The Highs and Lows of Macros in a Modern Language

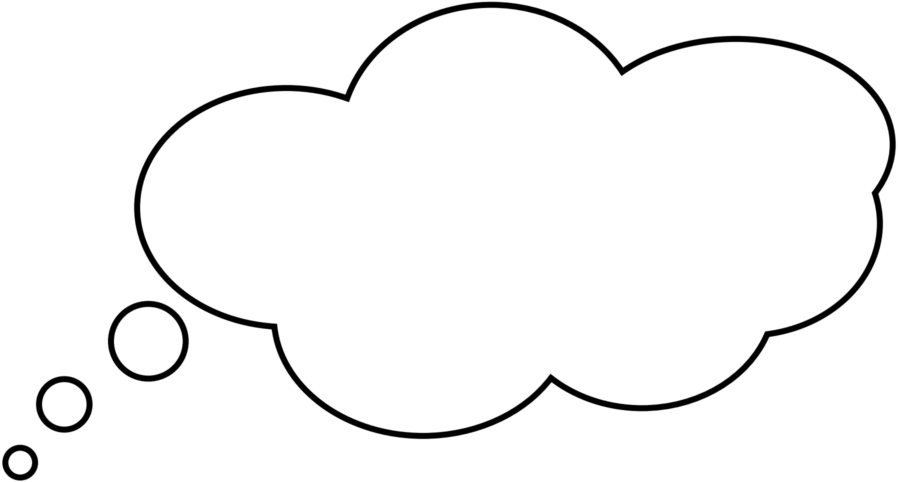
Laurence
Tratt

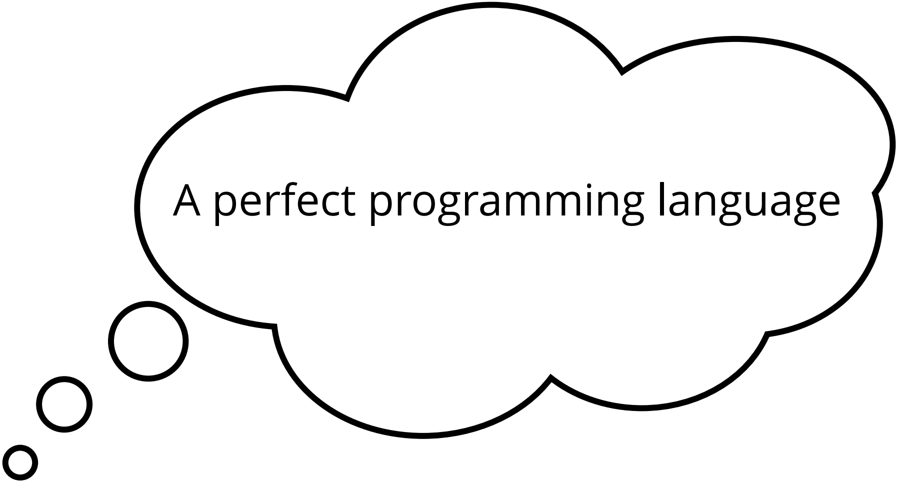
KING'S College LONDON

Software Development Team

2016-08-09

Background




A perfect programming language

Solution

Solution

A new programming language

Reality

Reality

Another imperfect programming language

What to expect from this talk

What to expect from this talk

1. What happens when you put macros into a modern programming language?

What to expect from this talk

1. What happens when you put macros into a modern programming language?

2. If it doesn't work out well, is there an alternative?

Part I

Defining the area

What is a macro?

What is a macro?

It's complicated…

What is a macro?

It's complicated...

Let's simplify to "a calculation that happens at compile-time".

Text substitution

This C fragment:

```
#define sq2(y) ((y) * (y))

int main() {
    printf("%d\n", sq2(3));
}
```

is *preprocessed* to:

```
int main() {
    printf("%d\n", ((3) * (3)));
}
```

and then compiled.

Text substitution: the good

Some clever (and useful) things are possible e.g.:

```
#define TRY { \
    jmp_buf _env; \
    if (setjmp(_env) == 0) { \
        add_exception_frame(_env);
#define CATCH(v) \
        remove_exception_frame(); \
    } \
    else { \
        (v) = read_and_reset_exception();
#define TRY_END } }
```

Text substitution: the good

Some clever (and useful) things are possible e.g.:

```
#define TRY { \
    jmp_buf _env; \
    if (setjmp(_env) == 0) { \
        add_exception_frame(_env);
#define CATCH(v) \
        remove_exception_frame(); \
    } \
    else { \
        (v) = read_and_reset_exception();
#define TRY_END } }
```

can be used – fairly naturally – for:

```
Exception *e;
TRY {
    ...
} CATCH (e) {
    ...
}
TRY_END
```

Text substitution: the bad

What does the following print out?

```
#define sq2(y) (y * y)
int main() {
    printf("%d\n", sq2(3));
    printf("%d\n", sq2(1+2));
}
```

Text substitution: the bad

What does the following print out?

```
#define sq2(y) (y * y)
int main() {
    printf("%d\n", sq2(3));
    printf("%d\n", sq2(1+2));
}
```

Obviously `9`, `5`?!

Text substitution: the bad

What does the following print out?

```
#define sq2(y) (y * y)
int main() {
    printf("%d\n", sq2(3));
    printf("%d\n", sq2(1+2));
}
```

Obviously `9`, `5`?! What about:

```
#define sq2(y) ((y) * (y))
typedef struct { int y; } C;
int main() {
    C x;
    x.y = 3;
    printf("%d\n", sq2(++x.y));
}
```

Text substitution: the bad

What does the following print out?

```
#define sq2(y) (y * y)
int main() {
    printf("%d\n", sq2(3));
    printf("%d\n", sq2(1+2));
}
```

Obviously `9`, `5`?! What about:

```
#define sq2(y) ((y) * (y))
typedef struct { int y; } C;
int main() {
    C x;
    x.y = 3;
    printf("%d\n", sq2(++x.y));
}
```

Obviously `20`?!

Text substitution: the bad

What does the following print out?

```
#define sq2(y) (y * y)
int main() {
    printf("%d\n", sq2(3));
    printf("%d\n", sq2(1+2));
}
```

Obviously `9`, `5`?! What about:

```
#define sq2(y) ((y) * (y))
typedef struct { int y; } C;
int main() {
    C x;
    x.y = 3;
    printf("%d\n", sq2(++x.y));
}
```

Obviously `20`?!

There are other problems too, but you get the idea...

Hetergeneous vs. homogeneous

Hetergeneous: where the meta-programming language/system (e.g. the C preprocessor) is different than the main language/system (e.g. C).

Homogeneous: where the two are the same.

Crudely: hetergeneous is powerful, but difficult to use, and unsafe; homogeneous is safe(r) and easier to use.

[See Sheard 2003 'Accomplishments and Research Challenges in Meta-programming']

Lisp

The ‘Lisp’ family is huge.

Lisp

The ‘Lisp’ family is huge. In a typical-ish Lisp, one might do:

```
(defmacro sq2 (e)
   (list ’* e e))

(print (macroexpand ’(* (+ 1 2) (+ 1 2))))
(print (macroexpand ’(sq2 (+ 1 2))))
```

which will print:

```
(* (+ 1 2) (+ 1 2))
(* (+ 1 2) (+ 1 2))
```

Note: everything is done on trees.

For decades, macro research *was* Lisp.

Why?

The tumbleweed years

For decades, macro research *was* Lisp.
Why?

Brackets (maybe); homoiconicity (definitely).

For decades, macro research *was* Lisp.
Why?

Brackets (maybe); homoiconicity (definitely).

Until MetaML and successors, including Template Haskell.

Part II

What happens when you put macros into a modern programming language?

Converge

Converge

Summary: Python + TH-esque macros

```
import Sys
func main():
  Sys::println("hello world")
```

Compile-time Meta-programming / Macros

Code (as trees, not text) is programatically generated.

Compile-time Meta-programming / Macros

Code (as trees, not text) is programatically generated.

Expression	`2 + 3`	evaluates to `5` (as one expects).
Splice	`$<x>`	evaluates `x` at compile-time; the AST returned overwrites the splice.
Quasi-quote	`[| 2 + 3 |]`	evaluates to a *hygienic* AST representing `2 + 3`.
Insertion	`[| 2 + ${x} |]`	'inserts' the AST `x` into the AST being created by the quasi-quotes.

When do things execute?

When are `x` and `y` evaluated?

```
$<x>
func main():
    y
```

The `power` Function

We want:

```
power3 := $<mk_power(3)>
```

to be compiled to:

```
power3 := func (x):
  return x * x * x * 1
```

How to do it?

The `printf` Function

What can we use this stuff for?

What can we use this stuff for?

IMHO, macros are useful if your language has:

1. very little syntax

What can we use this stuff for?

IMHO, macros are useful if your language has:

1. very little syntax and/or
2. a (restrictive) static type system.

What can we use this stuff for?

IMHO, macros are useful if your language has:

1. very little syntax and/or
2. a (restrictive) static type system.

Neither is true in modern dynamically typed languages.

What can we use this stuff for?

IMHO, macros are useful if your language has:

1. very little syntax and/or
2. a (restrictive) static type system.

Neither is true in modern dynamically typed languages.

Do macros have uses?

Embedding DSLs

Splice	`$<x>`	evaluates `x` at compile-time; the AST returned overwrites the splice.
Quasi-quote	`[| 2 + 3 |]`	evaluates to a *hygienic* AST representing `2 + 3`.
Insertion	`[| 2 + ${x} |]`	'inserts' the AST `x` into the AST being created by the quasi-quotes.

Embedding DSLs

Splice	`$<x>`	evaluates `x` at compile-time; the AST returned overwrites the splice.
Quasi-quote	`[| 2 + 3 |]`	evaluates to a *hygienic* AST representing `2 + 3`.
Insertion	`[| 2 + ${x} |]`	'inserts' the AST `x` into the AST being created by the quasi-quotes.
DSL blocks	`$<<x>>: y`	pass the string `y` to the function `x` at compile-time.

Building a DSL

DSL debugging

We normally assume that compilers are perfect

DSL debugging

We normally assume that compilers are perfect

DSL compilers are probably imperfect

DSL debugging

We normally assume that compilers are perfect

DSL compilers are probably imperfect

Are errors due to the user or the compiler?

Static error reporting

Run-time error reporting

Src infos are a triple: *(file ID, char offset, char span)*

Threaded throughout the compiler:

1. Each token/lexeme has one src info
2. Each parse tree has more than one src info
3. Each bytecode has more than one src info

Dynamic scoping is dangerous.

Dynamic scoping is dangerous.

Can it be made safe?

Meta-levels

Three *relative* meta-levels describe everything:

Meta-level	Description

Meta-levels

Three *relative* meta-levels describe everything:

Meta-level	Description
0	Normal compilation

Meta-levels

Three *relative* meta-levels describe everything:

Meta-level	Description
-1	Splicing (`$<...>`)
0	Normal compilation

Meta-levels

Three *relative* meta-levels describe everything:

Meta-level	Description
-1	Splicing (`$<...>`)
0	Normal compilation
+1	Quasi-quoting (`[| ...|]`)

What works well?

1. src infos make debugging possible.

What works well?

1. src infos make debugging possible.
2. `rename` enables building huge, name-safe trees.

What works well?

1. src infos make debugging possible.
2. `rename` enables building huge, name-safe trees.
3. DSL layers work and are useful.

What works well?

1. src infos make debugging possible.
2. `rename` enables building huge, name-safe trees.
3. DSL layers work and are useful.
4. The compiler is surprisingly simple

What works well?

1. src infos make debugging possible.
2. `rename` enables building huge, name-safe trees.
3. DSL layers work and are useful.
4. The compiler is surprisingly simple (though calculations with names make my head hurt).

What doesn't work?

1. Delimiters are *far* too ugly for repeated use.

What doesn’t work?

1. Delimiters are *far* too ugly for repeated use.
2. Macro evaluation is top-to-bottom. DSLs can’t validate e.g.:

```
$<<SQL>><SELECT c1 FROM t>
$<<SQL>><CREATE TABLE t ( c2 STR )>
```

What doesn't work?

1. Delimiters are *far* too ugly for repeated use.
2. Macro evaluation is top-to-bottom. DSLs can't validate e.g.:

   ```
   $<<SQL>><SELECT c1 FROM t>
   $<<SQL>><CREATE TABLE t ( c2 STR )>
   ```
3. Syntax composition is nearly impossible.

What doesn't work?

1. Delimiters are *far* too ugly for repeated use.
2. Macro evaluation is top-to-bottom. DSLs can't validate e.g.:

```
$<<SQL>><SELECT c1 FROM t>
$<<SQL>><CREATE TABLE t ( c2 STR )>
```

3. Syntax composition is nearly impossible.
4. Performance for mildly complex DSLs is poor.

Where do we go from here?

Part III

A different way

Language composition: two levels of challenge

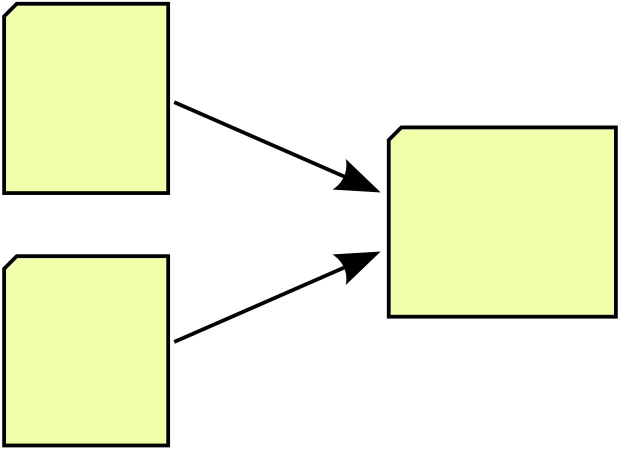
Language composition: two levels of challenge

Tooling

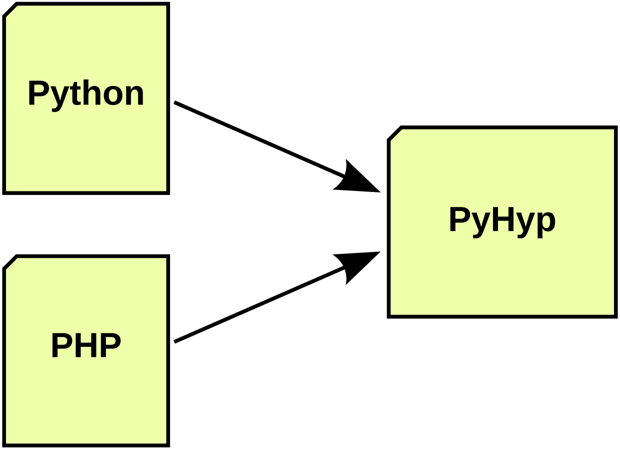
Language composition: two levels of challenge

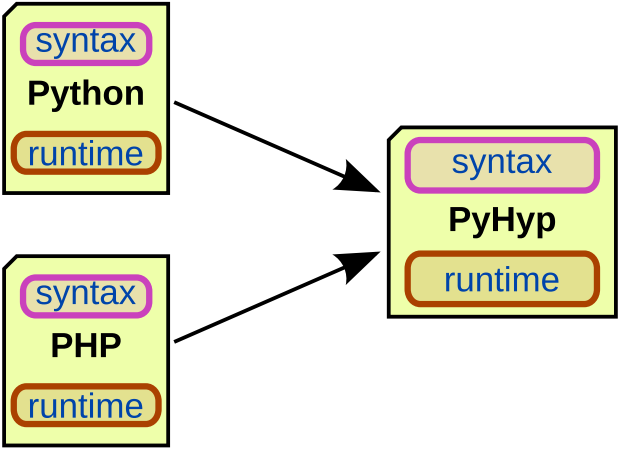
Tooling

Language friction

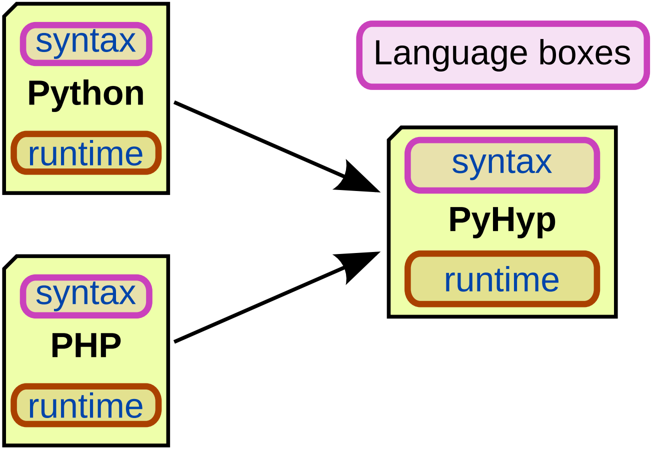


Tooling challenges

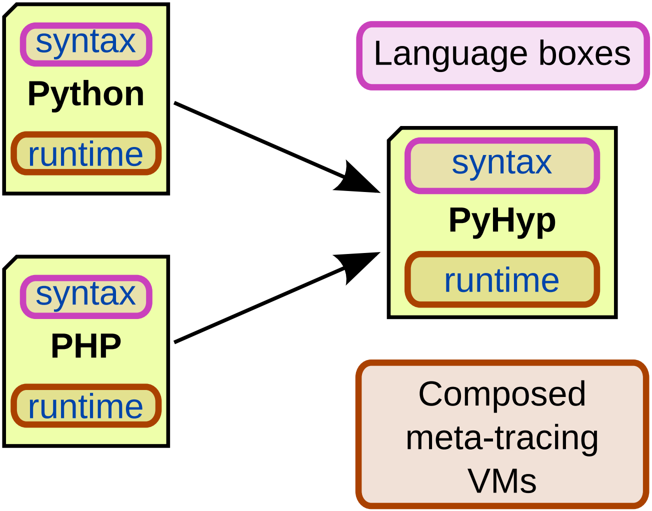



syntax
Python
runtime
syntax
PHP
runtime
syntax
PyHyp
runtime

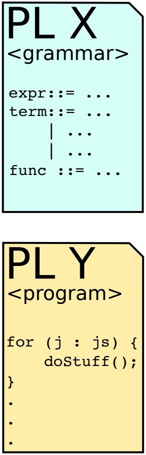
Tooling challenges



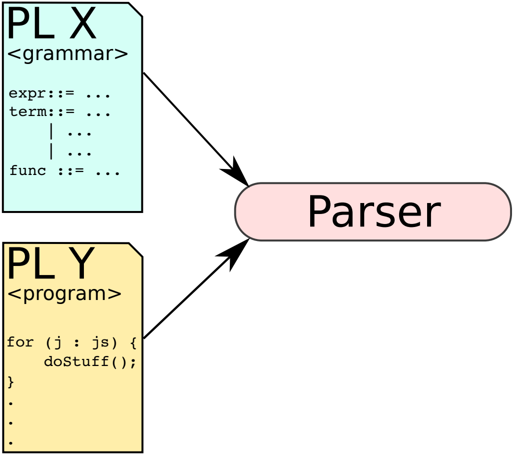
Tooling challenges



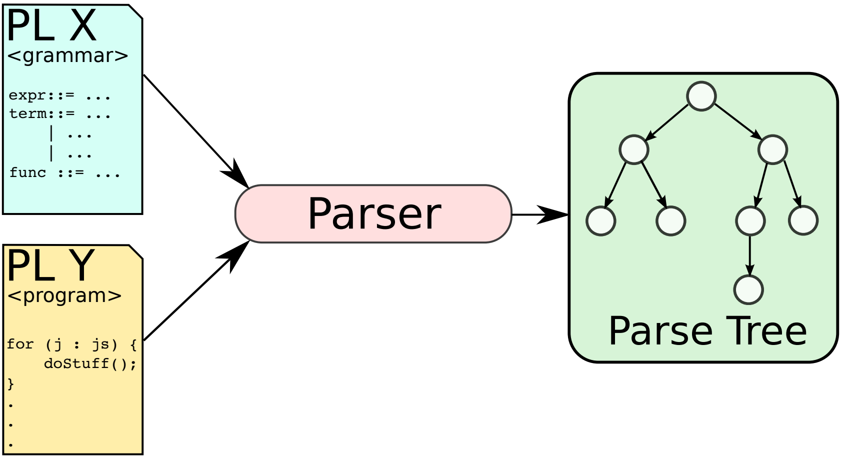
Syntax composition



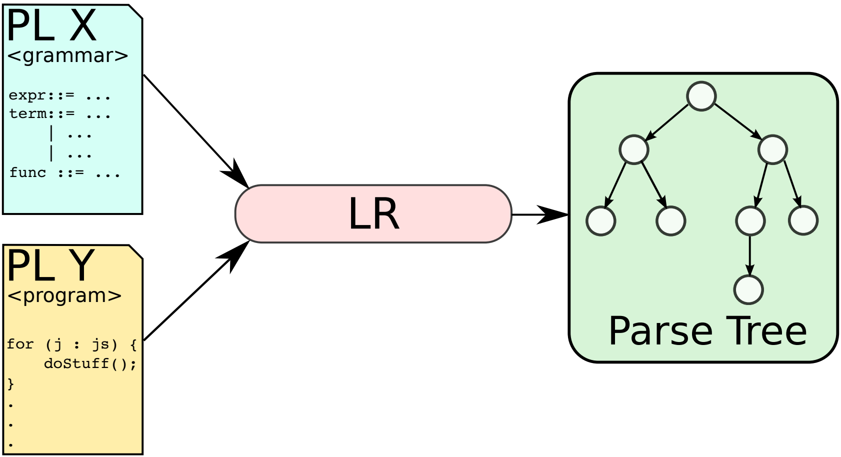
Syntax composition



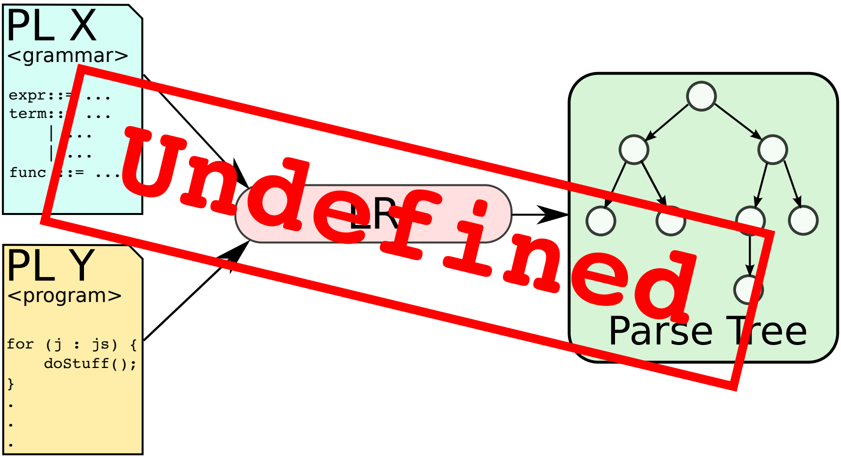
Syntax composition



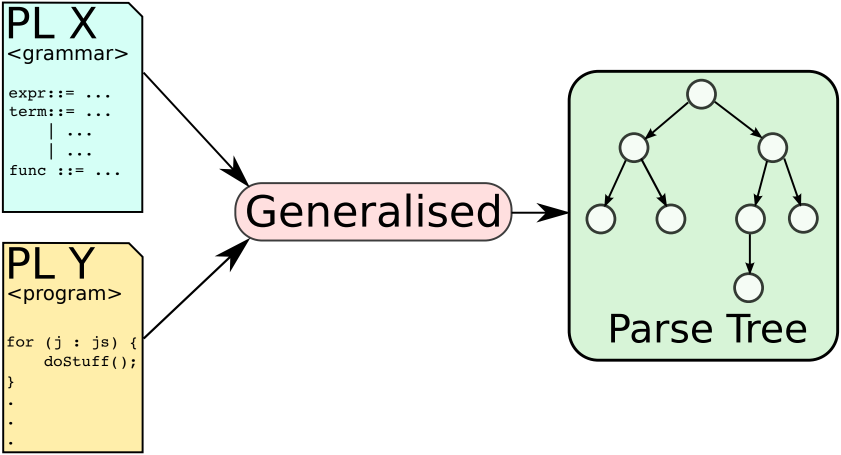
Syntax composition



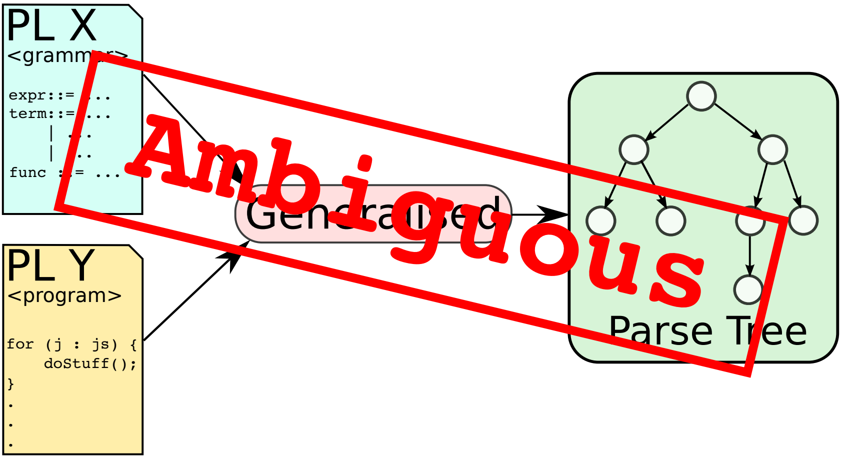
Syntax composition



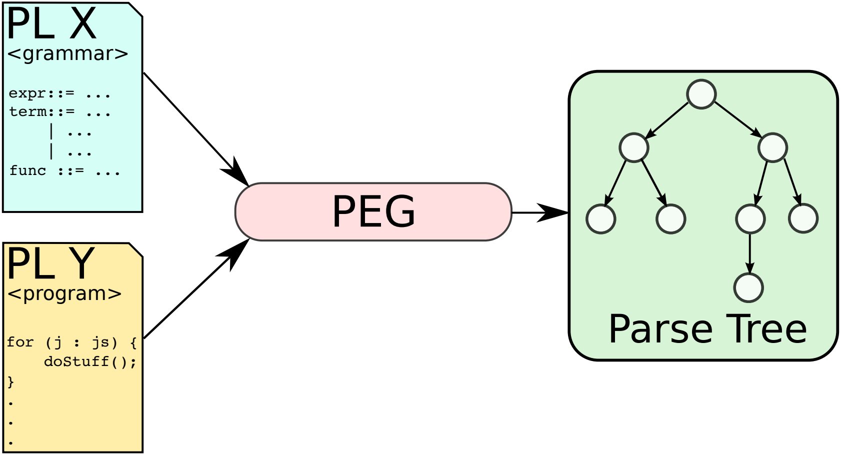
Syntax composition



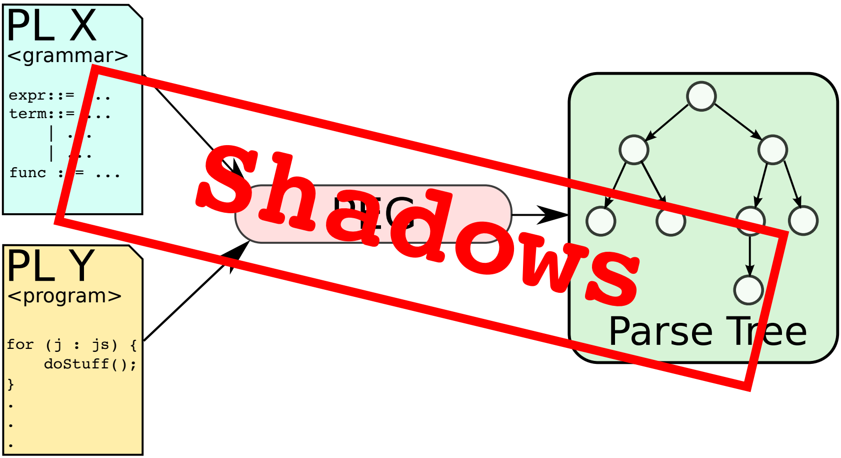
Syntax composition



Syntax composition



Syntax composition



The only choice?

The only choice?

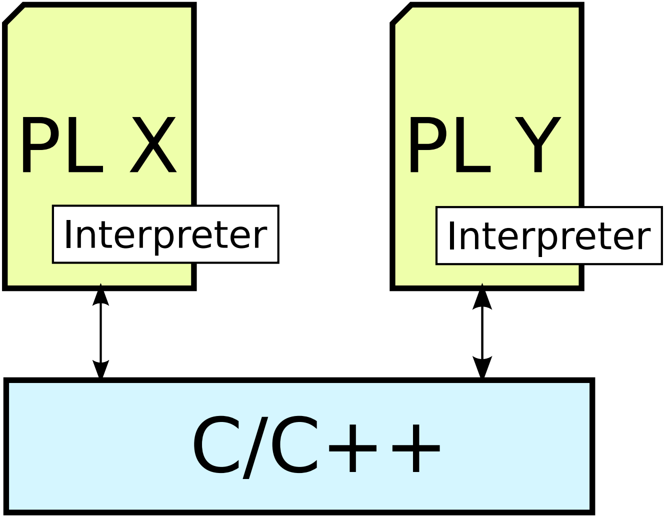
SDE

Challenge:
SDE's power $+$
a text editor feel?

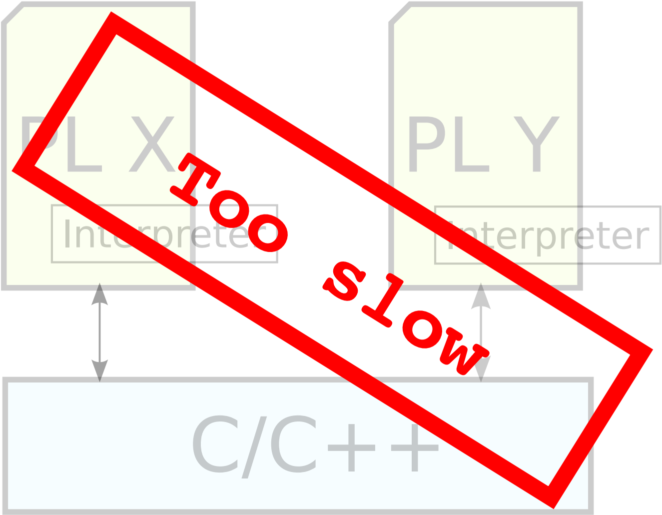
Eco demo

Runtime composition

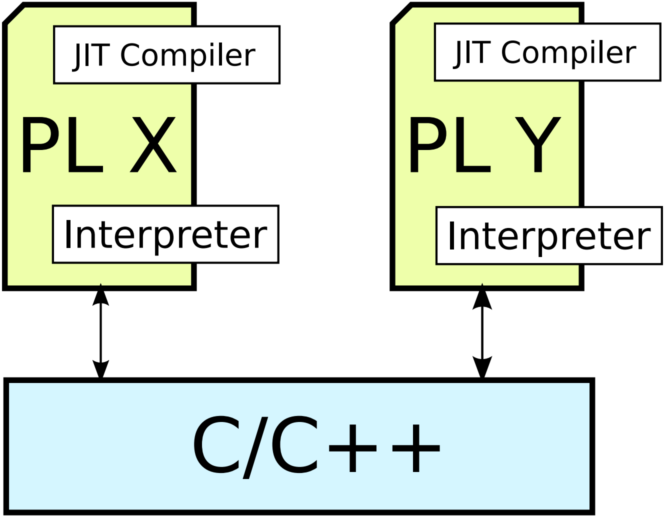
Runtime composition



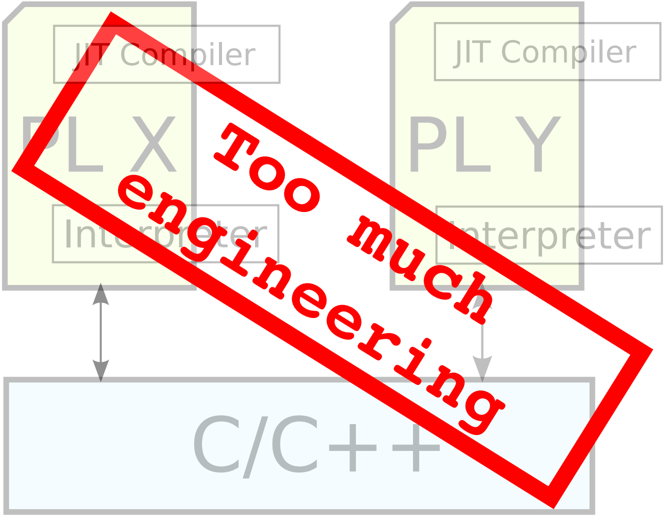
Runtime composition



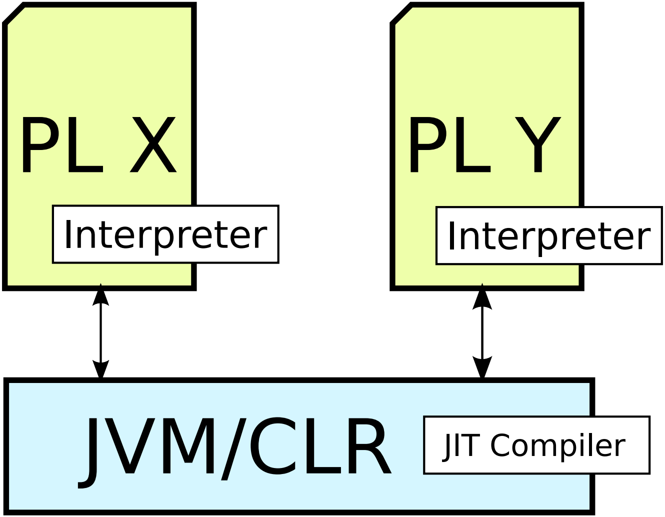
Runtime composition



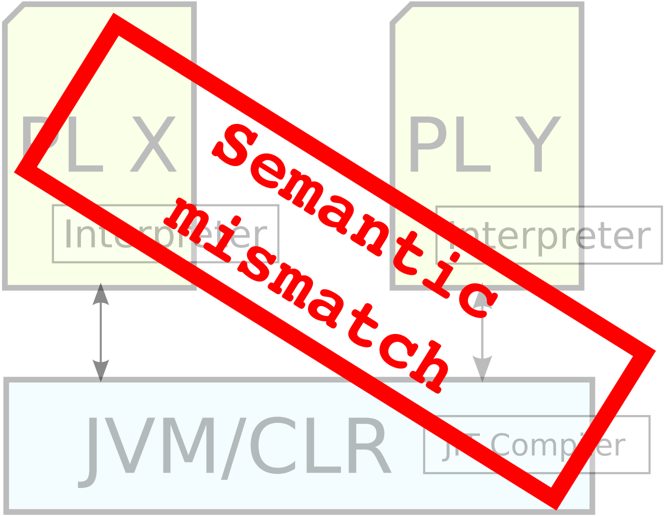
Runtime composition



Runtime composition

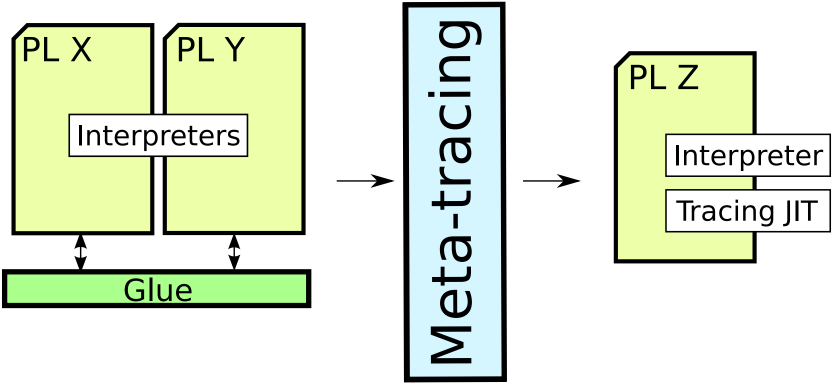


Runtime composition

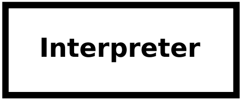


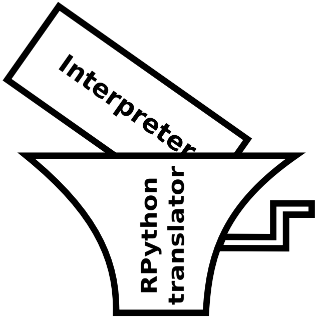
Runtime composition

Runtime composition

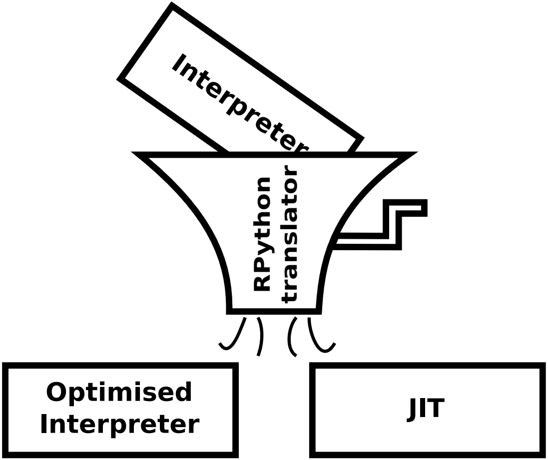


Meta-tracing translation with RPython

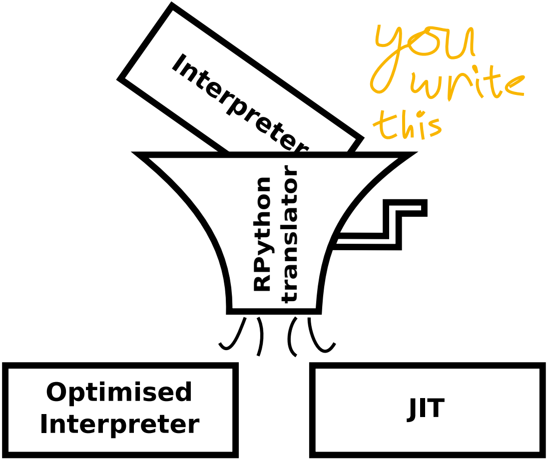



Interpreter
RPython
translator

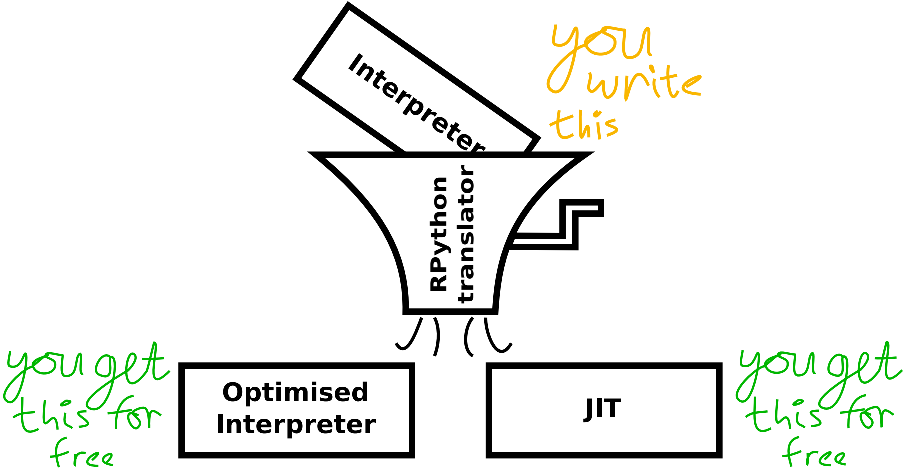
Meta-tracing translation with RPython



Meta-tracing translation with RPython



Meta-tracing translation with RPython



Adding a JIT compiler to an RPython interpreter

```
...
pc := 0
while 1:

    instr := load_next_instruction(pc)
    if instr == POP:
        stack.pop()
        pc += 1
    elif instr == BRANCH:
        off = load_branch_jump(pc)

        pc += off
    elif ...:
        ...
```

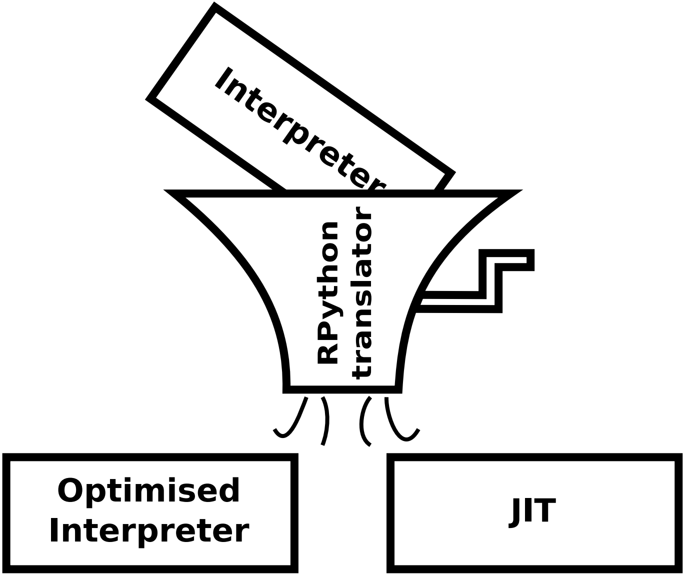
Observation: interpreters are big loops.

Adding a JIT compiler to an RPython interpreter

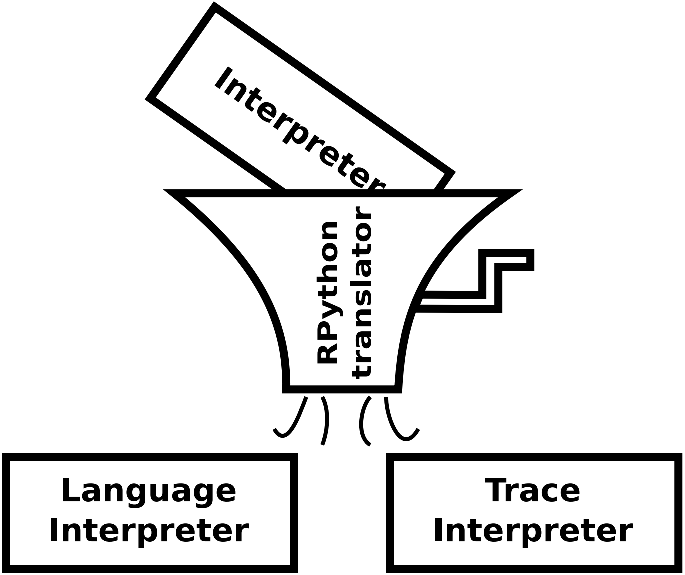
```
...
pc := 0
while 1:
    jit_merge_point(pc)
    instr := load_next_instruction(pc)
    if instr == POP:
        stack.pop()
        pc += 1
    elif instr == BRANCH:
        off = load_branch_jump(pc)
        if off < 0: can_enter_jit(pc)
        pc += off
    elif ...:
        ...
```

Observation: interpreters are big loops.

RPython translation



RPython translation



Tracing JITs

User program (lang *FL*)

```
if x < 0:
  x = x + 1
else:
  x = x + 2
x = x + 3
```

Tracing JITs

User program (lang *FL*)	Trace when x is set to 6

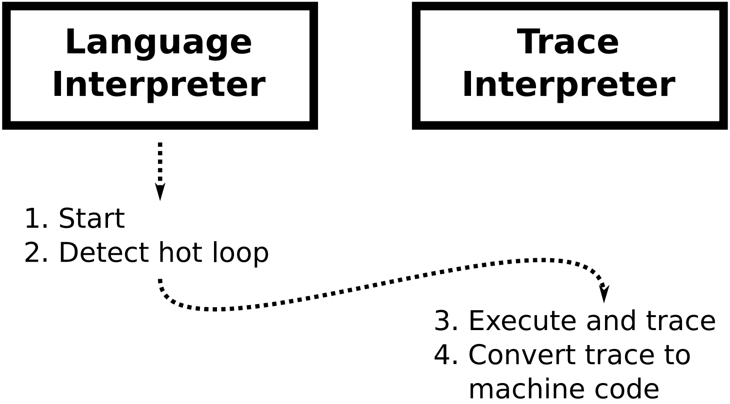
`if x < 0:`
`  x = x + 1`
`else:`
`  x = x + 2`
`x = x + 3`
	`guard_type(x, int)`
	`guard_not_less_than(x, 0)`
	`guard_type(x, int)`
	`x = int_add(x, 2)`
	`guard_type(x, int)`
	`x = int_add(x, 3)`

Tracing JITs

User program (lang *FL*)	Optimised trace

`if x < 0:`
`  x = x + 1`
`else:`
`  x = x + 2`
`x = x + 3`
	`guard_type(x, int)`
	`guard_not_less_than(x, 0)`
	`x = int_add(x, 5)`

Meta-tracing VM components



FL Interpreter

```
program_counter = 0; stack = []
vars = {...}
while True:
  jit_merge_point(program_counter)
  instr = load_instruction(program_counter)
  if instr == INSTR_VAR_GET:
    stack.push(
     vars[read_var_name_from_instruction()])
    program_counter += 1
  elif instr == INSTR_VAR_SET:
    vars[read_var_name_from_instruction()]
     = stack.pop()
    program_counter += 1
  elif instr == INSTR_INT:
    stack.push(read_int_from_instruction())
    program_counter += 1
  elif instr == INSTR_LESS_THAN:
    rhs = stack.pop()
    lhs = stack.pop()
    if isinstance(lhs, int) and isinstance(rhs, int):
      if lhs < rhs:
        stack.push(True)
      else:
        stack.push(False)
    else: ...
    program_counter += 1
```

```
  elif instr == INSTR_IF:
    result = stack.pop()
    if result == True:
      program_counter += 1
    else:
      program_counter +=
        read_jump_if_instruction()
  elif instr == INSTR_ADD:
    lhs = stack.pop()
    rhs = stack.pop()
    if isinstance(lhs, int)
     and isinstance(rhs, int):
      stack.push(lhs + rhs)
    else: ...
    program_counter += 1
```

FL Interpreter

```
program_counter = 0; stack = []
vars = {...}
while True:
  jit_merge_point(program_counter)
  instr = load_instruction(program_counter)
  if instr == INSTR_VAR_GET:
    stack.push(
     vars[read_var_name_from_instruction()])
    program_counter += 1
  elif instr == INSTR_VAR_SET:
    vars[read_var_name_from_instruction()]
     = stack.pop()
    program_counter += 1
  elif instr == INSTR_INT:
    stack.push(read_int_from_instruction())
    program_counter += 1
  elif instr == INSTR_LESS_THAN:
    rhs = stack.pop()
    lhs = stack.pop()
    if isinstance(lhs, int) and isinstance(rhs, int):
      if lhs < rhs:
        stack.push(True)
      else:
        stack.push(False)
    else: ...
    program_counter += 1
```

Meta-tracing JITs

FL Interpreter	User program (lang *FL*)

```
program_counter = 0; stack = []
vars = {...}
while True:
  jit_merge_point(program_counter)
  instr = load_instruction(program_counter)
  if instr == INSTR_VAR_GET:
    stack.push(
     vars[read_var_name_from_instruction()])
    program_counter += 1
  elif instr == INSTR_VAR_SET:
    vars[read_var_name_from_instruction()]
     = stack.pop()
    program_counter += 1
  elif instr == INSTR_INT:
    stack.push(read_int_from_instruction())
    program_counter += 1
  elif instr == INSTR_LESS_THAN:
    rhs = stack.pop()
    lhs = stack.pop()
    if isinstance(lhs, int) and isinstance(rhs, int):
      if lhs < rhs:
        stack.push(True)
      else:
        stack.push(False)
    else: ...
    program_counter += 1
```

```
if x < 0:
  x = x + 1
else:
  x = x + 2
x = x + 3
```

Meta-tracing JITs

FL Interpreter	Initial trace

```
program_counter = 0; stack = []
vars = {...}
while True:
  jit_merge_point(program_counter)
  instr = load_instruction(program_counter)
  if instr == INSTR_VAR_GET:
    stack.push(
     vars[read_var_name_from_instruction()])
    program_counter += 1
  elif instr == INSTR_VAR_SET:
    vars[read_var_name_from_instruction()]
     = stack.pop()
    program_counter += 1
  elif instr == INSTR_INT:
    stack.push(read_int_from_instruction())
    program_counter += 1
  elif instr == INSTR_LESS_THAN:
    rhs = stack.pop()
    lhs = stack.pop()
    if isinstance(lhs, int) and isinstance(rhs, int):
      if lhs < rhs:
        stack.push(True)
      else:
        stack.push(False)
    else: ...
    program_counter += 1
```

```
v0 = <program_counter>
v1 = <stack>
v2 = <vars>
v3 = load_instruction(v0)
guard_eq(v3, INSTR_VAR_GET)
v4 = dict_get(v2, "x")
list_append(v1, v4)
v5 = add(v0, 1)
v6 = load_instruction(v5)
guard_eq(v6, INSTR_INT)
list_append(v1, 0)
v7 = add(v5, 1)
v8 = load_instruction(v7)
guard_eq(v8, INSTR_LESS_THAN)
v9 = list_pop(v1)
v10 = list_pop(v1)
guard_type(v9, int)
guard_type(v10, int)
guard_not_less_than(v9, v10)
list_append(v1, False)
v11 = add(v7, 1)
v12 = load_instruction(v11)
guard_eq(v12, INSTR_IF)
v13 = list_pop(v1)
guard_false(v13)
...
```

Initial trace in full

```
v0 = <program_counter>
v1 = <stack>
v2 = <vars>
v3 = load_instruction(v0)
guard_eq(v3, INSTR_VAR_GET)
v4 = dict_get(v2, "x")
list_append(v1, v4)
v5 = add(v0, 1)
v6 = load_instruction(v5)
guard_eq(v6, INSTR_INT)
list_append(v1, 0)
v7 = add(v5, 1)
v8 = load_instruction(v7)
guard_eq(v8, INSTR_LESS_THAN)
v9 = list_pop(v1)
v10 = list_pop(v1)
guard_type(v9, int)
guard_type(v10, int)
guard_not_less_than(v9, v10)
list_append(v1, False)
v11 = add(v7, 1)
v12 = load_instruction(v11)
guard_eq(v12, INSTR_IF)
v13 = list_pop(v1)
guard_false(v13)
v14 = add(v11, 2)
v15 = load_instruction(v14)
guard_eq(v15, INSTR_VAR_GET)
v16 = dict_get(v2, "x")
list_append(v1, v16)
v17 = add(v14, 1)
v18 = load_instruction(v17)
guard_eq(v18, INSTR_INT)
list_append(v1, 2)
v19 = add(v17, 1)
v20 = load_instruction(v19)
guard_eq(v20, INSTR_ADD)
v21 = list_pop(v1)
v22 = list_pop(v1)
guard_type(v21, int)
guard_type(v22, int)
v23 = add(v22, v21)
list_append(v1, v23)
v24 = add(v19, 1)
v25 = load_instruction(v24)
guard_eq(v25, INSTR_VAR_SET)
v26 = list_pop(v1)
dict_set(v2, "x", v26)
v27 = add(v24, 1)
v28 = load_instruction(v27)
guard_eq(v28, INSTR_VAR_GET)
v29 = dict_get(v2, "x")
list_append(v1, v29)
v30 = add(v27, 1)
v31 = load_instruction(v30)
guard_eq(v31, INSTR_INT)
list_append(v1, 3)
v32 = add(v30, 1)
v33 = load_instruction(v32)
guard_eq(v33, INSTR_ADD)
v34 = list_pop(v1)
v35 = list_pop(v1)
guard_type(v34, int)
guard_type(v35, int)
v36 = add(v35, v34)
list_append(v1, v36)
v37 = add(v32, 1)
v38 = load_instruction(v37)
guard_eq(v38, INSTR_VAR_SET)
v39 = list_pop(v1)
dict_set(v2, "x", v39)
v40 = add(v37, 1)
```

Trace optimisation (1)

Removing constants (from `jit_merge_point`)

```
v1 = <stack>
v2 = <vars>
v4 = dict_get(v2, "x")
list_append(v1, v4)
list_append(v1, 0)
v9 = list_pop(v1)
v10 = list_pop(v1)
guard_type(v9, int)
guard_type(v10, int)
guard_not_less_than(v9, v10)
list_append(v1, False)
v13 = list_pop(v1)
guard_false(v13)
v16 = dict_get(v2, "x")
list_append(v1, v16)
list_append(v1, 2)
v21 = list_pop(v1)
v22 = list_pop(v1)
guard_type(v21, int)
guard_type(v22, int)
v23 = add(v22, v21)
list_append(v1, v23)
v26 = list_pop(v1)
dict_set(v2, "x", v26)
v29 = dict_get(v2, "x")
list_append(v1, v29)
list_append(v1, 3)
v34 = list_pop(v1)
v35 = list_pop(v1)
guard_type(v34, int)
guard_type(v35, int)
v36 = add(v35, v34)
list_append(v1, v36)
v39 = list_pop(v1)
dict_set(v2, "x", v39)
```

Optimisation #2 & #3

List folded trace

```
v1 = <stack>
v2 = <vars>
v4 = dict_get(v2, "x")
guard_type(v4, int)
guard_not_less_than(v4, 0)
v16 = dict_get(v2, "x")
guard_type(v16, int)
v23 = add(v16, 2)
dict_set(v2, "x", v23)
v29 = dict_get(v2, "x")
guard_type(v29, int)
v36 = add(v29, 3)
dict_set(v2, "x", v36)
```

Optimisation #2 & #3

List folded trace	Dict folded trace

`v1 = <stack>`
`v2 = <vars>`
`v4 = dict_get(v2, "x")`
`guard_type(v4, int)`
`guard_not_less_than(v4, 0)`
`v16 = dict_get(v2, "x")`
`guard_type(v16, int)`
`v23 = add(v16, 2)`
`dict_set(v2, "x", v23)`
`v29 = dict_get(v2, "x")`
`guard_type(v29, int)`
`v36 = add(v29, 3)`
`dict_set(v2, "x", v36)`
	`v1 = <stack>`
	`v2 = <vars>`
	`v4 = dict_get(v2, "x")`
	`guard_type(v4, int)`
	`guard_not_less_than(v4, 0)`
	`v23 = add(v4, 2)`
	`guard_type(v23, int)`
	`v36 = add(v23, 3)`
	`dict_set(v2, "x", v36)`

Type folded trace

```
v1 = <stack>
v2 = <vars>
v4 = dict_get(v2, "x")
guard_type(v4, int)
guard_not_less_than(v4, 0)
v23 = add(v4, 2)
v36 = add(v23, 3)
dict_set(v2, "x", v36)
```

Optimisation #4 & #5

Type folded trace	Arithmetic folded trace

`v1 = <stack>`
`v2 = <vars>`
`v4 = dict_get(v2, "x")`
`guard_type(v4, int)`
`guard_not_less_than(v4, 0)`
`v23 = add(v4, 2)`
`v36 = add(v23, 3)`
`dict_set(v2, "x", v36)`
	`v1 = <stack>`
	`v2 = <vars>`
	`v4 = dict_get(v2, "x")`
	`guard_type(v4, int)`
	`guard_not_less_than(v4, 0)`
	`v23 = add(v4, 5)`
	`dict_set(v2, "x", v23)`

Optimisation #4 & #5

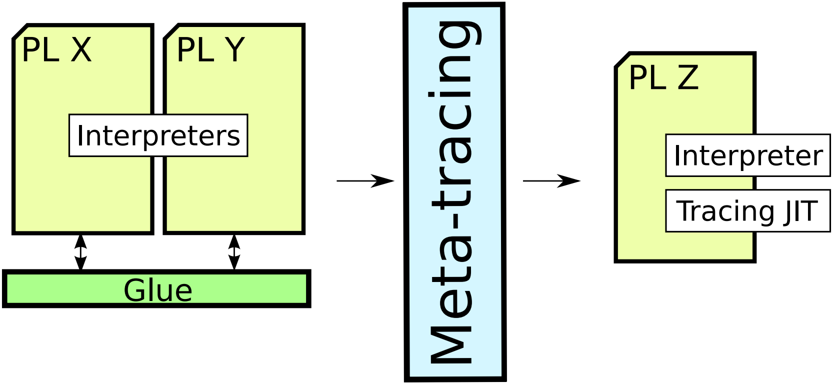
Type folded trace	Arithmetic folded trace

`v1 = <stack>`
`v2 = <vars>`
`v4 = dict_get(v2, "x")`
`guard_type(v4, int)`
`guard_not_less_than(v4, 0)`
`v23 = add(v4, 2)`
`v36 = add(v23, 3)`
`dict_set(v2, "x", v36)`
	`v1 = <stack>`
	`v2 = <vars>`
	`v4 = dict_get(v2, "x")`
	`guard_type(v4, int)`
	`guard_not_less_than(v4, 0)`
	`v23 = add(v4, 5)`
	`dict_set(v2, "x", v23)`

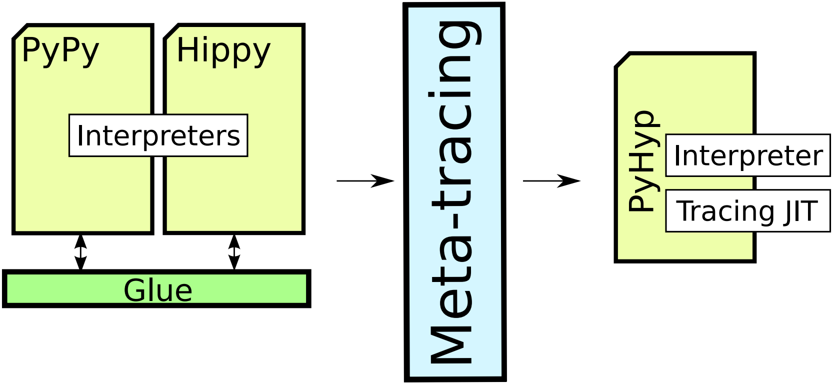
Trace optimisation: from 72 trace elements to 7.

Runtime composition recap

Runtime composition recap



Runtime composition recap



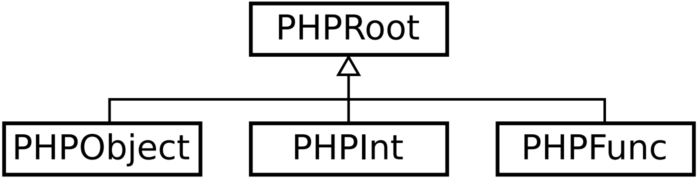
Composed Richards vs. other VMs

Type	VM	
Mono	CPython 2.7.7	9.475 $\pm$ 0.0127
	HHVM 3.4.0	4.264 $\pm$ 0.0386
	HippyVM	0.250 $\pm$ 0.0008
	PyPy 2.4.0	0.178 $\pm$ 0.0006
	Zend 5.5.13	9.070 $\pm$ 0.0361

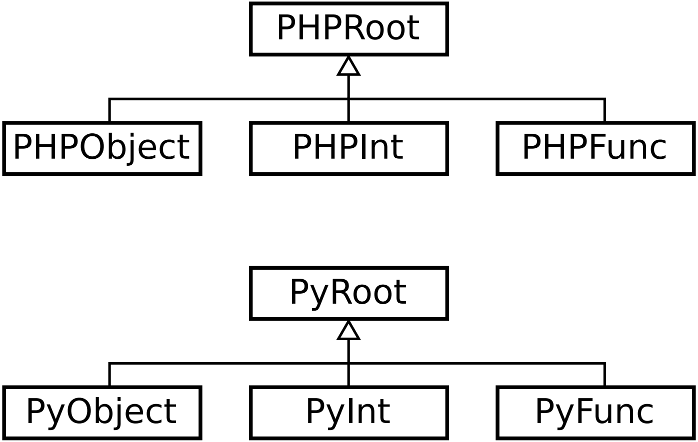
Composed Richards vs. other VMs

Type	VM	
Mono	CPython 2.7.7	9.475 $\pm$ 0.0127
	HHVM 3.4.0	4.264 $\pm$ 0.0386
	HippyVM	0.250 $\pm$ 0.0008
	PyPy 2.4.0	0.178 $\pm$ 0.0006
	Zend 5.5.13	9.070 $\pm$ 0.0361
Composed	PyHyp	0.335 $\pm$ 0.0012

Datatype conversion



Datatype conversion



Datatype conversion: primitive types

PHP	Python

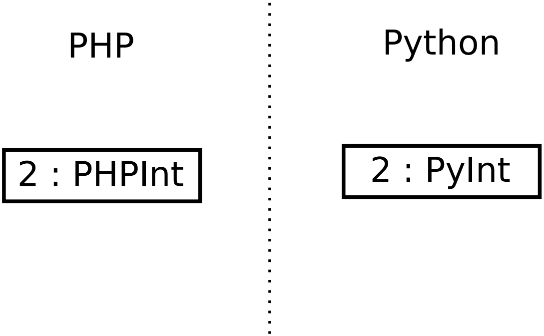
Datatype conversion: primitive types

PHP

Python

2 : PHPInt

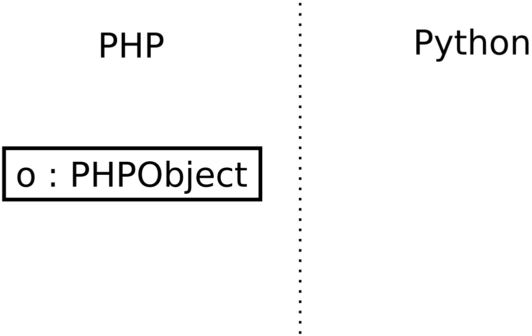
Datatype conversion: primitive types



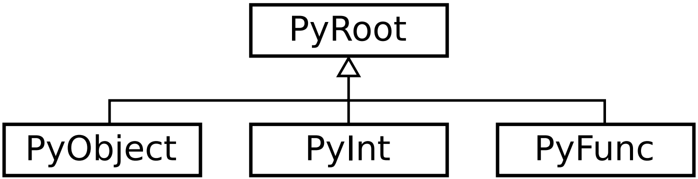
Datatype conversion: user types

PHP | Python

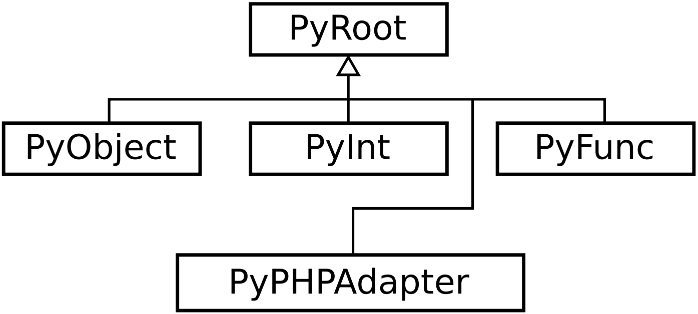
Datatype conversion: user types



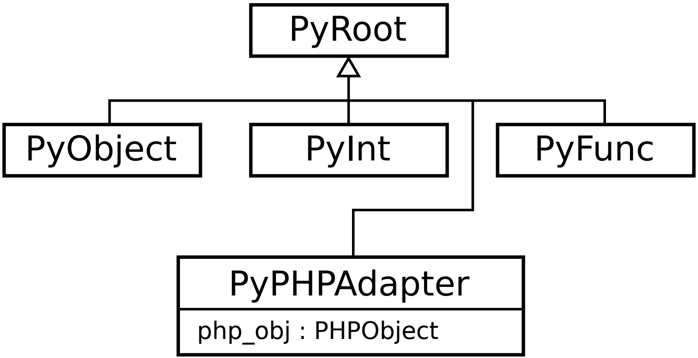
Datatype conversion: user types



Datatype conversion: user types



Datatype conversion: user types

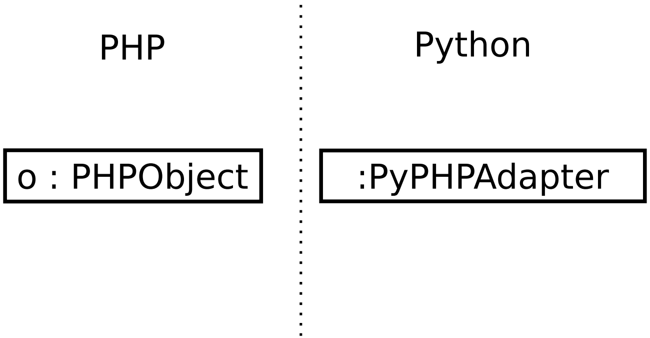


Datatype conversion: user types

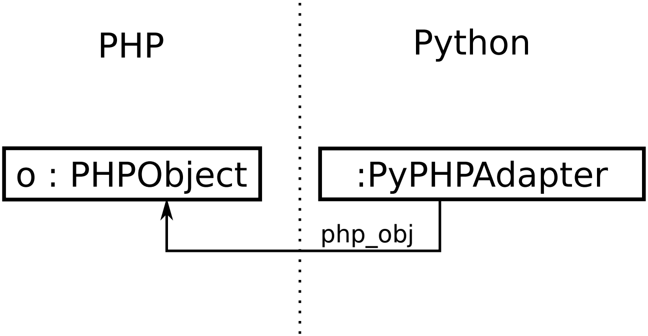
PHP

Python

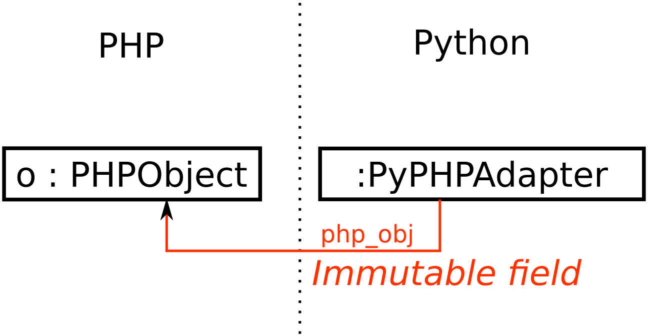
o : PHPObject


PHP
Python
o : PHPObject
:PyPHPAdapter

Datatype conversion: user types



Datatype conversion: user types



Friction

A good composition needs to reduce *friction*.

Friction

A good composition needs to reduce *friction*. Some examples:

- Lexical scoping (or lack thereof) in PHP and Python (semantic friction)

Friction

A good composition needs to reduce *friction*. Some examples:

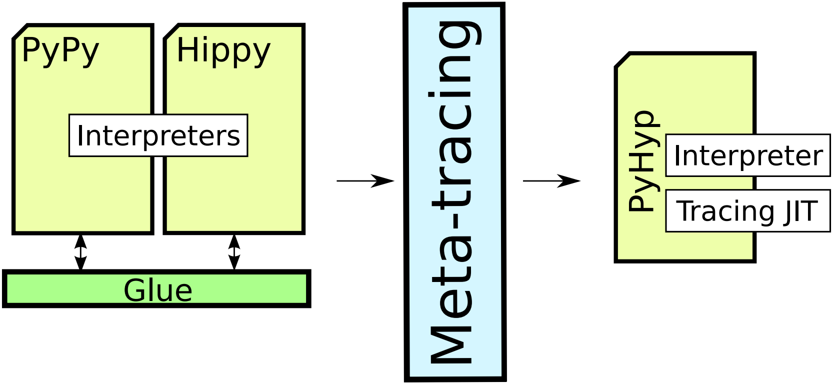
- Lexical scoping (or lack thereof) in PHP and Python (semantic friction)
- PHP datatypes are immutable except for references and objects; Python's are largely mutable (semantic and performance friction)

Friction

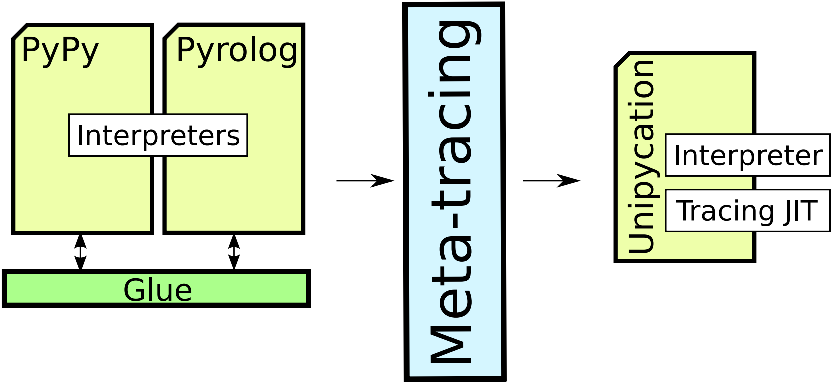
A good composition needs to reduce *friction*. Some examples:

- Lexical scoping (or lack thereof) in PHP and Python (semantic friction)
- PHP datatypes are immutable except for references and objects; Python's are largely mutable (semantic and performance friction)
- PHP has only dictionaries; Python has lists and dictionaries (semantic friction)

Unipycation



Unipycation



Unipycation demo

Absolute timing comparison

VM	Benchmark	*Python*		*Prolog*		*Python* → *Prolog*	
CPython-SWI	SmallFunc	0.125s	±0.007	0.257s	±0.002	28.893s	±0.227
	L1A0R	2.924s	±0.284	7.352s	±0.048	9.310s	±0.084
	L1A1R	4.184s	±0.038	18.890s	±0.111	20.865s	±0.067
	NdL1A1R	7.531s	±0.080	18.643s	±0.197	667.682s	±6.895
	TCons	264.415s	±2.250	48.819s	±0.252	2185.150s	±18.225
	Lists	9.374s	±0.059	25.148s	±0.221	2207.304s	±16.073
Unipycation	SmallFunc	0.001s	±0.000	0.006s	±0.001	0.001s	±0.000
	L1A0R	0.085s	±0.000	0.086s	±0.000	0.087s	±0.000
	L1A1R	0.112s	±0.000	0.114s	±0.000	0.115s	±0.000
	NdL1A1R	0.500s	±0.003	0.548s	±0.085	2.674s	±0.012
	TCons	6.053s	±0.288	2.444s	±0.003	36.069s	±0.225
	Lists	0.845s	±0.002	1.416s	±0.003	5.056s	±0.035
Jython-tuProlog	SmallFunc	0.088s	±0.003	3.050s	±0.053	52.294s	±0.475
	L1A0R	1.078s	±0.009	206.590s	±3.846	199.963s	±2.476
	L1A1R	2.145s	±0.232	293.311s	±5.691	294.781s	±6.193
	NdL1A1R	7.939s	±0.457	1857.687s	±5.169	1990.985s	±15.071
	TCons	543.347s	±3.289	8014.477s	±17.710	8202.362s	±24.904
	Lists	5.661s	±0.046	6981.873s	±18.795	5577.322s	±15.754

Relative timing comparison

VM	Benchmark	$\frac{\textit{Python}\rightarrow\textit{Prolog}}{\textit{Python}}$		$\frac{\textit{Python}\rightarrow\textit{Prolog}}{\textit{Prolog}}$		$\frac{\textit{Python}\rightarrow\textit{Prolog}}{\text{Unipycation}}$	
CPython-SWI	SmallFunc	231.770×	±13.136	112.567×	±1.242	27821.079×	±2331.665
	L1A0R	3.184×	±0.300	1.266×	±0.014	107.591×	±0.995
	L1A1R	4.987×	±0.049	1.105×	±0.007	181.899×	±0.590
	NdL1A1R	88.654×	±1.368	35.814×	±0.554	249.737×	±2.922
	TCons	8.264×	±0.101	44.760×	±0.453	60.583×	±0.637
	Lists	235.459×	±2.314	87.772×	±1.017	436.609×	±4.415
Unipycation	SmallFunc	1.295×	±0.105	0.182×	±0.054	1.000×	
	L1A0R	1.020×	±0.002	1.012×	±0.002	1.000×	
	L1A1R	1.025×	±0.002	1.002×	±0.003	1.000×	
	NdL1A1R	5.349×	±0.045	4.879×	±0.924	1.000×	
	TCons	5.959×	±0.282	14.756×	±0.092	1.000×	
	Lists	5.982×	±0.045	3.569×	±0.026	1.000×	
Jython-tuProlog	SmallFunc	592.904×	±19.517	17.143×	±0.338	50354.204×	±4341.413
	L1A0R	185.460×	±2.818	0.968×	±0.021	2310.844×	±28.093
	L1A1R	137.427×	±14.537	1.005×	±0.028	2569.873×	±52.847
	NdL1A1R	250.776×	±14.666	1.072×	±0.009	744.699×	±6.726
	TCons	15.096×	±0.106	1.023×	±0.004	227.409×	±1.592
	Lists	985.149×	±8.674	0.799×	±0.003	1103.206×	±8.338

What can we use this for?

What can we use this for?

First-class languages

What can we use this for?

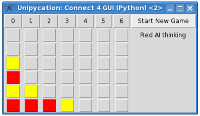
First-class languages

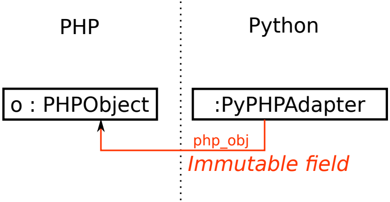
Language migration

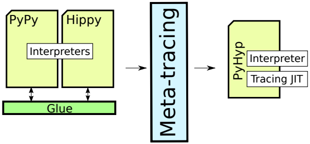
Thanks to our funders

- EPSRC: *COOLER* and *Lecture*.
- Oracle: various.

Thanks for listening







http://soft-dev.org/