# Python threads: Dive into GIL!

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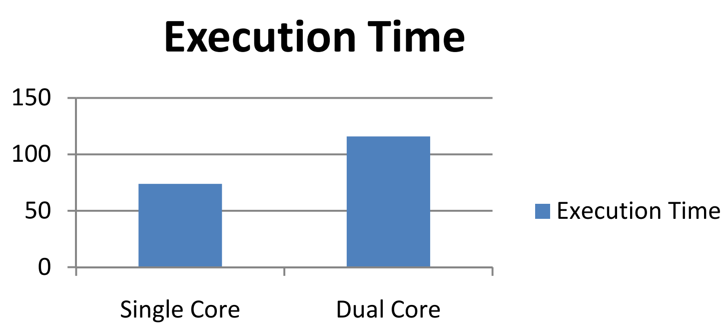
# A jaw dropping example!

- A simple python program – single function performing two operations for 10000000 iterations:
  - Divides two random numbers from specified range
  - Multiplies two random numbers from specified range
  - Called as two different threads on:
    - Single Core
    - Dual Core


| Python v2.7 | Execution Time |
|---|---|
| Single Core | 74 s |
| Dual Core | 116 s |

**57 % dip in Execution Time on dual core??!!**

# Abstract


- Benefit of multi-threaded application grows with ubiquity of multi-core architecture that potentially can simultaneously run multiple threads of execution.
- Python supports multi-threaded applications and developers are flocking to realize the assured gain of multiple cores with threaded applications.
- Unfortunately, Python has significant bottleneck for multi-threading.

- Any thread in CPython interpreter requires a special lock (GIL) which results in serial, rather than parallel execution of multi-threaded applications, irrespective of cores availability and design techniques.
- This talk focuses on the problem, dissects the root cause and its implications.

# Threads: Fundamentals

- Fundamental to a multi-tasking application
- Smallest possible, independent unit of execution
- Light weight processes (resource sharing including address space)
- Concurrent execution
  - Uni-core processor: Single thread at a time; Time division multiplexing
  - Multi-core processor: Threads run at the same time
- CPU bound and I/O bound

# Python Threads

- Real system threads (POSIX/ Windows threads)
- Python VM has no intelligence of thread management (priorities, pre-emption, and so on)
- Native operative system supervises thread scheduling
- Python interpreter just does the per-thread bookkeeping.

# Python threads: internals

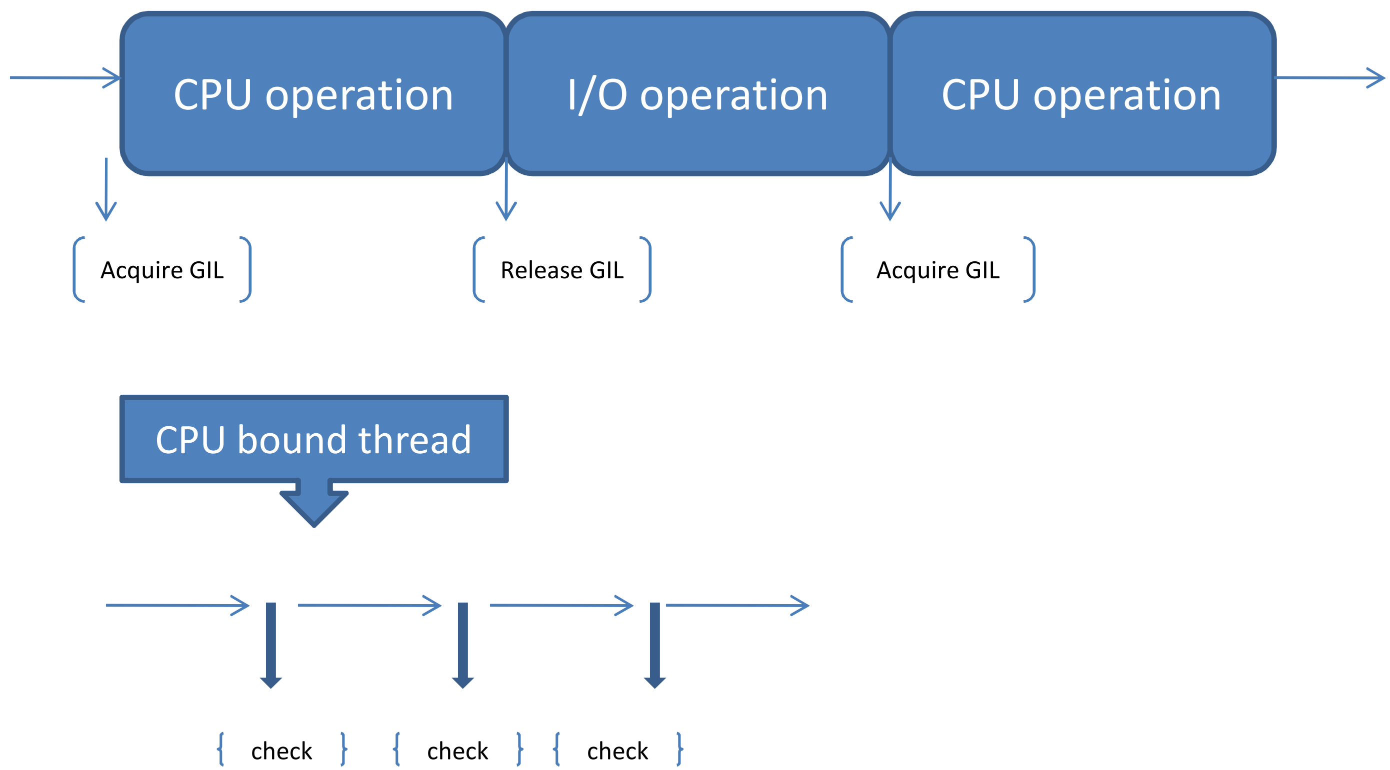
- Only one thread can be active in Python interpreter
- Each ‘running’ thread requires exclusive access to data structures in Python interpreter
- Global interpreter lock (GIL) provides this exclusive synchronization
- This lock is necessary mainly because CPython's memory management is *not* thread-safe.
- **Result**
  - A thread waits if another thread is holding the GIL, even on a multi-core processor! So, threads run sequentially, instead of parallel!

# Python threads

- How do Python manages GIL?
  - Python interpreter *regularly* performs a check


- A check is done after ‘n’ ticks.
  - It maps to ‘n’ number of Python VM’s byte-code instructions
  - A global counter; Ticks decrement as a thread executes
- As soon as ticks reach zero:
  - the active thread ***releases and reacquires*** the GIL
  - Signal handling (only in the main thread)
- Effectively, ticks dictate allowed CPU time-slice available to a thread
- Is independent of host/native OS scheduling
- Can be set with sys.setcheckinterval(*interval*)

# Python thread: internals



# GIL: Details and Bottleneck

- GIL is a conditional variable.
- What goes behind the scene?
  - If GIL is unavailable, a thread goes to sleep and wait.
  - At every ‘check’, a thread release the GIL, and tries to re-acquire
- GIL release is accompanied with a request to host OS to signal all waiting threads
- Regular GIL unlock, thread signaling, wake-up, and GIL relock are an expensive series of operations
- **Threads effectively run in the serial order**

# GIL: Battle in multi-cores

- Unlike single core, multiple cores allows the host OS to schedule many threads concurrently
- A thread that had just released the GIL, will send a signal to waiting threads (through host OS) and is ready to acquire the GIL again!
- This is a GIL contention among all threads

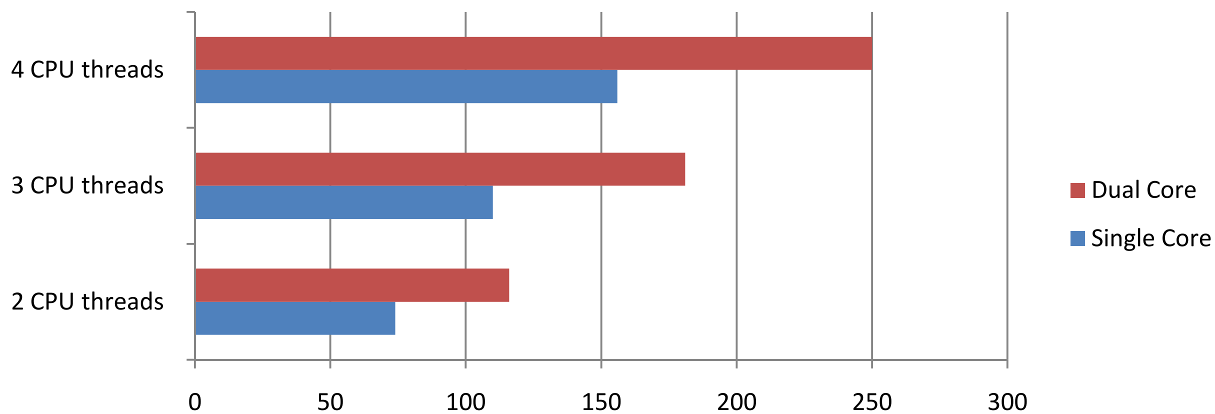
# GIL: Battle continues…

- There is considerable time lag of
  - Communication
  - Signal-handling
  - Thread wake-up
  - and acquire GIL
- These factors along with cache-hotness of influence new GIL owner which is usually the recent owner!
- In a [CPU,I/O]-bound mixed application, if the previous owner happens to be a CPU-bound thread, I/O bound thread starves!
  - Since I/O bound threads are preferred by OS over CPU-bound thread; Python presents a priority inversion on multi-core systems.

# Threads performance

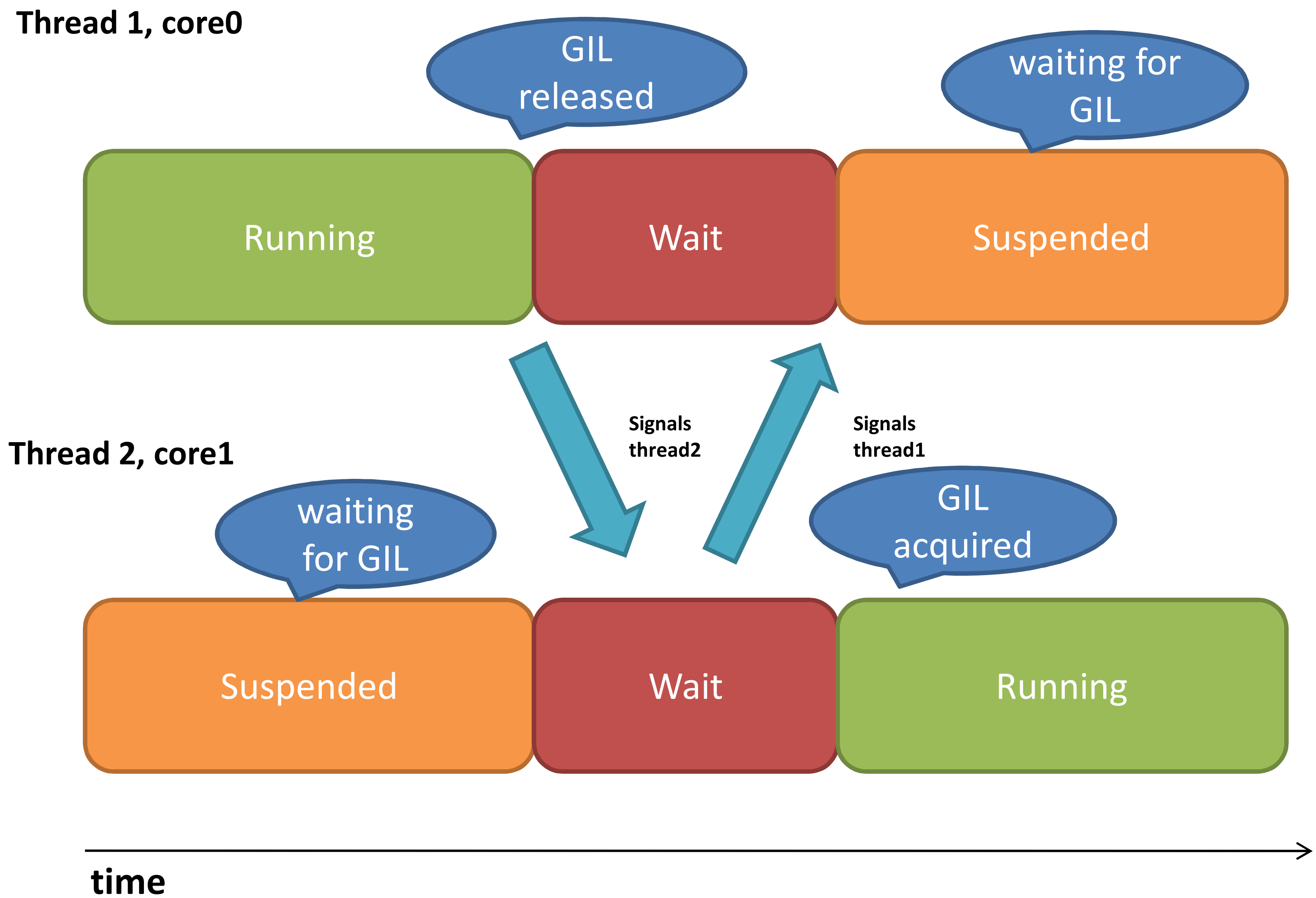
- Performance = f(cores, threads)
- Let's look at Execution Times (in secs):

| Python v2.7 | 2 CPU threads | 3 CPU threads | 4 CPU threads |
|---|---|---|---|
| Single Core | 74 s | 110 s | 156 s |
| Dual Core | 116 s | 181 s | 246 s |



# New GIL: Python v3.2

- Tries to avoid GIL battle. How?
- Regular “check” are discontinued and replaced with a time-out.
    - Default time-out= 5ms
    - Configurable through sys.setswitchinterval()
- For every time-out, current GIL holder, is forced to release it, signals the waiting threads and, *waits for a signal from the new owner of GIL*.
    – A thread does not compete for GIL in succession
- A sleeping thread wakes up, acquires the GIL, and signals the last owner.
- New GIL ensures that every thread gets a chance to run (on a multi-core system)



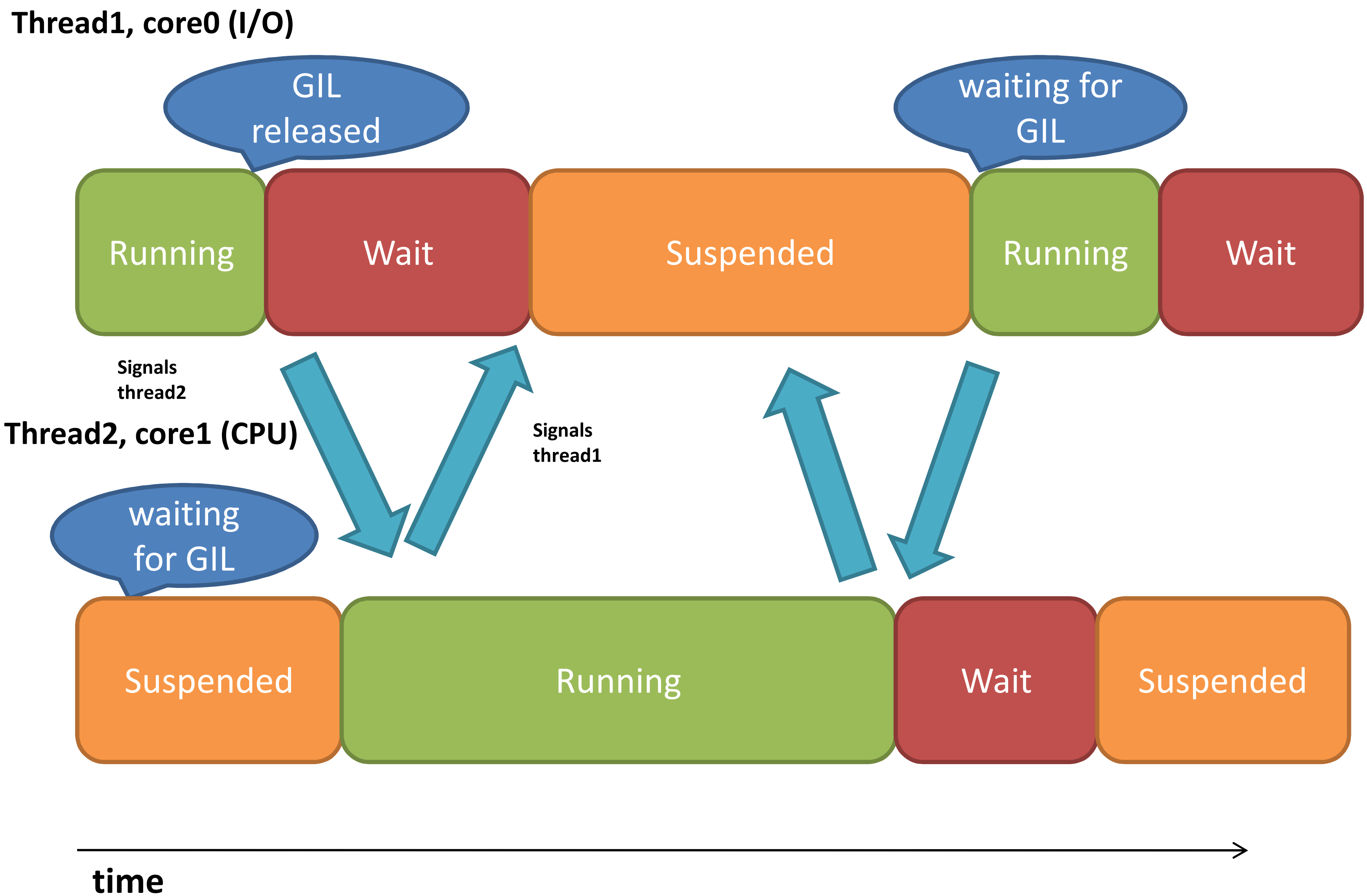
Thread 1, core0
GIL released
waiting for GIL
Running
Wait
Suspended
Signals thread2
Signals thread1
Thread 2, core1
waiting for GIL
GIL acquired
Suspended
Wait
Running
time

# Python v3.2: What’s good?

- More responsive threads
- Less overhead, lower lock contention
- No GIL battle
- All iz well☺

# New GIL: All is not well

- Convoy effect- observed in an application comprising I/O-bound and CPU-bound threads
- A side-effect of an optimization in Python interpreter
  - Release the GIL before executing an I/O service (read, write, send, recv calls)
- When an I/O thread releases the GIL, another ‘runnable’ CPU bound thread can acquire it (remember we are on multiple cores).
- It leaves the I/O thread waiting for another time-out (5ms)!
- Once CPU thread releases GIL, I/O thread acquires and release it again
- This cycle goes on => performance suffers ☹


Thread1, core0 (I/O)
GIL released
waiting for GIL
Running
Wait
Suspended
Running
Wait
Signals thread2
Thread2, core1 (CPU)
Signals thread1
waiting for GIL
Suspended
Running
Wait
Suspended
time

# Convoy effect

- Adversely impacts an I/O thread, if application has a CPU thread(s)
- Voluntary relinquish of GIL proves fatal for I/O thread's performance
- We performed following tests with Python3.2:
  - CPU thread spends less than few seconds (<10s)!

| I/O thread with CPU thread | I/O thread without CPU thread |
| --- | --- |
| 97 seconds | 23 seconds |

# Convoy effect: Python v2?

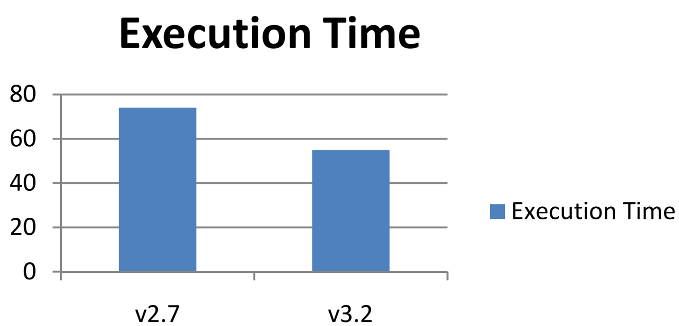
- Convoy effect holds true for Python v2 also
- The smaller interval of ‘check’ saves the day!
  - I/O threads don’t have to wait for a longer time (5 m) for CPU threads to finish
  - Should choose the setswitchinterval() wisely
- The effect is not so visible in Python v2.0

# Comparing: Python 2.7 & Python 3.2

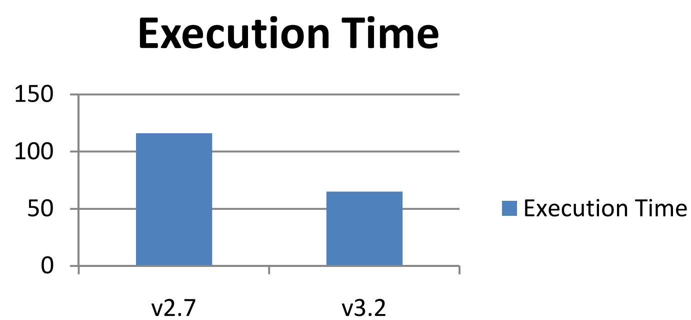
| Python v2.7 | Execution Time |
|---|---|
| Single Core | 74 s |
| Dual Core | 116 s |

| Python v3.2 | Execution Time |
|---|---|
| Single Core | 55 s |
| Dual Core | 65 s |

**On Single Core**




**On Dual Core**



# Solving GIL problems

- Thought #1: reduce the waiting time interval between threads.
  - Caveat: increases the overhead of context switching between threads
- Thought #2: implement GIL with C API extensions
  - Caveat: Lot of rework involved
- Thought #3: allow running of I/O threads with GIL if they are not blocking other threads.
  - Caveat: to be analyzed

# Jython: GIL

- Jython is free of GIL
- It can fully exploit multiple cores, as per our experiments
- Experiments with Jython2.5
  - Run with two CPU threads in tandem

| Jython2.5 | Execution time |
|---|---|
| Single core | 44 s |
| Dual core | 25 s |

- Experiment shows performance improvement on multi-core system

# Conclusion

- Multi-core systems are becoming ubiquitous
- Python application should exploit this abundant power
- Python inherently suffers the GIL limitation
- An intelligent awareness of Python interpreter behavior is helpful in developing multi-threaded applications
- Understand and use ☺

# References


- Understanding the Python GIL, http://dabeaz.com/talks.html
- GlobalInterpreterLock, http://wiki.python.org/moin/GlobalInterpreterLock
- Thread State and the Global Interpreter Lock, http://docs.python.org/c-api/init.html#threads
- Python v3.2.2 documentation, http://docs.python.org/py3k/
- Concurrency and Python, http://drdobbs.com/open-source/206103078?pgno=3

# Backup slides

# Python: GIL

- A thread needs GIL before updating Python objects, calling C/Python API functions
- Concurrency is emulated with regular 'checks' to switch threads
- Applicable to only CPU bound thread
- A blocking I/O operation implies relinquishing the GIL
  - ./Python2.7.5/Include/ceval.h

    *Py_BEGIN_ALLOW_THREADS*

    *Do some blocking I/O operation ...*

    *Py_END_ALLOW_THREADS*
- Python file I/O extensively exercise this optimization

# GIL: Internals

- The function Py_Initialize() creates the GIL
- A thread create request in Python is just a pthread_create() call
- ../Python/ceval.c
- static PyThread_type_lock interpreter_lock = 0; /* This is the GIL */
- o) thread_PyThread_start_new_thread: we call it for "each" user defined thread.
- calls PyEval_InitThreads() -> PyThread_acquire_lock() {}

# GIL: in action

- Each CPU bound thread requires GIL
- ‘ticks count’ determine duration of GIL hold
- new_threadstate() -> tick_counter
- We keep a list of Python threads and each thread-state has its tick_counter value
- As soon as tick decrements to zero, the thread release the GIL.

# GIL: Details

```
thread_PyThread_start_new_thread() ->
void PyEval_InitThreads(void)
{
    if (interpreter_lock)
        return;
    interpreter_lock = PyThread_allocate_lock();
    PyThread_acquire_lock(interpreter_lock, 1);
    main_thread = PyThread_get_thread_ident();
}
```