to GIL or not to GIL: the Future of Multi-Core (C)Python

Eric Snow
PyCon 2019

https://bit.ly/2UMMJey

@ericsnowcrntly

Who Am I?

- software engineer at Microsoft (Python extension for VS Code)
- CPython core developer (since 2012)
    - 8 PEPs (5 accepted, 3 open)
    - sys.implementation
    - module.__spec__
    - C OrderedDict

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    - sys.implementation
    - module.__spec__
    - C OrderedDict
- tired of hearing about how the GIL makes Python awful
- in late 2014 decided to do something about it

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Overview

1. Context
    - CPython’s Architecture
    - What happens when Python Runs?
    - Threads and Locks
2. The GIL
3. The Future
    - The C-API
    - Subinterpreters!
4. Q&A

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Context

An Overview of CPython’s Architecture

● process	- the OS process
● runtime	- everything Python-related in a process
● interpreter	- all Python threads and everything they share
● Python thread	- wrapper around OS thread with eval loop inside
● call stack	- stack of eval loop instances (i.e. Python function calls)
● eval loop	- executes the sequence of instructions in a code obj

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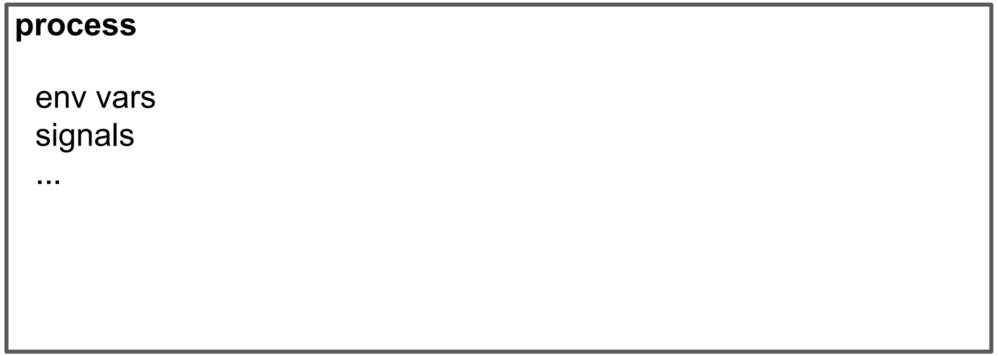
What Happens When Python Runs?



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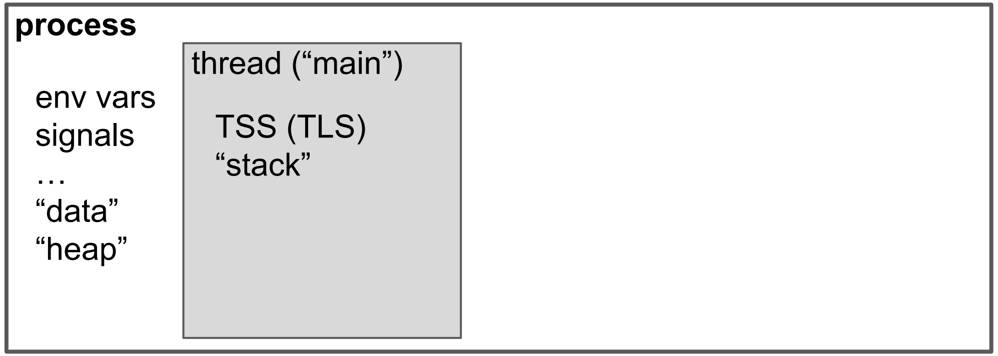

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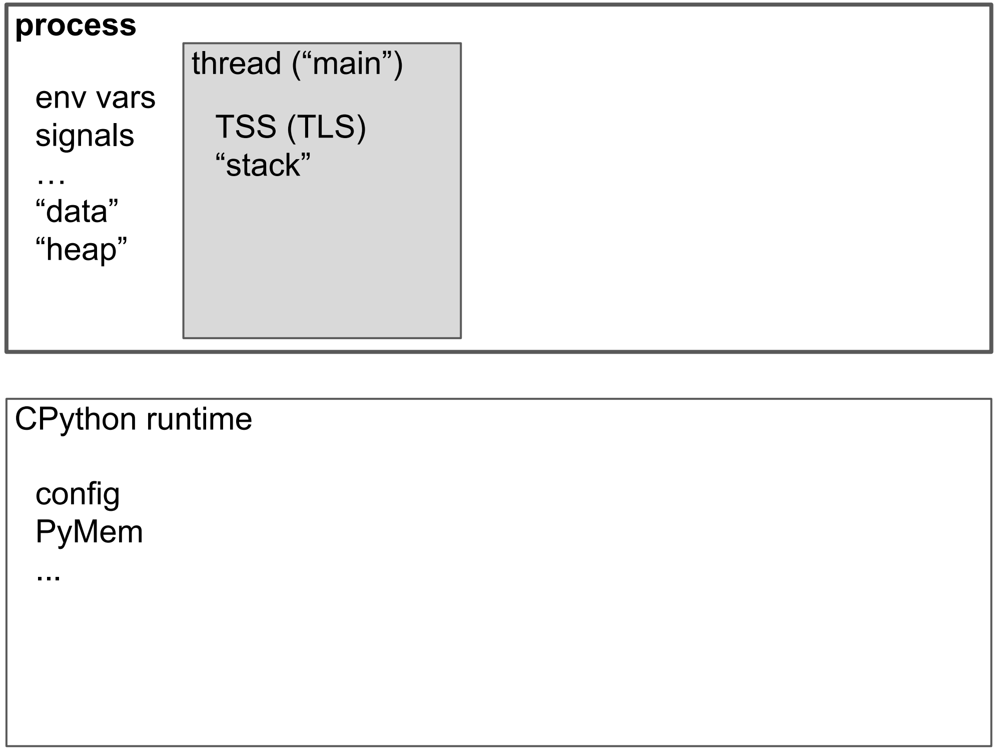

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3. Python runtime initializes

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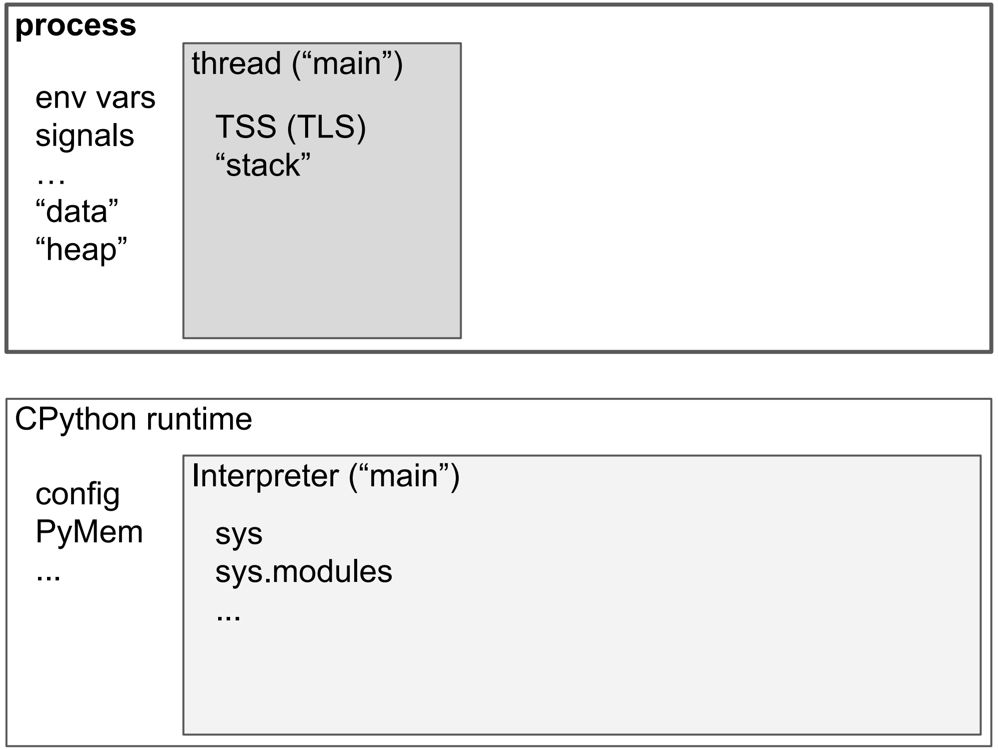

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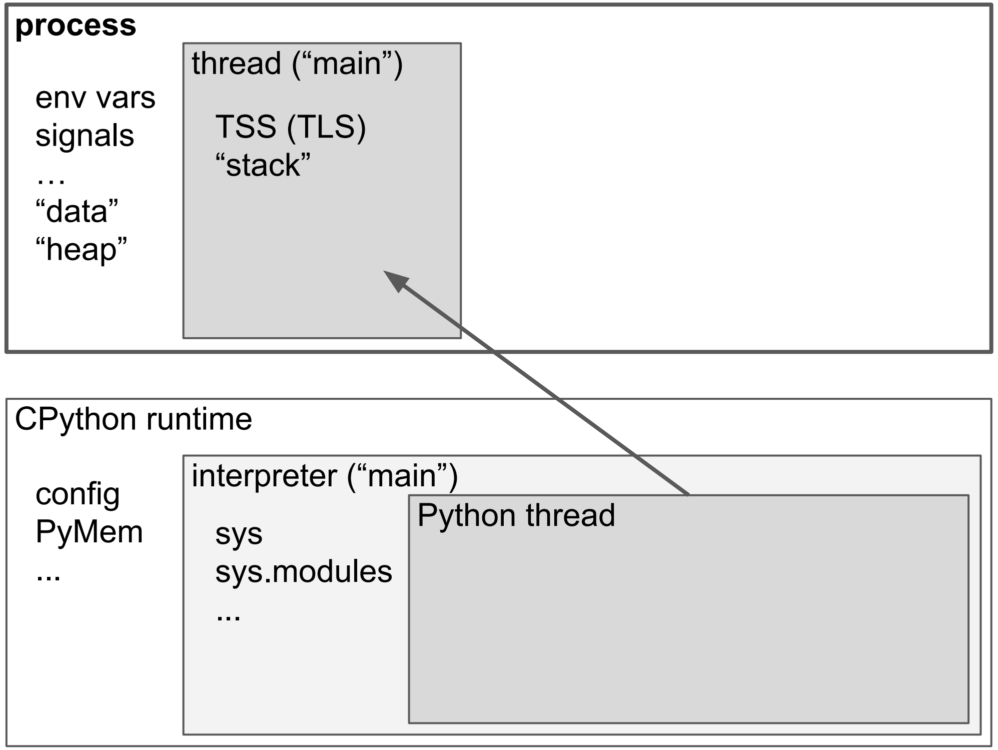

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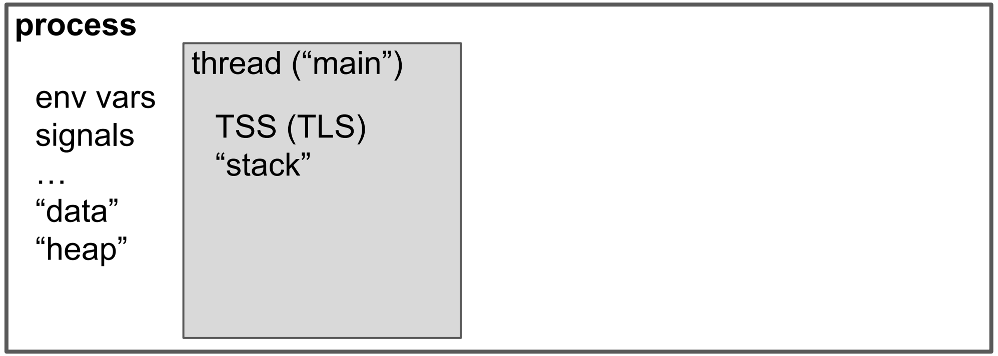

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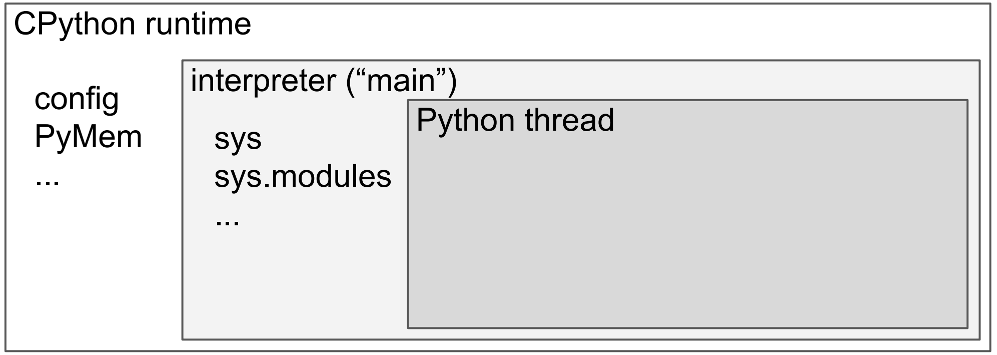

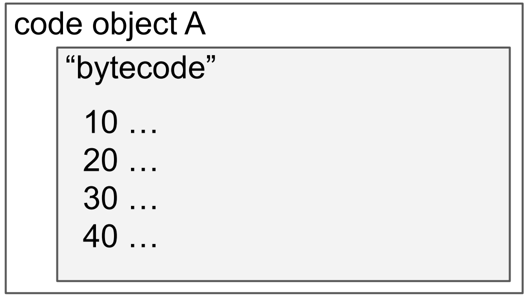

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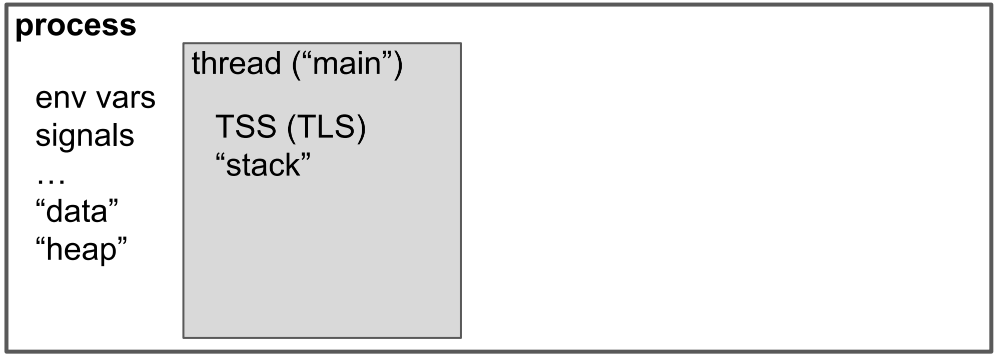

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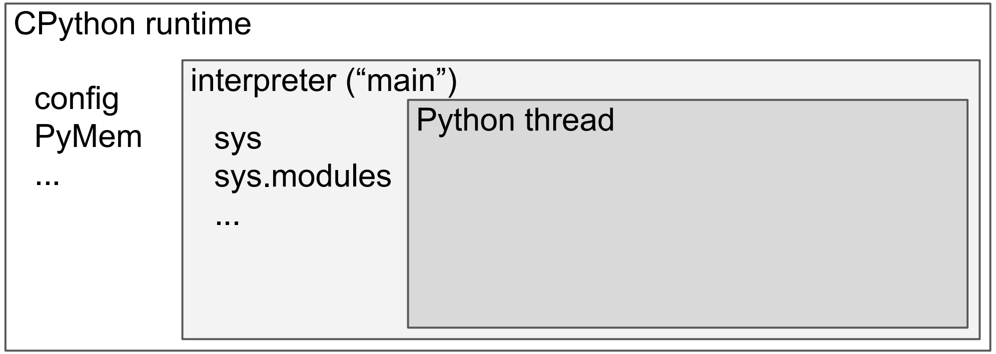

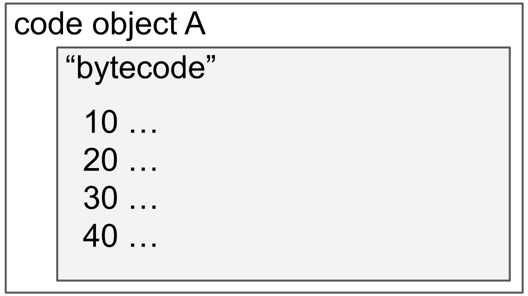

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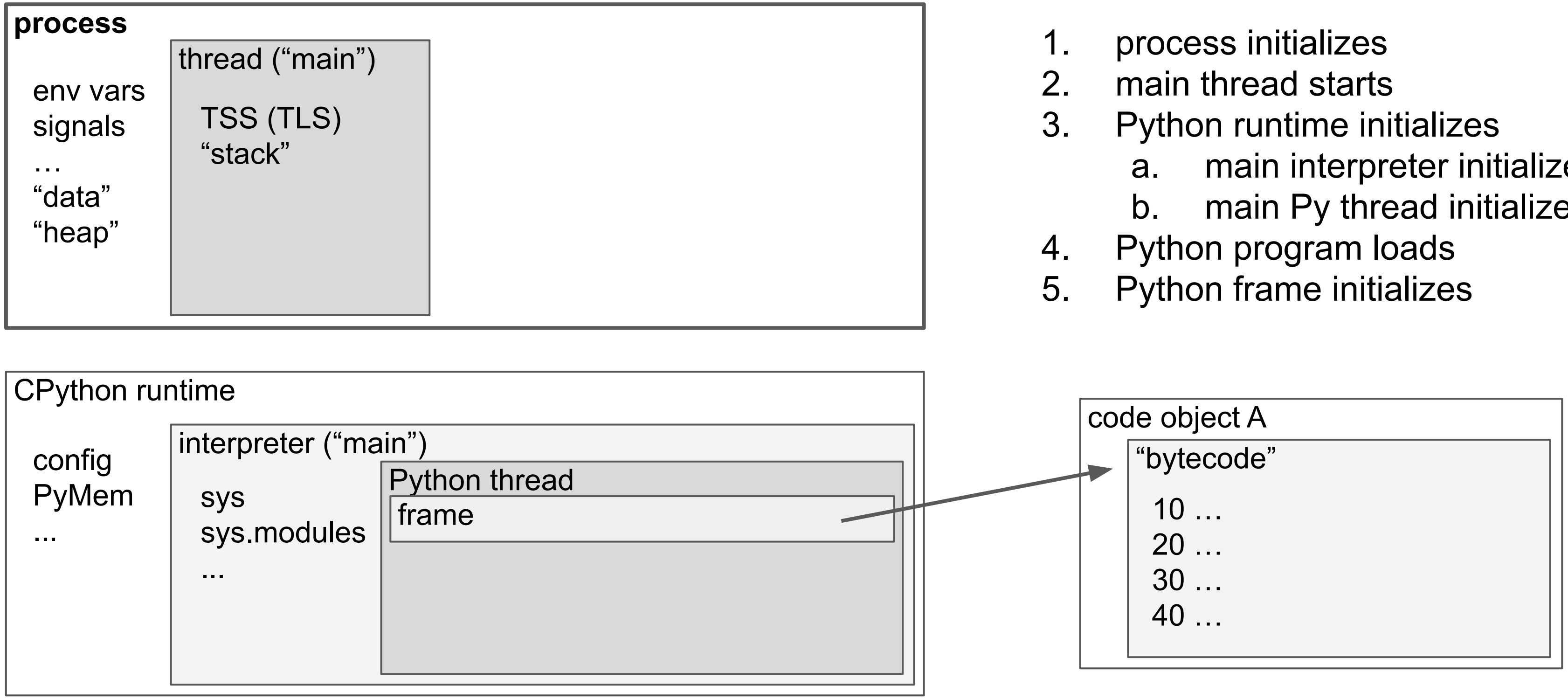

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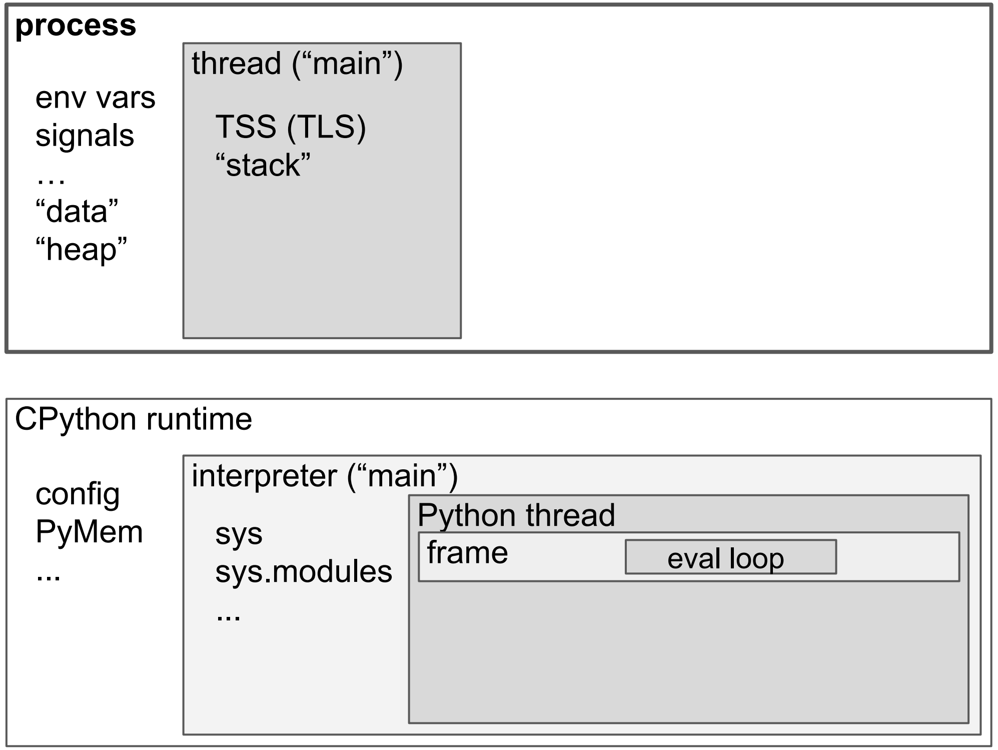

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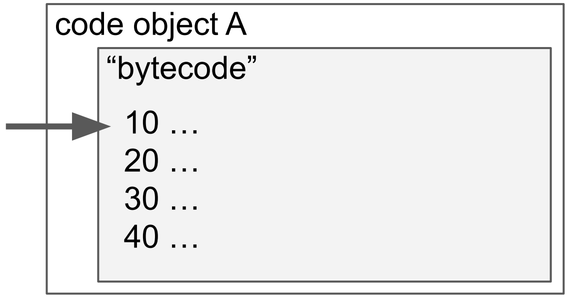

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The Eval Loop

```
<set up>

for instruction in code object:

    <maybe side-channel stuff>

    <occasionally release & re-acquire the GIL>

    <execute next instruction>
```

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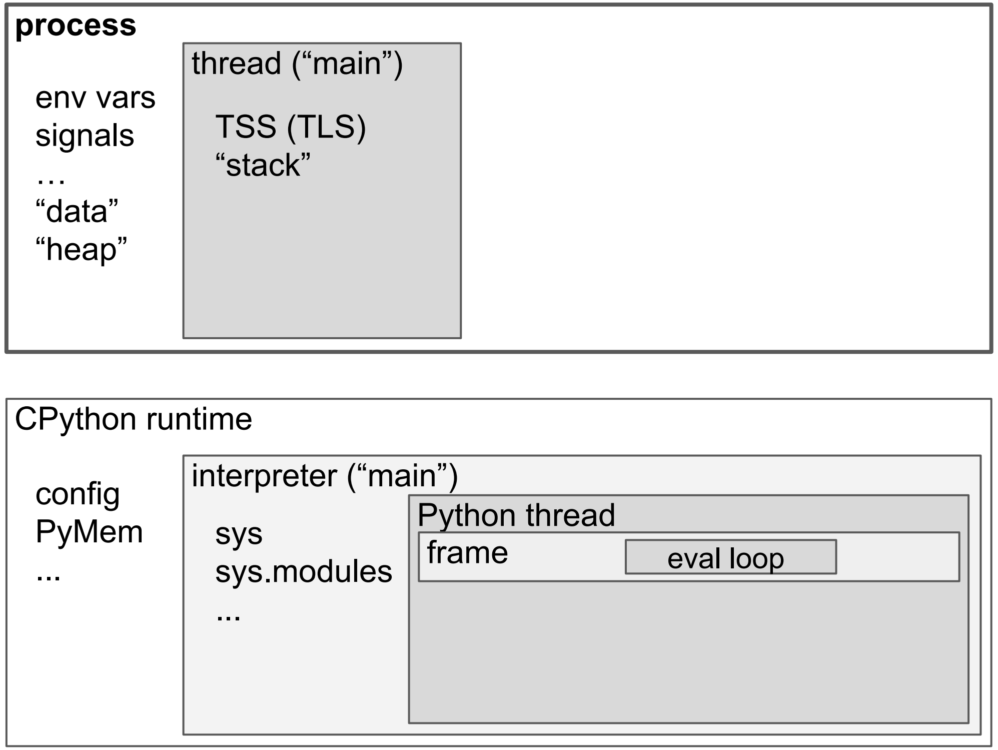

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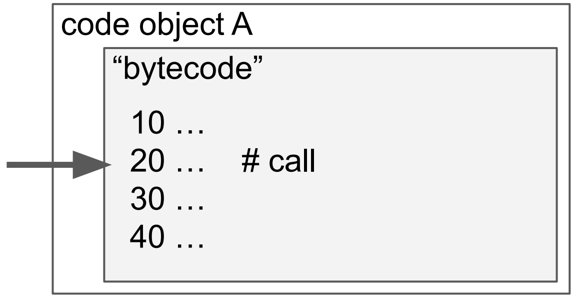

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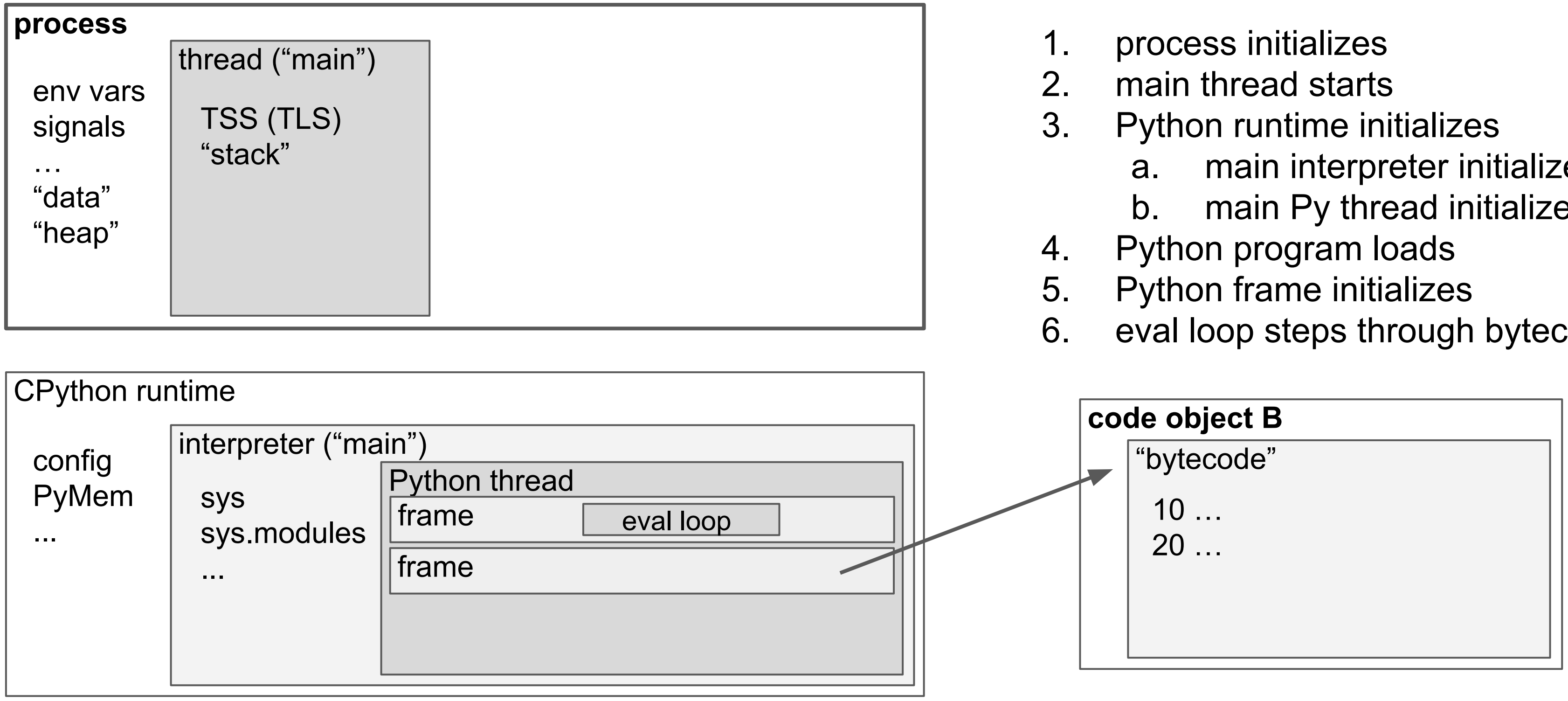

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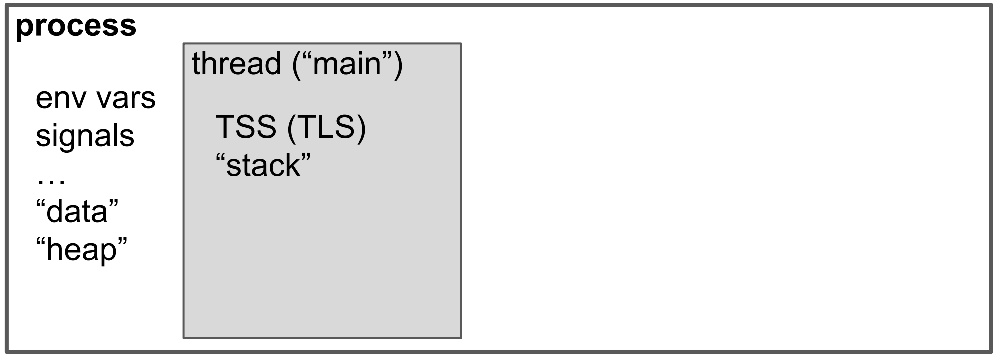

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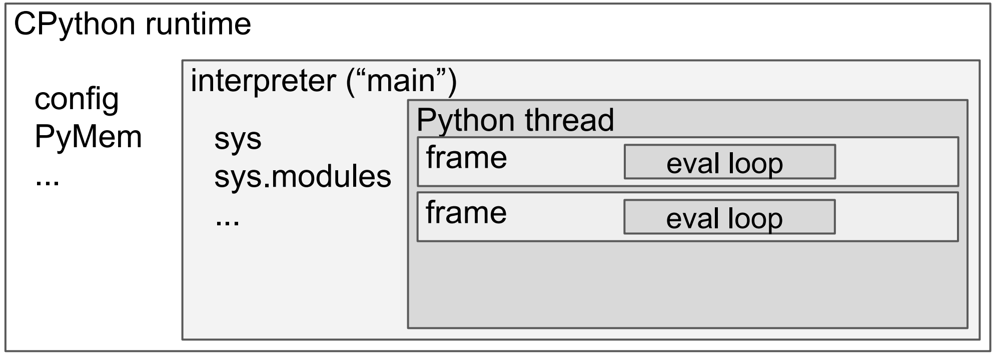

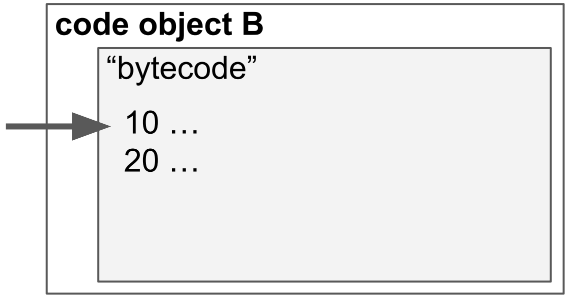

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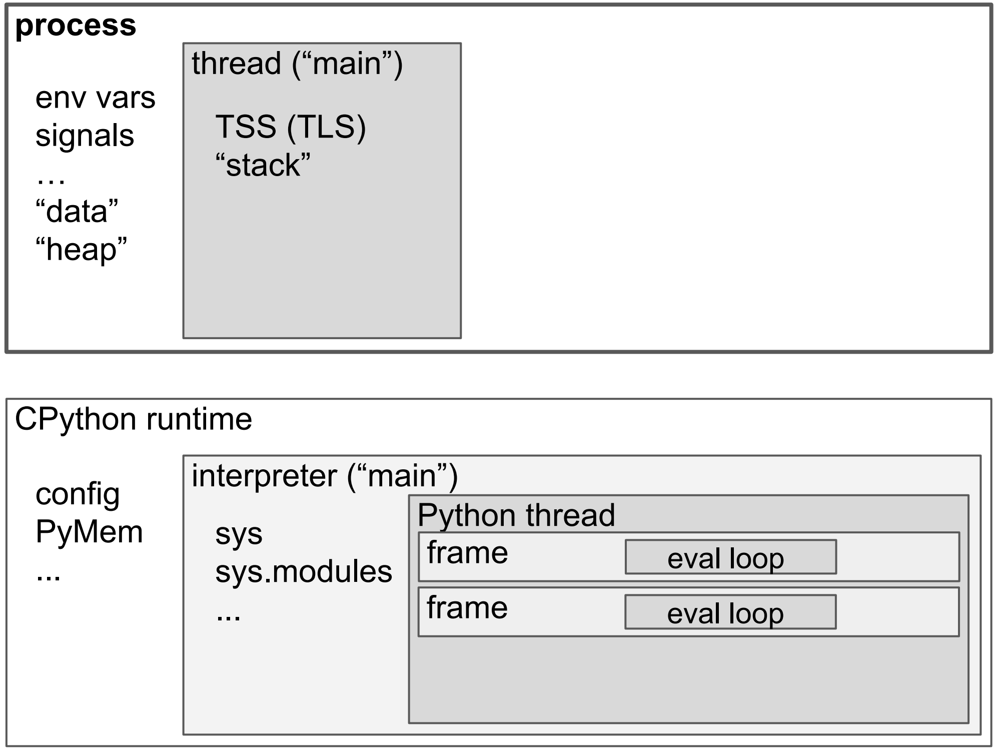

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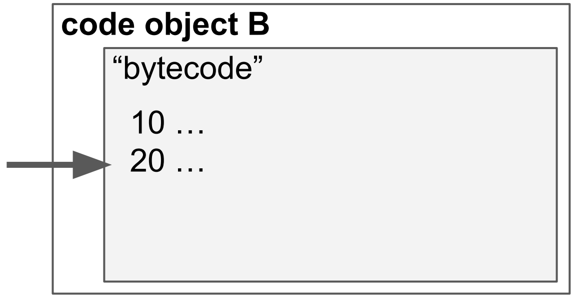

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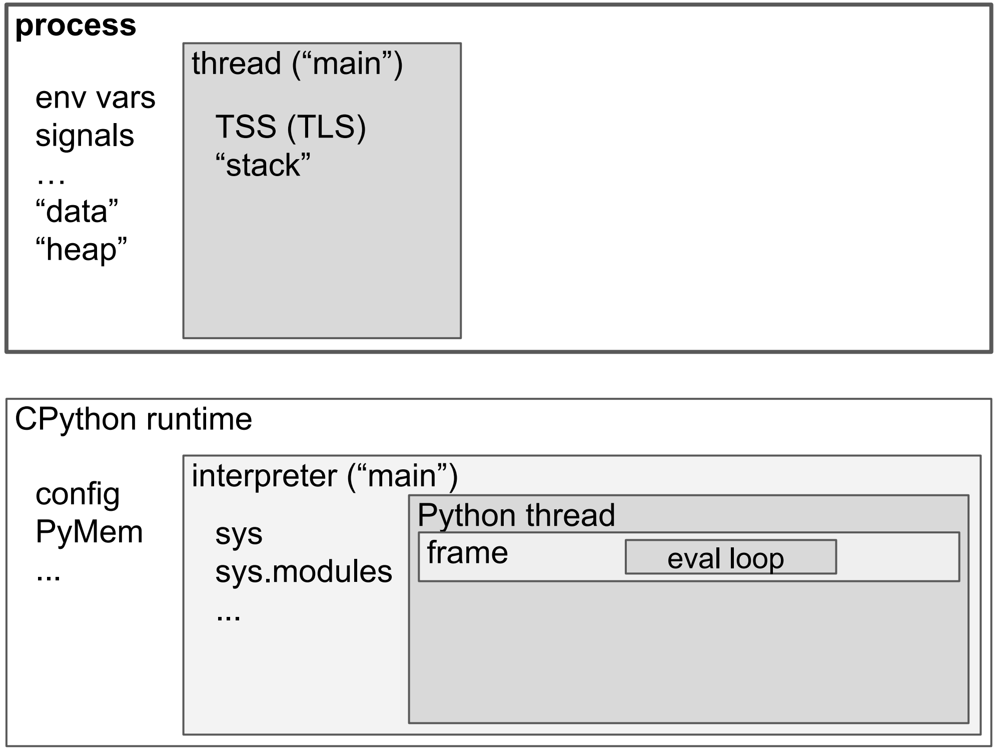

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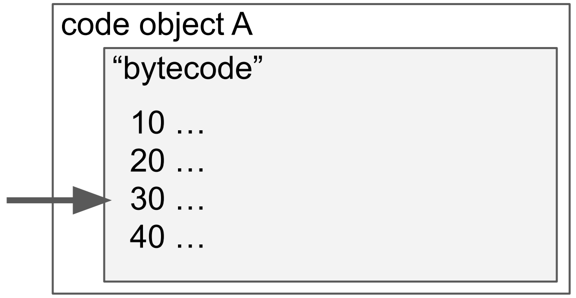

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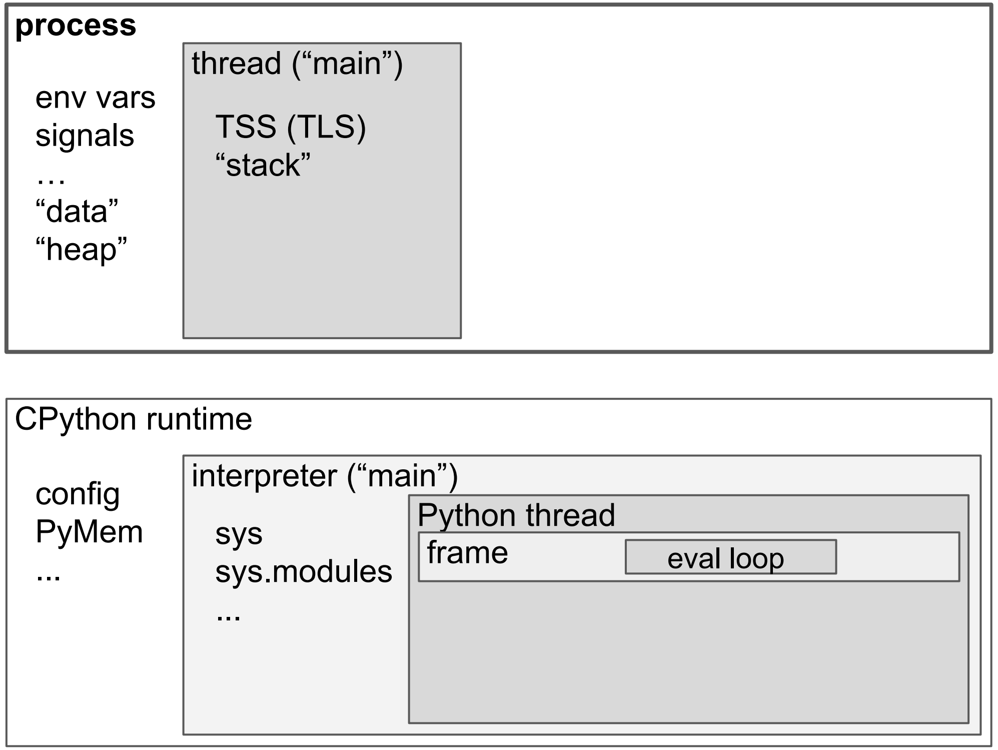

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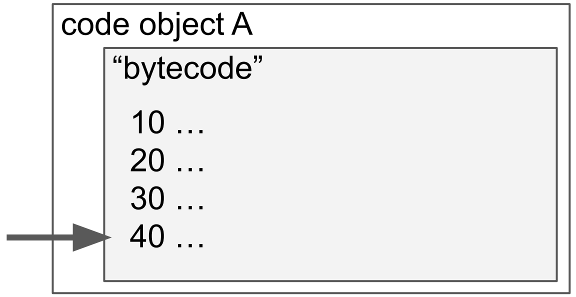

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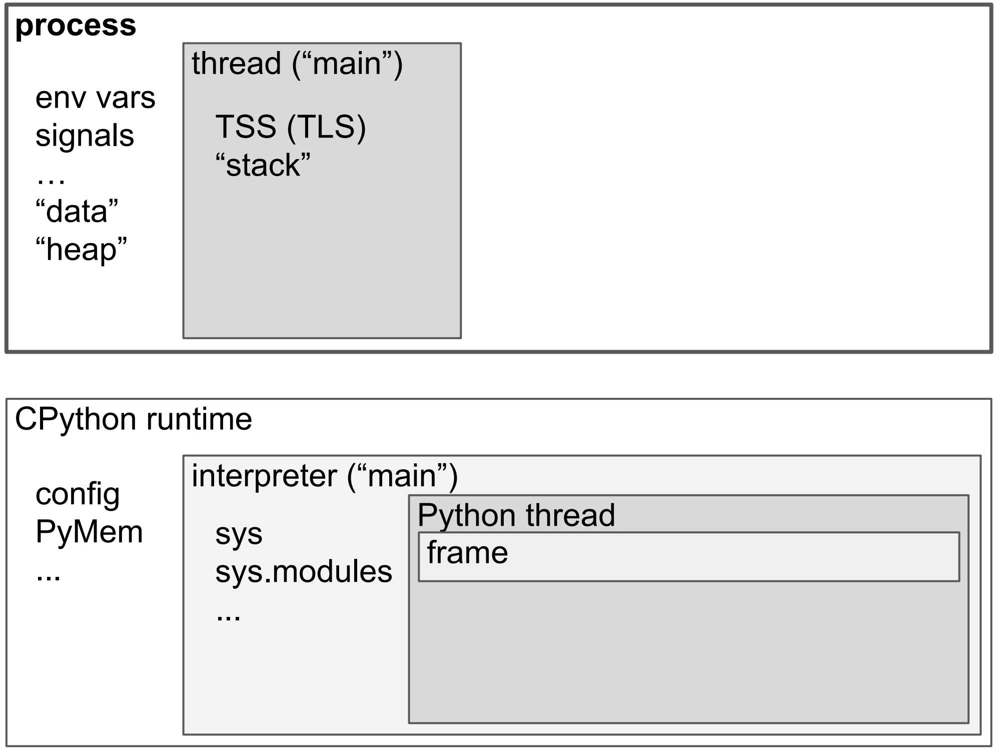

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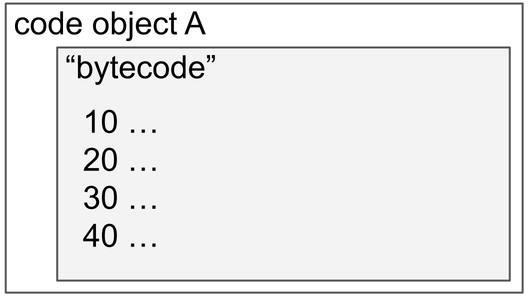

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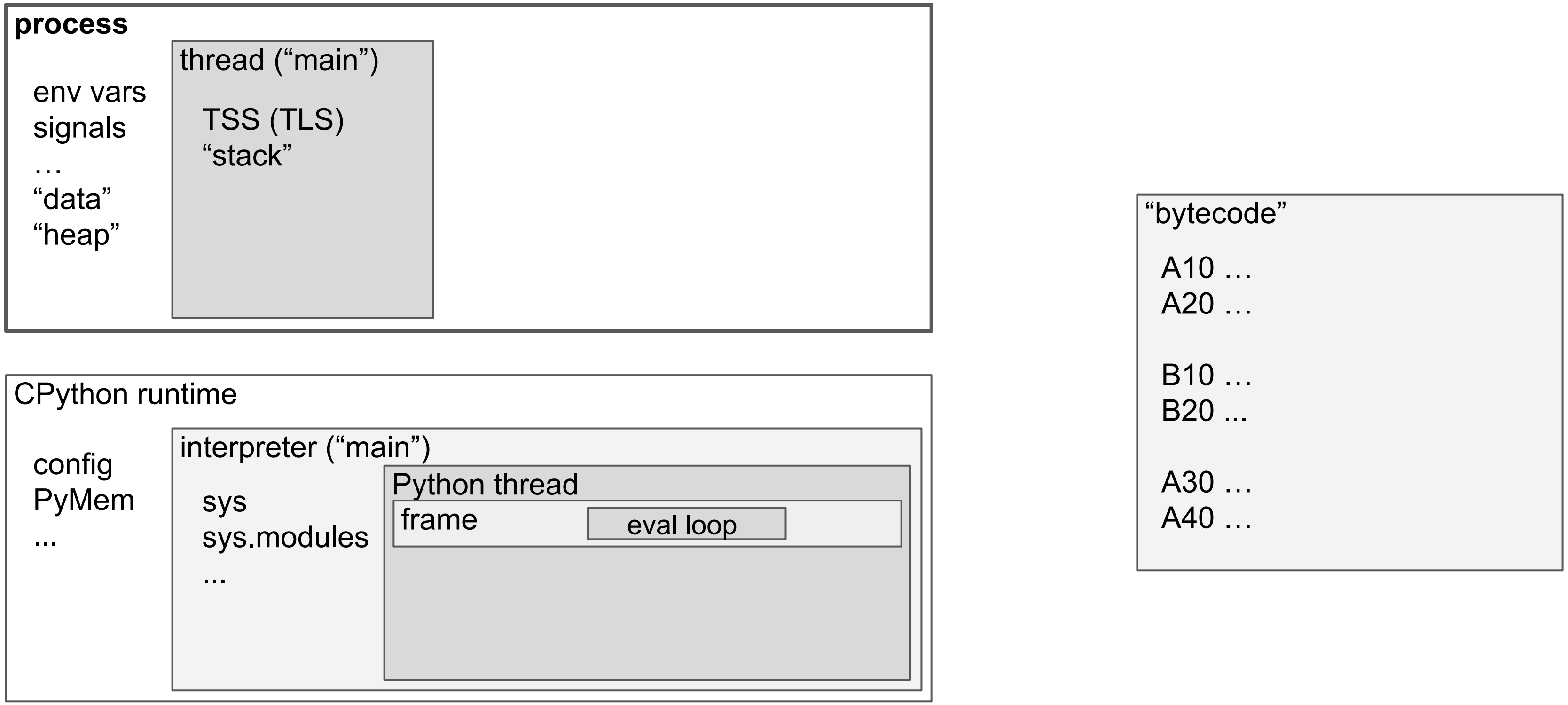

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Multi-threading!

```
def spam():
    …
t = threading.Thread(target=spam)
t.start()
…
t.join()
```

```
__main__

  A10 …
  A20 …
  B10 …
  B20 ...
  A30 …
  A40 …
```

```
spam()

  C10 …
  C20 …
```

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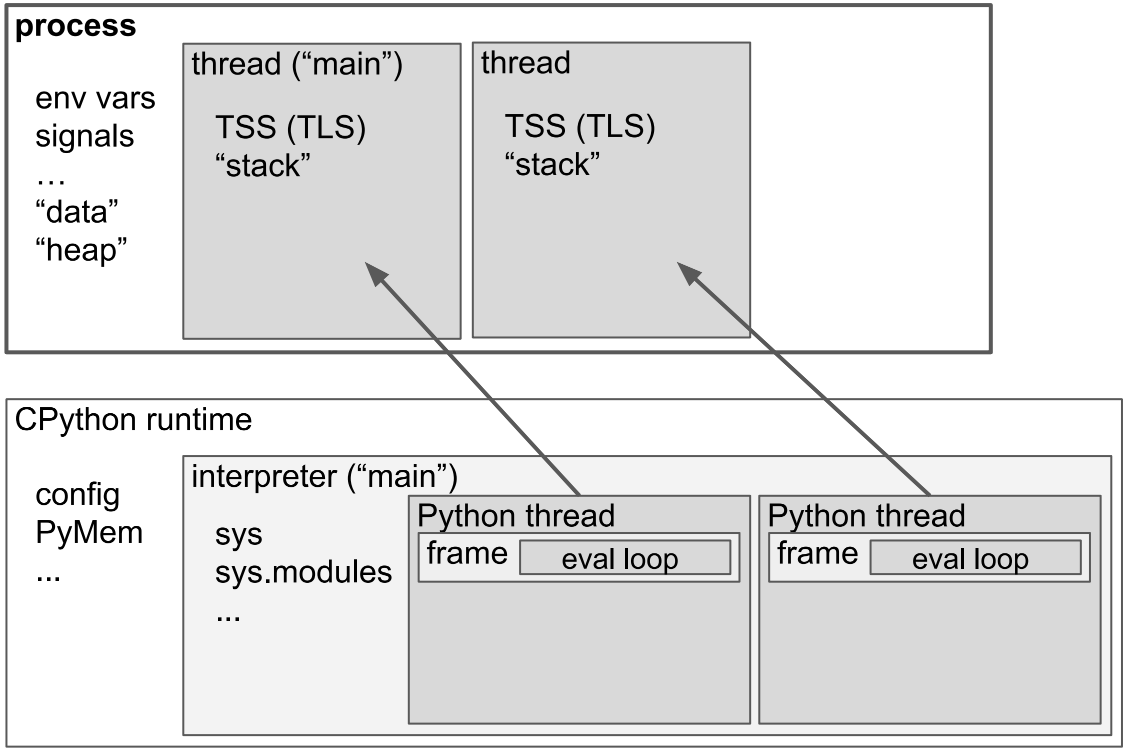

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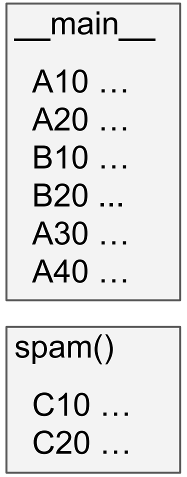

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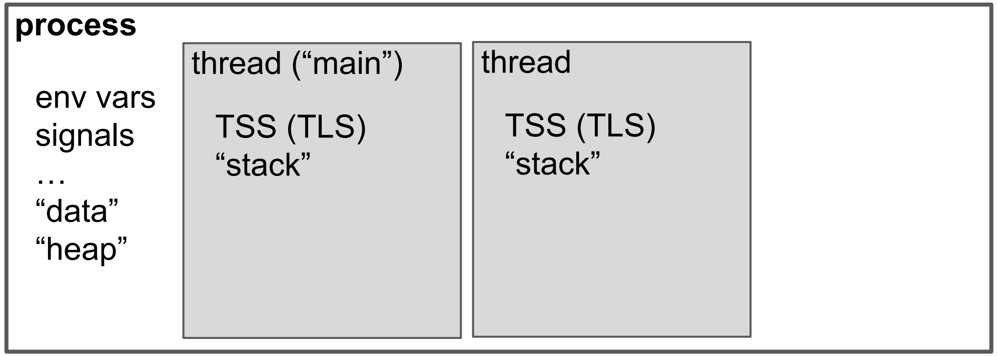

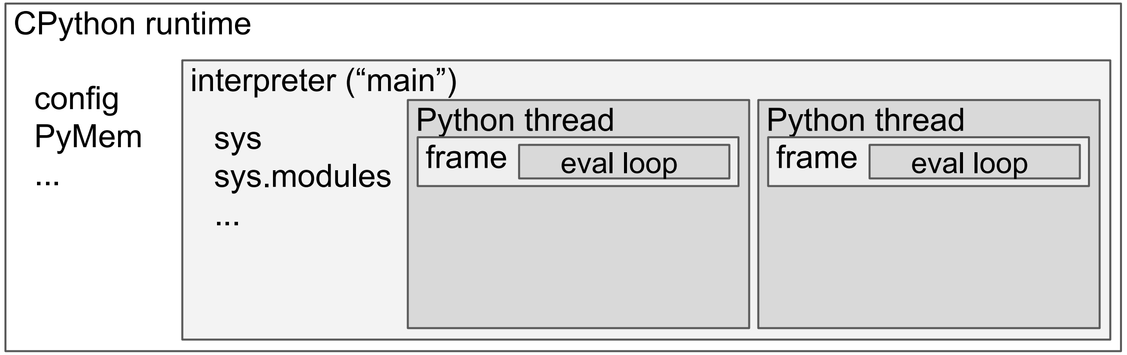

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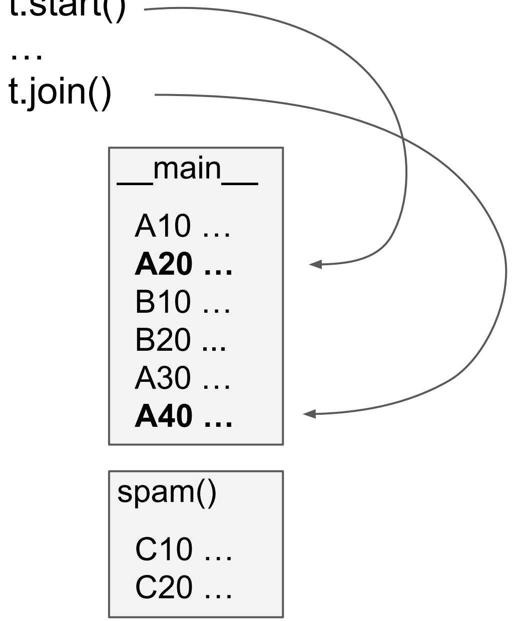

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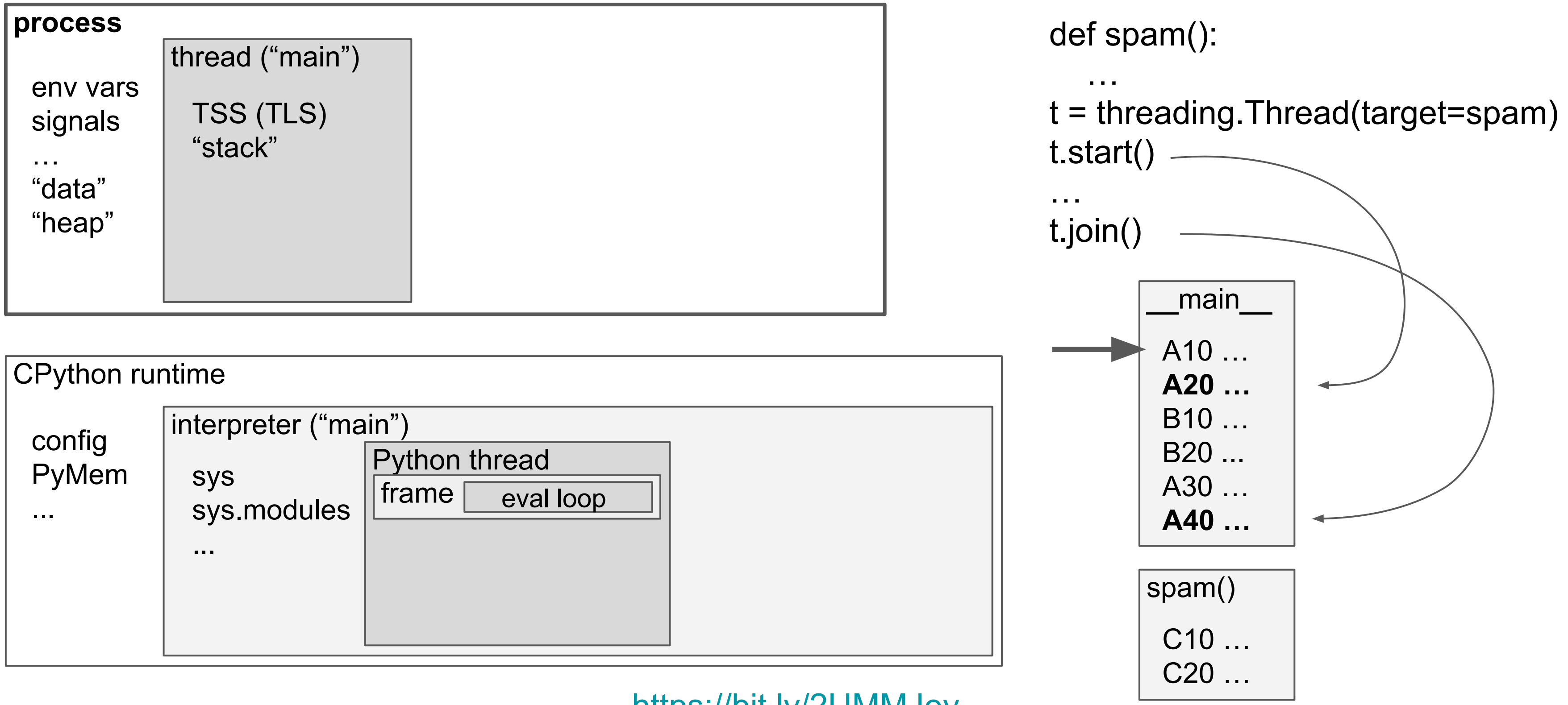

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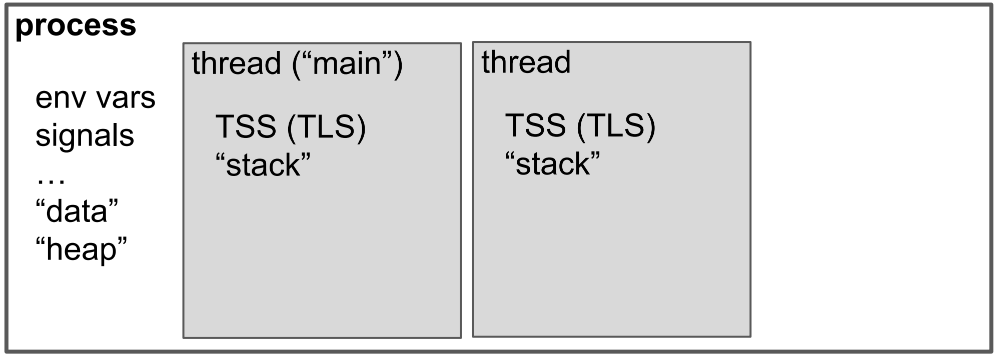

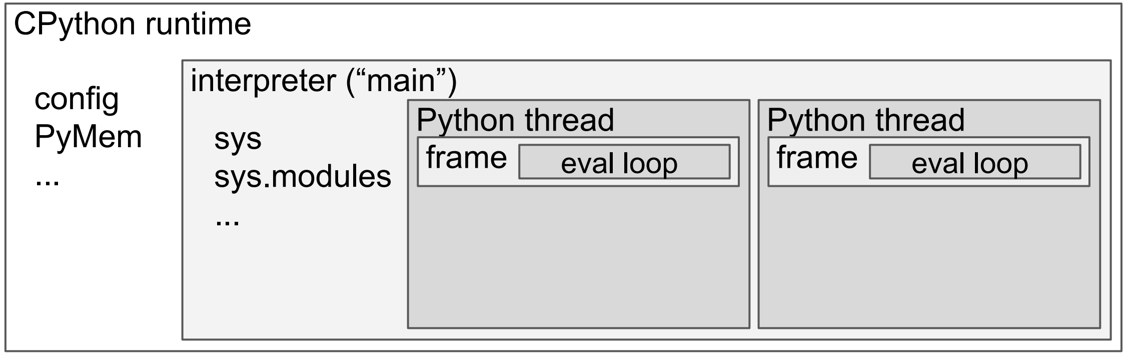

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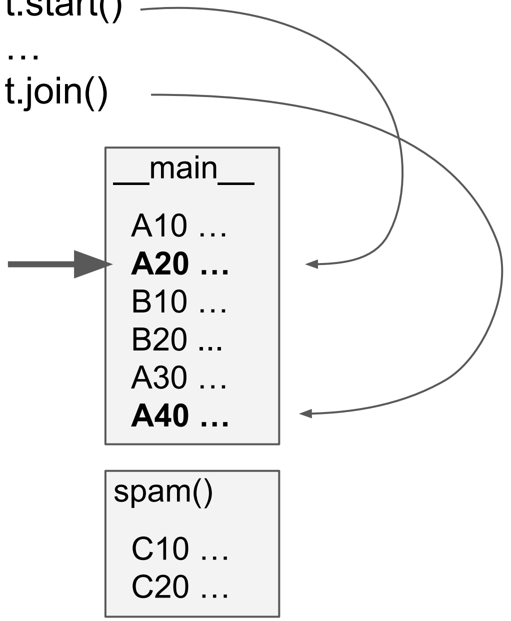

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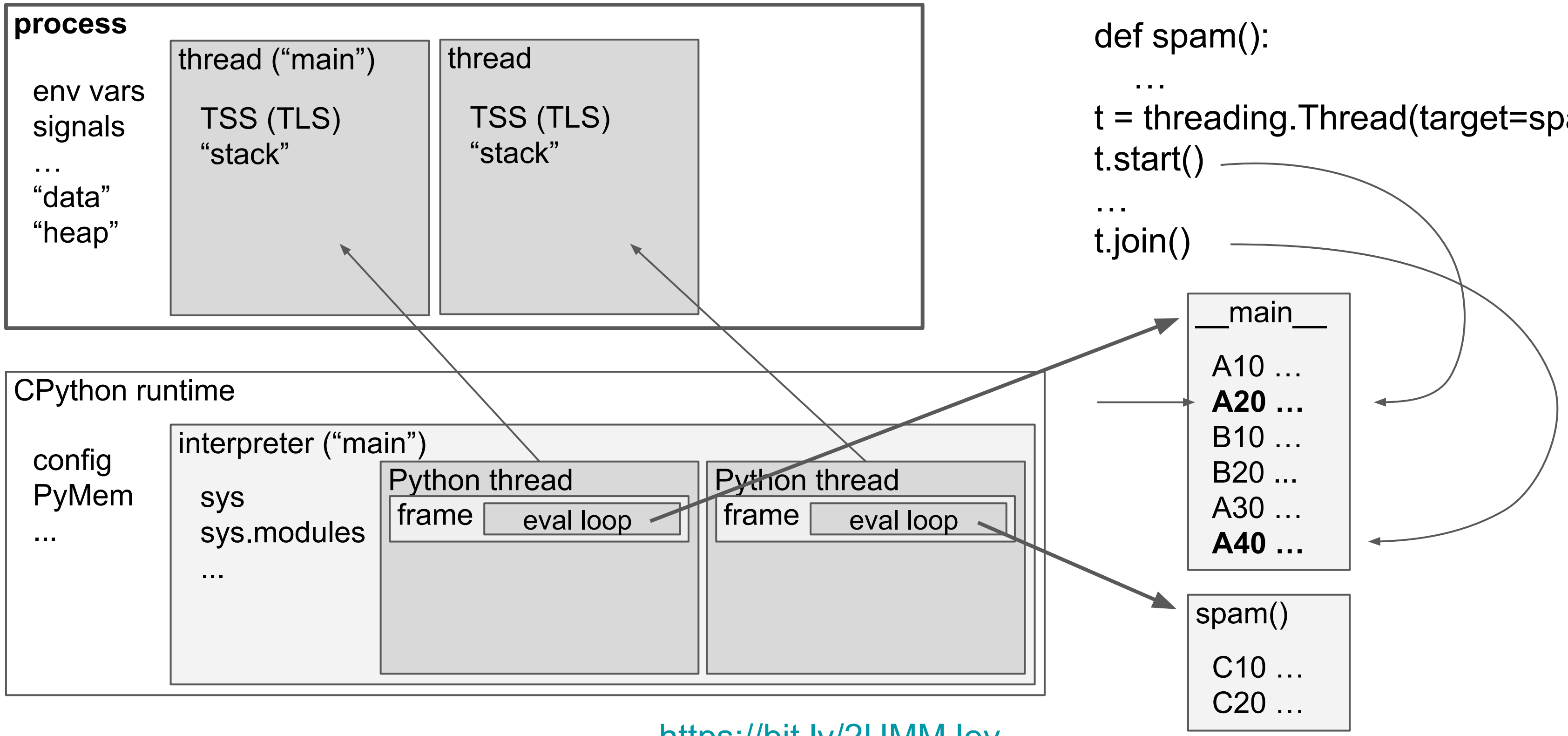

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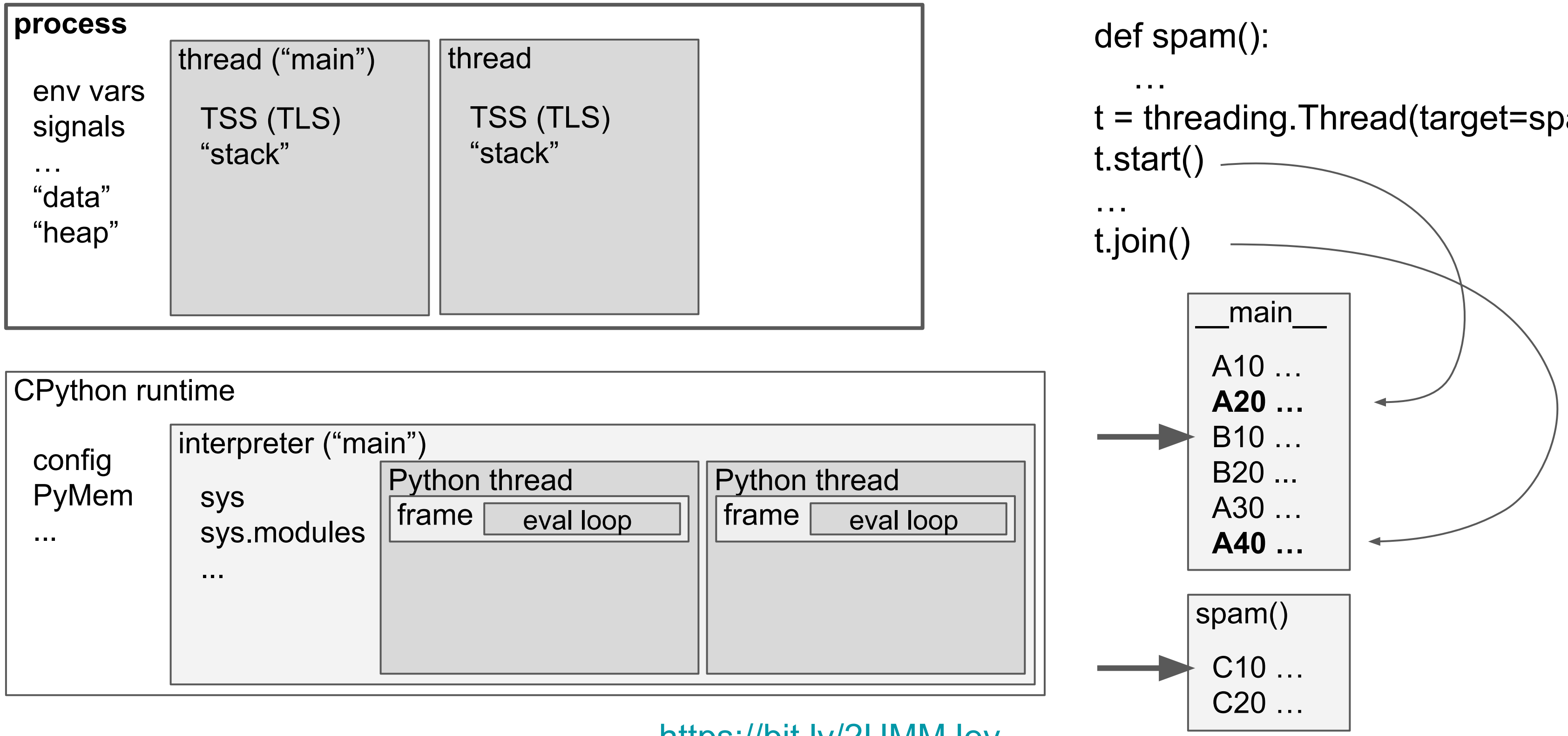

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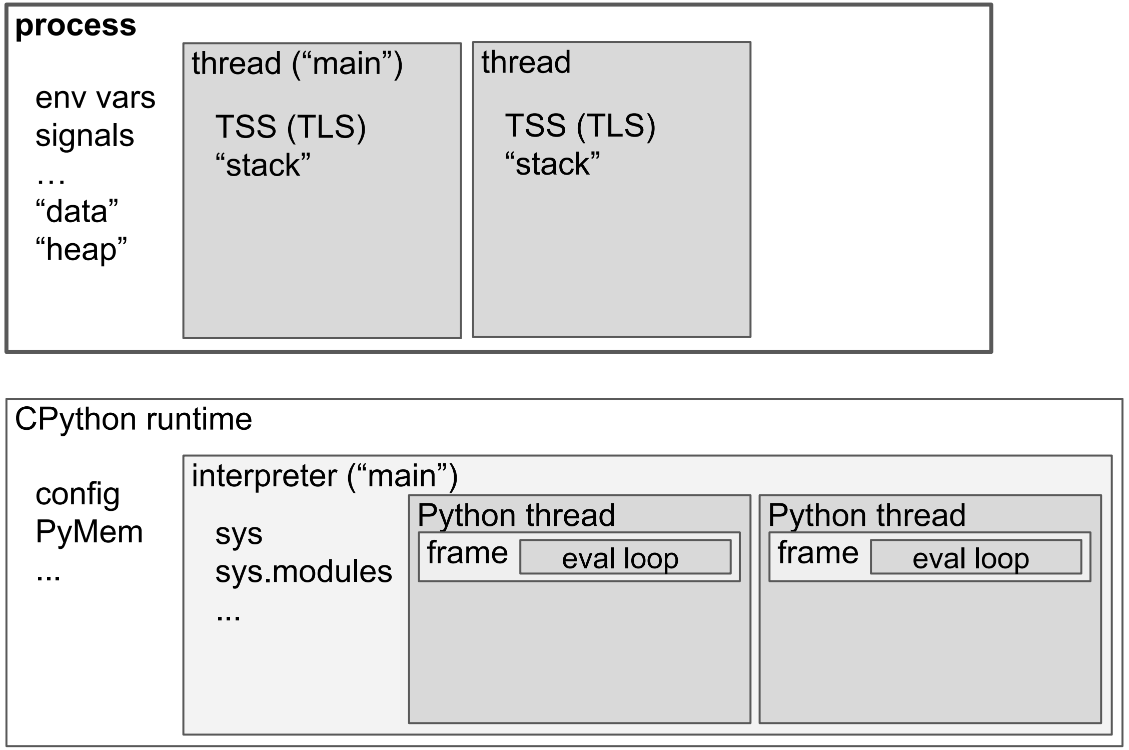

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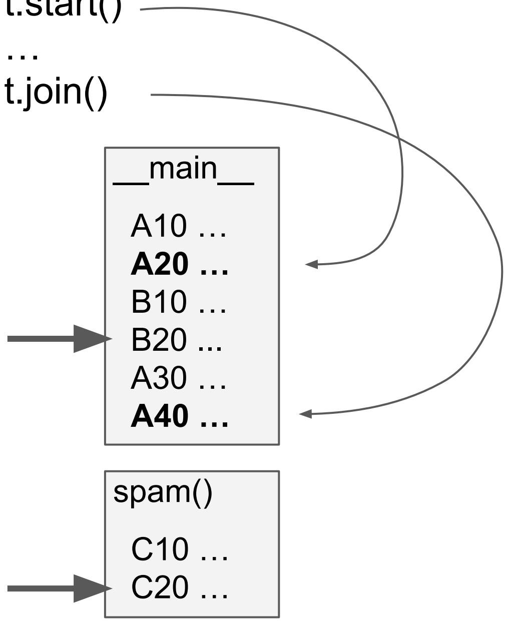

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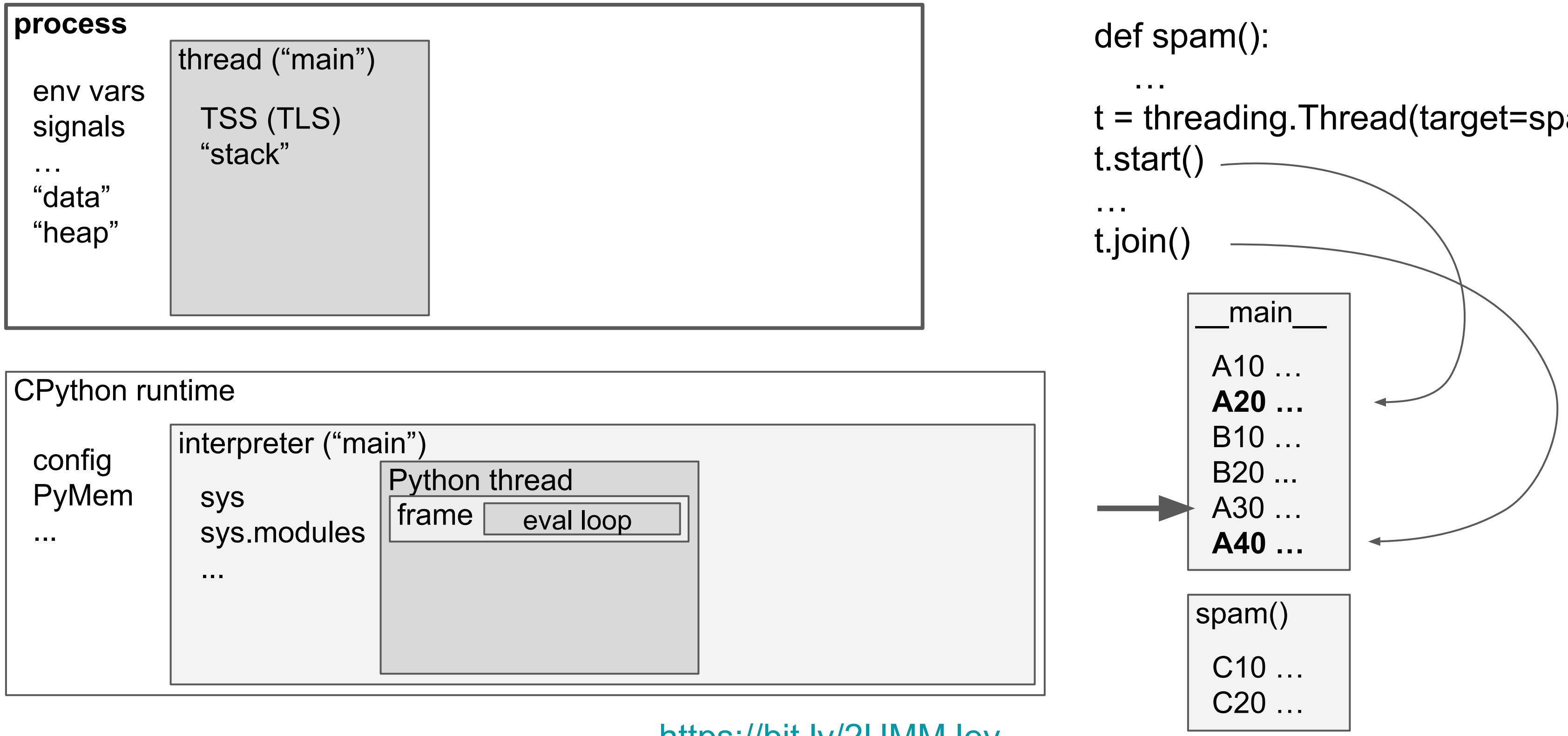

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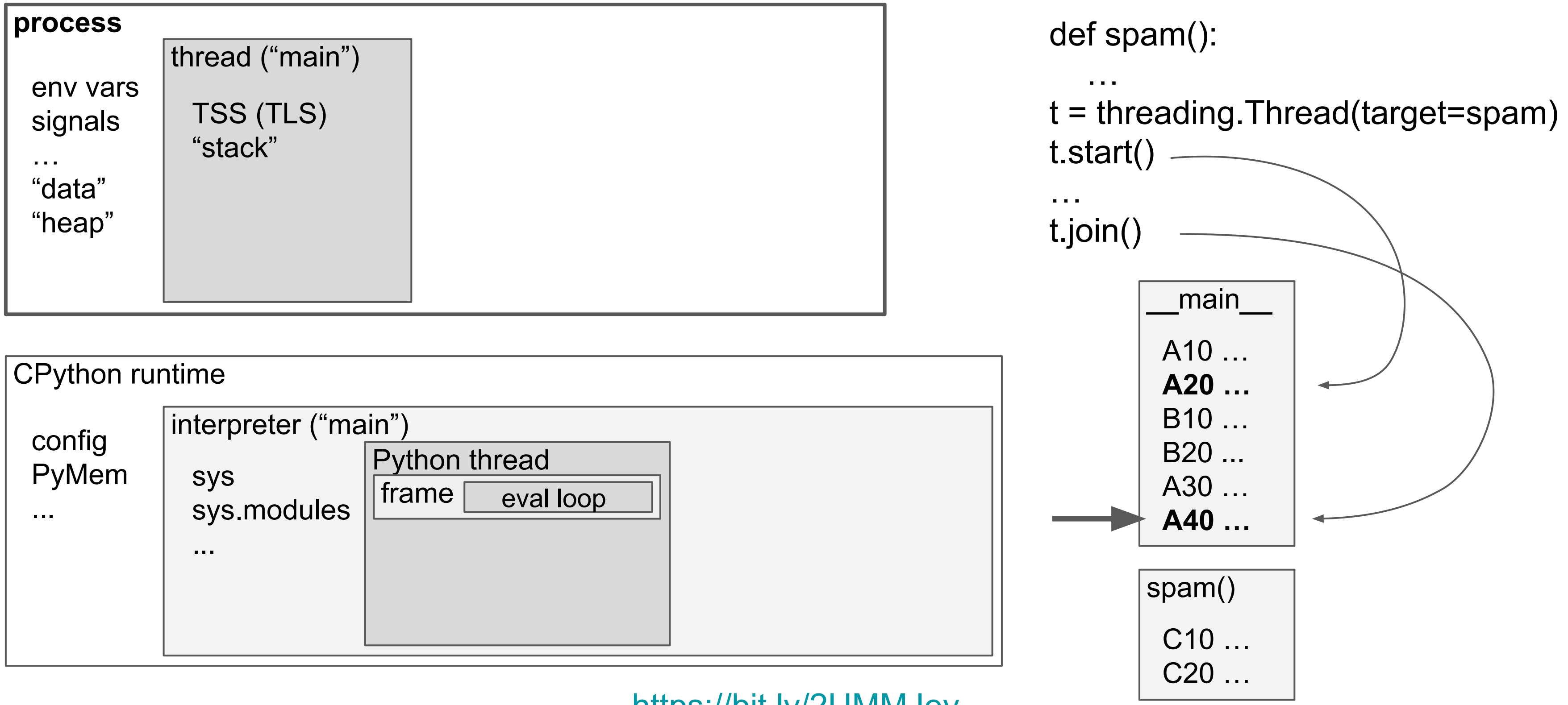

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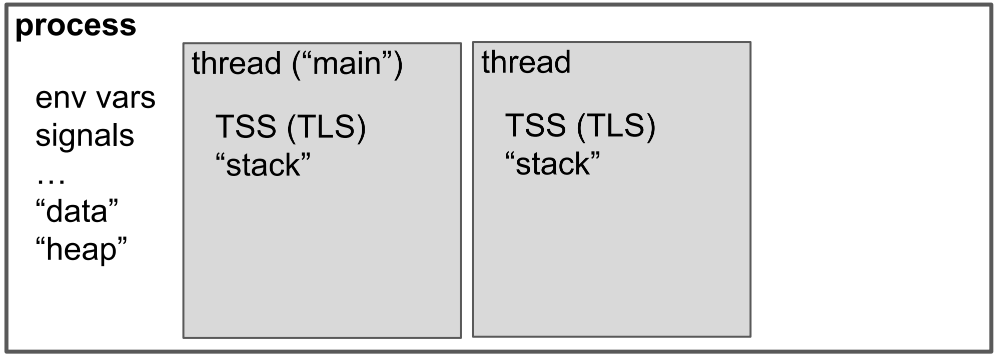

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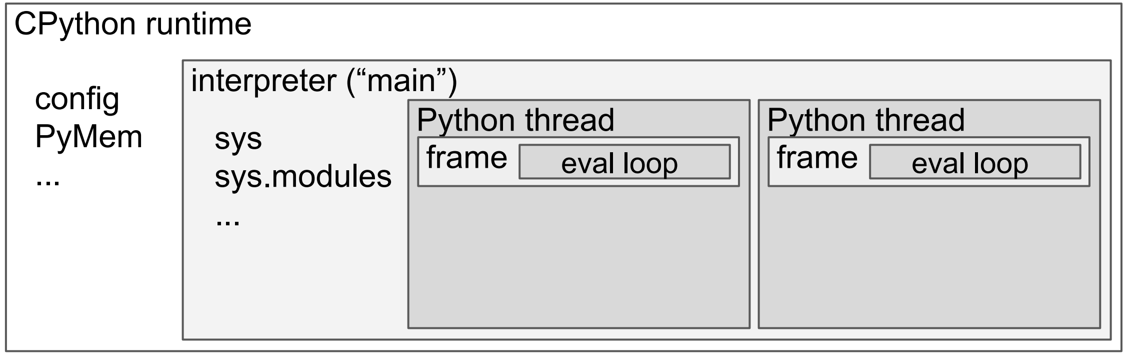

```
"bytecode"
 A10
 A20      # t.start()
 ----------------------------
 B10   C10   B10   C10
 B20   C20   C10   B10
 A30   B10   B20   B20
 C10   B20   C20   A30
 C20   A30   A30   C20
 ----------------------------
 A40      # t.join()
```

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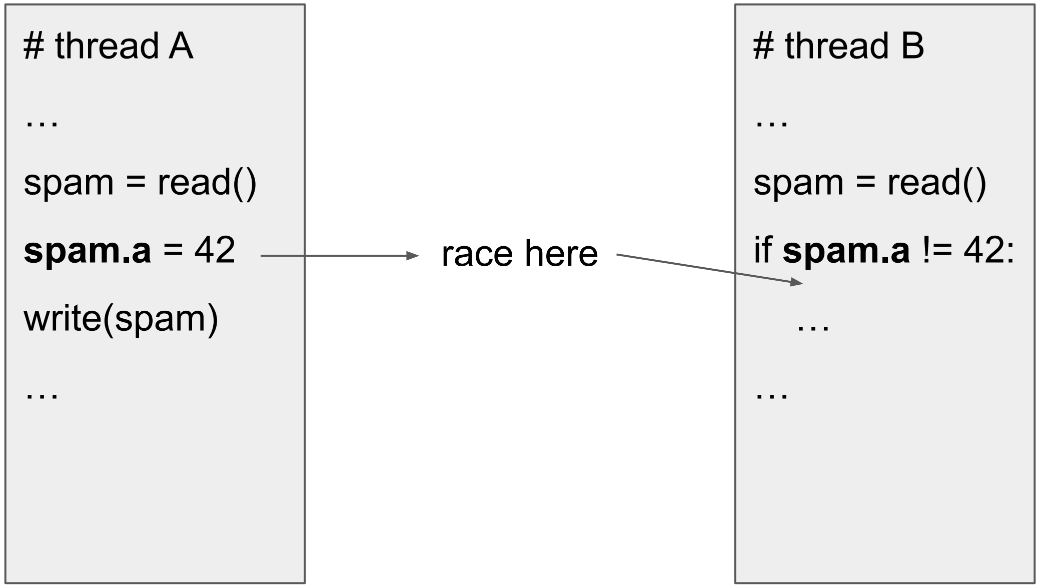
“Race Condition”

A.K.A. “Resource Contention”



```
# thread A
…
spam = read()
spam.a = 42
write(spam)
…
```

```
# thread B
…
spam = read()
if spam.a != 42:
    …
…
```

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“Race Condition”

A.K.A. “Resource Contention”

```
                    # thread A
                    …
acquire lock A ->
                    spam = read()
                    spam.a = 42
                    write(spam)
release lock A ->
                    …
```

```
                    # thread B
                    …
acquire lock A ->
                    spam = read()
                    if spam.a != 42:
                        …
release lock A ->
                    …
```

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A.K.A. “Resource Contention”

```
                        # thread A
                        …
acquire lock A ->       spam = read()
                        spam.a = 42
                        write(spam)
release lock A ->       …
```

```
                        # thread B
                        …
acquire lock A ->       spam = read()
                        if spam.a != 42:
                            …
release lock A ->       …
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                    …
acquire lock A ->
                    spam = read()
                    spam.a = 42
                    write(spam)
release lock A ->
                    …
```

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                    # thread B
                    …
acquire lock A ->
                    spam = read()
                    if spam.a != 42:
                        …
release lock A ->
                    …
```

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spam = read()
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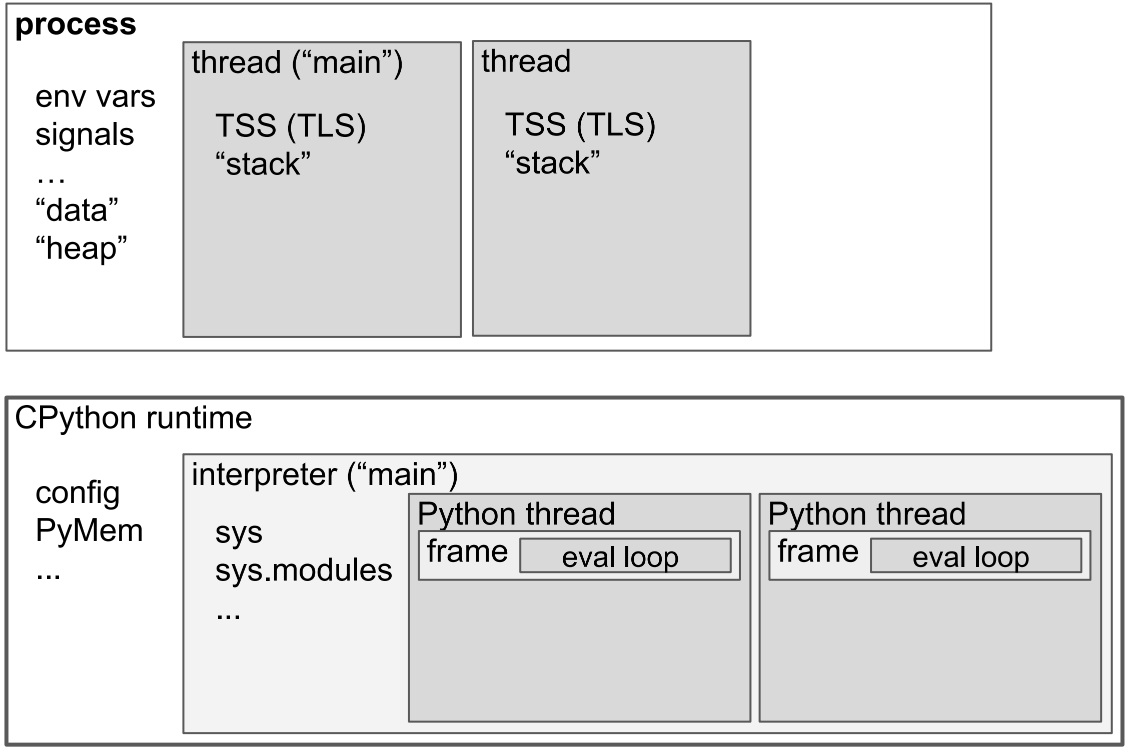
The GIL

The GIL ("Global Interpreter Lock")



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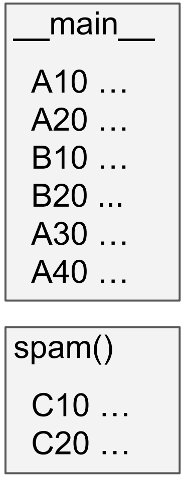

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State At Different Layers

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...	objects (w/ refcounts)	codecs	current exception
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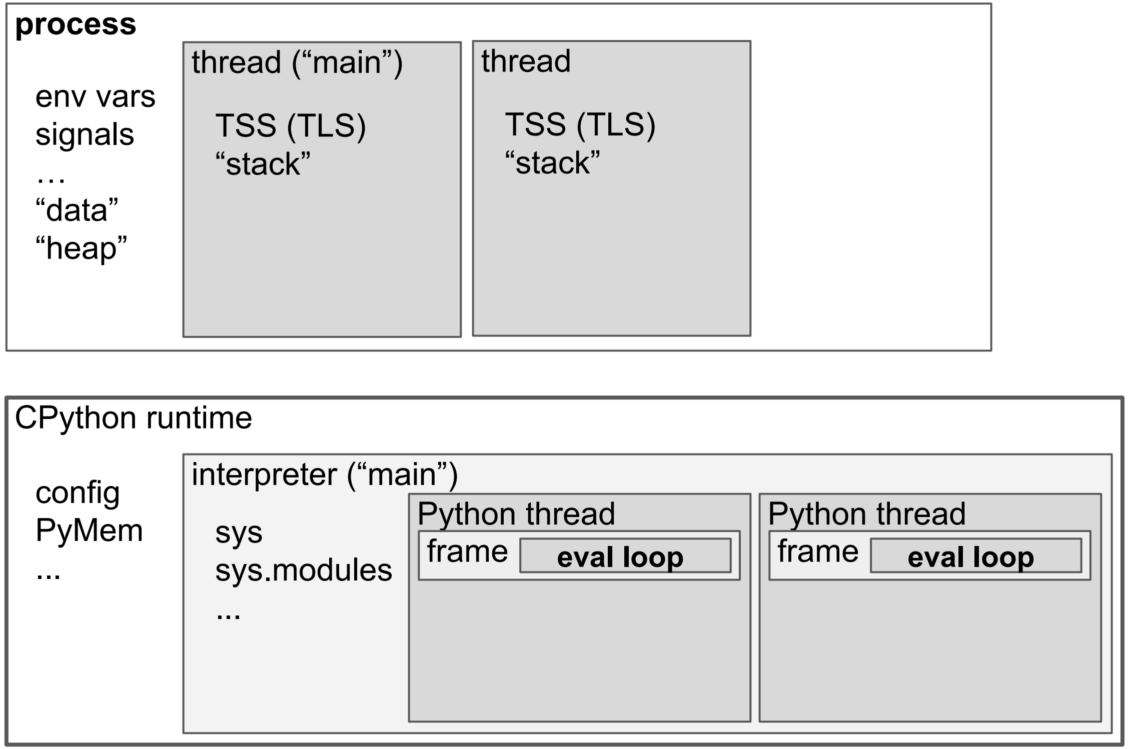
The GIL (“Global Interpreter Lock”)



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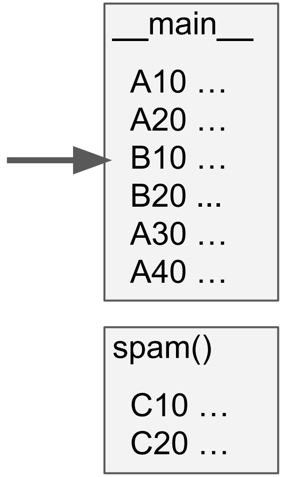

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The Eval Loop

```
<set up>

for instruction in code object:

    <maybe side-channel stuff>

    <occasionally release & re-acquire the GIL>

    <execute next instruction>
```

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When is the GIL Released?

- eval loop: every few instructions
- around C code that does not touch runtime resources
- around IO operations
- (by C extensions)

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Costs and Benefits of the GIL

- Multi-core parallelism of Python code
- ???

- Cheaper than fine-grained locks
- Simpler eval loop implementation
- Simpler object implementation
- Simpler C-API implementation

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Costs and **Benefits** of the GIL

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- Cheaper than fine-grained locks
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  - eval loop
  - object system
  - C-API

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Who does it really affect?

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Why? **C implementation releases the GIL around IO and CPU-intensive code.**

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Effect and Perception

Who does it really affect?

- Users with threaded, CPU-bound *Python* code (relatively few people)
- Basically no one else

So why does the GIL get such a bad wrap?

- Lack of understanding
- Experience with other programming languages
- Haters gonna hate

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Working Around the GIL

- C-extension modules
  - rewrite CPU-bound code in C
  - release the GIL around that code
- multi-processing
- (async / await)

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Past Efforts to Remove the GIL

- 1999 Greg Stein
- Larry Hastings' Gilectomy (on hold)
- other Python implementations
  - unladen swallow
  - …

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Other Python Implementations

	GIL?	C-API?	latest Py version
CPython	yes	yes	3.7
Jython	no	JyNI	2.7
IronPython	no	yes?	2.7
PyPy (& w/STM)	yes (no)	cffi, cpyext	3.6
MicroPython	~yes	no?	~3.4+

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The Future

A New C-API

- the history
- the problem
- the solutions

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The C-API

- historically fundamental to Python’s success
- organic growth
- early efforts to simplify
- core devs: growing concerns
- core devs: increasing efforts

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The Problem

- getting rid of GIL needs low-level changes
- parts of public C-API expose low-level details (e.g. refcounts)
- so...
- getting rid of GIL requires breaking parts of C-API

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The Causes

- didn’t think 20+ years into future
- “consenting adults”
- accidental leaks

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The Solutions

- someone has to care enough to do the work
- physically separate the categories of C-API
- more opaque structs
- Python (C)FFI
- (maybe) break compatibility in a few places
- deprecate C-API in favor of something like Cython (official)
- ...

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Categorizing the C-API

“internal”	“Do not touch!”
“private”	“Use at your own risk!”
“unstable”	“Go for it (but rebuild your extension each Python release)!”
“stable”	“Worry-free!”

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The Projects

- Victor Stinner’s, well, all of it
  - https://pythoncapi.readthedocs.io/roadmap.html
- Steve Dower's efforts
  - https://mail.python.org/archives/list/capi-sig@python.org/thread/B2VDVLABM4RQ4ATEJXFZYWEGTBZPUBKW/
- Petr Viktorin's projects
- bringing sanity to runtime initialization and finalization
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Beyond the C-API...

Subinterpreters

!!!

Interpreters in a Single Process

- initial interpreter: “main”
    - has certain responsibilities
- “subinterpreter”: any other interpreter created within the runtime
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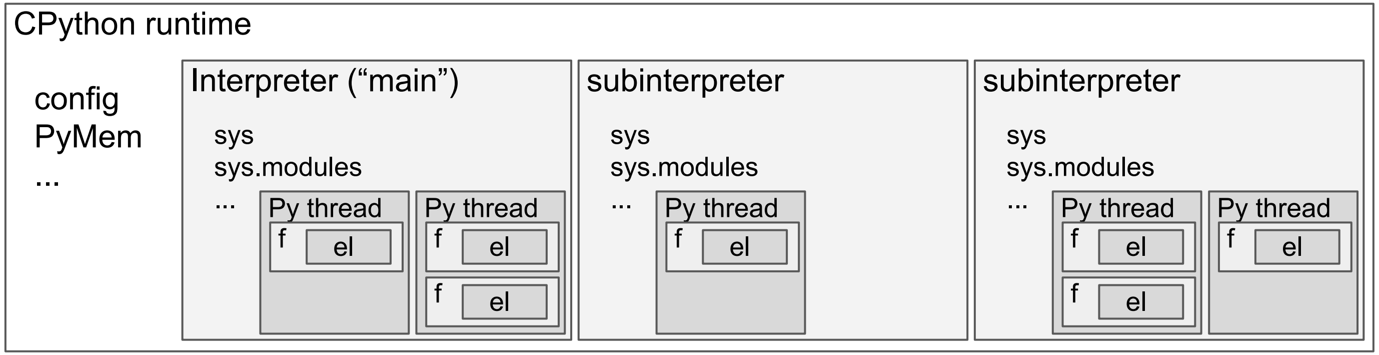

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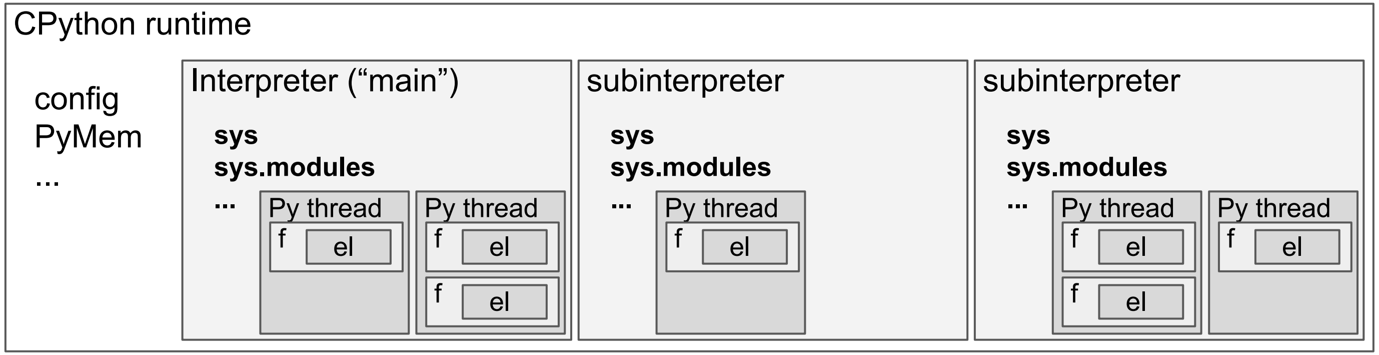

Subinterpreters

- initial interpreter: “main”
  - has certain responsibilities
- “subinterpreter”: any other interpreter created within the runtime
- isolated-ish
- C-API for over 20 years
- PEP 554: stdlib module

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PEP 554 - “Multiple Interpreters in the Stdlib”

- https://www.python.org/dev/peps/pep-0554/
- new “interpreters” module
    - create(), list_all(), etc.
    - Interpreter class
    - create_channel()
    - RecvChannel, SendChannel

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PEP 554: Example 1

```
import interpreters

interp = interpreters.create()

interp.run(dedent("""

    print('spam')

"""))
```

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PEP 554: Example 2

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def func():
    interp.run(dedent("""
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t = threading.Thread(target=func)
t.start()
```

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PEP 554: Example 3

```
interp = interpreters.create()
interp.run(dedent("""
    x = 'spam'
"""))
interp.run(dedent("""
    print(x)
"""))
```

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PEP 554: Example 3

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interp = interpreters.create()
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For now:

- limited supported types
  - str, int, None, etc.
  - PEP 3118 buffers
- actual objects not shared
- no buffering

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PEP 554: Example 4

```
(rchan, schan
 ) = interpreters.create_channel()
interp = interpreters.create()

def func():
    interp.run(dedent("""
        import spam
        data = spam.do_something()
        ch.send(data)    # blocks
    """, channels={ch: schan})
```

```
t = threading.Thread(target=func)
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data = rchan.recv()    # blocks
process_data(data)
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- a human-oriented concurrency model (IMHO)
    - "opt-in sharing"
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- allow each interpreter to execute independently
- threads within an interpreter would still share a “GIL”
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Why Hasn’t It Been Done Already?

- forgotten feature
- no one interested enough (to do the work)
- “good enough” alternatives
- scary! (or not)
- blockers...

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the blockers

- lingering bugs
- subinterpreters only in C-API
- how to guard against races between interpreters?
- enough time to do the work!
- C globals

(╯°□°)╯︵ ┻━┻

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C "Globals"

- “static globals”, "static locals"
- TSS/TLS (Thread-Specific Storage)
- in the CPython code base
- in extension modules
  - static types, exceptions, singletons; etc.
  - C globals in included shared libraries (e.g. OpenSSL in cryptography)
  - efforts to fix: PEPs 3121, 384, 489, (573), ~~575~~, (579), (580); Cython; Red Hat; Instagram
  - (type “slots”)

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the project

https://github.com/ericsnowcurrently/multi-core-python

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- PEP 554
- resolve bugs
- deal with C globals
- move some runtime state into the interpreter state
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Beneficial Side Effects

- find bugs and deficiencies in runtime (e.g. init/fini)
- motivation to fix them
- clean-up in runtime implementation (incl. globals, C-API, header files)
- reduce coupling between components in runtime implementation
- encourage fewer static globals in C extension modules
- (improve interpreter startup performance)
- (improve object isolation (e.g. in memory))
- ...

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What’s Next?

1. PEP 554, blockers, and per-interpreter GIL
2. low-hanging fruit (optimization)
3. deferred functionality

Thanks!

Thanks!

Questions?

Resources

- https://docs.google.com/presentation/d/1BuU6e-CKdZxDL5z9VBp19LAaIY8Ys2-jlcz-mD0Vr3c/
    - https://bit.ly/2UMMJey
- https://github.com/ericsnowcurrently/multi-core-python
- https://docs.python.org/3/c-api/init.html#thread-state-and-the-global-interpreter-lock
- https://wiki.python.org/moin/GlobalInterpreterLock#Eliminating_the_GIL
- twitter: @ericsnowcrntly