A Concurrent Hash Table for CPython

MSc Thesis Dissertation

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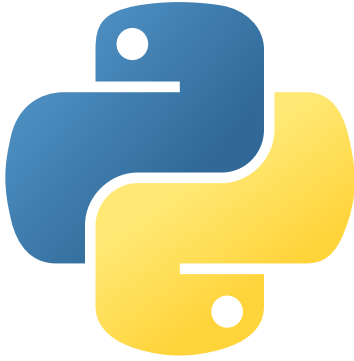
Python and CPython



Back to ~~the future~~ 1994

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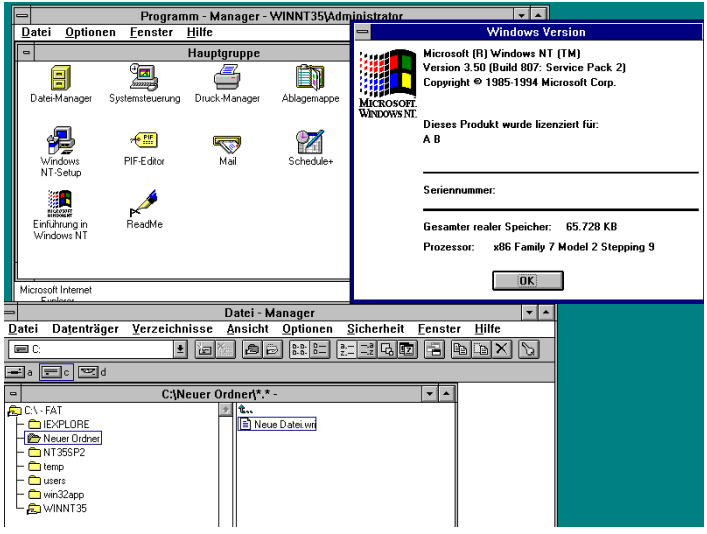

CPython and its GIL

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3.13

Free-threading

java.util.concurrent

* Semaphore ✓
* CyclicBarrier ✓
* Lock ✓
* Concurrent**HashMap**
* ConcurrentLinked**Queue**
* CopyOnWriteArray**List**
* Atomic**Boolean**
* Atomic**Integer**
* Atomic**Reference**
* ...

Thread synchronization utilities for Python.

The *Cereus Greggii* is a flower native to Arizona, New Mexico, Texas, and some parts of northern Mexico.
This flower blooms just one summer night every year and in any given area, all these flowers bloom in synchrony.

https://github.com/dpdani/cereggii

Exposes a so-called *natural parallelism*.
High-level design:

* linear probing
* resizable
* double-hashing
* split index and data tables
* lock-free*

Mostly inspired by:

* T. Maier's Growt concurrent hash table, and
* CPython's built-in sequential hash table (dict).

Concurrent Resizing

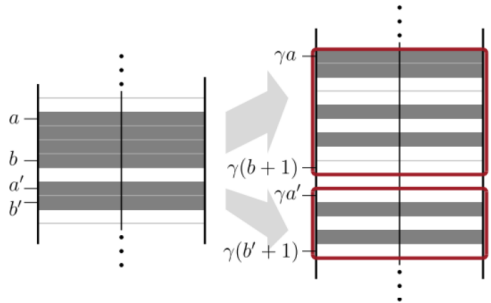

Figure: Growt's migration process.[1]

[1] T. Maier et al., Concurrent Hash Tables: Fast and General(?)!, Fig. 1.

Double-Hashing

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* AtomicDict:
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  3. use most-significant bits as position

Split Index and Data Tables

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* put keys and values into a separate *data* table
* actual hash table is an *index* over the data table
* so that:
  * the index stays sparse to better handle collisions
  * the large entry size decreases false sharing

* size of an index slot: 1 to 8 bytes
  * dependent on capacity
* size of a data entry: 32 bytes

Lock-freedom

Definition

At least one thread can always make progress. (No locks $\Rightarrow$ no deadlocks.)

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- For AtomicDict:
  - no deadlocks!
  - (unless a resizing is in progress)
  - lock-free resizing is not practical
  - if you correctly set `min_size`, no resizing ever happens

Small Contributions

* Partitioned iterations

```
d = AtomicDict(...)

def my_thread(thread_id, threads_count):
    for key, value in d.fast_iter(partitions=threads_count,
                                  this_partition=thread_id)
        do_some_stuff(key, value)
```

Small Contributions (cont.d)

* Reduce

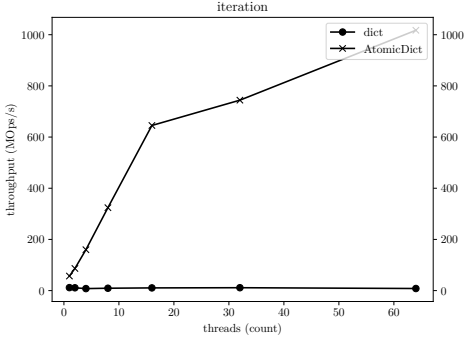
```
d = AtomicDict(...)

data = [
    ("red", 1),
    ("green", 42),
    ("blue", 3),
    ("red", 5),
]

def count(key, current, new):
    if current is NOT_FOUND:
        return new
    return current + new

d.reduce(data, count)
```

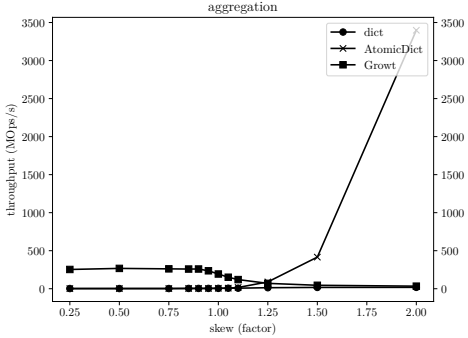
Small Contributions (cont.d)

* Batch Lookup

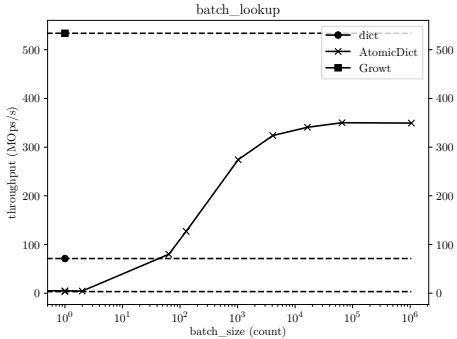
```
foo = AtomicDict({'a': 1, 'b': 2, 'c': 3})

result = foo.batch_getitem({
  'a': None,
  'b': None,
  'f': None,
})

assert result == {
  'a': 1,
  'b': 2,
  'f': cereggii.NOT_FOUND,
}
```

Measurements





Measurements (cont.d)



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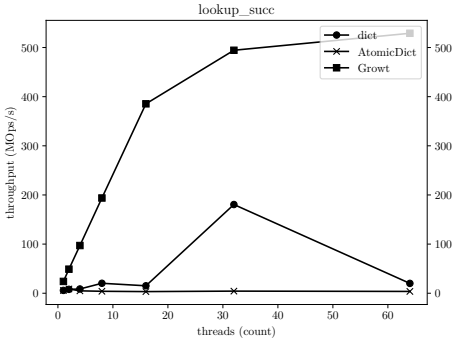

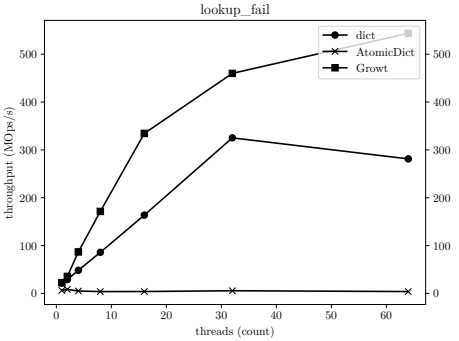

Pittsburgh (USA), May 2024.

Summary

1. Python = language / CPython = interpreter
2. CPython and its GIL
   - historical rationale
3. Free-threading in CPython 3.13
   - per-object locks
4. Java has atomic data structures, Python doesn't
5. cereggii
   - atomic data structures for Python (currently: AtomicRef, AtomicInt, AtomicDict)
6. AtomicDict
   - natural parallelism
   - inspired by:
     - Maier's Growt (concurrent)
     - CPython's dict (sequential)
   - linear probing
   - resizable
   - double-hashing
   - split index and data tables
   - lock-free*
   - partitioned iterations
   - reduce
   - batch lookup
7. Python Language Summit