PyPy – a progress report

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Michael Hudson mwh@python.net
Heinrich-Heine-Univeristät Düsseldorf

What is PyPy?

- PyPy is:
  - An implementation of Python
  - A very flexible compiler framework
  - An open source project (MIT license)
  - A STREP (“Specific Targeted REsearch Project”), partially funded by the EU
  - A lot of fun!

Demo

- We can currently produce a binary that looks very much like CPython to the user
- It’s fairly slow (around the same speed as Jython)
- Can also produce binaries that are more capable than CPython – with stackless-style coroutines, with logic variables, ...

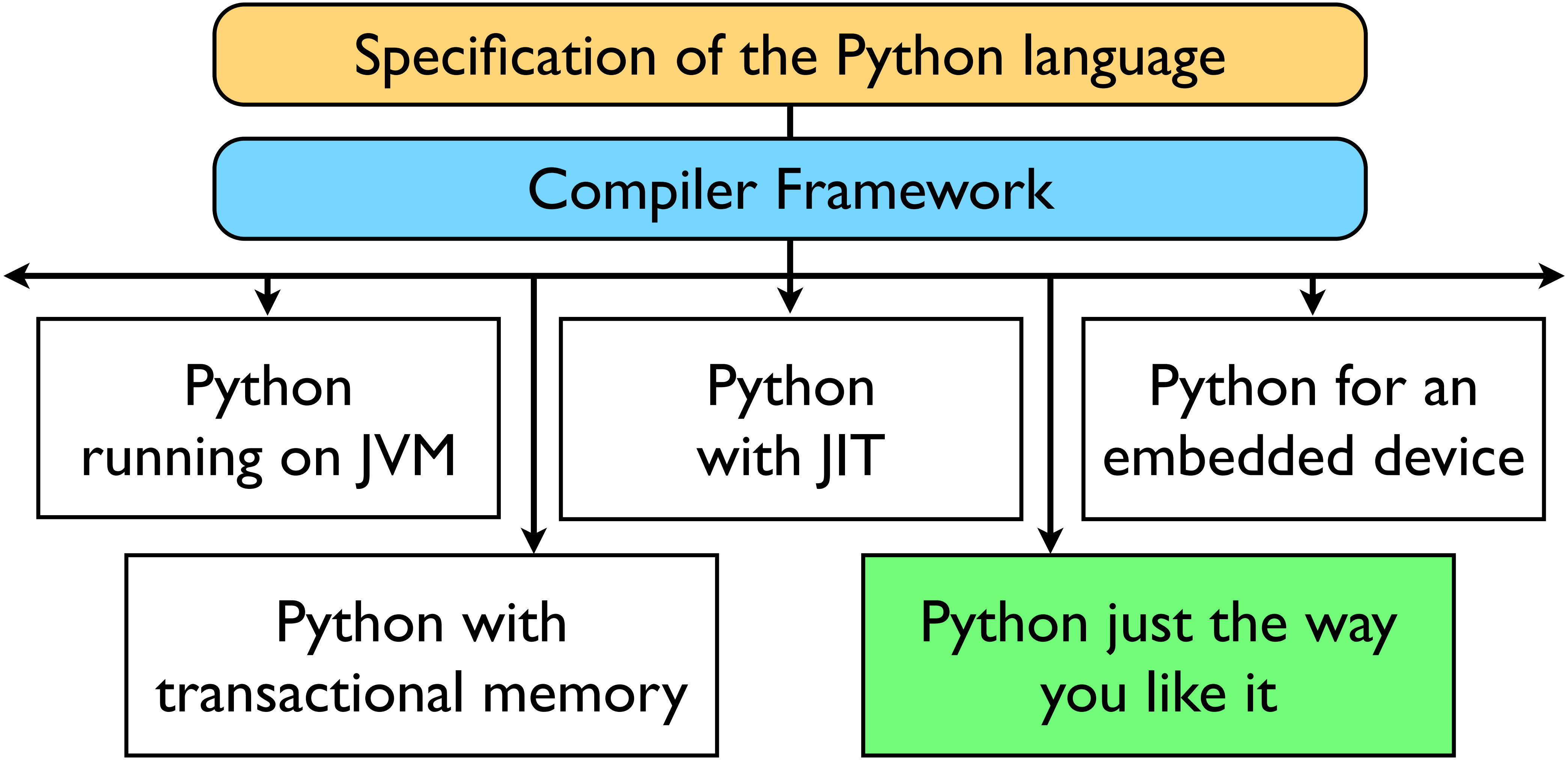
Motivation

- PyPy grew out of a desire to modify/extend the *implementation* of Python, for example to:
  - increase performance (psyco-style JIT compilation, better garbage collectors)
  - add expressiveness (stackless-style coroutines, logic programming)
  - ease porting (to new platforms like the JVM or CLI or to low memory situations)

Lofty goals, but first...

- CPython is a fine implementation of Python but:
  - it's written in C, which makes porting to, for example, the CLI hard
  - while psyco and stackless exist, they are very hard to maintain as Python evolves
  - some implementation decisions are very hard to change (e.g. refcounting)

Enter the PyPy platform



Specification of the Python language

Compiler Framework

Python running on JVM

Python with JIT

Python for an embedded device

Python with transactional memory

Python just the way you like it

How do you specify the Python language?

- The way we did it was to write an interpreter for Python in *RPython* – a subset of Python that is amenable to analysis
- This lets us write unit tests for our specification/implementation that run on top of CPython
- Can also test entire specification/implementation in same way

The “What is RPython?” question

- Restricted Python, or RPython, first and foremost it *is* Python
- It is a subset of Python that is static enough – *after initialization code has run* – for our analysis tools to cope with
- Somewhat Java-like – classes, methods, no pointers, no operator overloading

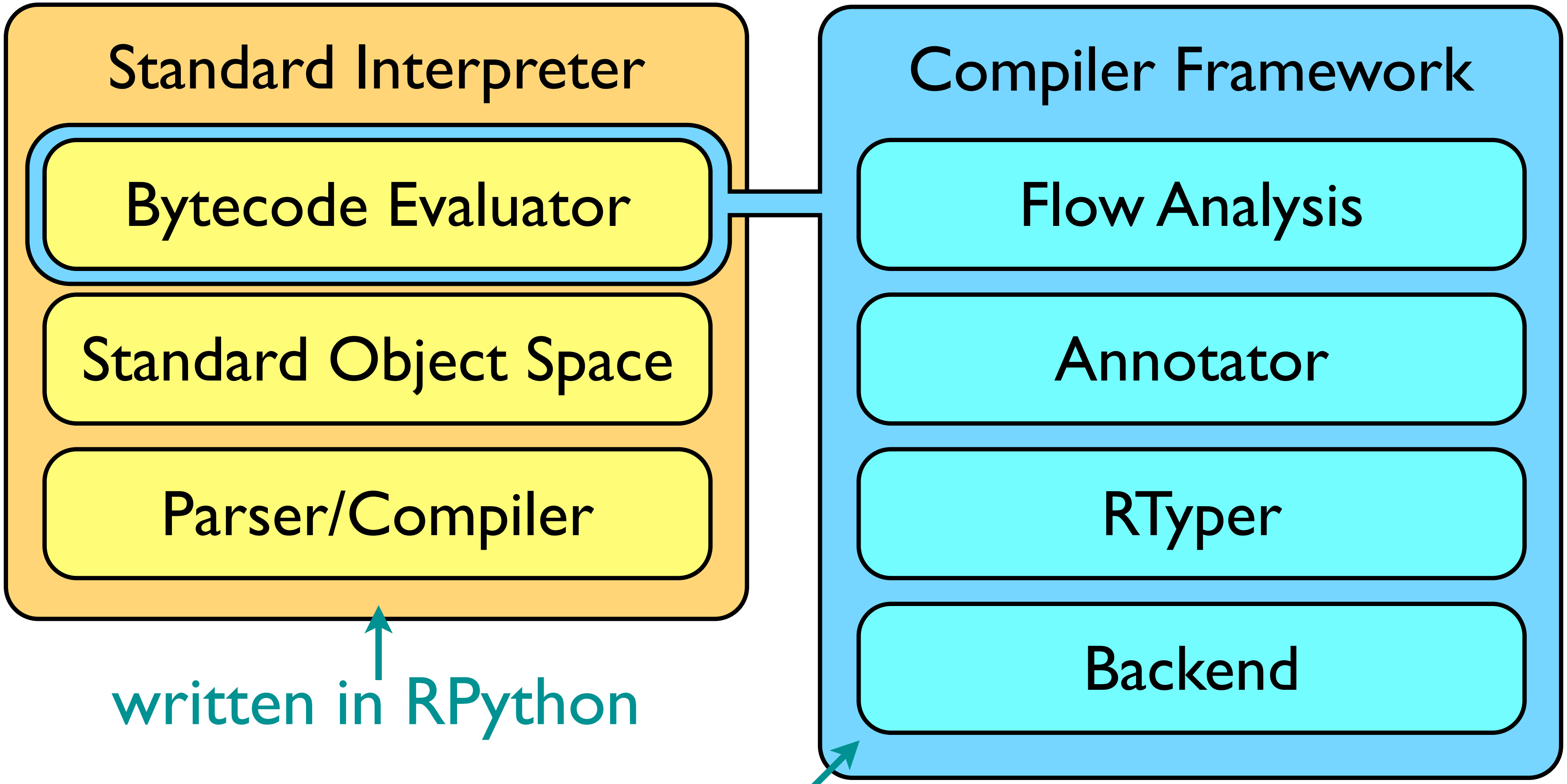
The “What is RPython?” question

- The definition of RPython is basically “what our compiler can analyze” – so changes (slowly) as toolchain does
- The property of “being RPython” belongs to entire programs and not, say, functions or modules because the annotator performs a global analysis

Translation Aspects

- Our Python implementation is very high level
- One of our Big Goals is to produce our customized Python implementations without compromising on this point
- We do this by weaving in so-called ‘translation aspects’ during the compilation process

In more detail...



Standard Interpreter

Bytecode Evaluator

Standard Object Space

Parser/Compiler

Compiler Framework

Flow Analysis

Annotator

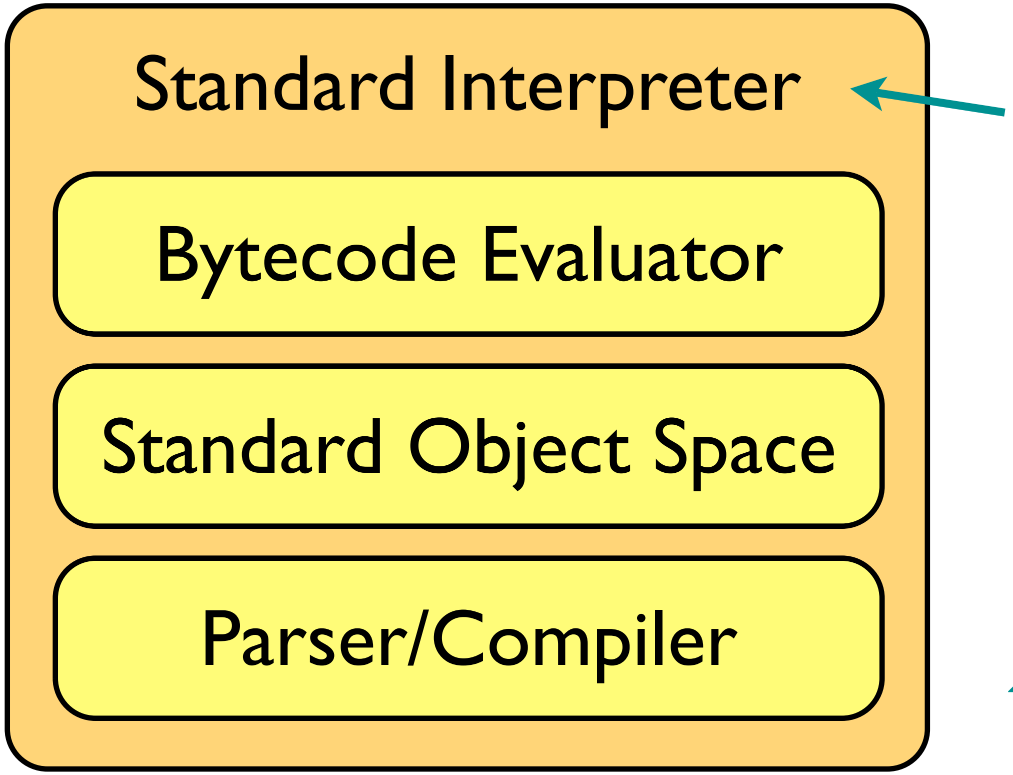
RTyper

Backend

written in RPython

written in full Python

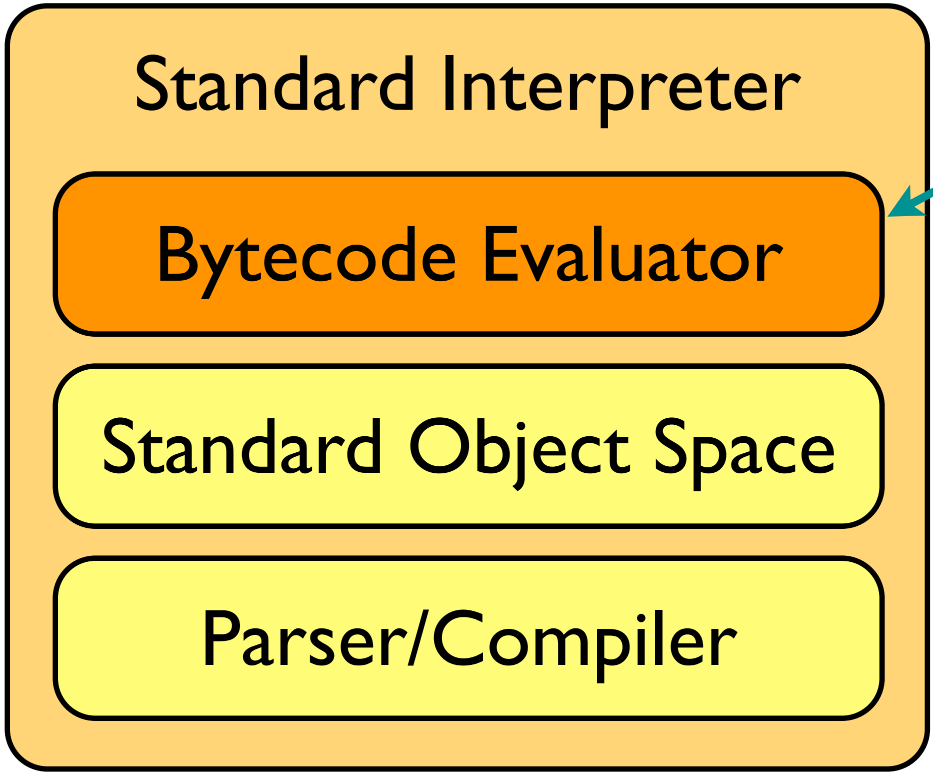
The Standard Interpreter



The standard interpreter does roughly speaking the same job as CPython does, and is split into three chunks

CPython can be split along the same lines with enough imagination – hardly a coincidence!

The Standard Interpreter

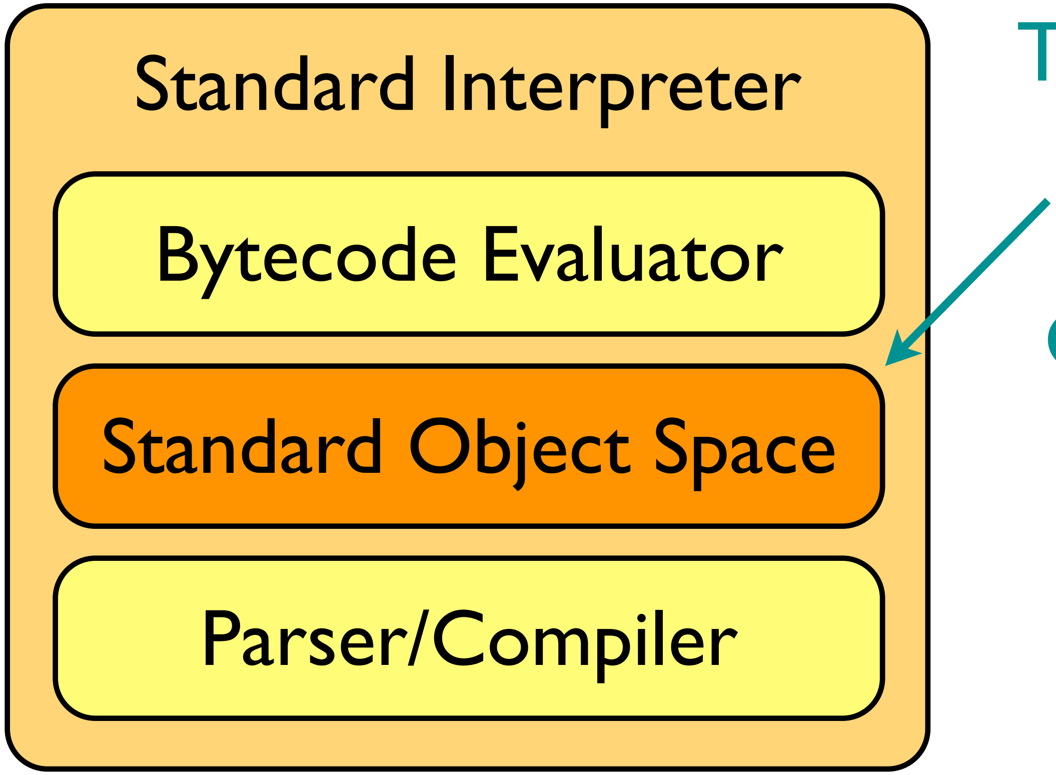


The bytecode evaluator evaluates the same bytecodes as CPython but treats objects as black boxes – it doesn't care if they are Python-like values, abstract `Variables` or even fruit

2 + 3 = 5

`Variable` + `Constant` = `Variable`

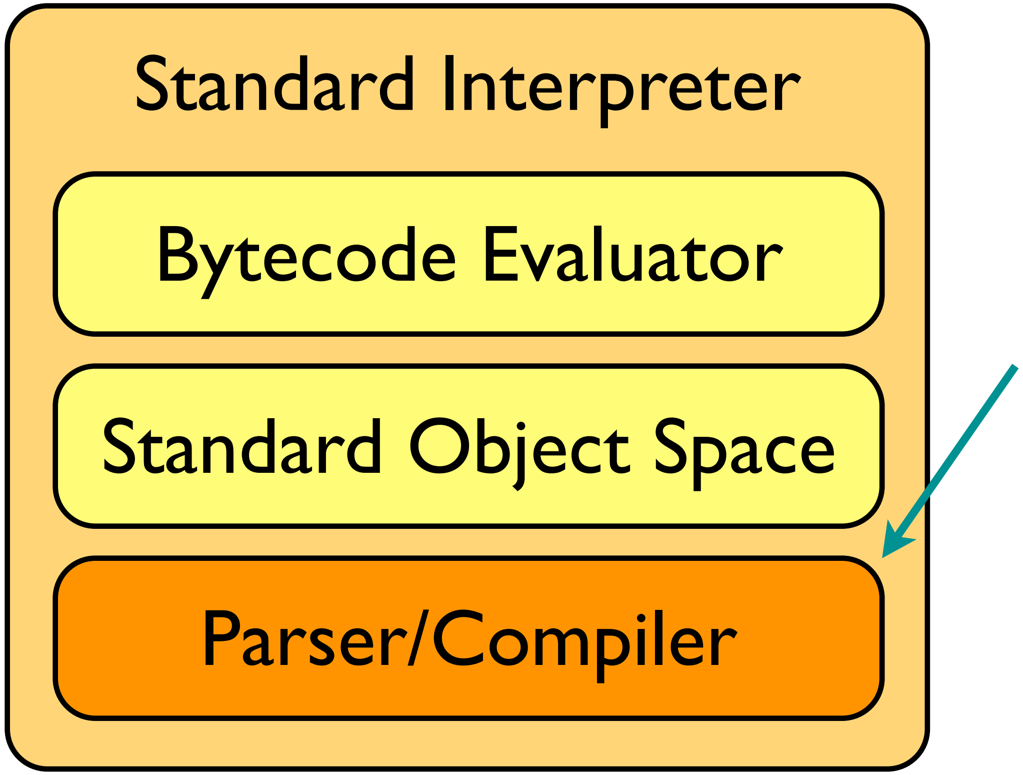
The Standard Interpreter



The Standard Object Space implements objects that look very much like CPython's – integers, lists, dictionaries, classes, etc

(it's a bit different on the inside though)

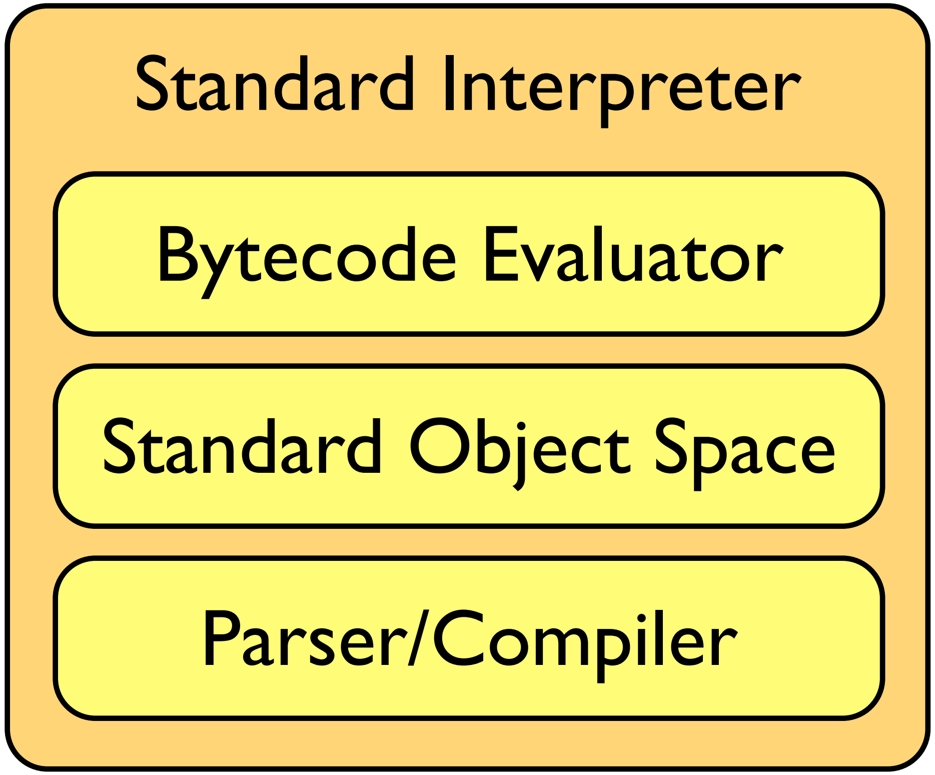
The Standard Interpreter



The parser and compiler, perhaps predictably, parses Python code and compiles it – to the same bytecode as CPython uses

Will sometime soon allow runtime modification of the grammar of the language

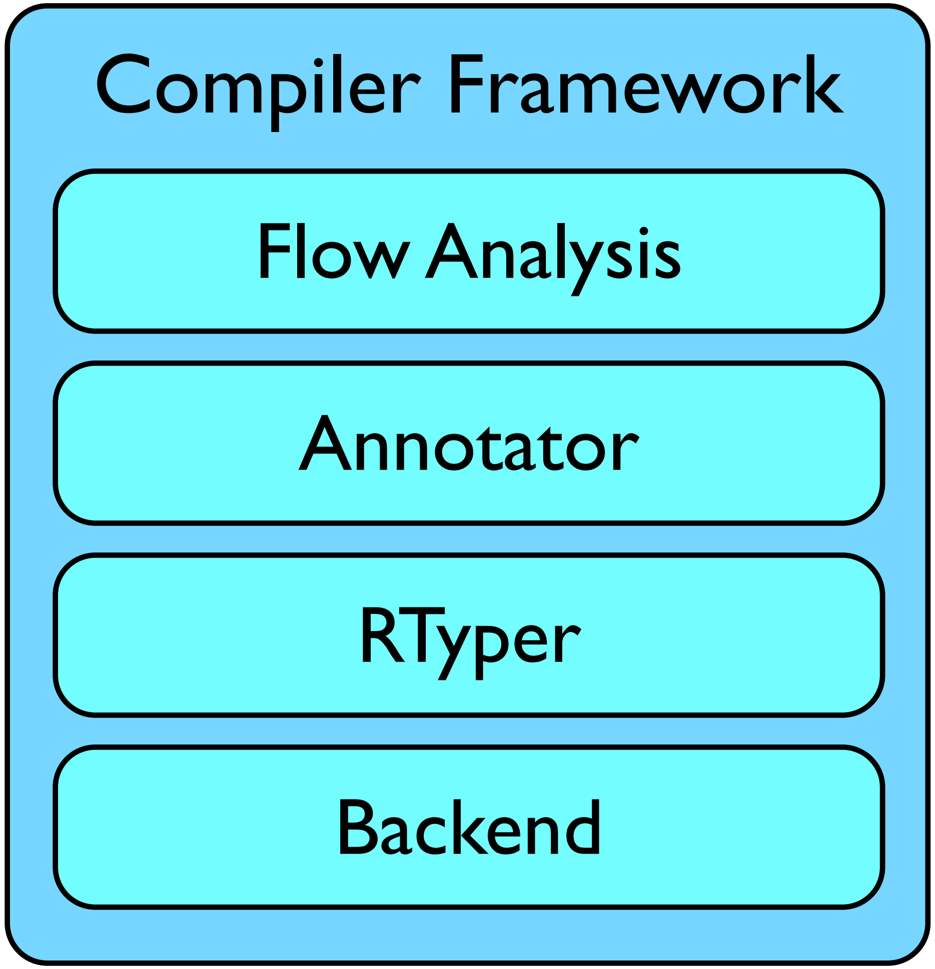
The Standard Interpreter



The standard interpreter is pretty stable now, implementing Python 2.4.3 (and some 2.5 features),

Some work to come on the parser/compiler and logic variable integration

Compiler Framework



Compiler Framework

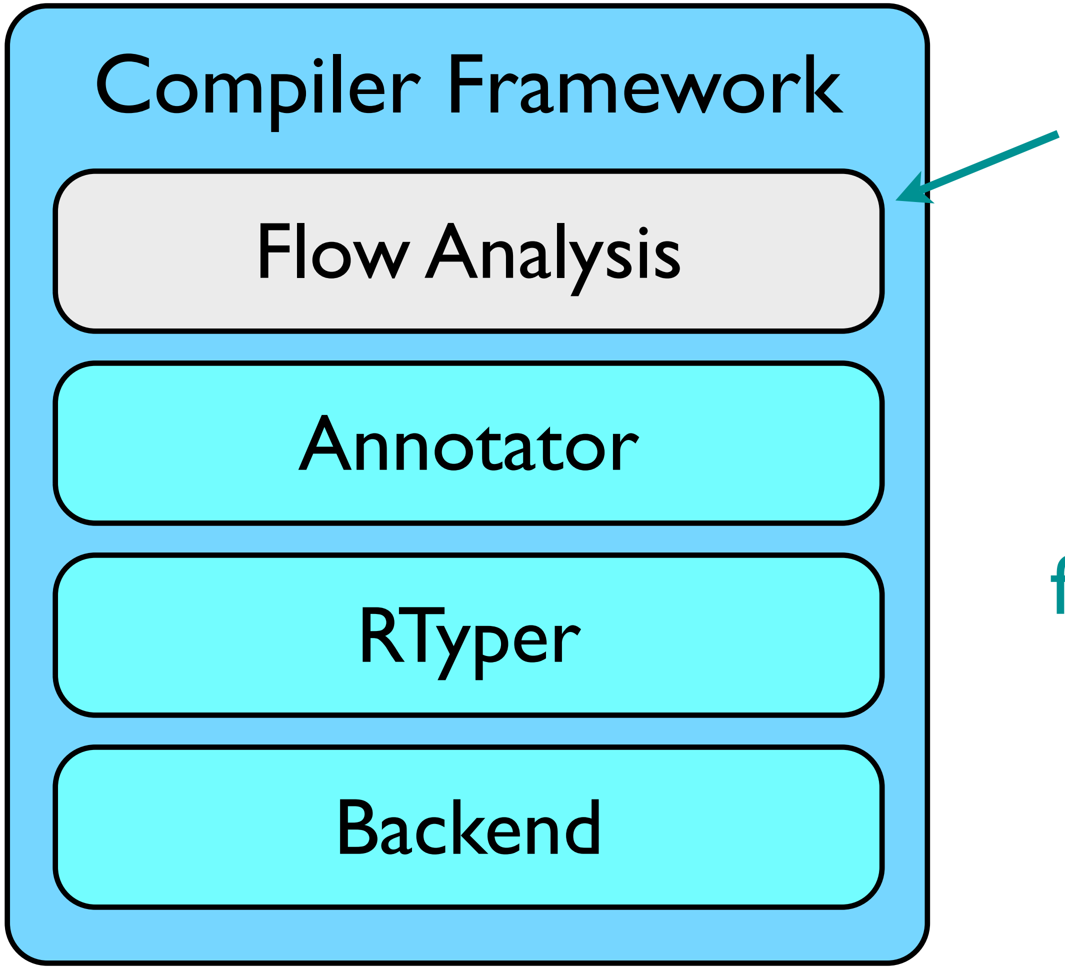
Flow Analysis

Annotator

RTyper

Backend

Compiler Framework



Compiler Framework

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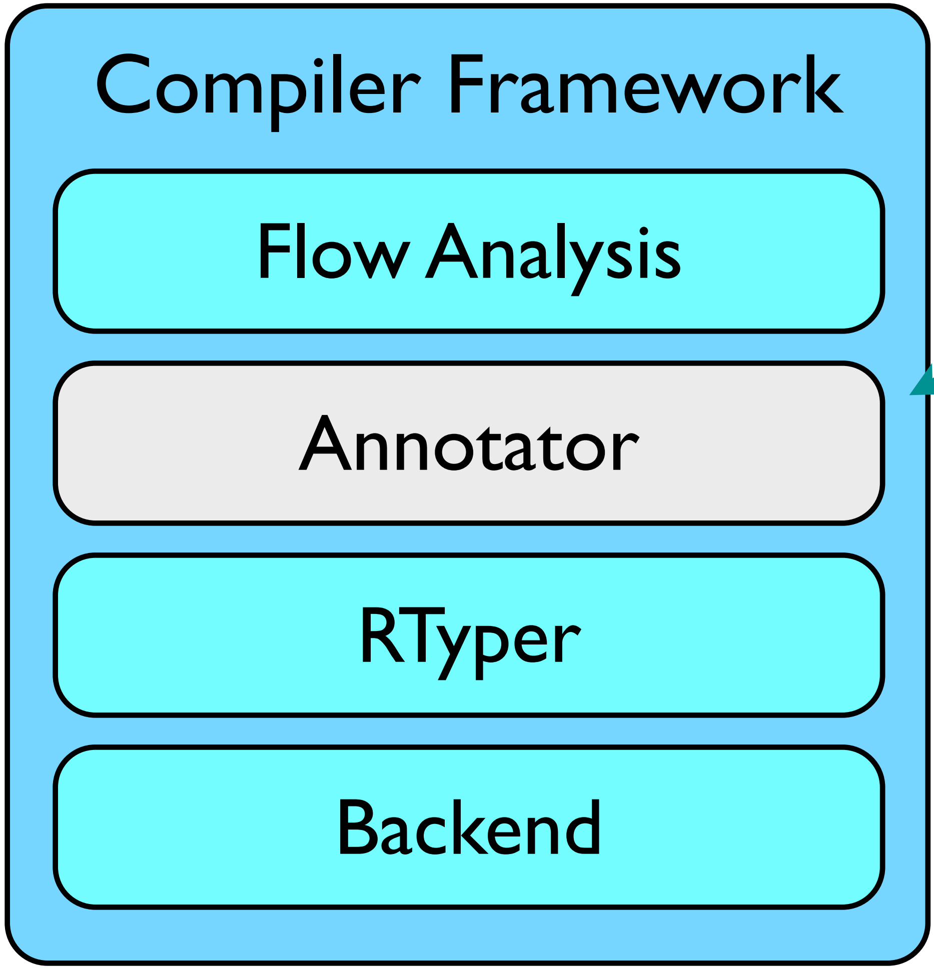
Analyzes a single code object to deduce control flow

We have a funky pygame flow graph viewer that we use to view these flow graphs

Compiler Framework



Compiler Framework

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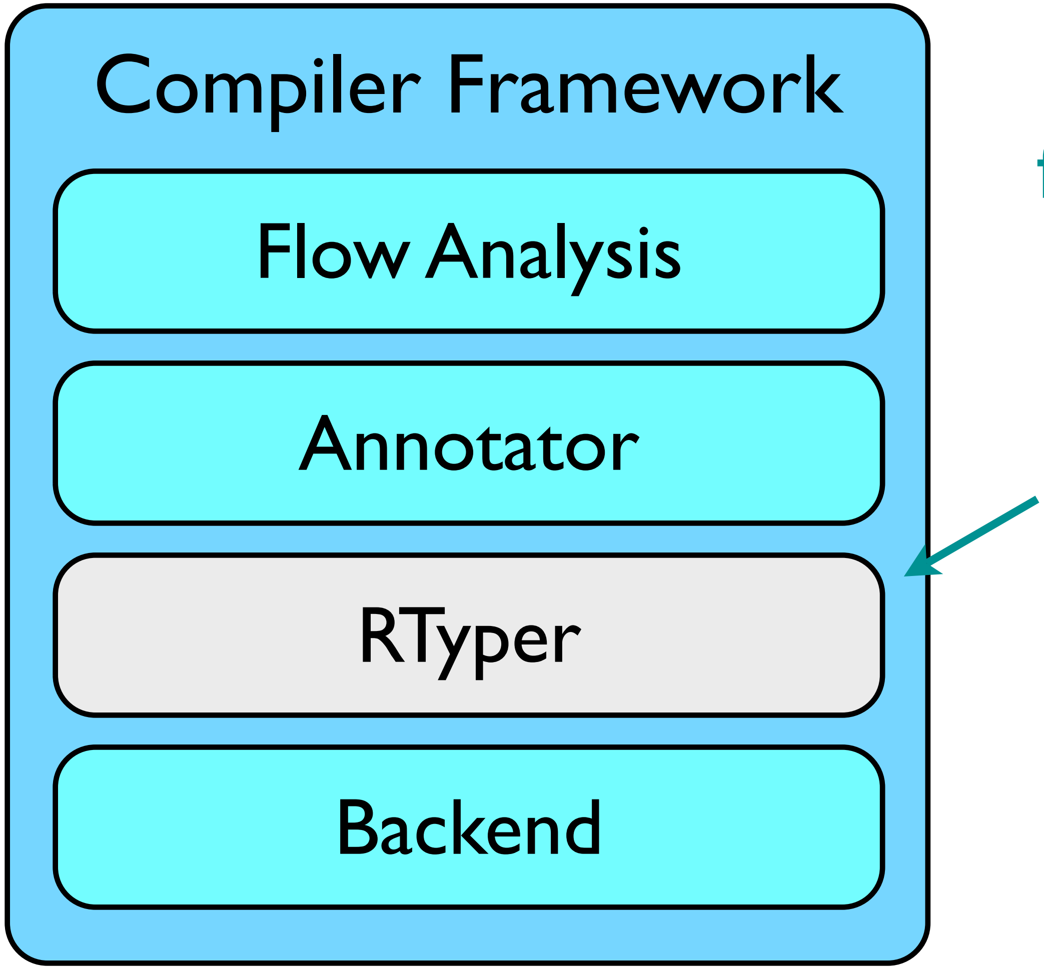
Analyzes an *entire program* to deduce type and other information

Uses abstract interpretation, rescheduling and other funky stuff

Compiler Framework



Compiler Framework

Flow Analysis

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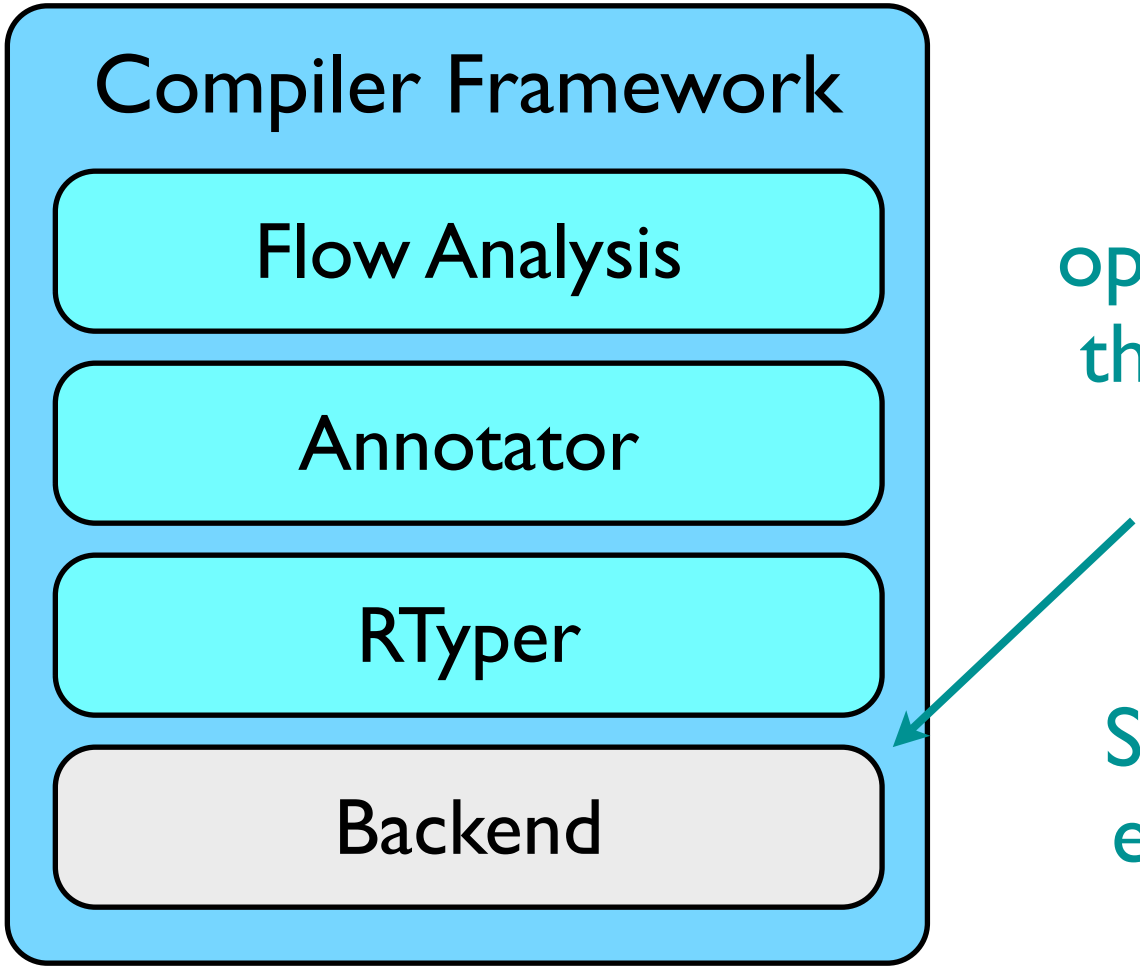
RTyper

Backend

Uses the information found by the annotator to decide how to lay out the types used by the input program in memory, and translates high level operations to lower level more pointer-ish operations

Compiler Framework



Translates low level operations and types from the RTyper to (currently) C, JavaScript or LLVM code

Sounds like it should be easy, in fact a bit painful

The Flow Model

- Without going into details of how the Flow Object Space works, it produces a control flow graph of a code object
- Values are either `Variable`s or `Constant`s
- Operations are described by `SpaceOperation`s like `"add"`
- `SpaceOperation`s live in `Block`s which are connected by `Link`s

The Flow Model

- `SpaceOperations` have an `opname`, a `result` variable and a list of `args`
- A few examples:
    - `c = a + b` → `v_c = add(v_a, v_b)`
    - `z = x.y` → `v_z = getattr(v_x,“y”)`
    - `t = f(u)` → `v_t = simple_call((f), v_u)`
- Demo!

The Annotator

- Type annotation is a fairly widely known concept – it associates variables with information about which values they might take at run time
- An unusual feature of PyPy's approach is that the annotator works on live objects
- This means it never sees initialization code, so that can use `exec` and other insane tricks

The Annotator

- Works by abstractly interpreting the control flow graphs produced by the flow analysis
- Annotation starts at a given entry point and discovers as it proceeds which functions may be called by the input program
- Read “Compiling dynamic language implementations” on the web site for more than is on these slides

The Annotator

- Does not modify the graphs; end result is essentially a big dictionary mapping `Variable`s to instances of a subclass of `SomeObject`
- Important subclasses are `SomeInteger`, `SomeList`, `SomeInstance`, `SomePBC` (“some pre-built constant”, includes classes and functions)
- Demo

The RTyper

- RTyper takes as input an annotated RPython program (e.g. our Python implementation)
- Performs "representation selection" and converts high-level operations to low-level
- Potentially can target a C-ish, pointer-using language or an OO language like Java or Smalltalk with classes and instances (OO backend not yet complete)

Representation Selection

- For example, in:

  ```
  for x in range(10):
      print x
  ```

  we represent the `range` as just start/stop/step

- But in:

  ```
  l = range(10)
  l[2] = 3
  ```

  `l` is represented as a full (mutable) list

Representation Selection

- Instances of the class `LowLevelType` describe a C-like *types* – structures or arrays, pointers or primitive types such as integer or float

- The RTyper attaches a `LowLevelType` to each `Variable` and `Constant` in each annotated control flow graph

Translating High Level to Low Level

- Many high level operations apply to different types; for example you can `"add"` strings, floats or integers and continually having to distinguish is annoying
- Easier for backends to have monomorphic operations `int_add`, `float_add`, `str_add`
- Some operations are more complex, e.g. instantiation of a class

Translating High Level to Low Level

- We saw that the code “`z = x + y`” becomes “`v_z = add(v_x, v_y)`”
- Assuming that `v_x` and `v_y` (and thus `v_z`) are annotated as `SomeInteger`, then:
  - `v_x`, `v_y`, `v_z` will get a `LowLevelType` of `Signed`
  - the `"add"` operation will be replaced with an `"int_add"` operation

The Backend(s)

- Maintained backends: C, JavaScript and LLVM (Smalltalk and CLI/.NET on the way)
- All proceed in two phases:
  - Traverse the forest of rtyped graphs, computing names for everything
  - Spit out the code

Status – what works

- The Standard Interpreter very nearly complete
- The compiler framework:
  - Produces standalone binaries
  - C and LLVM backends well supported
  - JavaScript backend works, but not for all of PyPy

Status – what works

- The C backend supports three garbage collection strategies:
  - reference counting,
  - using the conservative Boehm-Demers-Weiser collector
  - a precise mark and sweep collector we wrote

Status – what works

- The C and JavaScript backends support “stackless” features – coroutines, tasklets, recursion only limited by RAM
- Can use OS threads with a simple “GIL-thread” model
- Our Python specification/implementation has remained free of all these implementation decisions!

What we're working on now

- The Just-In-Time compiler – early stages, works for a very simple language
- More home-grown GCs (e.g. a semispace copying collector) and more GCs for LLVM
- Logic programming – some working code, interface and integration in progress

What we’re working on now

- “rctypes”, a uniform way of calling external functions based on the now-standard “ctypes” module for CPython
- CLI (.NET) and Smalltalk backends
- supporting stackless features in other backends

About the project

- Open source, of course (MIT license)
- Distributed – the 12 paid developers live in 6 countries, contributers from more
- Sprint driven development – focussed week long coding sessions every ~6 weeks
- Extreme Programming practices: pair programming, test-driven development

“We’re Hiring!”

- In the open source sense:
  - Read documentation:

    http://codespeak.net/pypy/

  - Come hang out in `#pypy` on freenode, post to pypy-dev
- Some opportunities for paid work too.