);
   }
   else end2 = TRUE;
   end_interrupt_handler();   /* EOI, IRET */
}
```

# Interrupt driven Input/Output - Example

**User program (synchronous I/O)**

```
main()
{
   char buff[80];

   change_interrupt_vector(DEV1,
                           interrupt_handler_1);
   change_interrupt_vector(DEV2,
                           interrupt_handler_2);
   while (TRUE)
   {
      in_routine_1(buff, 80, SYNC);
      out_routine_2(buff, 80, SYNC);
   }
}
```

**User program (sync. I, async. O)**

```
main()
{
   char v1[80], v2[80];

   change_interrupt_vector(DEV1,
                           interrupt_handler_1);
   change_interrupt_vector(DEV2,
                           interrupt_handler_2);
   while (TRUE)
   {
      in_routine_1(v1, 80, SYNC);
      synchronize(&end2);
      out_routine_2(v1, 80, ASYNC);
      in_routine_1(v2, 80, SYNC);
      synchronize(&end2);
      out_routine_2(v2, 80, ASYNC);
   }
}
```

# Interrupt driven Input/Output - Example

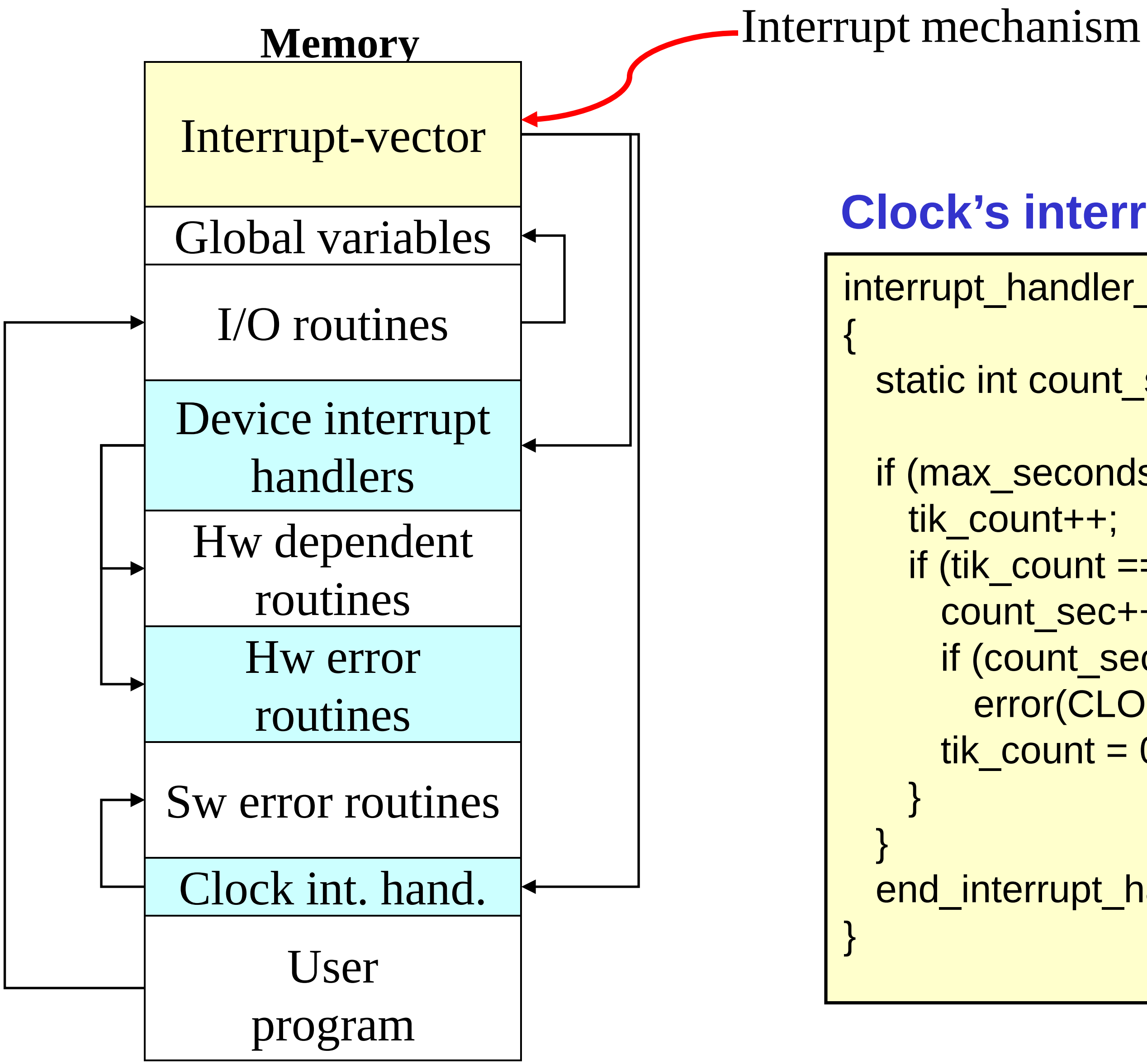
## User program (sync. I, async. O)

```
main()
{
   char v1[80], v2[80];

   change_interrupt_vector(DEV1,
                                   interrupt_handler_1);
   change_interrupt_vector(DEV2,
                                   interrupt_handler_2);
   while (TRUE) {
      in_routine_1(v1, 80, SYNC);
      synchronize(&end2);
      out_routine_2(v1, 80, ASYNC);
      in_routine_1(v2, 80, SYNC);
      synchronize(&end2);
      out_routine_2(v2, 80, ASYNC);
   }
}
```

## User program (asynchronous I/O)

```
main()
{
   char v1[80], v2[80];

   change_interrupt_vector(DEV1,
                                   interrupt_handler_1);
   change_interrupt_vector(DEV2,
                                   interrupt_handler_2);
   while (TRUE) {
      in_routine_1(v1, 80, ASYNC);
      synchronize(&end1);
      synchronize(&end2);
      out_routine_2(v1, 80, ASYNC);
      in_routine_1(v2, 80, ASYNC);
      synchronize(&end1);
      synchronize(&end2);
      out_routine_2(v2, 80, ASYNC);
   }
}
```

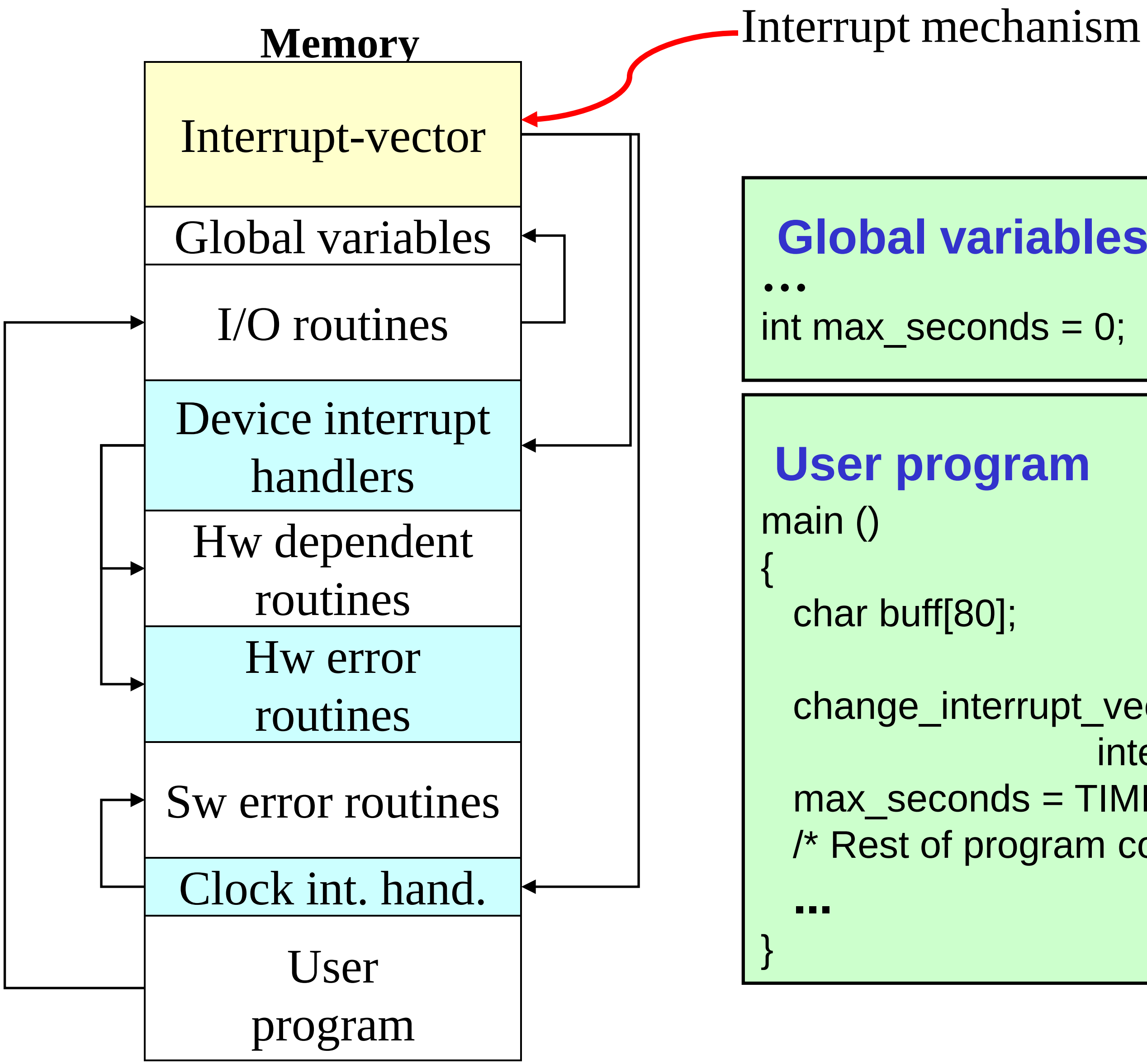
# Time and error control




**Clock's interrupt handler**

```
interrupt_handler_clock()
{
   static int count_sec = 0, tik_count = 0;

   if (max_seconds != 0) {
      tik_count++;
      if (tik_count == ONE_SECOND) {
         count_sec++;
         if (count_sec == max_seconds)
            error(CLOCK, OVERTIME);
         tik_count = 0;
      }
   }
   end_interrupt_handler();
}
```

# Time and error control



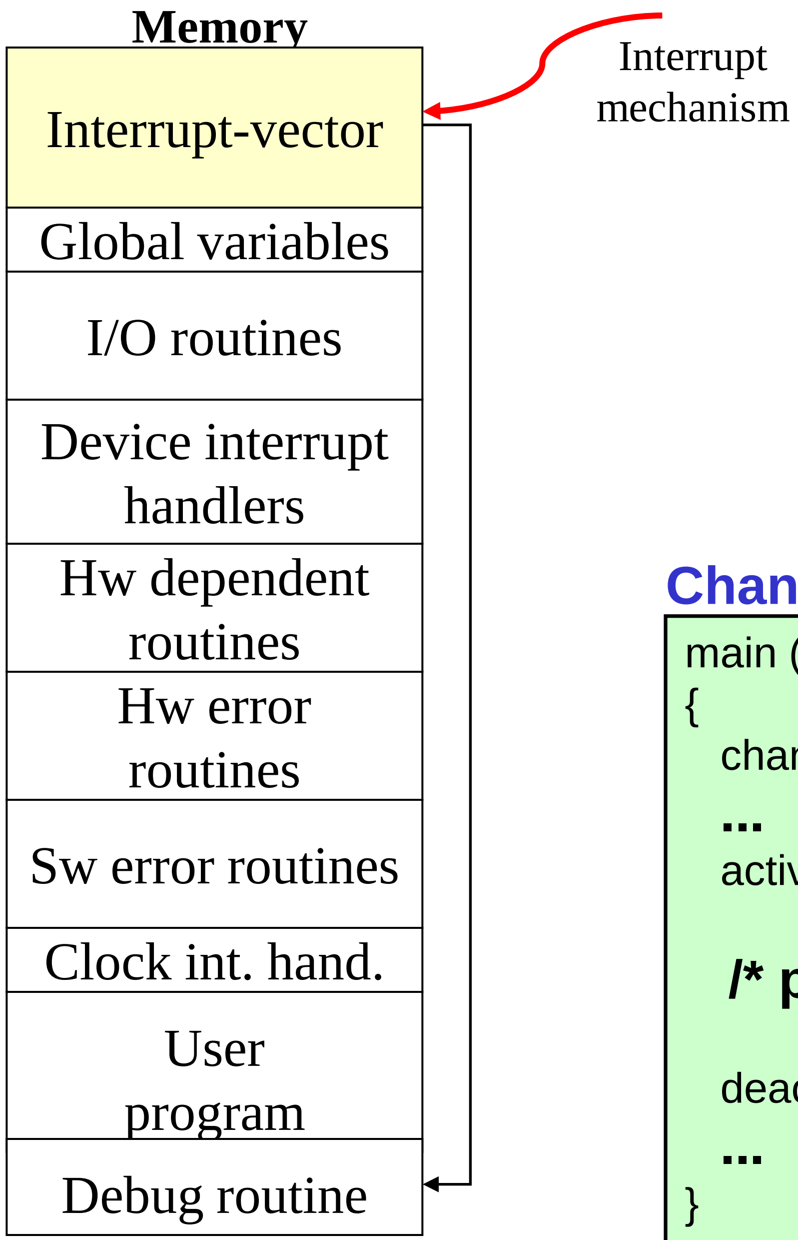

**Global variables**

```
...
int max_seconds = 0;
```

**User program**

```
main ()
{
   char buff[80];

   change_interrupt_vector(CLOCK,
                          interrupt_handler_clock);
   max_seconds = TIME_MAX;
   /* Rest of program code */
   ...
}
```

# Debugging



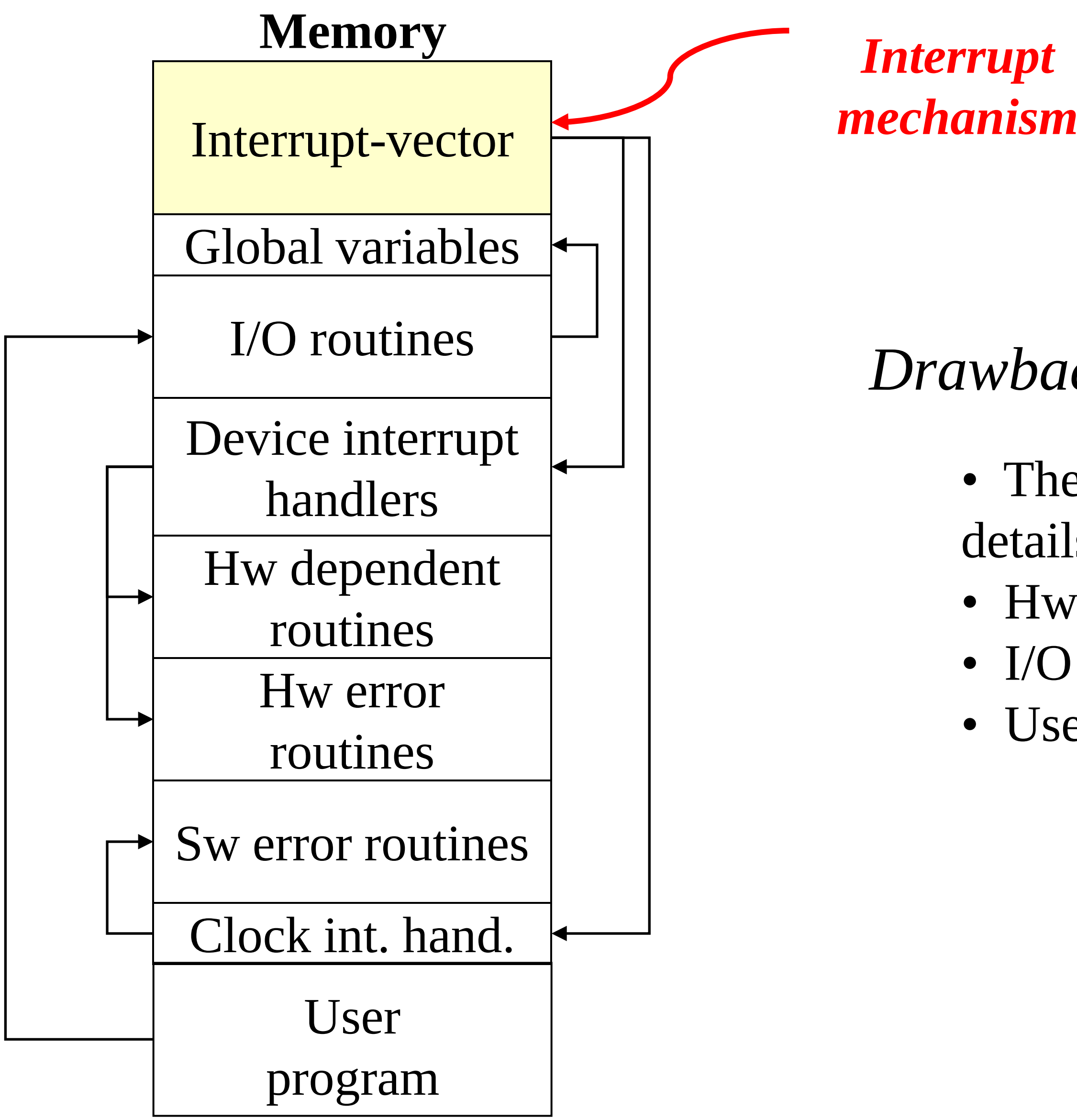

## Debugging routine

```
debug_routine()
{
   deactivate_debug_bit();

   /* debugging code */

   activate_debug_bit();
}
```

## Changes in the user program

```
main ()
{
   change_interrupt_vector(DEBUG, debug_routine);
   ...
   activate_debug_bit();

   /* program code */

   deactivate_debug_bit();
   ...
}
```

# Interrupt driven I/O general scheme




*Drawbacks of the mechanism:*

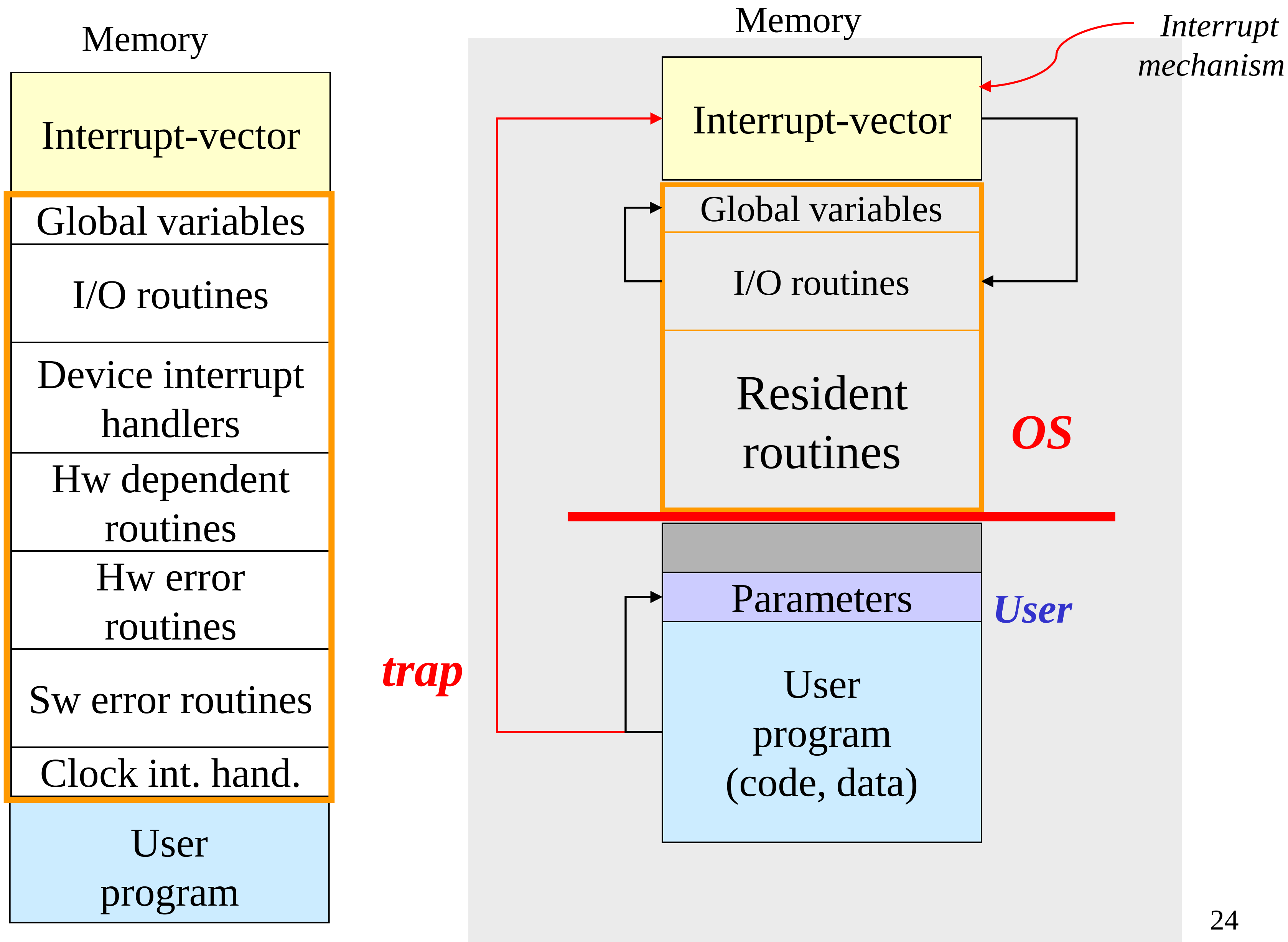
- The programmer must know the details of the machine/processor
- Hw dependency (changes?)
- I/O routine update
- User program update, life-cycle

# System calls

- Interface between the user program and the operating system
- Each system call has a concrete number
- System calls are usually implemented using a special instruction (software interrupt or *TRAP*) of the processor:

| | |
|---|---|
| INT xx, int86() | (Intel x86) |
| SVC | (IBM 360/370) – supervisory call |
| trap | (PDP 11) |
| tw | (PowerPC) – trap word |
| tcc | (Sparc) |
| break | (MIPS) |

# Interrupt-vector based system call



# System calls

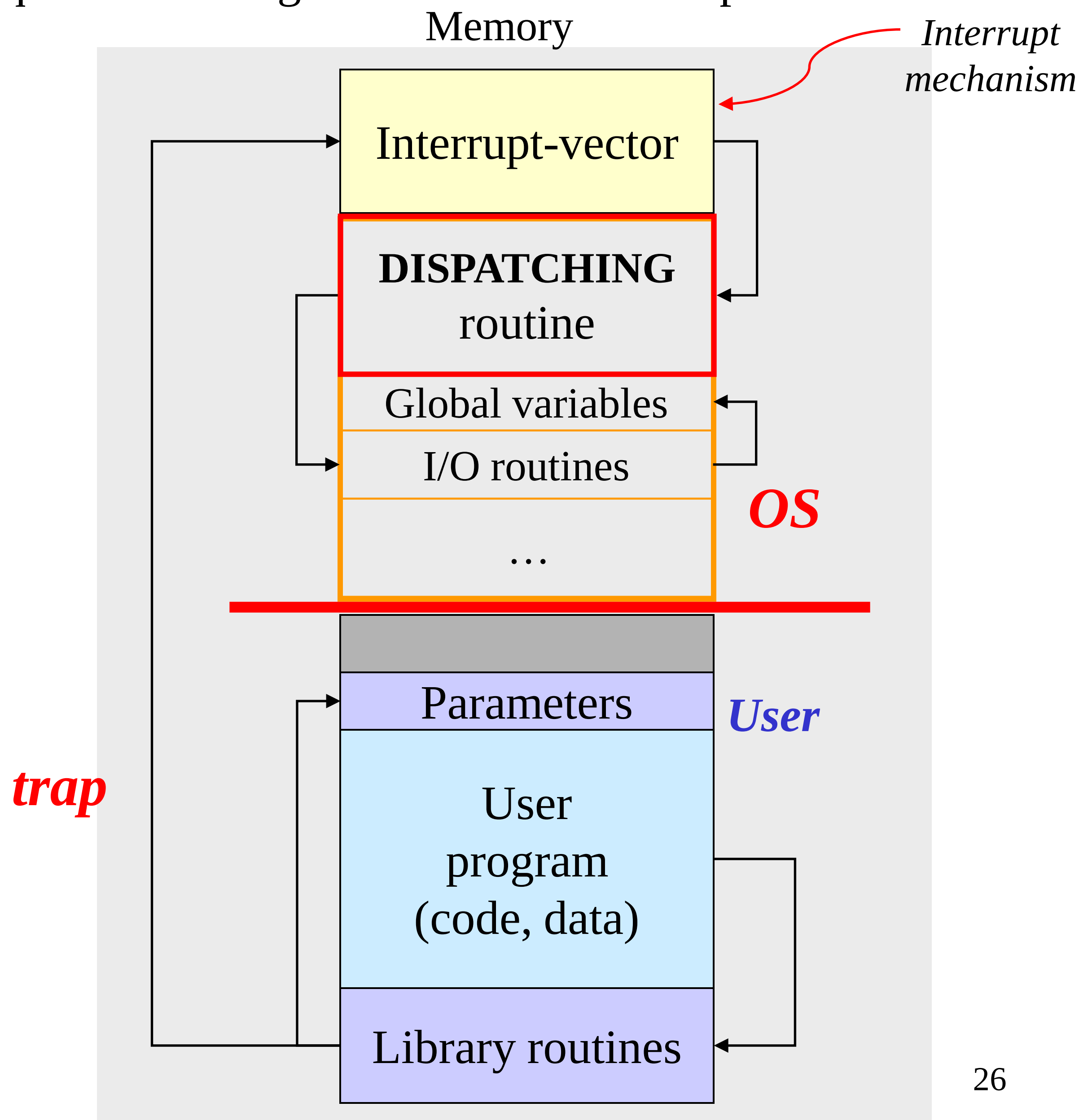
- Nowadays, system calls can be used through high level programming languages (e.g., C)
- Programming is easier:

  SVC 15 vs read(file-d, buffer, n-bytes)
- System calls execute instructions that access the resources of the machine, e.g., I/O instructions that access devices
- These instructions must be executed in a controlled way, under the control of the OS!

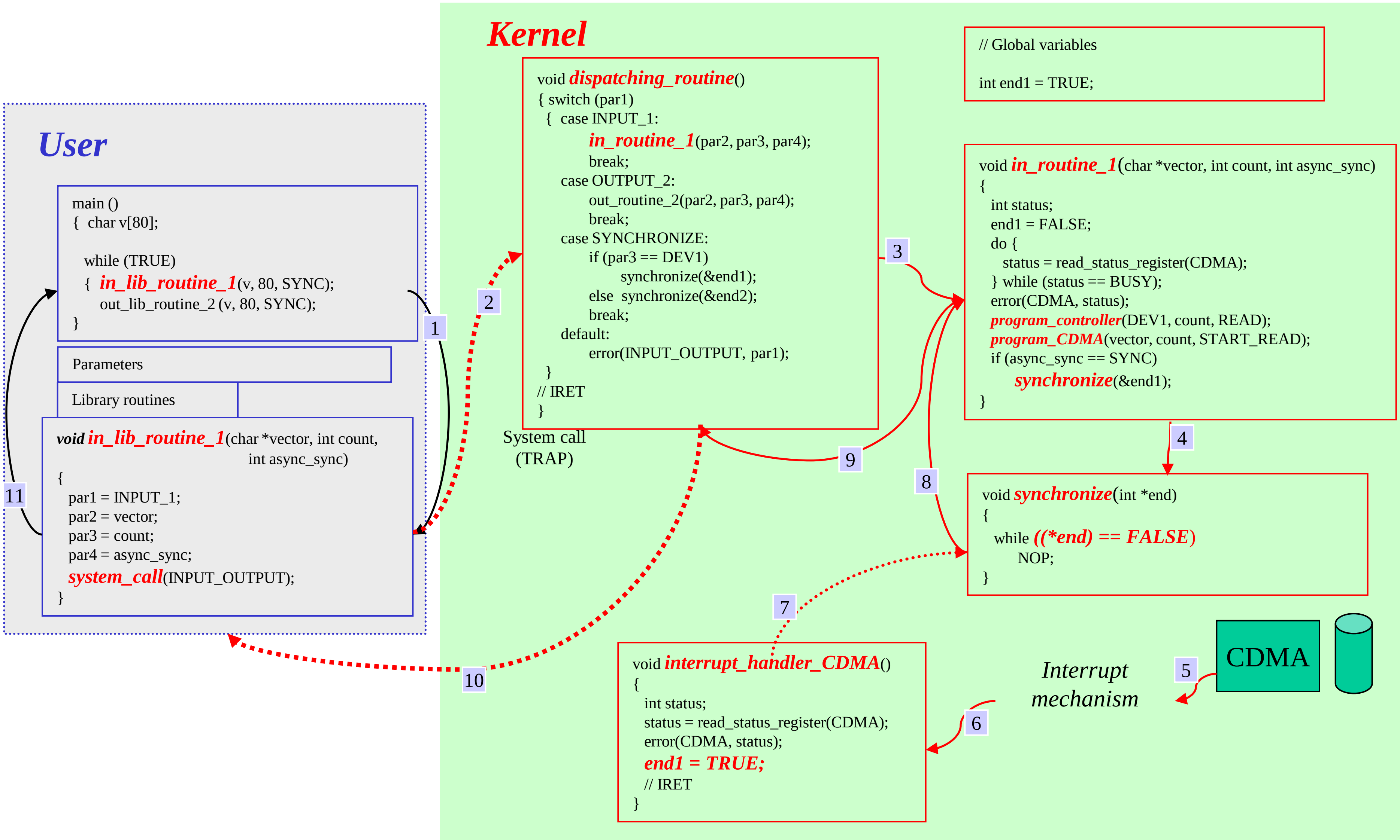
# Interrupt-vector based system call

Library + technique for limiting the size of the interrupt-vector

- Global variables
- I/O routines
- Device interrupt handlers
- Hw dependent routines
- Hw error routines
- Sw error routines
- Clock int. hand.



# Interrupt-vector based system call



# Abstraction techniques

- System calls are sometimes (if not always) wrapped by library functions
- Example: fopen() / fclose() – C abstractions
  - In Windows:
    - fopen() ⇨ CreateFile()
    - fclose() ⇨ CloseHandle()
  - In Unix:
    - fopen() ⇨ open()
    - fclose() ⇨ close()

# System calls (1)

| UNIX | Win32 | Description |
|---|---|---|
| fork | CreateProcess | Create a new process |
| waitpid | WaitForSingleObject | Can wait for a process to exit |
| execve | (none) | CreateProcess = fork + execve |
| exit | ExitProcess | Terminate execution |
| open | CreateFile | Create a file or open an existing file |
| close | CloseHandle | Close a file |
| read | ReadFile | Read data from a file |
| write | WriteFile | Write data to a file |
| lseek | SetFilePointer | Move the file pointer |
| stat | GetFileAttributesEx | Get various file attributes |
| mkdir | CreateDirectory | Create a new directory |
| rmdir | RemoveDirectory | Remove an empty directory |
| link | (none) | Win32 does not support links |
| unlink | DeleteFile | Destroy an existing file |
| mount | (none) | Win32 does not support mount |
| umount | (none) | Win32 does not support mount |
| chdir | SetCurrentDirectory | Change the current working directory |
| chmod | (none) | Win32 does not support security (although NT does) |
| kill | (none) | Win32 does not support signals |
| time | GetLocalTime | Get the current time |

# System calls (2)

**Process management**

| Call | Description |
|---|---|
| pid = fork( ) | Create a child process identical to the parent |
| pid = waitpid(pid, &statloc, options) | Wait for a child to terminate |
| s = execve(name, argv, environp) | Replace a process' core image |
| exit(status) | Terminate process execution and return status |

**File management**

| Call | Description |
|---|---|
| fd = open(file, how, ...) | Open a file for reading, writing or both |
| s = close(fd) | Close an open file |
| n = read(fd, buffer, nbytes) | Read data from a file into a buffer |
| n = write(fd, buffer, nbytes) | Write data from a buffer into a file |
| position = lseek(fd, offset, whence) | Move the file pointer |
| s = stat(name, &buf) | Get a file's status information |

# System calls (3)

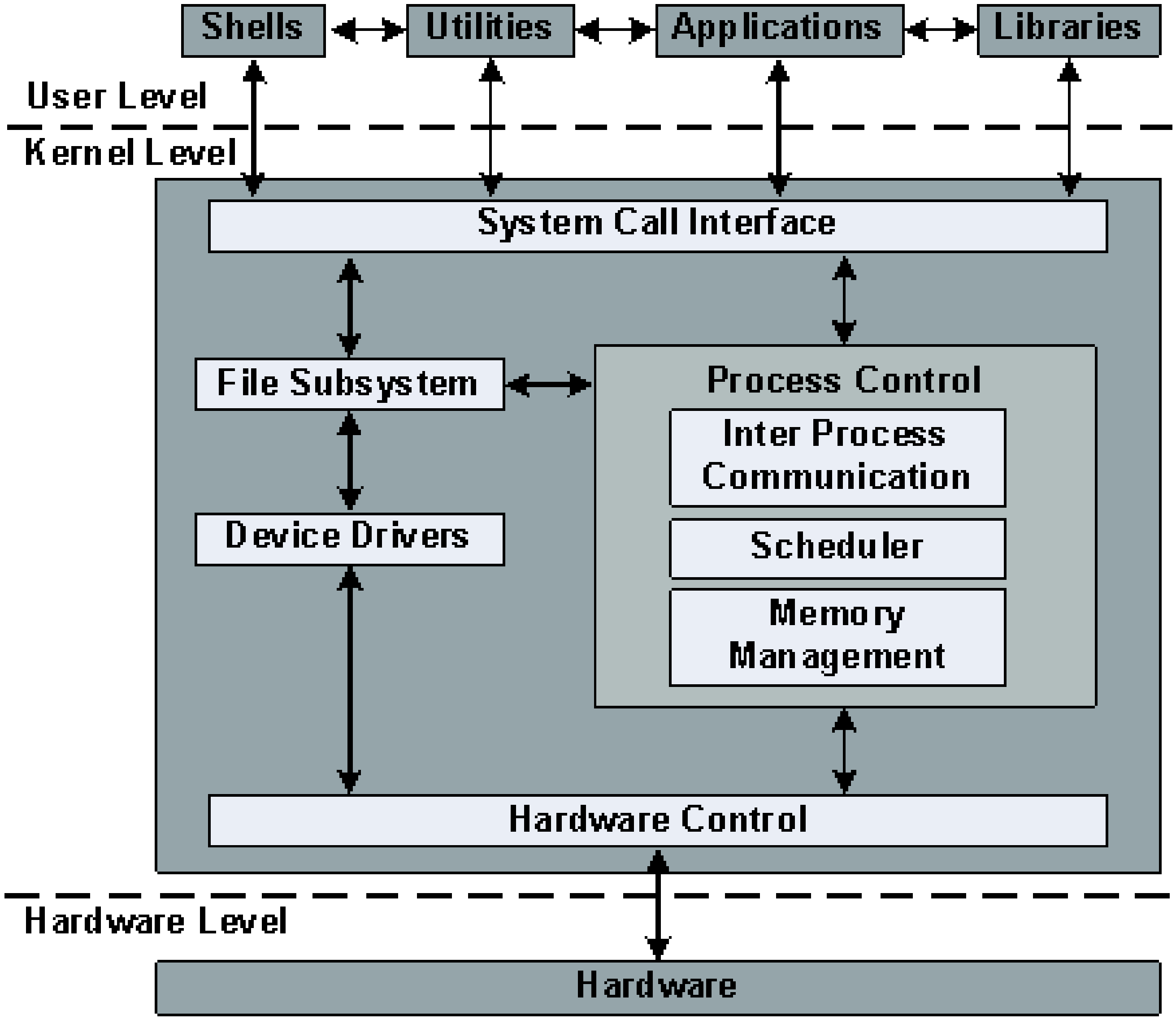
**Directory and file system management**

| Call | Description |
|---|---|
| s = mkdir(name, mode) | Create a new directory |
| s = rmdir(name) | Remove an empty directory |
| s = link(name1, name2) | Create a new entry, name2, pointing to name1 |
| s = unlink(name) | Remove a directory entry |
| s = mount(special, name, flag) | Mount a file system |
| s = umount(special) | Unmount a file system |

**Miscellaneous**

| Call | Description |
|---|---|
| s = chdir(dirname) | Change the working directory |
| s = chmod(name, mode) | Change a file's protection bits |
| s = kill(pid, signal) | Send a signal to a process |
| seconds = time(&seconds) | Get the elapsed time since Jan. 1, 1970 |

# Unix - Architecture



# Windows NT

- What is a system call in Windows?
  - A call to the API offered by a subsystem?

  or

  - a call to the *Native* API?

# Unix vs Windows NT

“Unix applications can call kernel functions, or *system calls*, directly. In Windows NT, applications call APIs that the OS environment to which they are coded (Win32, DOS, Windows 3.x, OS/2, POSIX) exports. The NT system-call interface, called the Native API, is hidden from programmers and largely undocumented (>1000 system calls).”

“The number of Unix system calls is around 200 to 300. The API that Unix applications write to is the Unix system-call interface, whereas the API that the majority of NT applications write to is the Win32 API, which translates Win32 APIs to Native APIs.”

# Windows NT - Architecture