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Scheduling

Course: Systems Architecture

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May, 2024

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Contents

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01

Processes

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Processes

```
└─ ps aux
USER               PID  %CPU %MEM      VSZ    RSS   TT  STAT STARTED      TIME COMMAND
glebodin           673  11,2  1,3 410311408 223424   ??  S    чт06    4:48.31 /Applicatio
_windowserver      362   7,4  0,7 411053248 123856   ??  Ss   чт06  160:06.67 /System/Lib
glebodin           739   4,6  0,4 442387360  71472   ??  S    чт06    8:43.04 /Applicatio
glebodin          4935   2,3  1,3 1598023296 226272   ??  S    11:30    36:54.08 /Applica
d
glebodin          1904   2,0  0,0 408304000   7600 s000  S     7:27     0:10.48 -zsh
glebodin           663   1,6  2,8 443056784 471312   ??  S    чт06   21:50.40 /Applicatio
glebodin         16795   1,5  0,3 408599296  46256   ??  S     7:05     0:00.15 /System/L
glebodin          2888   1,3  1,9 10423780 310688   ??  S     8:40    37:14.66 /Users/gle
glebodin           850   1,0  0,6 10731028  93072   ??  S    чт06    5:51.41 /opt/homebre
glebodin          2899   0,9  0,9 10209980 157136   ??  Ss    8:40    11:42.95 /Users/gle
glebodin         12056   0,9  1,7 410224016 289344   ??  S     2:02    57:40.31 /Applicat
root               323   0,5  0,1 409186000  10592   ??  Ss   чт06    1:43.82 /System/Lib
glebodin         16673   0,5  0,1 409183104  23008   ??  S     7:01     0:00.55 /System/L
root               449   0,5  0,1 408996432  22224   ??  Ss   чт06    5:43.93 /usr/libexe
glebodin           670   0,5  2,7 417848288 458752   ??  S    чт06   66:15.91 /Applicatio
glebodin         16794   0,4  0,2 408606272  37696   ??  S     7:05     0:00.14 /System/L
root               308   0,3  0,2 409905424  28912   ??  Ss   чт06    4:39.81 /System/Lib
glebodin          2922   0,2  2,5 14386044 426816   ??  S     8:40     2:17.90 /Users/gle
_networkd          436   0,2  0,1 408635696  14400   ??  Ss   чт06    0:18.64 /usr/libexe
root               532   0,2  0,5 414207504  86160   ??  Ss   чт06    3:35.34 /System/Lib
glebodin         16752   0,2  0,0 408067040   4720   ??  S     7:04     0:00.22 /System/L
root               281   0,1  0,0 408632224   6752   ??  Ss   чт06    1:31.28 /System/Lib
root               510   0,1  0,3 409251792  51808   ??  SN   чт06   22:11.07 /opt/osquer
root               292   0,1  0,2 408941920  25840   ??  Ss   чт06    5:38.02 /Library/Ap
glebodin         16698   0,1  0,1 409001184  19632   ??  Ss    7:02     0:00.19 /System/L
glebodin          4926   0,1  0,5 1585149744  89792   ??  S    11:30     1:04.29 /Applica
glebodin          5543   0,1  1,1 441033632 180832   ??  S    11:53     9:37.72 /Applicat
_locationd       16729   0,0  0,0 408361504   5152   ??  S     7:04     0:00.06 /usr/libe
root             16728   0,0  0,0 408361488   5024   ??  Ss    7:04     0:00.05 /usr/libe
glebodin         16727   0,0  0,1 408630528  11296   ??  S     7:04     0:00.15 /usr/libe
```

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Let’s touch them

```python
import itertools
import psutil

# getting all processes
all_processes = psutil.process_iter()

# getting 5 processes
limited_processes = itertools.islice(all_processes, 5)

# output info about processes
for process in limited_processes:
    pid = process.pid
    name = process.name()
    print(f"PID: {pid}, Name: {name}")

process = psutil.Process(16141)
print("process id:", process.pid)
print("process name:", process.name())
print("cp usage:", process.cpu_percent())
print("usage of memory:", process.memory_info().rss)
print("status:", process.status())
print("time of creation:", process.create_time())
print("parent id:", process.ppid())
```

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Let’s touch them

```
└─ python3 processes.py
PID: 0, Name: kernel_task
PID: 1, Name: launchd
PID: 277, Name: syslogd
PID: 278, Name: UserEventAgent
PID: 280, Name: uninstalld
process id: 16141
process name: deleted
cp usage: 0.0
usage of memory: 8601600
status: running
time of creation: 1685115830.214878
parent id: 1
```

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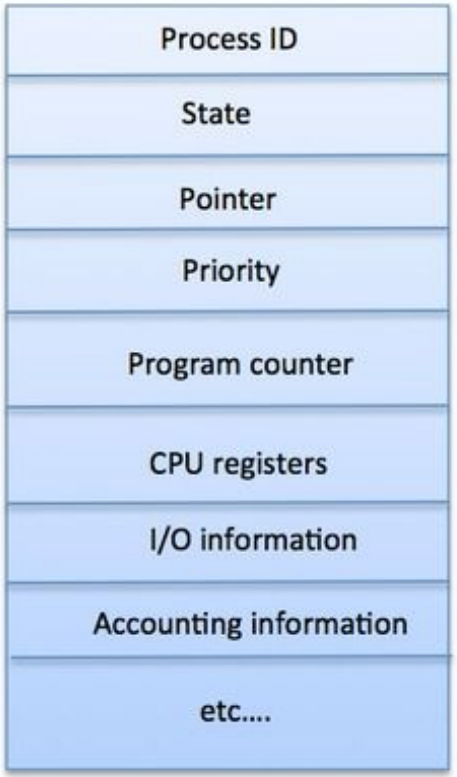
Process info



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Priority - NI. The smaller the "nice" value, the higher the priority of the process.

```
     F S UID  PID PPID   C PRI NI ADDR    SZ    WCHAN    TTY  TIME CMD
241801 S 200 7032 7286   0  60 20 1b4c   108          pts/2  0:00 ksh
200801 S 200 7568 7032   0  70 25 2310    88  5910a58  pts/2  0:00 vmstat
241801 S 200 8544 6494   0  60 20 154b   108          pts/0  0:00 ksh
```

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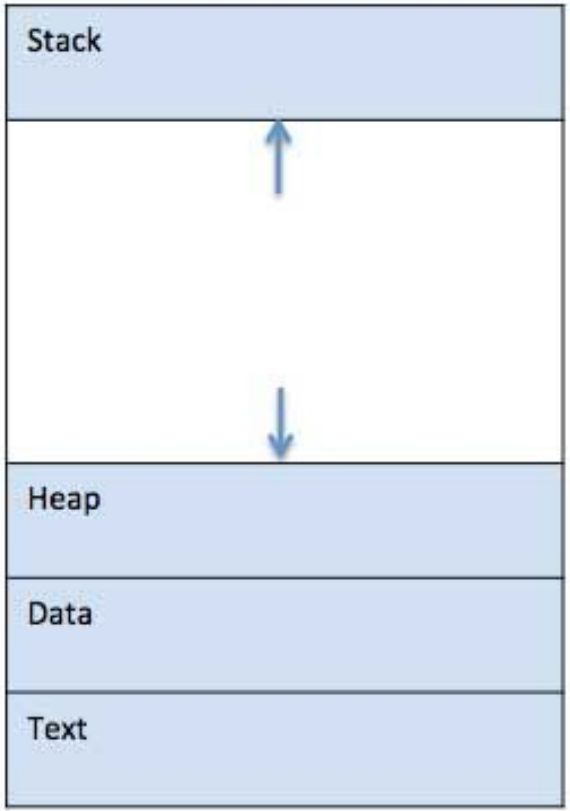
Process stack



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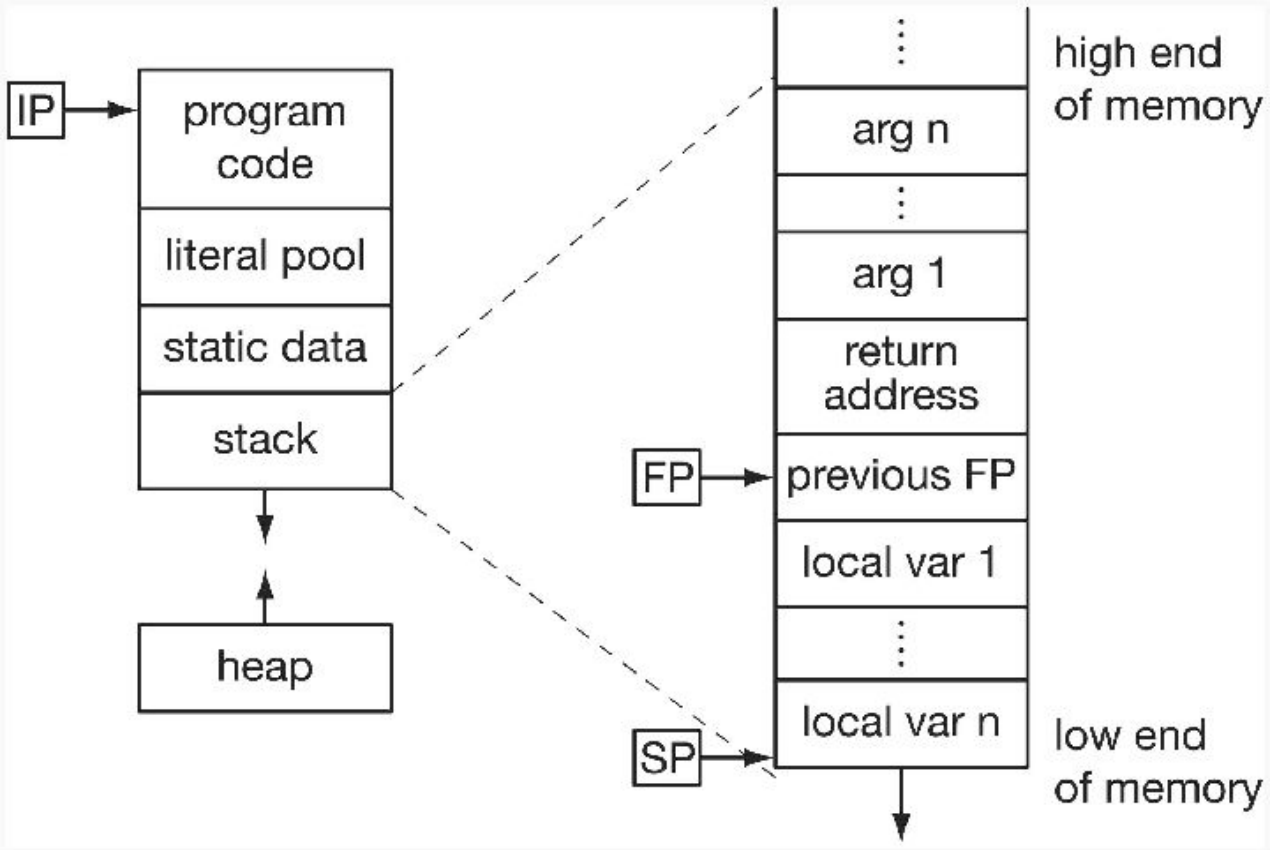
Context



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Component context

1) General Purpose Registers
2) Command Counter
3) Stack context

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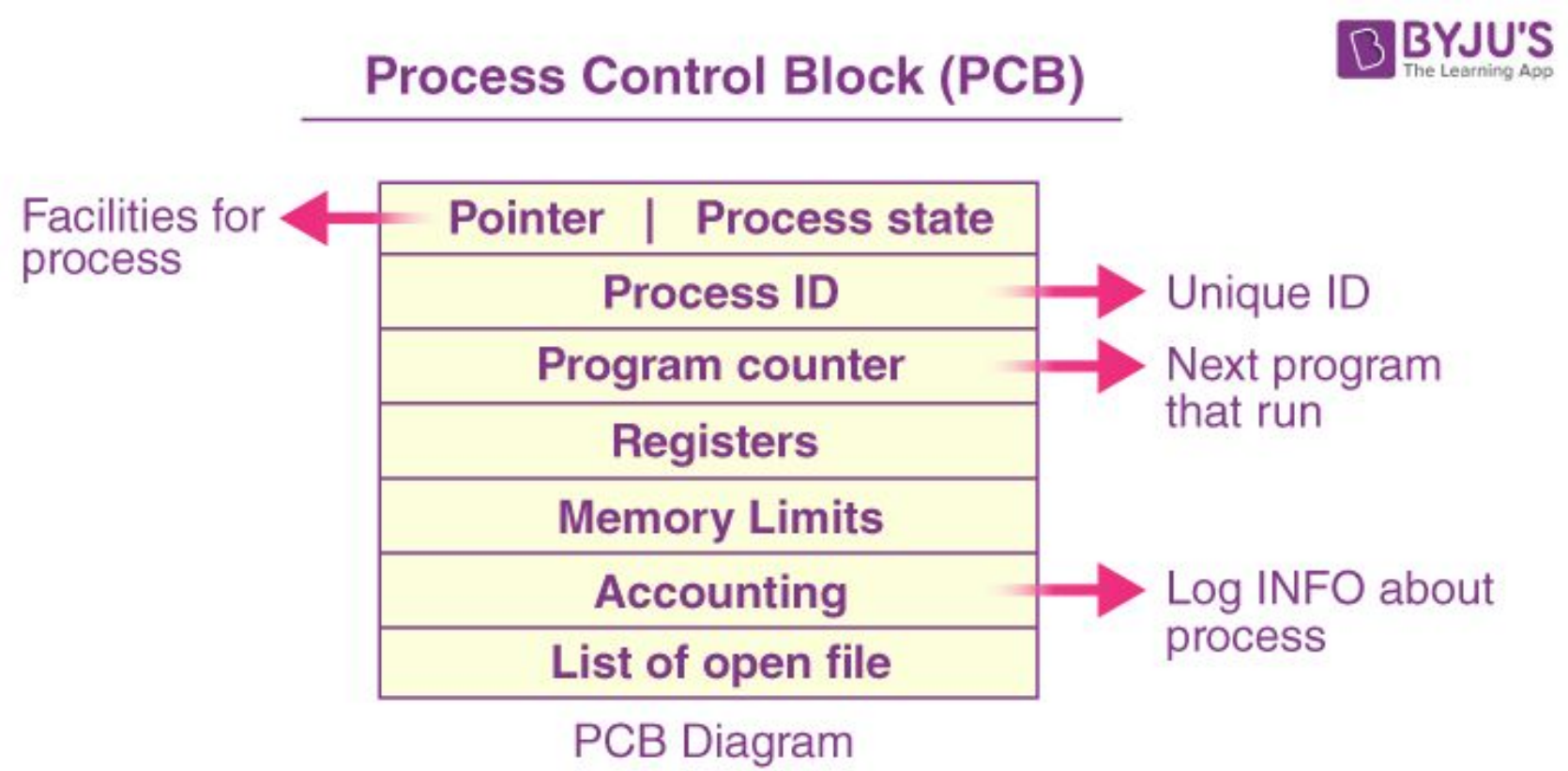
Process



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C++

not perfect)

```cpp
#include <iostream>
#include <cstdlib>
#include <unistd.h>

int main() {
    // Creating a new process
    pid_t pid = fork();

    if (pid == -1) {
        // Handling error in process creation
        std::cerr << "Error creating a process!" << std::endl;
        return 1;
    } else if (pid == 0) {
        // Code executed in the child process
        // Printing "Hello, World!"
        std::cout << "Hello, World!" << std::endl;
    } else {
        // Code executed in the parent process
        // Outputting child process ID
        std::cout << "Child process ID: " << pid << std::endl;
        // Waiting for the child process to finish
        int status;
        waitpid(pid, &status, 0);
    }
    return 0;
}
```

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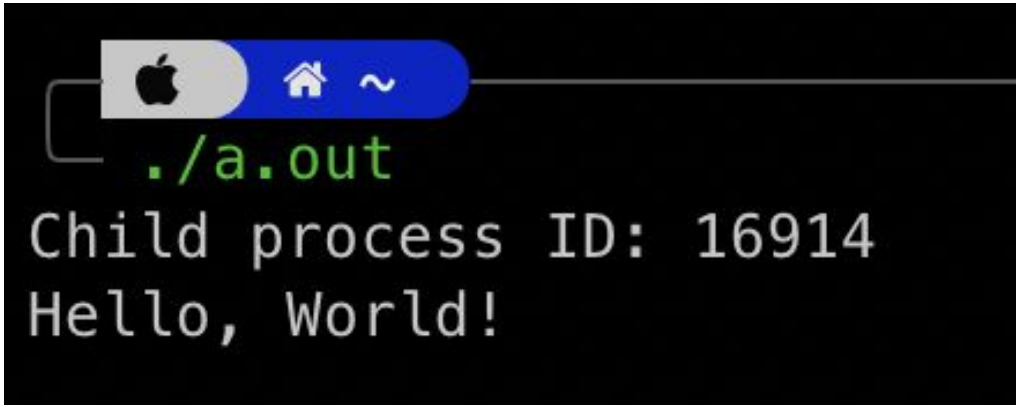
Result



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02

Protection

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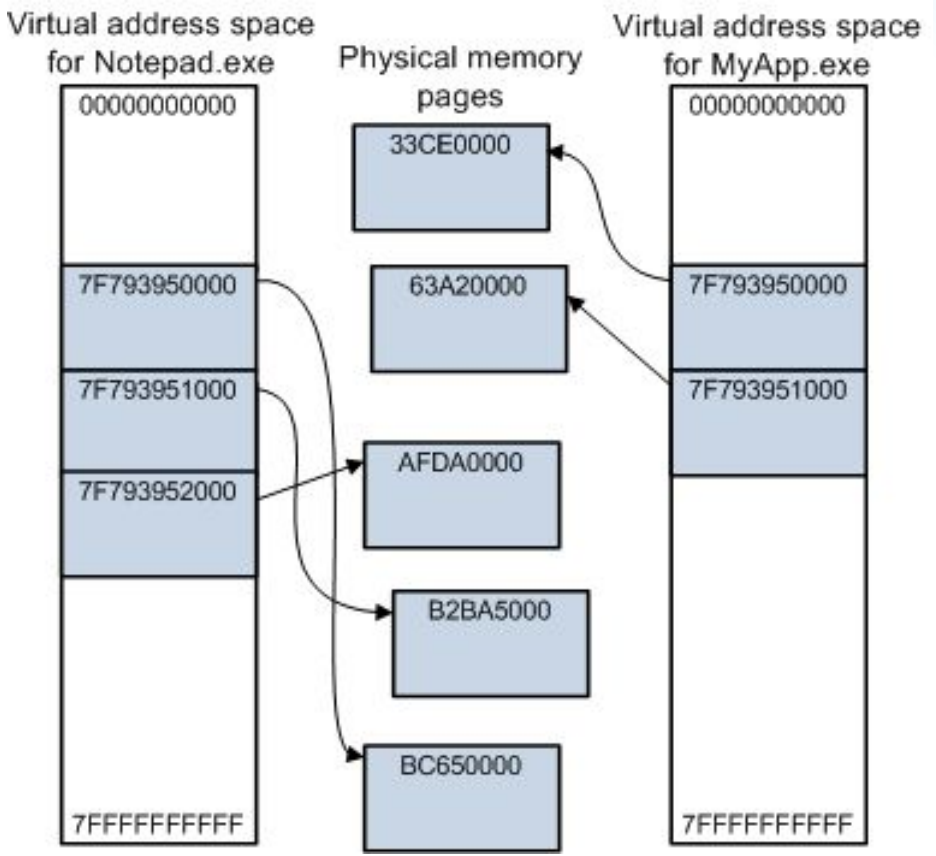
Virtual address space



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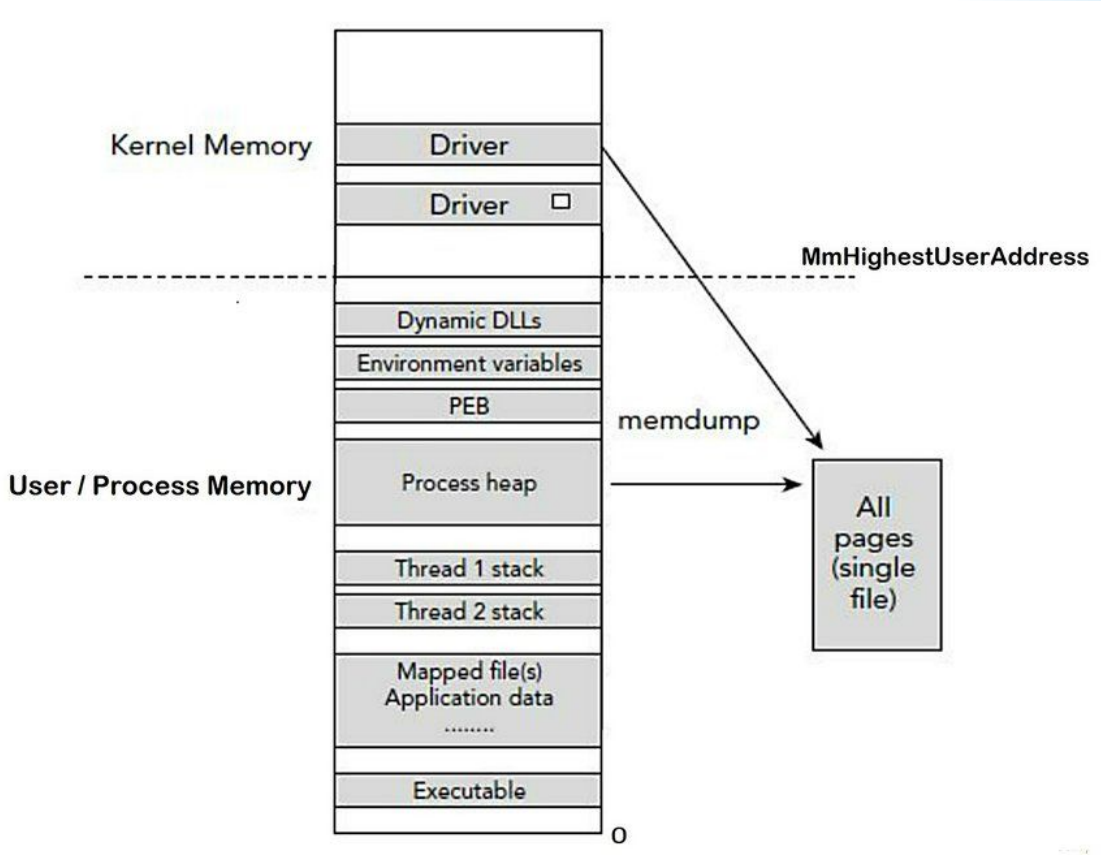
Virtual address space



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Protection

```
MPROTECT(2)                BSD System Calls Manual               MPROTECT(2)

NAME
     mprotect -- control the protection of pages

SYNOPSIS
     #include <sys/mman.h>

     int
     mprotect(void *addr, size_t len, int prot);

DESCRIPTION
     The mprotect() system call changes the specified pages to have protection prot.  Not all implementations will guarantee protection on a page basis but Mac
     OS X's current implementation does.

     When a program violates the protections of a page, it gets a SIGBUS or SIGSEGV signal.

     Currently prot can be one or more of the following:

     PROT_NONE   No permissions at all.
     PROT_READ   The pages can be read.
     PROT_WRITE  The pages can be written.
     PROT_EXEC   The pages can be executed.

RETURN VALUES
     Upon successful completion, a value of 0 is returned.  Otherwise, a value of -1 is returned and errno is set to indicate the error.

ERRORS
     mprotect() will fail if:

     [EACCES]           The requested protection conflicts with the access permissions of the process on the specified address range.

     [EINVAL]           addr is not a multiple of the page size (i.e.  addr is not page-aligned).

     [ENOMEM]           The specified address range is outside of the address range of the process or includes an unmapped page.

     [ENOTSUP]          The combination of accesses requested in prot is not supported.
```

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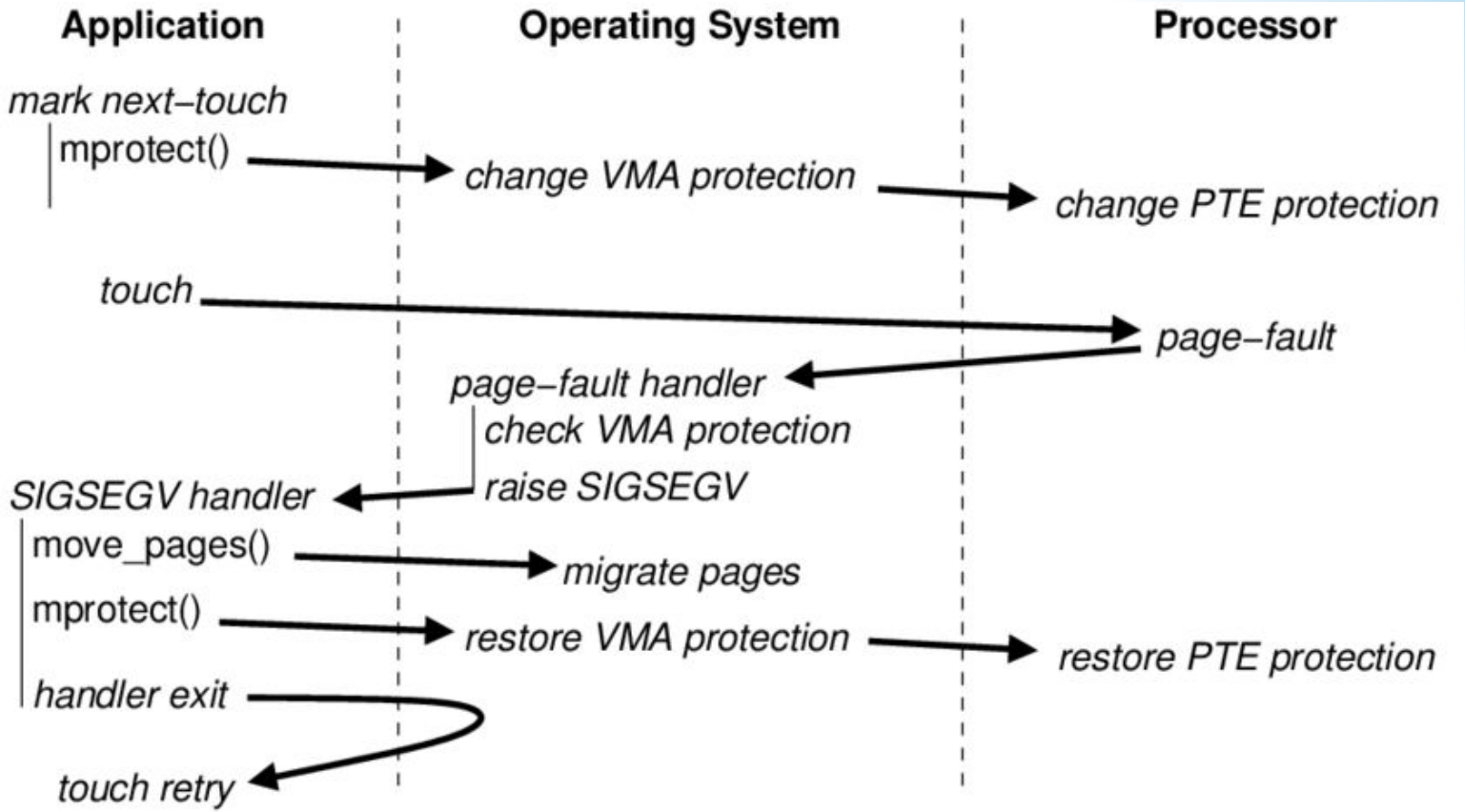
Protection



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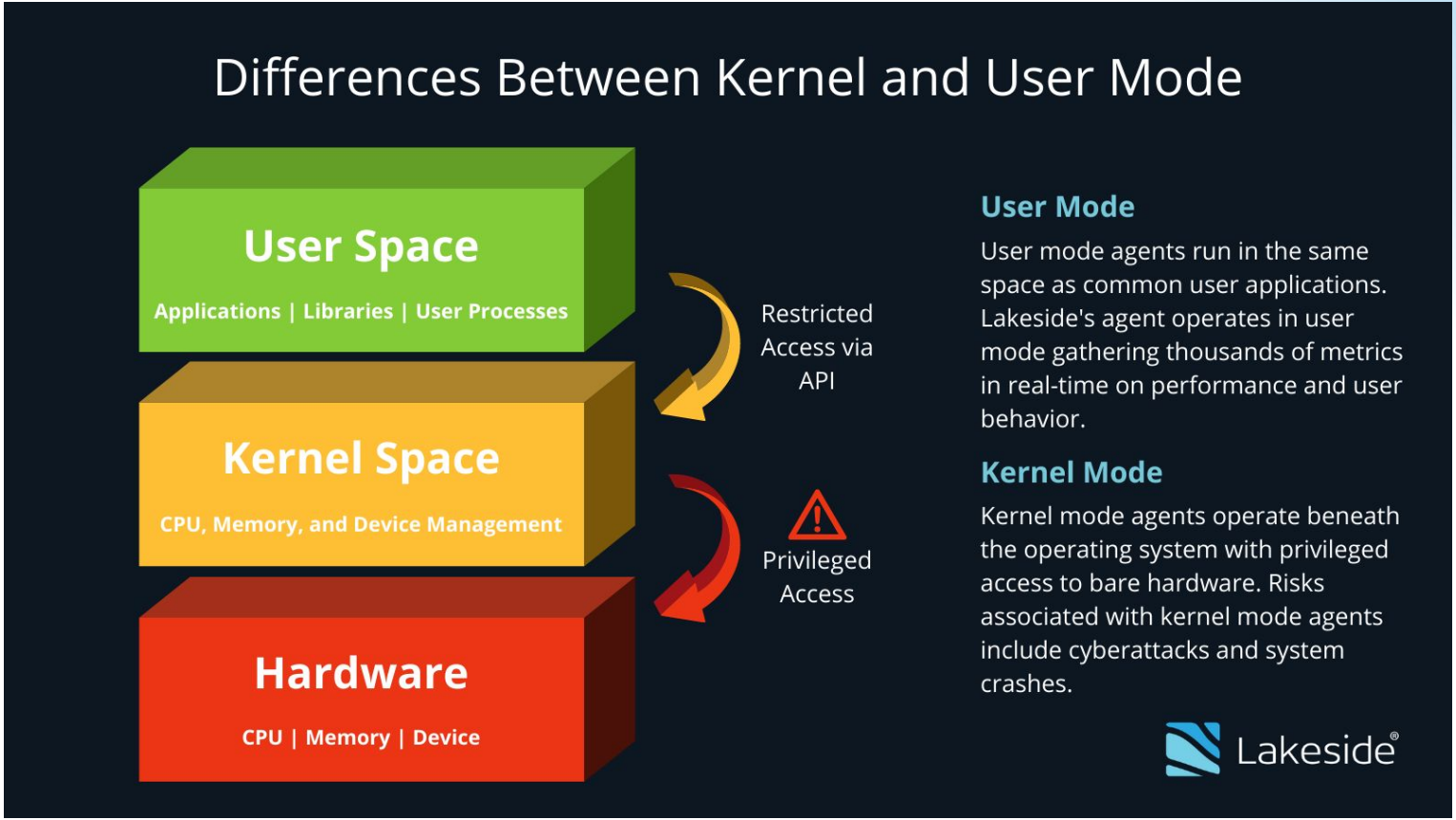
Modes



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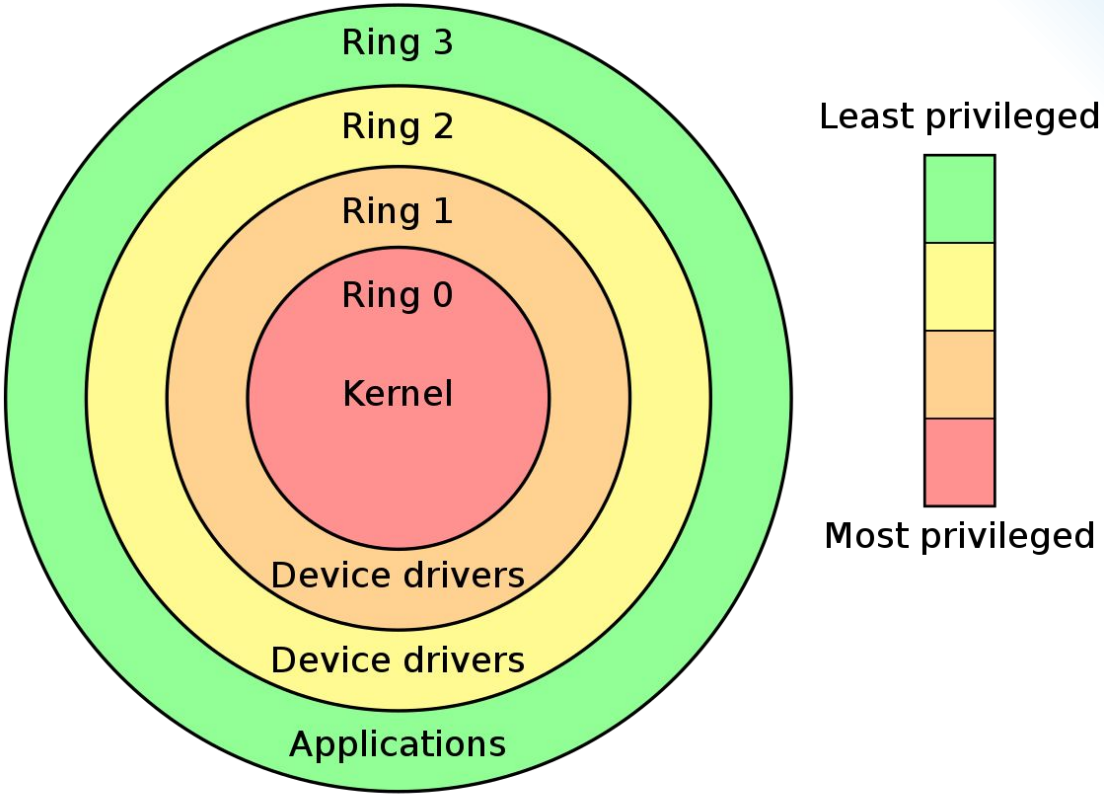
Rings



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Access of processes

1) Separation of execution modes
2) Permissions to access memory pages
3) Syscalls
4) Security modules and policies

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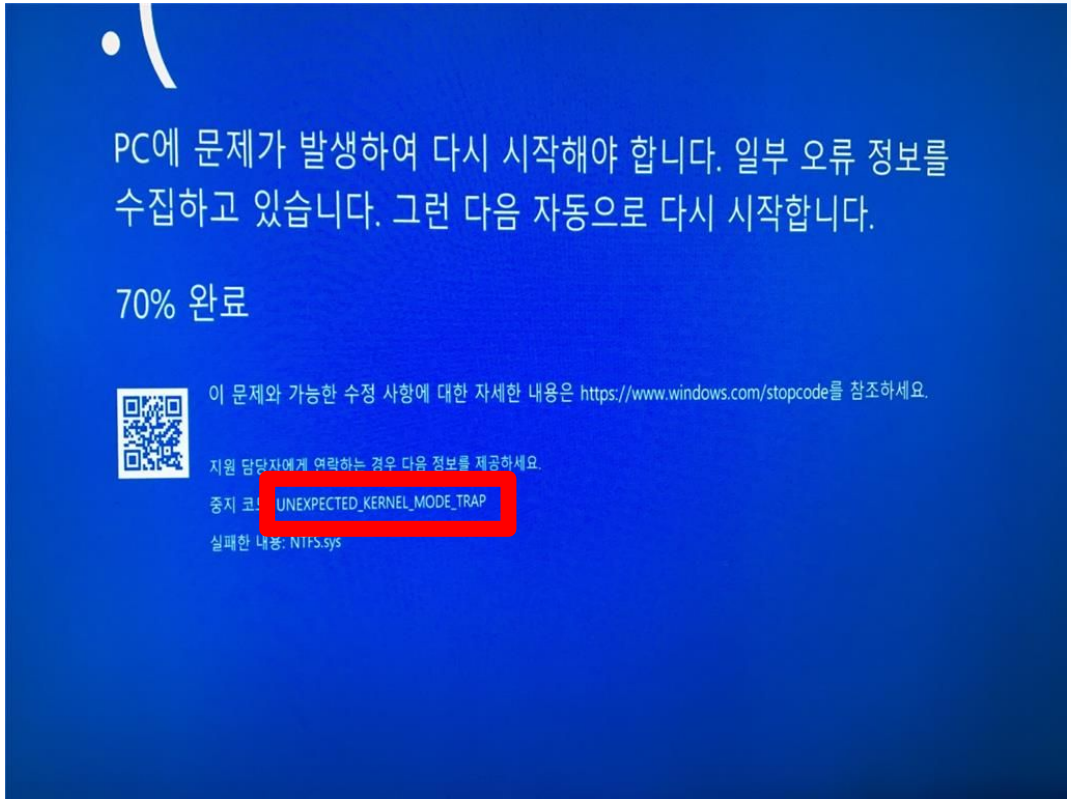
Blue screen



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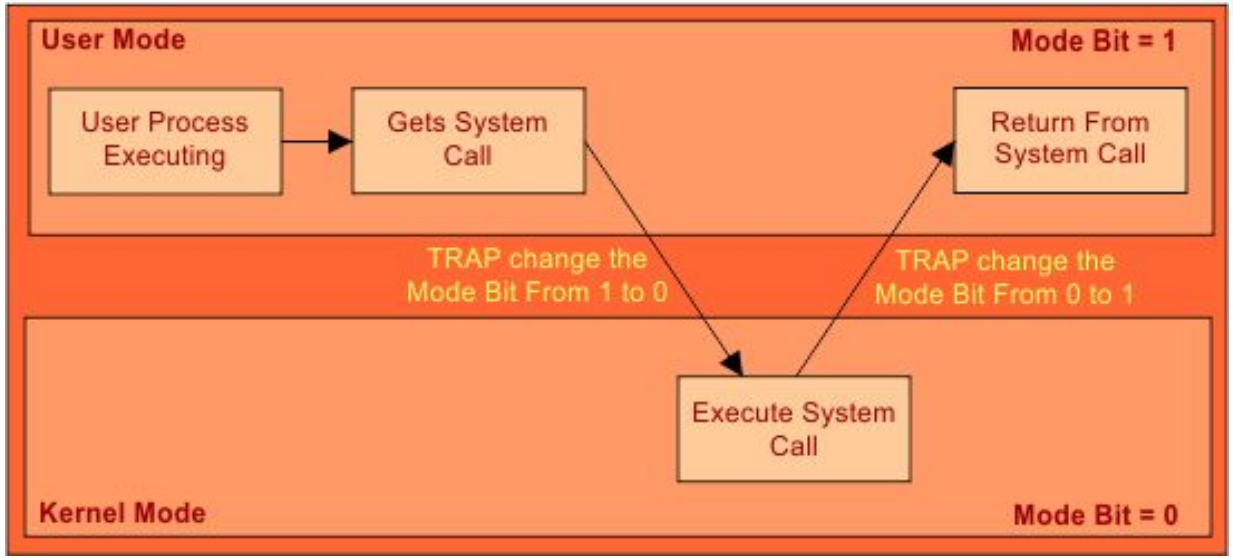
Syscalls



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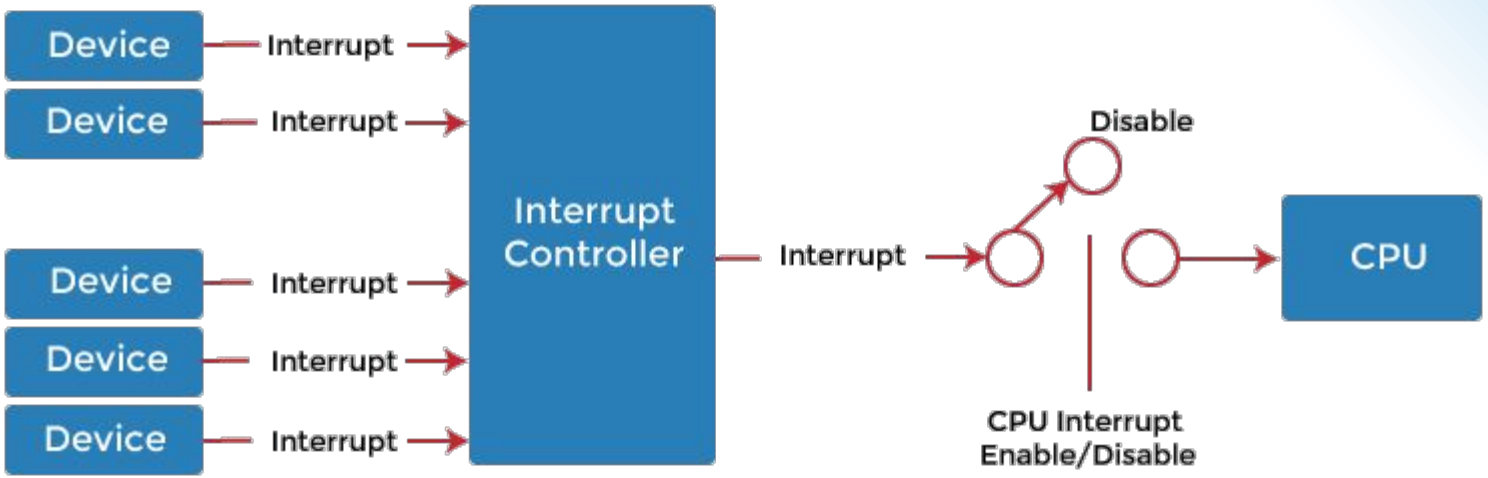
Interrupt



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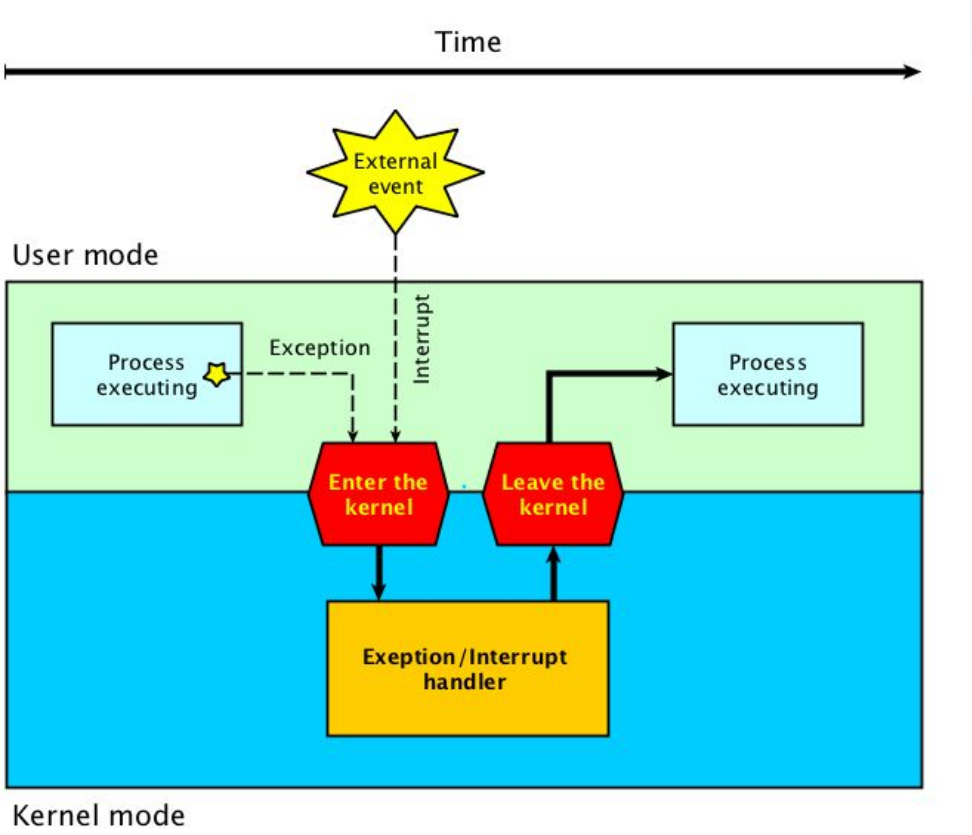
Interrupt handling



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Interrupt types

1) Hardware Interrupts
2) Software Interrupts
3) External Interrupts
4) Timer Interrupts
5) Virtual Interrupts

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Timer interrupts types

1) Task Scheduling
2) System time update
3) Operations with precise time

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Interrupt

```cpp
#include <iostream>

int main() {
    std::cout << "Before interrupt." << std::endl;

    // Calling a software interrupt
    asm volatile("int $3");  // Interrupt number 3

    std::cout << "After interrupt." << std::endl;

    return 0;
}
```

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03

Threads

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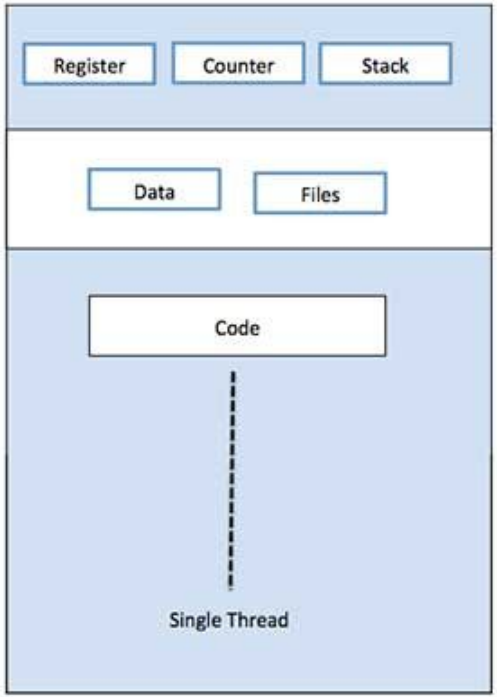
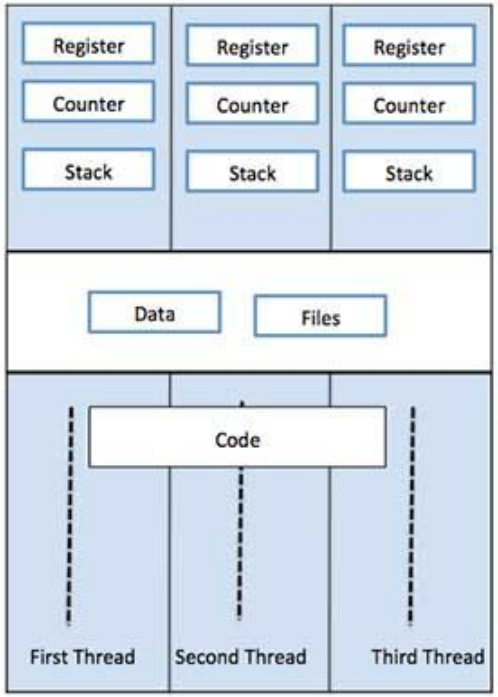
Threads



Single Process P with single thread



Single Process P with three threads

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Process vs Thread

Classification	Process	Threads
Definition	Execution of any program is a process	Segment or subset of a process is a thread
Communication	It takes more time to communicate between the different processes.	It takes less time for the communications
Resources	It consumes more resources	It consumes fewer resources
Memory	The process does not share the memory and is carried out alone	Threads are used to share their memory
Data Sharing	Process does not share their data	Threads share their data
Size	The process consumes more size	Threads are lightweight
Execution error	One process will not affect any other process due to an error	Threads will not run if one thread has an error
Termination time	Process usually takes more time to terminate	Threads take less time to terminate

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Threads code

```cpp
#include <iostream>
#include <thread>

// Function to be executed by the thread
void threadFunction() {
    std::cout << "This is a thread." << std::endl;
}

int main() {
    // Creating a thread object and passing it the function to execute
    std::thread myThread(threadFunction);

    std::cout << "This is the main thread." << std::endl;

    // Waiting for the thread to finish
    myThread.join();

    return 0;
}
```

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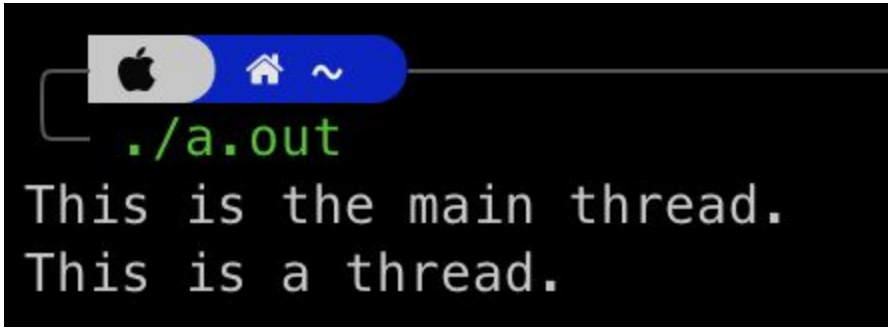
Result



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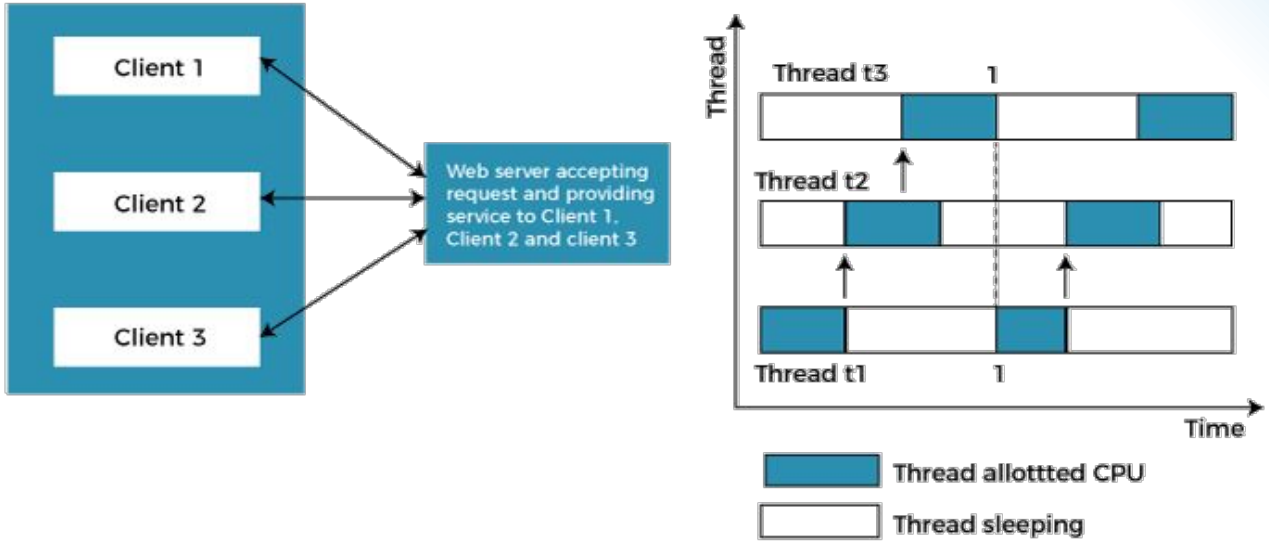
Threads control



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Threads control in OS

1) Creating streams
2) Scheduling flows
3) Context switching
4) Synchronization and interaction
5) Priority Management
6) Ending Flows

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Why we can’t make it simple?

1) Poor use of resources
2) Parallel computing
3) Responsiveness
4) Synchronization and collaboration
5) Multitasking support

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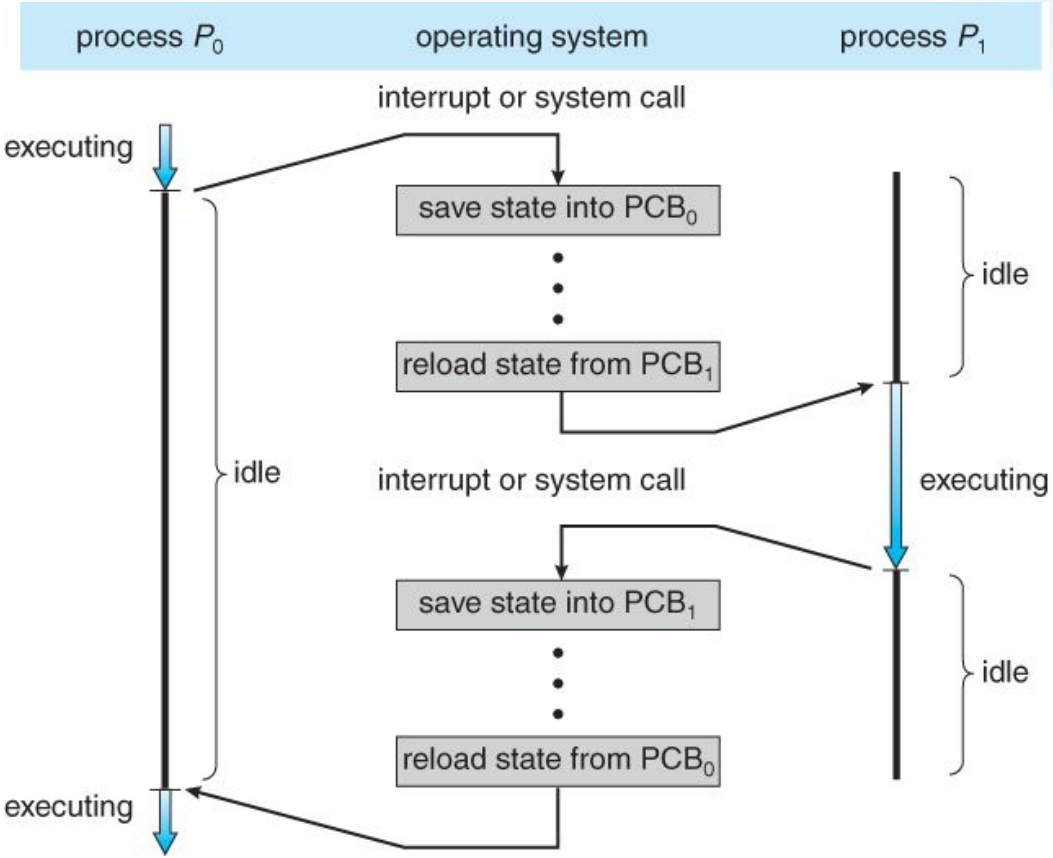
Switching



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How to change task?

1) Cooperative multitasking
2) Interruptions by time interval
3) Event-based interruptions
4) I/O multiplexing

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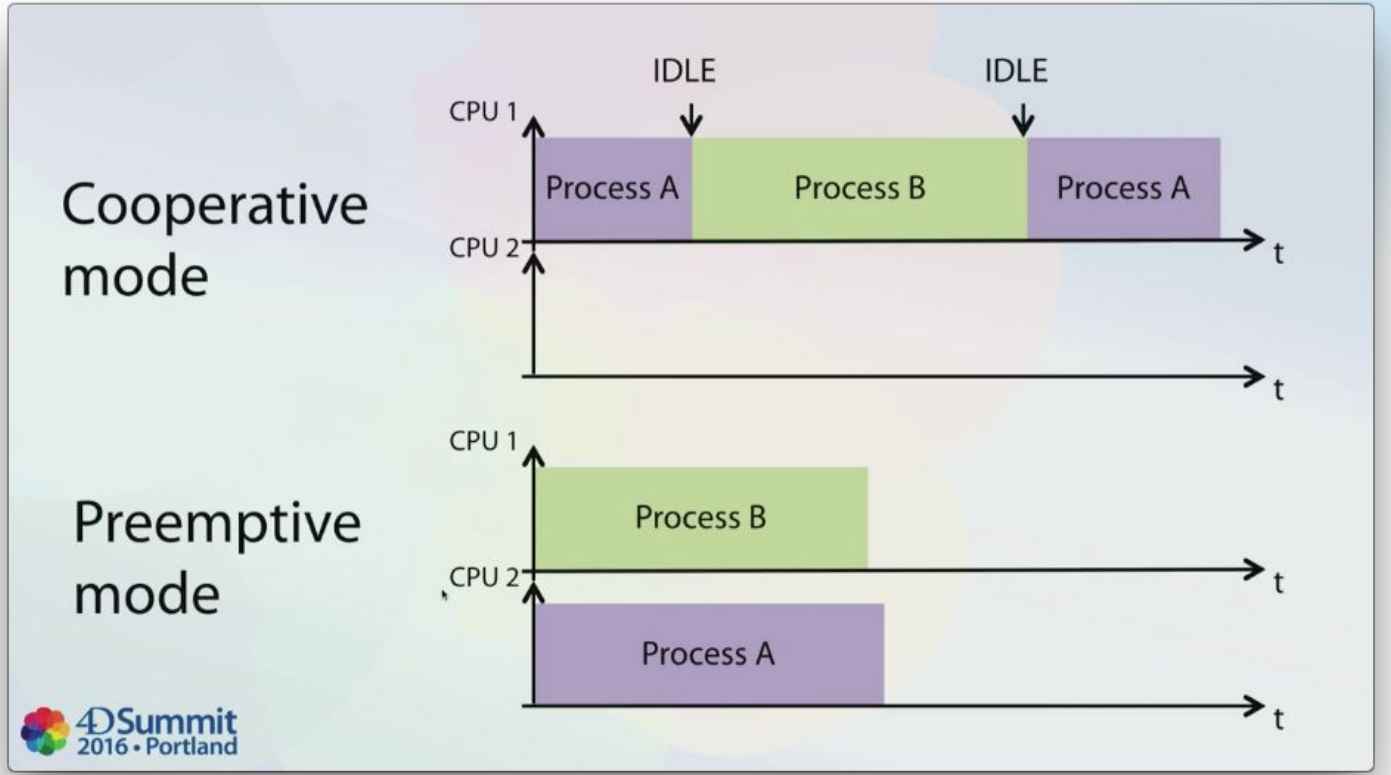
Multitasking



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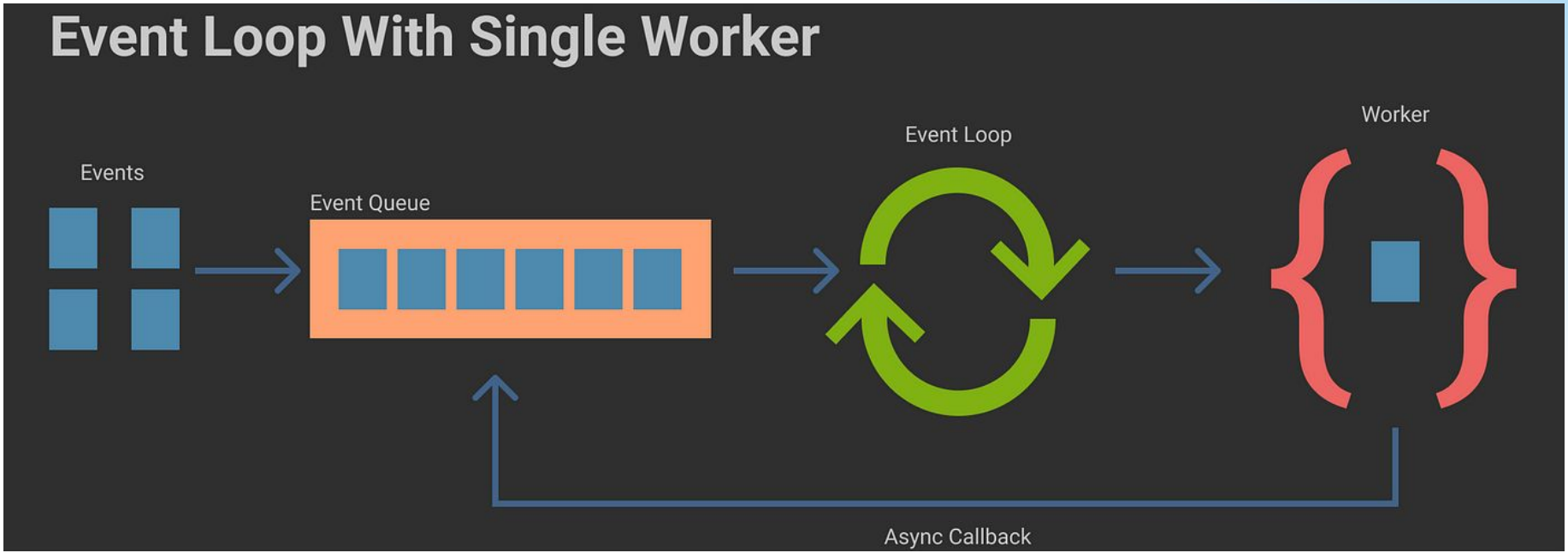
Event loop



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04

Race condition

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Race condition

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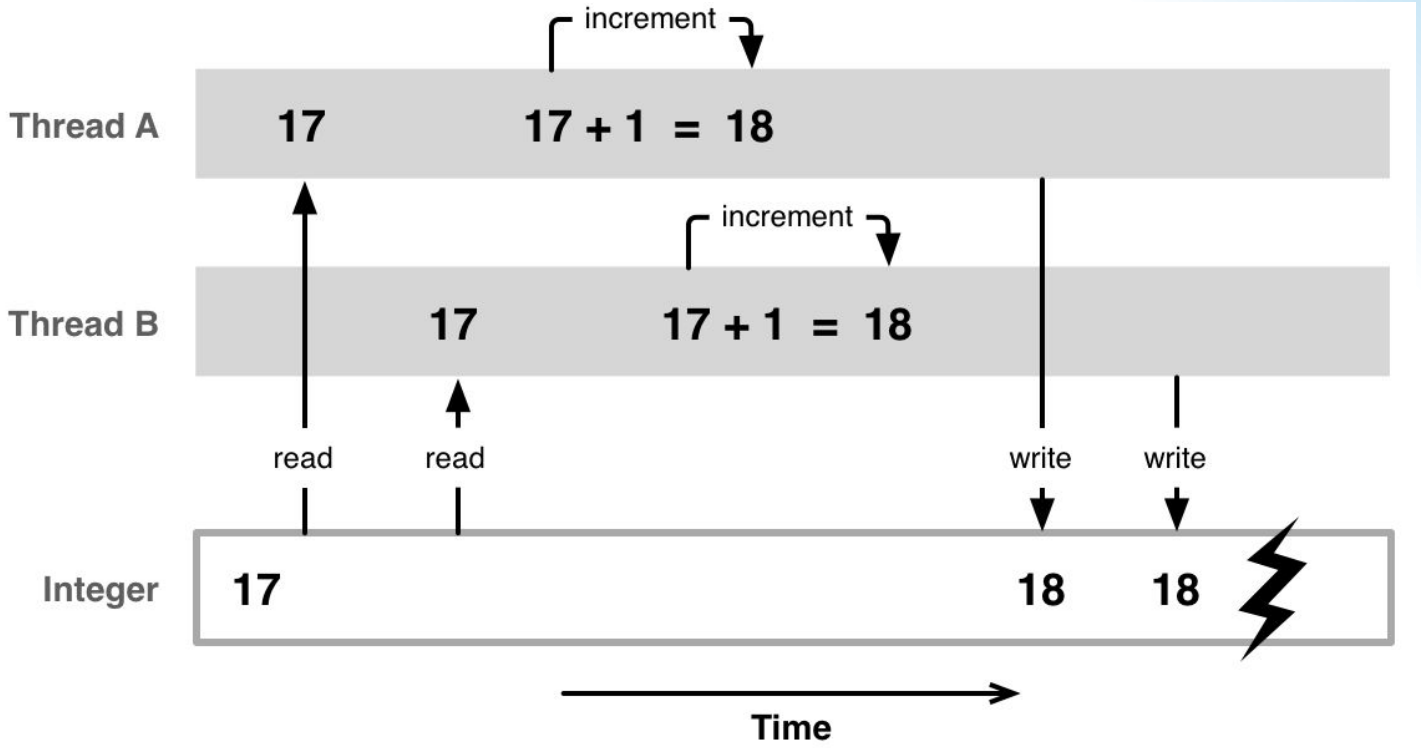
Race condition



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Bug bounty

Most of OAuth 2 API implementations seem to have multiple Race Condition vulnerabilities for processing requests for Access Token or Refresh Token.

Race Condition allows a malicious application to obtain several `access_token` and `refresh_token` pairs while only one pair should be generated. Further, it leads to authorization bypass when access would be revoked.

I've already tested for this vulnerability 11 different targets (web-services providing OAuth2 API), and 6 of them are vulnerable. Only one target seems to be certainly protected (or I just failed to catch into Race Condition time window). The rest 4 targets have Race Condition bug, but protected against further exploitation by one of the following reasons:

- only one of several tokens generated is valid (**1 target**)
- for any access revocation all tokens always are revoked (**1 target**)
- for all concurring requests finished successfully the same `access_token` values (or in pair with `refresh_token`) obtained (**2 targets**)

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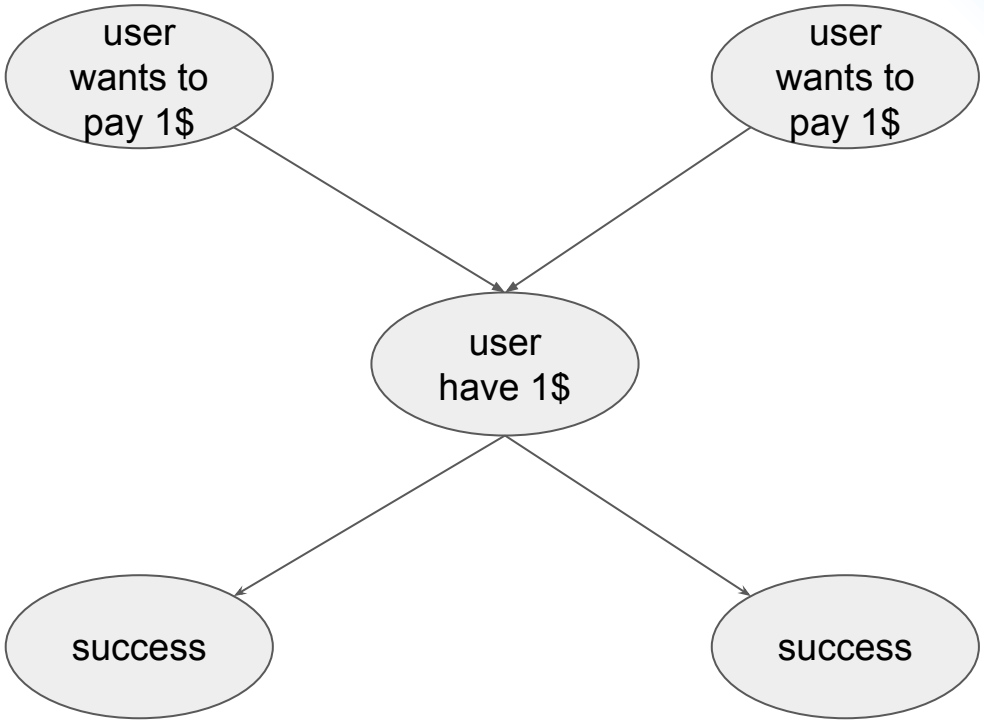
Banking



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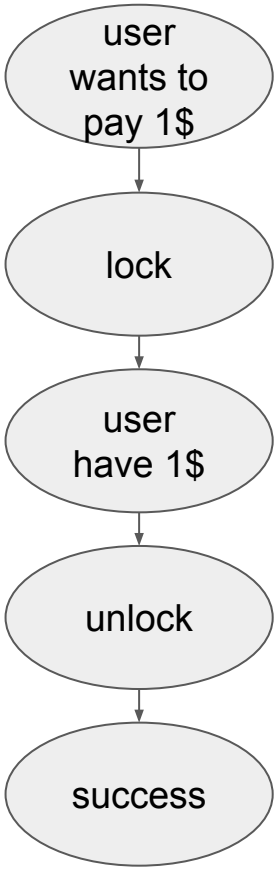
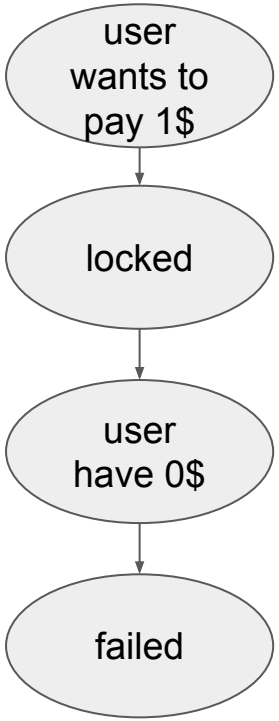
Solution





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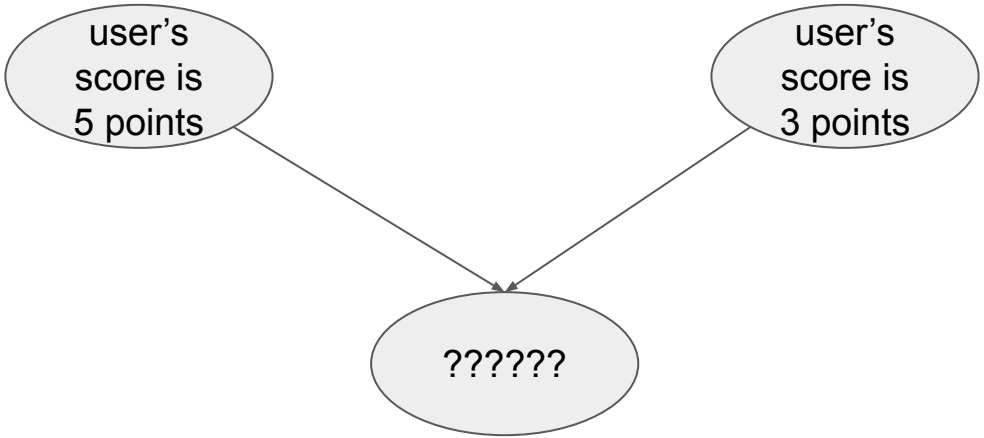
Game



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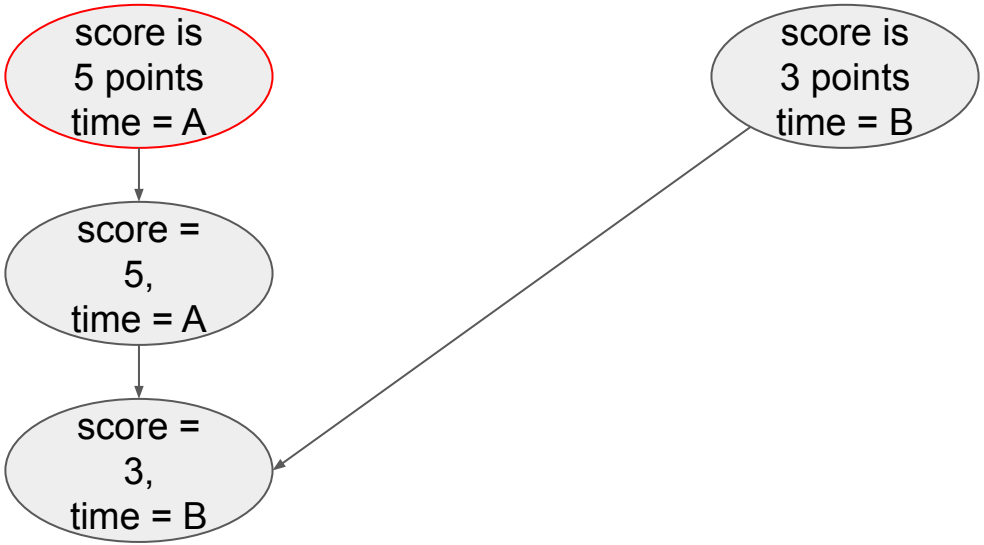
Solution



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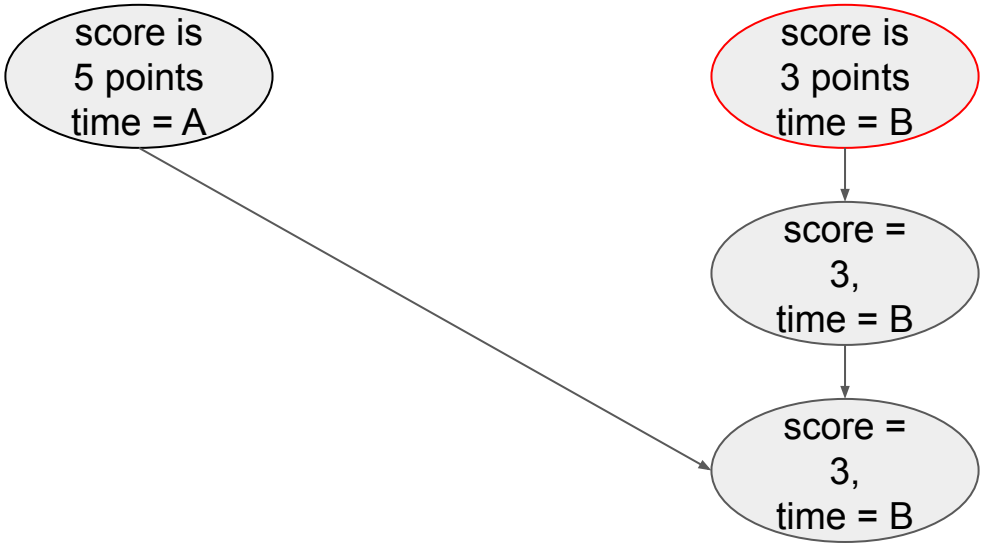
Solution



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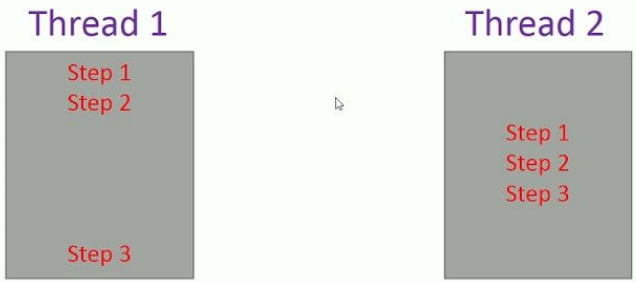
Atomicity

Atomic operation : is an indivisible operation. We cannot observe such an operation half-done from any thread in the system.

i++;

- Step 1 : Read the value of 'i' from memory
- Step 2 : Increment that value by one
- Step 3 : Store the modified value to the memory



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Atomicity

```cpp
#include <atomic>
#include <iostream>
#include <thread>

std::atomic<int> counter; // Atomic variable

void IncrementCounter()
{
    for (int i = 0; i < 1000000; ++i)
    {
        counter.fetch_add(1); // Atomic increment operation
    }
}

int main()
{
    counter = 0;

    std::thread t1(IncrementCounter);
    std::thread t2(IncrementCounter);

    t1.join();
    t2.join();

    std::cout << "Counter value: " << counter << std::endl;

    return 0;
}
```

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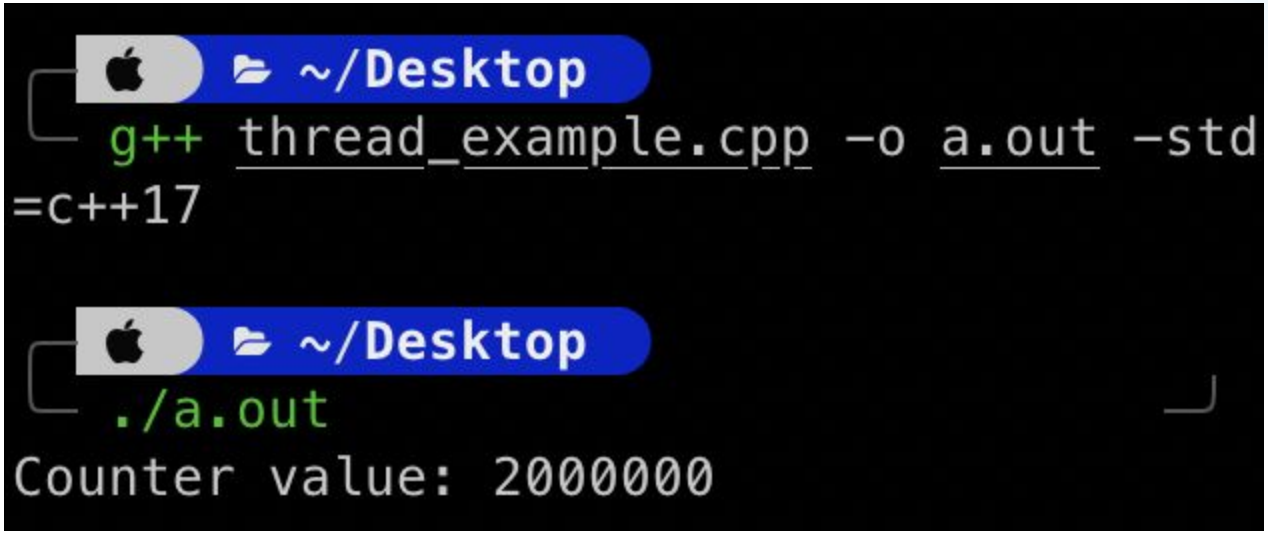
Atomicity



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05

Scheduling

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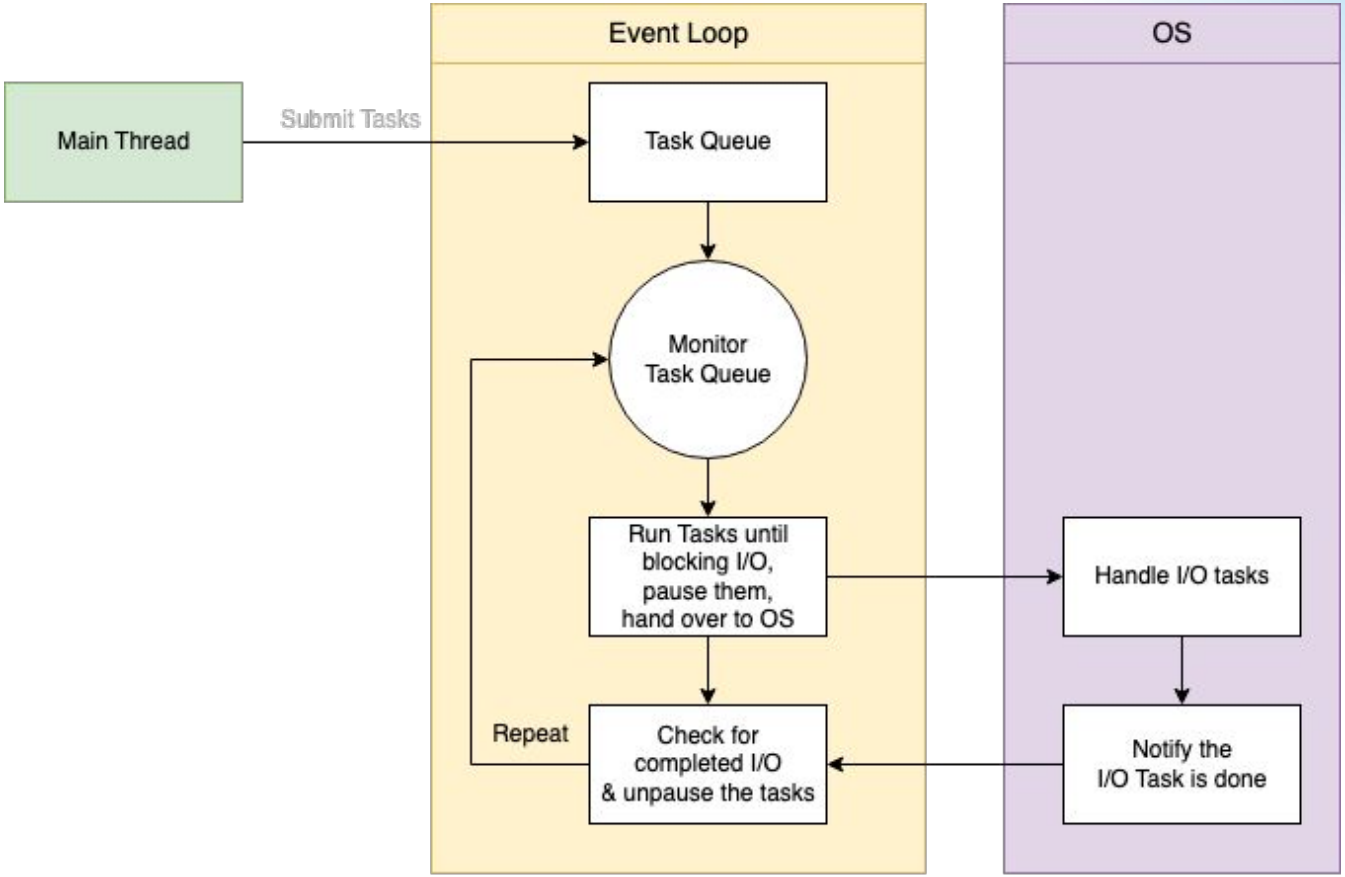
Sheduler



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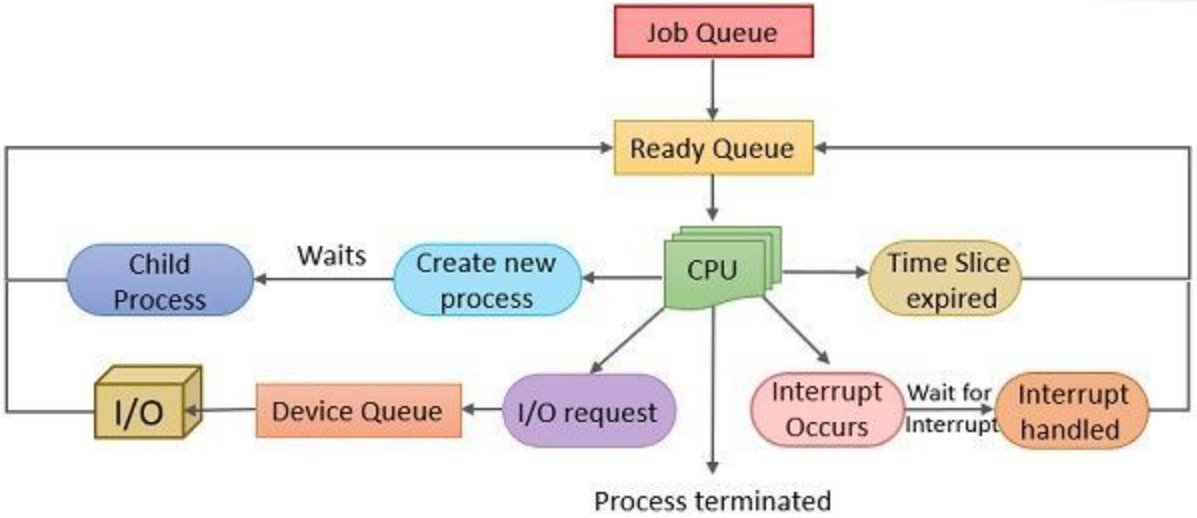
Scheduling



Scheduling Queue in Operating System

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Realizations

1) Round Robin
2) Priority Scheduling
3) Multilevel Queue
4) Earliest Deadline First
5) Adaptive Scheduling

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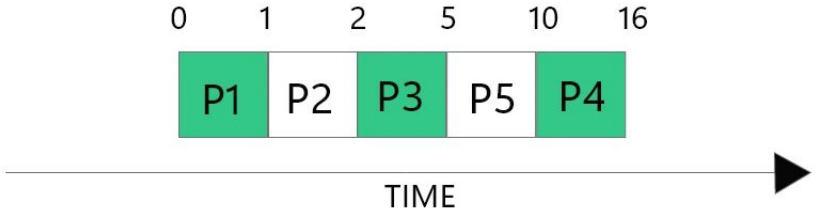
Priority

Priority Scheduling Algorithm

At time t=16ms



Process	P1	P2	P3	P4	P5	P6	P7
Burst Time	1	7	3	6	5	15	8
Priority	2	6	3	5	4	10	9
Arrival Time	0	1	2	3	4	5	15

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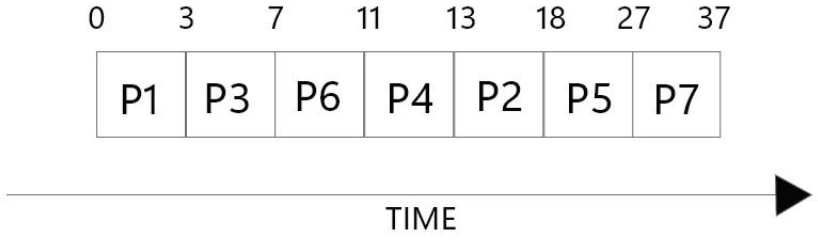
Priority

Priority Scheduling Algorithm



Process	P1	P2	P3	P4	P5	P6	P7
Burst Time	3	5	4	2	9	4	10
Priority	3	6	3	5	7	4	10
Arrival Time	0	2	1	4	6	5	7

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Priority Scheduling

PROS

1. Higher priority - faster solution
2. Scales well

CONS

1. Starvation
2. The demands of good priorities

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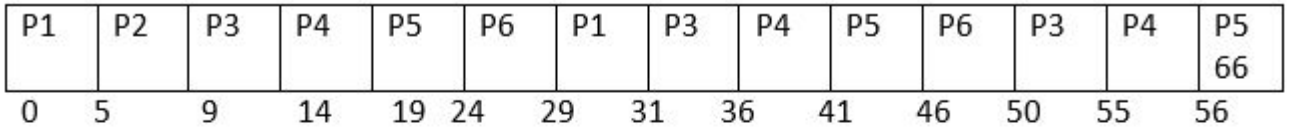
Round-Robin



Process ID	Arrival Time	Burst Time	Completion Time	Turn Around Time	Waiting Time
P1	0	7	31	31	24
P2	1	4	9	8	4
P3	2	15	55	53	38
P4	3	11	56	53	42
P5	4	20	66	62	42
P6	4	9	50	46	37

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Round-Robin

PROS

1. Fair distribution of time
2. Relatively simple implementation
3. Efficient use of CPU resources

CONS

1. Doesn't work well for different work times
2. Additional overhead for context switching between tasks

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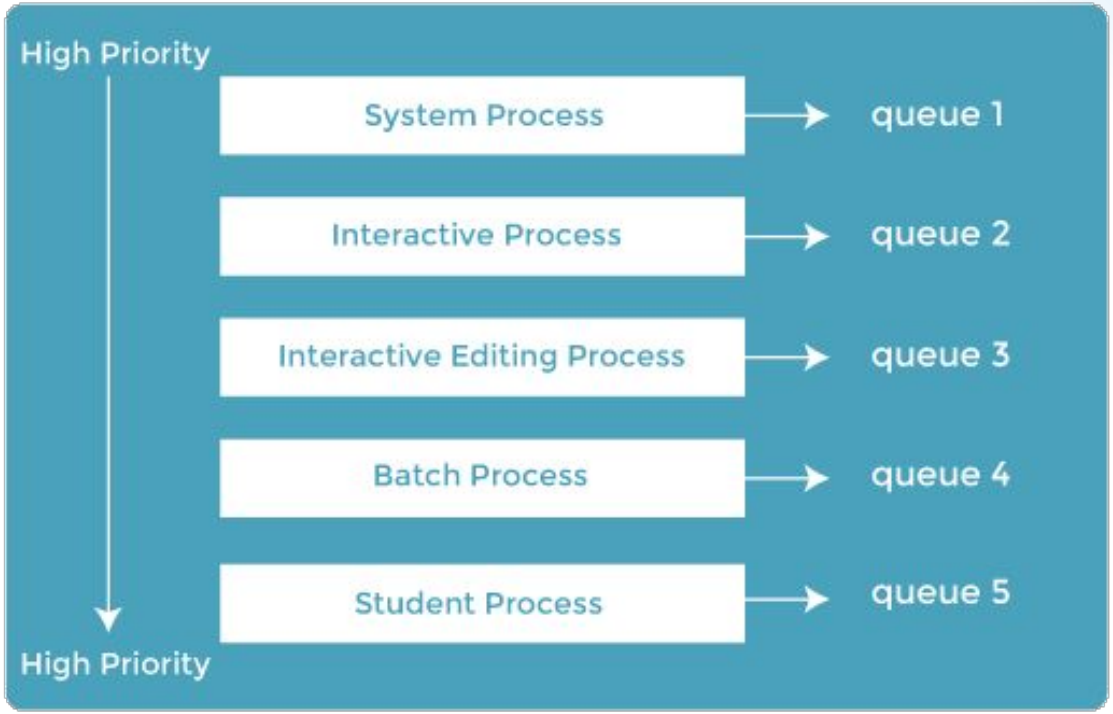
Multilevel Queue



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Multilevel Queue

PROS

1. Balance between different priorities
2. Work differentiation

CONS

1. Starvation
2. A lot of problems with the setup

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06

Fiber

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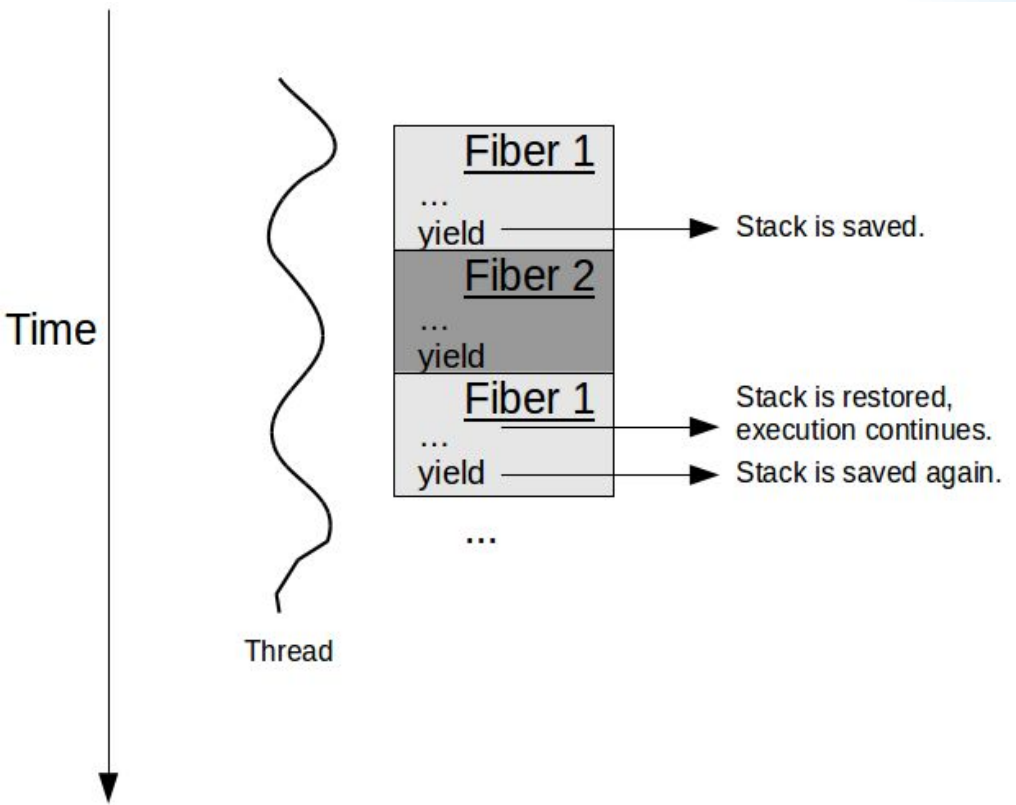
Fiber



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Why do we need fiber

1) Efficient use of CPU resources
2) Competition Management
3) Asynchronous operations
4) Parallel algorithms
5) Flexibility and control

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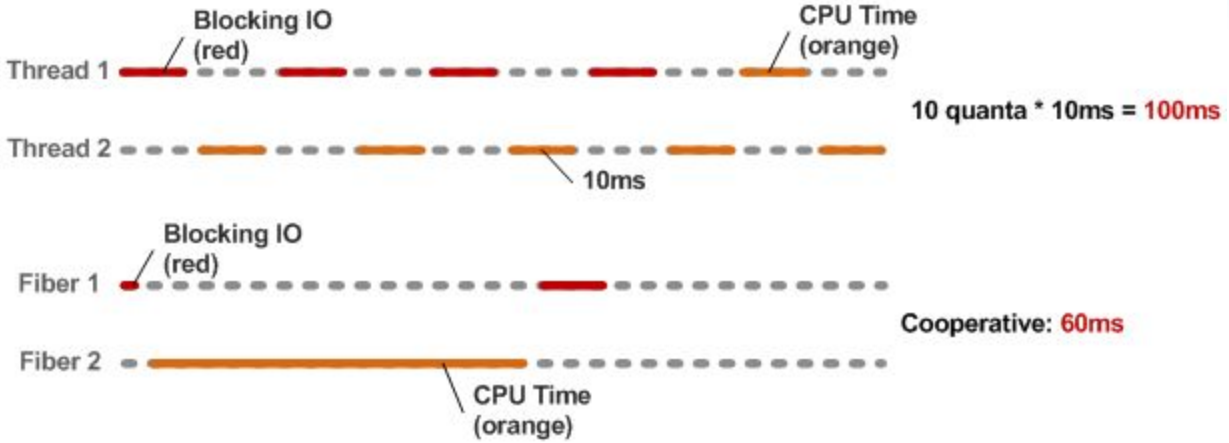
Fiber scheduling



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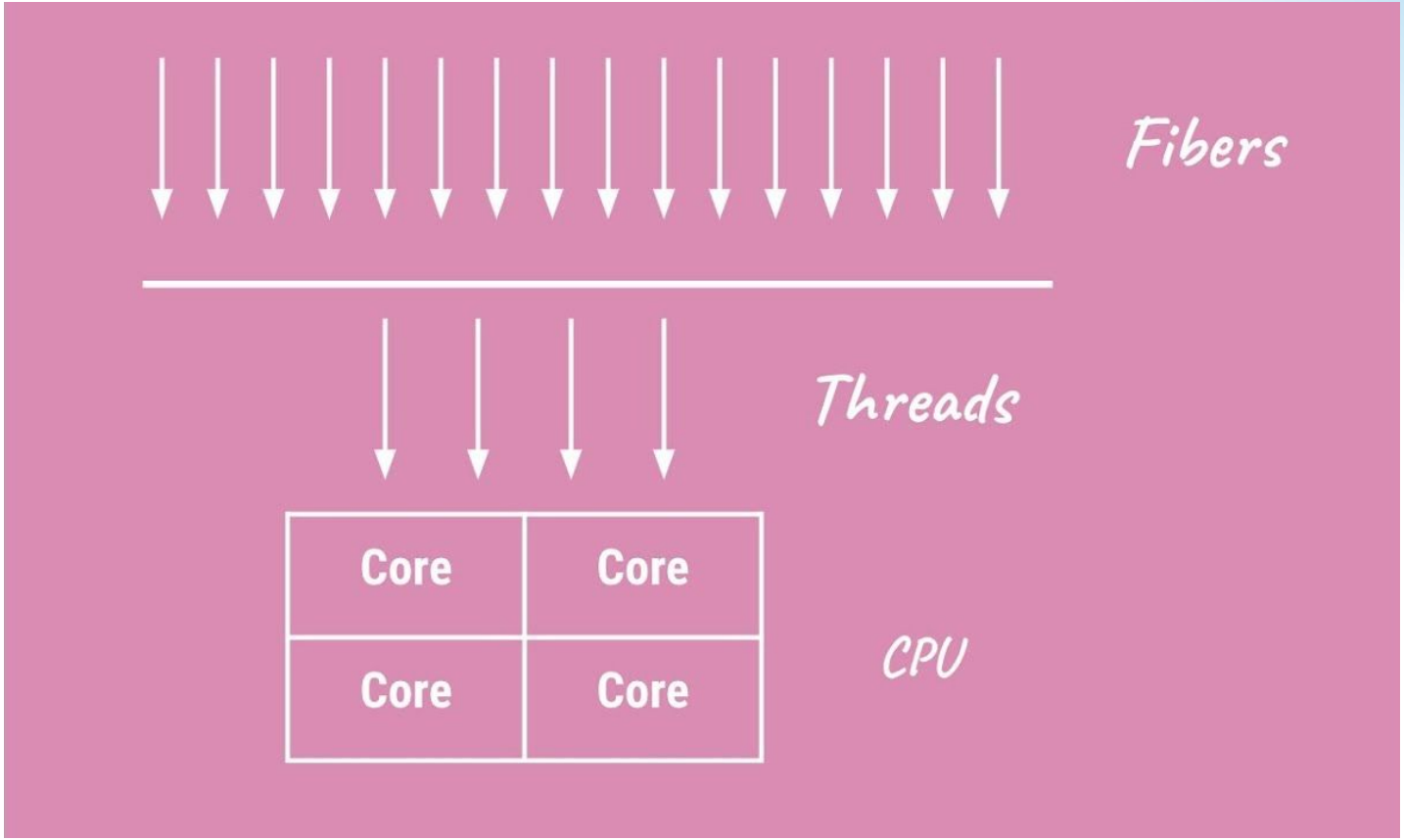
Why fibers better



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07

GIL

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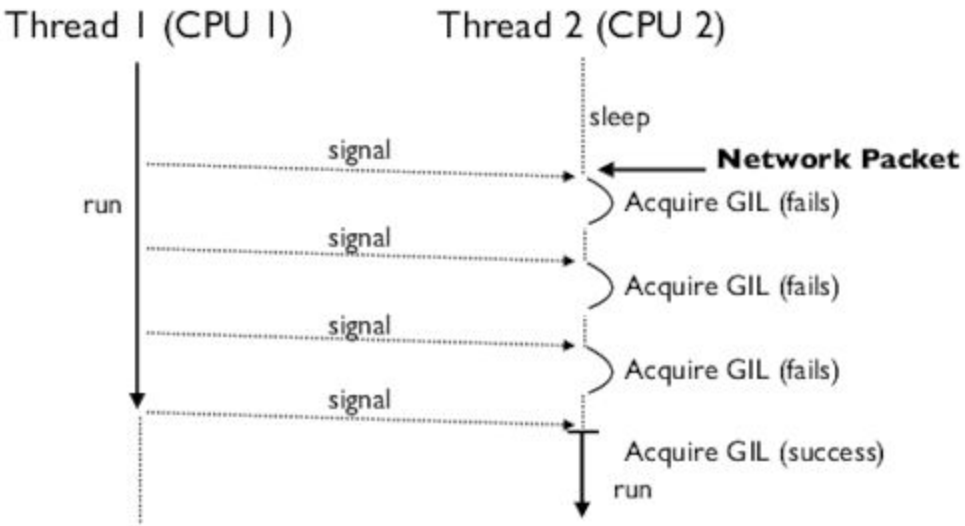
GIL



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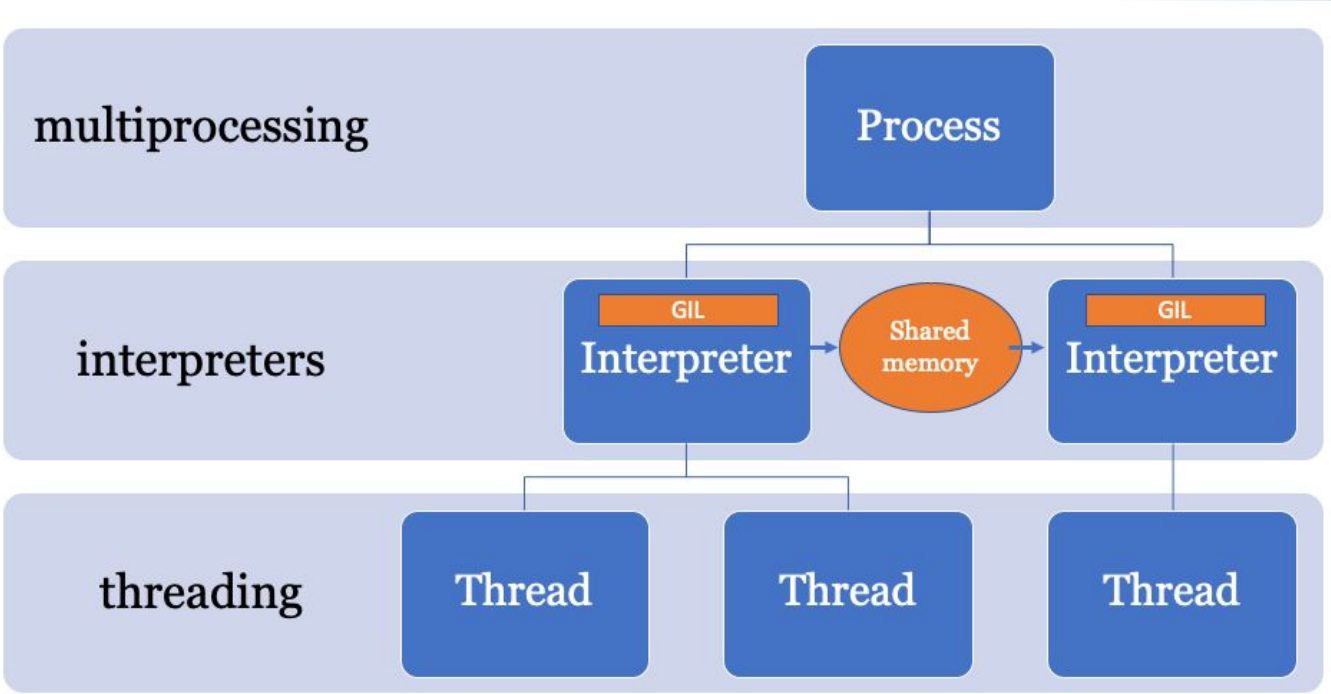
GIL



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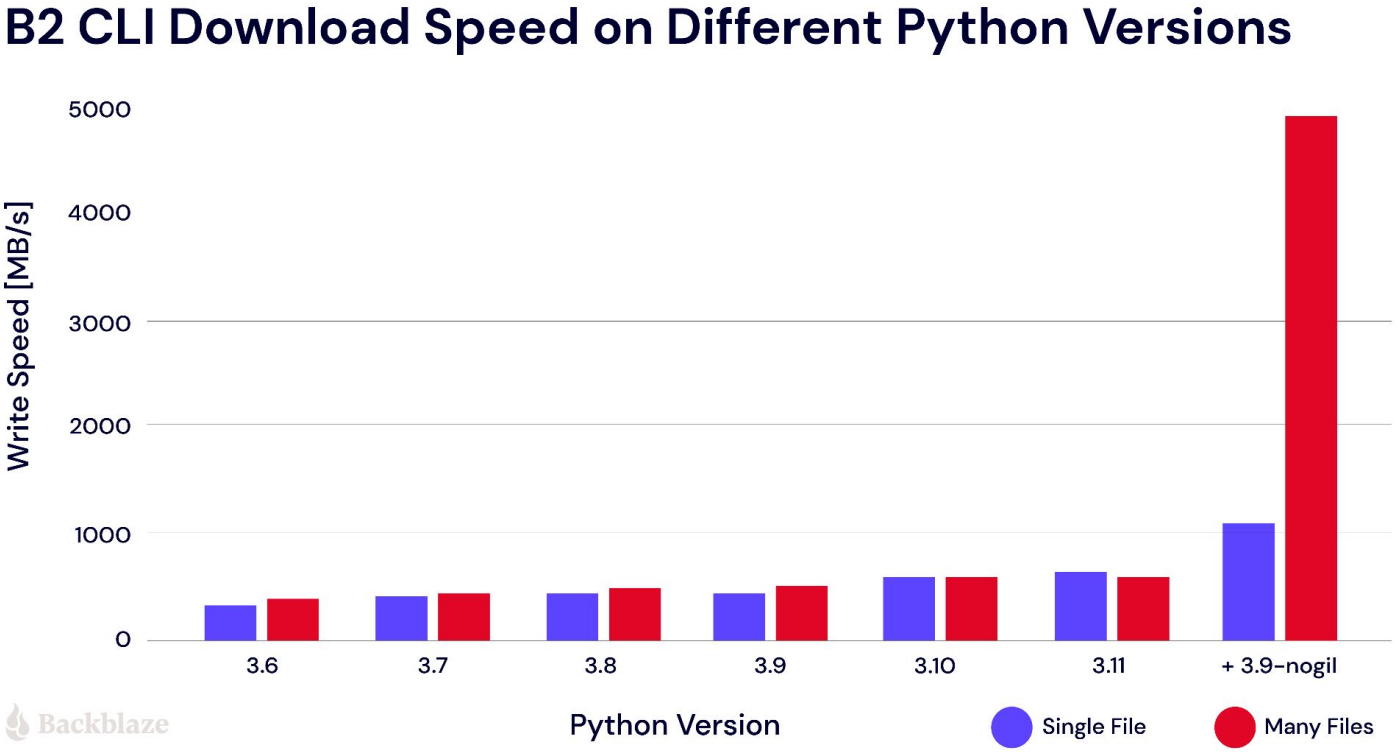
GIL



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*

Good to know

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Join

```cpp
#include <iostream>
#include <thread>

// Function to be executed by the thread
void threadFunction() {
    std::cout << "This is a thread." << std::endl;
}

int main() {
    // Creating a thread object and passing it the function to execute
    std::thread myThread(threadFunction);

    std::cout << "This is the main thread." << std::endl;

    // Waiting for the thread to finish
    myThread.join();

    return 0;
}
```

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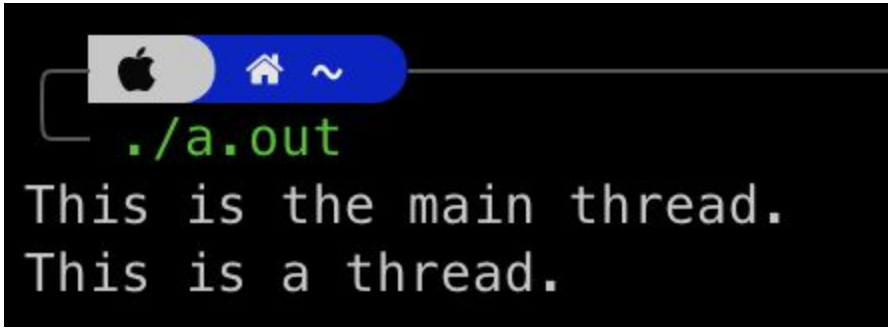
Join



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Forget join

```cpp
#include <iostream>
#include <thread>

// Function to be executed by thread
void threadFunction() {
    std::cout << "This is a thread." << std::endl;
}

int main() {
    // Creating a thread object
    std::thread myThread(threadFunction);

    std::cout << "This is the main thread" << std::endl;

    // Forget to wait
    // myThread.join();

    return 0;
}
```

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Forget join

```
~/Desktop
g++ thread_example.cpp -o a.out

~/Desktop
./a.out
This is the main thread
libc++abi: terminating
This is a thread.
zsh: abort      ./a.out
```

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Why?

```
~thread() _NOEXCEPT
{  // clean up
    if (joinable())
        XSTD terminate();
}
```

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Detach

```cpp
#include <iostream>
#include <thread>

// Function to be executed by thread
void threadFunction() {
    std::cout << "This is a thread." << std::endl;
}

int main() {
    // Creating a thread object
    std::thread myThread(threadFunction);

    std::cout << "This is the main thread" << std::endl;

    // Forget to wait
    myThread.detach();

    return 0;
}
```

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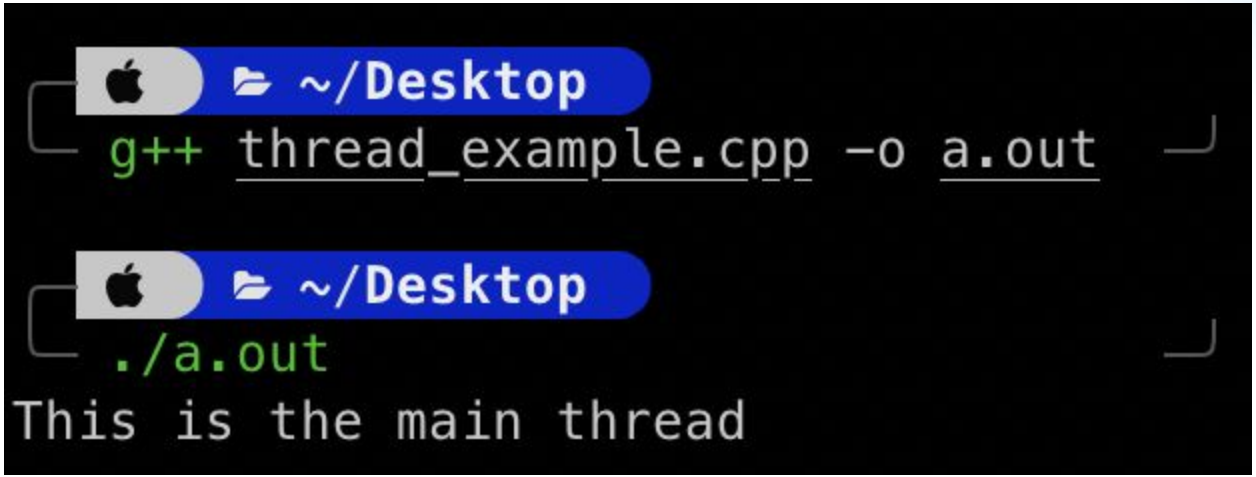
Detach



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Detach

```cpp
#include <iostream>
#include <thread>

// Function to be executed by thread
void threadFunction() {
    std::cout << "This is a thread." << std::endl;
}

int main() {
    // Creating a thread object
    std::thread myThread(threadFunction);

    std::cout << "This is the main thread" << std::endl;

    // Forget to wait
    myThread.detach();
}
```

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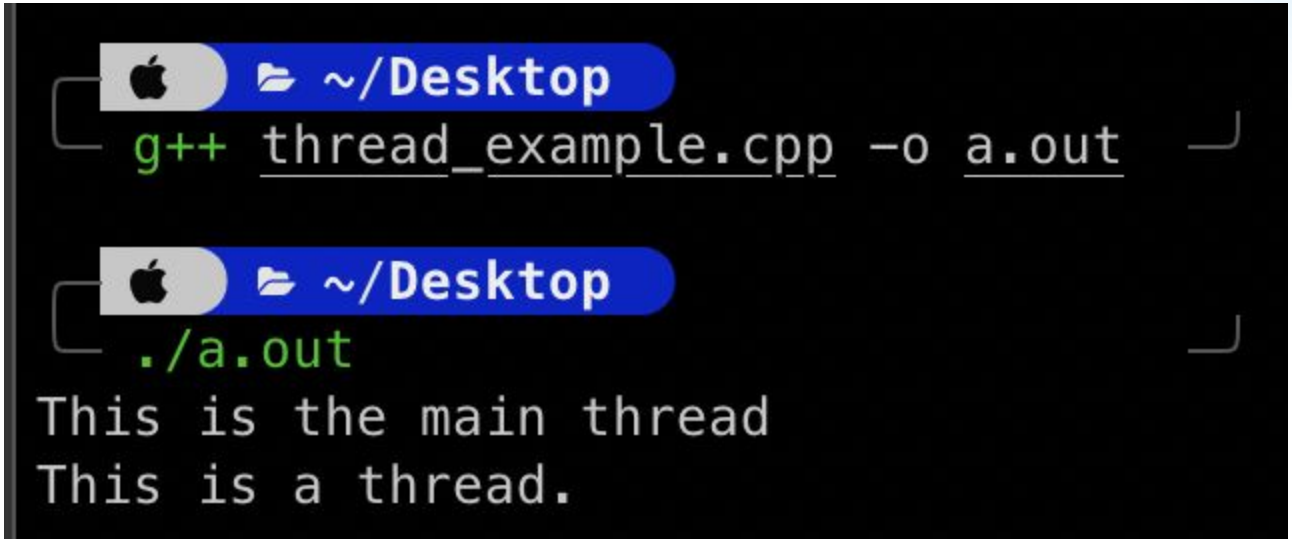
Detach



Join	Detach
1. Wait for the thread, so work longer	1. Don’t wait for the thread, so work faster
2. Wait for the thread, so work stable	2. Don’t wait for the thread, so we need to check that everything is finished

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Simple code

```cpp
#include <string>
#include <thread>
#include <iostream>
#include <functional>

using namespace std;

void ChangeCurrentMissileTarget(string& targetCity)
{
  targetCity = "Metropolis";
  cout << " Changing The Target City To " << targetCity << endl;
}

int main()
{
  string targetCity = "Star City";
  ChangeCurrentMissileTarget(targetCity);

  cout << "Current Target City is " << targetCity << endl;

  return 0;
}
```

Success #stdin #stdout 0.01s 5304KB comments (?)

stdin copy

```
Standard input is empty
```

stdout copy

```
 Changing The Target City To Metropolis
Current Target City is Metropolis
```

source

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Multithreading

edit fork download copy

```cpp
#include <string>
#include <thread>
#include <iostream>
#include <functional>

using namespace std;

void ChangeCurrentMissileTarget(string& targetCity)
{
  targetCity = "Metropolis";
  cout << " Changing The Target City To " << targetCity << endl;
}

int main()
{
  string targetCity = "Star City";
  thread t1(ChangeCurrentMissileTarget, targetCity);
  t1.join();
  cout << "Current Target City is " << targetCity << endl;

  return 0;
}
```

Compilation error #stdin compilation error #stdout 0s 0KB comments (?)

stdin copy

```
Standard input is empty
```

compilation info

```
In file included from prog.cpp:2:
/usr/include/c++/8/thread: In instantiation of 'std::thread::thread(_Callable&&, _Args&& ...) [wit
h _Callable = void (&)(std::__cxx11::basic_string<char>&); _Args = {std::__cxx11::basic_string<cha
r, std::char_traits<char>, std::allocator<char> >&}; <template-parameter-1-3> = void]':
prog.cpp:17:51:   required from here
/usr/include/c++/8/thread:120:17: error: static assertion failed: std::thread arguments must be in
vocable after conversion to rvalues
```

[source]

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Correct

```cpp
#include <string>
#include <thread>
#include <iostream>
#include <functional>

using namespace std;

void ChangeCurrentMissileTarget(string& targetCity)
{
  targetCity = "Metropolis";
  cout << " Changing The Target City To " << targetCity << endl;
}

int main()
{
  string targetCity = "Star City";
  thread t1(ChangeCurrentMissileTarget, std::ref(targetCity));
  t1.join();
  cout << "Current Target City is " << targetCity << endl;

  return 0;
}
```

Success #stdin #stdout 0.01s 5304KB

stdin

```
Standard input is empty
```

stdout

```
 Changing The Target City To Metropolis
Current Target City is Metropolis
```

source

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Possible reasons

1. Security
2. Easy realization
3. More independence to threads

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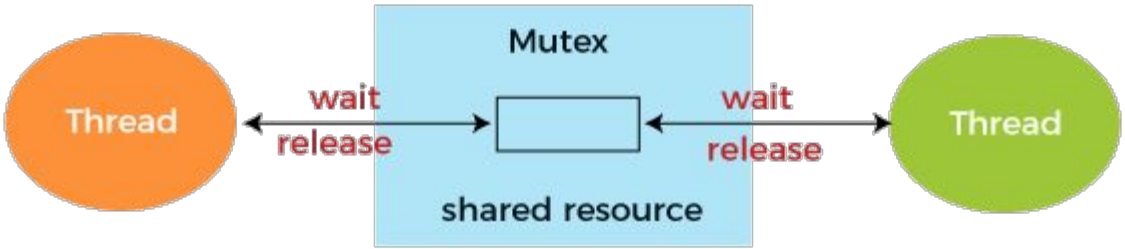
Mutex



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Mutex usage

```cpp
#include <mutex>
#include <thread>
#include <iostream>

std::mutex mtx; // Create a mutex object

void PrintMessage(const std::string& message)
{
    mtx.lock();
    // Critical section where the thread works with shared data
    std::cout << message << std::endl;
    mtx.unlock();
    // make something without mutex
}

int main()
{
    std::thread t1(PrintMessage, "Hello from Thread 1");
    std::thread t2(PrintMessage, "Hello from Thread 2");

    t1.join();
    t2.join();

    mtx.unlock(); // Release the mutex

    return 0;
}
```

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Mutex usage

```
~/Desktop
g++ thread_example.cpp -o a.out -std=c++17

~/Desktop
./a.out
Hello from Thread 1
Hello from Thread 2
```

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Mistake

```cpp
#include <mutex>
#include <thread>
#include <iostream>

std::mutex mtx; // Create a mutex object

void PrintMessage(const std::string& message)
{
    mtx.lock();
    // Critical section where the thread works with shared data
    std::cout << message << std::endl;
    // mtx.unlock();
    // make something without mutex
}

int main()
{
    std::thread t1(PrintMessage, "Hello from Thread 1");
    std::thread t2(PrintMessage, "Hello from Thread 2");

    t1.join();
    t2.join();

    mtx.unlock(); // Release the mutex

    return 0;
}
```

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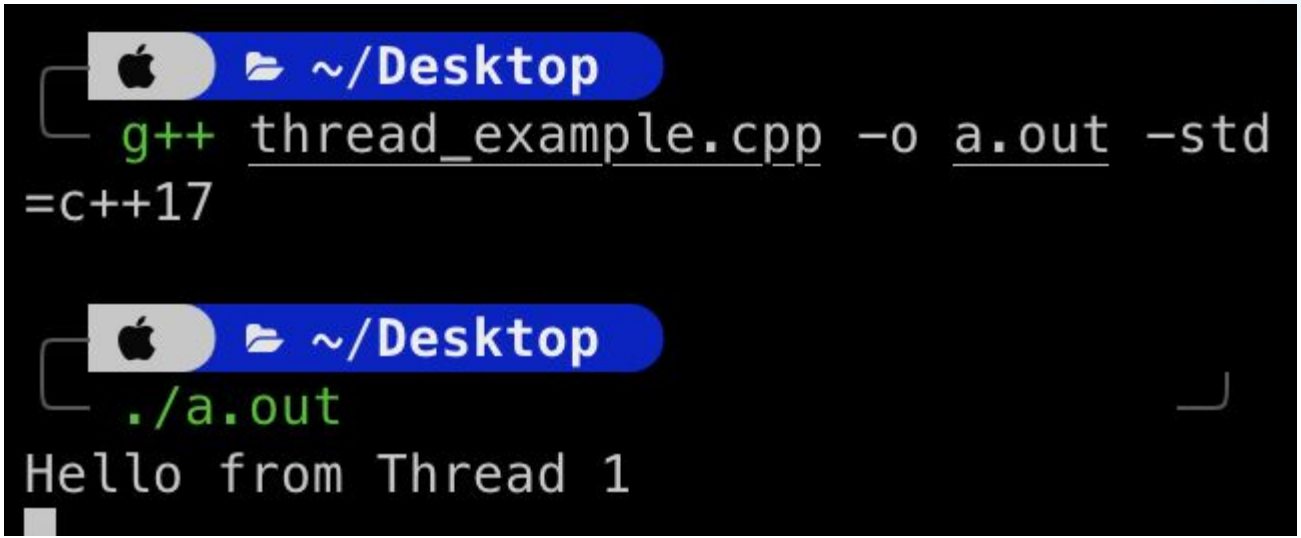
Mistake



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With guard

```cpp
#include <mutex>
#include <thread>
#include <iostream>

std::mutex mtx; // Create a mutex object

void PrintMessage(const std::string& message)
{
    std::lock_guard<std::mutex> lock(mtx); // Acquire the mutex
    // Critical section where the thread works with shared data
    std::cout << message << std::endl;
    // The mutex is automatically released when the lock_guard goes out of scope
}

int main()
{
    std::thread t1(PrintMessage, "Hello from Thread 1");
    std::thread t2(PrintMessage, "Hello from Thread 2");

    t1.join();
    t2.join();

    return 0;
}
```

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With guard

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Comparison

lock/unlock	lock_guard
1. Worry about unlock 2. Can work less time because of good unlock	1. Don’t worry about unlock 2. Can work more time because of bad unlock

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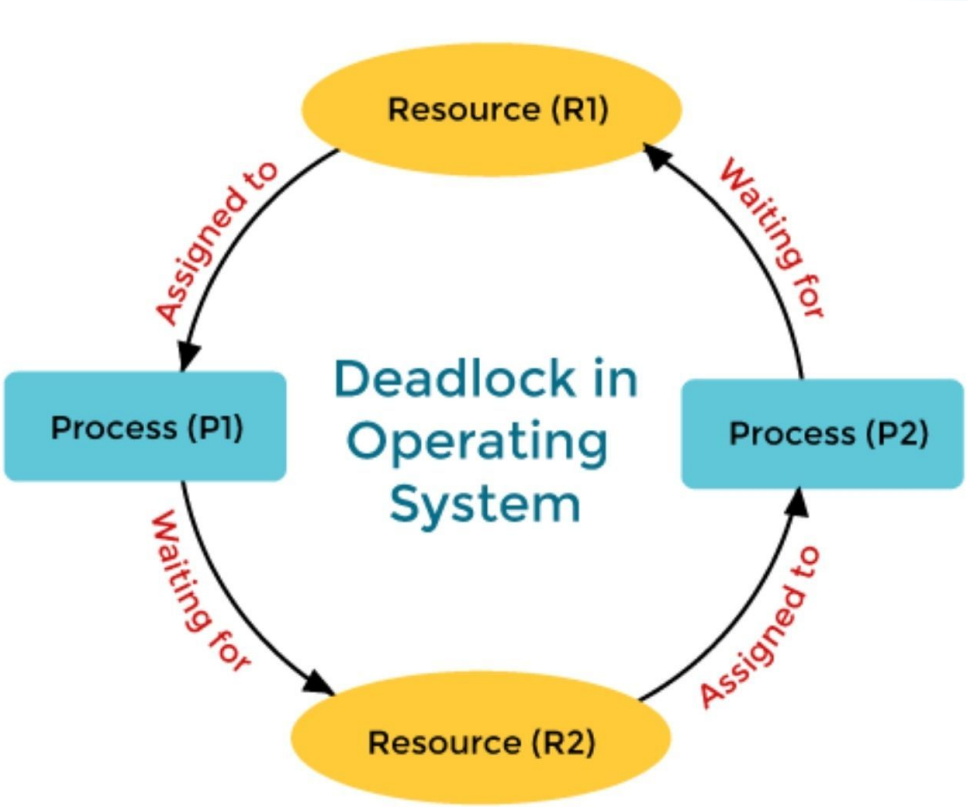
Deadlock



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Deadlock

```cpp
#include <iostream>
#include <string>
#include <thread>
#include <mutex>

using namespace std;

std::mutex muA;
std::mutex muB;

void CallHome_Th1(string message)
{
    muA.lock();
    std::this_thread::sleep_for(std::chrono::milliseconds(100));
    muB.lock();

    cout << "Thread " << this_thread::get_id() << " says " << message << endl;

    muB.unlock();
    muA.unlock();
}

void CallHome_Th2(string message)
{
    muB.lock();
    std::this_thread::sleep_for(std::chrono::milliseconds(100));
    muA.lock();

    cout << "Thread " << this_thread::get_id() << " says " << message << endl;

    muA.unlock();
    muB.unlock();
}

int main()
{
  thread t1(CallHome_Th1, "Hello from Jupiter");
  thread t2(CallHome_Th2, "Hello from Pluto");

  t1.join();
  t2.join();

  return 0;
}
```

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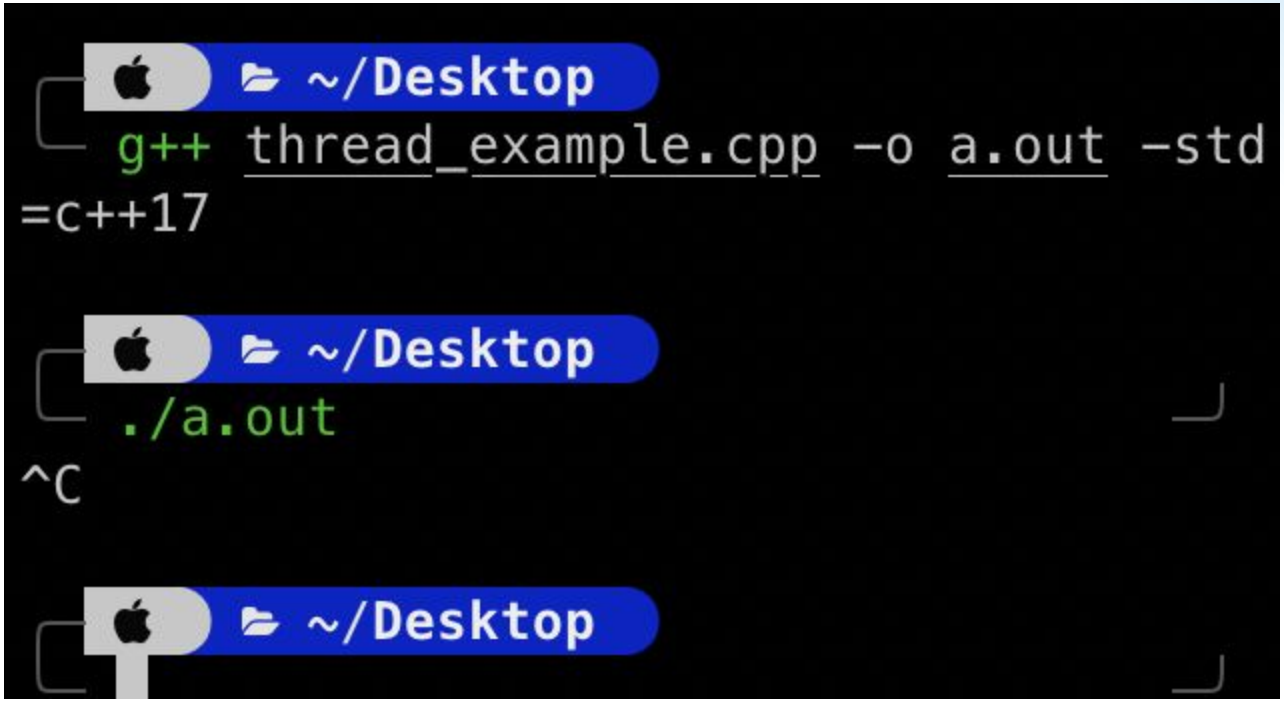
Deadlock



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That's All Folks!