Beyond the GIL: Python's Journey to Free Threading

RND Light Talk, July 2025

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Timeline

- 1991: Python 0.9.0

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- 2007: python-safethread (Adam Olsen)
- 2016: Gilectomy (Larry Hastings)

Timeline

- 2021: nogil (Sam Gross)

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- 2021: nogil (Sam Gross)
- 2023: PEP 703 published (Jan 2023)

PEP 703 – Making the Global Interpreter Lock Optional in CPython

Author:	Sam Gross <colesbury at gmail.com>
Sponsor:	Łukasz Langa <lukasz at python.org>
Discussions-To:	Discourse thread
Status:	Accepted
Type:	Standards Track
Created:	09-Jan-2023
Python-Version:	3.13
Post-History:	09-Jan-2023, 04-May-2023
Resolution:	24-Oct-2023

Source: https://peps.python.org/pep-0703

Timeline

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- 2023: Meta supports and commits three engineer-years through 2025

A fast, free threading Python

Ideas

Carl Meyer carljm CPython core developer Jul 2023

> Guido van Rossum:
>
> it would be great if Meta or another tech company could spare some engineers with established CPython internals experience to help the core dev team with this work.

We've had a chance to discuss this internally with the right people. Our team believes in the value that nogil will provide, and we are committed to working collaboratively to improve Python for everyone.

If PEP 703 is accepted, Meta can commit to support in the form of three engineer-years (from engineers experienced working in CPython internals) between the acceptance of PEP 703 and the end of 2025, to collaborate with the core dev team on landing the PEP 703 implementation smoothly in CPython and on ongoing improvements to the compatibility and performance of nogil CPython.

Source: https://discuss.python.org/t/a-fast-free-threading-python/27903/99

Timeline

- 2023: PEP 703 **accepted** with clear proviso (Oct 2023)

Note

The Steering Council accepts PEP 703, but with clear proviso: that the rollout be gradual and break as little as possible, and that we can roll back any changes that turn out to be too disruptive – which includes potentially rolling back all of PEP 703 entirely if necessary (however unlikely or undesirable we expect that to be).

Source: https://peps.python.org/pep-0703

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    - Not **experimental**, not yet the default build
- 2030~: Python default build?

> ***The free-threaded mode is experimental*** *and work is ongoing to improve it: expect some bugs and a substantial single-threaded performance hit.*

Source: https://docs.python.org/3/howto/free-threading-python.html

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- Now, after years of effort, **free-threaded Python** is becoming real

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- Especially limited when using **threads** on multi-core machines
- The **GIL** has been a long-standing pain point
- Now, after years of effort, **free-threaded Python** is becoming real
- Let's talk about what it means — and why it's exciting

The Global Interpreter Lock (GIL)

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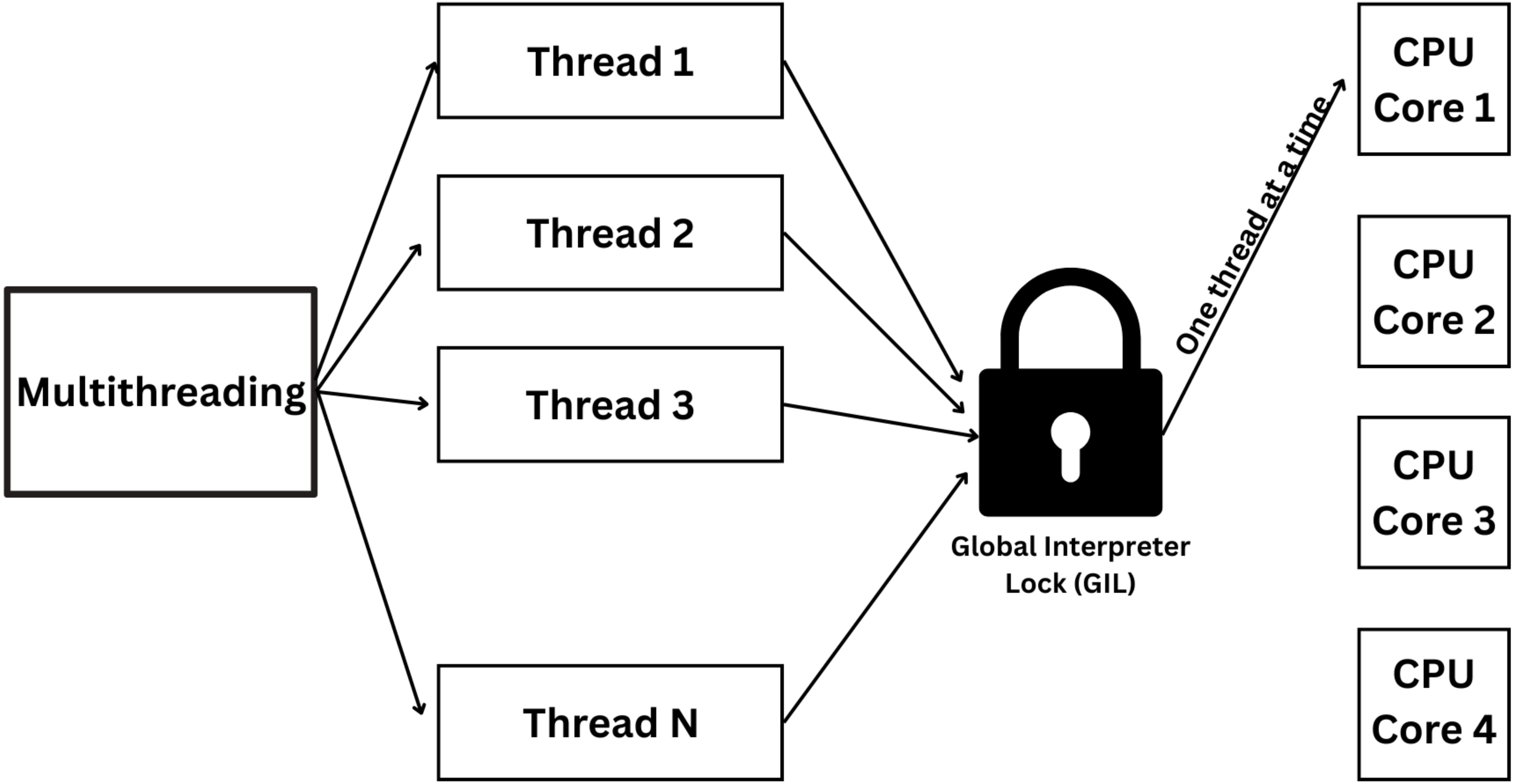
- Global lock in CPython
- Blocks true multi-core parallelism
- Key reason behind Python’s single-thread limitations



Source: https://www.codecademy.com/article/understanding-the-global-interpreter-lock-gil-in-python

```
$ uv python install 3.14t
Installed Python 3.14.0a6 in 15ms
 + cpython-3.14.0a6+freethreaded-linux-x86_64-gnu
```

```python
import time
from concurrent.futures import ThreadPoolExecutor

N = 50_000_000
THREADS = 10

def work(n):
    for _ in range(n):
        pass

start = time.time()

with ThreadPoolExecutor(max_workers=THREADS) as pool:
    list(pool.map(work, [N] * THREADS))

```

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print(f"Done in {time.time() - start:.2f} sec")
```

```
$ uv run --python=3.14t python demo.py
Done in 2.21 sec
$ uv run --python=3.14 python demo.py
Done in 7.90 sec
```

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- Simpler memory management
- Ensures thread safety in CPython
- Made sense in single-core era (Moore's law etc.)

GIL and Thread Safety

- Prevents data corruption

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- Protects internal Python objects

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- Prevents data corruption
- Protects internal Python objects
- Not all race conditions eliminated

The GIL in the Multi-Core Era

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- GIL bottlenecks CPU-bound apps
- Wastes hardware potential

Bypassing the GIL

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- Asyncio → concurrency in one thread

The Goal — Free-Threaded Python

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- **True** multi-core parallelism
- **Preserve** single-thread speed
- Unlock Python’s full performance

Challenges

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- Containers

Reference Counting

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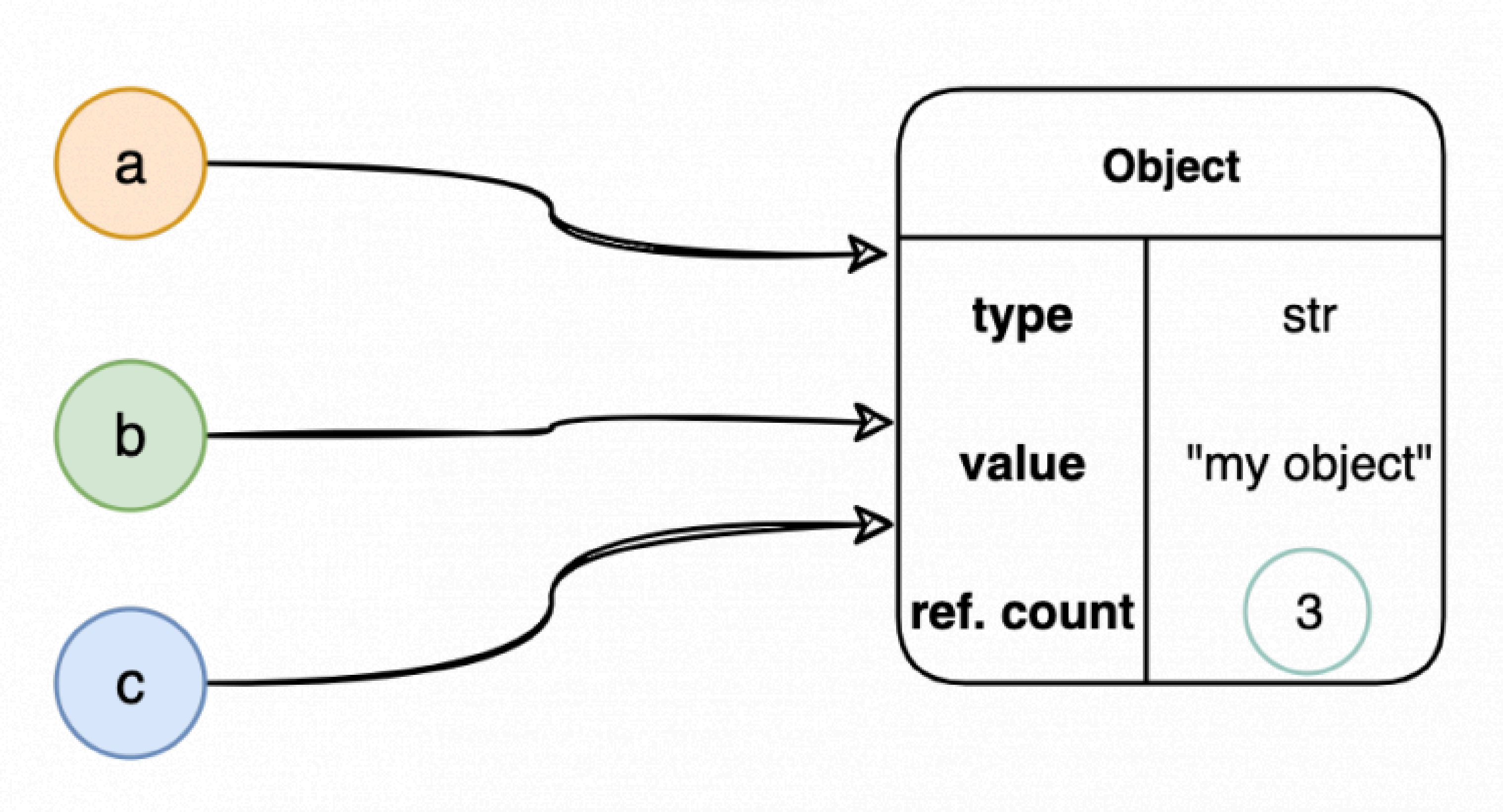
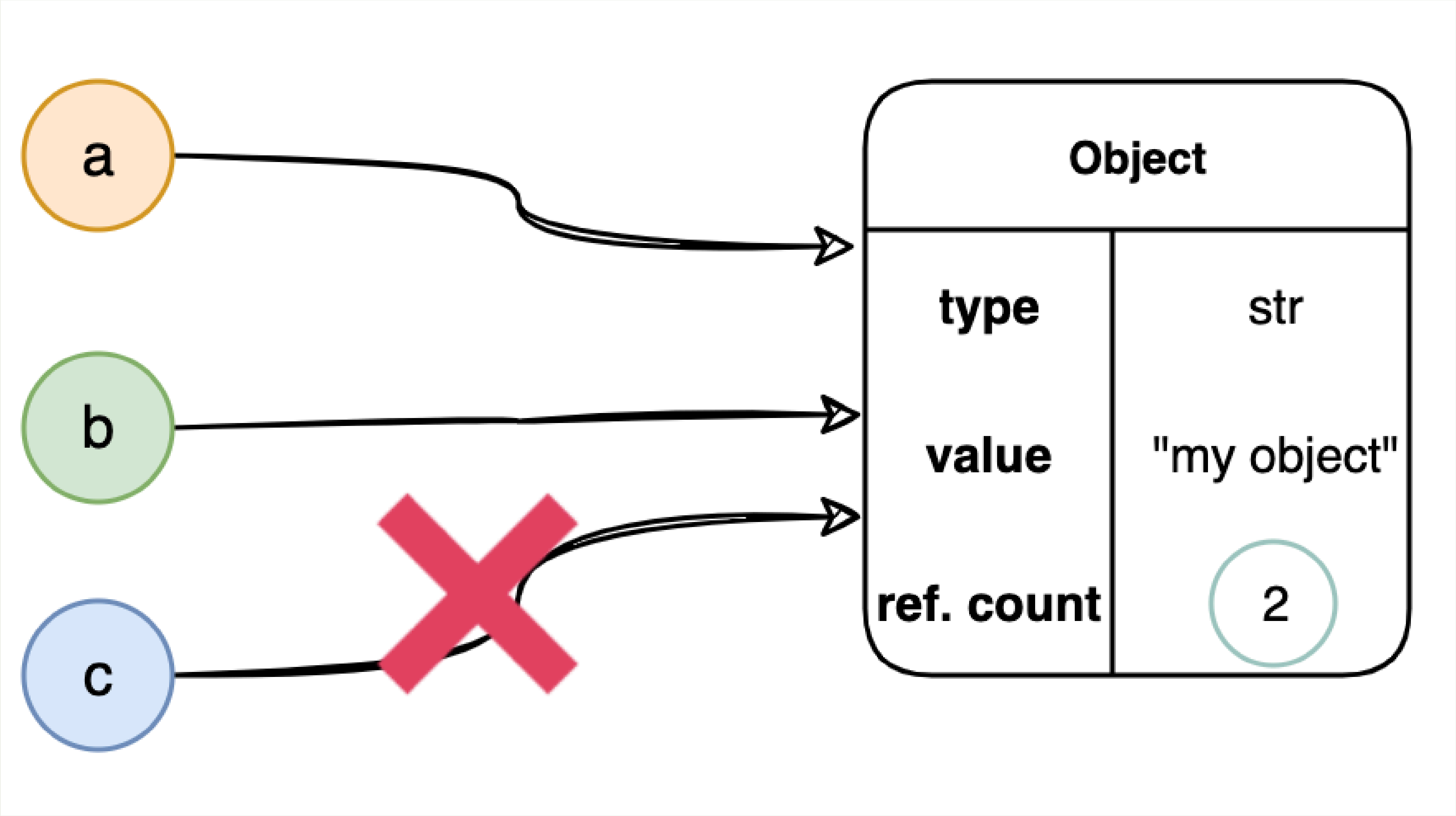
- When it hits zero — the object is immediately freed



Source: https://jenaiz.com/2022/02/understanding-how-the-python-garbage-collector-works/



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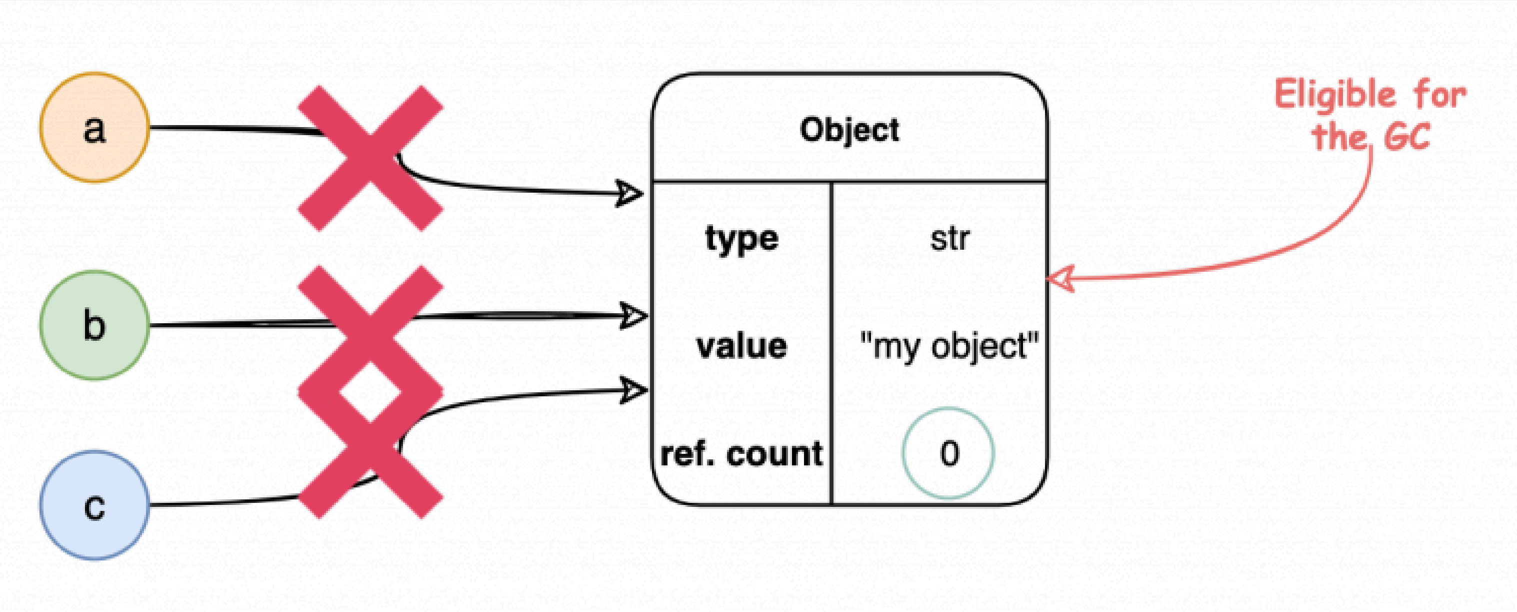

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Why Reference Counting Is a Problem

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- GIL protects those updates today
- Without GIL → race conditions

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- Fast for owning thread
- Atomic ops only when needed

```c
struct _object {
  _PyObject_HEAD_EXTRA
  uintptr_t ob_tid;          // owning thread id (4-8 bytes)
  uint16_t __padding;        // reserved for future use (2 bytes)
  PyMutex ob_mutex;          // per-object mutex (1 byte)
  uint8_t ob_gc_bits;        // GC fields (1 byte)
  uint32_t ob_ref_local;     // local reference count (4 bytes)
  Py_ssize_t ob_ref_shared; // shared reference count and state bits (4-8 bytes)
  PyTypeObject *ob_type;
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  - `True`, `False`, `None`, small integers, etc.
- Skip reference count updates
- Reduce thread contention

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- GC handles cleanup later
- Used for code, functions, modules

Garbage Collection (GC)

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- Uses **generational GC**: objects are grouped by age; older ones are scanned less often

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- “Stop-the-world” GC needed
    - All threads pause during collection to avoid race conditions

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  - **Generational GC is less critical** in Python — young objects are usually cleaned up early via **reference counting**
- Integration with deferred and biased reference counting

Locking and atomic APIs

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- Using **multiple locks** can cause **deadlocks** (e.g., double locks)
- Python uses **critical sections locked on individual objects**
    - Lock acquired only when accessing that object
    - Released if thread needs another lock or pauses (e.g., for blocking I/O)

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```c
Py_BEGIN_CRITICAL_SECTION(a->ob_mutex);
item = a->ob_item[i];
Py_INCREF(item);
Py_END_CRITICAL_SECTION(a->ob_mutex);
```

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- **Read-write locks** are expensive and complex
  - Instead, Python prefers **try-fast approaches** with reference count checks
  - Similar to **Read-Copy-Update (RCU)** pattern in Linux for efficient simple field access (e.g., `list[0]`)

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- `list`, `set`, `dict`...
- Per-object locks replace GIL safety
- Read operations may skip locks

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- A **borrowed reference** is a pointer to a Python object you get **without** increasing its reference count
- To keep an object alive beyond immediate use, code must **convert borrowed to owned** by calling `Py_INCREF`

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- Borrowed references were safe under the GIL
  → No other thread could mutate the object in between
- Now unsafe:
  → Another thread might free the object before `Py_INCREF`
  → Leads to **use-after-free** bugs

```c
// 'item' is a borrowed reference returned by PyList_GetItem
PyObject *item = PyList_GetItem(list, idx);

// Another thread might free 'item' here before we increment its refcount

// Trying to increment the refcount to keep 'item' alive
// ❌ Unsafe: 'item' might be already freed, leading to use-after-free
Py_INCREF(item);
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```

Atomic “Fetch” APIs (Slower)

New APIs return **owned references** safely in one step

```
// ✅ Safe – Py_INCREF is done internally
PyObject *item = PyList_FetchItem(list, idx);`
```

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  - Conditionally increment reference count (`Py_INCREF`) if safe
  - Verify no changes during access

Optimistic Fast Access

- Common list/dict accesses **avoid locks** for better speed and scalability
- How it works:
  - Atomically read slots and items
  - Conditionally increment reference count (`Py_INCREF`) if safe
  - Verify no changes during access
- If any check fails, **fallback** acquires a lock to ensure safety

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- Big speedups for multi-threaded programs
- New memory designs keep things safe
- Still the same Python we know
- **But:** Work still in progress, not all code will see speedups yet

Any Questions?

Yonatan Bitton @bityob

linktr.ee/bityob

Sources

- PEP 703 – Making the Global Interpreter Lock Optional in CPython (peps.python.org)
- PEP 779 – Criteria for supported status for free-threaded Python (peps.python.org)
- Python Free-Threading Guide (py-free-threading.github.io)

Learn More

- Multithreaded Python without the GIL - presented by Sam Gross (youtube.com)
- High-Performance Python: Faster Type Checking and Free Threaded Execution (youtube.com)
- Python Docs How To - Python experimental support for free (docs.python.org)