[544] Locks

Meenakshi Syamkumar

Learning Objectives

- identify critical sections in code
- protect critical sections with locks
- write code that avoids concurrency bugs, such as race conditions and deadlocks
- use Python packages written in non-Python languages to get around the GIL (global interpreter lock)

Outline

Critical Sections and Locks

Worksheet and Demos

Advanced Topics

- Global Interpreter Lock
- Instruction Reordering and Caching

Critical Sections

```python
# in dollars
bank_accounts = {"x": 25, "y": 100, "z": 200}

def transfer_euros(src, dst, euros):
    dollars = euros_to_dollars(euros)
    success = False

    if bank_accounts[src] >= dollars:
        bank_accounts[src] -= dollars
        bank_accounts[dst] += dollars
        success = True

    print("transferred" if success else "denied")
```

If two threads are calling transfer_euros concurrently, ***during which lines would a context switch between those two be problematic?***

A section of code we don't want interrupted by certain other code is a "critical section"

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critical section

Goals:

Atomiticy: want withdrawal+deposit seen together (never seen half done).

Consistency: rules (called "invarants") like "no account goes negative" must be enforced

Locks

```python
# in dollars
bank_accounts = {"x": 25, "y": 100, "z": 200}
lock = threading.Lock() # protects bank_accounts

def transfer_euros(src, dst, euros):
    lock.acquire()
    dollars = euros_to_dollars(euros)
    success = False
    if bank_accounts[src] >= dollars:
        bank_accounts[src] -= dollars
        bank_accounts[dst] += dollars
        success = True
    print("transferred" if success else "denied")
    lock.release()
```

Lock Rules

- between acquire and release, a lock is held by the thread that acquired it
- **a lock may only be held by one thread at a time**
- if T2 wants to acquire a lock held by T1, T2 blocks until T1 releases it

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Tradeoffs

- different patterns may accomplish the same goal
- some are more efficient; some are simpler

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Tradeoffs

- different patterns may accomplish the same goal
- some are more efficient; some are simpler
- be careful! (this incorrect version provides atomicity but not consistency)

Worksheet and Demos...

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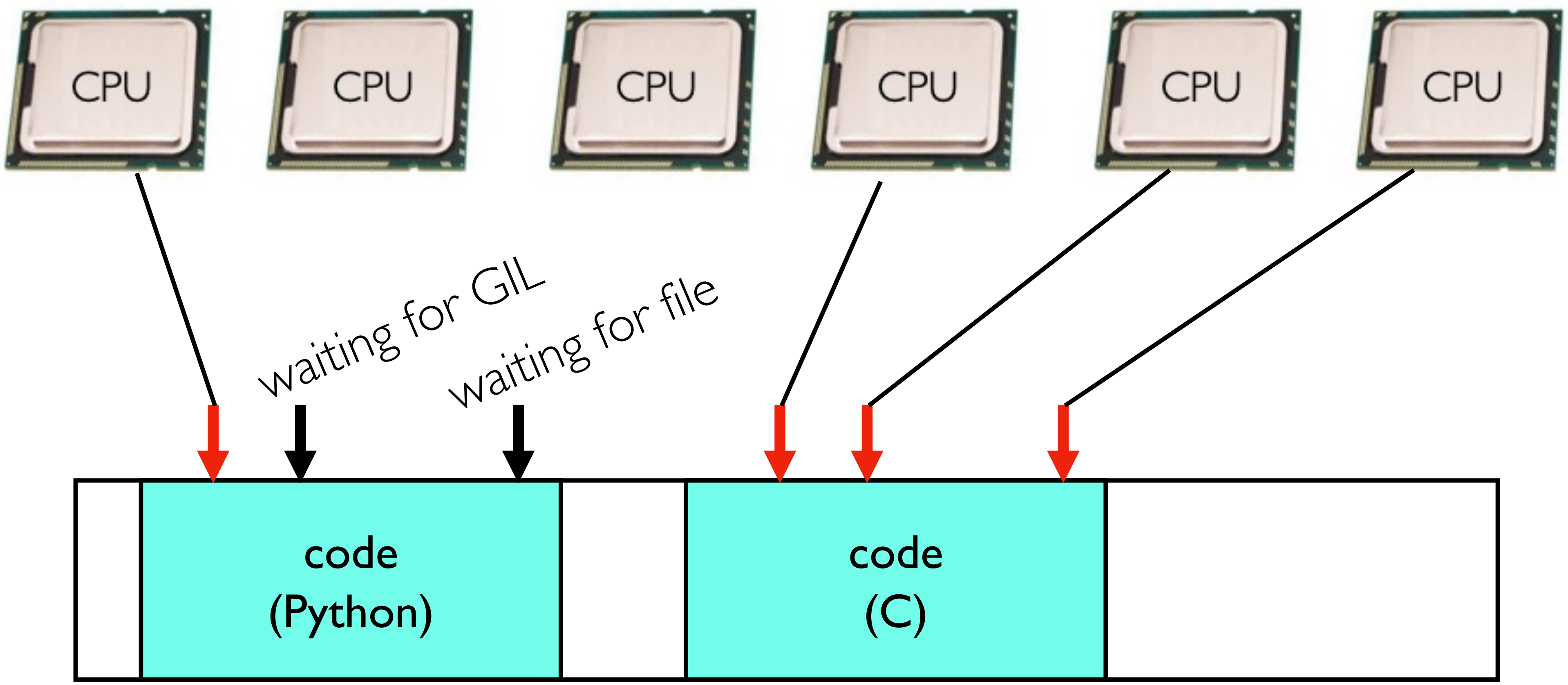
Python's GIL (Global Interpreter Lock)



Global Interpreter Lock

- Only one thread can be running Python code in a process at once
- Python threads are bad for using multiple cores
- They're still useful for threads blocked on I/O
- Some Python libraries using other languages allow parallelism

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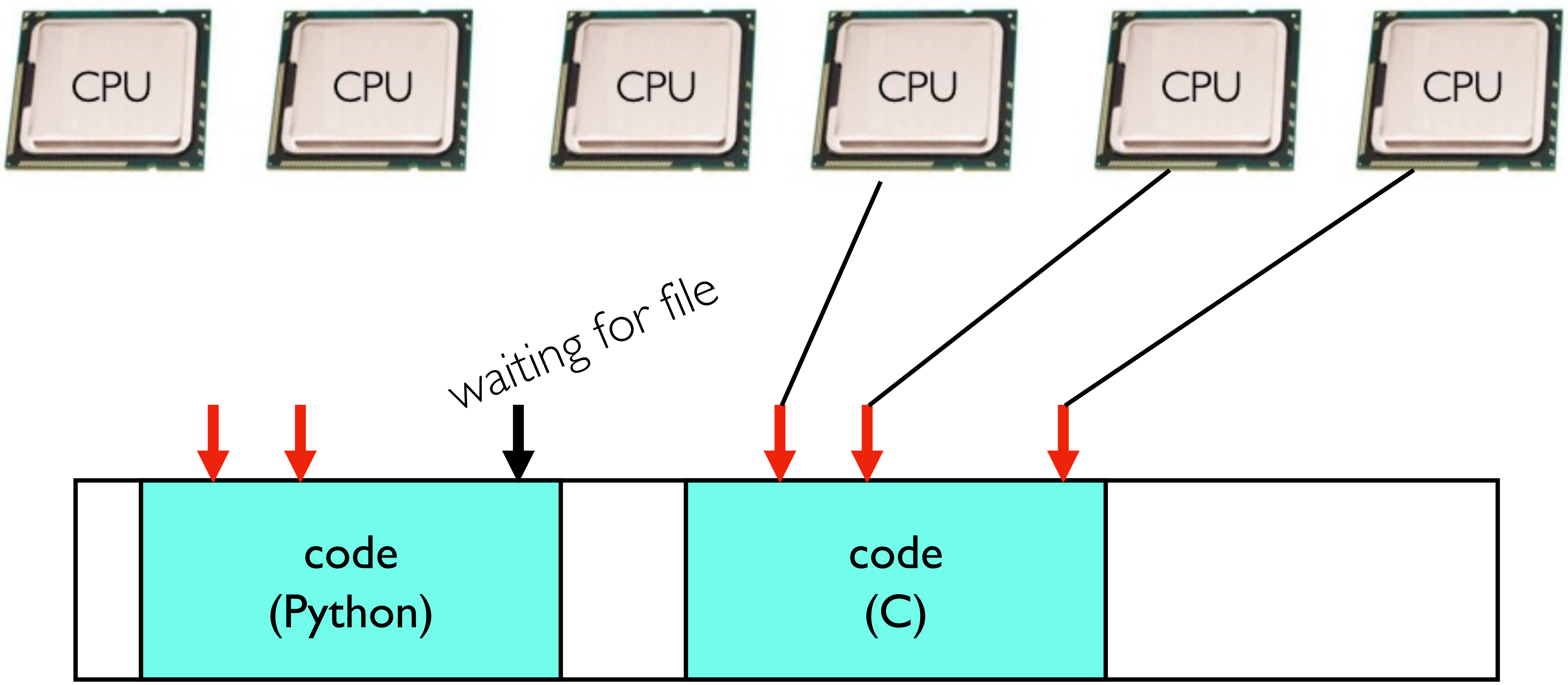

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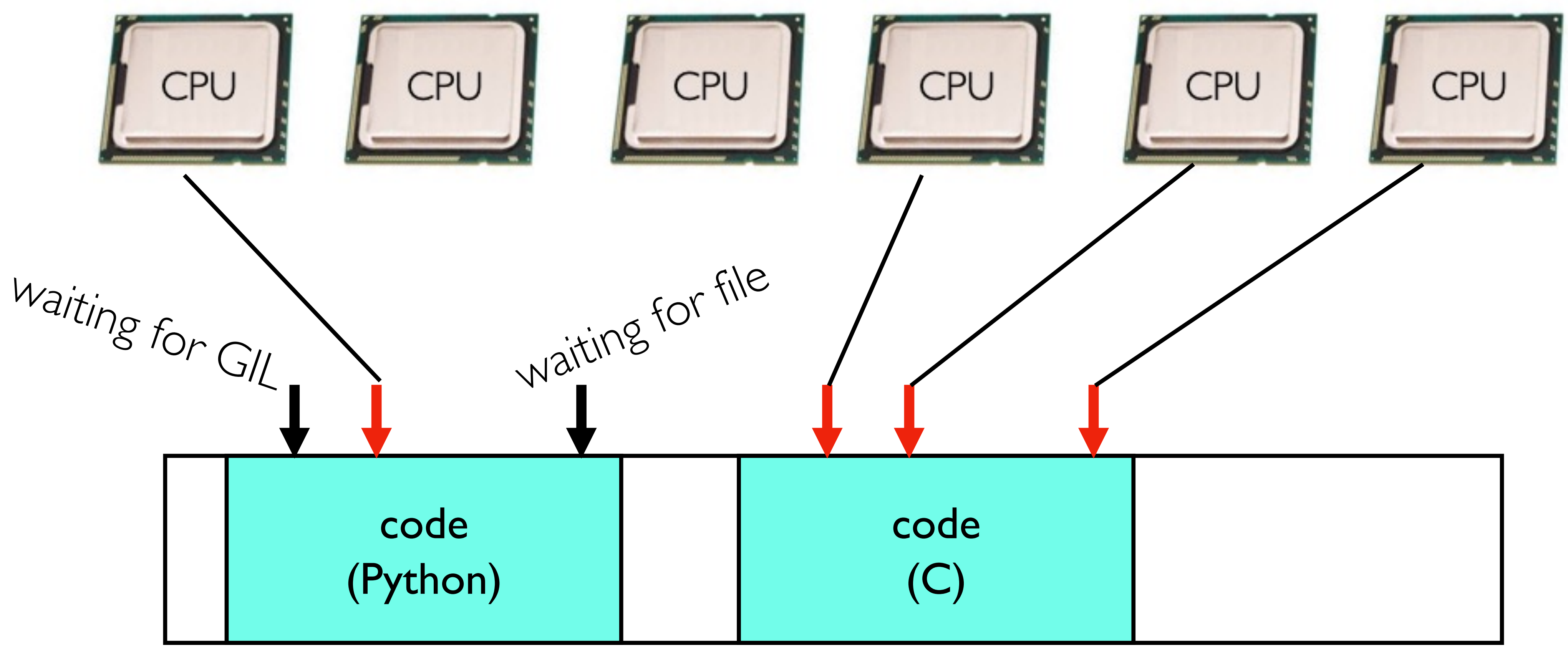

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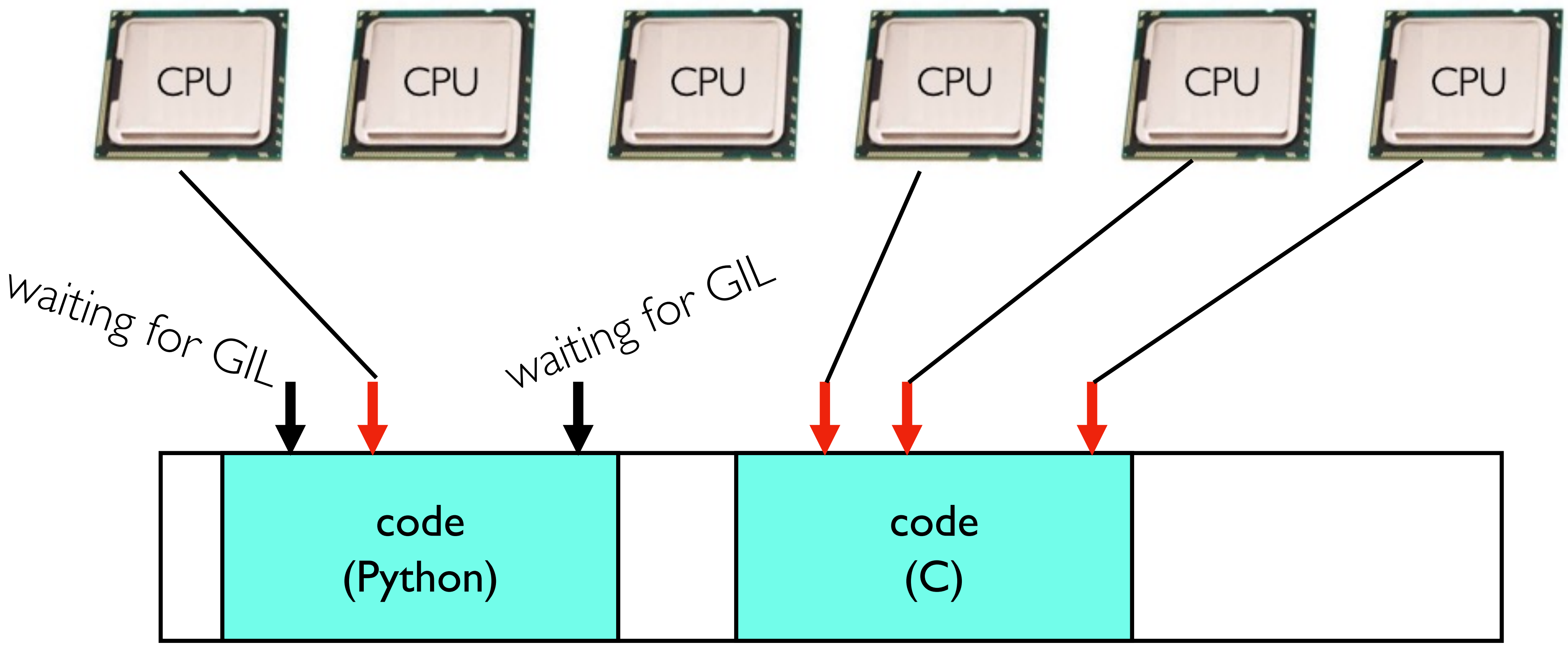

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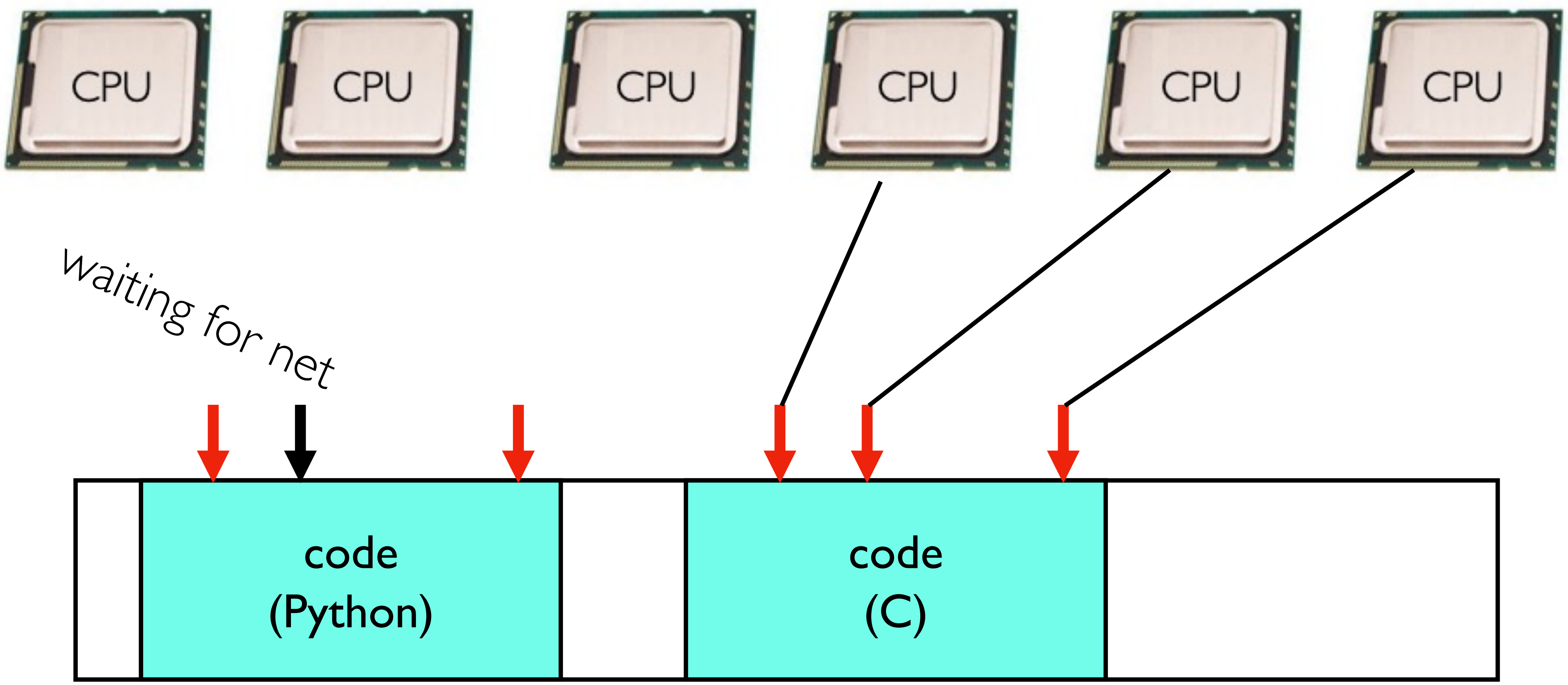

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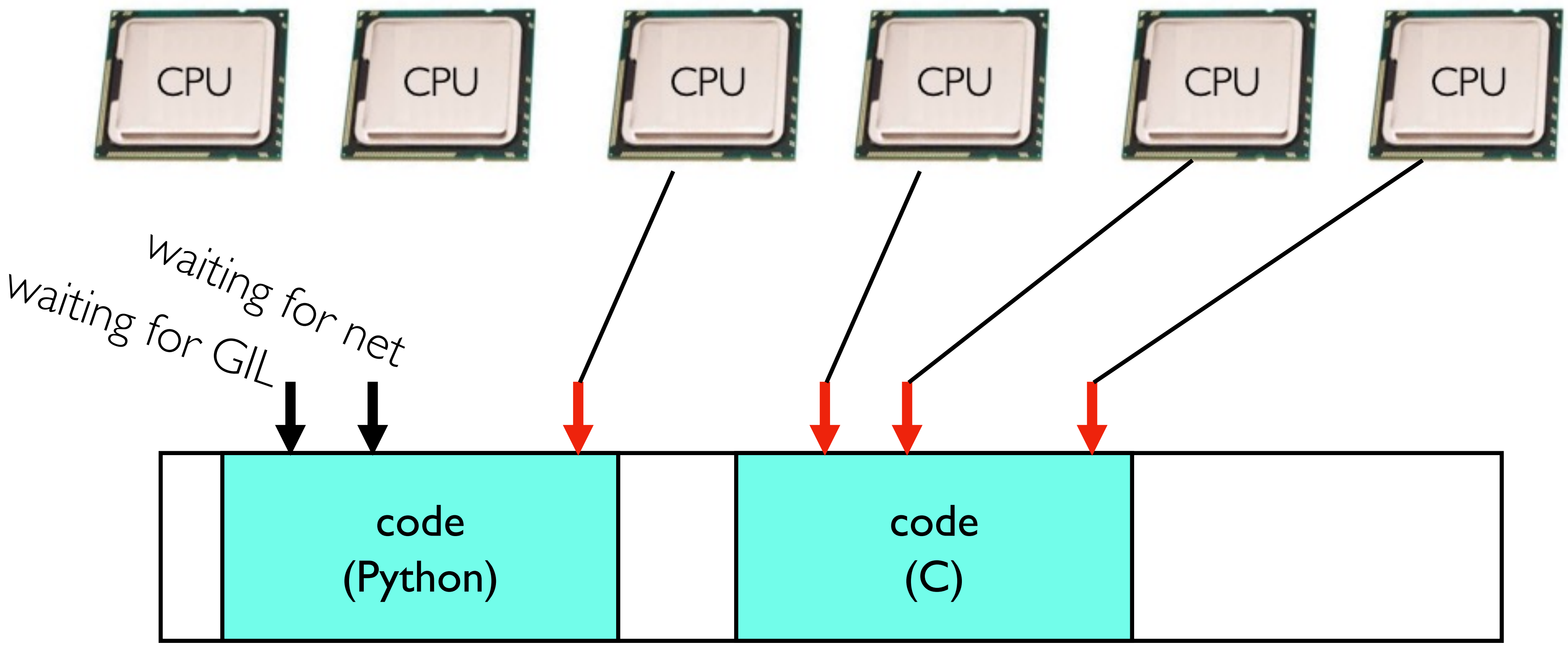

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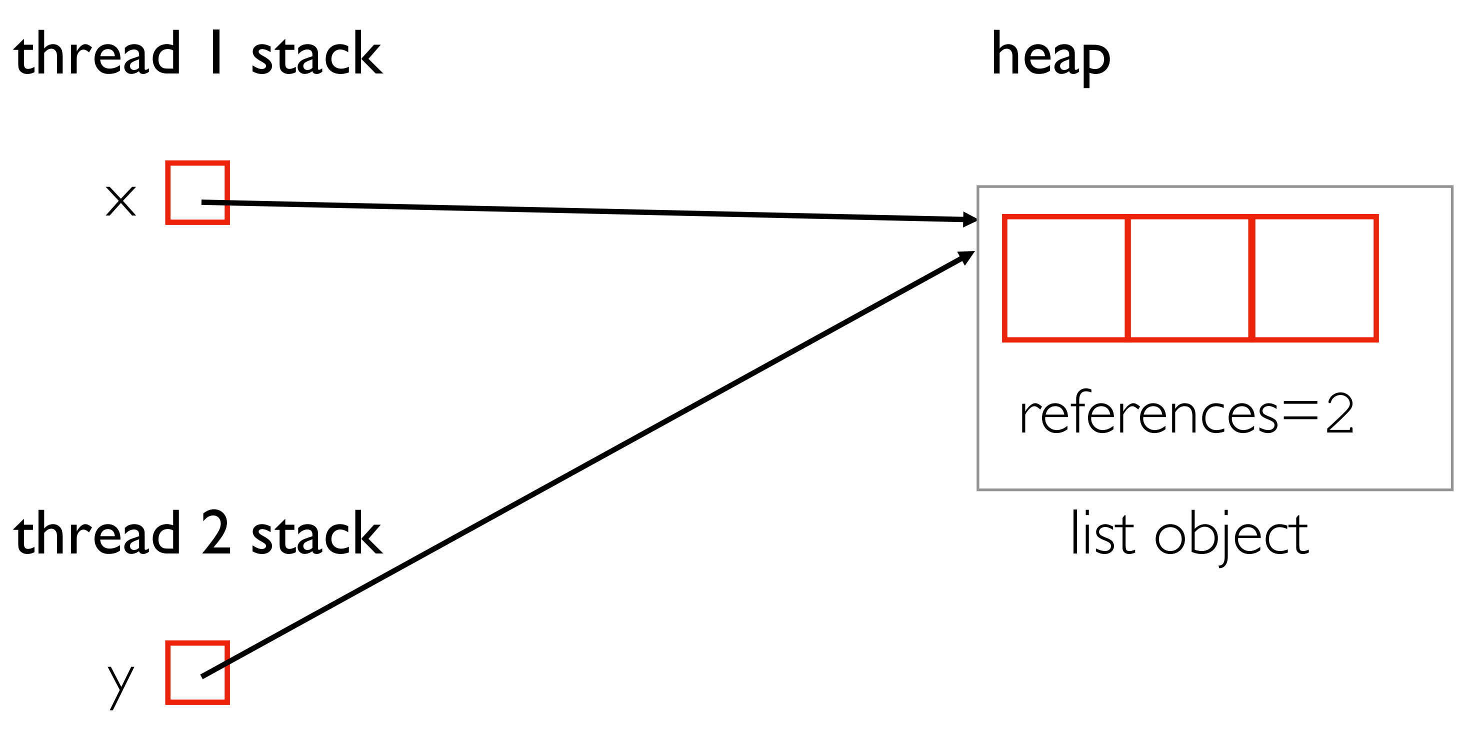
Why the GIL?

\# thread 1
x = *some list*
x = None

\# thread 2
y = ***that same list***
y = None



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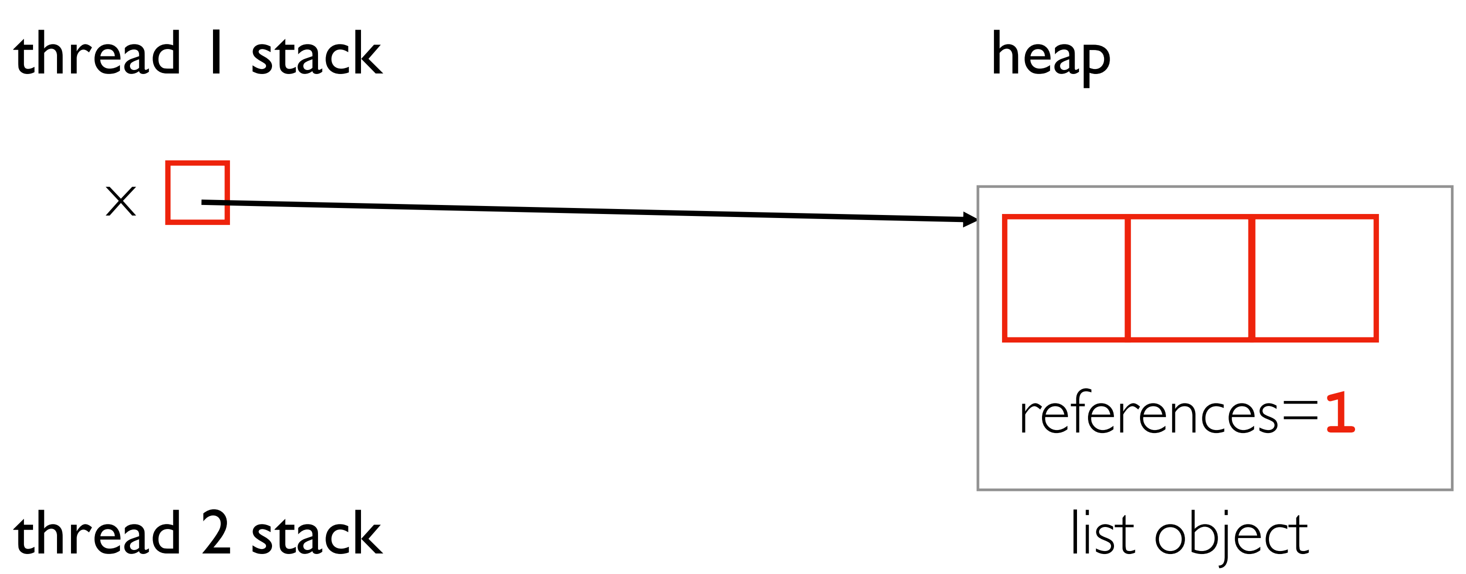

object will be freed when references is 0

Why the GIL?

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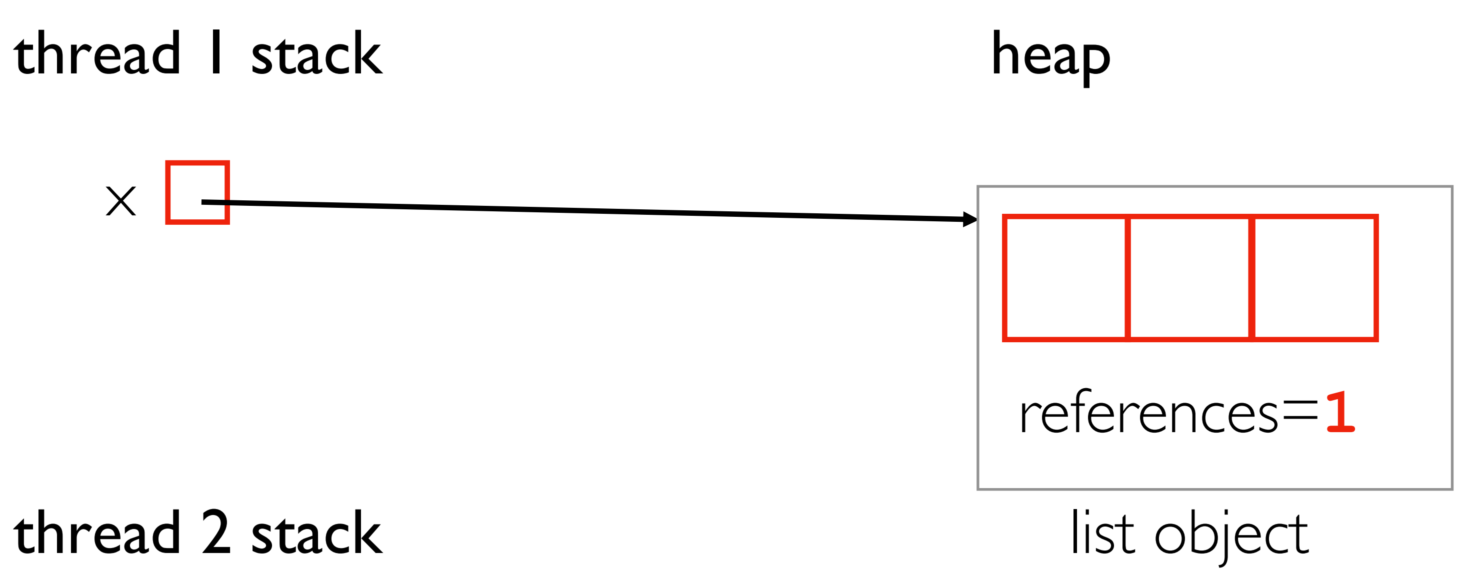
situation

- cpython (main Python interpreter) uses reference counting internally to know when it can free objects
- implication: multiple threads modifying same integer

solutions

- run one thread at a time (Python's approach)
- lots of locking (slower for single-threaded code)



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Challenges Beyond Interleaving

```
import threading

y = 0
ready = False

def task(x):
    global y
    y = x ** 2
    ready = True

t = threading.Thread(target=task, args=[5])
t.start()
while not ready:
    pass
print(y) # want 25 (not 0)
```

no interleaving is problematic, but it's still not correct on a modern CPU!

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out-of-order execution
(CPU optimization)

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main

core 1 (running task)

L1 cache:
y = 25
ready = True

core 2 (running main)

L1 cache:
y = 0 (stale)
ready = False (stale)

no interleaving is problematic, but it's still not correct on a modern CPU!

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Concluding Advice

Use provided primitives (like locks+joins) to control isolation+ordering

- these calls control interleavings AND memory barriers (topic beyond 544)
- it's easy to get lockless approaches wrong

Correctness tips (keep it simple to avoid bugs!):

- can you use multiple processes instead of threads?
- is one big lock good enough for protecting all your data?
- is it OK to hold the lock through a whole function call?

Performance tips:

- avoid holding a lock while blocking on I/O (network, disk, user input, etc)
- if you have multiple updates, can you hold the lock for more than one of them?
- use performant packages like numpy
  - the code in C/C++/Fortran/Rust can often run without the GIL
  - these will often create threads for you