[544] Locks

Tyler Caraza-Harter

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

```
1     # in dollars
2     bank_accounts = {"x": 25, "y": 100, "z": 200}
3
4     def transfer_euros(src, dst, euros):
5         dollars = euros_to_dollars(euros)
6         success = False
7
8         if bank_accounts[src] >= dollars:
9             bank_accounts[src] -= dollars
10            bank_accounts[dst] += dollars
11            success = True
12
13        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

```
1     # in dollars
2     bank_accounts = {"x": 25, "y": 100, "z": 200}
3     lock = threading.Lock() # protects bank_accounts
4
5     def transfer_euros(src, dst, euros):
6         lock.acquire()
7         dollars = euros_to_dollars(euros)
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13        print("transferred" if success else "denied")
14        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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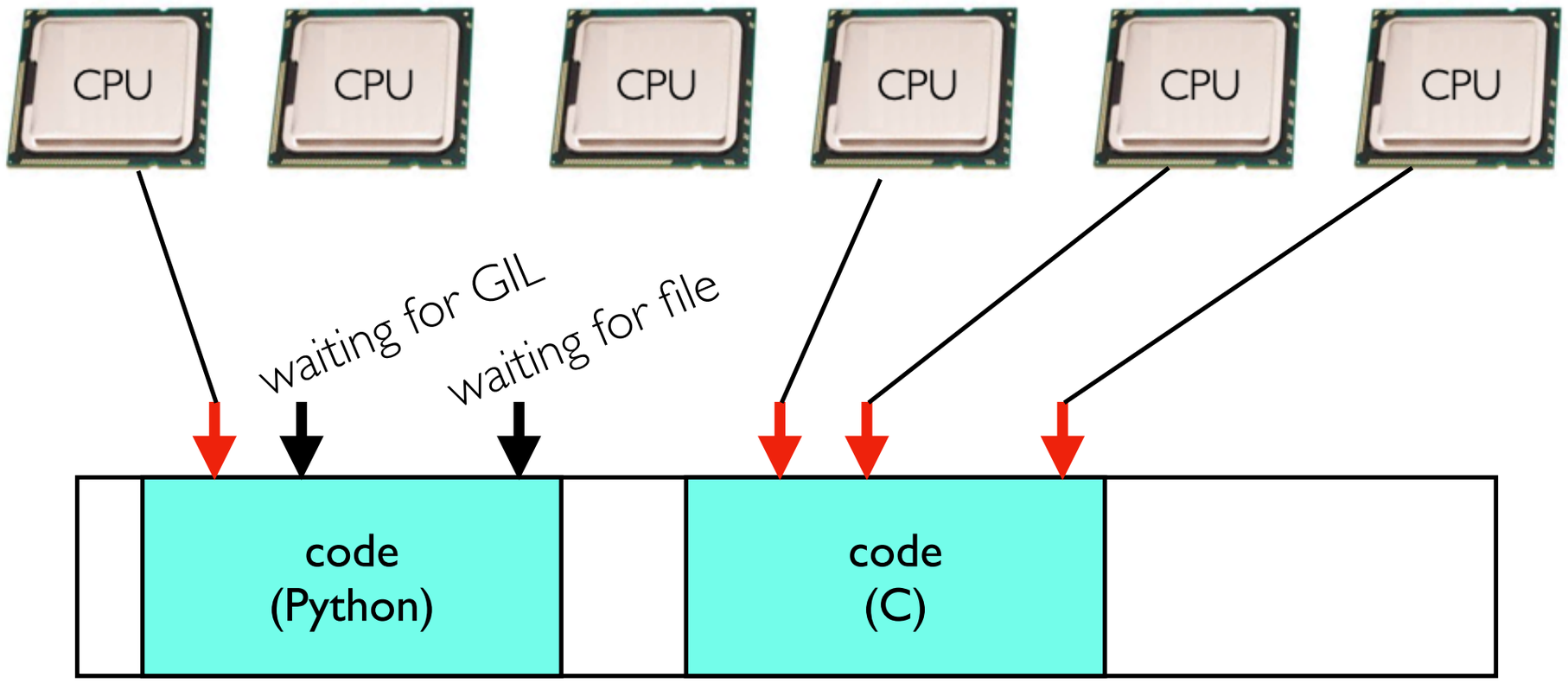
Python's GIL (Global Interpreter Lock)



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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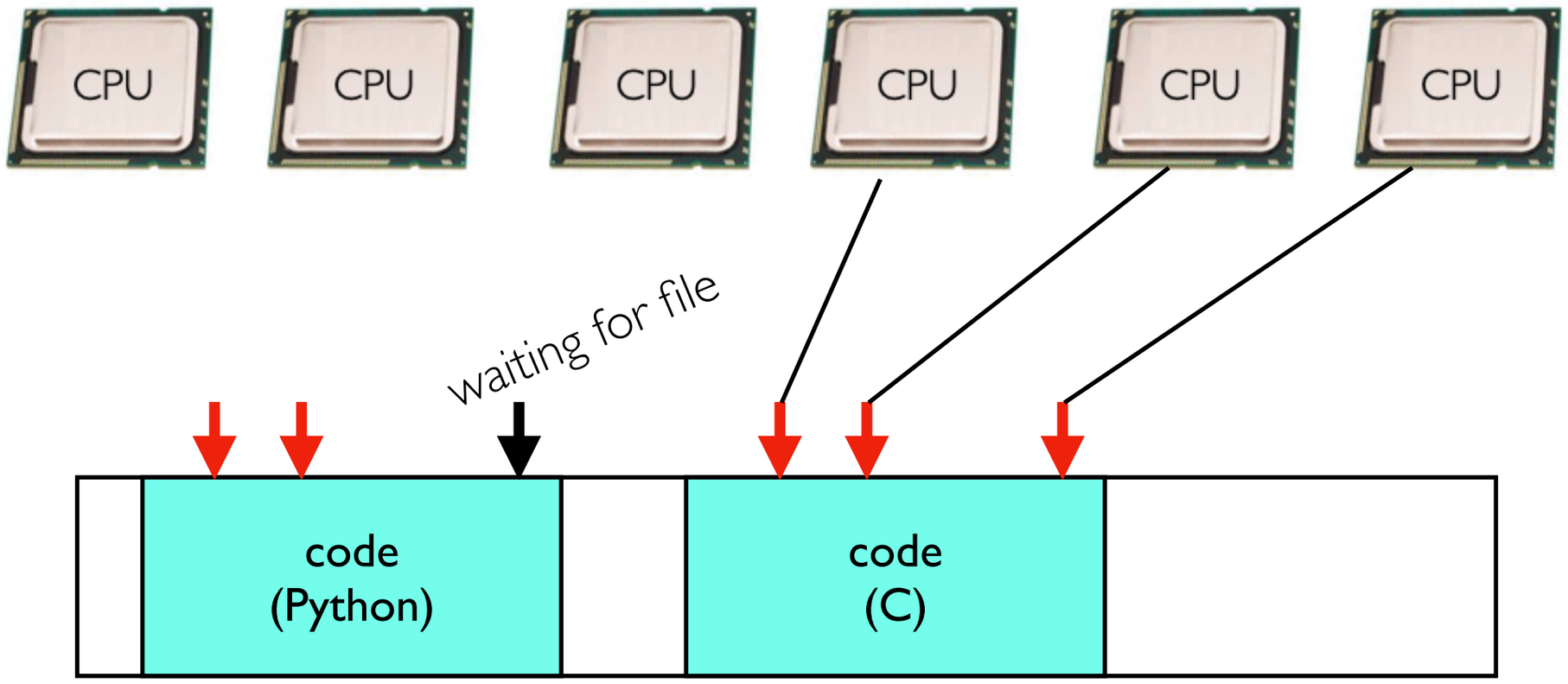

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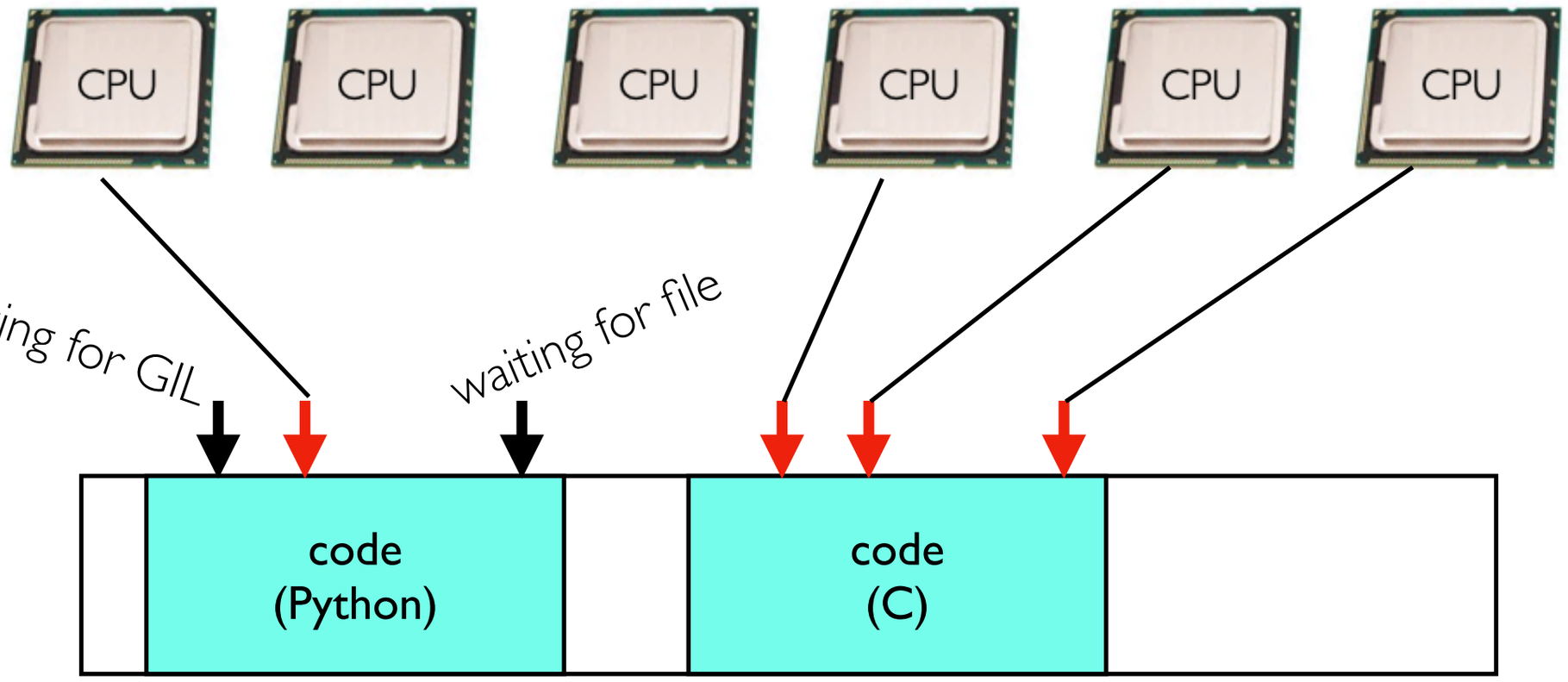

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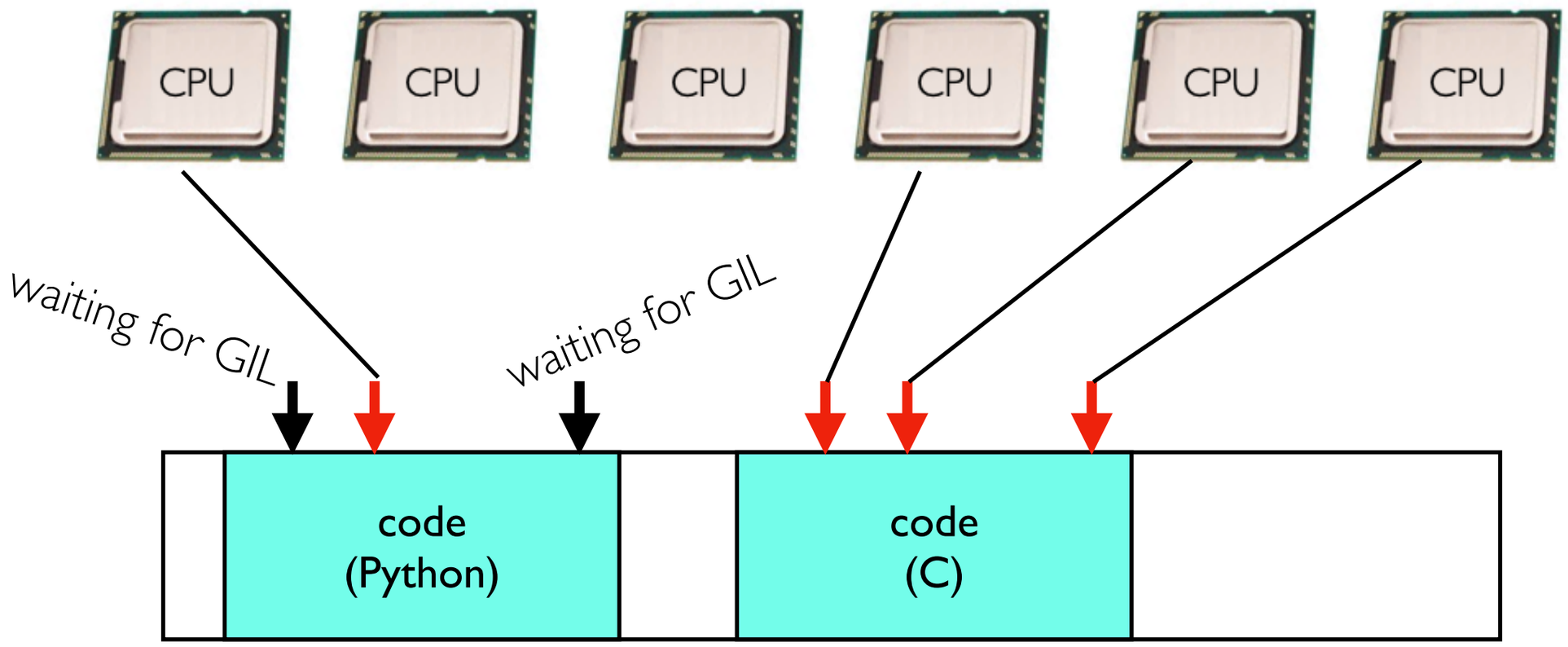

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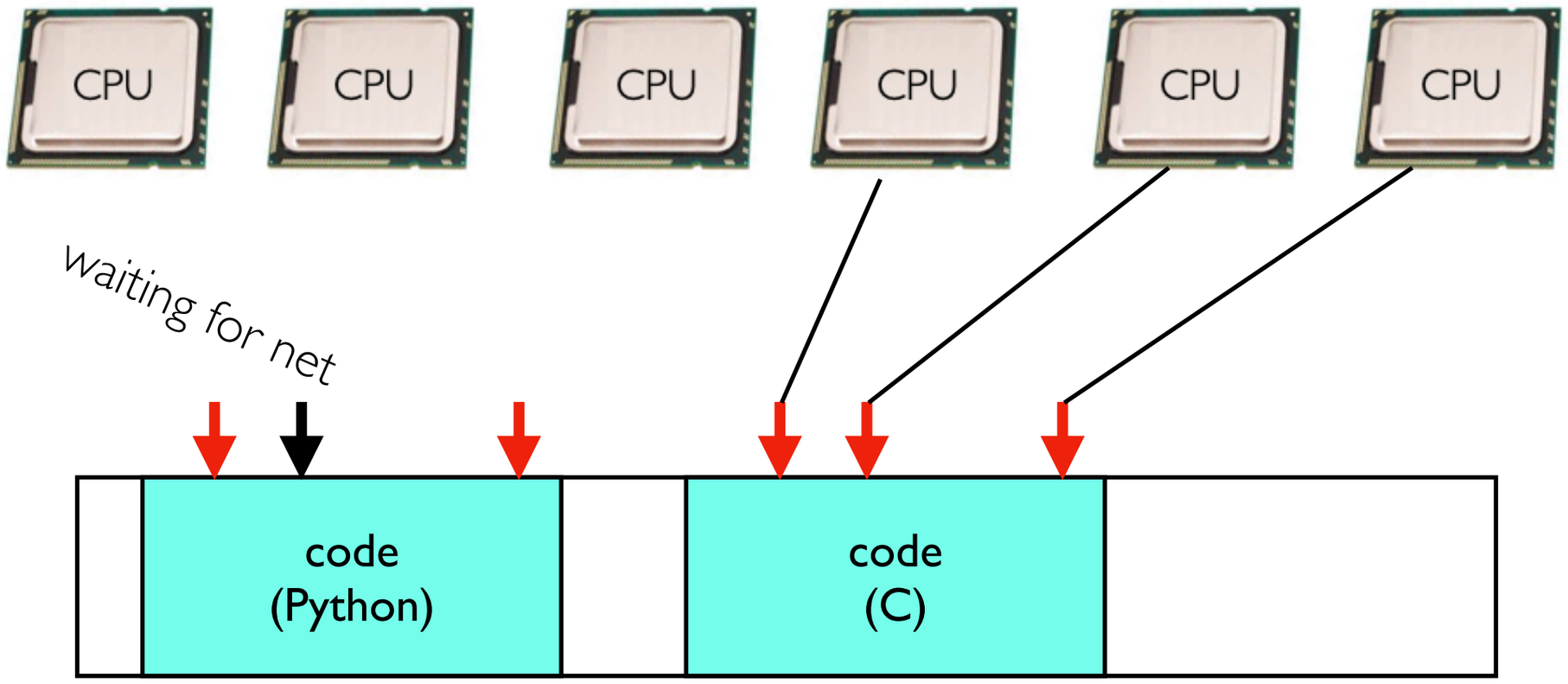

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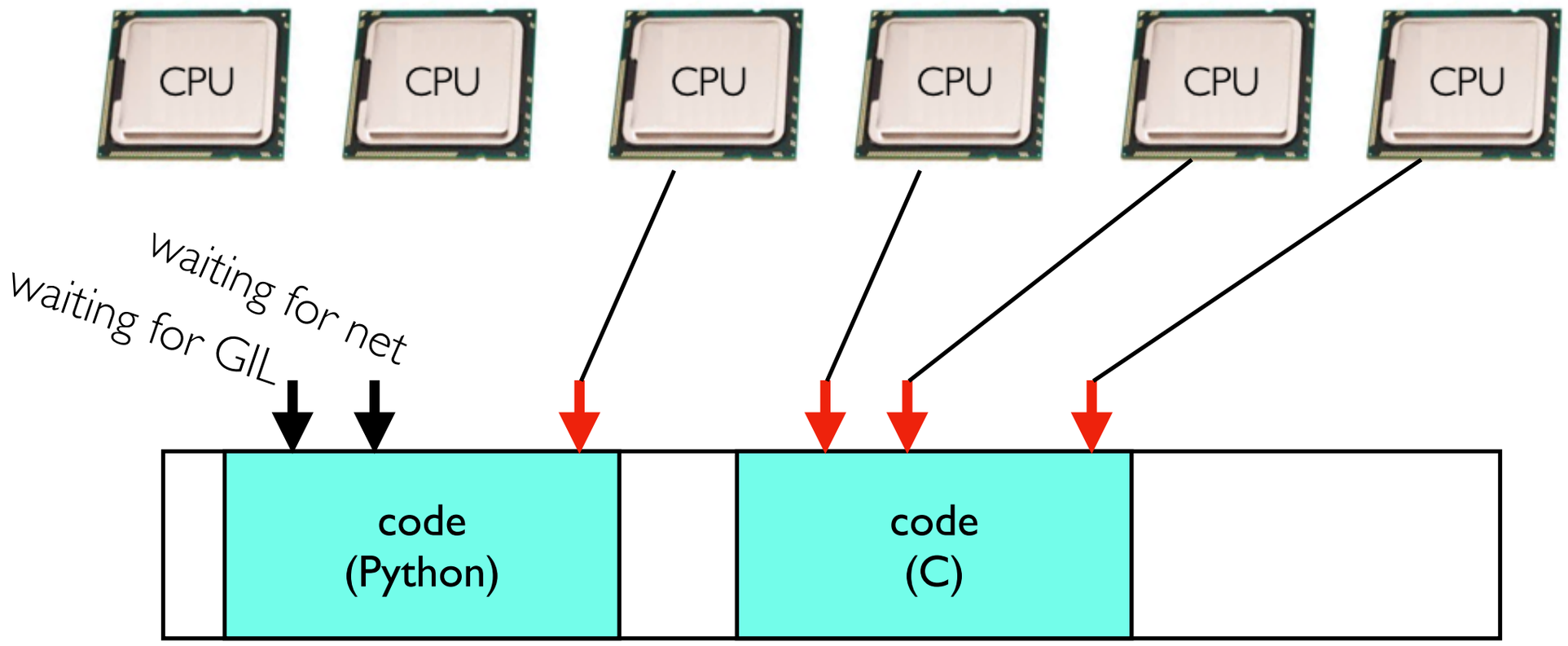

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Why the GIL?

```
# thread 1
x = some list
x = None

# thread 2
y = that same list
y = None
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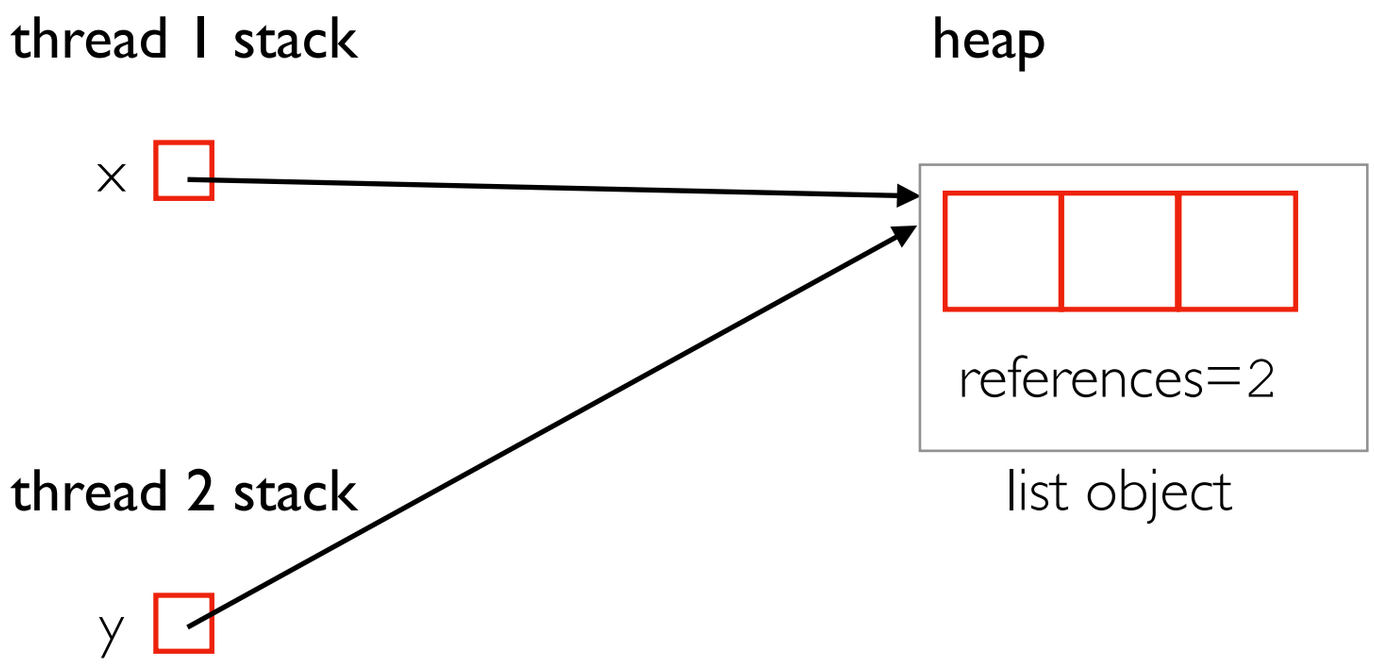

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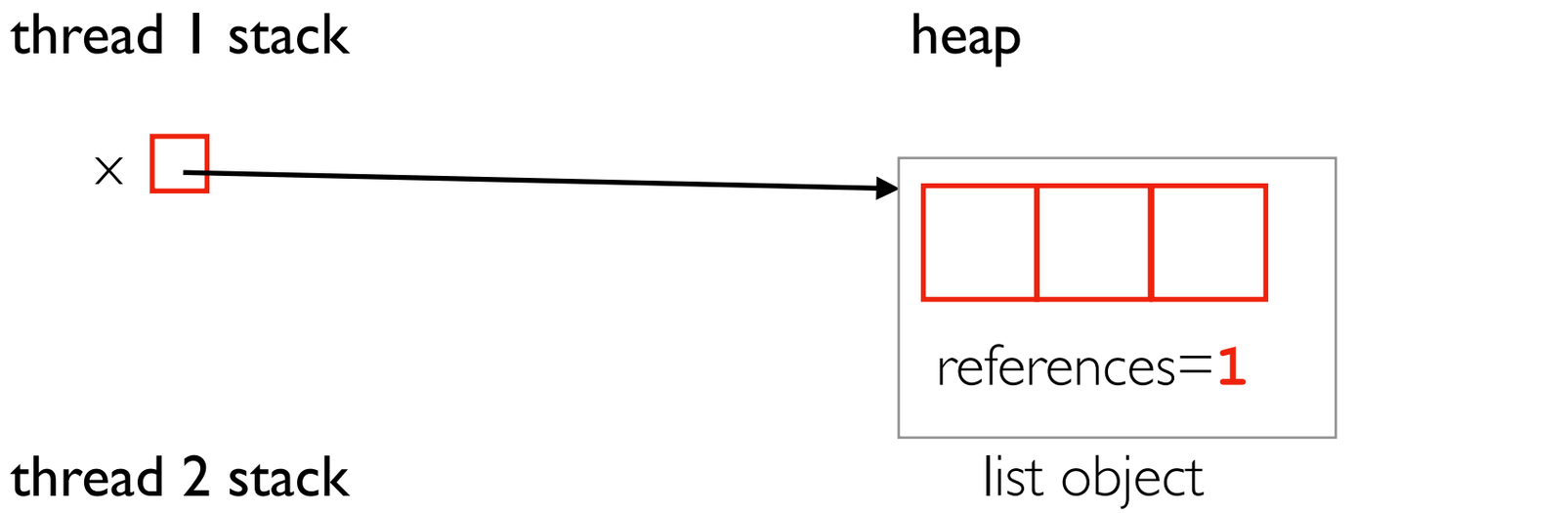

object will be freed when references is 0

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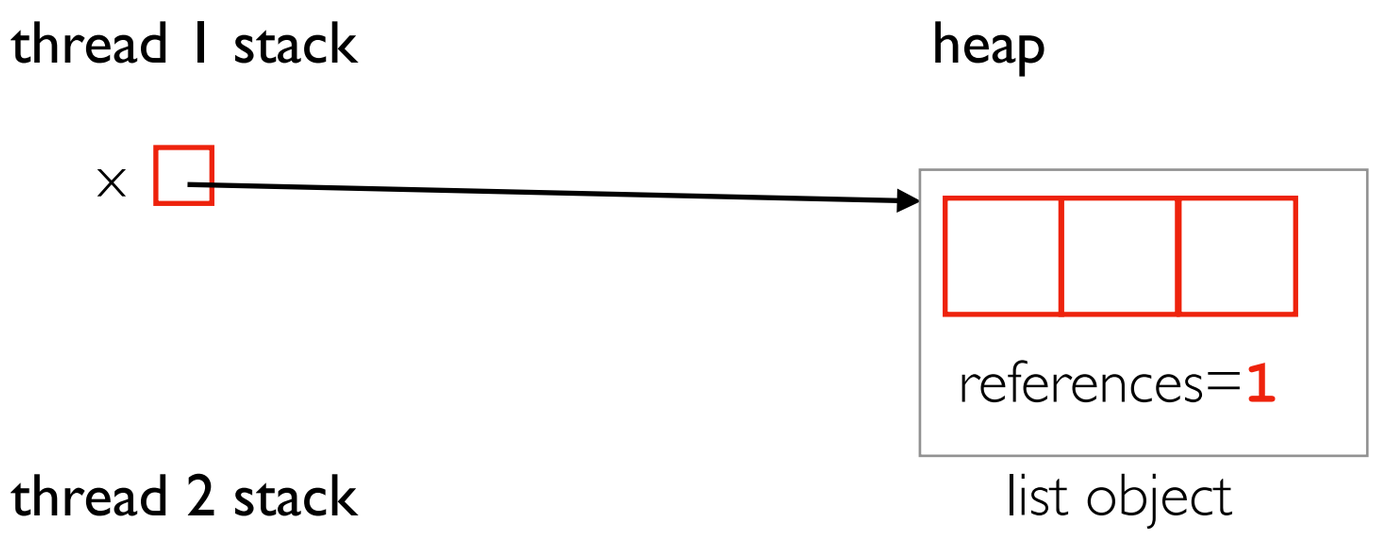
situation

- 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 = True

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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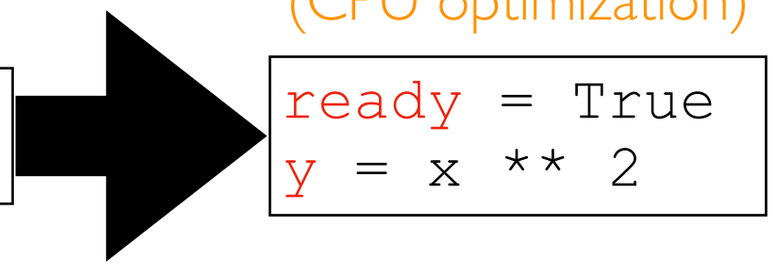

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main

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

Keep it simple:

- 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