Heterogeneous Computing for AI - Lecture ~04

Parallel Programming using Multiple Processors in Python

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Many slides are taken from the following authors with due respect to their contributions.
1) An Introduction to Python Concurrency by David Beazley

Outline

- The Inside Story on Python Threads
- Processes and Messages
- Multiprocessing Module
- Multiprocessing Module
  - Pipes
  - Queues
  - Process Pools

Learning goals for today

Theoretical

- Gain knowledge about various multi-process parallel programming primitives in Python
- Understand the foundations of Process Pools, Queues, Pipes, and others

Practical

- Be able to write programs that can run on multicore processors/CPUs
- Understand how to pass messages between different processes

The Inside Story on Python Threads

Python and GIL Lock

The Infamous GIL

- Here's the rub...
- Only one Python thread can execute in the interpreter at once
- There is a "global interpreter lock" that carefully controls thread execution
- The GIL ensures that sure each thread gets exclusive access to the entire interpreter internals when it's running

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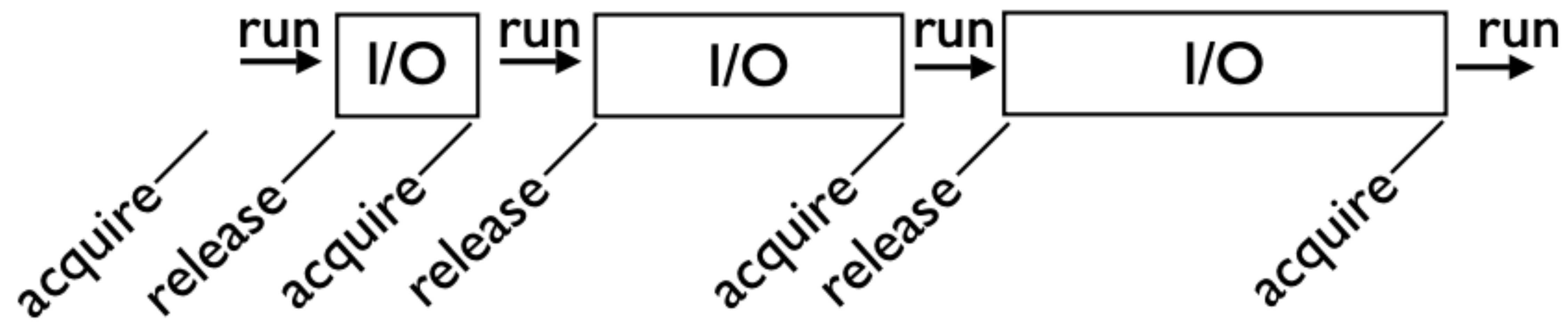
Python and GIL Lock

GIL Behavior

- Whenever a thread runs, it holds the GIL
- However, the GIL is released on blocking I/O



- So, any time a thread is forced to wait, other "ready" threads get their chance to run
- Basically a kind of "cooperative" multitasking

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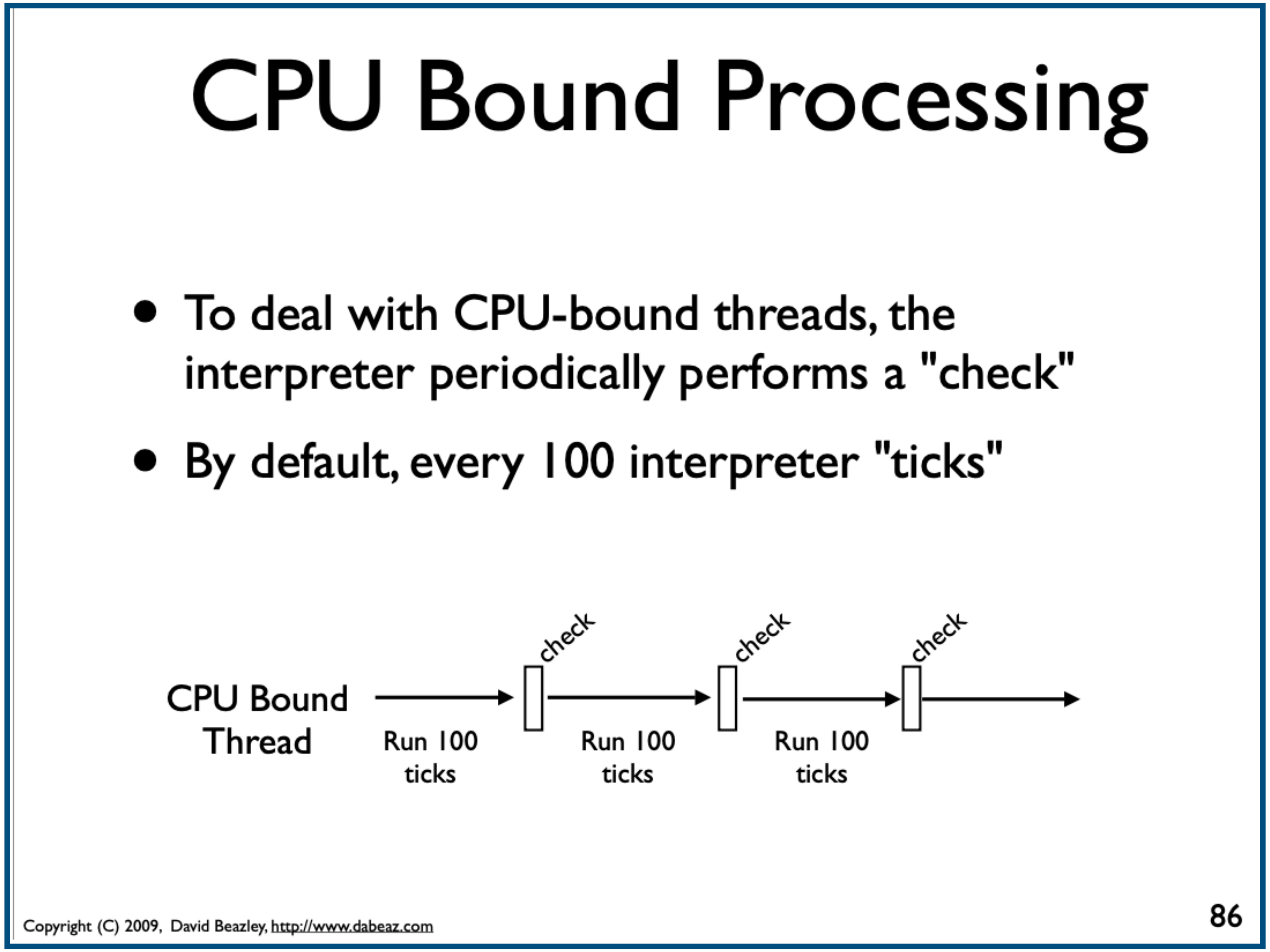
Python and GIL Lock



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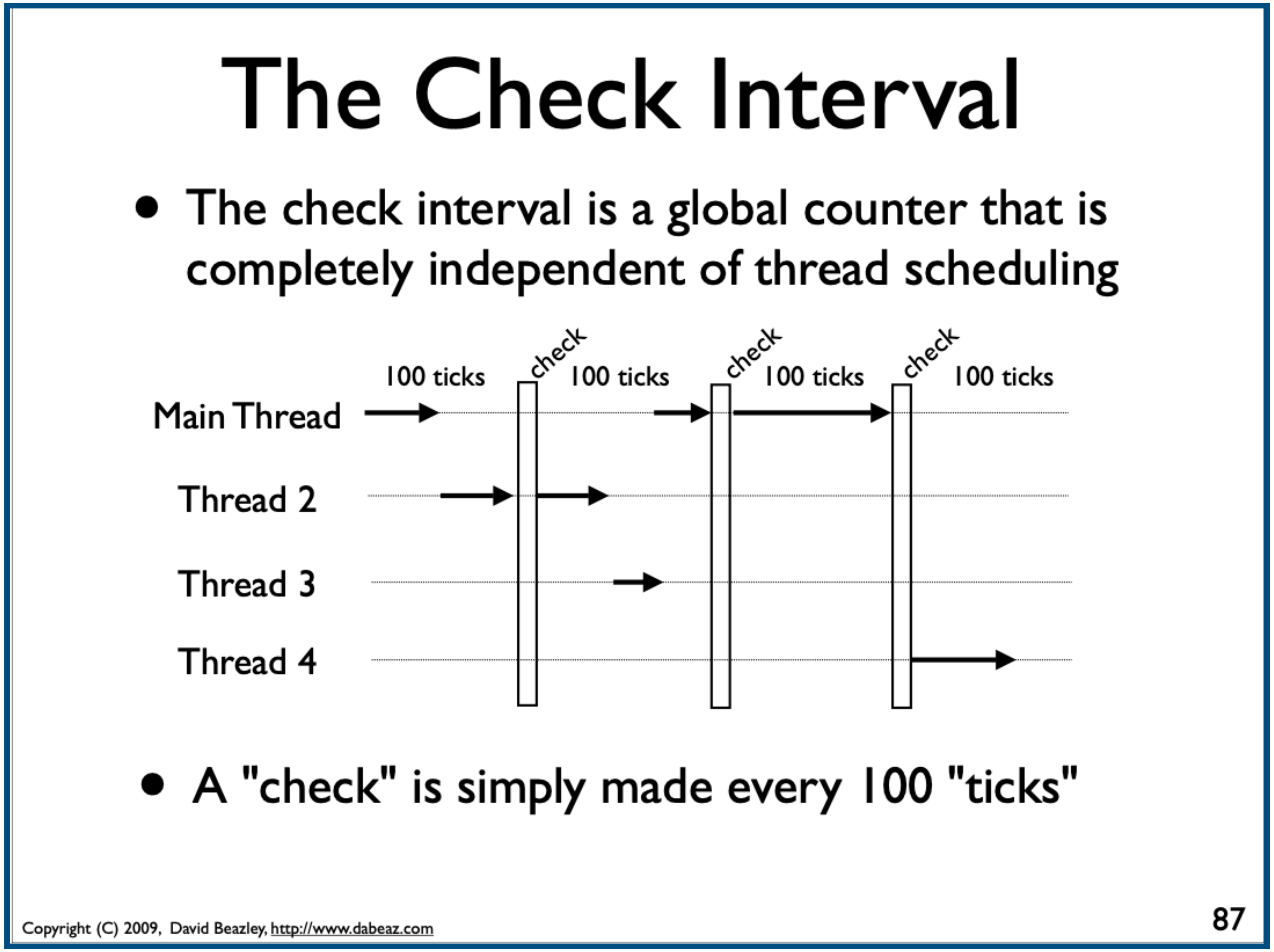
Python and GIL Lock



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Python and GIL Lock

The Periodic Check

- What happens during the periodic check?
  - In the main thread only, signal handlers will execute if there are any pending signals
  - Release and reacquisition of the GIL
- That last bullet describes how multiple CPU-bound threads get to run (by briefly releasing the GIL, other threads get a chance to run).

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Python and GIL Lock

Thread Scheduling

- Python does not have a thread scheduler
- There is no notion of thread priorities, preemption, round-robin scheduling, etc.
- For example, the list of threads in the interpreter isn't used for anything related to thread execution
- All thread scheduling is left to the host operating system (e.g., Linux, Windows, etc.)

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Python and GIL Lock

GIL Implementation

- The GIL is not a simple mutex lock
- The implementation (Unix) is either...
  - A POSIX unnamed semaphore
  - Or a pthreads condition variable
- All interpreter locking is based on signaling
  - To acquire the GIL, check if it's free. If not, go to sleep and wait for a signal
  - To release the GIL, free it and signal

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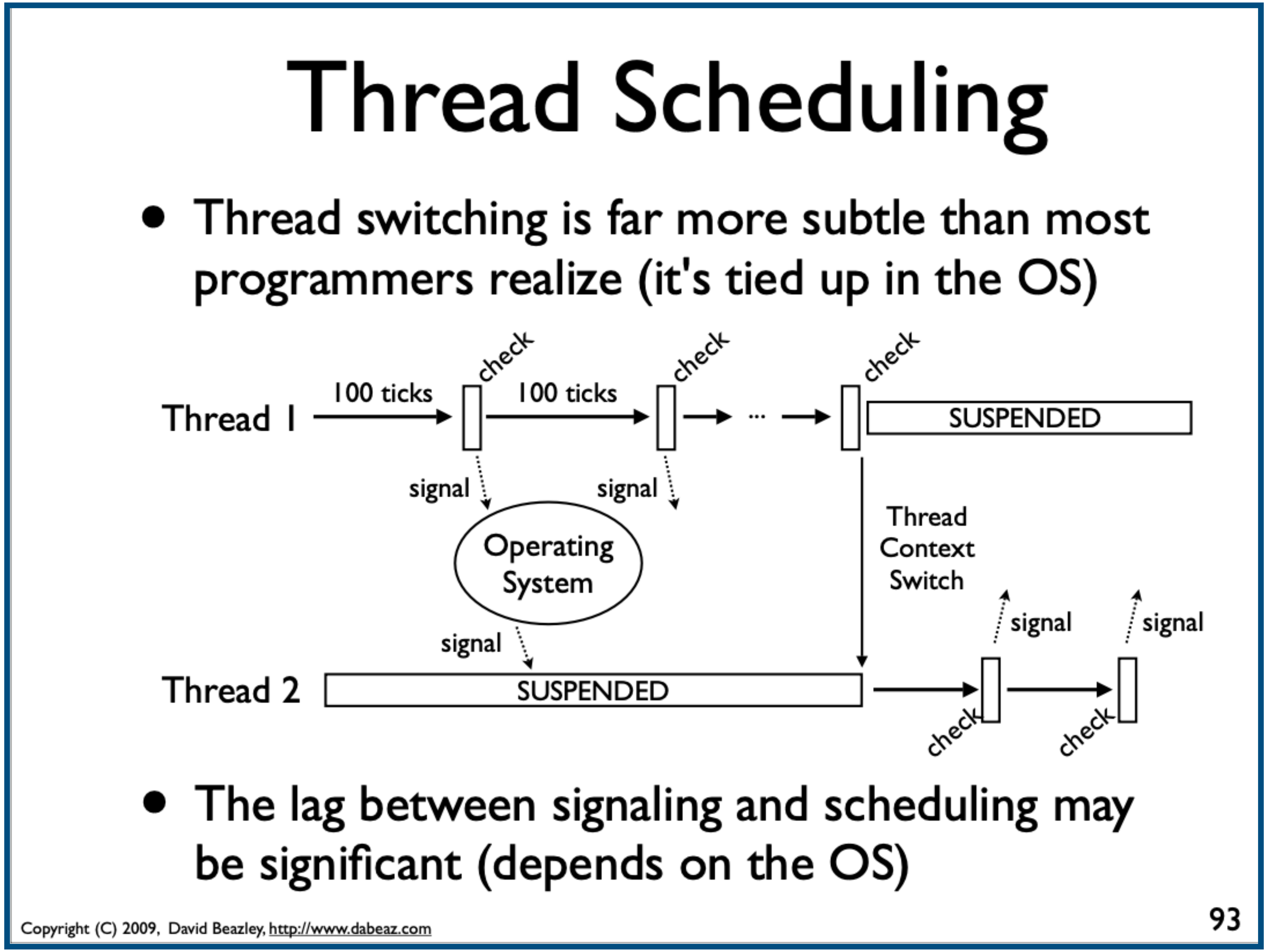
Python and GIL Lock



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Python and GIL Lock

CPU-Bound Threads

- As we saw earlier, CPU-bound threads have <u>horrible</u> performance properties
- Far worse than simple sequential execution
  - 24.6 seconds (sequential)
  - 45.5 seconds (2 threads)
- A big question : Why?
  - What is the source of that overhead?

example in Python file in PyCharm

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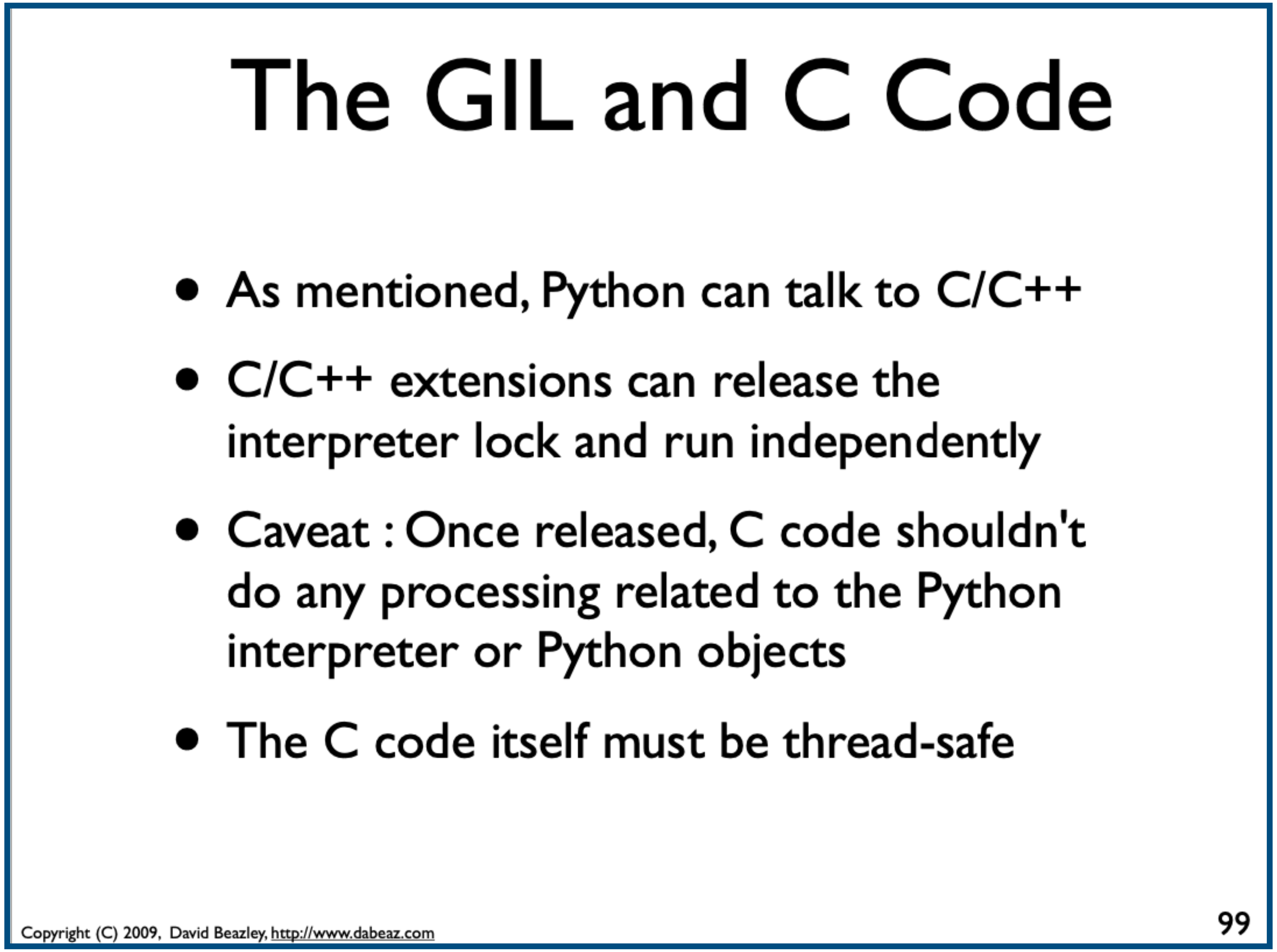
Python and GIL Lock



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Python and GIL Lock

Why is the GIL there?

- Simplifies the implementation of the Python interpreter (okay, sort of a lame excuse)
- Better suited for reference counting (Python's memory management scheme)
- Simplifies the use of C/C++ extensions. Extension functions do not need to worry about thread synchronization
- And for now, it's here to stay... (although people continue to try and eliminate it)

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Processes and Messages

Processes and Messages

Concept: Message Passing

- An alternative to threads is to run multiple independent copies of the Python interpreter
- In separate processes
- Possibly on different machines
- Get the different interpreters to cooperate by having them send messages to each other

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Processes and Messages

Message Passing

- On the surface, it's simple
- Each instance of Python is independent
- Programs just send and receive messages
- Two main issues
  - What is a message?
  - What is the transport mechanism?

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Processes and Messages

Messages

- A message is just a bunch of bytes (a buffer)
- A "serialized" representation of some data
- Creating serialized data in Python is easy

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Processes and Messages

pickle Module

- A module for serializing objects
- Serializing an object onto a "file"

```
import pickle
...
pickle.dump(someobj,f)
```

- Unserializing an object from a file

```
someobj = pickle.load(f)
```

- Here, a file might be a file, a pipe, a wrapper around a socket, etc.

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Processes and Messages

Pickle Commentary

- Using pickle is almost too easy
- Almost any Python object works
    - Builtins (lists, dicts, tuples, etc.)
    - Instances of user-defined classes
    - Recursive data structures
- Exceptions
    - Files and network connections
    - Running generators, etc.

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Processes and Messages

Message Transport

- Python has various low-level mechanisms
  - Pipes
  - Sockets
  - FIFOs
- Libraries provide access to other systems
  - MPI
  - XML-RPC (and many others)

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Processes and Messages

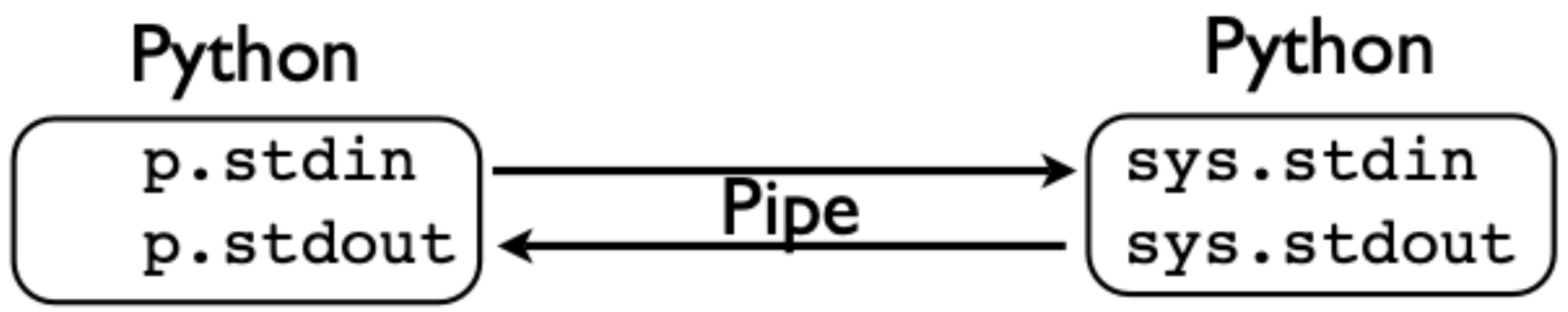
An Example

- Launching a subprocess and hooking up the child process via a pipe
- Use the subprocess module

```
import subprocess

p = subprocess.Popen(['python','child.py'],
                     stdin=subprocess.PIPE,
                     stdout=subprocess.PIPE)

p.stdin.write(data)     # Send data to subprocess
p.stdout.read(size)     # Read data from subprocess
```



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Processes and Messages

Pipes and Pickle

- Most programmers would use the subprocess module to run separate programs and collect their output (e.g., system commands)
- However, if you put a pickling layer around the files, it becomes much more interesting
- Becomes a communication channel where you can send just about any Python object

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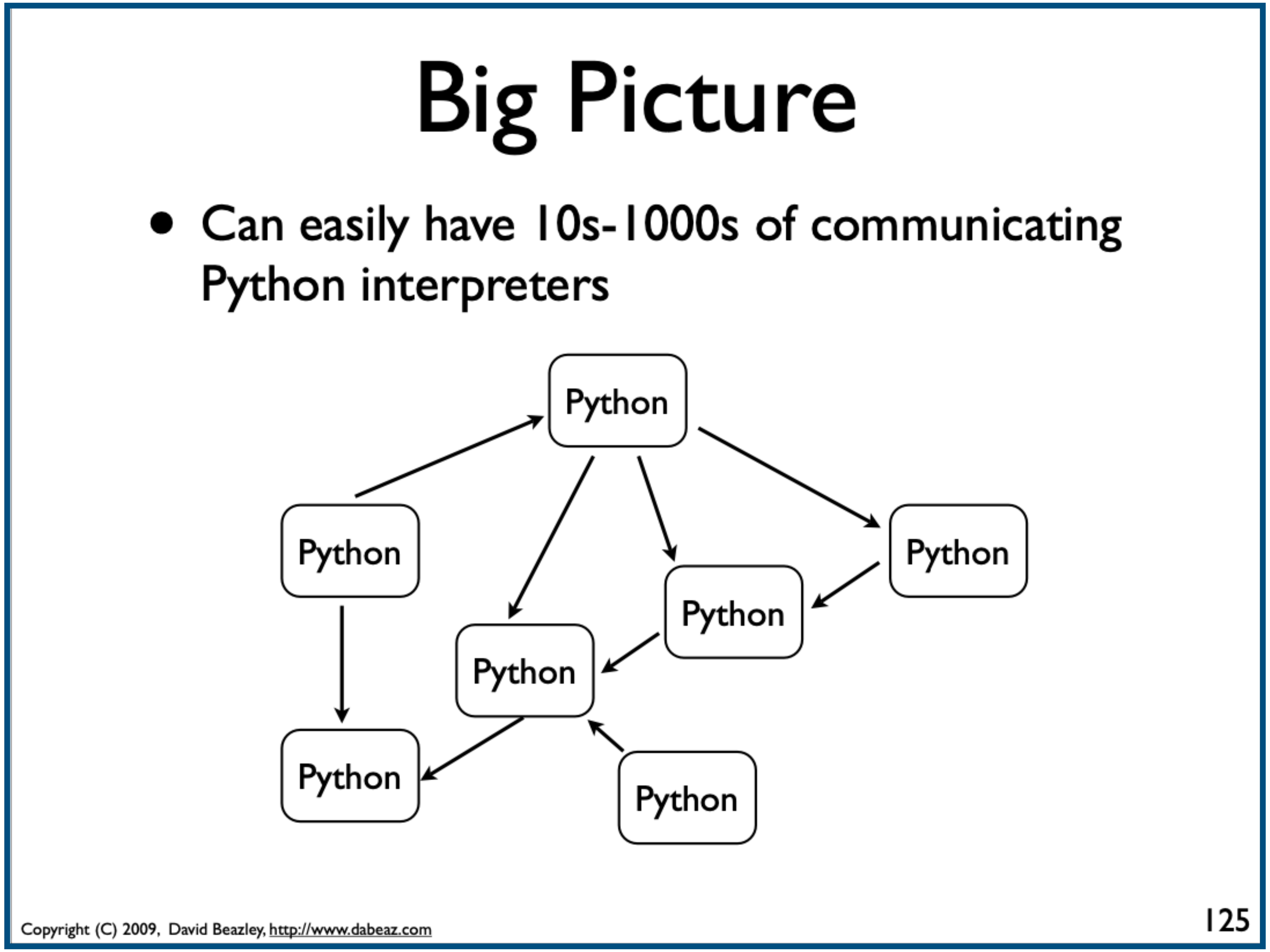
Processes and Messages



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Processes and Messages

Interlude

- Message passing is a fairly general concept
- However, it's also kind of nebulous in Python
- No agreed upon programming interface
- Vast number of implementation options
- Intersects with distributed objects, RPC, cross-language messaging, etc.

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Multiprocessing Module

Multiprocessing Module

multiprocessing Module

- A new library module added in Python 2.6
- Originally known as pyprocessing (a third-party extension module)
- This is a module for writing concurrent Python programs based on communicating processes
- A module that is especially useful for concurrent CPU-bound processing

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Multiprocessing Module

Using multiprocessing

- Here's the cool part...
- You already know how to use multiprocessing
- At a very high-level, it simply mirrors the thread programming interface
- Instead of "Thread" objects, you now work with "Process" objects.

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Multiprocessing Module

multiprocessing Example

- Define tasks using a Process class

```
import time
import multiprocessing

class CountdownProcess(multiprocessing.Process):
    def __init__(self,count):
        multiprocessing. Process.__init__(self)
        self.count = count
    def run(self):
        while self.count > 0:
            print "Counting down", self.count
            self.count -= 1
            time.sleep(5)
        return
```

- You inherit from Process and redefine run()

example in Python file in PyCharm

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Multiprocessing Module

Launching Processes

- To launch, same idea as with threads

```
if __name__ == '__main__':
    p1 = CountdownProcess(10)  # Create the process object
    p1.start()                 # Launch the process

    p2 = CountdownProcess(20)   # Create another process
    p2.start()                  # Launch
```

- Processes execute until run() stops
- A critical detail : Always launch in main as shown (required for Windows)

example in Python file in PyCharm

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Multiprocessing Module

Functions as Processes

- Alternative method of launching processes

```
def countdown(count):
    while count > 0:
        print "Counting down", count
        count -= 1
        time.sleep(5)

if __name__ == '__main__':
    p1 = multiprocessing.Process(target=countdown,
                                 args=(10,))
p1.start()
```

- Creates a Process object, but its run() method just calls the given function

example in Python file in PyCharm

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Multiprocessing Module

Does it Work?

- Consider this CPU-bound function

```
def count(n):
    while n > 0:
        n -= 1
```

- Sequential Execution:

```
count(100000000)
count(100000000)
```

→ 24.6s

- Multiprocessing Execution

```
p1 = Process(target=count,args=(100000000,))
p1.start()
p2 = Process(target=count,args=(100000000,))
p2.start()
```

→ 12.5s

- Yes, it seems to work

example in Python file in PyCharm

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Multiprocessing Module

Other Process Features

- Joining a process (waits for termination)

```
p = Process(target=somefunc)
p.start()
...
p.join()
```

- Making a daemonic process

```
p = Process(target=somefunc)
p.daemon = True
p.start()
```

- Terminating a process

```
p = Process(target=somefunc)
...
p.terminate()
```

- These mirror similar thread functions

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Multiprocessing Module

Distributed Memory

- With multiprocessing, there are no shared data structures
- Every process is completely isolated
- Since there are no shared structures, forget about all of that locking business
- Everything is focused on messaging

Some are implemented in later versions of Python e.g. > 3.0

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Multiprocessing Module - Pipes

Pipes in Multiprocessing Module

Pipes

- A channel for sending/receiving objects

```
(c1, c2) = multiprocessing.Pipe()
```

- Returns a pair of connection objects (one for each end-point of the pipe)
- Here are methods for communication

```
c.send(obj)              # Send an object
c.recv()                 # Receive an object

c.send_bytes(buffer)     # Send a buffer of bytes
c.recv_bytes([max])      # Receive a buffer of bytes

c.poll([timeout])        # Check for data
```


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Pipes in Multiprocessing Module

Using Pipes

- The Pipe() function largely mimics the behavior of Unix pipes
- However, it operates at a higher level
- It's not a low-level byte stream
- You send discrete messages which are either Python objects (pickled) or buffers

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Pipes in Multiprocessing Module

Pipe Example

- A simple data consumer

```
def consumer(p1, p2):
    p1.close()   # Close producer's end (not used)
    while True:
        try:
            item = p2.recv()
        except EOFError:
            break
        print item      # Do other useful work here
```

- A simple data producer

```
def producer(sequence, output_p):
    for item in sequence:
        output_p.send(item)
```


example in
Python file
in PyCharm

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Pipes in Multiprocessing Module

Pipe Example

```
if __name__ == '__main__':
    p1, p2 = multiprocessing.Pipe()

    cons = multiprocessing.Process(
               target=consumer,
               args=(p1,p2))
    cons.start()

    # Close the input end in the producer
    p2.close()

    # Go produce some data
    sequence = xrange(100)  # Replace with useful data
    producer(sequence, p1)

    # Close the pipe
    p1.close()
```


example in Python file in PyCharm

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Multiprocessing Module - Queues

Queue in Multiprocessing Module

Message Queues

- multiprocessing also provides a queue
- The programming interface is the same

```
from multiprocessing import Queue

q = Queue()
q.put(item)        # Put an item on the queue
item = q.get()     # Get an item from the queue
```

- There is also a joinable Queue

```
from multiprocessing import JoinableQueue

q = JoinableQueue()
q.task_done()      # Signal task completion
q.join()           # Wait for completion
```


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Queue in Multiprocessing Module

Queue Implementation

- Queues are implemented on top of pipes
- A subtle feature of queues is that they have a "feeder thread" behind the scenes
- Putting an item on a queue returns immediately (allowing the producer to keep working)
- The feeder thread works on its own to transmit data to consumers

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Queue in Multiprocessing Module

Queue Example

- A consumer process

```
def consumer(input_q):
    while True:
        # Get an item from the queue
        item = input_q.get()
        # Process item
        print item
        # Signal completion
        input_q.task_done()
```

- A producer process

```
def producer(sequence,output_q):
    for item in sequence:
        # Put the item on the queue
        output_q.put(item)
```


example in Python file in PyCharm

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Queue in Multiprocessing Module

Queue Example

- Running the two processes

```
if __name__ == '__main__':
    from multiprocessing import Process, JoinableQueue
    q = JoinableQueue()

    # Launch the consumer process
    cons_p = Process(target=consumer,args=(q,))
    cons_p.daemon = True
    cons_p.start()

    # Run the producer function on some data
    sequence = range(100)    # Replace with useful data
    producer(sequence,q)

    # Wait for the consumer to finish
    q.join()
```


example in Python file in PyCharm

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Queue in Multiprocessing Module

Commentary

- If you have written threaded programs that strictly stick to the queuing model, they can probably be ported to multiprocessing
- The following restrictions apply
  - Only objects compatible with pickle can be queued
  - Tasks can not rely on any shared data other than a reference to the queue

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Queue in Multiprocessing Module

Other Features

- multiprocessing has many other features
  - Process Pools
  - Shared objects and arrays
  - Synchronization primitives
  - Managed objects
  - Connections
- Will briefly look at one of them

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Multiprocessing Module - Process Pools

Process Pools in Multiprocessing Module

Process Pools

- Creating a process pool

```
p = multiprocessing.Pool([numprocesses])
```

- Pools provide a high-level interface for executing functions in worker processes
- Let's look at an example...

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Process Pools in Multiprocessing Module

Pool Example

- Define a function that does some work
- Example : Compute a SHA-512 digest of a file

```
import hashlib

def compute_digest(filename):
    digest = hashlib.sha512()
    f = open(filename,'rb')
    while True:
        chunk = f.read(8192)
        if not chunk: break
        digest.update(chunk)
    f.close()
    return digest.digest()
```

- This is just a normal function (no magic)

example in Python file in PyCharm

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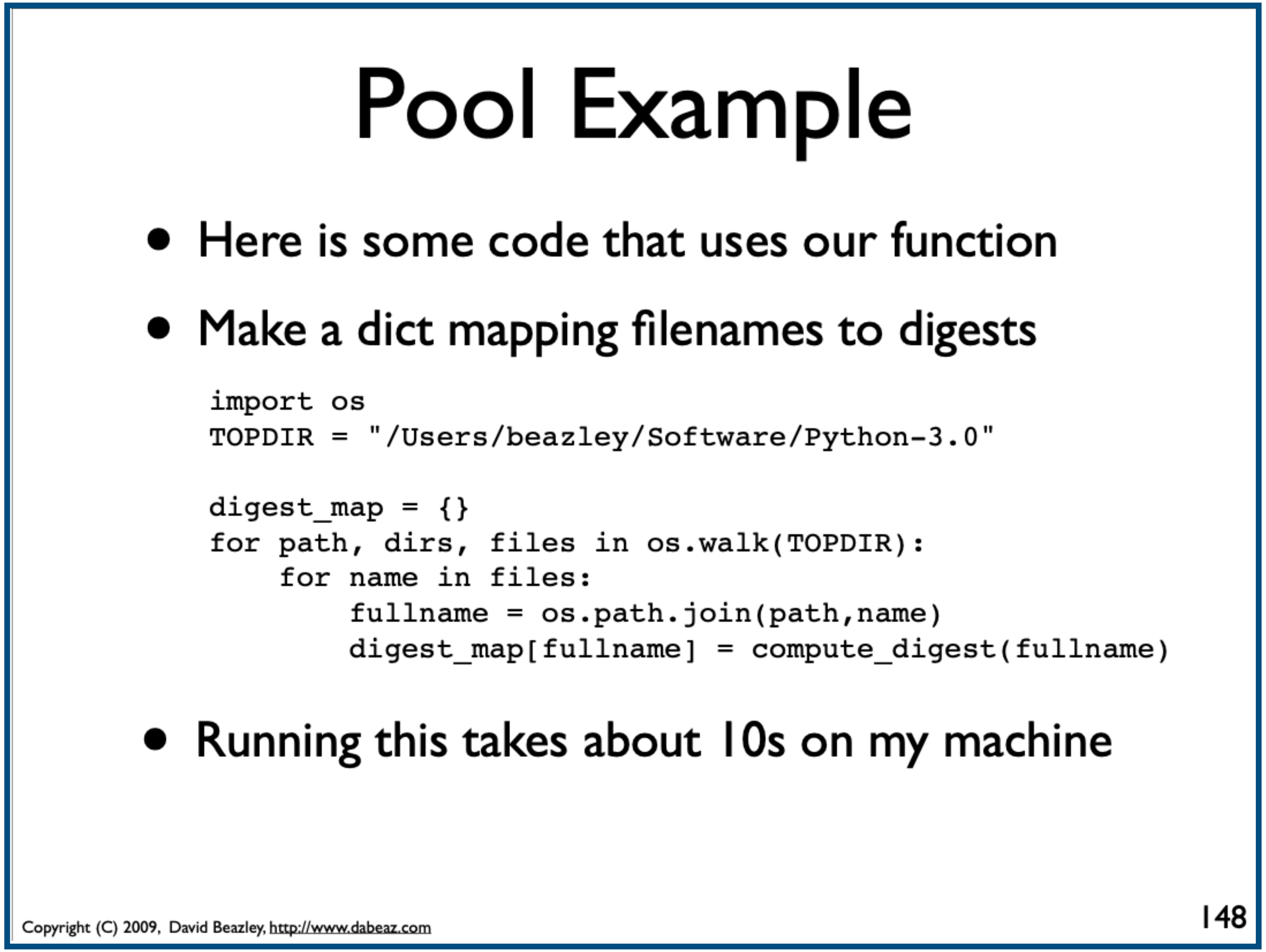
Process Pools in Multiprocessing Module



example in Python file in PyCharm

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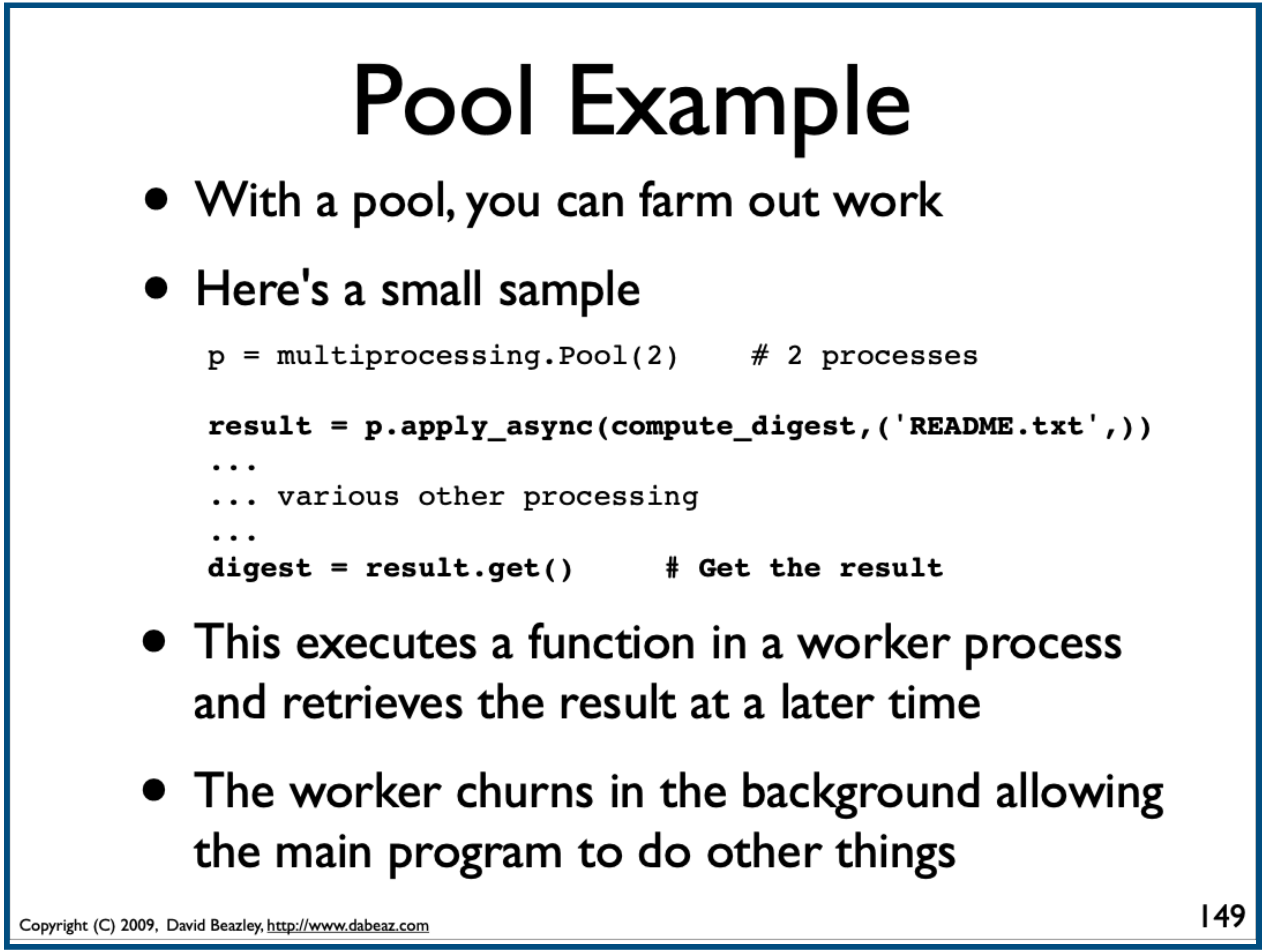
Process Pools in Multiprocessing Module



Pool Example

- With a pool, you can farm out work
- Here's a small sample

```
p = multiprocessing.Pool(2)    # 2 processes

result = p.apply_async(compute_digest,('README.txt',))
...
... various other processing
...
digest = result.get()      # Get the result
```

- This executes a function in a worker process and retrieves the result at a later time
- The worker churns in the background allowing the main program to do other things

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example in Python file in PyCharm

Process Pools in Multiprocessing Module

Pool Example

- Make a dictionary mapping names to digests

```
import multiprocessing
import os
TOPDIR = "/Users/beazley/Software/Python-3.0"

p = multiprocessing.Pool(2)      # Make a process pool
digest_map = {}
for path, dirs, files in os.walk(TOPDIR):
    for name in files:
        fullname = os.path.join(path,name)
        digest_map[fullname] = p.apply_async(
              compute_digest, (fullname,)
        )

# Go through the final dictionary and collect results
for filename, result in digest_map.items():
    digest_map[filename] = result.get()
```

- This runs in about 5.6 seconds

example in
Python file
in PyCharm

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Resources

- **An Introduction to Python Concurrency**. http://www.dabeaz.com/usenix2009/concurrent/index.html
- **Slides on Concurrency** http://www.dabeaz.com/usenix2009/concurrent/Concurrent.pdf
- **Python Multiprocessing: The Complete Guide** https://superfastpython.com/multiprocessing-in-python/

The End