Ownership

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The plan:

- What's the problem?

  Manual memory management

- C++ Unique pointers and <u>ownership</u>

  Rules of ownership and <u>borrowing</u>

- Rust Statically checked ownership

Last time...

infinite memory

refcounting / garbage collection

finite memory

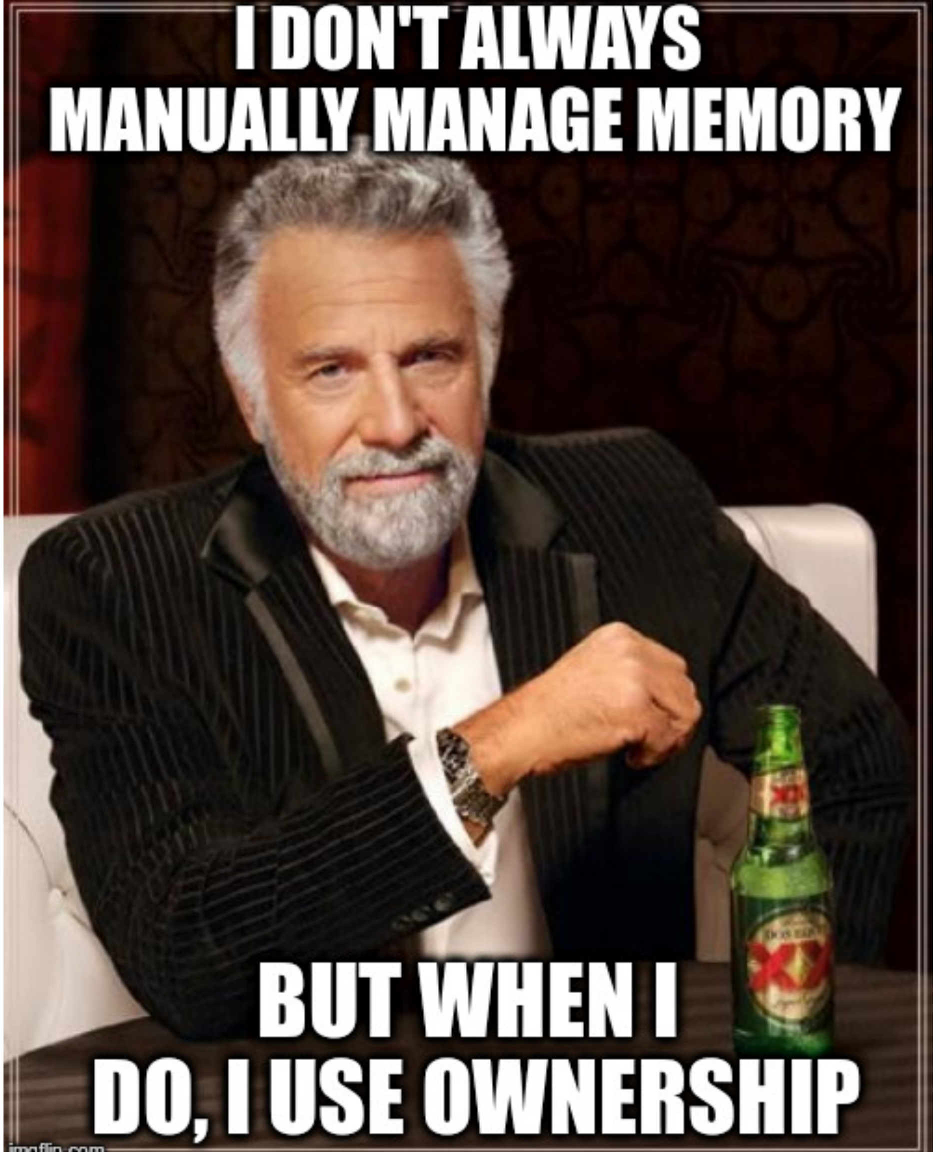
Last time...

but there are tradeoffs!
atomic incref/decref, pauses

infinite memory

refcounting / garbage collection

finite memory


I DON'T ALWAYS
MANUALLY MANAGE MEMORY
BUT WHEN I
DO, I USE OWNERSHIP

What is manual memory management?

Memory management on the stack:

```
void f() {
    int x[20];
```

array is available

```
}
```

when scope exits, array is freed

What is manual memory management?

Memory management on the stack:

```
void f() {
    int x[20];
}
```

array is available

What if I want the array to live on?

Memory management on the heap

In C:

```
int* p = (int*) malloc(sizeof(int) * 4);
    // do some stuff to p
free(p);
```

In C++:

```
A* p = new A();
    // do some stuff to p
delete p;
```

Memory management on the heap

```
A* p = foobar();
// do some stuff with p
```

ok... now what?

Memory management on the heap

```
inline void
THPUtils_packInt64Array(
  PyObject *tuple,
  size_t size,
  const int64_t *sizes
) {
  for (size_t i = 0; i != size; ++i) {
    PyObject *i64 = THPUtils_packInt64(sizes[i]);
    if (!i64) {
      throw python_error();
    }
    PyTuple_SET_ITEM(tuple, i,
                     THPUtils_packInt64(sizes[i]));
  }
}
```

spot the bug...

Memory management on the heap

```
inline void
THPUtils_packInt64Array(
  PyObject *tuple,
  size_t size,
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) {
  for (size_t i = 0; i != size; ++i) {
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    }
    PyTuple_SET_ITEM(tuple, i,
                     THPUtils_packInt64(sizes[i]));
  }
}
```

what does this function do?

spot the bug...

Memory management on the heap

```
inline void
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    PyTuple_SET_ITEM(tuple, i,
                     THPUtils_packInt64(sizes[i]));
  }
}
```

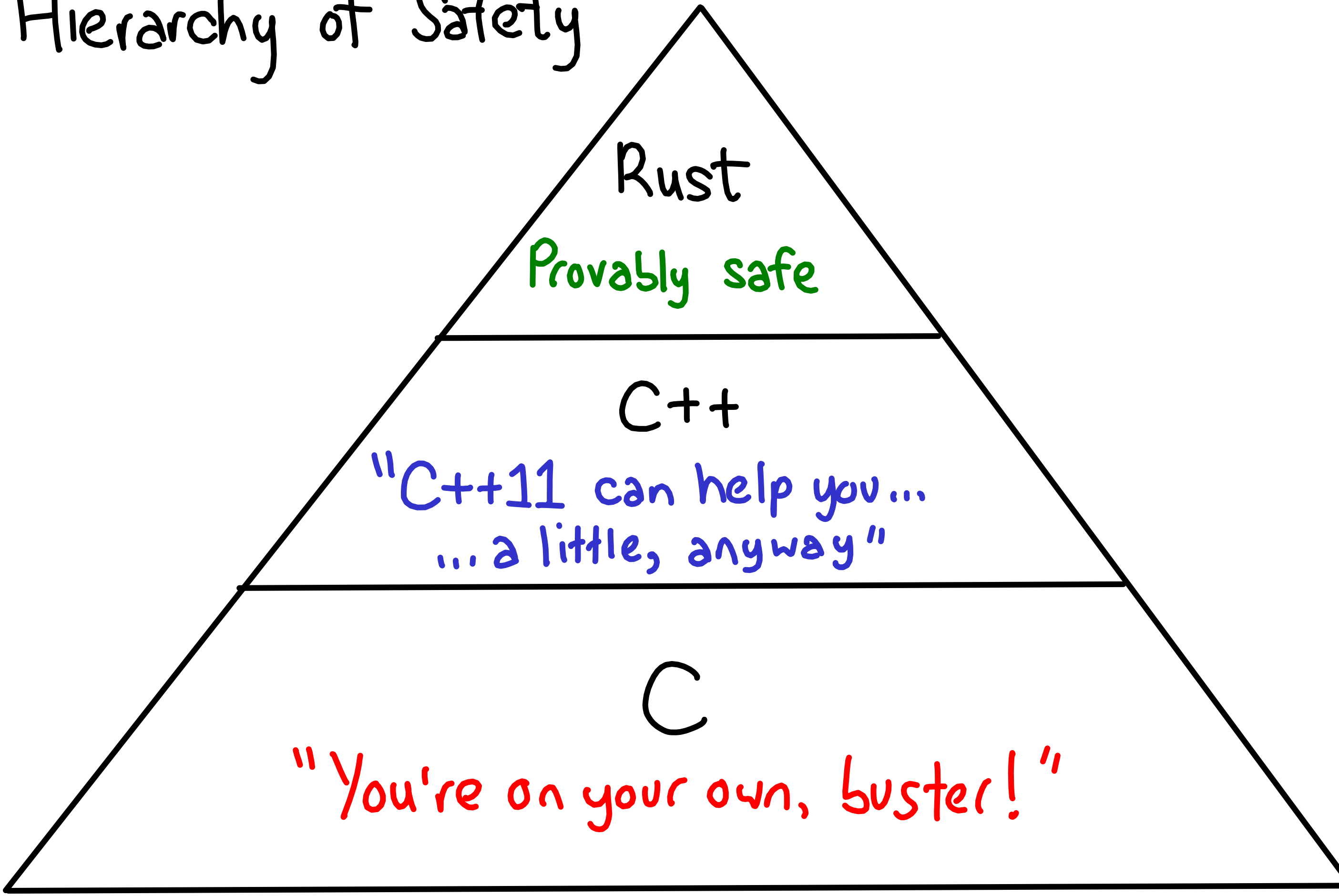
what about this one?

spot the bug...

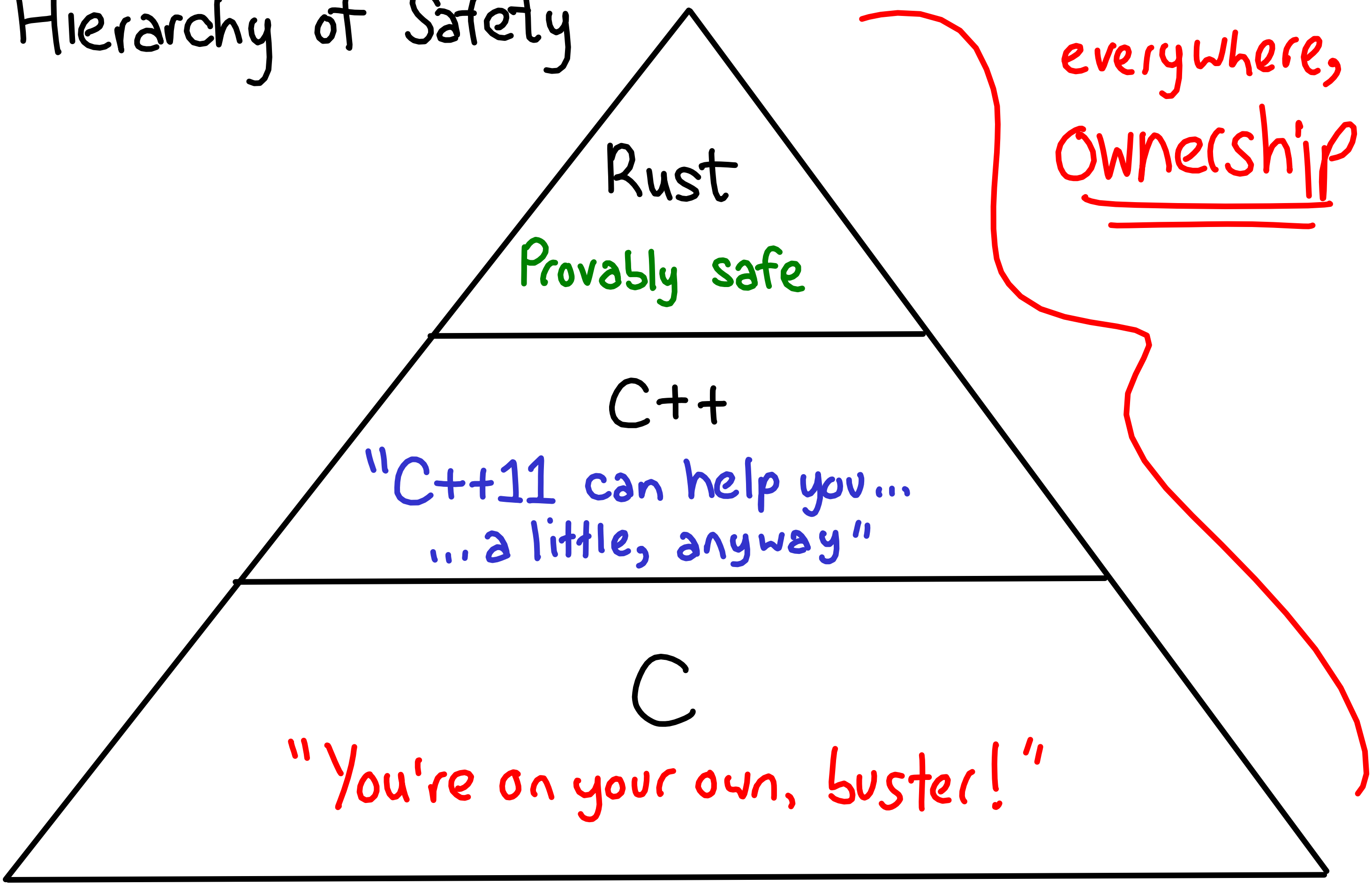
Bug farm

- I have a pointer: should I destroy it when I'm done using it?
- How should I destroy a pointer when I'm done with it?
- Did I delete exactly once in all codepaths?
- Did I already free this pointer? (Is it dangling?)

Hierarchy of Safety



Hierarchy of Safety



What is ownership? It's a set of rules

Every allocation has a <u>unique</u> owner

The owner is <u>responsible</u> for deallocating memory when it is done using it.

```
inline void
THPUtils_packInt64Array(
  PyObject *tuple,
  size_t size,
  const int64_t *sizes
) {
  for (size_t i = 0; i != size; ++i) {
    PyObject *i64 = THPUtils_packInt64(sizes[i]);
    if (!i64) {
      throw python_error();
    }
    PyTuple_SET_ITEM(tuple, i,
                       THPUtils_packInt64(sizes[i]));
  }
}
```

allocates a new PyObject, and transfers ownership to the caller

error is failing to free i64

steals ownership, absolving caller of responsibility to free

Ownership is everywhere

(P.S. PyObject is refcounted: still has notion of ownership for incref/decref)

topic
and Memoryview

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Changed in version 2.5: This function returned an `int` type. This might r
your code for properly supporting 64-bit systems.

PyObject* **`PyTuple_GetItem`**(PyObject **p*, Py_ssize_t *pos*)

Return value: Borrowed reference.

Return the object at position *pos* in the tuple pointed to by *p*. If *pos*
return *NULL* and sets an `IndexError` exception.

Changed in version 2.5: This function used an `int` type for *pos*. Th
changes in your code for properly supporting 64-bit systems.

PyObject* **`PyTuple_GET_ITEM`**(PyObject **p*, Py_ssize_t *pos*)

Return value: Borrowed reference.

Like `PyTuple_GetItem()`, but does no checking of its arguments.

Changed in version 2.5: This function used an `int` type for *pos*. Th
changes in your code for properly supporting 64-bit systems.

PyObject* **`PyTuple_GetSlice`**(PyObject **p*, Py_ssize_t *low*, Py_ssize_t *high*)

Return value: New reference.

Take a slice of the tuple pointed to by *p* from *low* to *high* and return it a

Changed in version 2.5: This function used an `int` type for *low* and
require changes in your code for properly supporting 64-bit systems.

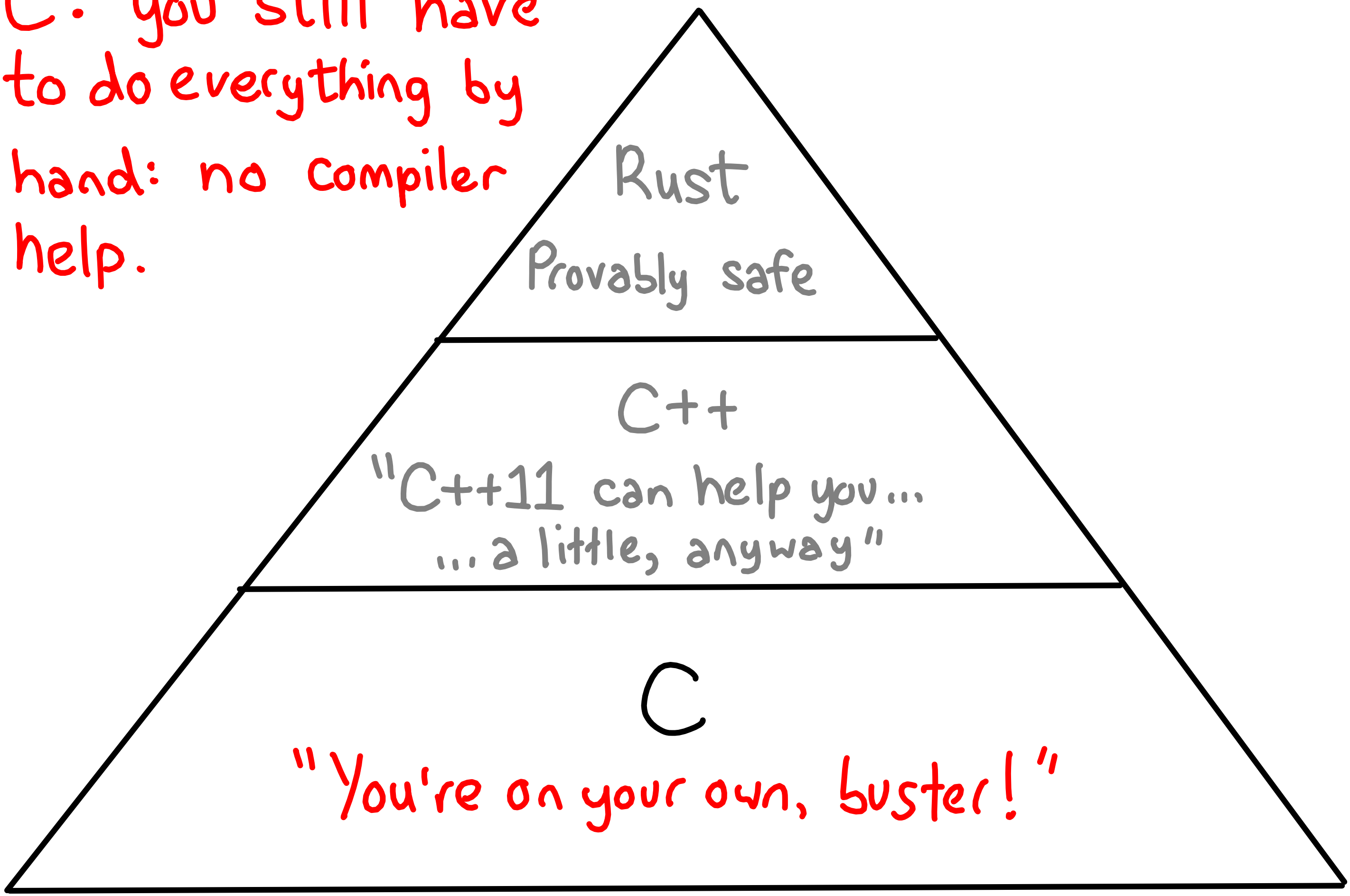
int **`PyTuple_SetItem`**(PyObject **p*, Py_ssize_t *pos*, PyObject **o*)

Insert a reference to object *o* at position *pos* of the tuple pointed to

```
PyObject *p = alloc_obj();
borrow_obj(p);
Py_CLEAR(p);
```

borrow
(function is not responsible for freeing)

C: you still have to do everything by hand: no compiler help.



C++11 to the rescue: smart pointers

std::shared_ptr<T>

std::unique_ptr<T>

owning pointers

const T&

T*

non-owning references

C

Basics

```
T* allocate();
void borrow(T*);
void free(T*);
```

```
T* p = allocate();
borrow(p);
free(p);
```

still own p

C++11

```
std::unique_ptr<T>
    allocate();
void borrow(T*);
```

~~void free(T*);~~

Basics

```
auto p = allocate();
borrow(p.get())
```

(automatically freed)

How? std::unique_ptr is itself an object allocated on the stack! (RAII)

C

```
T* allocate();

void steal(T*);
```

Ownership transfer

```
T* p = allocate();
steal(p);
```

(we no longer own p; we must not use it, and must not free it!

C++11

```
std::unique_ptr<T>
    allocate();

void steal(
  std::unique_ptr<T>
);
```

compare with:

```
void borrow(T*);
```

↑ different!

Ownership transfer

```
auto p = allocate();

steal(std::move(p));

// p is now nullptr!
```

The exact mechanism by which this works is complex: it involves implicit move construction of a new unique_ptr. This was not added until C++11

C++11 benefits

- Automatic disposal of owning pointers (e.g., unique_ptr) when they exit scope

- Type level distinction between owning and non-owning pointers

C++11: The ugly bits

```
#include <memory>

struct T {
    int x = 0;
};

int main() {
    auto* p = std::make_unique<T>().get();
    p->x = 2;
    return 0;
}
```

is this OK?

no complaints from the compiler...

no complaints even with warnings!

```
ezyang@sabre:~$ gcc test.cpp -std=c++14 -fsanitize=address
ezyang@sabre:~$ ./a.out
==========================================================
==10991==ERROR: AddressSanitizer: heap-use-after-free
on address 0x60200000eff0 at pc 0x0000004009cc
bp 0x7ffcdb7b1090 sp 0x7ffcdb7b1080
WRITE of size 4 at 0x60200000eff0 thread T0
    #0 0x4009cb in main (/home/ezyang/a.out+0x4009cb)
    #1 0x7fbf7f20282f in __libc_start_main
       (/lib/x86_64-linux-gnu/libc.so.6+0x2082f)
    #2 0x400888 in _start (/home/ezyang/a.out+0x400888)
```

C++11: The ugly bits

Automatic disposal and type-system encoded ownership are all you get.

You MUST ensure that borrows don't extend beyond lifetime of owning pointer non-owning pointer

borrows reference to T

```
#include <memory>

struct T {
    int x = 0;
};

int main() {
    auto* p = std::make_unique<T>().get();
    p->x = 2;
    return 0;
}
```

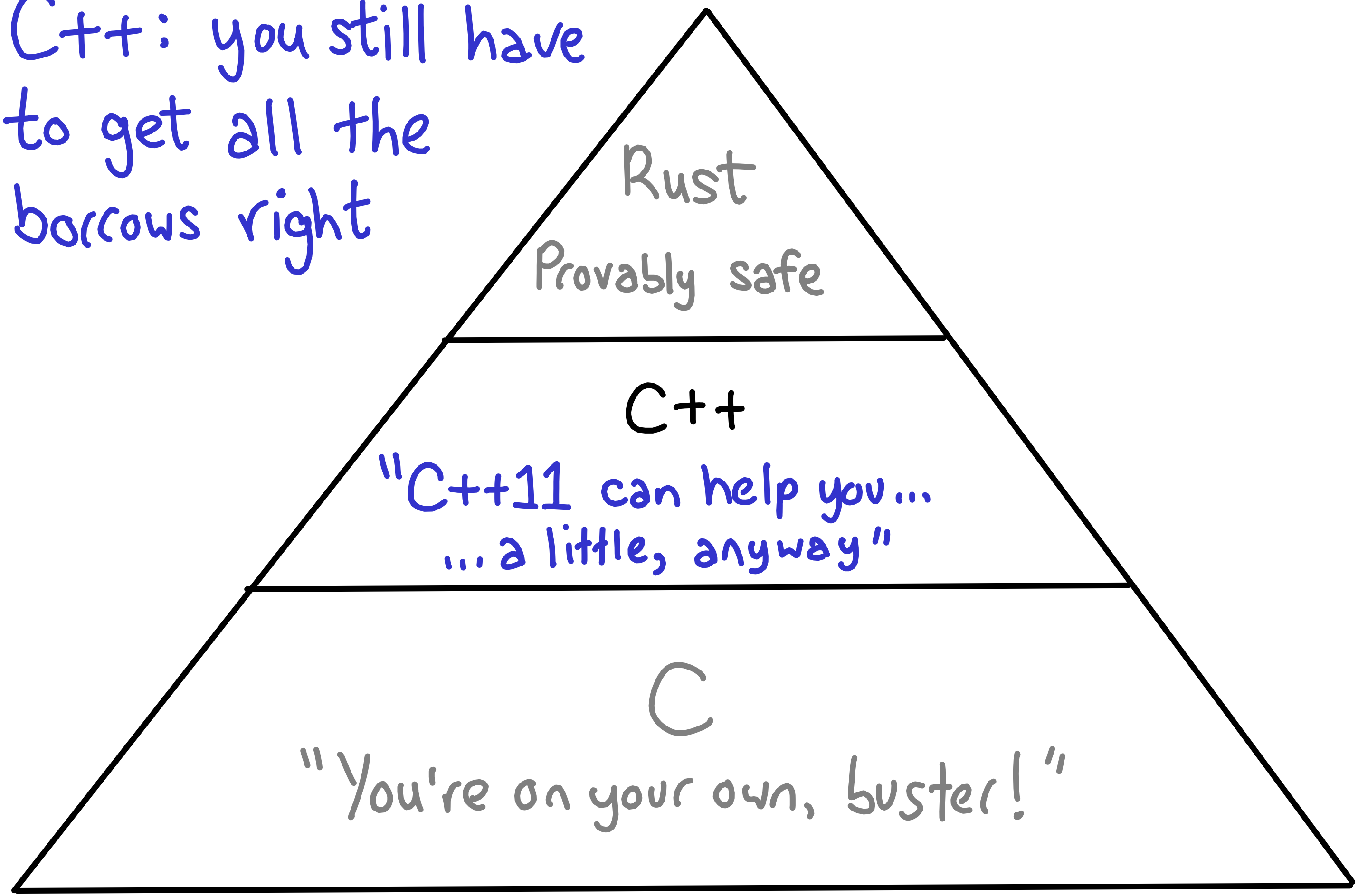
temporary unique_ptr<T>, dies when the statement finishes evaluating

It can be non-obvious

```
class Foo {
  Foo(const Foo&); // copy-constructor
  Field* mutable_field();
}

class Field {
  void set_int(int);
}

const Foo& borrow_foo();
void run_with_borrow(Field*);

void run_with_modified_copy_of_field() {
  auto* field = Foo(borrow_foo()).mutable_field();
  field->set_int(23);
  run_with_borrow(field);
}
```

trouble! temporary!

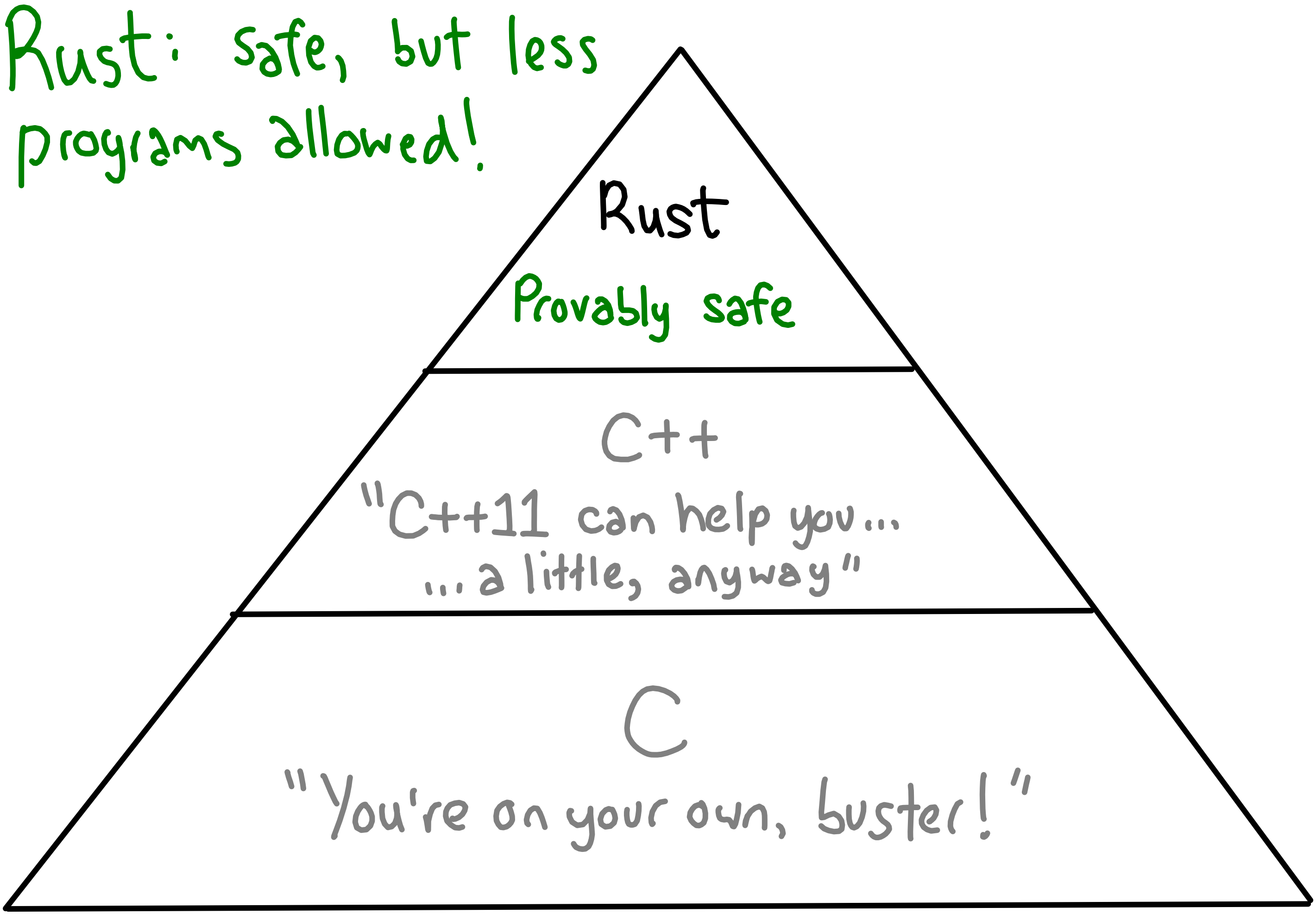
C++: you still have to get all the borrows right



Rust

Rust

- Conceptually, same principles as C++
  - No mutable aliases: fearless concurrency
- All borrows checked by the borrow checker
- Some programs not expressible in Safe Rust (doubly-linked list)
  → unsafe escape hatch


Rust: safe, but less programs allowed!
Rust
Provably safe
C++
"C++11 can help you... ...a little, anyway"
C
"You're on your own, buster!"