Concurrent Programming (Part 4)

Robert M. Dondero, Ph.D.
Princeton University

Objectives

- We will cover:
  - Environment variables
  - Realistic example: I/O delays
  - Realistic example: compute delays
  - The Python GIL
  - Concurrency commentary

Agenda

- **Environment variables**
- Realistic example: I/O delays
- Realistic example: compute delays
- The Python GIL
- Concurrency commentary

Environment Vars

- ***Environment variables***
  - Each process has a set of environment vars
    - PATH=...
    - SHELL=...
    - QUERY_STRING=...
    - …
  - Each child process inherits the environment vars of its parent process

Environment Vars

In the Bash shell (on Linux or Mac):

```
$ export SOMEVAR=somevalue
```

```
$ printenv
$ printenv SOMEVAR
$ echo $SOMEVAR
```

Environment Vars

In a Command Prompt window (on MS Windows):

```
C:\>set SOMEVAR=somevalue
```

```
C:\>echo %SOMEVAR%
```

Environment Vars

In Python:

```
import os
…
os.environ['SOMEVAR'] = somevalue
```

```
import os
…
somevalue = os.environ['SOMEVAR']
somevalue = os.environ.get('SOMEVAR', default)
```

Environment Vars

- **Question**:
  - How can a Python process accept data from its user?
- **Answers**:
  - By reading it (from stdin, a file, a socket, or a pipe)
  - Through a command-line argument
  - Through an **environment variable**

Environment Vars

- See **envvar1.py**

```
$ unset GREETING
$ python envvar1.py
hi
$
```

In the bash shell (Mac/Linux):

```
$ export GREETING=hello
$ python envvar1.py
hello
$
```

In a Command Prompt window (MS Windows):

```
$ set GREETING=hello
$ python envvar1.py
hello
$
```

Environment Vars

- The Python ***dotenv*** module
  - Python-specific mechanism for setting/getting env vars
  - To install:

```
$ python -m pip install python-dotenv
```

Environment Vars

- The Python ***dotenv*** module (cont.)
  - To use in Python code (step 1)

.env file:

```
SOMEVAR=somevalue
…
```

Environment Vars

- The Python ***dotenv*** module (cont.)
  - To use in Python code (step 2)

.py file:

```
import dotenv
…
dotenv.load_dotenv()
SOME_VAR = os.environ.get('SOMEVAR', default)
…
```

(1) Looks for SOMEVAR as env var; if not found…
(2) Looks for SOMEVAR in .env file, if not found…
(3) Uses default

Environment Vars

- See **.env**, **envvar2.py**

```
$ export GREETING=bonjour
$ python envvar2.py
bonjour
$
```

```
$ unset GREETING
$ python envvar2.py
hello
$
```

```
$ rm .env
$ python envvar2.py
hi
$
```

Agenda

- Environment variables
- **Realistic example: I/O delays**
- Realistic example: compute delays
- The Python GIL
- Concurrency commentary

Realistic Example: I/O Delays

- See **DaytimeIODelay** application
  - Almost same as DayTime app from *Network Programming* lectures
  - **daytimeclient.py**
  - **daytimeserver.py**
    - Enhanced to implement **iodelay**
      - Delay caused by waiting for another service (e.g., database)

Realistic Example: I/O Delays

See **DaytimeIODelay** app:

```
$ date
Wed Sep 25 13:23:52 EDT 2024
$
```

```
$ python daytimeclient.py localhost 55555
Wed Sep 25 13:23:58 2024
$
```

```
$ python daytimeclient.py localhost 55555
Wed Sep 25 13:24:03 2024
$
```

```
$ python daytimeclient.py localhost 55555
Wed Sep 25 13:24:08 2024
$
```

```
$ export IODELAY=5
$ python daytimeserver.py 55555
Opened server socket
Bound server socket to port
Listening
Accepted connection
Opened socket
Closed socket
Accepted connection
Opened socket
Closed socket
Accepted connection
Opened socket
Closed socket
```

Realistic Example: I/O Delays

- See **DaytimeIODelayP**
  - daytimeclient.py
  - **daytimeserver.py**
    - Forks a new process to handle each client request

Realistic Example: I/O Delays

See **DaytimeIODelayP** app:

```
$ date
Wed Sep 25 13:25:48 EDT 2024
$
```

```
$ python daytimeclient.py localhost 55555
Wed Sep 25 13:25:54 2024
$
```

```
$ python daytimeclient.py localhost 55555
Wed Sep 25 13:25:55 2024
$
```

```
$ python daytimeclient.py localhost 55555
Wed Sep 25 13:25:55 2024
$
```

```
$ export IODELAY=5
$ python daytimeserver 55555
Opened server socket
Bound server socket to port
Listening
Accepted connection
Opened socket
Closed socket in parent process
Forked child process
Closed socket in child process
Exiting child process
Accepted connection
Opened socket
Closed socket in parent process
Forked child process
Closed socket in child process
Exiting child process
Accepted connection
Opened socket
Closed socket in parent process
Forked child process
Closed socket in child process
Exiting child process
```

Aside: Waiting in Python

```
Parent process forks child process
Parent process waits for child process
```

Proper pattern

```
Parent process forks child process
Parent process proceeds
Child process exits
Parent process receives SIGCHLD signal
Parent process waits for child process
```

Alternative proper pattern

```
Parent process forks child process
Parent process proceeds
Parent process forks child process
```

Acceptable in Python

Realistic Example: I/O Delays

- See **DaytimeIODelayT**
  - daytimeclient.py
  - **daytimeserver.py**
    - Spawns a new thread to handle each client request

Realistic Example: I/O Delays

See **DaytimeIODelayT** app:

```
$ date
Wed Sep 25 13:27:01 EDT 2024
$
```

```
$ python daytimeclient.py localhost 55555
Wed Sep 25 13:27:06 2024
$
```

```
$ python daytimeclient.py localhost 55555
Wed Sep 25 13:27:07 2024
$
```

```
$ python daytimeclient.py localhost 55555
Wed Sep 25 13:27:07 2024
$
```

```
$ export IODELAY=5
$ python daytimeserver.py 55555
Opened server socket
Bound server socket to port
Listening
Accepted connection
Opened socket
Spawned child thread
Closed socket in child thread
Exiting child thread
Accepted connection
Opened socket
Spawned child thread
Closed socket in child thread
Exiting child thread
Accepted connection
Opened socket
Spawned child thread
Closed socket in child thread
Exiting child thread
```

Agenda

- Environment variables
- Realistic example: I/O delays
- **Realistic example: compute delays**
- The Python GIL
- Concurrency commentary

Realistic Example: Compute Delays

- See **DaytimeCDelay** application
  - [Almost same as DayTime app from *Network Programming* lectures]
  - daytimeclient.py
  - **daytimeserver.py**
    - Enhanced to implement **cdelay**
      - Delay caused by performing a time-consuming computation (e.g., matrix manipulation)
-

Realistic Example: Compute Delays

See **DaytimeCDelay** app:

```
$ date
Wed Sep 25 13:40:48 EDT 2024
$
```

```
$ python daytimeclient.py localhost 55555
Wed Sep 25 13:40:54 2024
$
```

```
$ python daytimeclient.py localhost 55555
Wed Sep 25 13:40:59 2024
$
```

```
$ python daytimeclient.py localhost 55555
Wed Sep 25 13:41:04 2024
$
```

```
$ export CDELAY=5
$ python daytimeserver.py 55555
Opened server socket
Bound server socket to port
Listening
Accepted connection
Opened socket
Closed socket
Accepted connection
Opened socket
Closed socket
Accepted connection
Opened socket
Closed socket
```

Realistic Example: Compute Delays

- See **DaytimeCDelayP**
  - daytimeclient.py
  - **daytimeserver.py**
    - Forks a new process to handle each client request

Realistic Example: Compute Delays

See **DaytimeCDelayP** app:

```
$ date
Wed Sep 25 13:42:13 EDT 2024
$
```

```
$ python daytimeclient.py localhost 55555
Wed Sep 25 13:42:18 2024
$
```

```
$ python daytimeclient.py localhost 55555
Wed Sep 25 13:42:19 2024
$
```

```
$ python daytimeclient.py localhost 55555
Wed Sep 25 13:42:19 2024
$
```

```
$ export CDELAY=5
$ python daytimeserver.py 55555
Opened server socket
Bound server socket to port
Listening
Accepted connection
Opened socket
Closed socket in parent process
Forked child process
Closed socket in child process
Exiting child process
Accepted connection
Opened socket
Closed socket in parent process
Forked child process
Closed socket in child process
Exiting child process
Accepted connection
Opened socket
Closed socket in parent process
Forked child process
Closed socket in child process
Exiting child process
```

Realistic Example: Compute Delays

- See **DaytimeCDelayT**
  - daytimeclient.py
  - **daytimeserver.py**
    - Spawns a new thread to handle each client request

Realistic Example: Compute Delays

See **DaytimeCDelayT** app:

```
$ date
Wed Sep 25 13:45:09 EDT 2024
$
```

```
$ python daytimeclient.py localhost 55555
Wed Sep 25 13:45:24 2024
$
```

```
$ python daytimeclient.py localhost 55555
Wed Sep 25 13:45:23 2024
$
```

```
$ python daytimeclient.py localhost 55555
Wed Sep 25 13:45:24 2024
$
```

```
$ export CDELAY=5
$ python daytimeserver.py 55555
Opened server socket
Bound server socket to port
Listening
Accepted connection
Opened socket
Spawned child thread
Closed socket in child thread
Exiting child thread
Accepted connection
Opened socket
Spawned child thread
Closed socket in child thread
Exiting child thread
Accepted connection
Opened socket
Spawned child thread
Closed socket in child thread
Exiting child thread
```

What!!! Why???

Agenda

- Environment variables
- Realistic example: I/O delays
- Realistic example: Compute delays
- **The Python GIL**
- Concurrency commentary

The Python GIL

- Suppose process has threads T1 and T2
- In **principle**:
  - Multiple processors available =>
    T1 and T2 run in parallel
- In **Java** and **C/pthread**:
  - Multiple processors available =>
    T1 and T2 run in parallel

The Python GIL

- In **Python** (specifically **CPython**):
  - Multiple processors available =>
    T1 and T2 **do not** run in parallel!!!
  - ***Global Interpreter Lock (GIL)***
    - Allows only one of P1's threads to execute at a time…
    - As if only one processor exists

The Python GIL

- GIL advantages
  - Simplifies Python memory management (reference counting)
- GIL disadvantage
  - Multi-threaded programs can use only one processor (at a time)
    - Multiple threads cannot run in parallel

The Python GIL

- So, in Python…

Kind of Program	Example	Then use:
I/O-bound	Program waits for DB comm to complete	**Thread**-level concurrency
Compute-bound	Program performs complex math computation	**Process**-level concurrency *

* But better not to use Python at all!

Agenda

- Environment variables
- Realistic example: I/O delays
- Realistic example: compute delays
- The Python GIL
- **Concurrency commentary**

Concurrency Commentary

- **Process**-level concurrency is:
  - **Essential**, esp. at system level
  - **Safe**: concurrent processes share no data
  - **Slow**: forking processes is slow
- **Thread**-level concurrency is:
  - **Essential**, esp. at application level
  - **Dangerous**: concurrent threads can share objects => potential race conditions, potential deadlocks
  - **Fast**: spawning threads is fast

Concurrency Commentary

- Some rhetorical questions:
  - Should all objects automatically be thread-safe?
    - Should all fields automatically be private and all methods automatically be “locked”?

> **“It is astounding to me that Java’s insecure parallelism is taken seriously by the programming community, a quarter of a century after the invention of monitors and Concurrent Pascal. It has no merit.”**
> -- Per Brinch Hansen, 1999

Concurrency Commentary

- Some rhetorical questions (cont.):
  - Should methods be “locked” by default?
  - Should we use process-level concurrency instead of thread-level concurrency whenever possible?
  - In the long run, is thread-level concurrency a passing phase?

Concurrency Resources

- For more information:
  - Alex Martelli, Anna Ravenscroft, and Steve Holden. *Python in a Nutshell*, Chapter 14.
  - Cay Horstmann. *Core Java (Volume 1)*, Chapter 14.
  - And then OS textbooks

Summary

- We have covered:
  - Environment variables
  - Realistic example: I/O delays
  - Realistic example: compute delays
  - The Python GIL
  - Concurrency commentary

Summary

- We have covered:
  - How to fork and wait for processes
  - How to spawn and join threads
  - Race conditions and how to avoid them
  - Environment variables
  - Realistic example
  - The Python GIL
  - Commentary
- See also:
  - **Appendix 1**: Deadlocks

Appendix 1: Deadlocks

Deadlocks

- **Problem:** ***Deadlock***
  - Simplest case…
  - Thread1
    - Has the lock on object1
    - Needs the lock on object2
  - Thread2
    - Has the lock on object2
    - Needs the lock on object1
  - Thread1 and thread2 block forever

Deadlocks

- See **deadlock.py**
  - alice_acct: 0
  - bob_acct: 0
  - **alice_to_bob_thread**
    - Transfer 1 from alice_acct to bob_acct, 1000 times
  - **bob_to_alice_thread**
    - Transfer 1 from bob_acct to alice_acct, 1000 times
  - alice_acct: 0
  - bob_acct: 0

Deadlocks

- See **deadlock.py** (cont.)

```
$ python deadlock.py
…
Alice: -26
Bob: 26
Alice: -27
Bob: 27
Alice: -28
Bob: 28
Alice: -29
Bob: 29
Alice: -30
Bob: 30
```

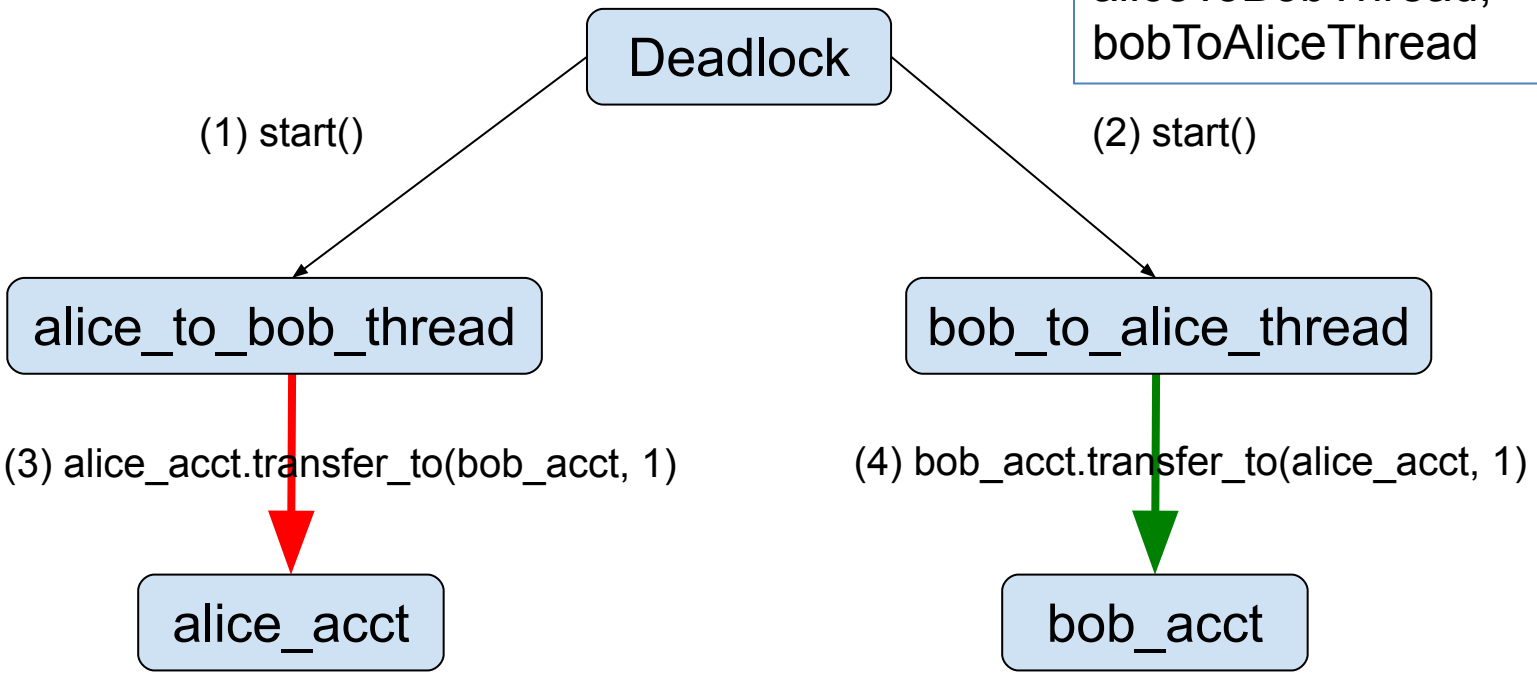
```
$ python deadlock.py
…
Alice: -100
Bob: 100
Alice: -101
Bob: 101
Alice: -102
Bob: 102
Alice: -103
Bob: 103
Alice: -104
Bob: 104
```

Deadlocks

- See **deadlock.py**

Two BankAcct objects:
aliceAcct, bobAcct

Two Threads:
aliceToBobThread,
bobToAliceThread



alice_to_bob_thread
Has lock on alice_acct
Needs lock on bob_acct

bob_to_alice_thread
Has lock on bob_acct
Needs lock on alice_acct

Deadlocks

- See **deadlockw.py**
    - Uses `with` statement

Deadlocks

- Deadlock general case (circular chain):
  - Thread1 has the lock on object1; needs the lock on object2
  - Thread2 has the lock on object2; needs the lock on object3
  - …
  - Thread N has the lock on object N; needs the lock on object 1

Deadlocks

- **Solution:**
  - Make sure there are no circular chains!
  - Give each shared resources a *sequence number*
  - **Pact**: Thread must acquire shared resources in order by *sequence number*

Deadlocks

- See **nodeadlock.py**

```
$ python nodeadlock.py
…
Alice: -4
Bob: 3
Alice: -3
Bob: 2
Alice: -2
Bob: 1
Alice: -1
Bob: 0
Alice: 0
Finished
$
```

```
$ python nodeadlock.py
…
Bob: -4
Alice: 3
Bob: -3
Alice: 2
Bob: -2
Alice: 1
Bob: -1
Alice: 0
Bob: 0
Finished
$
```

Deadlocks

- See **nodeadlockw.py**
    - Uses `with` statement