Run interpreters in parallel

Language Summit 2021

Dong-hee Na

LINE

Victor Stinner

Red Hat

Use Cases

Embed Python

- vim
- Blender
- LibreOffice
- pybind11 (C++ applications)

LINE

Subinterpreters

- mod_wsgi: handle HTTP requests
- weechat plugins (IRC client written in C)

LINE

Red Hat

(A) Embed Python

- Valgrind lists leaks at exit
- `Py_Finalize()` must release all memory allocations done by Python.
- More important for `Py_EndInterpreter()`
- `https://bugs.python.org/issue1635741` (created in 2007! work started in 2019)

LINE

Red Hat

(A) Plugin in Python

- Use subinterpreters for plugins
- IRC client written in C
- Plugin A uses Python
- Plugin B also uses Python
- Plugins are not aware of each others
- Unloading a plugin must release all memory

LINE

(B) Run in parallel

- Run multiple interpreters in parallel
- One interpreter per thread per CPU
- N CPUs → N interpreters
- multiprocessing use cases
- Distribute Machine Learning

LINE

Red Hat

(B) Single process

- A single process is more convenient and can be efficient (specific use cases)
- Admin tools are more convenient with 1 process than with N processes
- Some APIs don't work cross-processes
- Windows: creating a thread is faster than creating a process
- macOS: slow multiprocessing spawn

LINE

Red Hat

(B) No shared object

- Problem: concurrent access on object refcnt
- Lock or atomic operation?
  → performance bottleneck
- Pressure on few CPU cachelines for most common objects: None, True, 1, ()
- Solution: **don't share any object**, even immutable

LINE

Red Hat

Subinterp drawbacks

- On a crash (segfault), all interpreters are killed.
- All imported extensions must support subinterpreters.

LINE

Red Hat

PEPs

- PEP 384: Defining a Stable ABI
- PEP 489: Multi-phase extension module initialization
- PEP 554: Multiple Interpreters in the Stdlib
- PEP 573: Module State Access from C Extension Methods
- PEP 630: Isolating Extension Modules
- PEP 3121: Extension Module Initialization and Finalization

LINE

C API & extensions

Heap types

- PEP 384 & PEP 573: Support HeapType
- PyType_FromSpec()
- PyType_FromModuleAndSpec()

LINE

Red Hat

FromSpec

Modules defining heap types with PEP 384 `PyType_FromSpec()`:

- Python 3.8: 3 modules
- Python 3.9: 9 modules
- Python 3.10: 6 modules

LINE

Red Hat

FromModuleAndSpec

Modules defining heap types with PEP 573 `PyType_FromModuleAndSpec()`:

- Python 3.8: 0 modules
- Python 3.9: 2 modules
- Python 3.10: 32 modules

LINE

Red Hat

Static types

Modules still defining types as static types:

- Python 3.8: 48 modules
- Python 3.9: 39 modules
- Python 3.10: only 16 modules!

LINE

Red Hat

Module state

Modules using PEP 573 module state:

- Python 3.8: 8 modules
- Python 3.9: 23 modules
- Python 3.10: 48 modules!

LINE

Red Hat

Multiphase init

Modules using the PEP 489 multiphase initialization API:

- Python 3.8: 3 modules
- Python 3.9: 30 modules
- Python 3.10: 72 modules

LINE

Red Hat

_abc extension

_abc module example

- Convert static type into heap type
- Define module state
- Convert module to use multi-phase initialization

LINE

Red Hat

_abc heap type

- PyType_Slot and PyType_Spec must be implemented to define heap types.
- To manage heap type memory:
  - Py_tp_new
  - Py_tp_dealloc
  - Py_tp_traverse (!)
  - Py_tp_clear

  must be implemented carefully

LINE

Red Hat

PyType_Slot

```
static PyType_Slot
_abc_data_type_spec_slots[] = {
 {Py_tp_doc, (void *)abc_data_doc},
 {Py_tp_new, abc_data_new},
 {Py_tp_dealloc, abc_data_dealloc},
 {Py_tp_traverse, abc_data_traverse},
 {Py_tp_clear, abc_data_clear},
 {0, 0}
};
```

LINE

Red Hat

PyType_Spec

```
static PyType_Spec _abc_data_type_spec = {
    .name = "_abc._abc_data",
    .basicsize = sizeof(_abc_data),
    .flags = Py_TPFLAGS_DEFAULT
             | Py_TPFLAGS_HAVE_GC,
    .slots = _abc_data_type_spec_slots,
};
```

LINE

Red Hat

_abc module state

- Module state should have heap type attribute.
- Also, `get_abc_state()` API should be implemented, since accessing module state is frequently needed.

LINE

Red Hat

_abc module state

```
typedef struct {
    PyTypeObject *_abc_data_type;
    unsigned long abc_invalidation_counter;
} _abcmodule_state;

static inline _abcmodule_state*
get_abc_state(PyObject *module)
{
    void *state = PyModule_GetState(module);
    assert(state != NULL);
    return (_abcmodule_state *)state;
}
```

LINE

Red Hat

_abc PyModuleDef

- Define _abcmodule to implement PEP 489 **multiphase initialization**
- To manage heap type
  m_**traverse**
  m_**clear**
  m_**free**
  should be implemented carefully

LINE

Red Hat

_abc PyModuleDef

```
static struct PyModuleDef _abcmodule = {
    PyModuleDef_HEAD_INIT,
    .m_name = "_abc",
    .m_doc = _abc__doc__,
    .m_size = sizeof(_abcmodule_state),
    .m_methods = _abcmodule_methods,
    .m_slots = _abcmodule_slots,
    .m_traverse = _abcmodule_traverse,
    .m_clear = _abcmodule_clear,
    .m_free = _abcmodule_free,
};
```

LINE

Red Hat

_abc exec func

- Initialize heap type through Py_mod_exec API
- If initialization is failed return -1 if not return 0

LINE

Red Hat

_abc exec func

```
static int _abcmodule_exec(PyObject *module) {
    _abcmodule_state *state;
    state = get_abc_state(module);
    state->abc_nvalidation_counter = 0;
    state->_abc_data_type =
        PyType_FromModuleAndSpec(module,
        &_abc_data_type_spec, NULL);
    if (state->_abc_data_type == NULL) {
        return -1;
    }
    return 0;
}
```

LINE

Red Hat

Get module state

Python 3.8:

```
static unsigned long abc_invalidation_counter;

static PyObject*
_abc_get_cache_token_impl(PyObject *module)
{
    return PyLong_FromUnsignedLong(
        abc_invalidation_counter);
}
```

LINE

Red Hat

Get module state

Python 3.9:

```
static PyObject*
_abc_get_cache_token_impl(PyObject *module)
{
    _abcmodule_state *state;
    state = get_abc_state(module);
    return PyLong_FromUnsignedLong(
        state->abc_invalidation_counter);
}
```

LINE

Red Hat

Get module state

- Python 3.8: 50.2 ns
- Python 3.10: 50.8 ns (+0.6 ns)

```
import pyperf
runner = pyperf.Runner()
runner.timeit(
     name='bench _abc',
     setup = 'import _abc',
     stmt='_abc.get_cache_token()')
```

LINE

Red Hat

Work done

Per-interp free lists

- float
- tuple, list, dict, slice
- frame, context, asynchronous generator
- MemoryError

LINE

Red Hat

Per-interp singletons

- small integer ([-5; 256])
- empty bytes string
- empty Unicode string
- empty tuple
- single byte char (`b'\x00'` – `b'\xFF'`)
- single Unicode char (`U+0000` – `U+00FF`)

LINE

Red Hat

Per-interpreter ...

- slice cache
- pending calls
- type attribute lookup cache
- interned strings: `PyUnicode_InternInPlace()`
- identifiers: `_PyUnicode_FromId()`

LINE

Red Hat

Get empty tuple

```
static PyObject* tuple_get_empty(void)
{
  PyInterpreterState *interp;
  interp = _PyInterpreterState_GET();
  PyObject *op = interp->tuple.free_list[0];
  return Py_NewRef(op);
}
```

LINE

Red Hat

Per-interpreter state

- ast
- gc
- parser
- warnings

LINE

Red Hat

Fix daemon threads

- Random crashes at Python exit when using daemon threads
- take_gil() now checks in 3 places if the current thread must exit immediately (if Python exited)
- Don't read any Python internal structure after Python exited (freed memory)

LINE

Red Hat

Proof of Concept

- Same factorial function on **4 CPUs**
- Sequential: 1.99 sec +- 0.01 sec (ref)
- Threads: 3.15 sec +- 0.97 sec (1.5x slower)
- **Multiprocessing**: 560 ms +- 12 ms (**3.6x** faster)
- **Subinterpreters**: 583 ms +- 7 ms (**3.4x** faster)
- (Email to python-dev, May 2020)

LINE

TODO

TODO (easy)

- Convert remaining extensions and static types
- Make _PyArg_Parser per-interpreter
- GIL itself (“already done”)
- Fix unknown bugs ;-)
- Easy but lot of small issues to fix

LINE

Red Hat

TODO (hard)

- Remove static types from the public C API
- Make None, True, False singletons per interpreter
- Get the Python Thread State (tstate) from a thread local storage (TLS)

LINE

Red Hat

Public static types

- Remove static types from the public C API
- Replace `&PyLong_Type` with `PyLong_GetType()`
- Guido's idea: use `&PyHeapType.ht_type` for `&PyLong_Type`
- Need a PEP if the C API is broken.
- `https://bugs.python.org/issue40601`

LINE

Red Hat

None singleton

- Add an `if` to `Py_INCREF`/`Py_DECREF`
  → 10% slower & CPU cacheline pressure
- `#define Py_None Py_GetNone()`
  → no API issue!
- `Py_GetNone() { return interp->none; }`
- https://bugs.python.org/issue39511
  Draft PR 18301

LINE

Red Hat

Get tstate from TLS

- `_PyThreadState_GET()` perf issue
- C11 `_Thread_local` and `<threads.h>` **`thread_local`**
- x86: single MOV with FS register
- Fallback: `pthread_getspecific()`
- Function call for extensions
- `https://bugs.python.org/issue40522`
  Draft PR 23976

Open questions

- Need a PEP for the overall isolated interpreters design.
- Extensions wrapping C libraries with shared states: need a lock somewhere.
- Another Python 2 vs Python 3 mess? No.
- Opt-in feature, adoption can be slow.

LINE

Red Hat

Future

Later

- API to share Python objects
- Share data and use one Python object per interpreter with locks
- Support spawning subprocesses (fork)

LINE

Red Hat

Questions?

Play with:

```
./configure
  --with-experimental-isolated-subinterpreters
```

```
#ifdef EXPERIMENTAL_ISOLATED_SUBINTERPRETERS
```

LINE