PyPy
Crash Course/Sprint Intro

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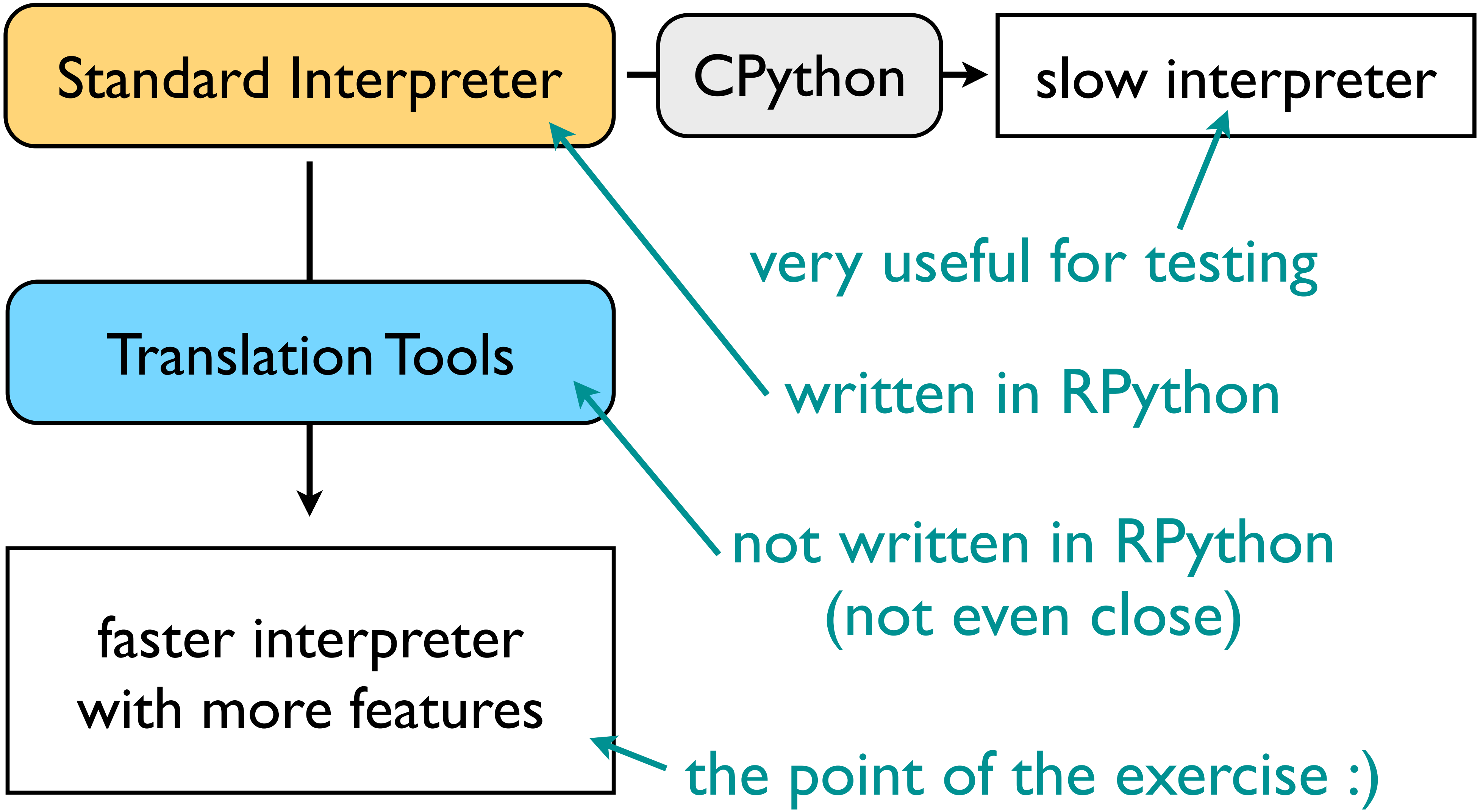
Something to look at if I'm too boring

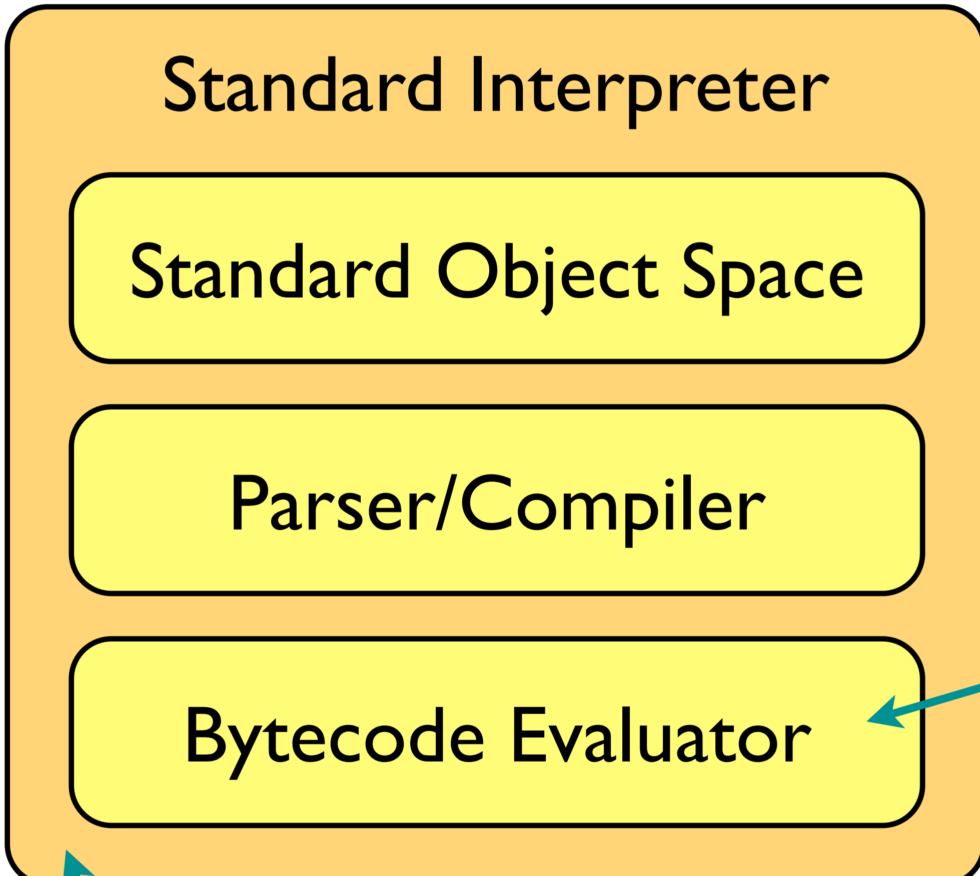
- Getting started has a lot of good stuff, including where to get the source, links to subversion clients and entry points:

http://codespeak.net/pypy/dist/pypy/doc/getting-started.html

Big Picture


Standard Interpreter
CPython
slow interpreter
very useful for testing
written in RPython
Translation Tools
not written in RPython
(not even close)
faster interpreter
with more features
the point of the exercise :)

Standard Interpreter



CPython can be divided into the same parts with sufficient imagination – which is hardly a coincidence

independent of object space implementation, which is important

all written in RPython

The "what is RPython?" question

- RPython is first and foremost Python code
- Basically defined by being static enough for our toolchain to be able to cope with it
- Some of the restrictions are documented in the coding guide

Some Jargon

- There are many levels in PyPy
- Two of the more important, defined in terms of running PyPy on top of CPython:
  - “interp-level”: code that will be executed by CPython (and get translated to C)
  - “app-level”: code that will be executed by PyPy’s bytecode evaluator, not CPython’s

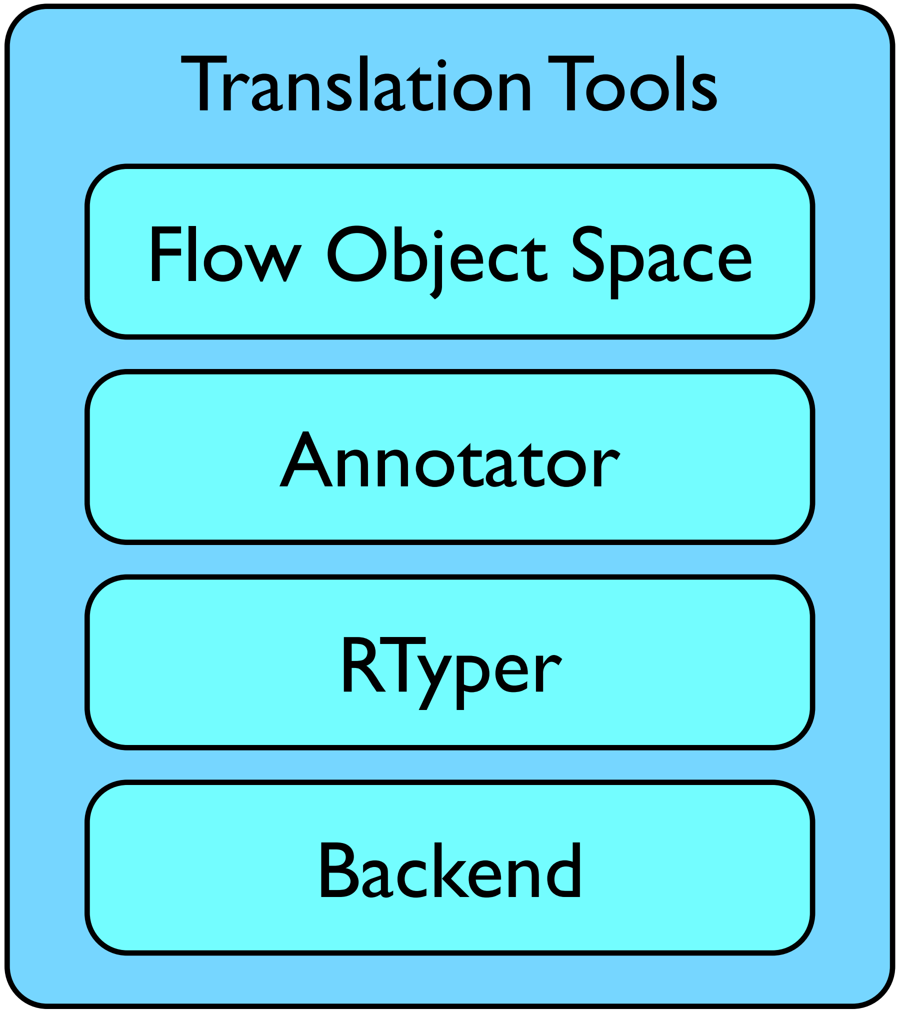
Interp/App-level

- The standard interpreter is written in a mixture of app-level and interp-level code
- Can call from one to the other
- Advantages of app-level: can use full power of Python, less code
- Advantages of interp-level: faster, closer to the metal

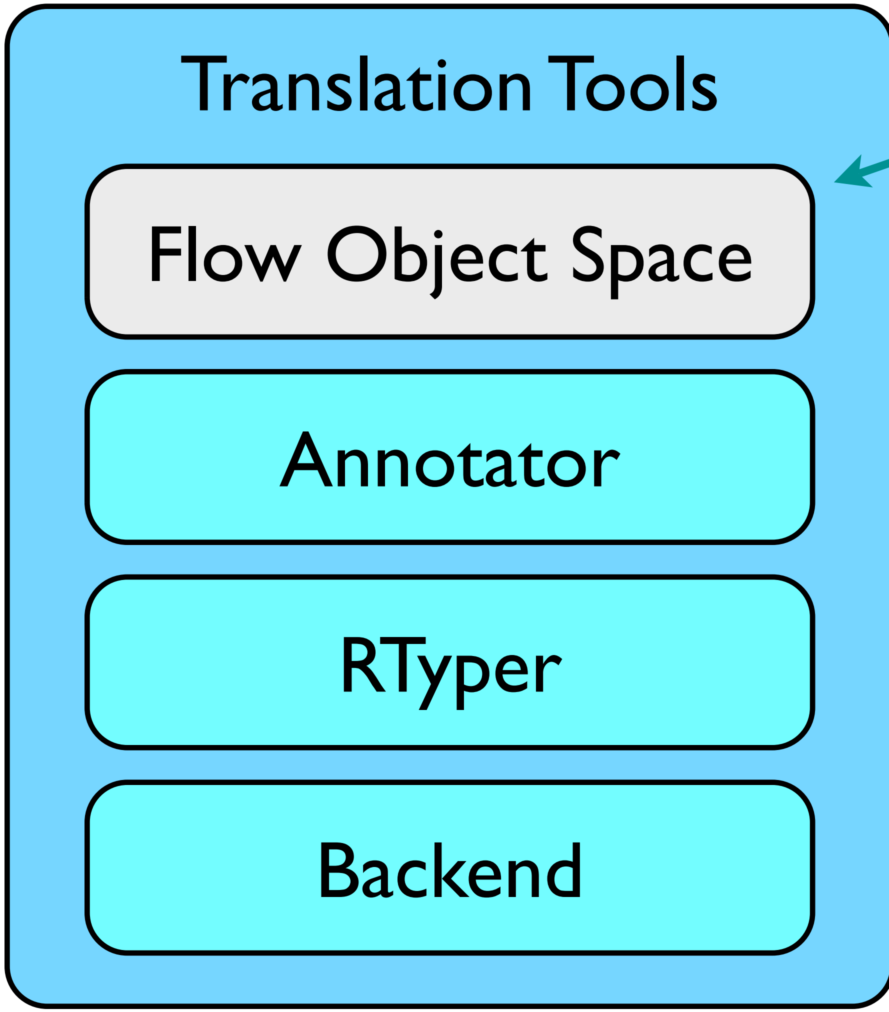
Status

- Standard Interpreter very complete, passes a large majority (>90%) of CPython's core regression tests
- Work being done on making the parser/ compiler configurable at runtime
- Standard Object Space and bytecode evaluator now very stable
- Only 2.4 compliant though

Translation Tools



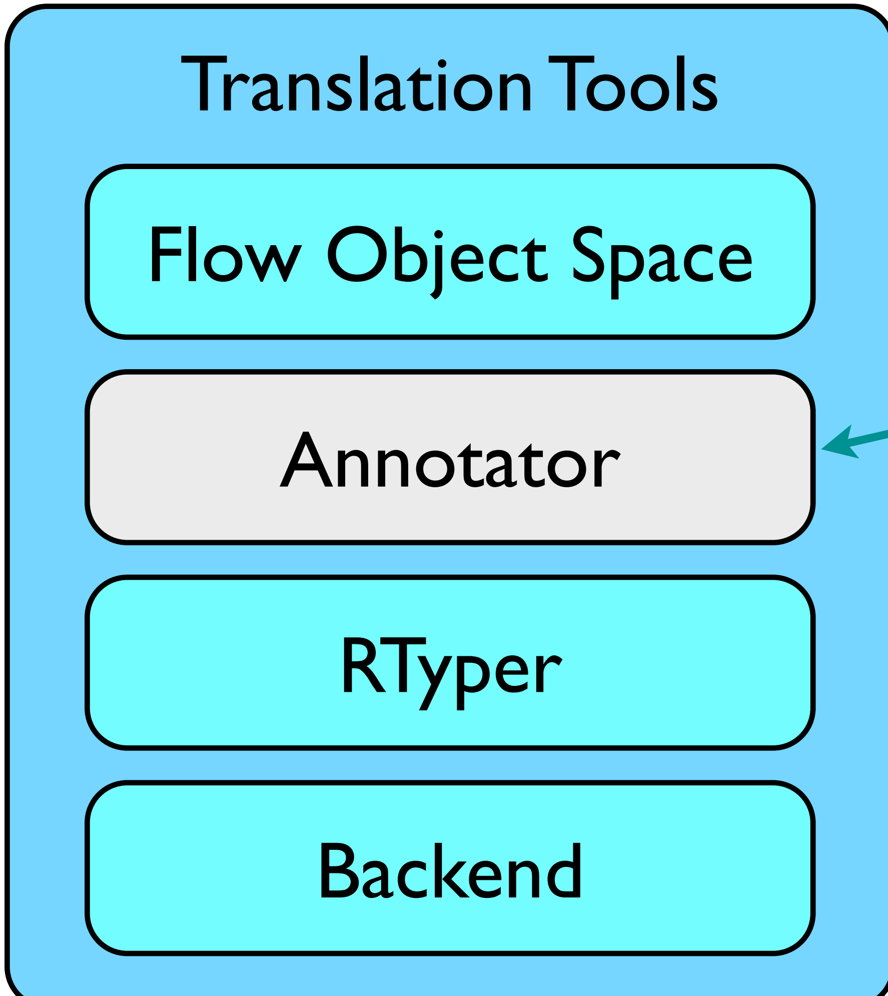
Translation Tools



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
(demo)

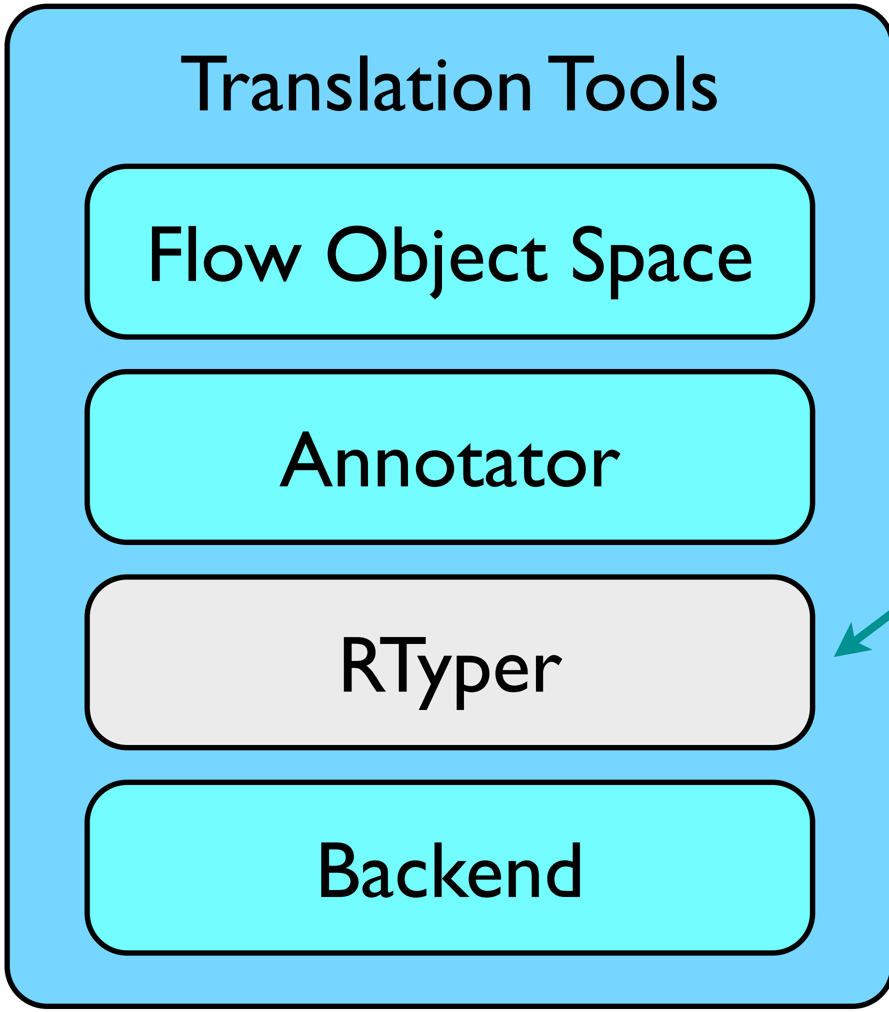
Translation Tools



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

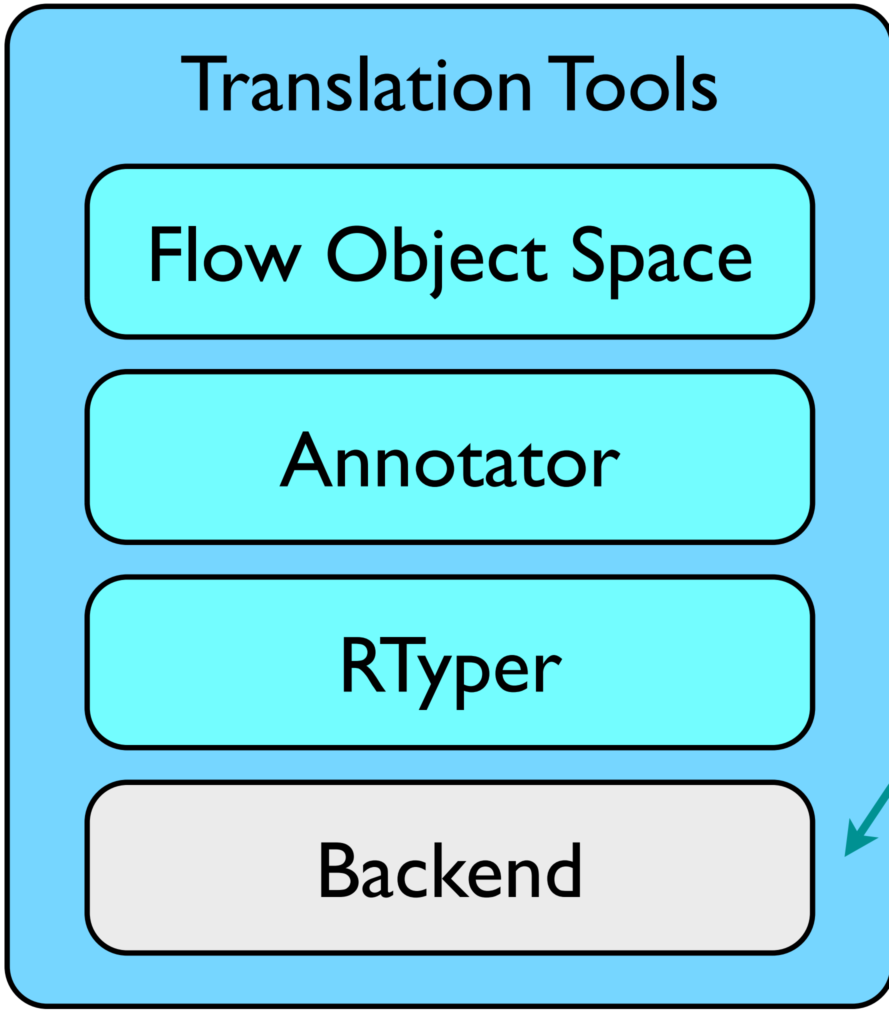
Uses abstract interpretation, rescheduling and other funky stuff

Translation Tools



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

Translation Tools



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

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

Flow Analysis

- Control flow graphs are built by abstractly interpreting the code object using the standard interpreter's bytecode evaluator in an *abstract domain* – the Flow Object Space
- Uses state-saving tricks to consider both parts of a branch
- That's enough on how it works – what it produces is much more relevant today

The Flow Model

- All defined in `pypy.objspace.flow.model`
- Values are either `Variable`s or `Constant`s
- A function's control flow graph is described by a `FunctionGraph`
- This contains `Block`s and `Link`s
- Blocks contain a list of `SpaceOperation`s

The Flow Model

- `SpaceOperation`s have an `opname`, a `result` variable and a list of `args`.
- The graph is naturally produced in *Static Single Information* form, which is very handy for later analysis
- This means each `Variable` is used in exactly one block and is renamed if it needs to be passed across a link

The Flow Model

- Some examples:
  - `z=x.y` → `SpaceOperation("getattr", [v_x, Constant("y")], v_z)`
  - `c=a+b` → `SpaceOperation("add", [v_a, v_b], v_c)`
  - `t=f(u)` → `SpaceOperation("simple_call", [Constant(f), v_u], v_t)`

The Annotator

- Type annotation is a fairly widely known concept – it associates variables with information about what 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 (a popular phrase :) the control flow graphs produced by the flow analysis
- Annotation starts at an entry point and discovers as it proceeds which functions are needed
- Read "Compiling dynamic language implementations" on the web site for more

The Annotator

- Works a block at a time, maintaining a pile of blocks that need analysis
- As analysis proceeds, the information about a block may get invalidated – in other words, the annotation reschedules as needed
- A fix-point approach:

```
while work_to_do: do_work()
```

The Annotation Model

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

The RTyper

- An apology: "RTyping" is a pretty bad name. Just treat it as a random atomic identifier ("Frobnostication" is too hard to spell)
- Performs "representation selection" and converts high-level operations to low-level
- Potentially can target a C-ish language or an OO-language like Java or Smalltalk (OO backend somewhat theoretical at this point)

The RTyper

- Originally we tried to do the job the RTyper does at the same time as source generation
- Failed
- Miserably
- It does a job that's not part of the standard "Introduction to Compilers 101" course

Representation Selection

- The fact that the annotator performs a global analysis gives us a novel opportunity
- For example, in:

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

  can represent the return value of range as just start/stop/step, but if we know the return value of range() is going to be mutated we just return a normal list

lltypes

- `pypy.rpython.lltypesystem.lltype` contains a collection of Python classes that describe (and implement!) a C-like memory model with `Struct`s, `Array`s, `Pointer`s, `Signed`s (integers), `GcStruct`s, `Float`s... all subclasses of `LowLevelType`
- Convention is that variables holding instances of lltypes are in ALLCAPS:

```
TYPE = GcStruct(“T”, (“x”, Signed))
```

Representation Selection

- The RTyper attaches an attribute "`concretetype`" containing an lltype to all `Constant`s and `Variable`s
- During the process of RTyping, however, an instance of `pypy.rpython.rmodel.Repr` is created and associated with each `Variable`'s annotation, which knows how to translate operations involving the `Variable`

Translating High Level to Low Level

- The high level operations such as "`add`" apply to different types; you can add strings, floats or integers and continually having to distinguish is annoying
- Better to have monomorphic operations `int_add`, `float_add`, `str_add` (well...)
- Some operations are more complex, e.g. instantiation of a class.

Translating High Level to Low Level

- For each operation:
  - an instance of a subclass of `Repr` is created/found for each argument's annotation
  - and these are asked what low-level operation(s) the high level operation should be replaced with

Translating High Level to Low Level, example

- Start with, say, `SpaceOperation("add", [v_x, v_y], v_z)` with `v_x` and `v_y` (and `v_z`) all annotated as `SomeInteger()`
- `rtype.getrepr(v_x)` returns an instance of `IntegerRepr` (same for `v_y`)
- We end up calling a method `rtype_add` on a "`pairtype`" which makes a "`int_add`" operation

Source Generation

- Maintained backends: C, JavaScript(!) and LLVM
- Both proceed in two phases:
  - Traverse the forest of rtyped graphs, computing names for everything
  - Spit out the code

Things I haven't talked about

- Specialization of functions/annotation policies
- External functions
- Low level helpers
- Garbage collection policies
- The JIT
- Constraint solving
- Geninterp
- Pairtypes

Coding Issues

- See: http://codespeak.net/pypy/dist/pypy/doc/coding-guide.html
- But in summary: PEP 8, test driven development (using py.test)