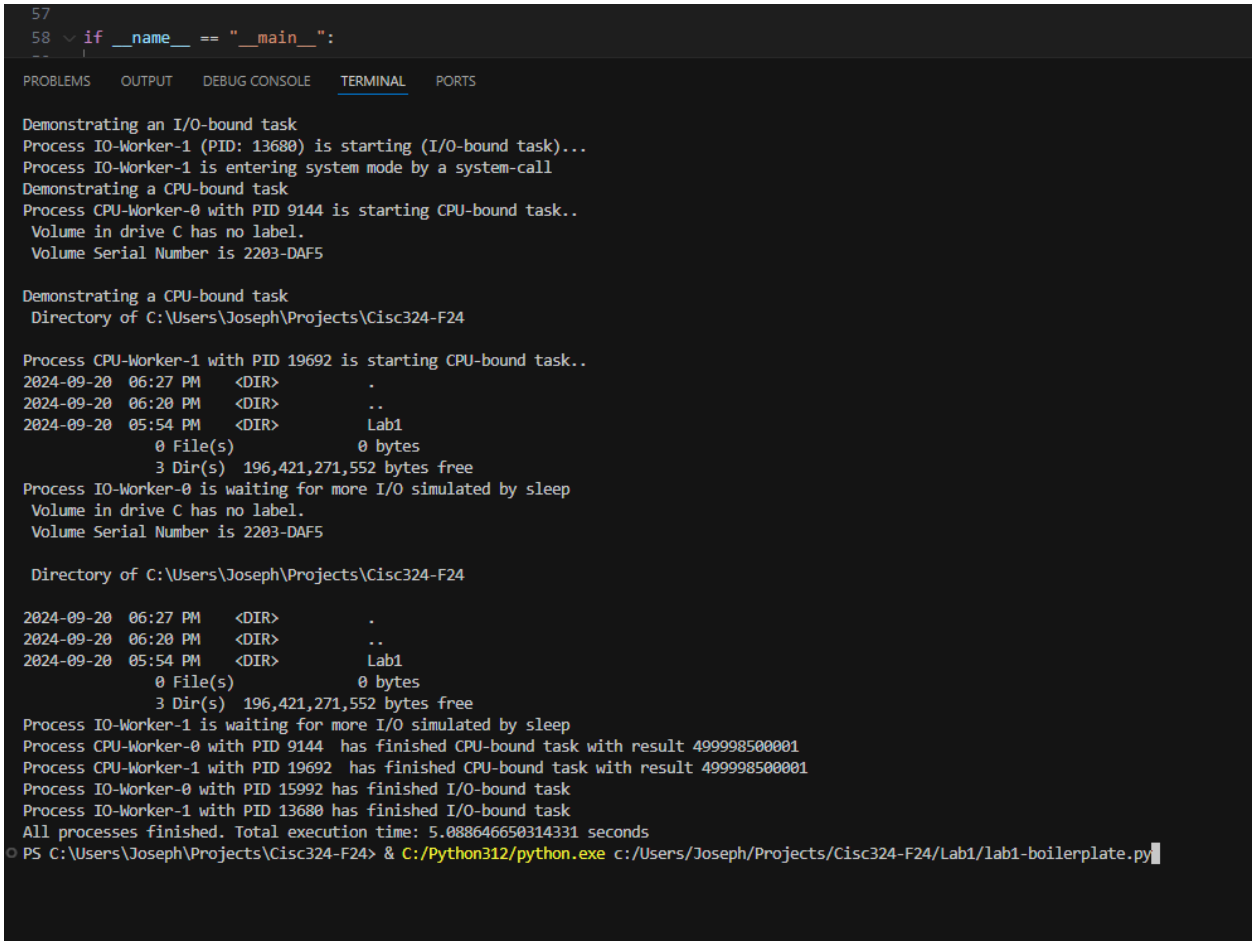
Question 1: After implementing the full code, answer whenever you see the directory content immediately after an I/O bound process starts. Why or why not? Justify. Provide a screenshot of program output. Write your answer in a file named lab1.pdf.

Yes, the directory content is printed immediately after the I/O-bound process starts. This is because the I/O-bound process uses a system call.



Question 2:
In the current example, the I/O-bound tasks simulate waiting for I/O by a fixed time delay. Can you modify the code to simulate I/O completion dynamically, where the completion time for I/O-bound tasks varies with each run (i.e., random I/O delays)? Execute the updated program and report the outcome in the same file as above.

Using the random library I set the time delay to a random variable between 1-13 which simulates random I/O delays:

```python
    # After system call, simulate additional I/O wait time
    # TODO-2:
    print(f"Process {name} is waiting for more I/O simulated by sleep")

    random_io_delay = random.uniform(1, 13)

    time.sleep(random_io_delay)
    print(f"Process {name} with PID {os.getpid()} has finished I/O-bound task")

    # 4- Print "Process {name} is waiting for more I/O simulated by sleep"
```

RESULT:

```
PS C:\Users\Joseph\Projects\Cisc324-F24> & C:/Python312/python.exe c:/Users/Joseph/Projects/Cisc324-F24/Lab1/lab1-boilerplate.py
Demonstrating an I/O-bound task
Process IO-Worker-0 (PID: 6460) is starting (I/O-bound task)...
Process IO-Worker-0 is entering system mode by a system-call
Demonstrating an I/O-bound task
Process IO-Worker-1 (PID: 21276) is starting (I/O-bound task)...
Process IO-Worker-1 is entering system mode by a system-call
Demonstrating a CPU-bound task
Process CPU-Worker-0 with PID 4392 is starting CPU-bound task..
Demonstrating a CPU-bound task
 Volume in drive C has no label.
Process CPU-Worker-1 with PID 31140 is starting CPU-bound task..
 Volume Serial Number is 2203-DAF5

 Directory of C:\Users\Joseph\Projects\Cisc324-F24

2024-09-20  06:27 PM    <DIR>          .
2024-09-20  06:20 PM    <DIR>          ..
2024-09-20  05:54 PM    <DIR>          Lab1
               0 File(s)              0 bytes
               3 Dir(s)  196,420,374,528 bytes free
 Volume in drive C has no label.
Process IO-Worker-0 is waiting for more I/O simulated by sleep
 Volume Serial Number is 2203-DAF5

 Directory of C:\Users\Joseph\Projects\Cisc324-F24

2024-09-20  06:27 PM    <DIR>          .
2024-09-20  06:20 PM    <DIR>          ..
2024-09-20  05:54 PM    <DIR>          Lab1
               0 File(s)              0 bytes
               3 Dir(s)  196,420,374,528 bytes free
Process IO-Worker-1 is waiting for more I/O simulated by sleep
Process CPU-Worker-0 with PID 4392  has finished CPU-bound task with result 499998500001
Process CPU-Worker-1 with PID 31140  has finished CPU-bound task with result 499998500001
Process IO-Worker-0 with PID 6460 has finished I/O-bound task
Process IO-Worker-1 with PID 21276 has finished I/O-bound task
All processes finished. Total execution time: 10.541388988494873 seconds
PS C:\Users\Joseph\Projects\Cisc324-F24>
```

Question 3: Can you modify the code to measure and display the CPU usage of both CPU-bound and I/O-bound tasks? How does CPU utilization change when running more CPU-bound processes compared to I/O-bound processes? Hint. Modify the code to use psutil.cpu_percent(interval=1) or another method to measure CPU utilization for the entire program, and compare the CPU usage for different types of tasks. Record the output in the same file as above.

```
 Directory of C:\Users\Joseph\Projects\Cisc324-F24

2024-09-20  06:40 PM    <DIR>          .
2024-09-20  06:20 PM    <DIR>          ..Demonstrating a CPU-bound task

Process CPU-Worker-1 with PID 13816 is starting CPU-bound task..
2024-09-20  06:40 PM    <DIR>          .venv
2024-09-20  05:54 PM    <DIR>          Lab1
               0 File(s)              0 bytes
               4 Dir(s)  196,028,030,976 bytes free
Process IO-Worker-0 is waiting for more I/O simulated by sleep
 Volume in drive C has no label.
 Volume Serial Number is 2203-DAF5

 Directory of C:\Users\Joseph\Projects\Cisc324-F24

2024-09-20  06:40 PM    <DIR>          .
2024-09-20  06:20 PM    <DIR>          ..
2024-09-20  06:40 PM    <DIR>          .venv
2024-09-20  05:54 PM    <DIR>          Lab1
               0 File(s)              0 bytes
               4 Dir(s)  196,028,030,976 bytes free
Process IO-Worker-1 is waiting for more I/O simulated by sleep
Process CPU-Worker-0 with PID 4760 has finished CPU-bound task with result 499998500
Process CPU-Worker-1 with PID 13816 has finished CPU-bound task with result 49999850
Process IO-Worker-1 with PID 19788 has finished I/O-bound task
Process IO-Worker-0 with PID 21292 has finished I/O-bound task
Final CPU usage: 1.1%
All processes finished. Total execution time: 6.876247406005859 seconds
PS C:\Users\Joseph\Projects\Cisc324-F24>
```

```
Initial CPU usage: 0.6%
CPU usage after I/O-bound tasks: 0.5%
CPU usage after CPU-bound tasks: 0.6%
Total execution time: 15.952975273132324 seconds
```

CPU bound tasks increase CPU usage.

Question 4: What happens if you dramatically increase the number of CPU-bound or I/O-bound processes? How does the program's total execution time and CPU utilization change? Report the output in the same file as above.

CPU BOUND RESULTS:

2 Processes

```
Demonstrating a CPU-bound task
Process CPU-Worker-1 with PID 15028 is starting CPU-bound task..
Process CPU-Worker-0 with PID 3716 has finished CPU-bound task with result 499998500001
Process CPU-Worker-1 with PID 15028 has finished CPU-bound task with result 499998500001
CPU usage after CPU-bound tasks: 0.9%
Final CPU usage: 0.5%
All processes finished. Total execution time: 9.21359896659851 seconds
PS C:\Users\Joseph\Projects\Cisc324-F24>
```

20 Processes

```
Process CPU-Worker-13 with PID 29584 has finished CPU-bound task with result 499998500001
Process CPU-Worker-15 with PID 21768 has finished CPU-bound task with result 499998500001
Process CPU-Worker-14 with PID 27852 has finished CPU-bound task with result 499998500001
Demonstrating a CPU-bound task
Process CPU-Worker-19 with PID 29840 is starting CPU-bound task..
Process CPU-Worker-16 with PID 7192 has finished CPU-bound task with result 499998500001
Process CPU-Worker-18 with PID 13796 has finished CPU-bound task with result 499998500001
Process CPU-Worker-17 with PID 26084 has finished CPU-bound task with result 499998500001
Process CPU-Worker-19 with PID 29840 has finished CPU-bound task with result 499998500001
CPU usage after CPU-bound tasks: 0.2%
Final CPU usage: 2.2%
All processes finished. Total execution time: 9.359914541244507 seconds
PS C:\Users\Joseph\Projects\Cisc324-F24>
```

Changed from 2 to 20 processes CPU usage increased execution time is around the same

IO BOUND RESULTS:

2 Processes

```
Process CPU-Worker-0 with PID 23320 has finished CPU-bound task with result 499998500001
Process CPU-Worker-1 with PID 26528 has finished CPU-bound task with result 499998500001
CPU usage after CPU-bound tasks: 1.2%
Final CPU usage: 0.7%
All processes finished. Total execution time: 9.207788228988647 seconds
PS C:\Users\Joseph\Projects\Cisc324-F24>
```

20 Processes

```
CPU usage after I/O-bound tasks: 0.2%
Demonstrating a CPU-bound task
Process CPU-Worker-0 with PID 21520 is starting CPU-bound task..
Demonstrating a CPU-bound task
Process CPU-Worker-1 with PID 32424 is starting CPU-bound task..
Process CPU-Worker-0 with PID 21520 has finished CPU-bound task with result 499998500001
Process CPU-Worker-1 with PID 32424 has finished CPU-bound task with result 499998500001
CPU usage after CPU-bound tasks: 0.4%
Final CPU usage: 0.7%
All processes finished. Total execution time: 9.396578311920166 seconds
PS C:\Users\Joseph\Projects\Cisc324-F24>
```

Little to no change on cpu usage