CYCRAFT

Python FFI 的陰暗角落

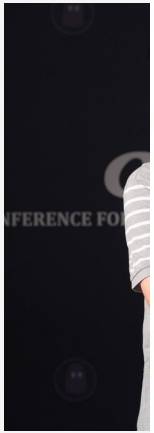
PyCon TW 2025

scc@scc.tw

SCC

SWE @ cycraft

C++ Lover



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超過 10 個回應 · 2 年前

奧義冰淇淋也會出沒在會場，為大家的週末時光增

各大資訊社群活動中 出沒的「奧義冰淇淋」，也將和濁水溪以南最大的
一起強勢回歸啦 炎炎夏日，讓奧義冰淇淋陪您度過逛展會的美好時 ...

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奧義智慧科技是世界頂尖的AI 資安公司，除了 ...

【來MOPCON 想吃奧義冰淇淋～】 今晚，我想來點... 奧義智慧贊助的
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HackMD
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轉生到資安公司的我，竟開啟了遊戲人生？！

奧義智慧科技. 一般人眼中的奧義. 世界頂尖的台灣自研技術AI 資安公司
奧義. 冰淇淋公司. 各大conf 都能看到奧義的冰淇淋. 遊戲公司. 兩款桌遊

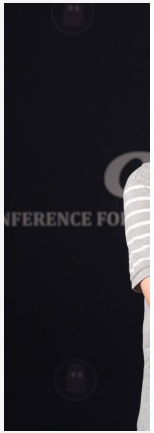
Instagram · mopcon.tw
1 年前

MOPCON 行動科技年會on Instagram: "🖐奧義智慧at ...

奧義智慧再次出沒濁水溪以南最大的行動科技年會MOPCON 啦 今年很遺憾地沒辦法帶
來經典的奧義冰淇淋，但聽說可以到奧義智慧攤位免費獲得大受好評的資安桌 ...

CYCRAFT 奧義智慧科技

先別說冰淇淋了，你聽過奧義智慧嗎？



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來經典的奧義冰淇淋，但聽說可以到奧義智慧攤位免費獲得

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CYBERCONS

為了突出不同產業對於資產防禦的側重，奧義智慧推出八張產業角色卡，分別為半導體業、金融業、政府單位、能源產業、黑色產業、遊戲業、電商產業、醫療業。

《Cybercans 2：紅色動員令》內除了產業角色卡，還能結合第一代的卡牌擴充出全新玩法，可以用更快速、刺激的方式進行攻防體驗。

Download The Slide

Outline

- What is Python FFI
- The Hidden Corner
  - Benchmark ctypes, cffi, pybind11, PyO3
  - Why Free-Threaded Makes Them Slower?
  - Why PyO3 fast, but ctypes slow?
  - Racing FFI after No-GIL
  - Higher Risk for Arena Leakage in GLibc

Background knowledge

- GIL
- Race conditions
- Memory Arena

Slides are heavy, listen first.

The hidden corner you might be aware

- Application level:
  - **GIL Semantics**, **Thread Pinning**, Refcount Edges & Ownership, Error Propagation, Reentrancy…
- OS level:
  - **Race Conditions**, **Dynamic Loading** / lazy binding, **System Libraries Features**, Loader Search Path, Permissions…
- Hardware level:
  - **ABI Compatibility**, **Cache Locality**, Modern CPU Affinity Binding, TLB, Branch Prediction, I/O Topology…

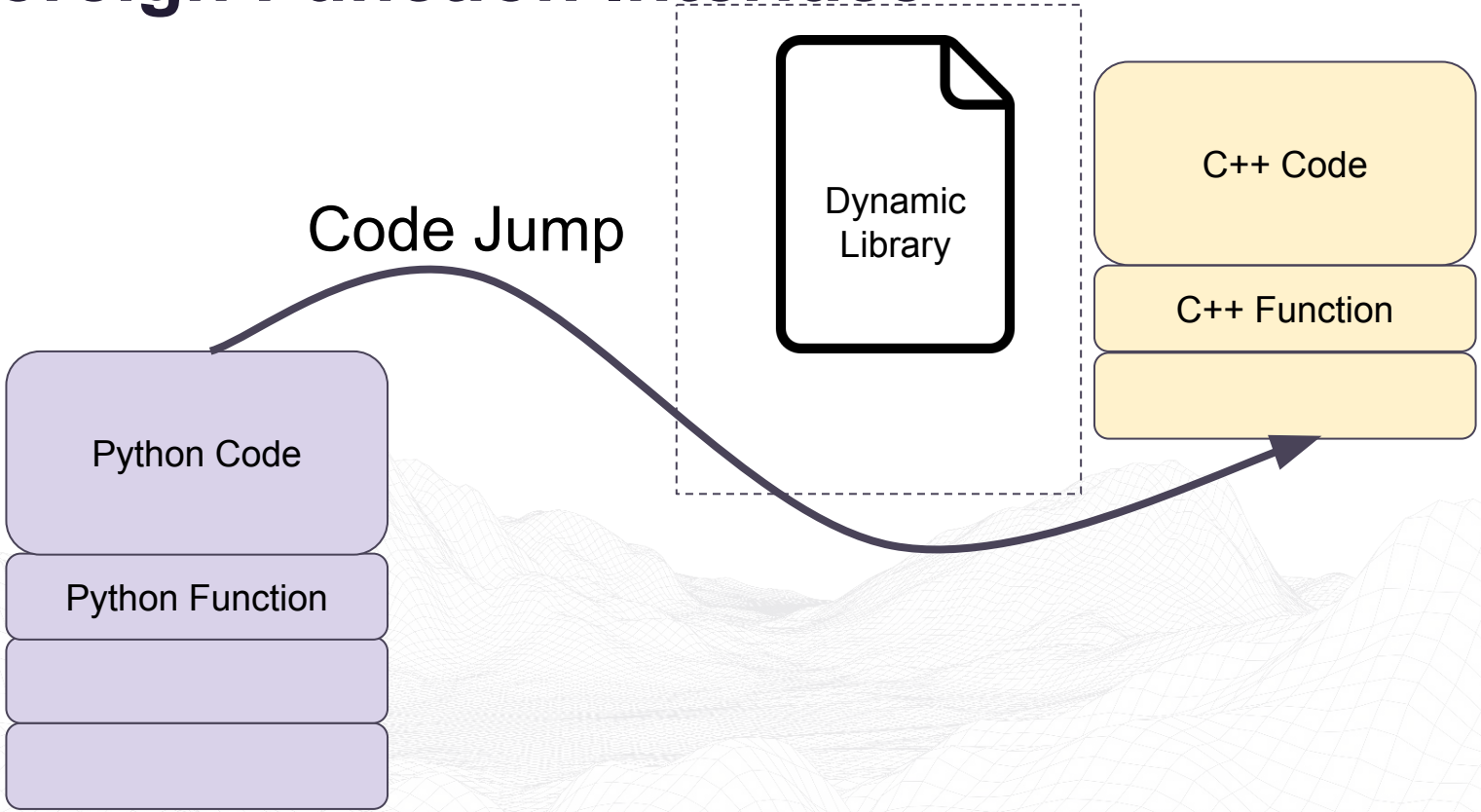
The hidden corner you might be aware

- 💪Reliability Issues:
  - **GIL Semantics**, **Thread Pinning**, **Race Conditions**, **ABI Compatibility**,

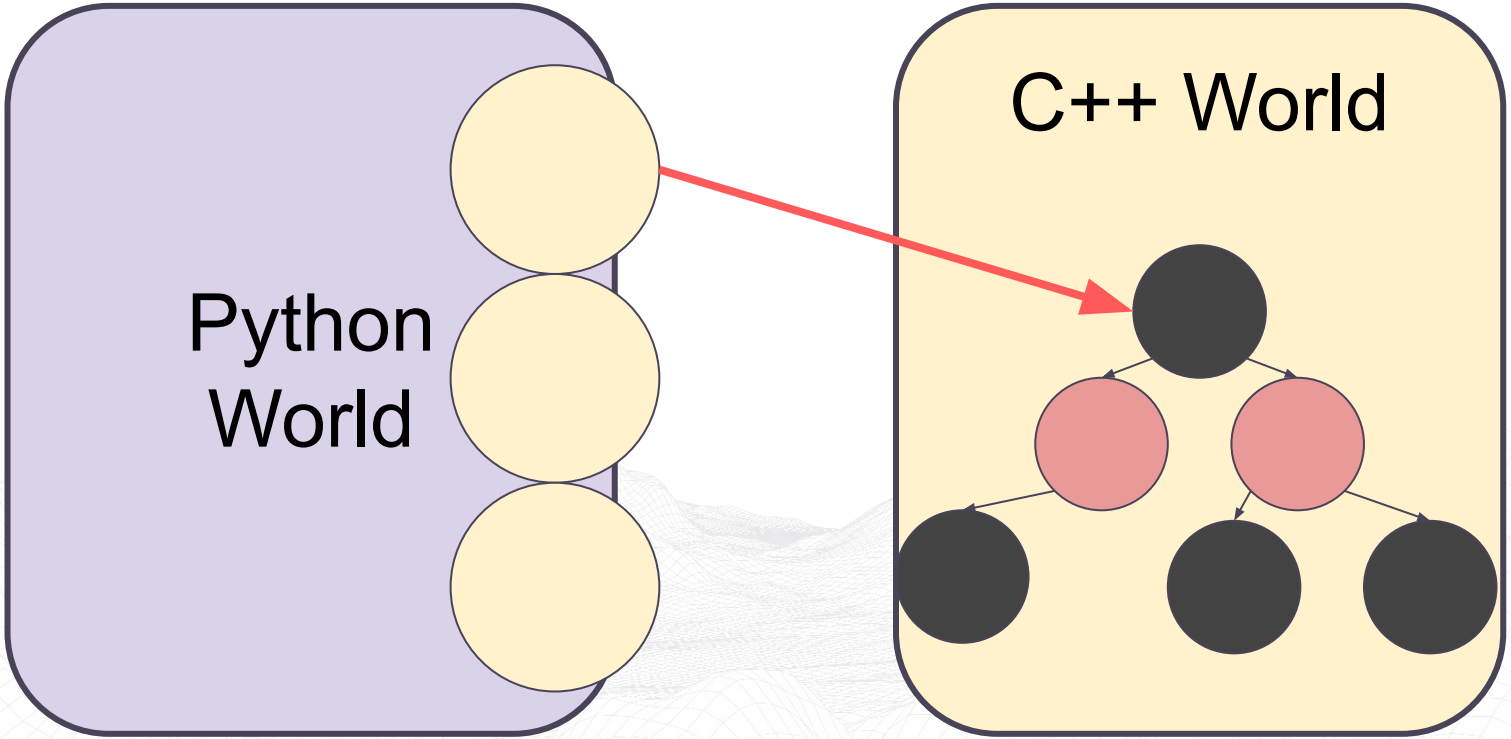
- 🚀Performance Issues:
  - **Dynamic Loading**, **System Libraries Features**, **Cache Locality**,

What is Python FFI

Foreign Function Interface



Why this issue



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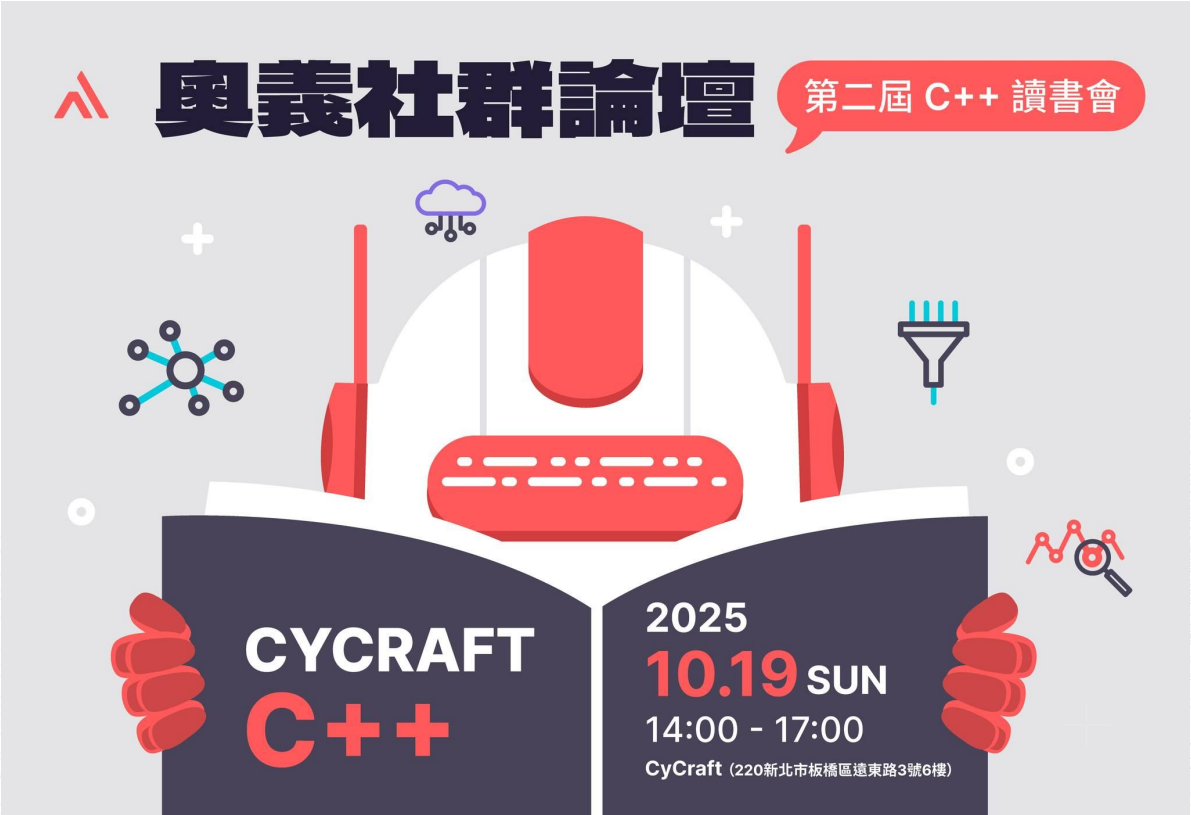

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The Hidden Corner

Benchmark ctypes, cffi, pybind11, PyO3

Linux 6.15.9-arch1-1, isolcpus=2-7 nohz_full=2-7 rcu_nocbs=2-7

i5-13500 (2.5G lock freq), 32G DDR4-3200

Disable Turbo Boost, SMT/Hyper-Threading, ASLR

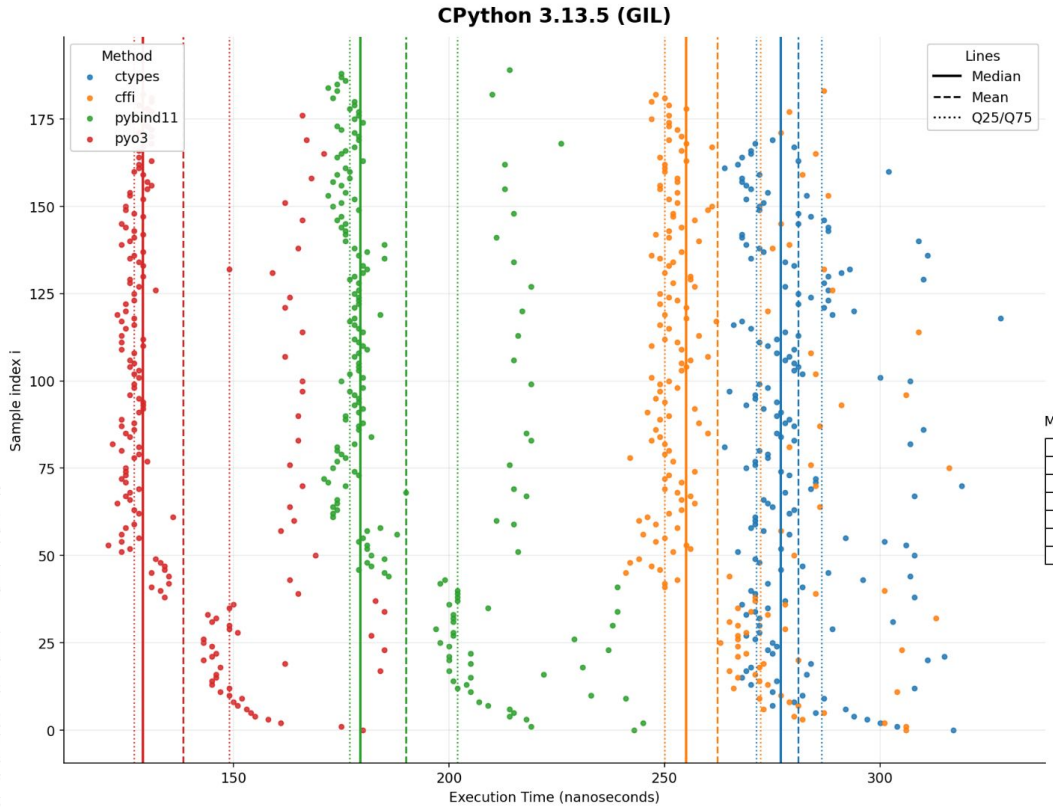
numactl --physcpubind=0-7 --membind=0

Huge pages 128k

GCC 15.1.1 20250729, Glibc 2.42, Rust 1.88.0

CPython: 3.13.5, 3.14.0rc1

Benchmark ctypes, cffi, pybind11, PyO3



Method statistics (shown data)

Indicator	Cv	Skewness	Kurtosis	Std	mad
ctypes	0.047	1.30	1.01	13.1	8.90
cffi	0.063	1.22	0.782	16.4	8.90
pybind11	0.098	1.14	0.182	18.6	7.41
pyo3	0.119	1.15	0.121	16.5	5.93

Mann–Whitney U p-values and Benjamini–Hochberg adjusted p-values

Comparison	U p-value	BH p-value	Faster
ctypes vs cffi	9.71e-25	9.71e-25	cffi
ctypes vs pybind11	1.30e-61	2.59e-61	pybind11
ctypes vs pyo3	3.55e-63	1.58e-62	pyo3
cffi vs pybind11	3.90e-60	5.84e-60	pybind11
cffi vs pyo3	5.28e-63	1.58e-62	pyo3
pybind11 vs pyo3	8.13e-49	9.75e-49	pyo3

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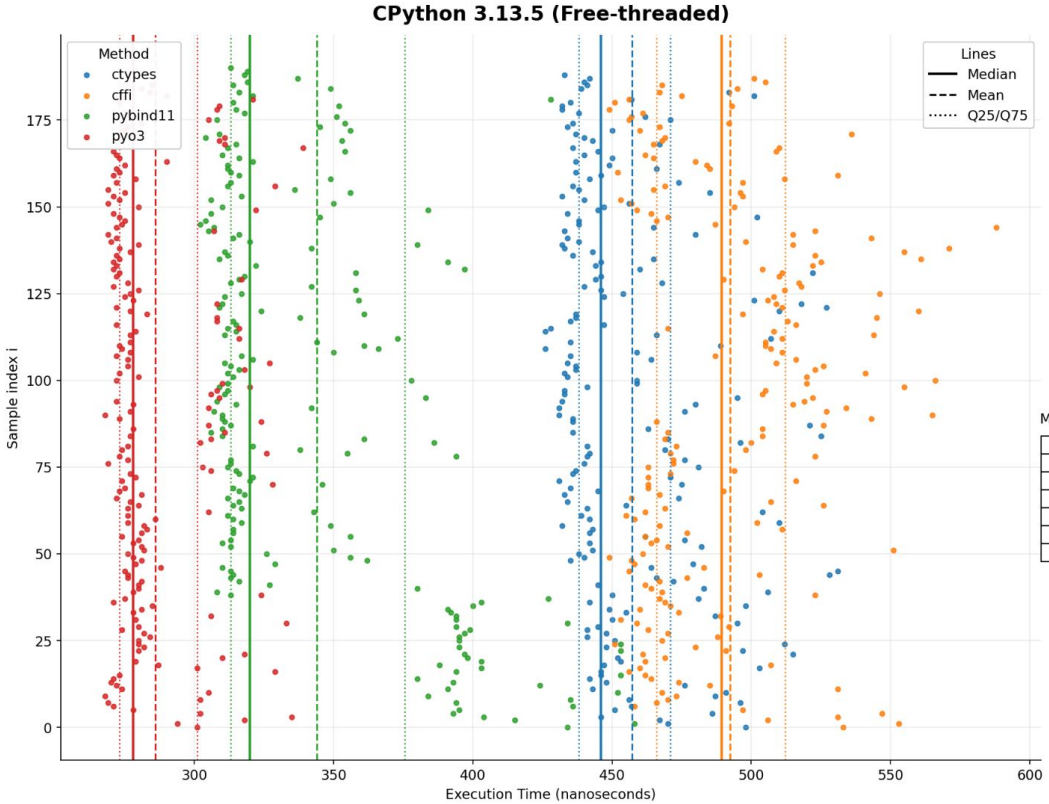
Benchmark ctypes, cffi, pybind11, PyO3



Method statistics (shown data)

Indicator	Cv	Skewness	Kurtosis	Std	mad
ctypes	0.056	1.10	0.213	25.6	16.3
cffi	0.062	0.637	-0.411	30.8	34.8
pybind11	0.117	1.04	-0.020	40.2	17.8
pyo3	0.062	1.22	0.228	17.6	8.15

Mann–Whitney U p-values and Benjamini–Hochberg adjusted p-values

Comparison	U p-value	BH p-value	Faster
ctypes vs cffi	6.94e-26	6.94e-26	ctypes
ctypes vs pybind11	4.53e-56	6.80e-56	pybind11
ctypes vs pyo3	1.33e-61	4.01e-61	pyo3
cffi vs pybind11	3.70e-60	7.39e-60	pybind11
cffi vs pyo3	1.34e-61	4.01e-61	pyo3
pybind11 vs pyo3	1.89e-43	2.27e-43	pyo3

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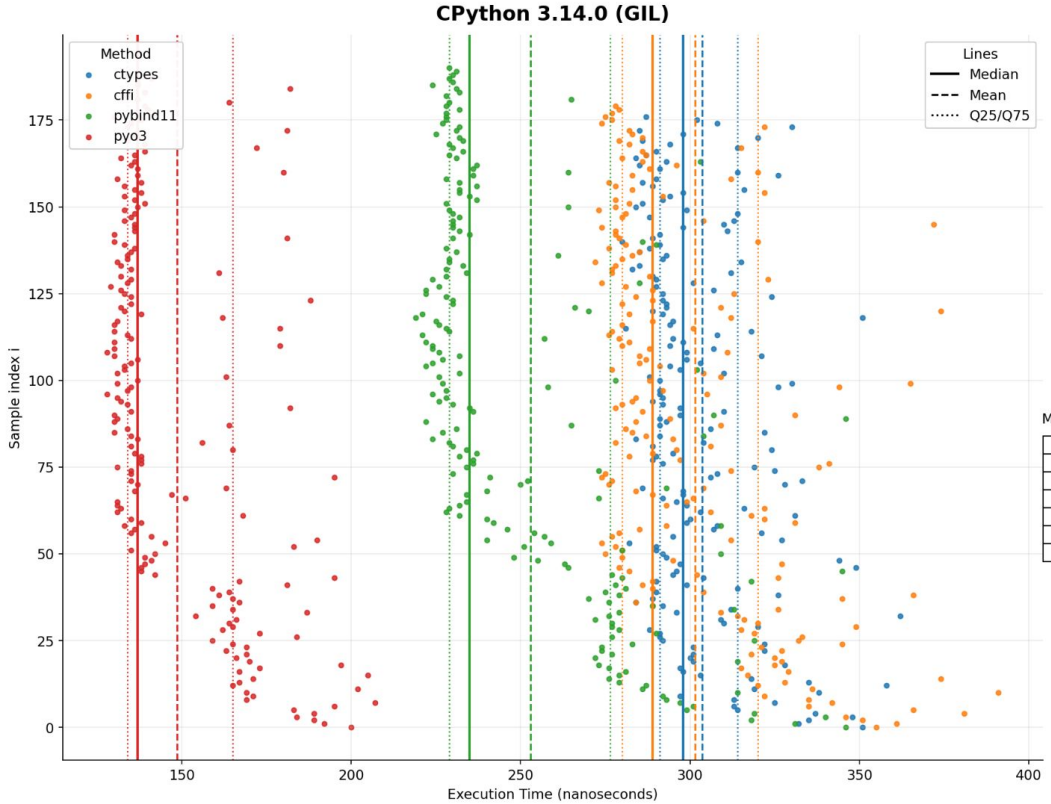
Benchmark ctypes, cffi, pybind11, PyO3



Method statistics (shown data)

Indicator	Cv	Skewness	Kurtosis	Std	mad
ctypes	0.056	1.14	0.803	17.0	13.3
cffi	0.088	1.12	0.561	26.6	17.8
pybind11	0.123	1.04	0.149	31.0	16.3
pyo3	0.139	1.05	-0.165	20.6	7.41

Mann–Whitney U p-values and Benjamini–Hochberg adjusted p-values

Comparison	U p-value	BH p-value	Faster
ctypes vs cffi	1.18e-03	1.18e-03	cffi
ctypes vs pybind11	3.46e-42	5.18e-42	pybind11
ctypes vs pyo3	3.88e-64	1.17e-63	pyo3
cffi vs pybind11	1.12e-36	1.34e-36	pybind11
cffi vs pyo3	3.84e-64	1.17e-63	pyo3
pybind11 vs pyo3	1.24e-62	2.48e-62	pyo3

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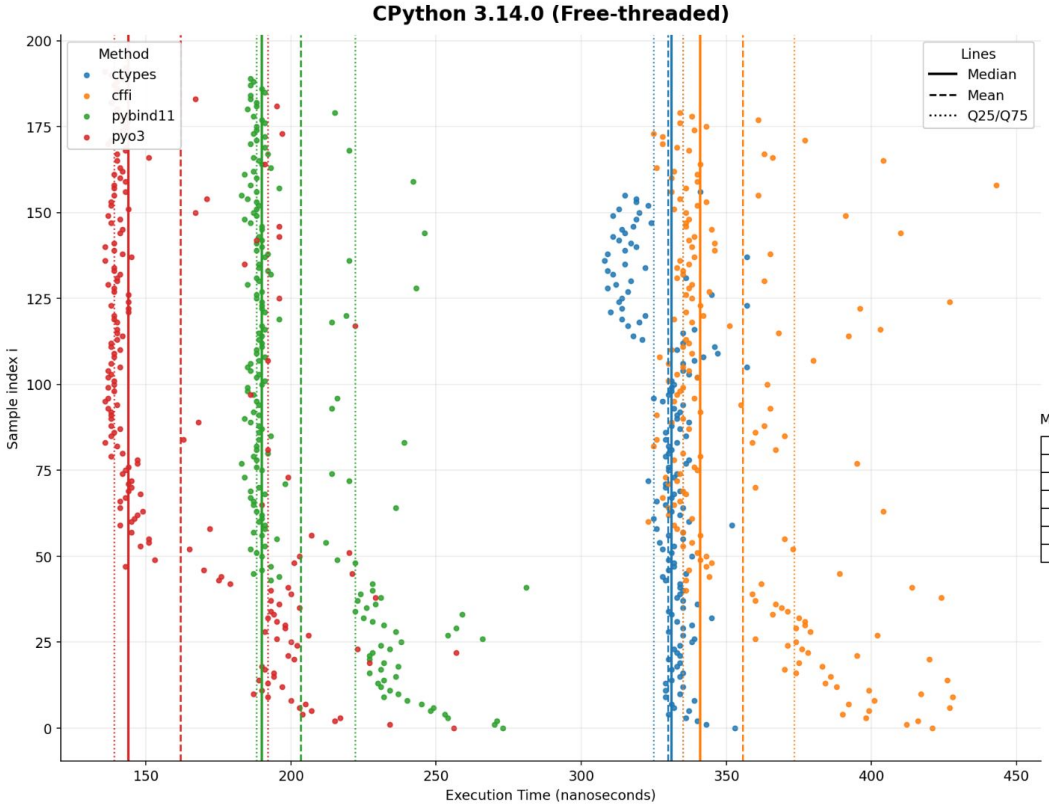
Benchmark ctypes, cffi, pybind11, PyO3



Method statistics (shown data)

Indicator	Cv	Skewness	Kurtosis	Std	mad
ctypes	0.030	-0.131	0.372	9.85	5.93
cffi	0.079	1.08	0.128	28.2	14.8
pybind11	0.115	1.28	0.497	23.5	4.45
pyo3	0.182	0.963	-0.267	29.5	8.90

Mann–Whitney U p-values and Benjamini–Hochberg adjusted p-values

Comparison	U p-value	BH p-value	Faster
ctypes vs cffi	2.47e-18	2.47e-18	ctypes
ctypes vs pybind11	1.02e-62	1.54e-62	pybind11
ctypes vs pyo3	3.75e-64	1.12e-63	pyo3
cffi vs pybind11	6.61e-63	1.32e-62	pybind11
cffi vs pyo3	3.75e-64	1.12e-63	pyo3
pybind11 vs pyo3	5.64e-24	6.76e-24	pyo3

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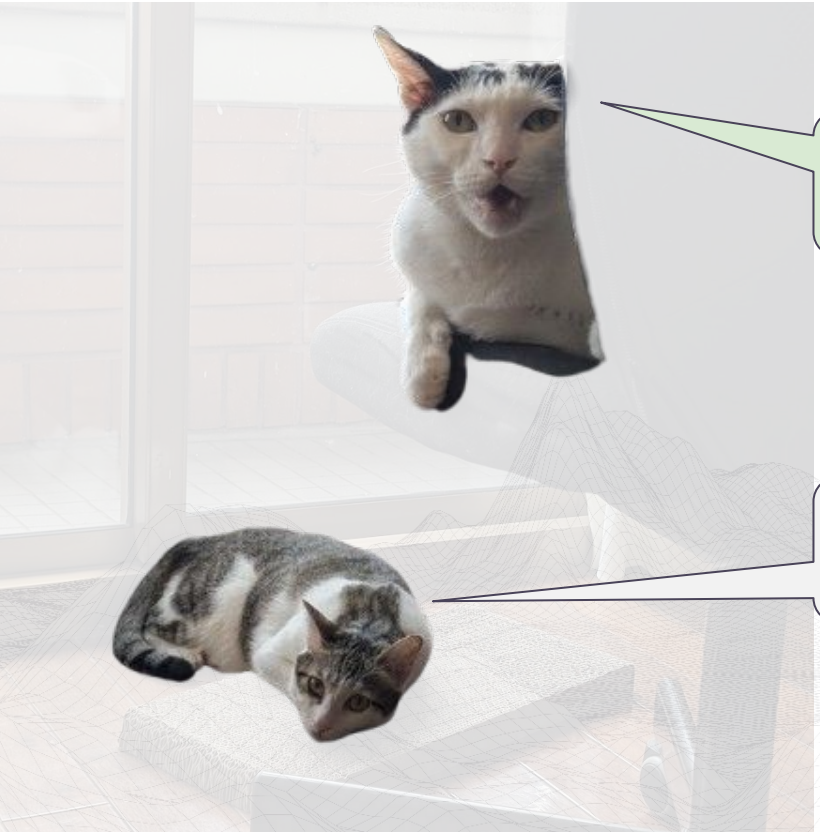
Benchmark ctypes, cffi, pybind11, PyO3



Why Free-Threaded Makes Them Slower?

Why PyO3 fast, but ctypes slow?

Why Free-Threaded Makes Them Slower?

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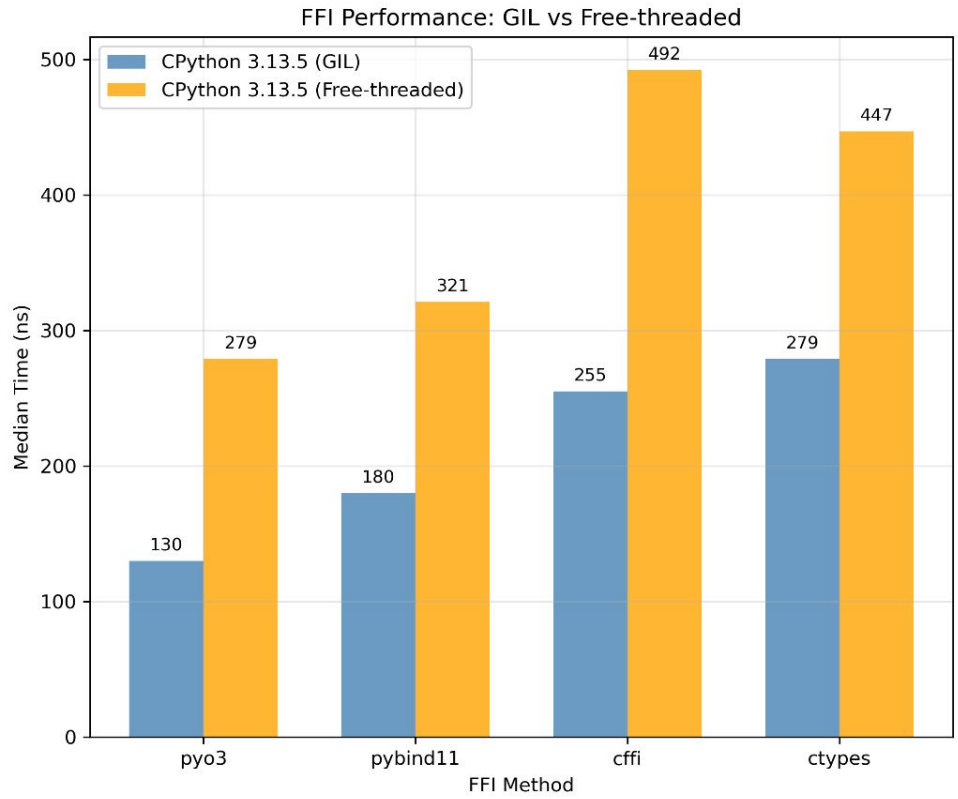

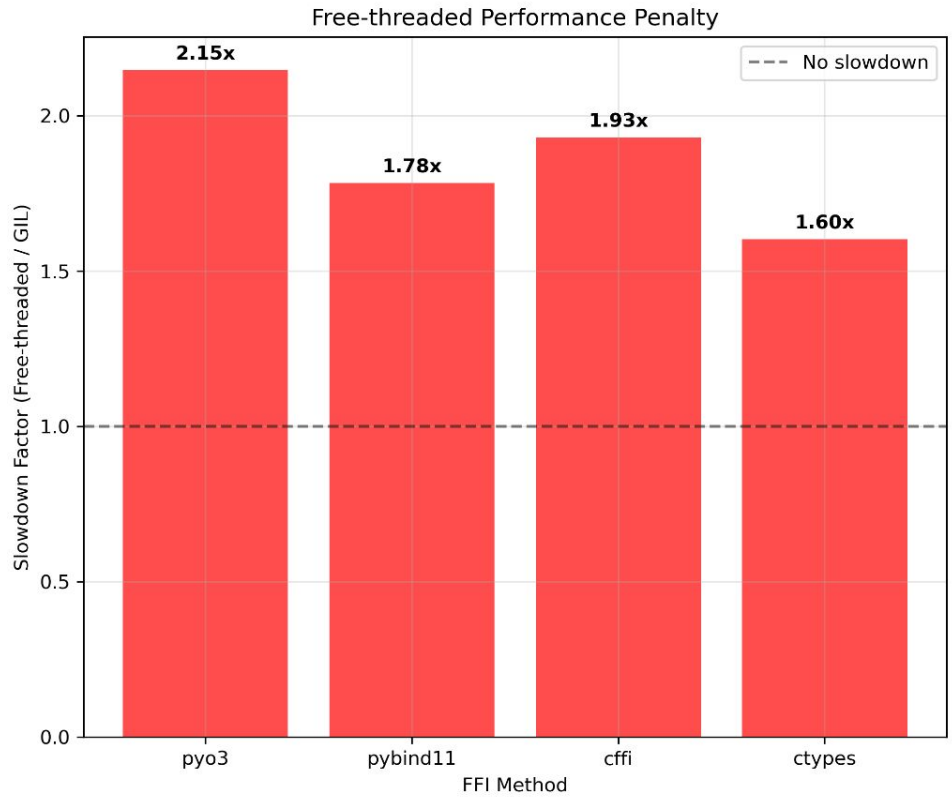

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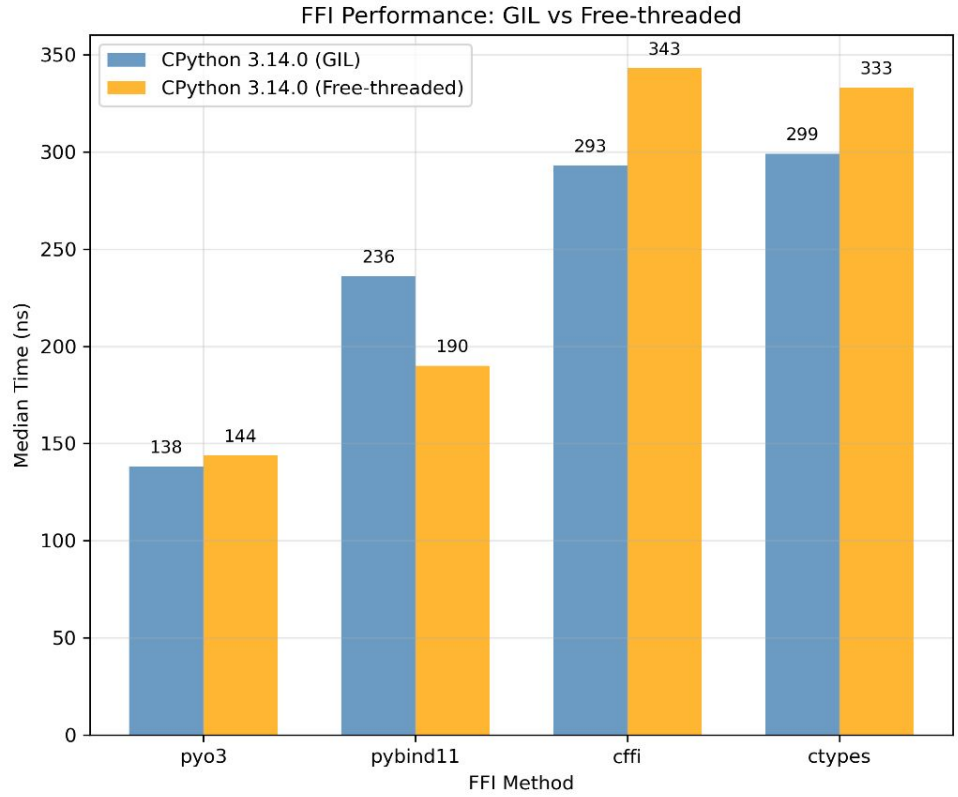

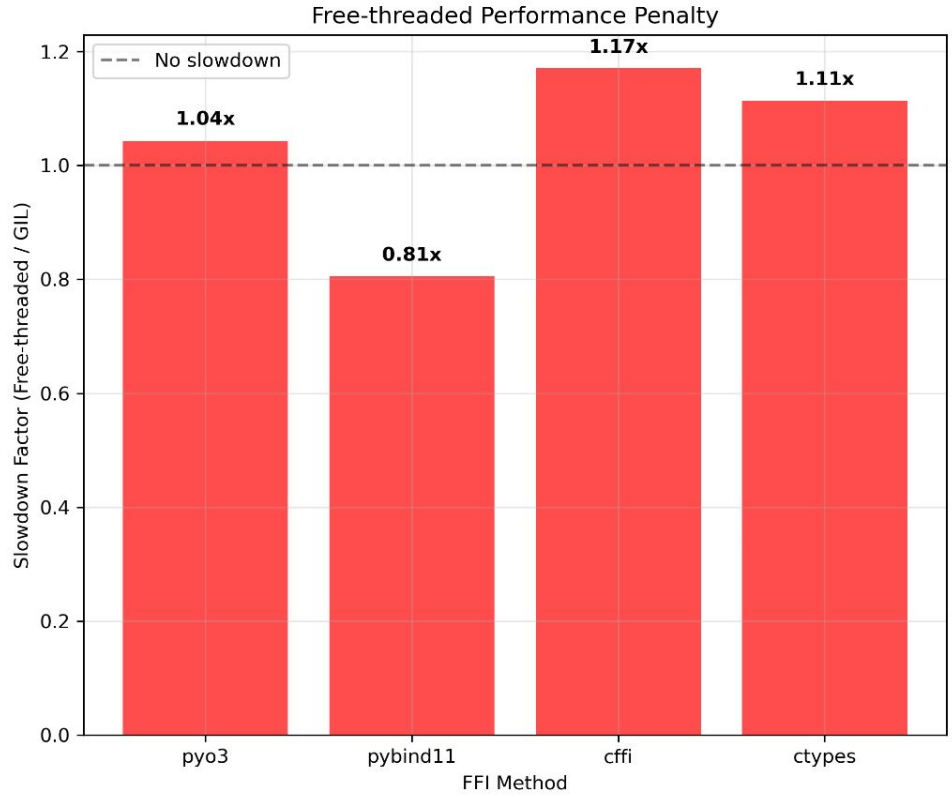

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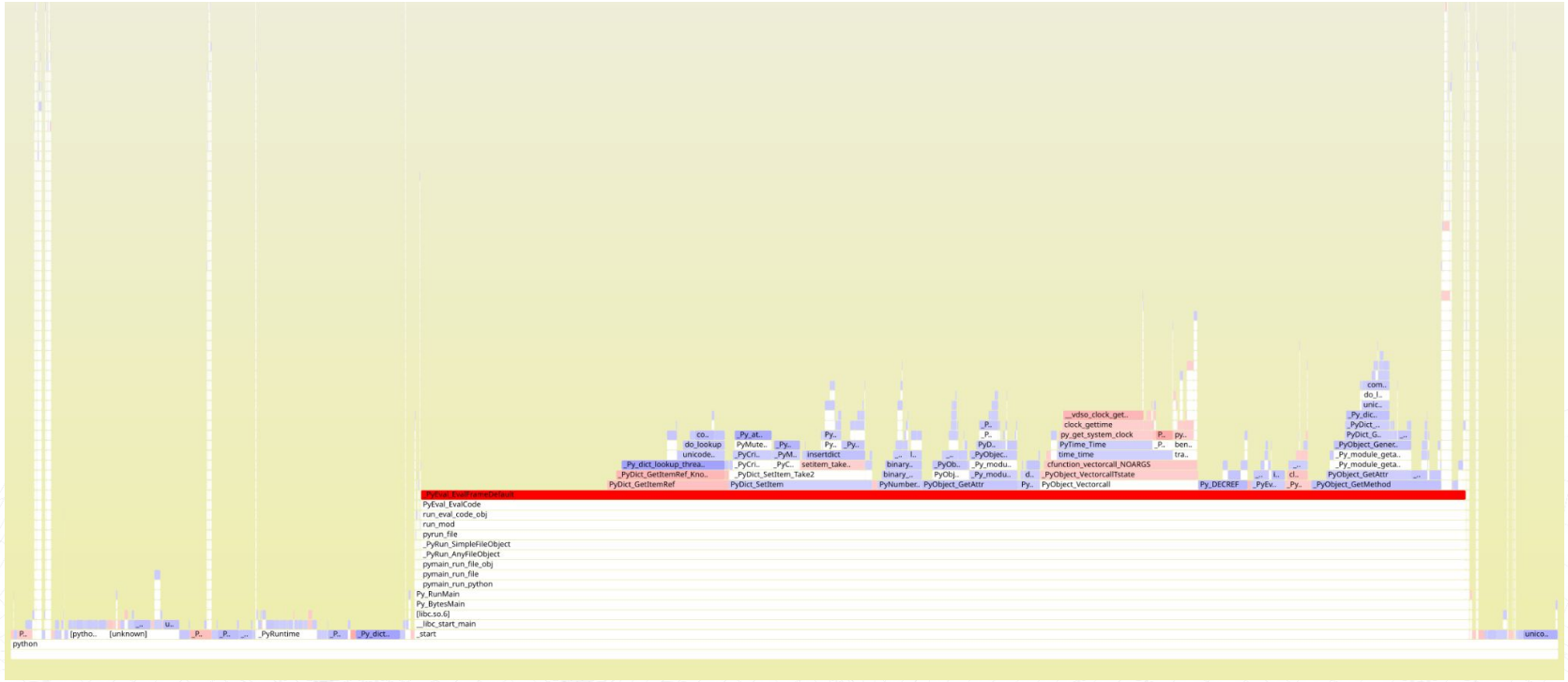
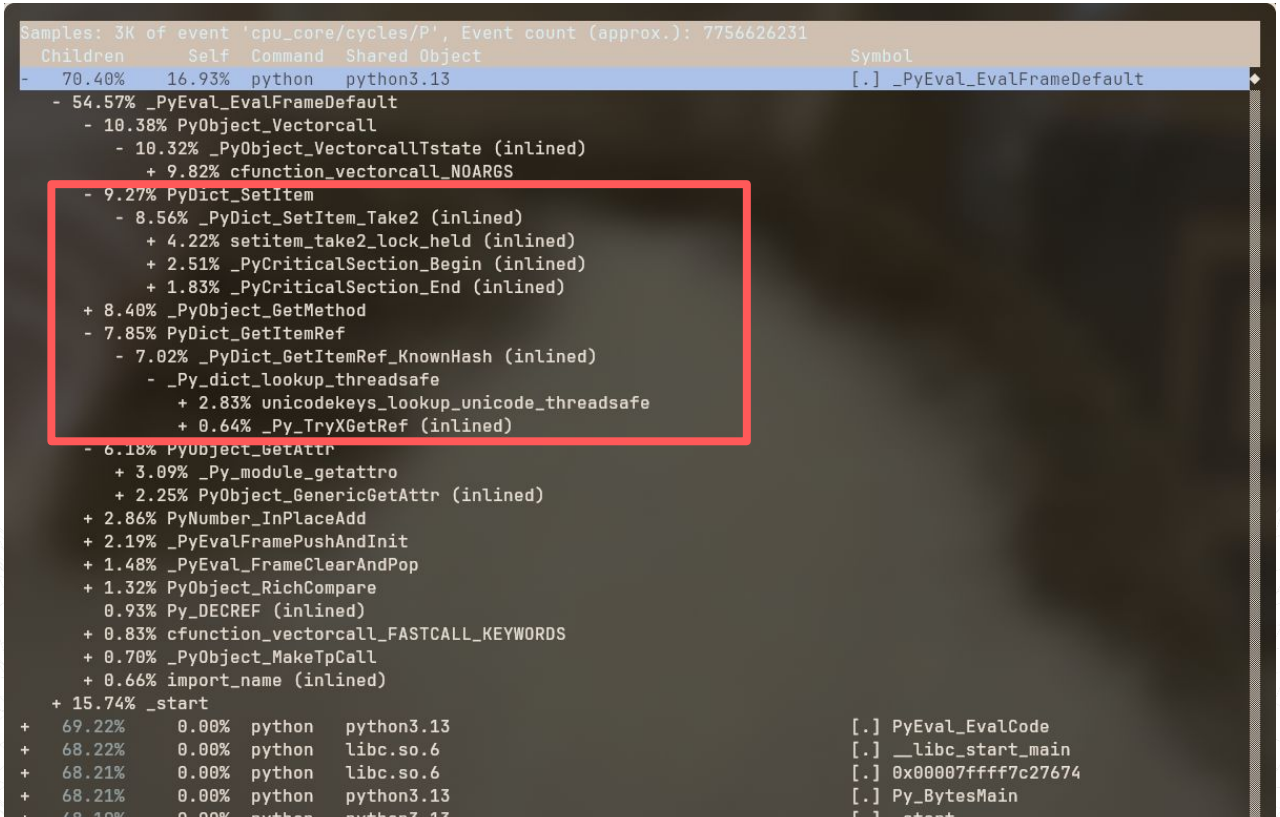


Why Free-Threaded Makes Them Slower?

```
scc ~/git/pycon2025-ffi-hidden-corner (main) +4 ?8 ~2
❯❯ for F in "$P_GIL" "$P_NOGIL"; do
  echo "==== $(basename $F) ===="
  perf report --stdio --no-children -i "$F" --sort symbol \
    | grep -E 'futex|pthread_mutex|_PyCriticalSection|_Py_mutex|PyMutex|_Py_atomic|__x64_sys_|do_syscall|do_futex' \
    | sed 's/^/  /'
done | tee pyo3_lock_syscall_evidence.txt
==== pyo3_profile_1754689040.perf.data ====
==== pyo3_profile_1754689074.perf.data ====
              --0.77%--_Py_atomic_store_uint32_relaxed (inlined)
              --4.09%--_Py_atomic_compare_exchange_uint8 (inlined)
                        |--2.41%--PyMutex_LockFast (inlined)
                        |          _PyCriticalSection_BeginMutex (inlined)
                        |          _PyCriticalSection_Begin (inlined)
                         --1.67%--_PyMutex_Unlock (inlined)
                                   _PyCriticalSection_End (inlined)
              --0.61%--_Py_atomic_load_uint32_relaxed (inlined)

scc ~/git/pycon2025-ffi-hidden-corner (main) +4 ?8 ~2
❯❯
```

Why Free-Threaded Makes Them Slower?



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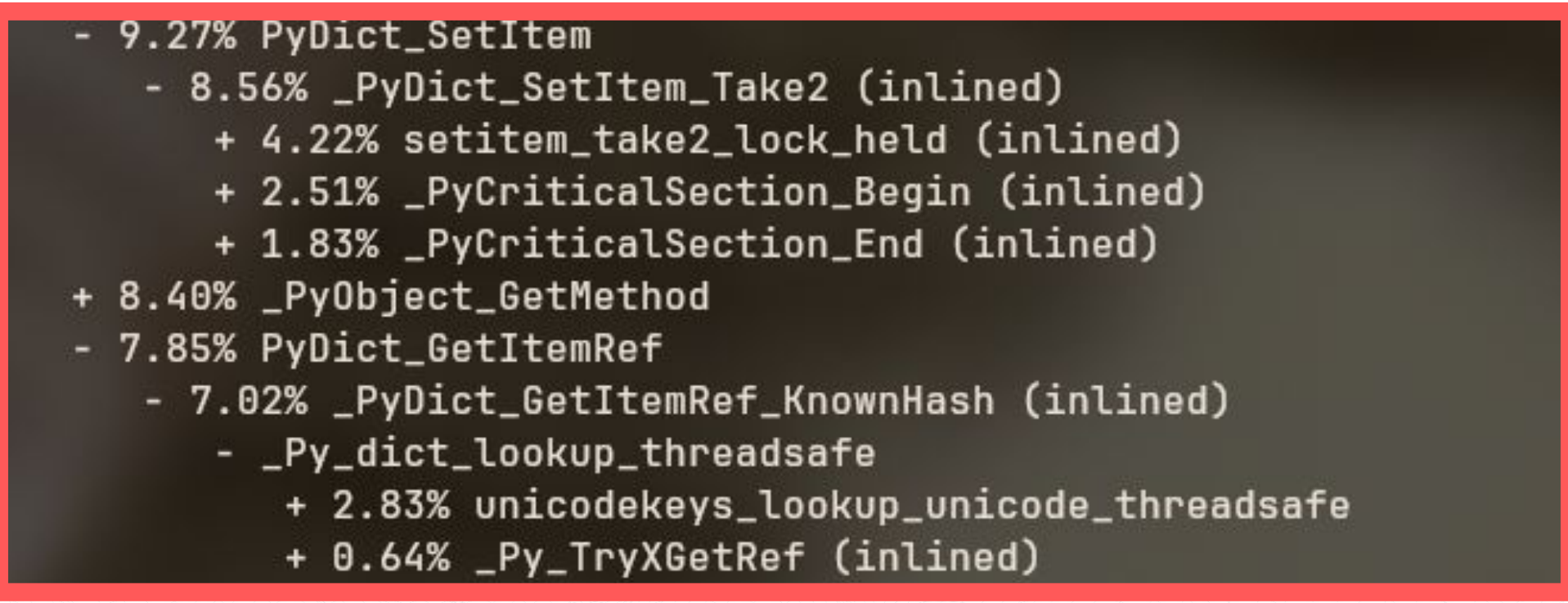

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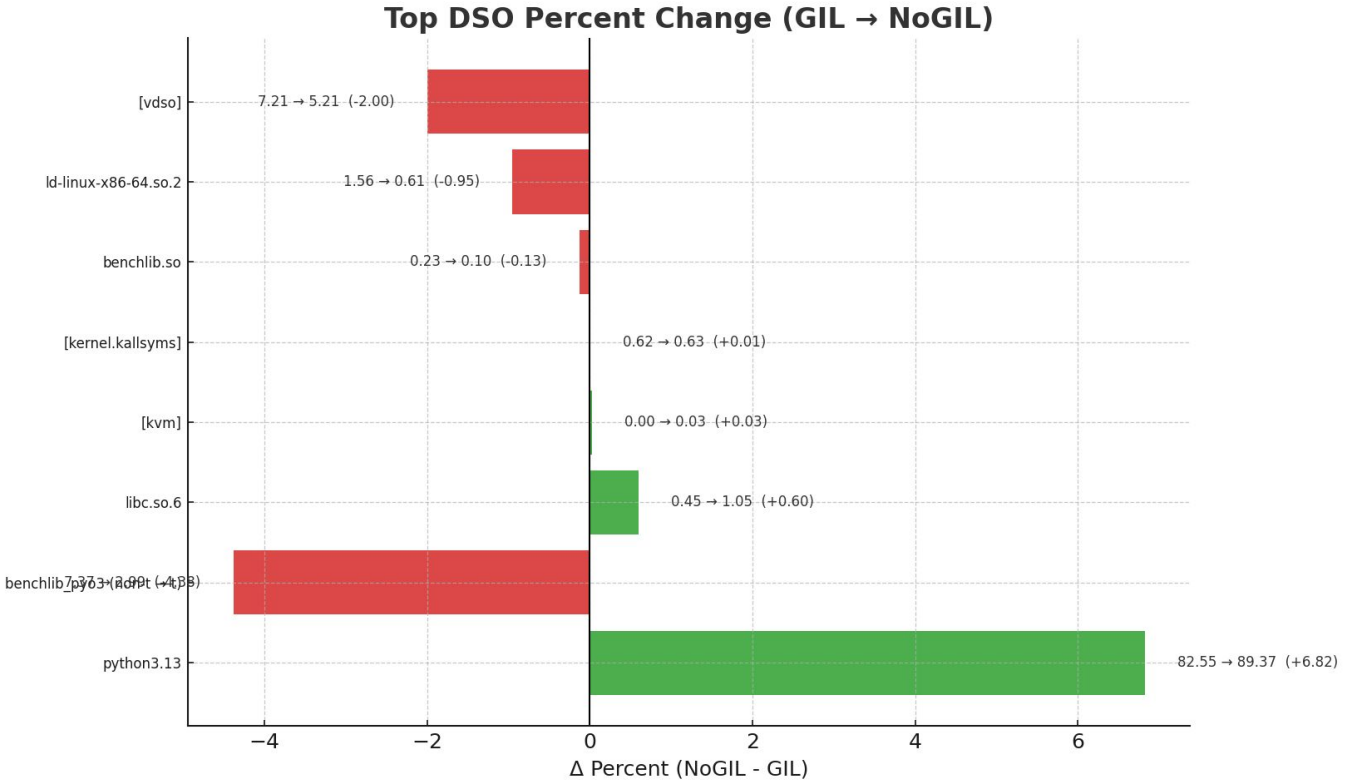

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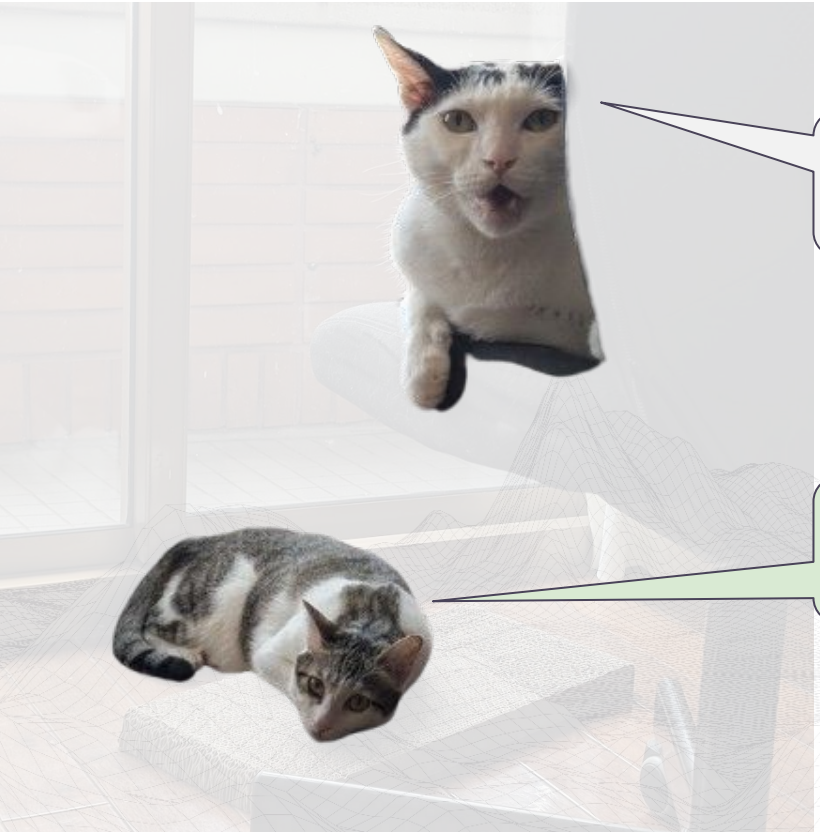
Recap

- Python 3.13-NoGIL shows higher overhead than 3.13-GIL when crossing FFI boundaries.
- Python 3.14-NoGIL achieves perf close to 3.14-GIL for FFI calls.

- Lock-free execution does not guarantee speedups

  in some cases the locked implementation is faster.
- Unicode translation carries a significant overhead in NoGIL mode.

Benchmark ctypes, cffi, pybind11, PyO3



Why Free-Threaded Makes Them Slower?

Why PyO3 fast, but ctypes slow?

Why PyO3 fast, but ctypes slow?

Why PyO3 fast, but ctypes slow?

PyO3

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Why PyO3 fast, but ctypes slow?

ctypes

CYCRAFT

Why PyO3 fast, but ctypes slow?

ctypes

```
16.36%  [.] _PyEval_EvalFrameDefault                    -      -
        |
        |--14.26%--_PyEval_EvalFrameDefault
        |          |
        |          |--12.04%--PyEval_EvalCode
        |          |          |
        |          |           --11.74%--run_eval_code_obj
        |          |                     run_mod
        |          |                     pyrun_file
        |          |                     _PyRun_SimpleFileObject
        |          |                     _PyRun_AnyFileObject
        |          |                     pymain_run_file_obj (inlined)
        |          |                     pymain_run_file (inlined)
        |          |                     pymain_run_python (inlined)
        |          |                     Py_RunMain
        |          |                     Py_BytesMain
        |          |                     0x7ffff7c27674
        |          |                     __libc_start_main
        |          |                     _start
        |          |
        |           --0.63%--_PyObject_VectorcallTstate (inlined)
        |
         --0.66%--Py_INCREF (inlined)

  6.99%  [.] pthread_mutex_lock                         -      -
        |
        |--4.93%--take_gil
        |          _PyThreadState_Attach
        |          _call_function_pointer (inlined)
        |          _ctypes_callproc (inlined)
        |          PyCFuncPtr_call
        |          _PyObject_MakeTpCall
        |          _PyEval_EvalFrameDefault
        |          PyEval_EvalCode
        |          run_eval_code_obj
        |          run_mod
        |          pyrun_file
        |          _PyRun_SimpleFileObject
        |          _PyRun_AnyFileObject
        |          pymain_run_file_obj (inlined)
        |          pymain_run_file (inlined)
        |          pymain_run_python (inlined)
        |          Py_RunMain
        |          Py_BytesMain
        |          0x7ffff7c27674
        |          __libc_start_main
        |          _start
        |
         --1.86%--drop_gil_impl (inlined)
                   drop_gil (inlined)
                   _PyEval_ReleaseLock
                   PyEval_SaveThread
                   |
                    --1.84%--_call_function_pointer (inlined)
                              _ctypes_callproc (inlined)
                              PyCFuncPtr_call
                              _PyObject_MakeTpCall
                              _PyEval_EvalFrameDefault
```

perf report --stdio --no-children \
-i "$CTYPES" --sort symbol

```
  6.99%  [.] pthread_mutex_lock
         |
         |--4.93%--take_gil
         |          _PyThreadState_Attach
         |          _call_function_pointer (inlined)
         |          _ctypes_callproc (inlined)
         |          PyCFuncPtr_call
         |          _PyObject_MakeTpCall
         |          _PyEval_EvalFrameDefault
```

perf r

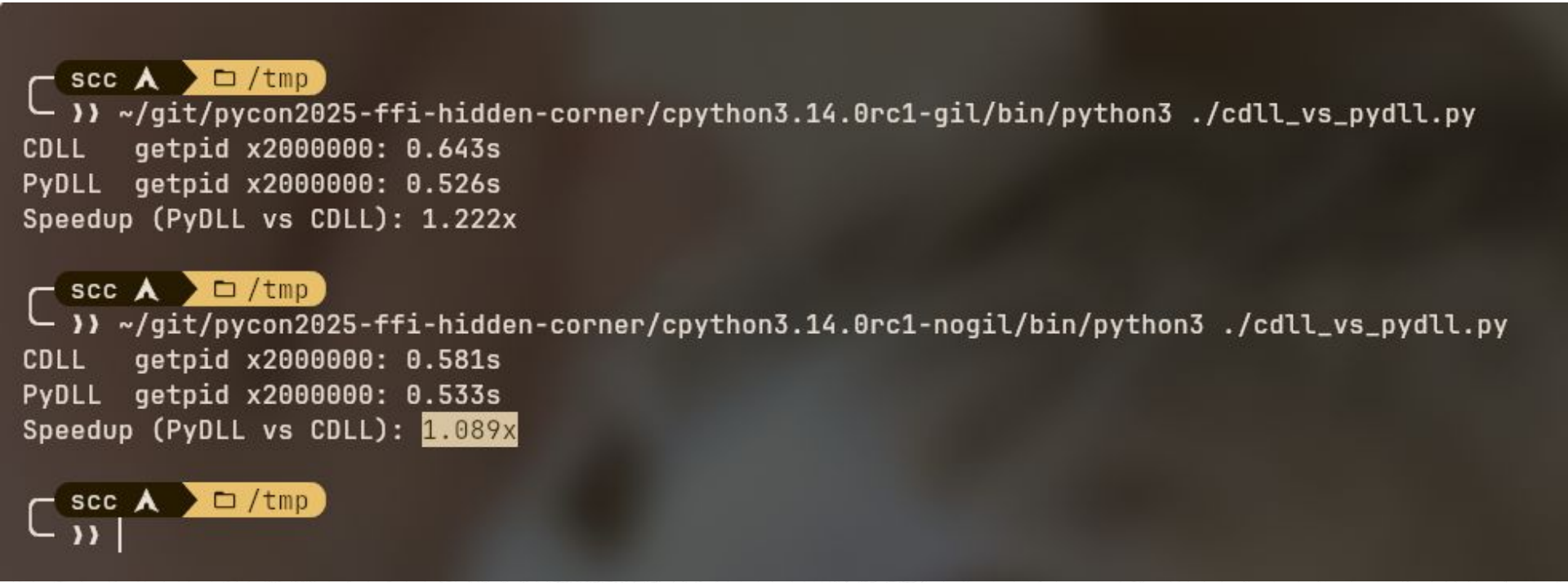
claude perf report --stdio --no-children -i "$CTYPES" --sort symbol

Why PyO3 fast, but ctypes slow?

Loader	GIL Released?	Best for	Risk
CDLL	Yes	Long-running C code, multi-thread	Unsafe for Python C API calls
PyDLL	No	Short C calls, Python C API usage, single-thread	Blocks other threads, can deadlock

```
A = ctypes.CDLL(_lib_path)
B = ctypes.PyDLL(_lib_path)
```

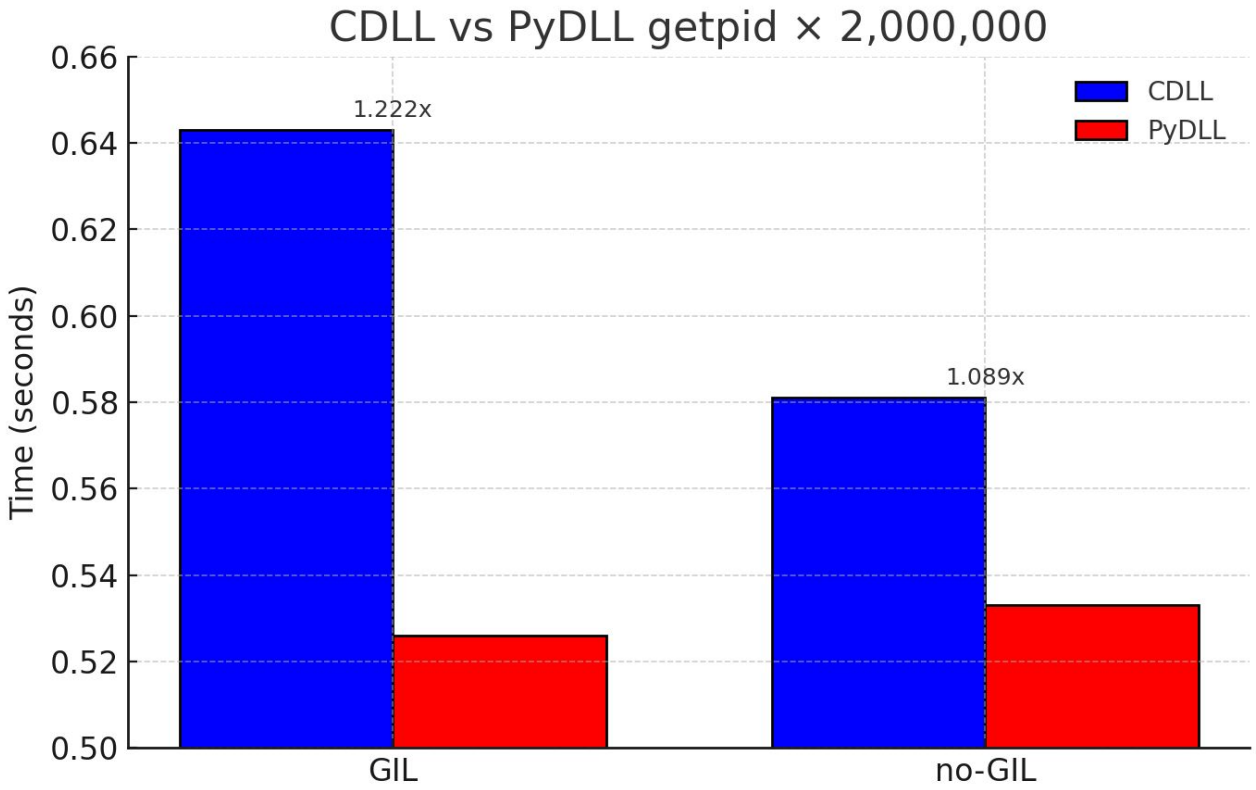
Why PyO3 fast, but ctypes slow?



https://godbolt.org/z/js38oYsae

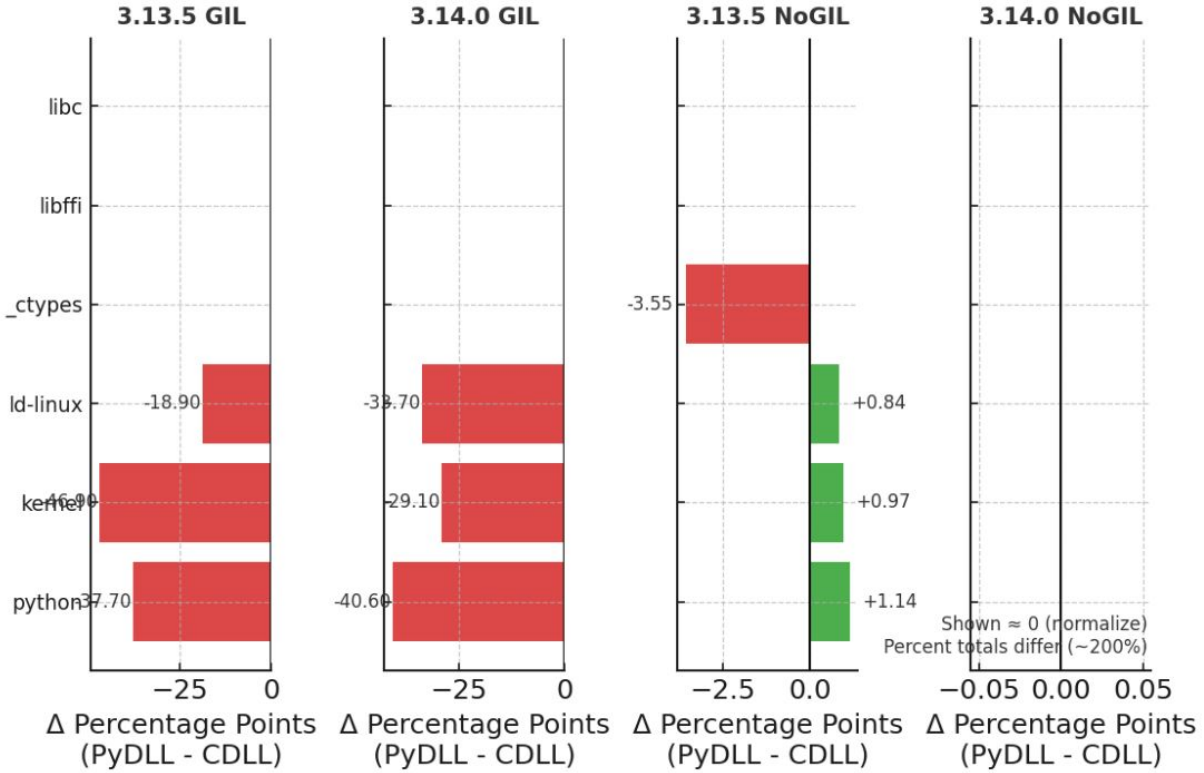
Why PyO3 fast, but ctypes slow?

```
scc  /tmp
 ~/git/pycon2025-ffi-hidden
CDLL   getpid x2000000: 0.643s
PyDLL  getpid x2000000: 0.526s
Speedup (PyDLL vs CDLL): 1.222x

scc  /tmp
 ~/git/pycon2025-ffi-hidden
CDLL   getpid x2000000: 0.581s
PyDLL  getpid x2000000: 0.533s
Speedup (PyDLL vs CDLL): 1.089x

scc  /tmp
```



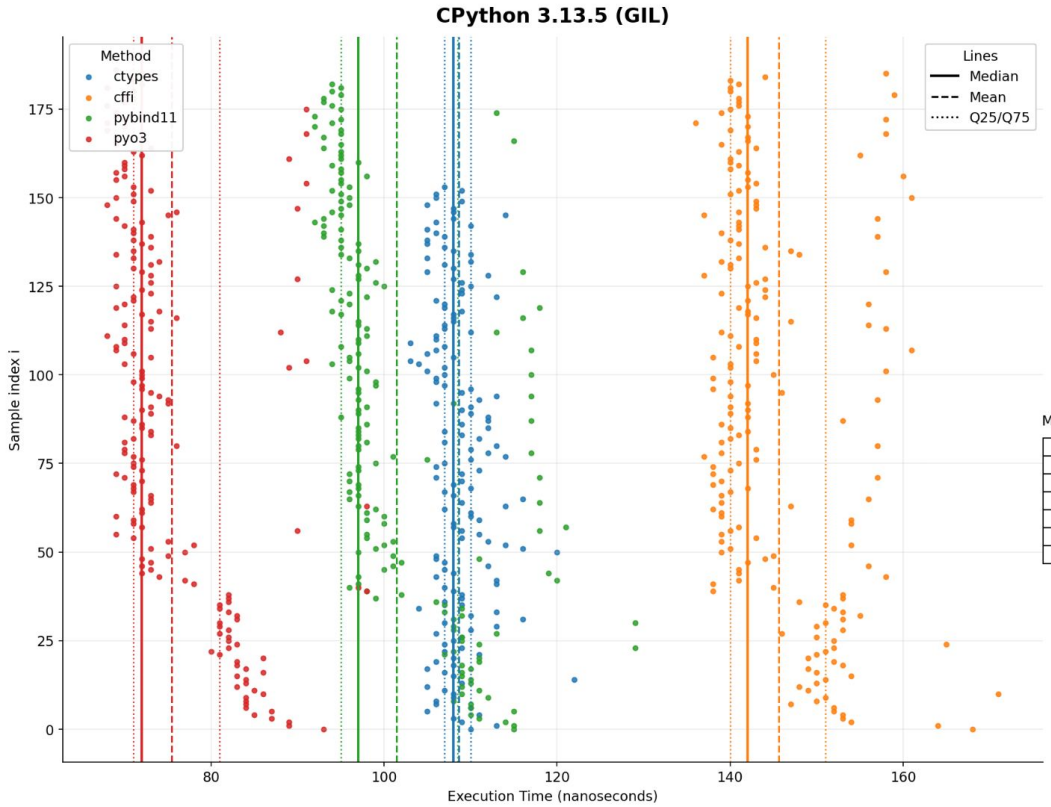
https://godbolt.org/z/js38oYsae

Why PyO3 fast, but ctypes slow?



CYCRAFT

Why PyO3 fast, but ctypes slow?



Method statistics (shown data)

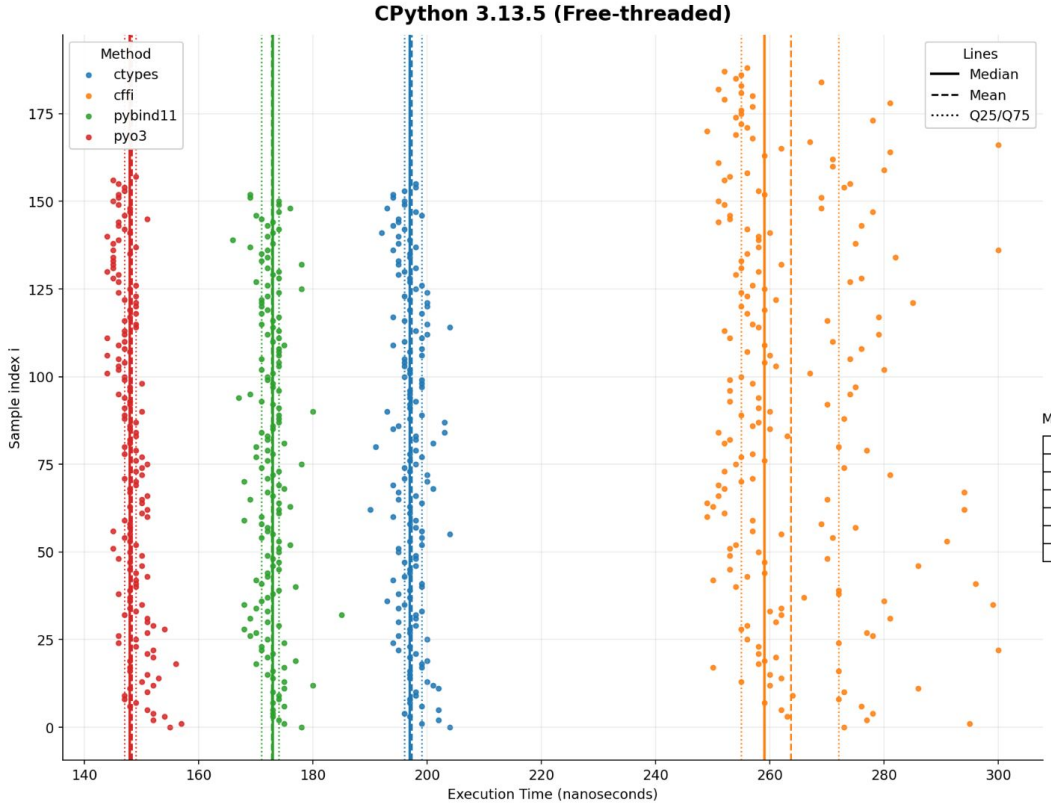
Indicator	Cv	Skewness	Kurtosis	Std	mad
ctypes	0.027	1.24	2.77	2.98	2.97
cffi	0.050	1.01	0.196	7.21	4.45
pybind11	0.081	1.10	0.225	8.23	2.97
pyo3	0.093	1.21	0.507	7.03	2.97

Mann–Whitney U p-values and Benjamini–Hochberg adjusted p-values

Comparison	U p-value	BH p-value	Faster
ctypes vs cffi	5.29e-57	7.94e-57	ctypes
ctypes vs pybind11	9.58e-20	9.58e-20	pybind11
ctypes vs pyo3	8.52e-62	2.56e-61	pyo3
cffi vs pybind11	9.82e-59	1.96e-58	pybind11
cffi vs pyo3	5.07e-63	3.04e-62	pyo3
pybind11 vs pyo3	5.41e-56	6.49e-56	pyo3

CYCRAFT

Why PyO3 fast, but ctypes slow?



Method statistics (shown data)

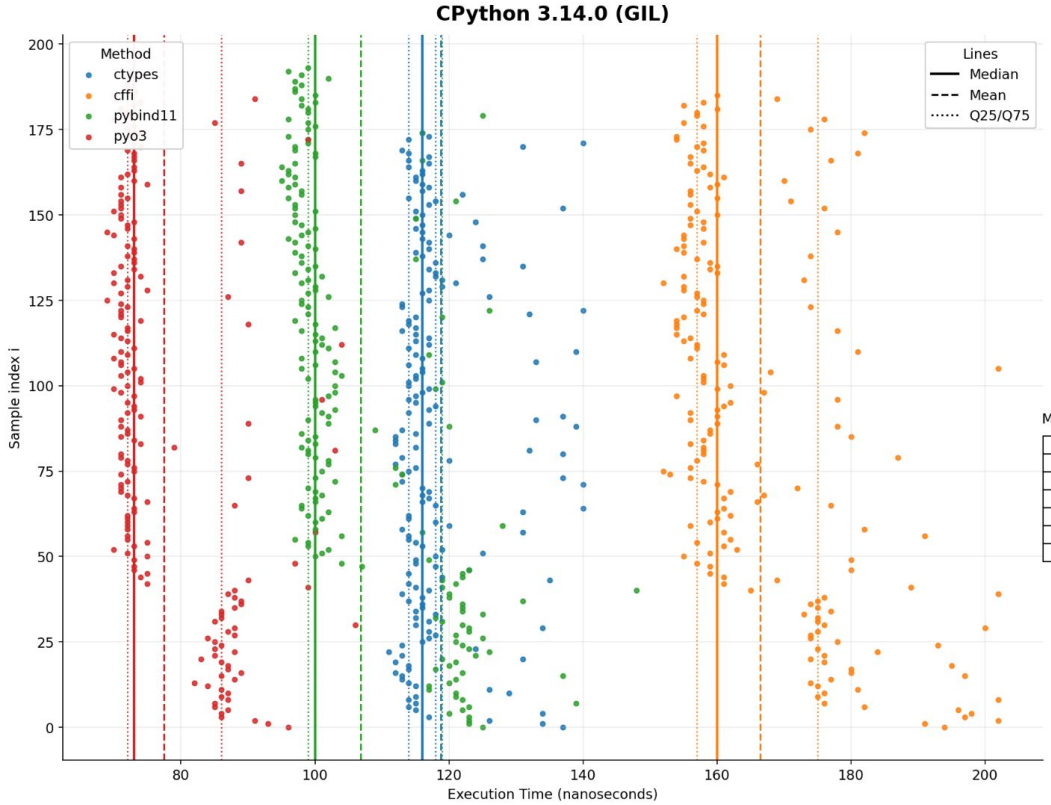
Indicator	Cv	Skewness	Kurtosis	Std	mad
ctypes	0.012	0.212	0.822	2.38	1.48
cffi	0.045	1.14	0.666	11.9	8.90
pybind11	0.014	0.851	3.76	2.49	1.48
pyo3	0.016	0.800	1.28	2.33	1.48

Mann–Whitney U p-values and Benjamini–Hochberg adjusted p-values

Comparison	U p-value	BH p-value	Faster
ctypes vs cffi	1.61e-65	9.67e-65	ctypes
ctypes vs pybind11	1.42e-47	1.42e-47	pybind11
ctypes vs pyo3	5.13e-63	1.03e-62	pyo3
cffi vs pybind11	8.30e-63	1.24e-62	pybind11
cffi vs pyo3	2.46e-64	7.38e-64	pyo3
pybind11 vs pyo3	3.84e-56	4.61e-56	pyo3

CYCRAFT

Why PyO3 fast, but ctypes slow?



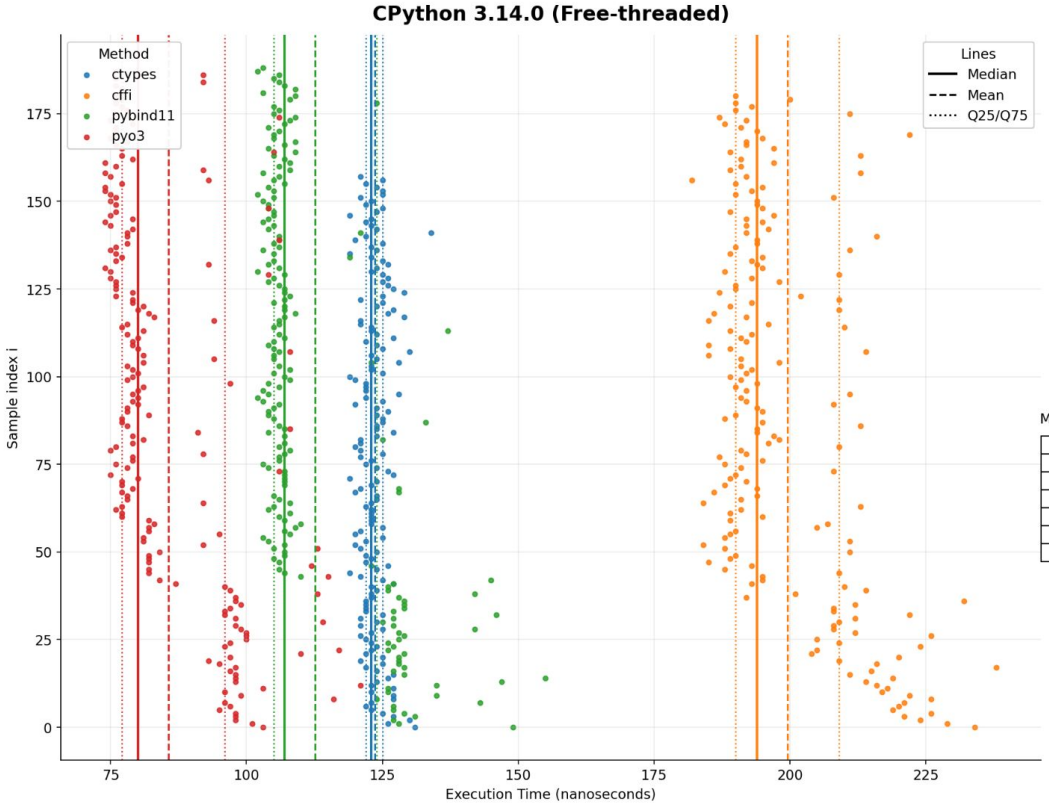
Method statistics (shown data)

Indicator	Cv	Skewness	Kurtosis	Std	mad
ctypes	0.061	1.67	1.57	7.30	2.97
cffi	0.075	1.13	0.413	12.6	7.41
pybind11	0.104	0.963	-0.159	11.2	4.45
pyo3	0.110	1.23	0.537	8.53	2.97

Mann–Whitney U p-values and Benjamini–Hochberg adjusted p-values

Comparison	U p-value	BH p-value	Faster
ctypes vs cffi	1.84e-65	1.10e-64	ctypes
ctypes vs pybind11	5.37e-21	5.37e-21	pybind11
ctypes vs pyo3	4.02e-61	6.02e-61	pyo3
cffi vs pybind11	3.42e-64	6.85e-64	pybind11
cffi vs pyo3	2.92e-64	6.85e-64	pyo3
pybind11 vs pyo3	3.73e-55	4.48e-55	pyo3

Why PyO3 fast, but ctypes slow?



Method statistics (shown data)

Indicator	Cv	Skewness	Kurtosis	Std	mad
ctypes	0.020	0.776	1.55	2.46	2.97
cffi	0.061	0.943	-0.104	12.2	7.41
pybind11	0.105	1.37	0.855	11.8	2.97
pyo3	0.135	1.01	-0.090	11.5	5.93

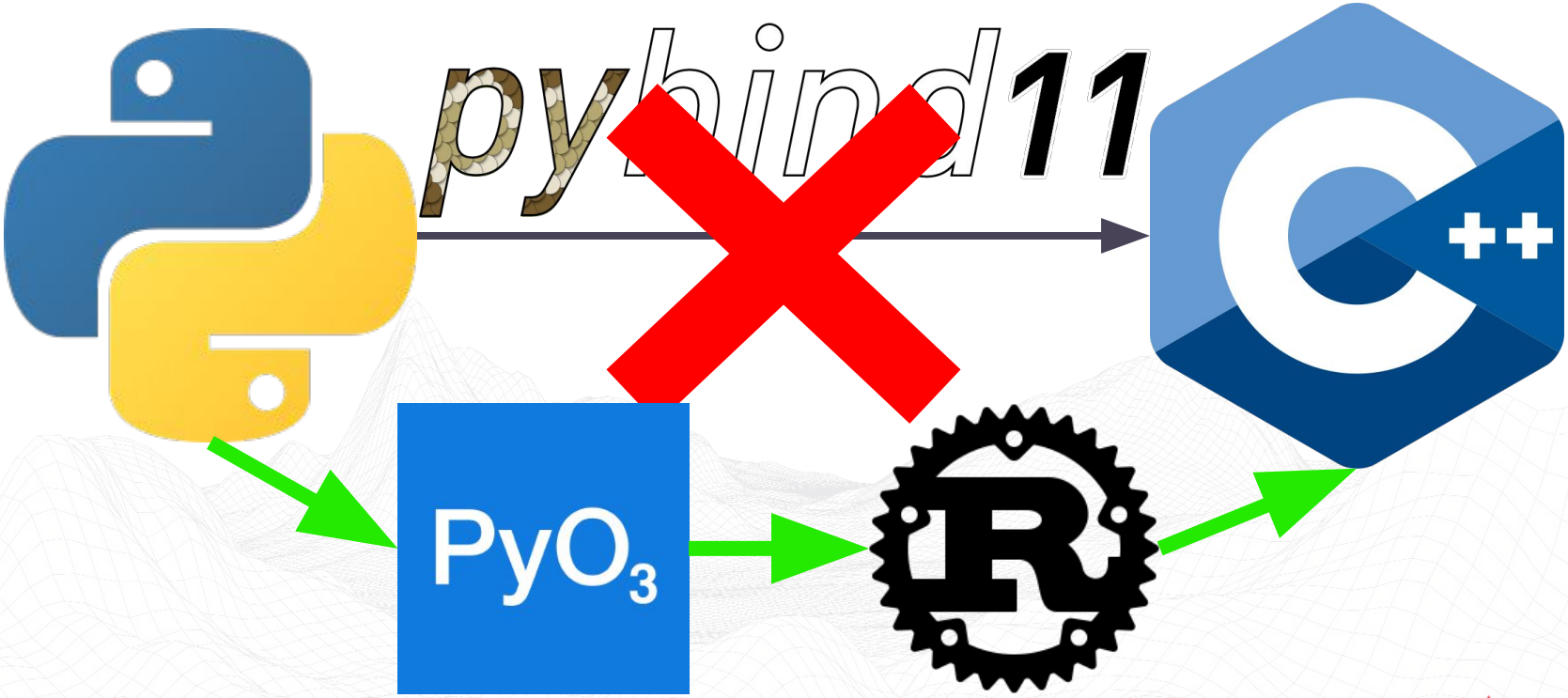
Mann–Whitney U p-values and Benjamini–Hochberg adjusted p-values

Comparison	U p-value	BH p-value	Faster
ctypes vs cffi	2.71e-64	1.63e-63	ctypes
ctypes vs pybind11	1.69e-20	1.69e-20	pybind11
ctypes vs pyo3	4.57e-57	6.86e-57	pyo3
cffi vs pybind11	2.75e-63	5.69e-63	pybind11
cffi vs pyo3	2.85e-63	5.69e-63	pyo3
pybind11 vs pyo3	2.25e-46	2.70e-46	pyo3

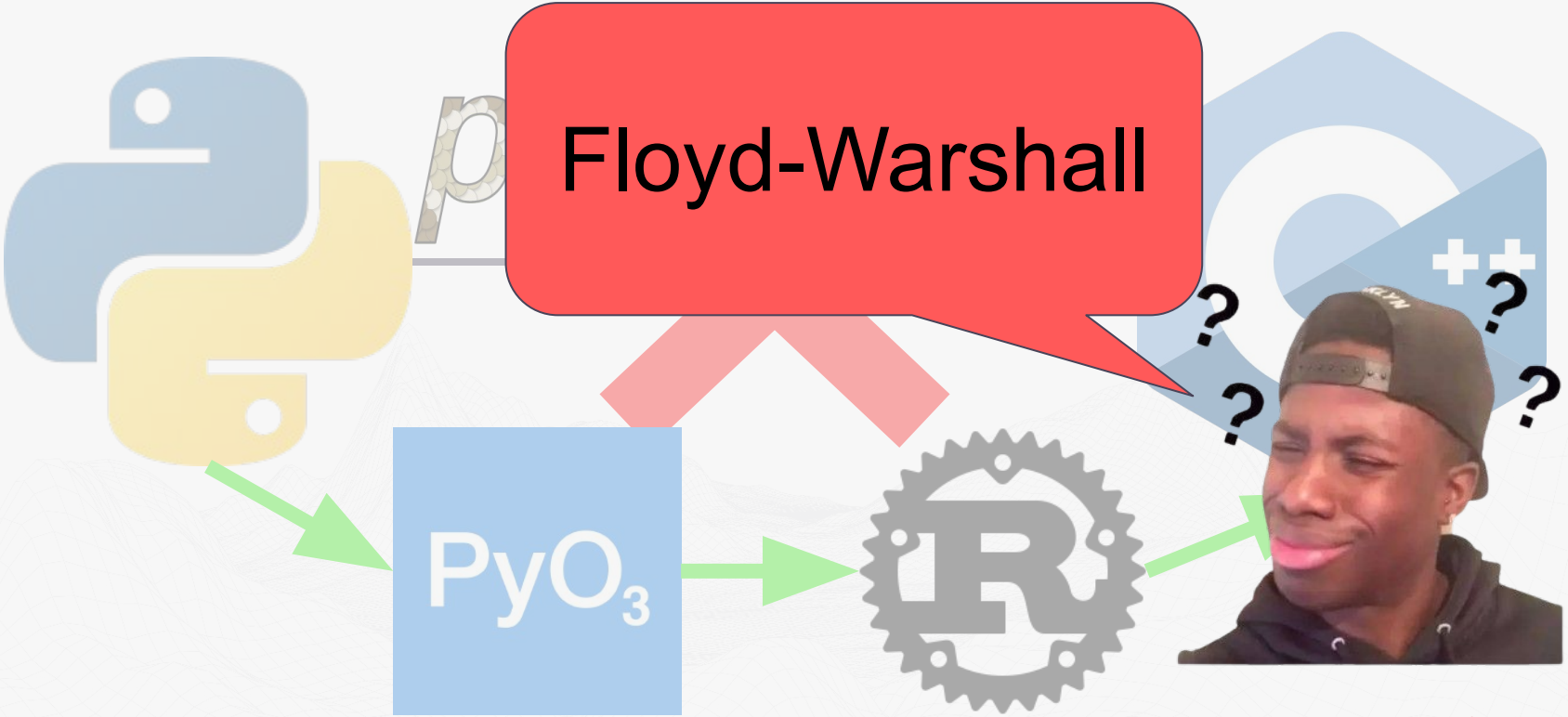
CYCRAFT

The Fastest Solution for C++ Binding

The Fastest Solution for C++ Binding



The Fastest Solution for C++ Binding

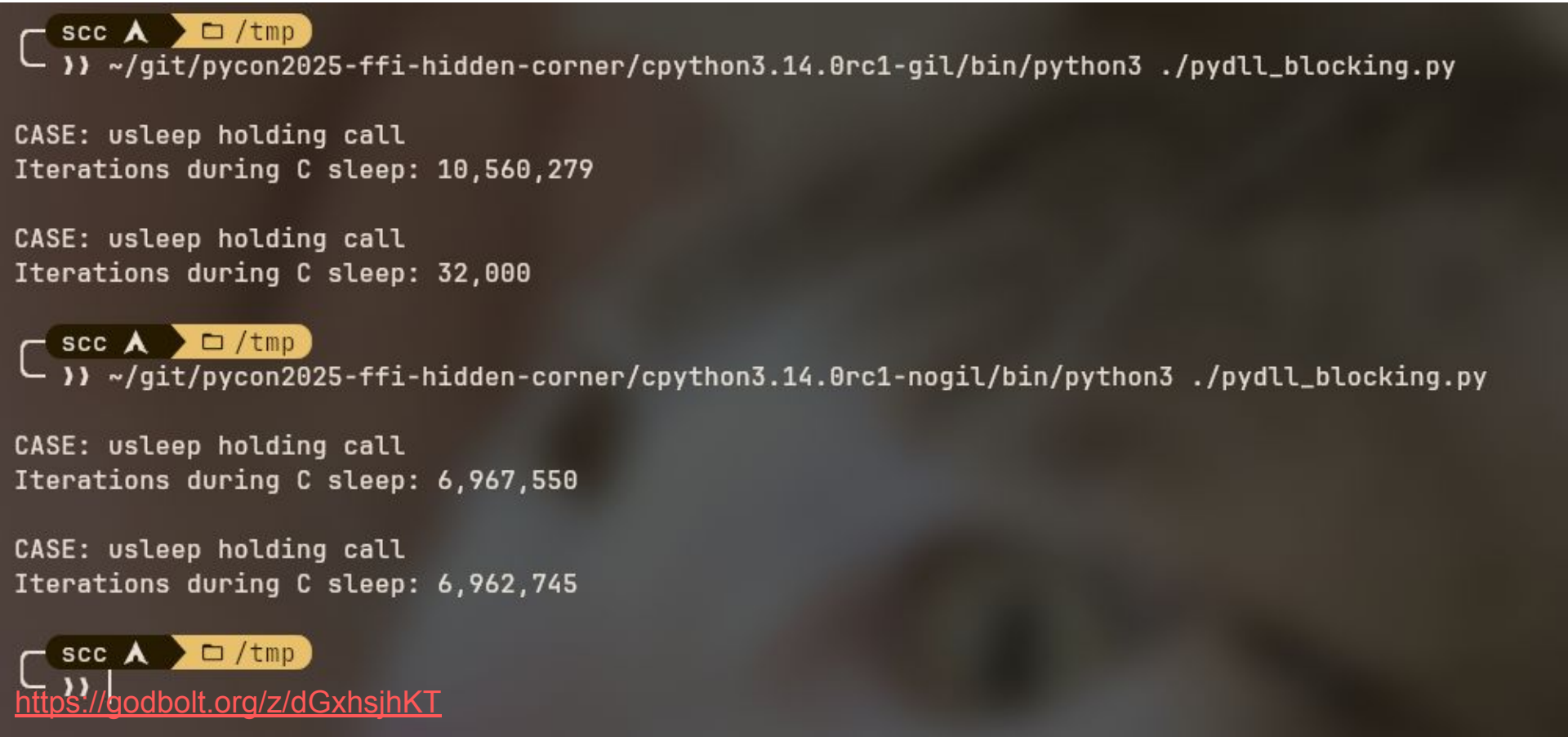


Not Release GIL, But Built with Free-Threaded

Loader	GIL Released?	Best for	Risk
CDLL	Yes	Long-running C code, multi-thread	Unsafe for Python C API calls
PyDLL	**No**	Short C calls, Python C API usage, single-thread	Blocks other threads, can deadlock

```
A = ctypes.CDLL(_lib_path)
B = ctypes.PyDLL(_lib_path)
```

Not Release GIL, But Built with Free-Threaded

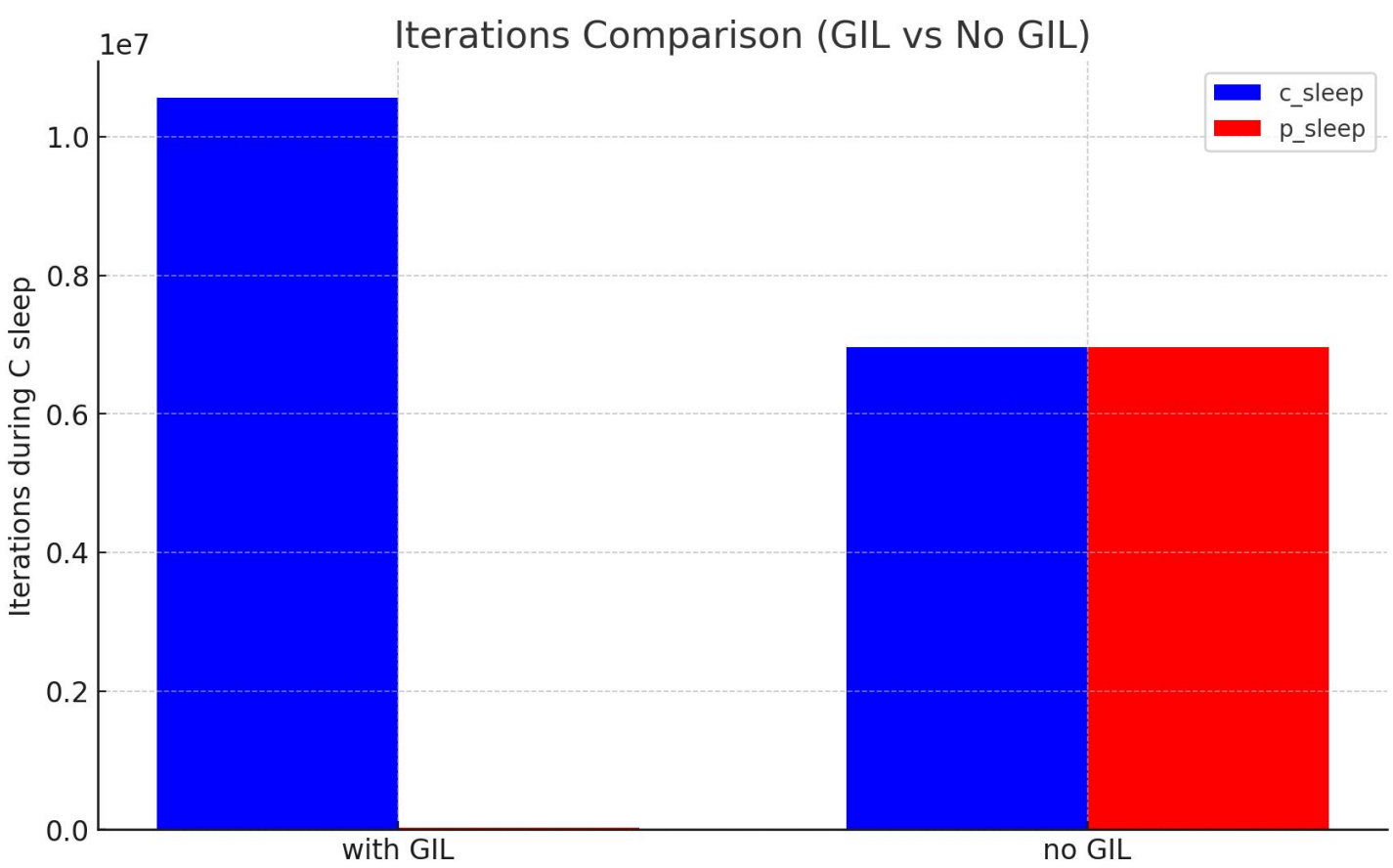


https://godbolt.org/z/dGxhsjhKT

Not Release GIL, But Built with Free-Threaded

```
scc  /tmp
 ~/git/pycon2025-ff

CASE: usleep holding cal
Iterations during C slee

CASE: usleep holding cal
Iterations during C slee

scc  /tmp
 ~/git/pycon2025-ff

CASE: usleep holding cal
Iterations during C slee

CASE: usleep holding cal
Iterations during C slee

scc  /tmp
```

https://godbolt.org/z/dGxhsjE



Why PyO3 fast, but ctypes slow?

ctypes

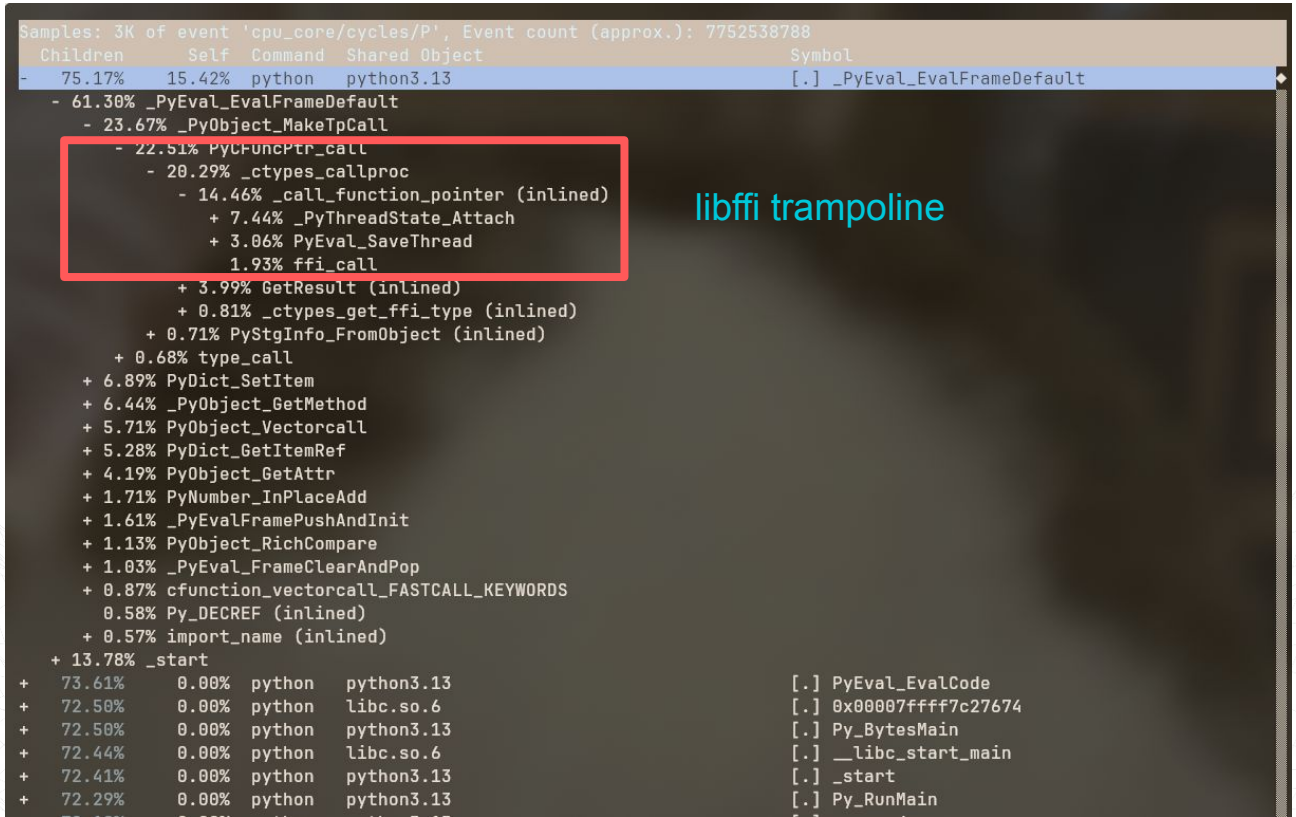
```
16.36%  [.] _PyEval_EvalFrameDefault                                -      -
        |
        |--14.26%--_PyEval_EvalFrameDefault
        |          |
        |          |--12.04%--PyEval_EvalCode
        |          |          |
        |          |           --11.74%--run_eval_code_obj
        |          |                     run_mod
        |          |                     pyrun_file
        |          |                     _PyRun_SimpleFileObject
        |          |                     _PyRun_AnyFileObject
        |          |                     pymain_run_file_obj (inlined)
        |          |                     pymain_run_file (inlined)
        |          |                     pymain_run_python (inlined)
        |          |                     Py_RunMain
        |          |                     Py_BytesMain
        |          |                     0x7ffff7c27674
        |          |                     __libc_start_main
        |          |                     _start
        |          |
        |           --0.63%--_PyObject_VectorcallTstate (inlined)
        |
         --0.66%--Py_INCREF (inlined)

 6.99%  [.] pthread_mutex_lock                                      -      -
        |
        |--4.93%--take_gil
        |          _PyThreadState_Attach
        |          _call_function_pointer (inlined)
        |          _ctypes_callproc (inlined)
        |          PyCFuncPtr_call
        |          _PyObject_MakeTpCall
        |          _PyEval_EvalFrameDefault
        |          PyEval_EvalCode
        |          run_eval_code_obj
        |          run_mod
        |          pyrun_file
        |          _PyRun_SimpleFileObject
        |          _PyRun_AnyFileObject
        |          pymain_run_file_obj (inlined)
        |          pymain_run_file (inlined)
        |          pymain_run_python (inlined)
        |          Py_RunMain
        |          Py_BytesMain
        |          0x7ffff7c27674
        |          __libc_start_main
        |          _start
        |
         --1.86%--drop_gil_impl (inlined)
                  drop_gil (inlined)
                  _PyEval_ReleaseLock
                  PyEval_SaveThread
                  |
                   --1.84%--_call_function_pointer (inlined)
                            _ctypes_callproc (inlined)
                            PyCFuncPtr_call
                            _PyObject_MakeTpCall
                            _PyEval_EvalFrameDefault
```

```
perf report --stdio --no-children \
-i "$CTYPES" --sort symbol
```

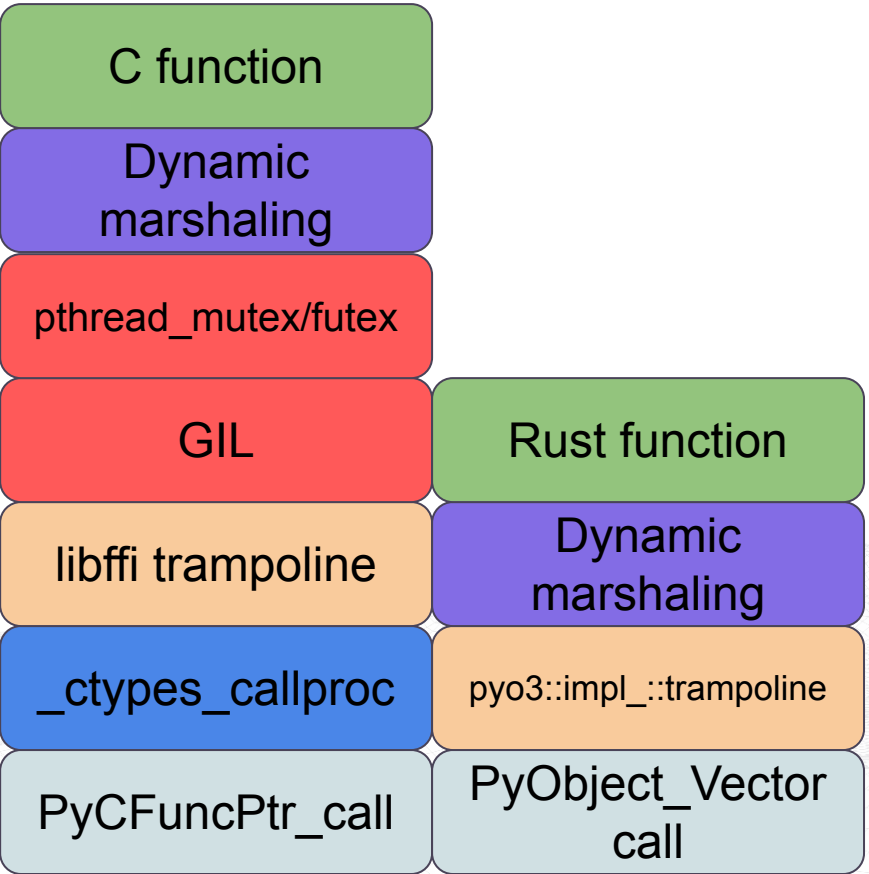
```
6.99%  [.] pthread_mutex_lock
       |
       |--4.93%--take_gil
       |          _PyThreadState_Attach
       |          _call_function_pointer (inlined)
       |          _ctypes_callproc (inlined)
       |          PyCFuncPtr_call
       |          _PyObject_MakeTpCall
       |          _PyEval_EvalFrameDefault
```

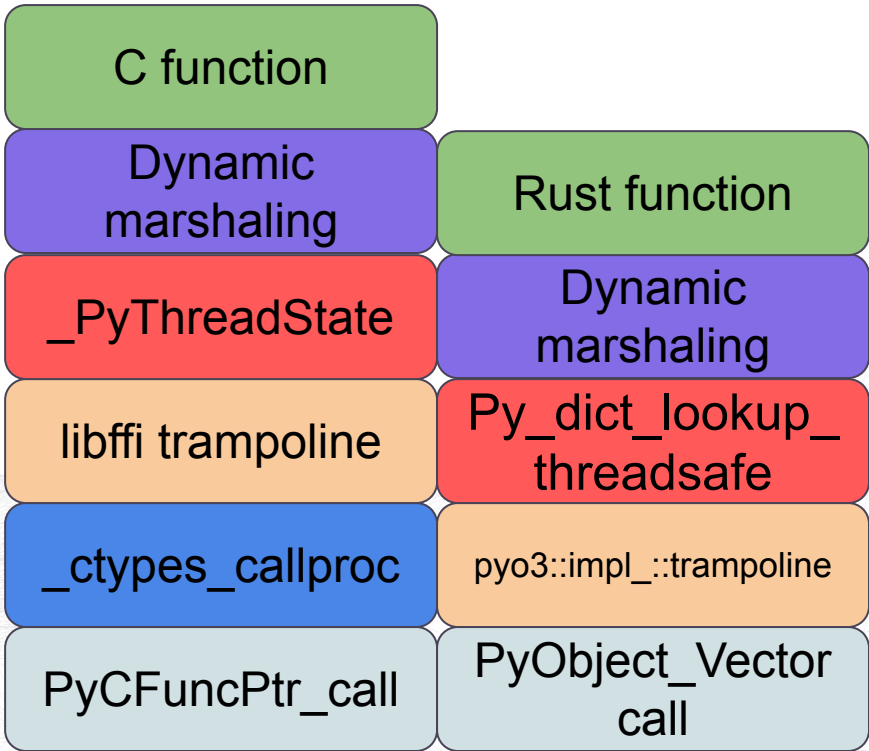
```
claude    perf report --stdio --no-children -i "$CTYPES" --sort symbol
```

Why PyO3 fast, but ctypes slow?



Why PyO3 fast, but ctypes slow?



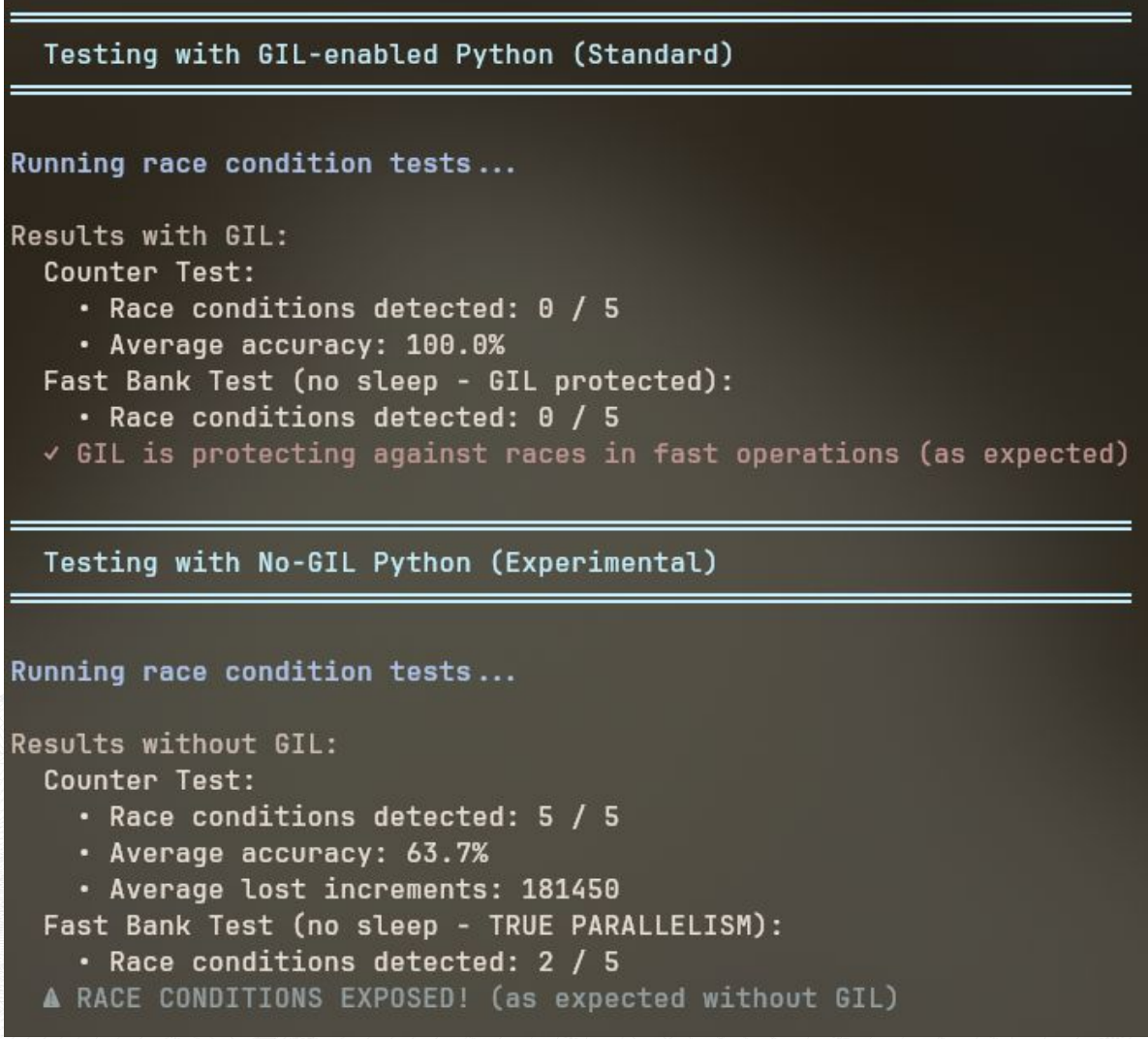


Recap

- PyDLL > CDLL over a 20% performance when GIL.
- PyO3 includes deep opt for vector calls without the GIL.
- The libffi trampoline emerges as the next bottleneck.

Racing FFI after No-GIL

Racing global states after No-GIL



Racing global states after No-GIL

```
lib = ctypes.PyDLL(str(lib path))
threads = [threading.Thread(target=unsafe_worker) for _
in range(num_threads)]
```

Racing global states after No-GIL

```
lib = ctypes.PyDLL(str(lib path))
threads = [threading.Thread(target=unsafe_worker) for _
in range(num_threads)]


long unsafe_increment(int iterations) {
    for (int _ = 0; _ < iterations; _++) {
        long temp = global_counter;  // Read  - RACE condition!
        COMPILER_BARRIER();
        global_counter = temp + 1;   // Write - RACE condition!
        COMPILER_BARRIER();
    }
    return global_counter;
}
```

Racing global states after No-GIL

```
lib = ctypes.PyDLL(str(lib_path))
threads = [threading.Thread(target=unsafe_worker) for _
in range(num_threads)]


long unsafe_increment(int it
    for (int _ = 0; _ < iterations; _++) {
        long temp = global_counter;  // Read  - RACE condition!
        COMPILER_BARRIER();
        global_counter = temp + 1;   // Write - RACE condition!
        COMPILER_BARRIER();
    }
    return global_counter;
}
```

It's safe when PyDLL + GIL.

Racing global states after No-GIL

```
lib = ctypes.PyDLL(str(lib pa
t                                                    t
i
                                                     af
l
                                                     ;
                                                     ;
```

```
    global_counter = temp + 1;
    COMPILER_BARRIER();
  }
  return global_counter;
}
```

```
uv run --python
../../cpython3.13.5-gil/bin/python3 python
demo_race_condition.py
```

```
== Counter Increment Race Condition Demo ==

Threads: 50
Iterations per thread: 10,000
Expected final value: 500,000

Testing UNSAFE increment...
Testing SAFE increment (mutex)...
Testing ATOMIC increment...

Counter Increment Comparison
```

Method	Final Value	Expected	Lost Increments	Accuracy	Status
UNSAFE	500,000	500,000	0	100.0%	✅ OK
SAFE (mutex)	500,000	500,000	0	100.0%	✅ OK
ATOMIC	500,000	500,000	0	100.0%	✅ OK

```
== Bank Withdrawal Race Condition Demo ==

Initial balance: $1000
Threads: 100
Withdrawal amount: $50
Attempts per thread: 3
Max possible withdrawals: 300 = $15000

Testing UNSAFE withdrawal (with race condition)...

Testing SAFE withdrawal (thread-safe)...

Race Condition Comparison
```

Method	Successful Withdrawa…	Total Withdrawn	Final Balance	Balance + Withdrawn	Consisten…	Time (s)
UNSAFE	20	$1000	$0	$1000	✅ OK	0.010
SAFE	20	$1000	$0	$1000	✅ OK	0.005

```
== Fast Bank Withdrawal Race (No Sleep) ==

Iterations: 5
Race conditions detected: 0/5
Average withdrawals: 50.0

✓ No race conditions detected (GIL protected)
```

CYCRAFT

Racing global states after No-GIL

```
lib = ctypes.PyDLL(str(lib_pa
t
i
l
```

```
        global_counter = temp + 1;
        COMPILER_BARRIER();
    }
    return global_counter;
}
```

```
uv run --python
../../cpython3.13.5-nogil/bin/python3 python
demo_race_condition.py
```

```
== Counter Increment Race Condition Demo ==

Threads: 50
Iterations per thread: 10,000
Expected final value: 500,000

Testing UNSAFE increment...
Testing SAFE increment (mutex)...
Testing ATOMIC increment...

Counter Increment Comparison
```

Method	Final Value	Expected	Lost Increments	Accuracy	Status
UNSAFE	400,766	500,000	99,234	80.2%	❌ RACE
SAFE (mutex)	500,000	500,000	0	100.0%	✅ OK
ATOMIC	500,000	500,000	0	100.0%	✅ OK

```
⚠ RACE CONDITION: Lost 99,234 increments (19.8% data loss)!
```

```
== Bank Withdrawal Race Condition Demo ==

Initial balance: $1000
Threads: 100
Withdrawal amount: $50
Attempts per thread: 3
Max possible withdrawals: 300 = $15000

Testing UNSAFE withdrawal (with race condition)...

Testing SAFE withdrawal (thread-safe)...

Race Condition Comparison
```

Method	Successful Withdrawa…	Total Withdrawn	Final Balance	Balance + Withdrawn	Consisten…	Time (s)
UNSAFE	300	$15000	$300	$15300	❌ BROKEN	0.021
SAFE	20	$1000	$0	$1000	✅ OK	0.006

```
⚠ RACE CONDITION DETECTED: Total is off by $14300!
```

Racing global states after No-GIL

	GIL	No-GIL
Thread Safe FF	Safe	Safe
Non Thread Safe FF	Uncertain	Race!

Recap

- Be aware that the GIL protects unsafe global states.
- Not all FFI calls are protected by the GIL.
- Ensure your FFI code is thread-safe.

Higher Risk for Arena Leakage in GLibc

Scenario	glibc malloc (ptmalloc2+tcache)	macOS libmalloc (zones+magazines+nano)	jemalloc	tcmalloc	Windows HeapAlloc (NT/Segment+LFH)
many short-lived threads	△ (cap `arena_max`, pool threads)	×	★ (many arenas, decay purge)	○ (per-thread caches)	×
Long-lived server, RSS-sensitive	△ (trim/mmap tuning)	×	★ (decay + background purge)	△ (raise release rate)	×
Latency-critical, multi-threaded	○ (tcache helps)	×	○	★ (lock-free fast paths)	△ (enable LFH/Segment Heap)
Cloud functions / short-lived processes	★ (simple, low setup)	×	○ (defaults fine)	○	×
Tight memory limit (containers, 256–512 MiB)	○ (tune thresholds)	×	★ (predictable footprint)	△ (cap thread caches)	×
Backgrounding app	×	★ (UI latency; pressure-relief)	△ (uncommon on macOS)	△	×
High thread-count backend	×	×	○ (if linked)	○ (if linked)	△ (enable LFH; consider Segment Heap)
Fork/exec heavy (prefork workers)	○	×	★ (copy-on-write friendly decay)	○	×
NUMA / many-core (>32 cores)	△ (no strong NUMA policy)	×	★ (arena sharding, pinning options)	○ (per-CPU caches)	△
Production leak/frag profiling needed	△ (basic)	○ (Instruments/stack logging)	★ (heap profiling, mallctl stats)	○ (heap profiler)	○ (ETW/!heap/PageHeap)

Use GLIBC_TUNABLES when it is matter

Default tunable malloc

```
scc ~
)) /lib64/ld-linux-x86-64.so.2 --list-tunables | grep malloc
glibc.malloc.arena_max: 0x0 (min: 0x1, max: 0xffffffffffffffff)
glibc.malloc.arena_test: 0x0 (min: 0x1, max: 0xffffffffffffffff)
glibc.malloc.check: 0 (min: 0, max: 3)
glibc.malloc.hugetlb: 0x0 (min: 0x0, max: 0xffffffffffffffff)
glibc.malloc.mmap_max: 0 (min: 0, max: 2147483647)
glibc.malloc.mmap_threshold: 0x0 (min: 0x0, max: 0xfffffffffffff
glibc.malloc.mxfast: 0x0 (min: 0x0, max: 0xffffffffffffffff)
glibc.malloc.perturb: 0 (min: 0, max: 255)
glibc.malloc.tcache_count: 0x0 (min: 0x0, max: 0xffffffffffffffff
glibc.malloc.tcache_max: 0x0 (min: 0x0, max: 0xffffffffffffffff)
glibc.malloc.tcache_unsorted_limit: 0x0 (min: 0x0, max: 0xffffffff
glibc.malloc.top_pad: 0x20000 (min: 0x0, max: 0xffffffffffffffff)
glibc.malloc.trim_threshold: 0x0 (min: 0x0, max: 0xfffffffffffff
```

M_MMAP_THRESHOLD

For allocations greater than or equal to the limit specified (in bytes) by **M_MMAP_THRESHOLD** that can't be satisfied from the free list, the memory-allocation functions employ mmap(2) instead of increasing the program break using sbrk(2).

Allocating memory using mmap(2) has the significant advantage that the allocated memory blocks can always be independently released back to the system. (By contrast, the heap can be trimmed only if memory is freed at the top end.) On the other hand, there are some disadvantages to the use of mmap(2): deallocated space is not placed on the free list for reuse by later allocations; memory may be wasted because mmap(2) allocations must be page-aligned; and the kernel must perform the expensive task of zeroing out memory allocated via mmap(2). Balancing these factors leads to a default setting of 128*1024 for the **M_MMAP_THRESHOLD** parameter.

The lower limit for this parameter is 0. The upper limit is **DEFAULT_MMAP_THRESHOLD_MAX**: 512*1024 on 32-bit systems or *4*1024*1024*sizeof(long)* on 64-bit systems.

Note: Nowadays, glibc uses a dynamic mmap threshold by default. The initial value of the threshold is 128*1024, but when blocks larger than the current threshold and less than or equal to **DEFAULT_MMAP_THRESHOLD_MAX** are freed, the threshold is adjusted upward to the size of the freed block. When dynamic mmap thresholding is in effect, the threshold for trimming the heap is also dynamically adjusted to be twice the dynamic mmap threshold. Dynamic adjustment of the mmap threshold is disabled if any of the **M_TRIM_THRESHOLD**, **M_TOP_PAD**, **M_MMAP_THRESHOLD**, or **M_MMAP_MAX** parameters is set.

M_TRIM_THRESHOLD

When the amount of contiguous free memory at the top of the heap grows sufficiently large, free(3) employs sbrk(2) to release this memory back to the system. (This can be useful in programs that continue to execute for a long period after freeing a significant amount of memory.) The **M_TRIM_THRESHOLD** parameter specifies the minimum size (in bytes) that this block of memory must reach before sbrk(2) is used to trim the heap.

The default value for this parameter is 128*1024. Setting **M_TRIM_THRESHOLD** to -1 disables trimming completely.

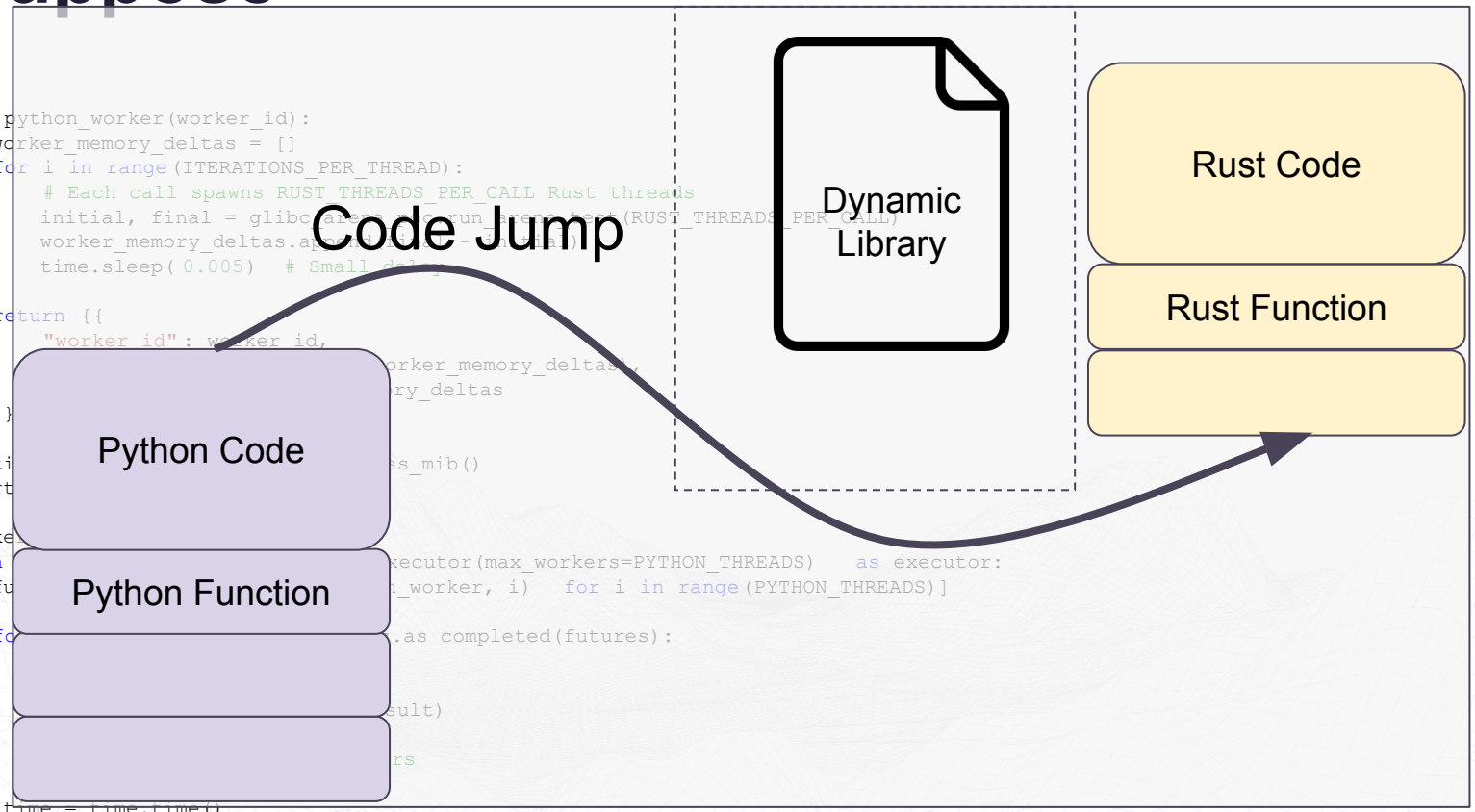
Modifying **M_TRIM_THRESHOLD** is a trade-off between increasing the number of system calls (when the parameter is set low) and wasting unused memory at the top of the heap (when the parameter is set high).

Suppose

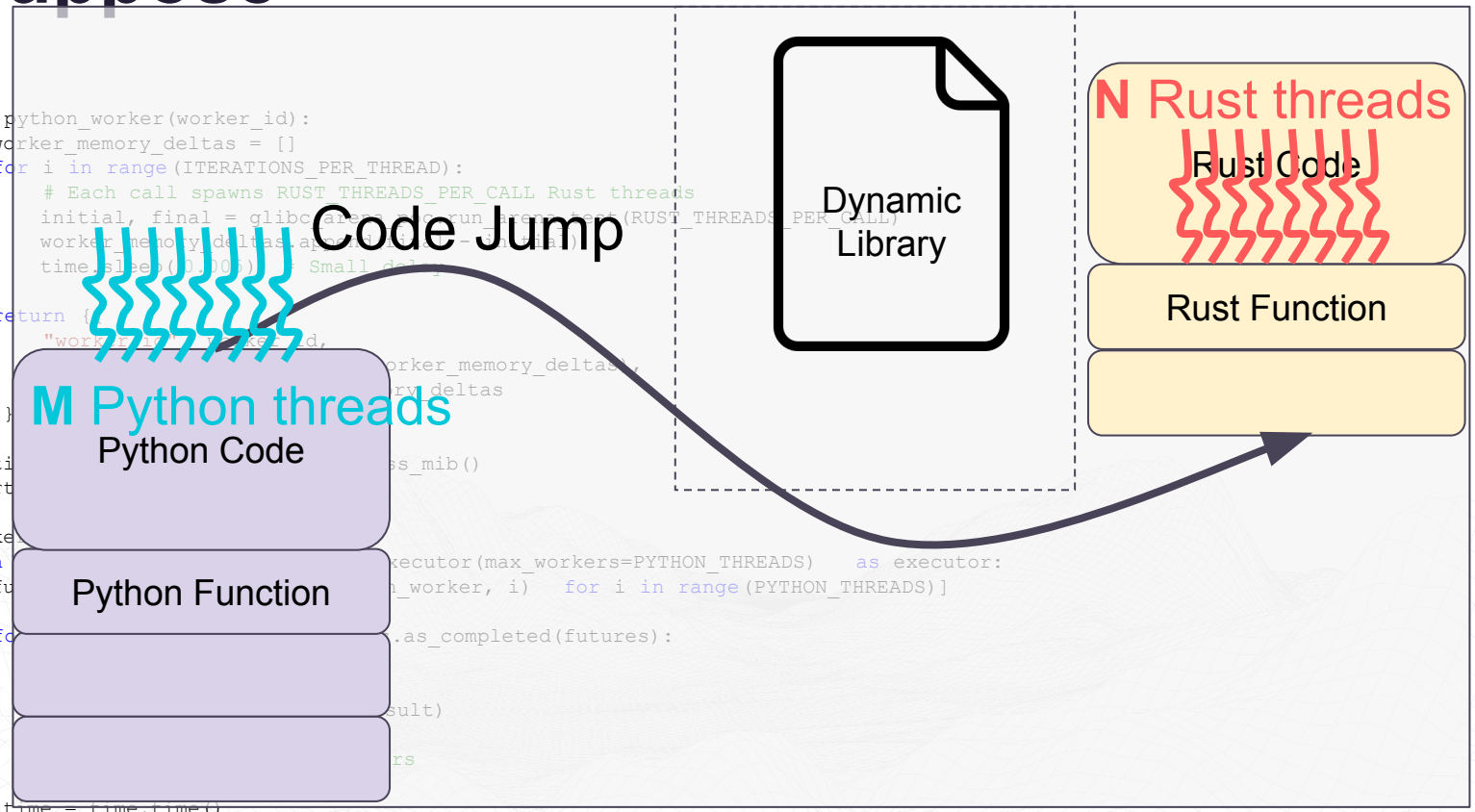
```
def python_worker(worker_id):
    worker_memory_deltas = []
    for i in range(ITERATIONS_PER_THREAD):
        # Each call spawns RUST_THREADS_PER_CALL Rust threads
        initial, final = glibc_arena_poc.run_arena_test(RUST_THREADS_PER_CALL)
        worker_memory_deltas.append(final - initial)
        time.sleep( 0.005)  # Small delay

    return {{
        "worker_id": worker_id,
        "total_memory_delta" : sum(worker_memory_deltas),
        "memory_deltas" : worker_memory_deltas
    }}

initial_rss = glibc_arena_poc.get_rss_mib()
start_time = time.time()

worker_results = []
with concurrent.futures.ThreadPoolExecutor(max_workers=PYTHON_THREADS)   as executor:
    futures = [executor.submit(python_worker, i)   for i in range(PYTHON_THREADS)]

    for future in concurrent.futures.as_completed(futures):
        try:
            result = future.result()
            worker_results.append(result)
        except Exception as e:
            pass  # Continue on errors

end_time = time.time()
final_rss = glibc_arena_poc.get_rss_mib()
```

CYCRAFT

Suppose


Code Jump
Dynamic Library
Rust Code
Rust Function
Python Code
Python Function

Suppose

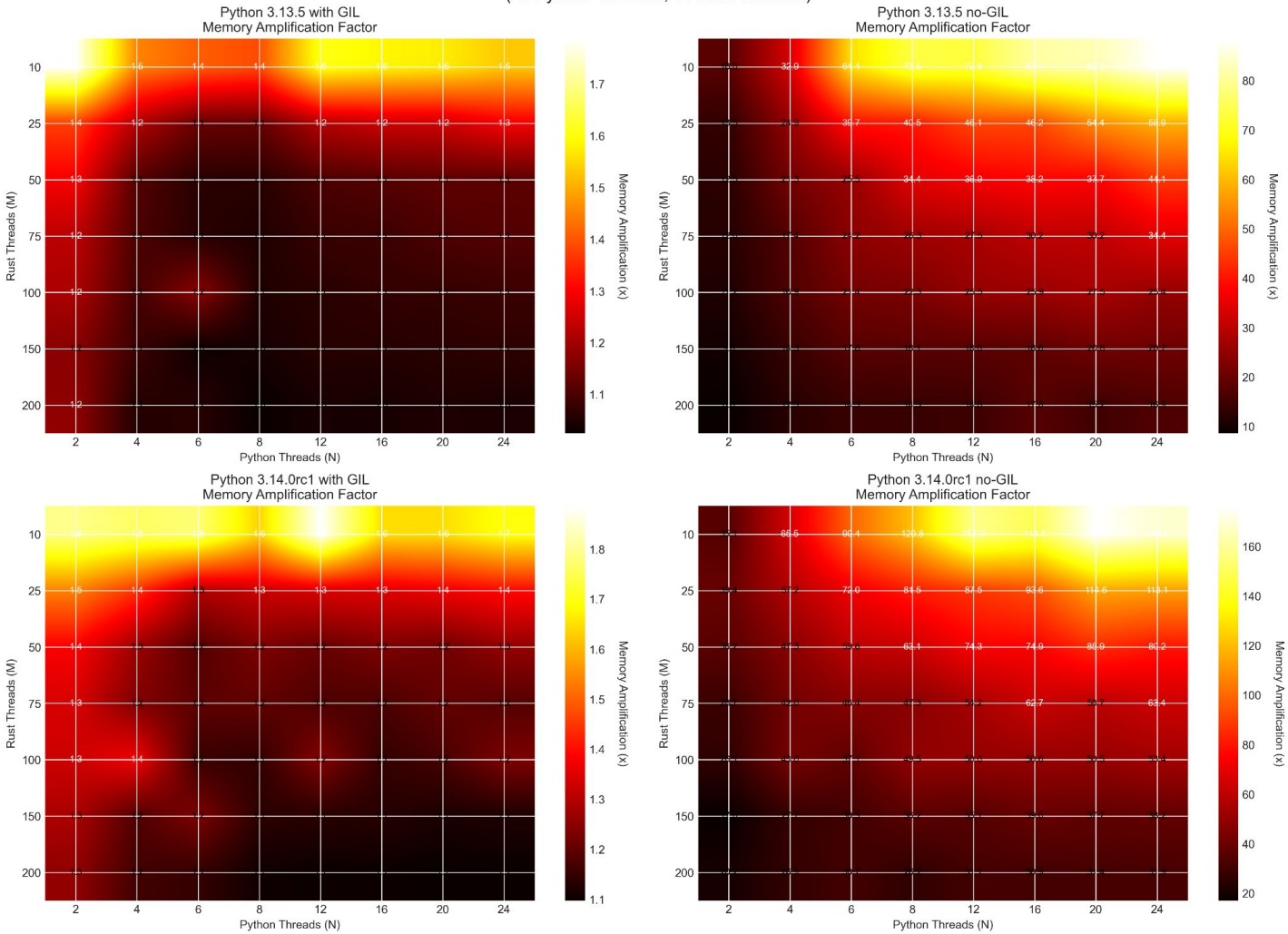



```
def python_worker(worker_id):
    worker_memory_deltas = []
    for i in range(ITERATIONS_PER_THREAD):
        # Each call spawns RUST_THREADS_PER_CALL Rust threads
        initial, final = glibc_arena_poc.run_threads(RUST_THREADS_PER_CALL)
        worker_memory_deltas.append(final - initial)
        time.sleep(0.001)  # Small delay

    return {
        "worker_id": worker_id,
        "memory_deltas": worker_memory_deltas,
        "total_memory_increase": sum(worker_memory_deltas)
    }

initial_rss = glibc_arena_poc.get_rss_mib()
start_time = time.time()

worker_ids = list(range(PYTHON_THREADS))
with concurrent.futures.ThreadPoolExecutor(max_workers=PYTHON_THREADS) as executor:
    futures = [executor.submit(python_worker, i) for i in range(PYTHON_THREADS)]

    for future in concurrent.futures.as_completed(futures):
        result = future.result()
        results.append(result)

end_time = time.time()
final_rss = glibc_arena_poc.get_rss_mib()
```

```
scc  ~/git/pycon2025-ffi-hidden-corner/tests/arena/rust
 (main) +3 ?1  3.13.5
❯❯ python3 arena_test.py benchmark --arena-risk --python-threads 8 --rust-threads 50
🔬 Running Arena Risk Analysis...
   Python Threads (N): 8
   Rust Threads per call (M): 50
   Expected complexity: O(N*M) = O(400)
[2025-08-15 21:55:46] [INFO] 🔬 Comparing Arena Risk - Python 3.13.5: GIL vs no-GIL
[2025-08-15 21:55:46] [INFO] ✅ Arena risk test completed for 3.13.5-gil: 0.56 MiB delta, 0.0x p
arallelism
[2025-08-15 21:55:46] [INFO] ✅ Arena risk test completed for 3.13.5-nogil: 16.57 MiB delta, 0.0
x parallelism
[2025-08-15 21:55:46] [INFO]    GIL memory delta: 0.56 MiB
[2025-08-15 21:55:46] [INFO]    no-GIL memory delta: 16.57 MiB
[2025-08-15 21:55:46] [INFO]    Risk amplification: 29.46x
[2025-08-15 21:55:46] [INFO] 🔬 Comparing Arena Risk - Python 3.14.0rc1: GIL vs no-GIL
[2025-08-15 21:55:46] [INFO] ✅ Arena risk test completed for 3.14.0rc1-gil: 0.59 MiB delta, 0.0
x parallelism
[2025-08-15 21:55:46] [INFO] ✅ Arena risk test completed for 3.14.0rc1-nogil: 32.60 MiB delta,
0.0x parallelism
[2025-08-15 21:55:46] [INFO]    GIL memory delta: 0.59 MiB
[2025-08-15 21:55:46] [INFO]    no-GIL memory delta: 32.60 MiB
[2025-08-15 21:55:46] [INFO]    Risk amplification: 55.26x

🚨 Arena Leakage Risk Analysis Results:
================================================================================

Python 3.13.5 - Arena Risk Assessment:
  🔒 GIL Memory Delta:          0.56 MiB (amplification: 1.09x)
  🆓 no-GIL Memory Delta:      16.57 MiB (amplification: 32.38x)
  📈 Risk Amplification:       29.46x
  🎯 Risk Level:            HIGH
  🔄 Parallelism Increase:      0.00x
  ⚠️  HIGH RISK: no-GIL shows significant arena leakage amplification!

Python 3.14.0rc1 - Arena Risk Assessment:
  🔒 GIL Memory Delta:          0.59 MiB (amplification: 1.18x)
  🆓 no-GIL Memory Delta:      32.60 MiB (amplification: 62.28x)
  📈 Risk Amplification:       55.26x
  🎯 Risk Level:            HIGH
  🔄 Parallelism Increase:      0.00x
  ⚠️  HIGH RISK: no-GIL shows significant arena leakage amplification!
```

CYCRAFT

Arena Leakage Risk Matrix: GIL vs no-GIL
(X: Python Threads, Y: Rust Threads)

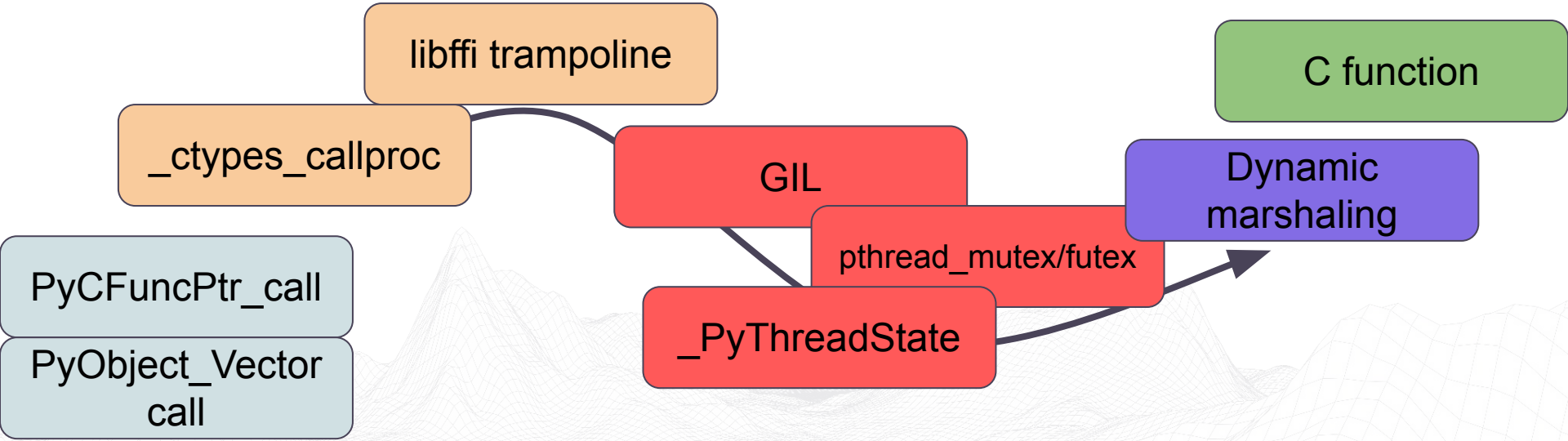


CYCRAFT

Best Practice

- Pin the thread
- Aware multi-threading bugs
- Thread safe for each component

The hidden corner you might be aware



The hidden corner you might be aware

- Application level:
  - **GIL Semantics**, **Thread Pinning**, Refcount Edges & Ownership, Error Propagation, Reentrancy…
- OS level:
  - **Race Conditions**, **Dynamic Loading** / lazy binding, **System Libraries Features**, Loader Search Path, Permissions…
- Hardware level:
  - **ABI Compatibility**, **Cache Locality**, Modern CPU Affinity Binding, TLB, Branch Prediction, I/O Topology…

Takeaway

- Python 3.14t is Impressive
- Canary or Shadow Deployment
- Make Sure All Components are Thread-Safe

Thank you!

scc@scc.tw

Q&A

py-free-threading.github.io

Free-Threaded Wheels

ft-checker.com