Language integration and migration


Edd Barrett


Carl Friedrich Bolz


Lukas Diekmann


Laurence Tratt


Naveneetha Krishnan Vasudevan

KING'S College LONDON

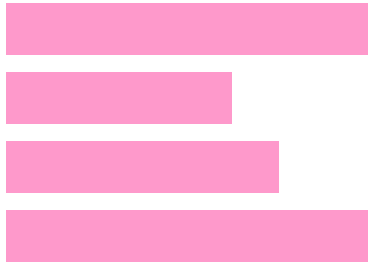
Software Development Team

2015-01-20

What to expect from this talk

A

B



What to expect from this talk

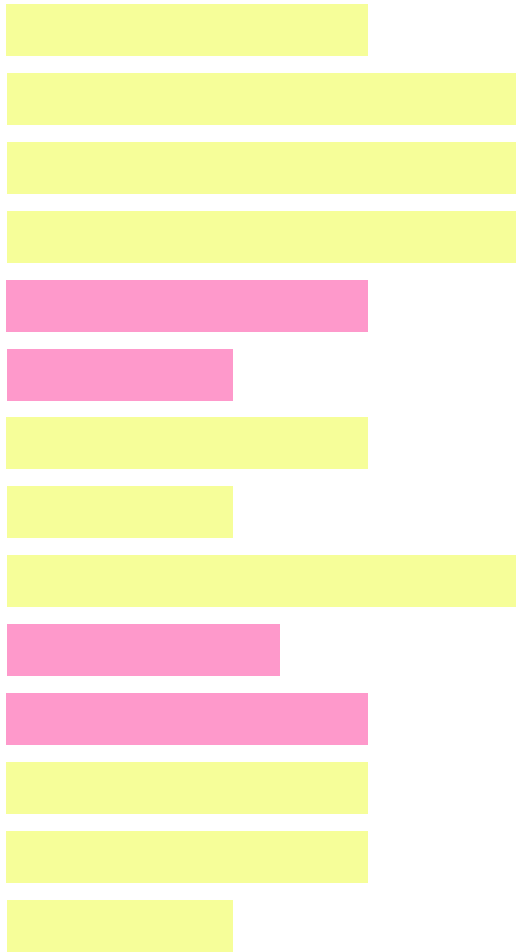
$$A \cup B$$

What to expect from this talk

Python ∪ Prolog

What to expect from this talk

Python ∪ PHP



Our problem

Our problem

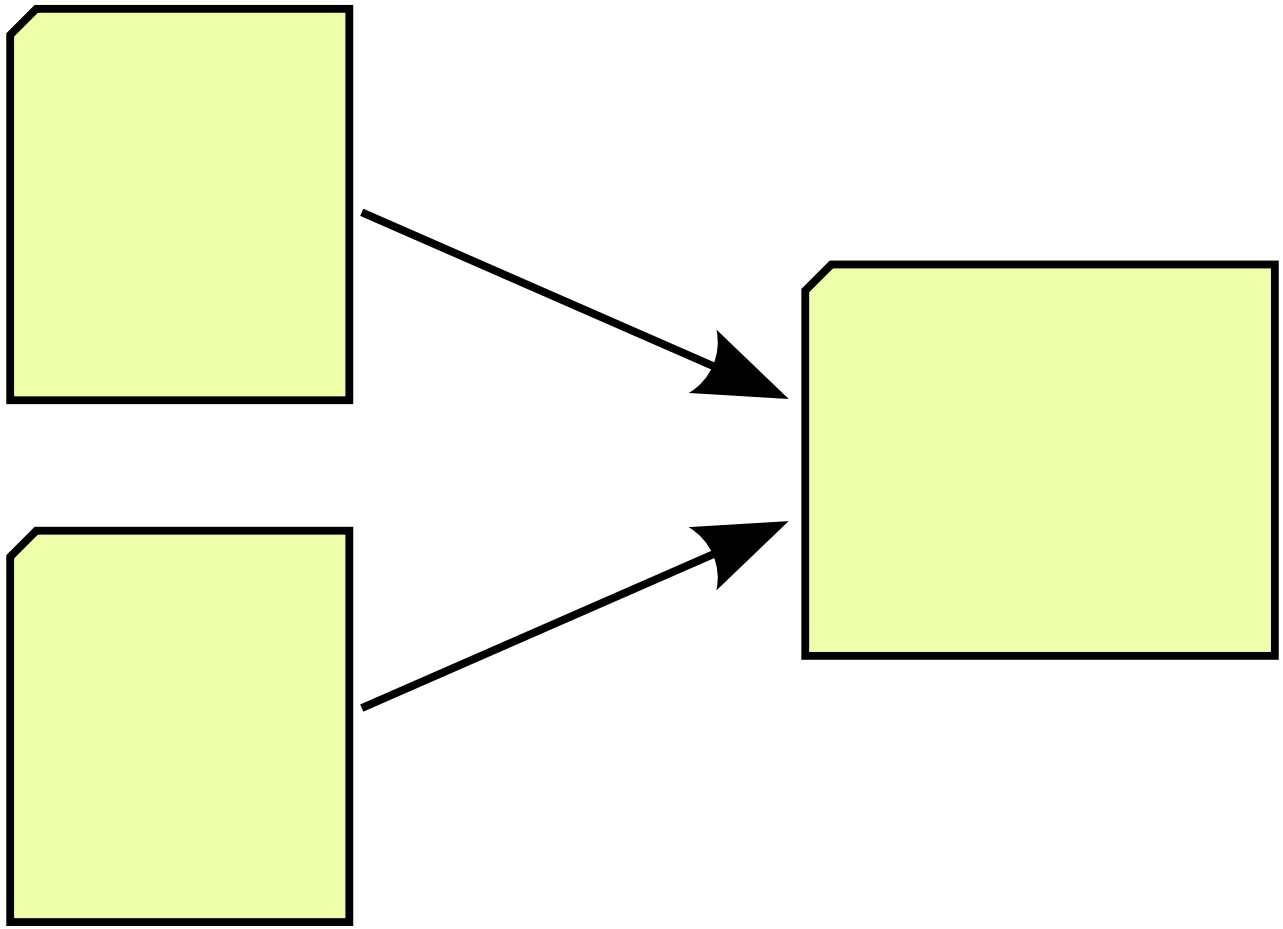
We want **better** programming languages

Our problem

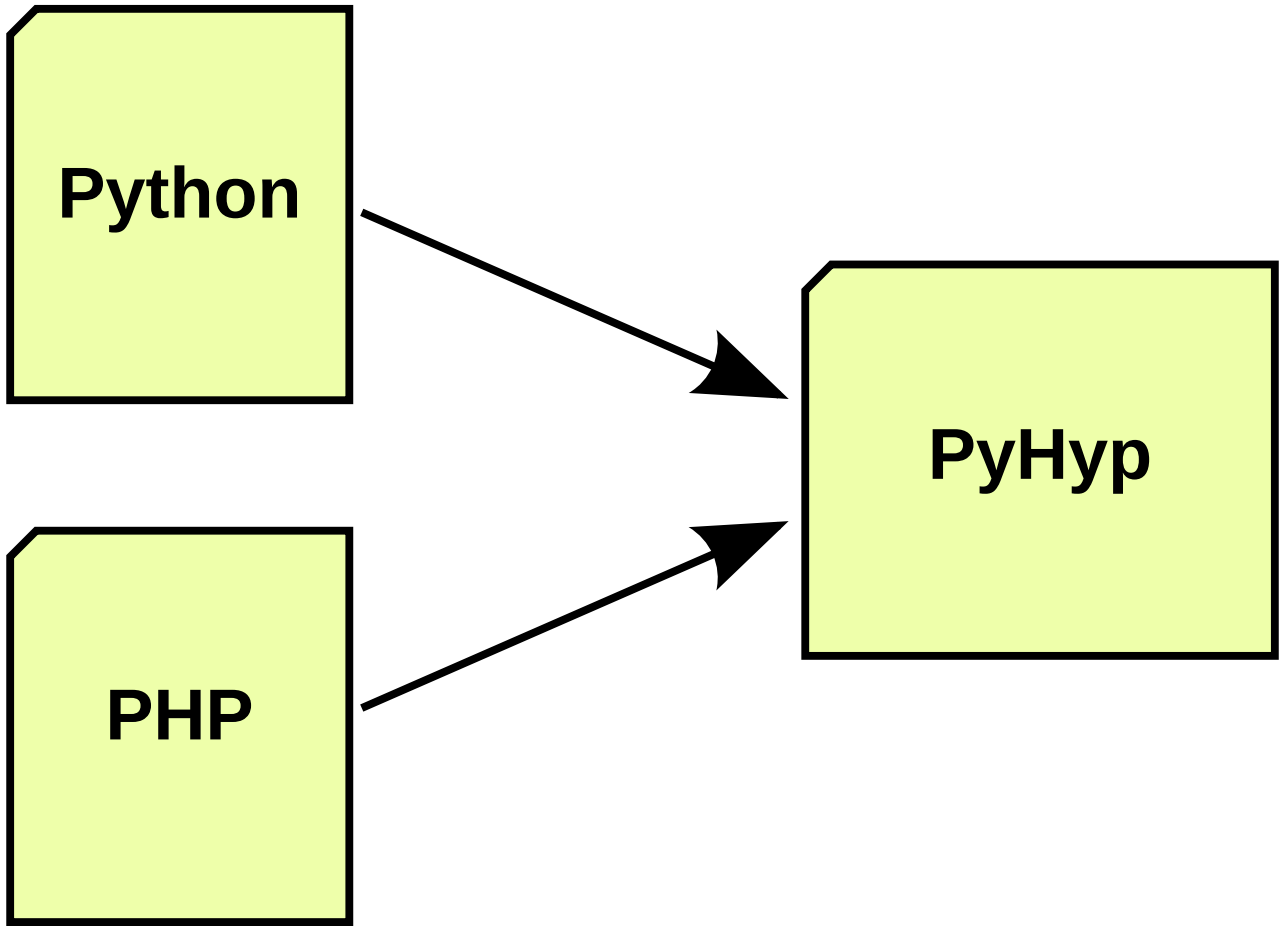
We want **better** programming languages

But better always seems to end up **bigger**

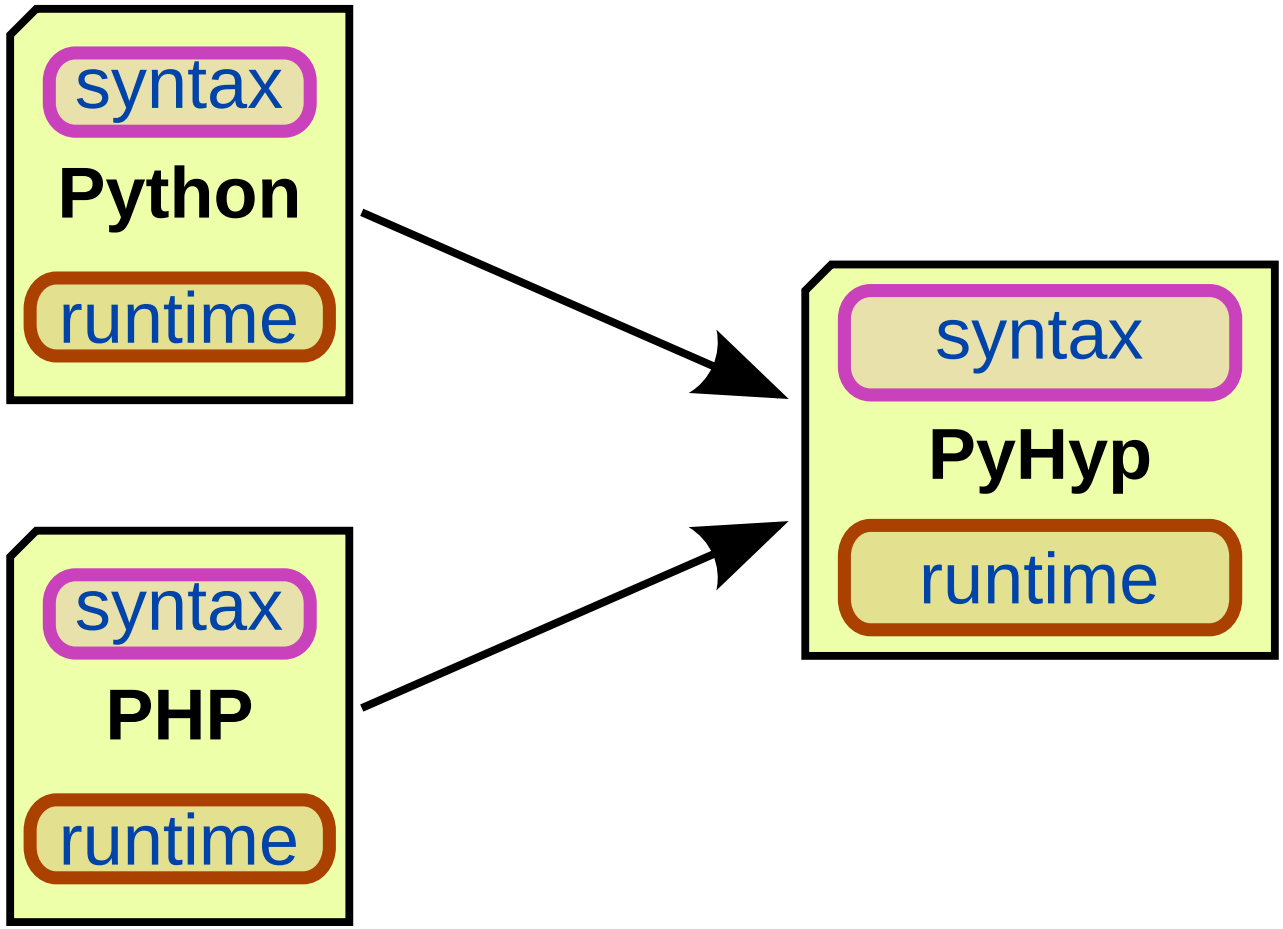
Underlying language composition challenges



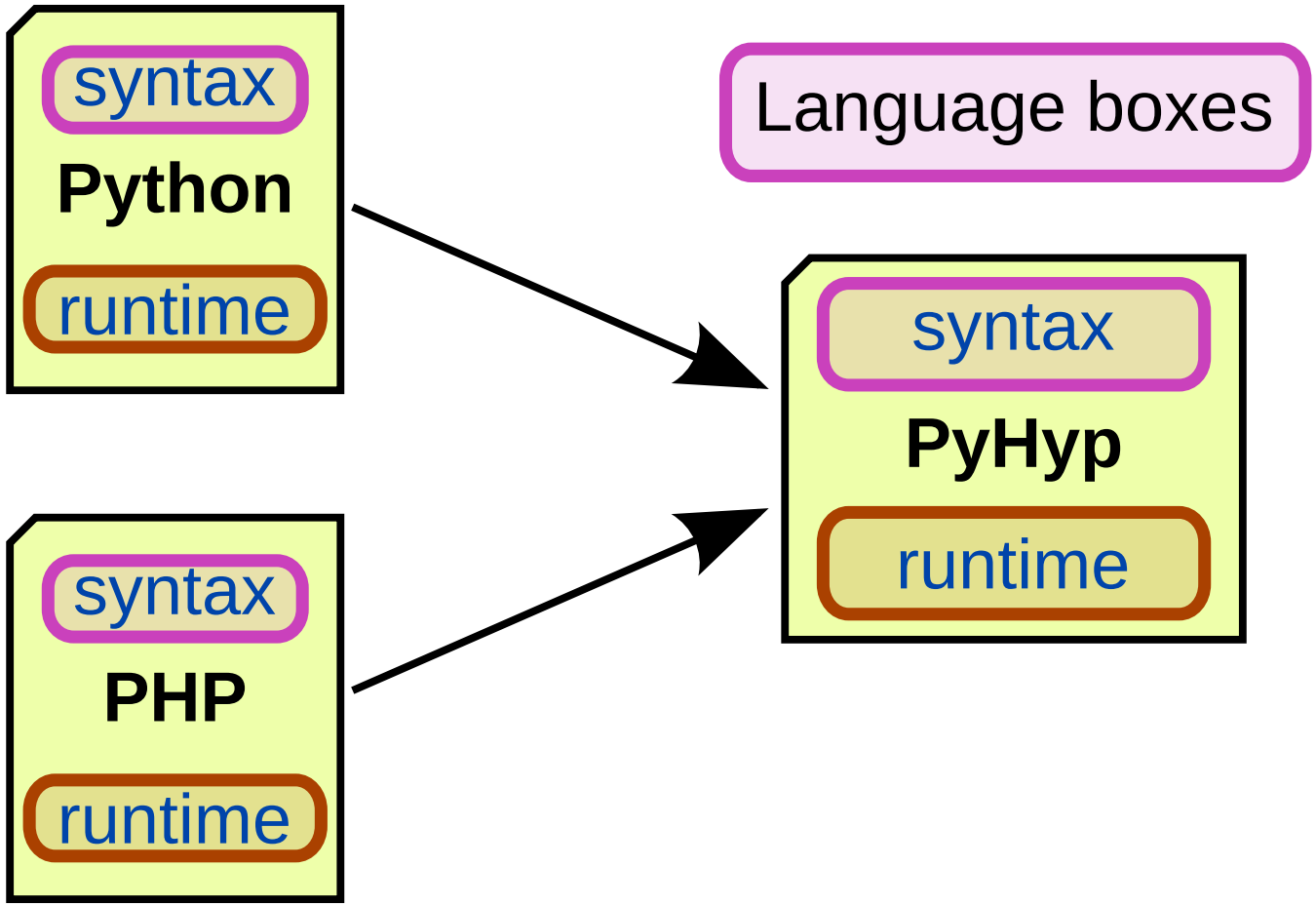
Underlying language composition challenges



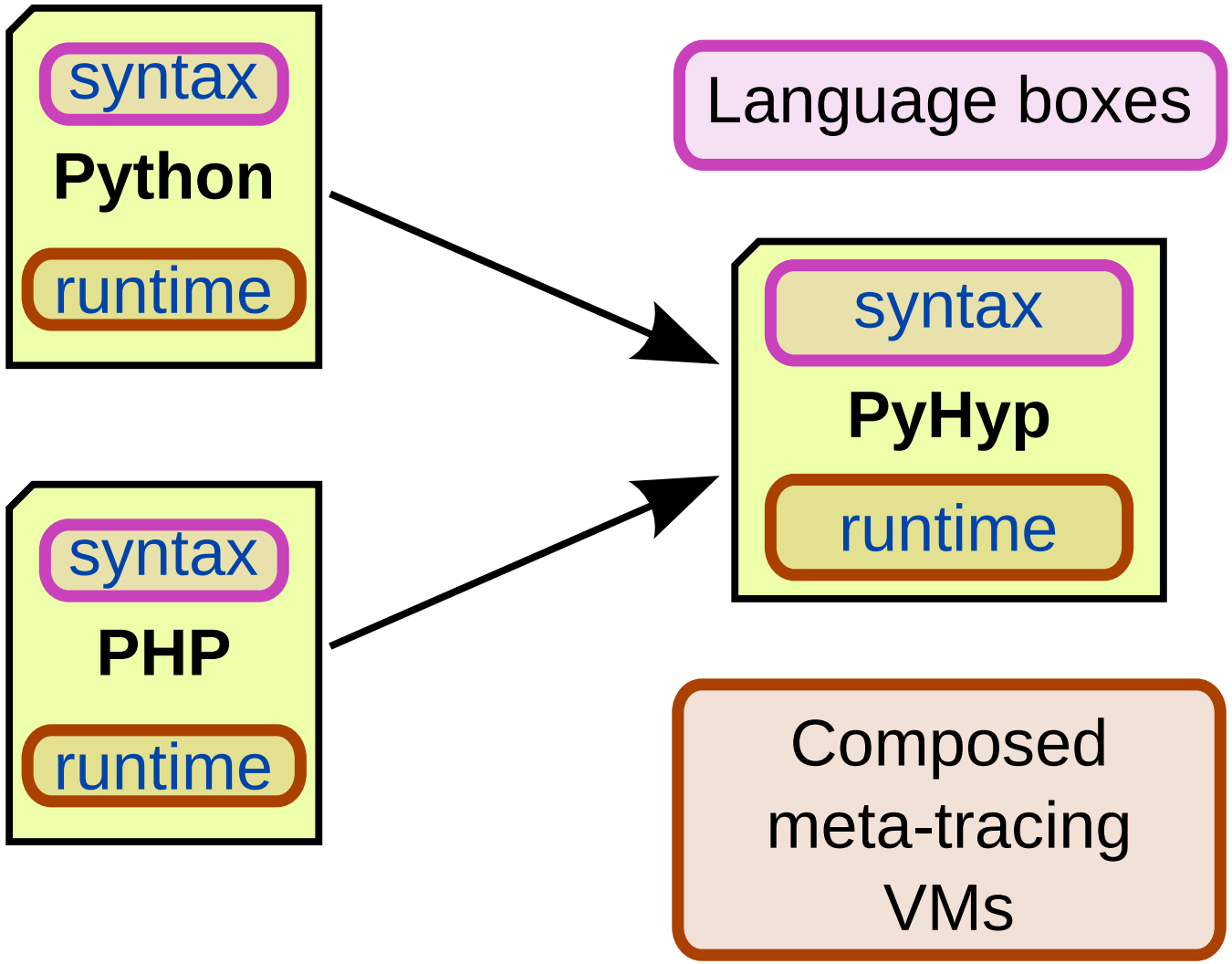
Underlying language composition challenges



Underlying language composition challenges



Underlying language composition challenges



Syntax composition

PL X

<grammar>

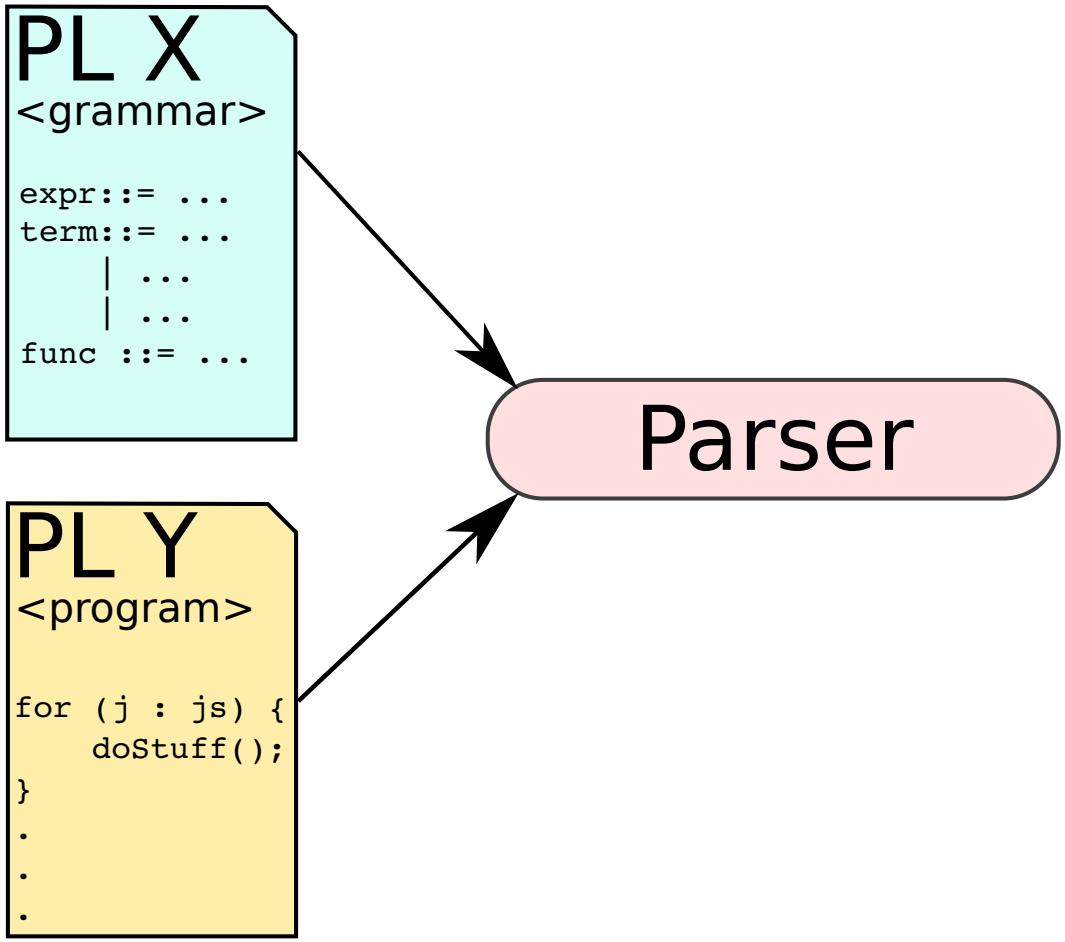
```
expr::= ...
term::= ...
    | ...
    | ...
func ::= ...
```

PL Y

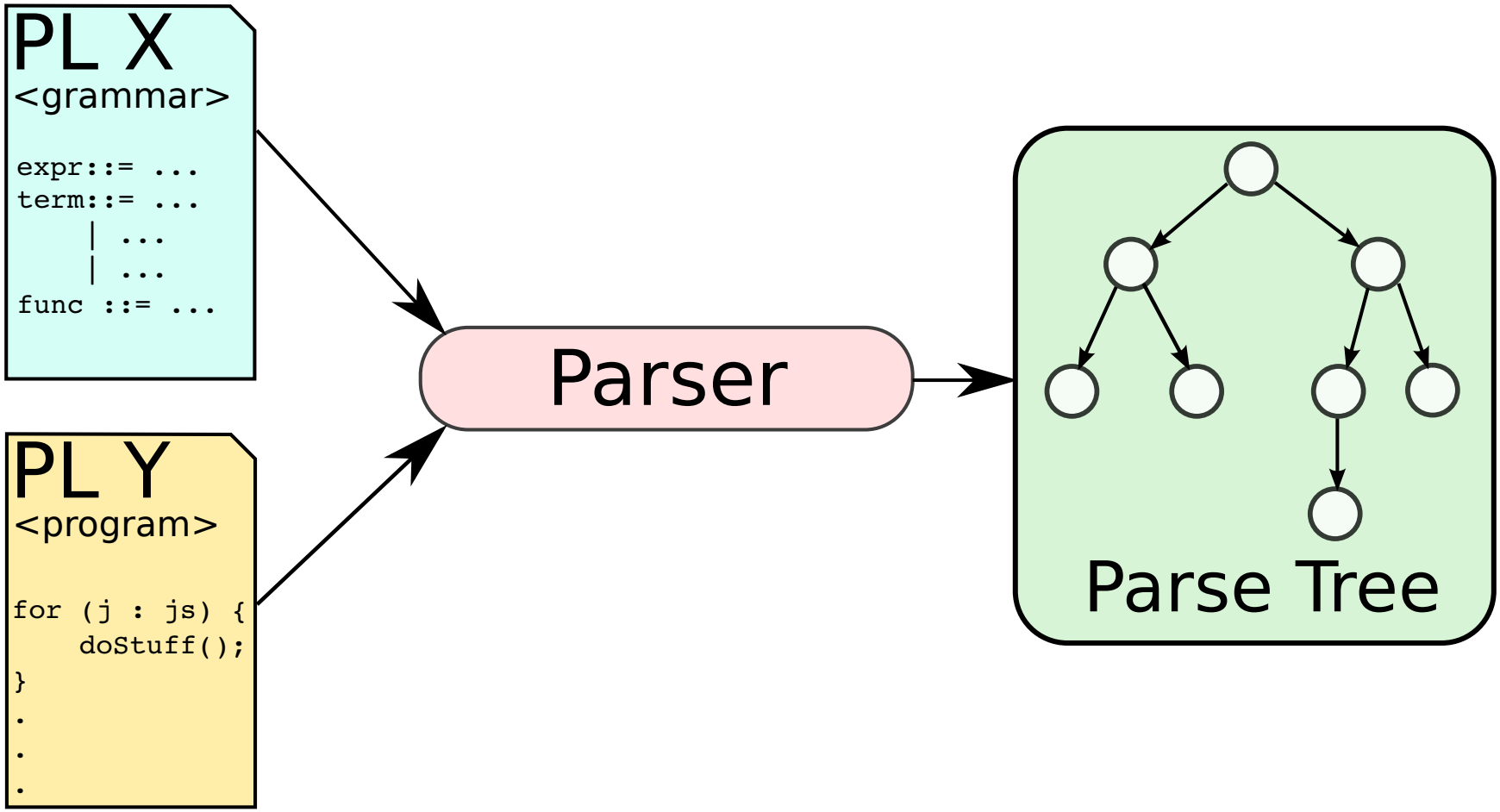
<program>

```
for (j : js) {
    doStuff();
}
.
.
.
```

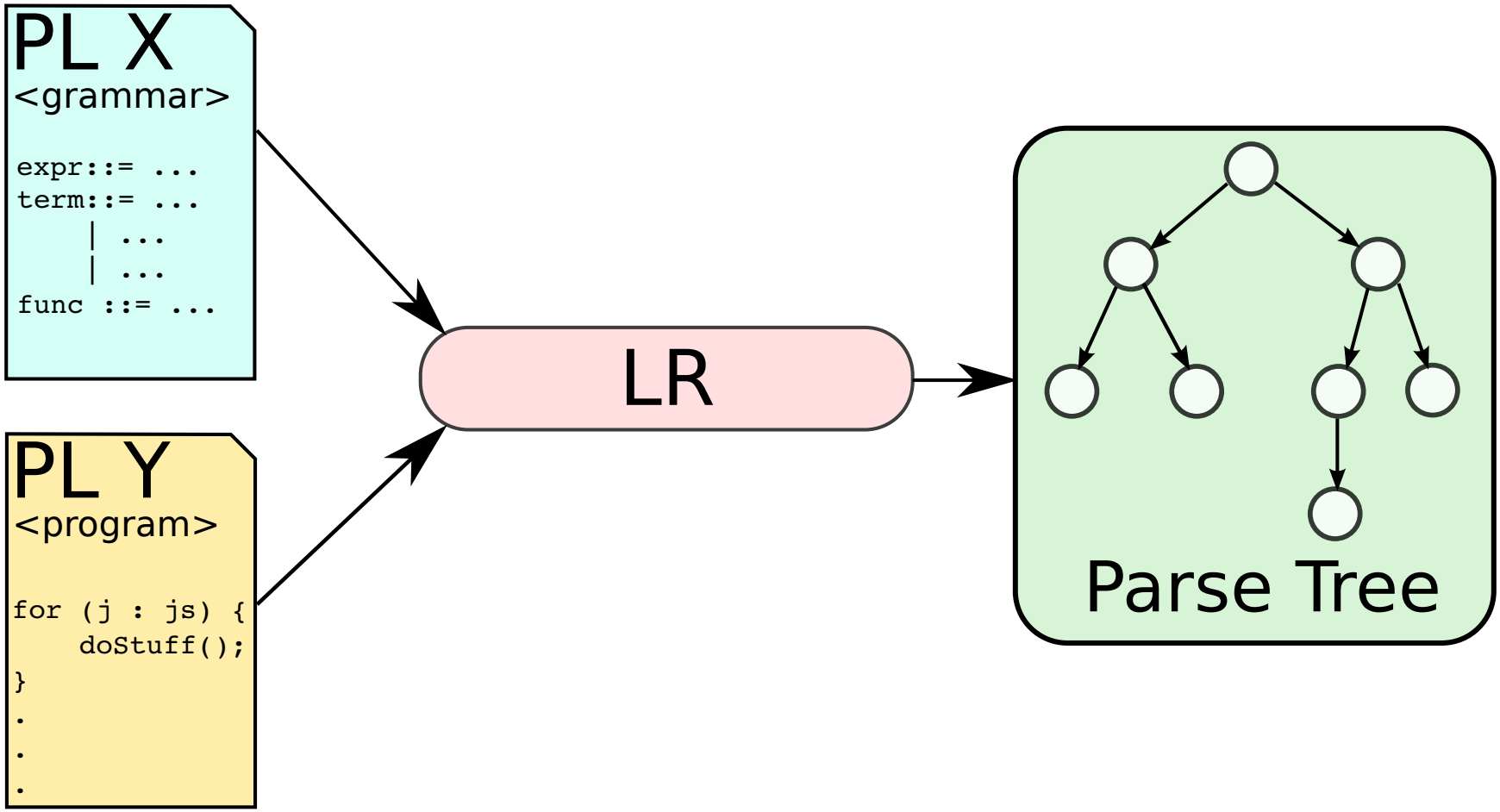
Syntax composition



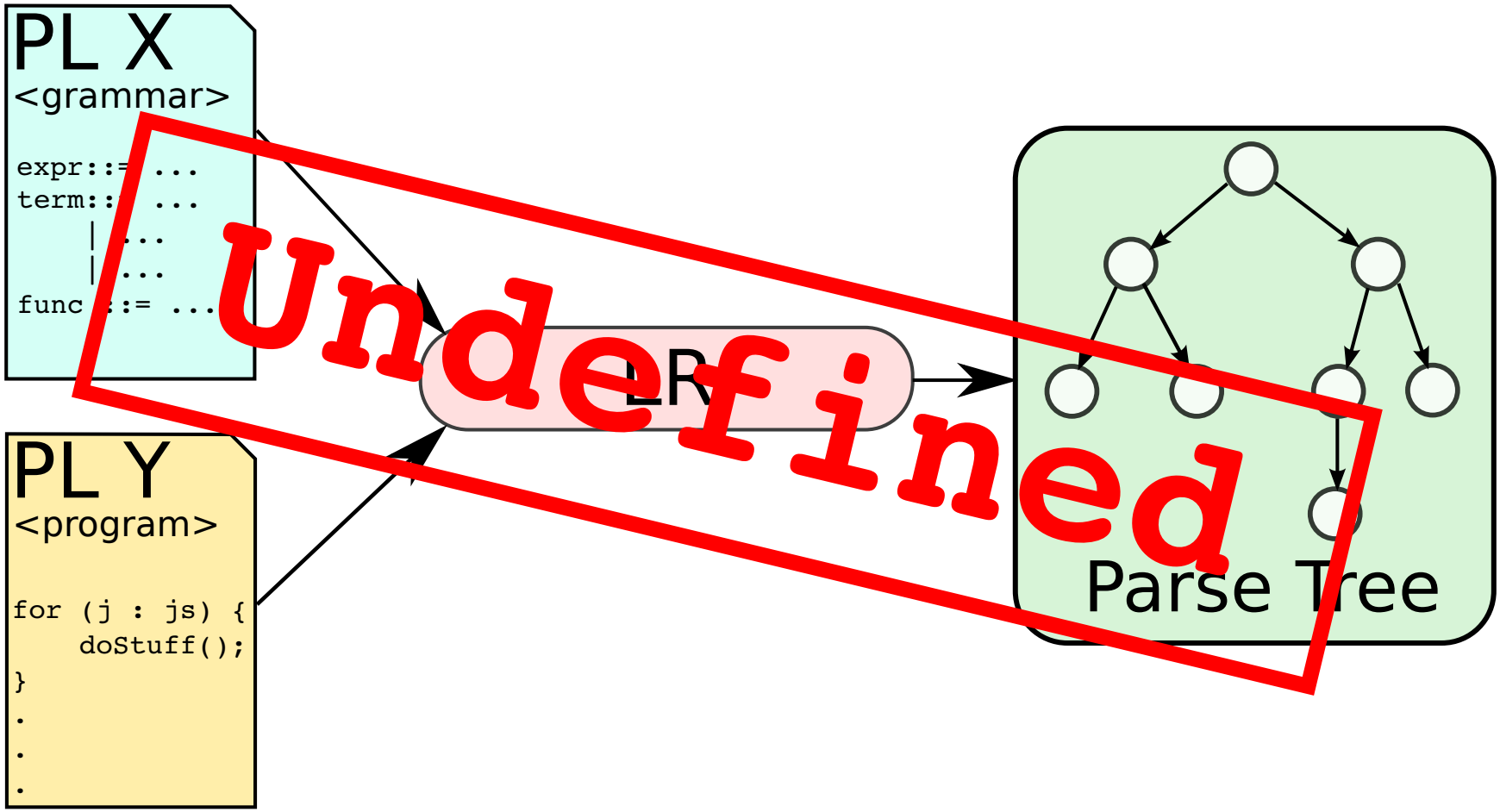
Syntax composition



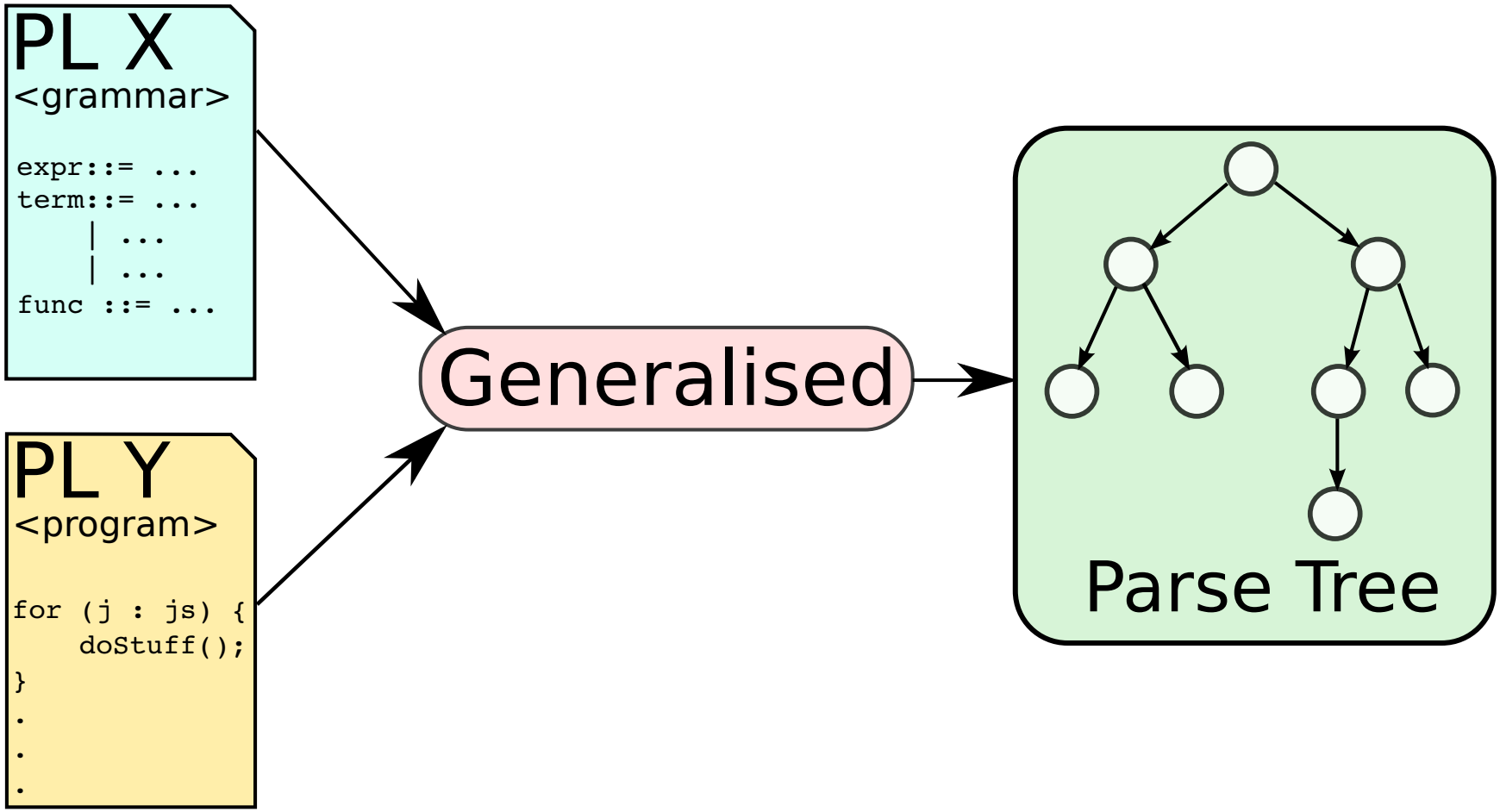
Syntax composition



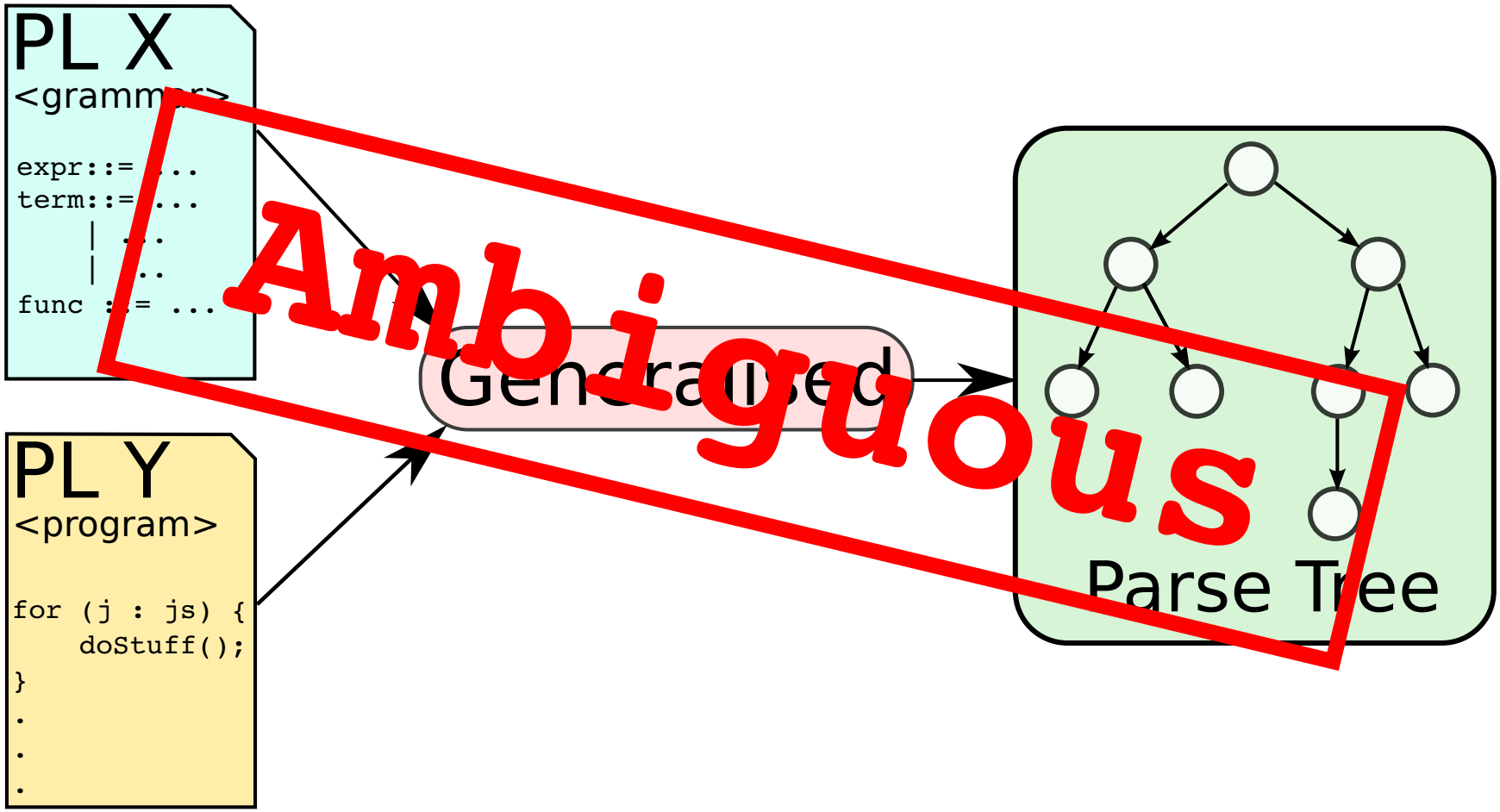
Syntax composition



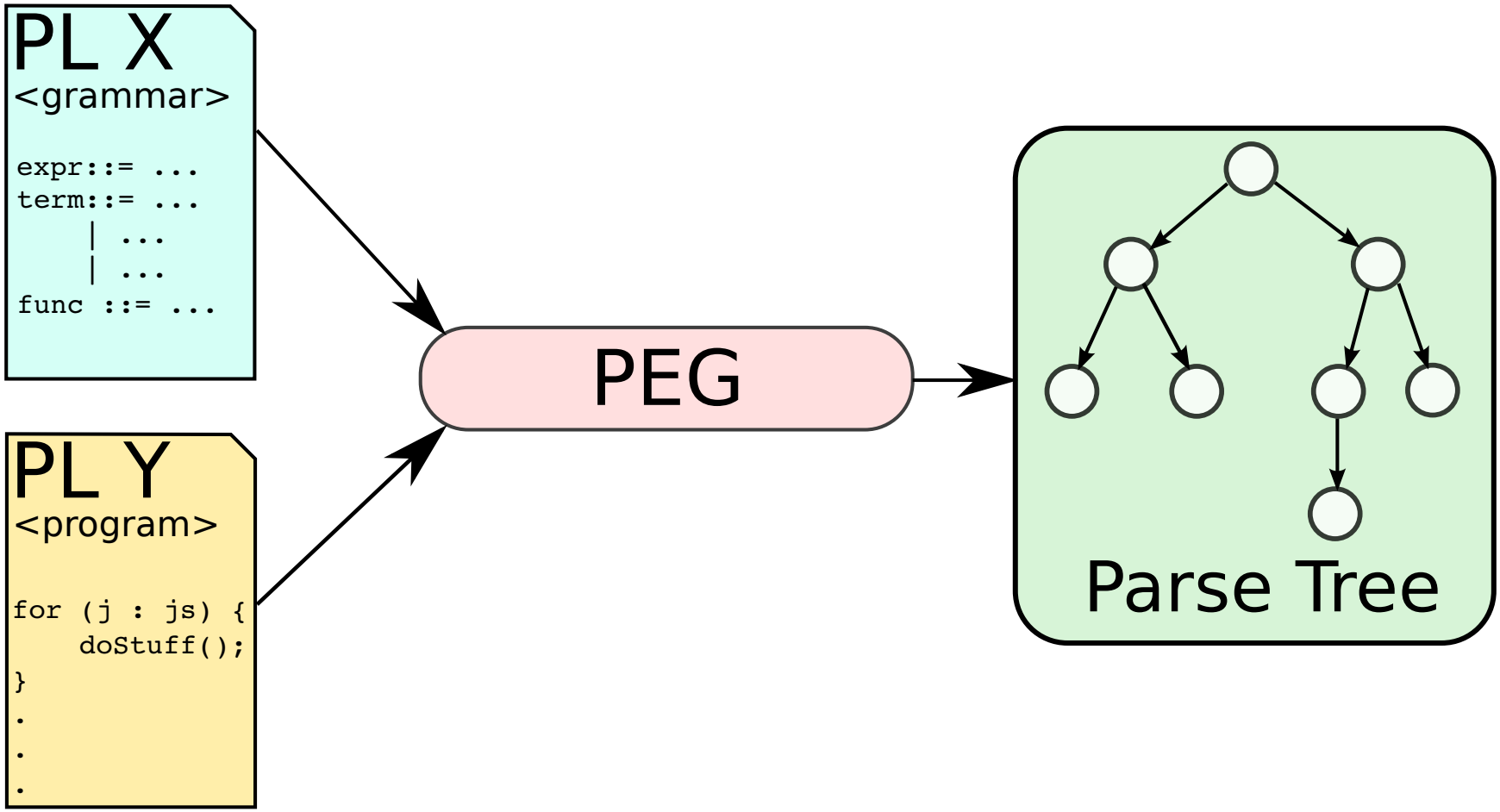
Syntax composition



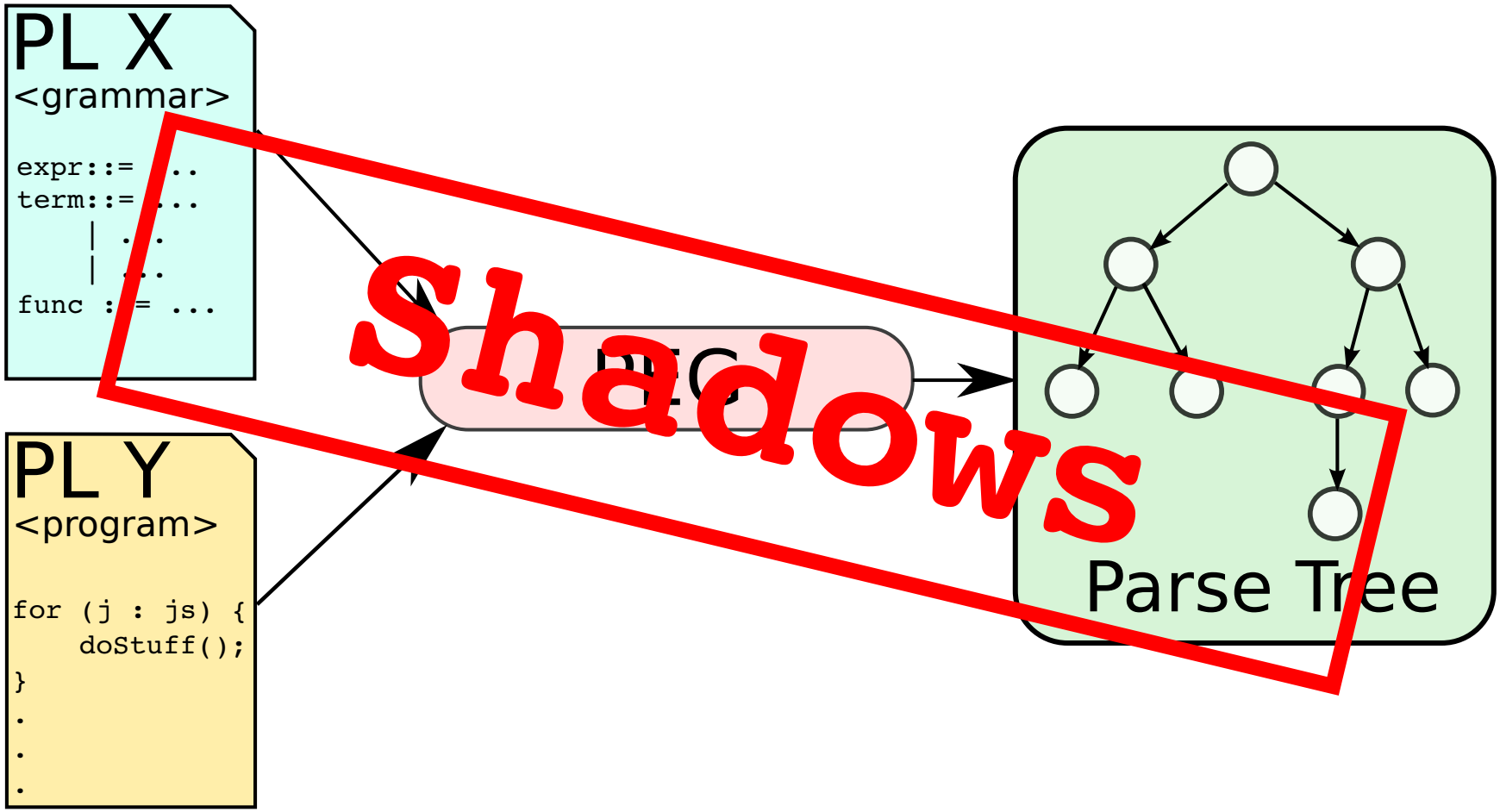
Syntax composition



Syntax composition



Syntax composition



The only choice?

The only choice?

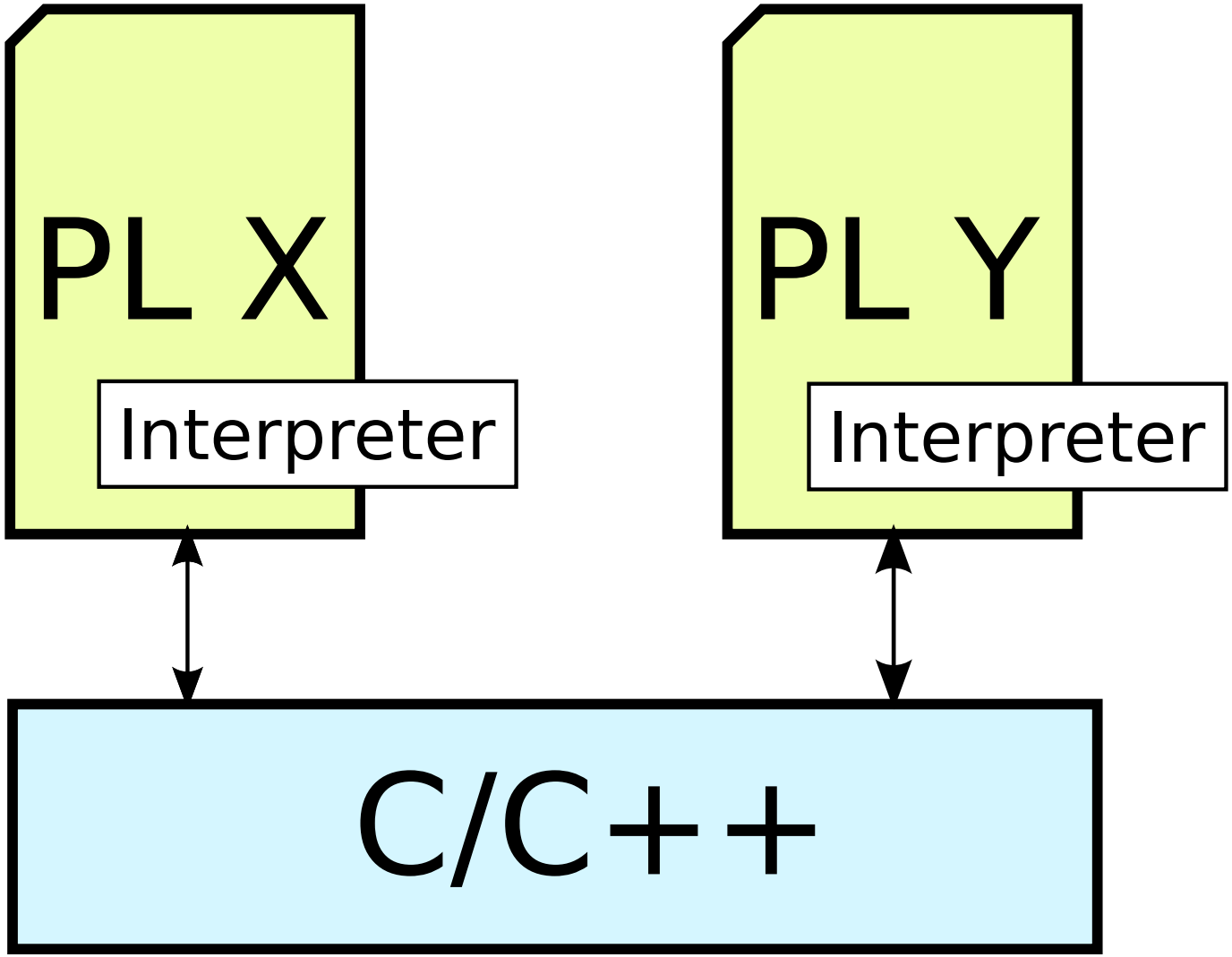
SDE

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

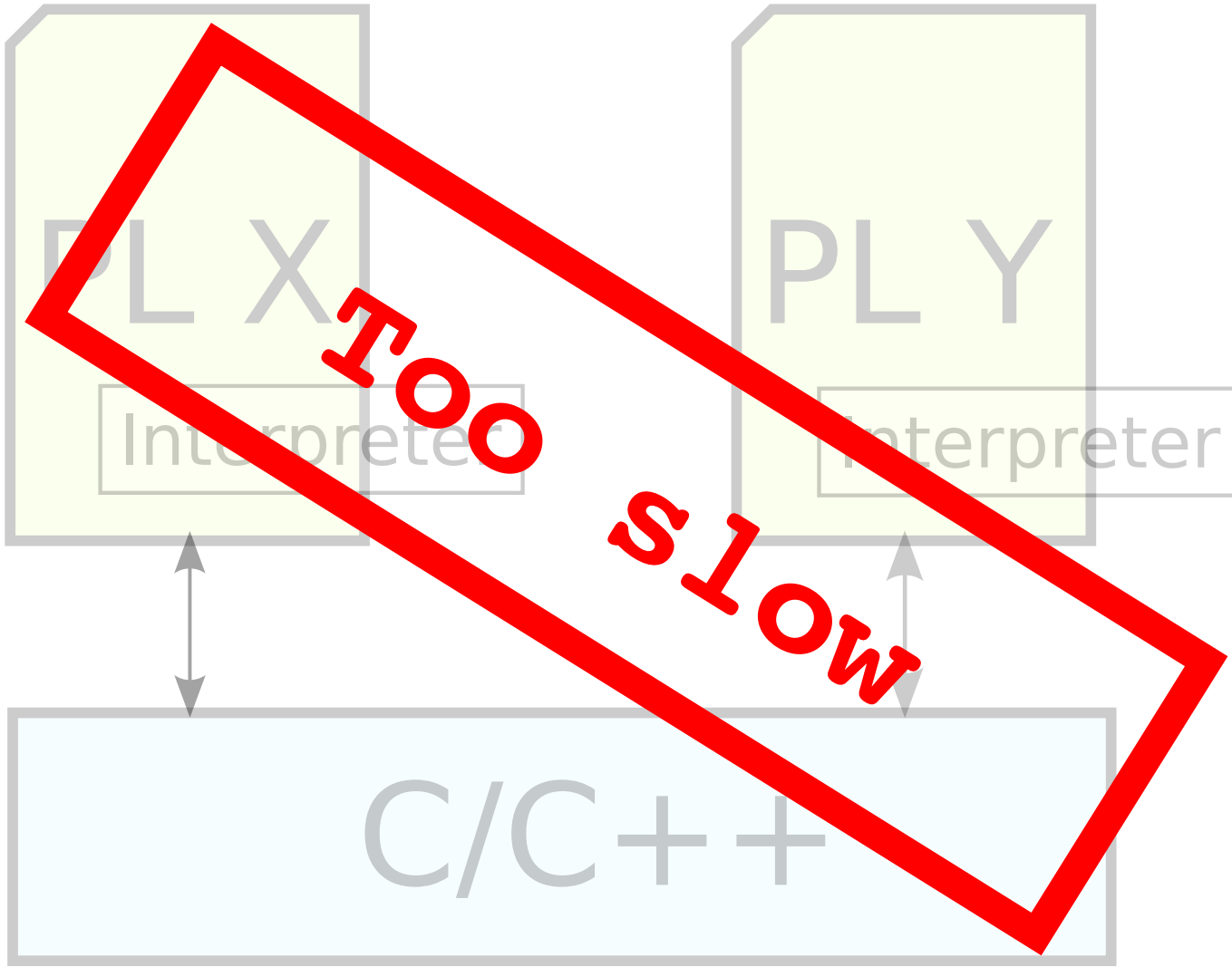
Eco demo

Runtime composition

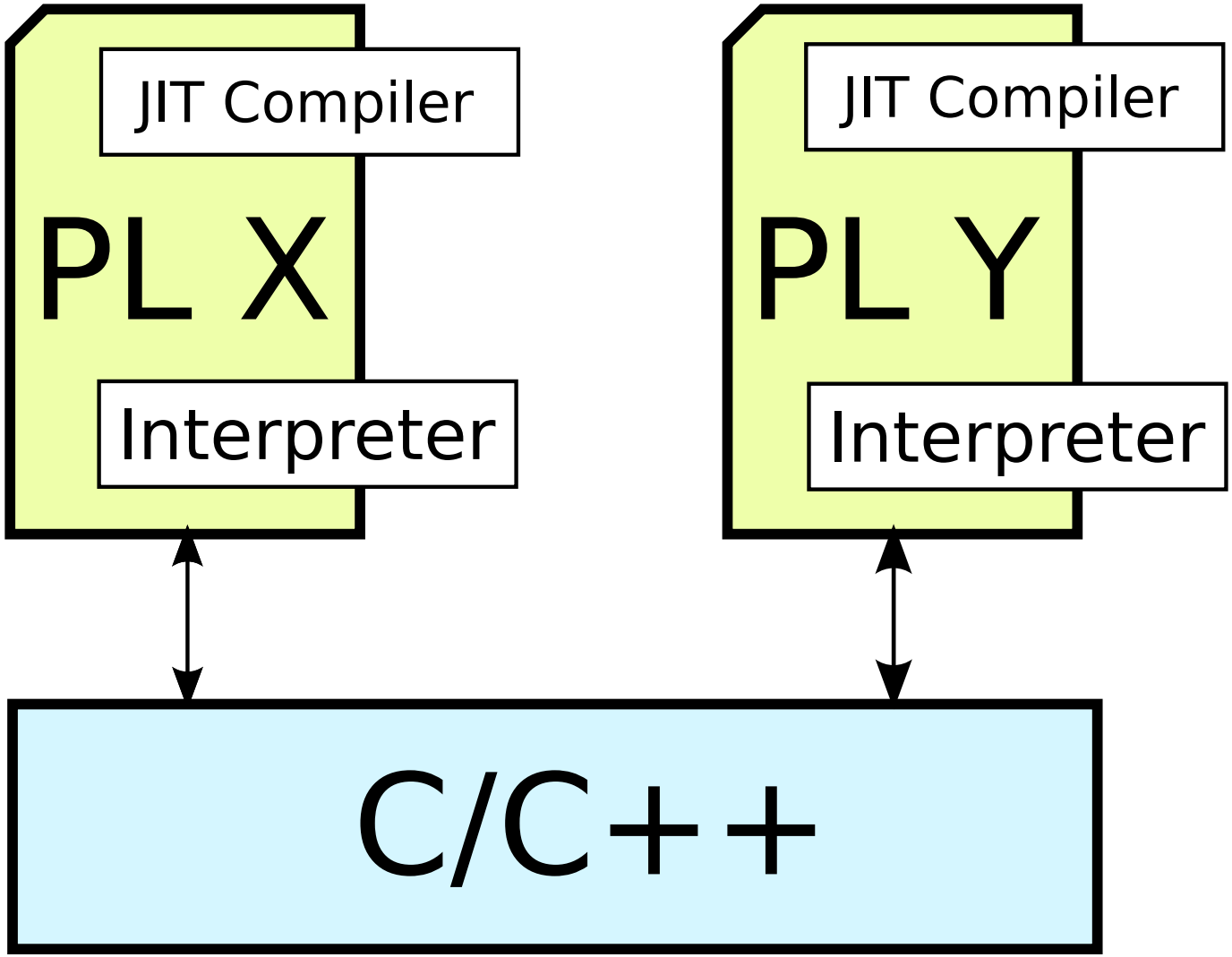
Runtime composition



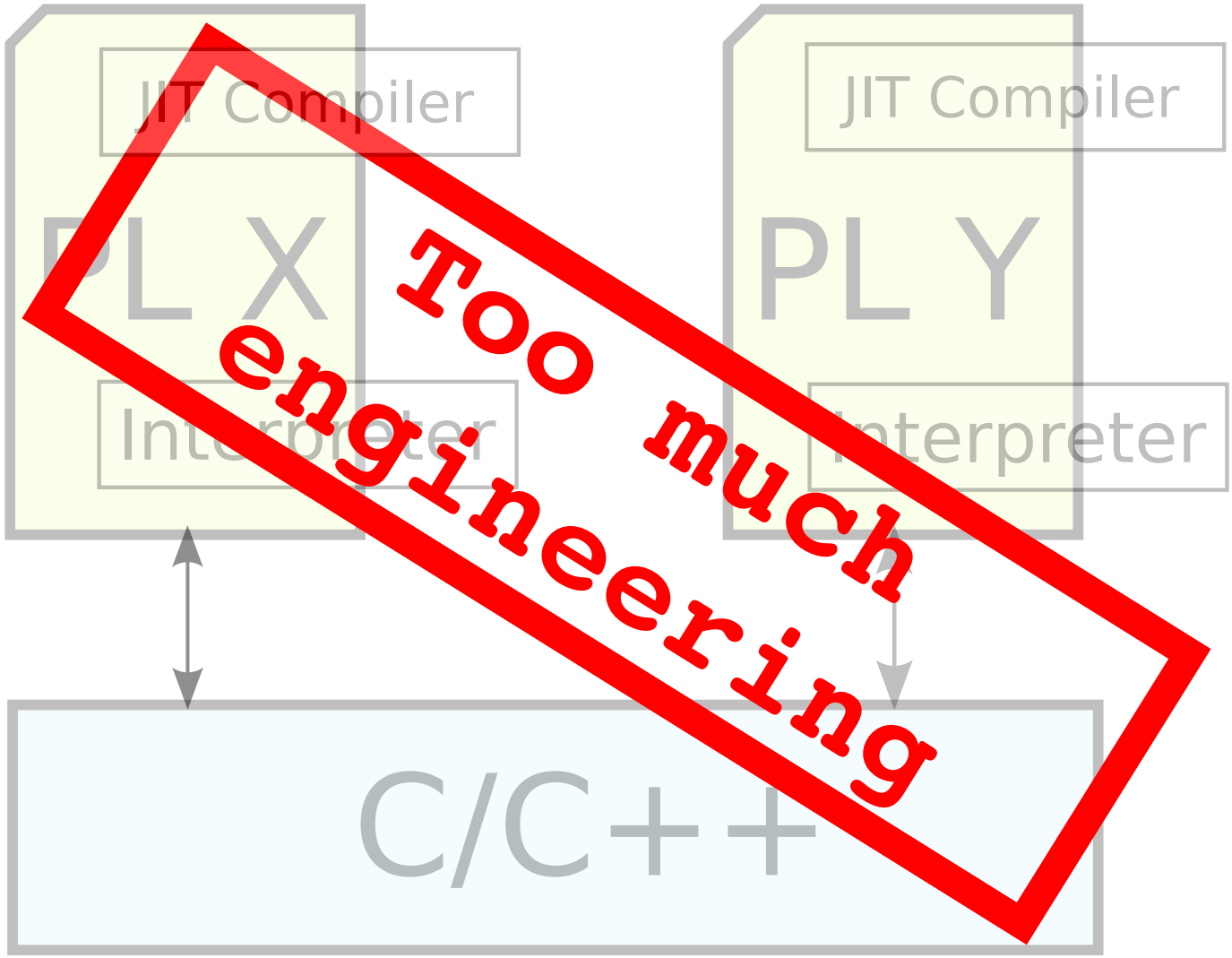
Runtime composition



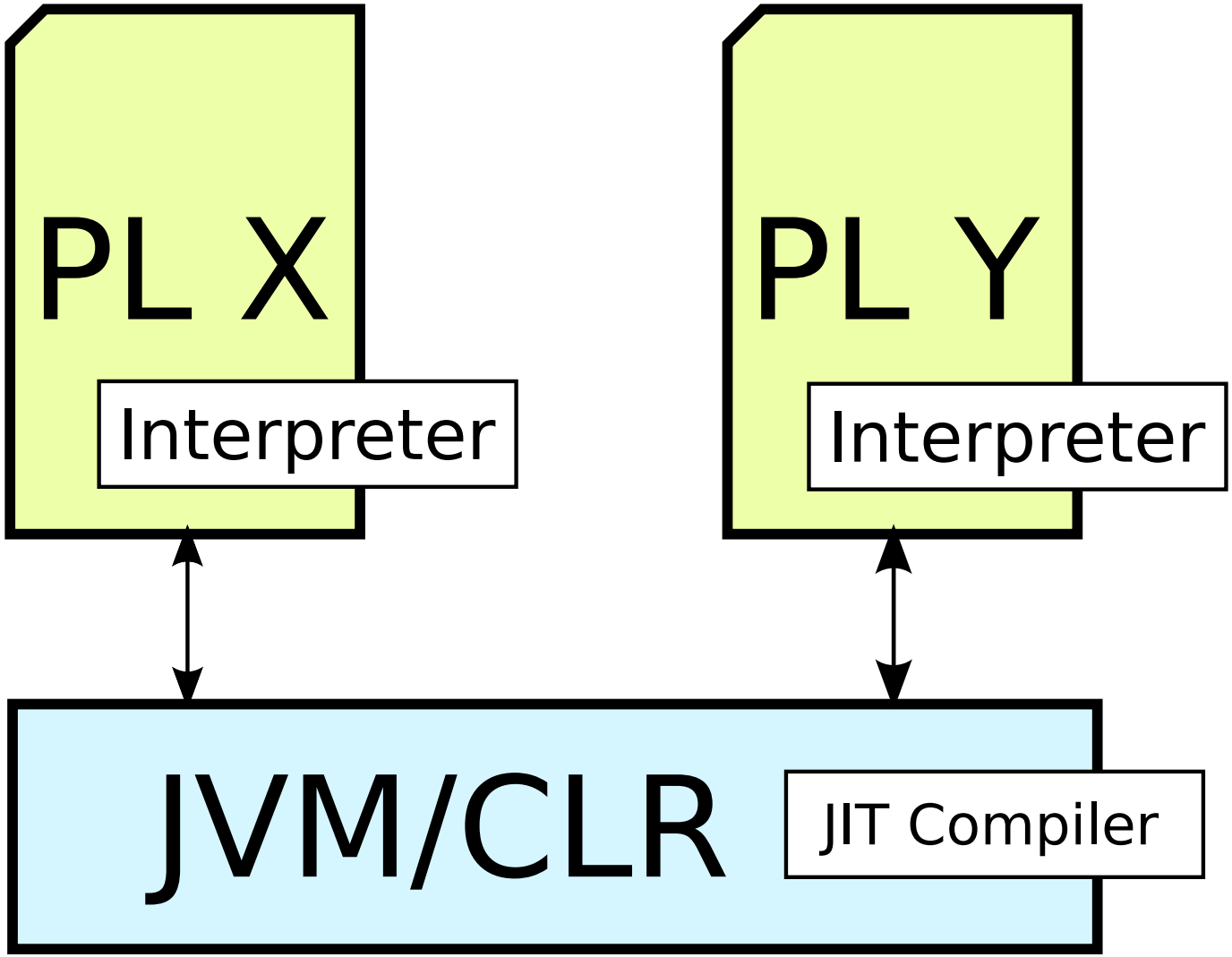
Runtime composition



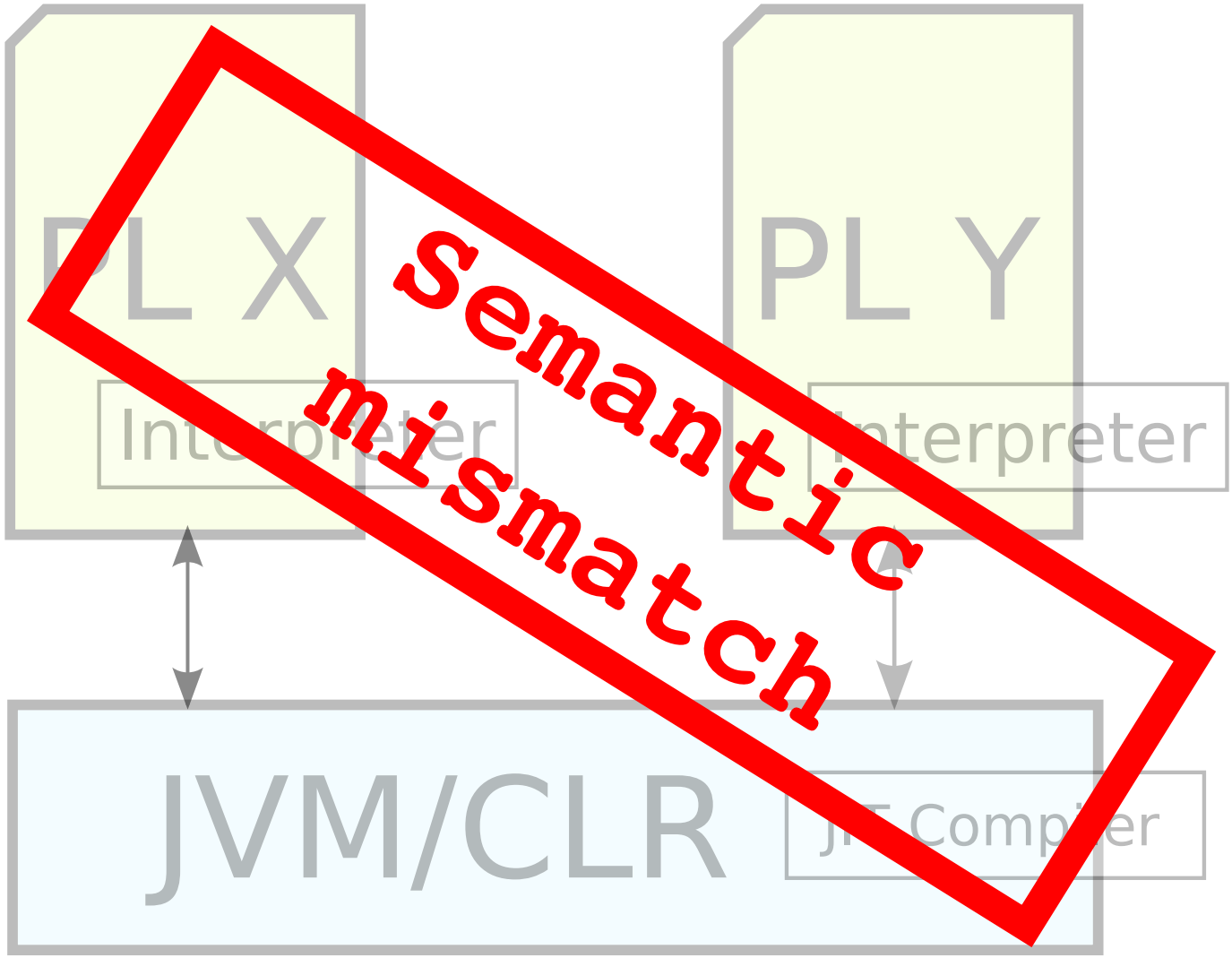
Runtime composition



Runtime composition

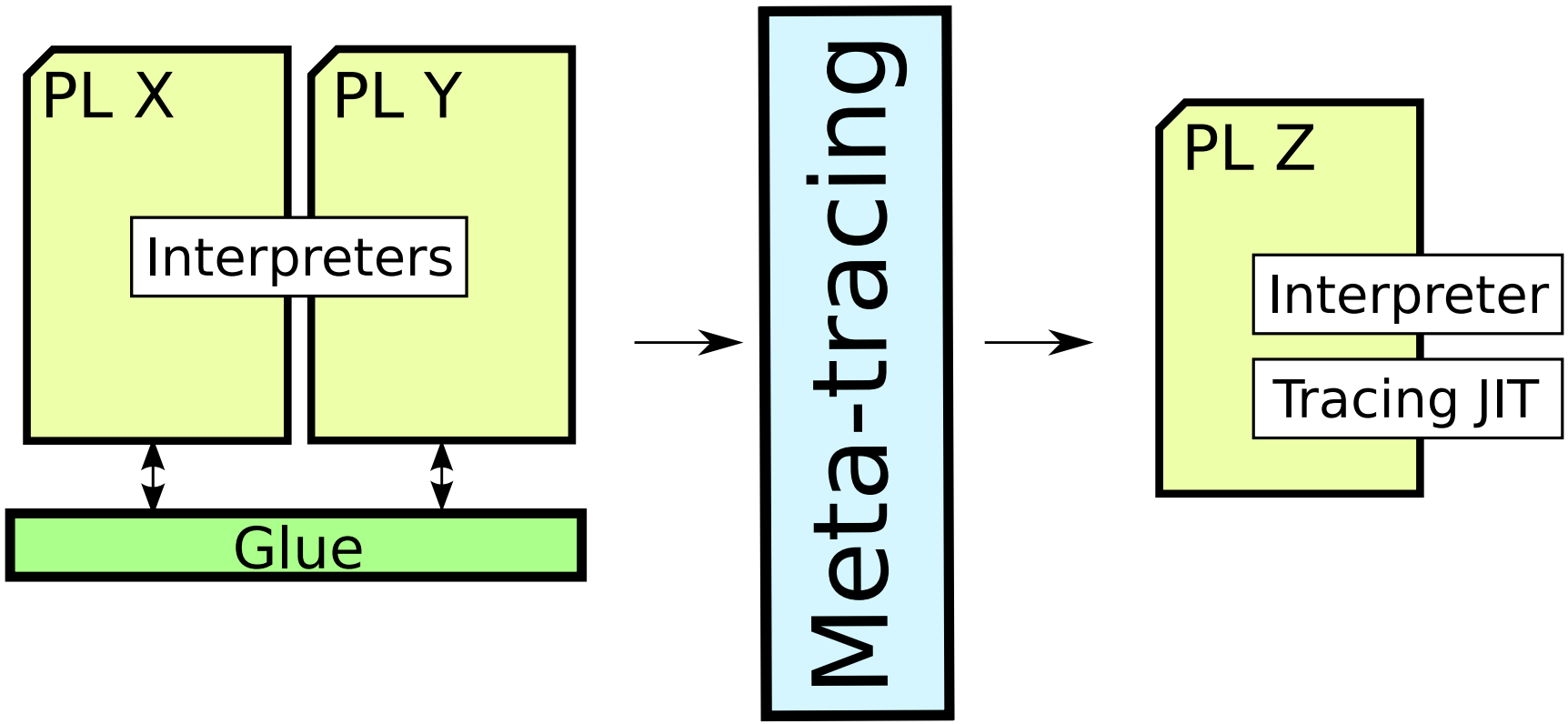


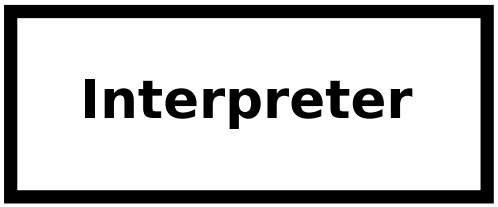
Runtime composition



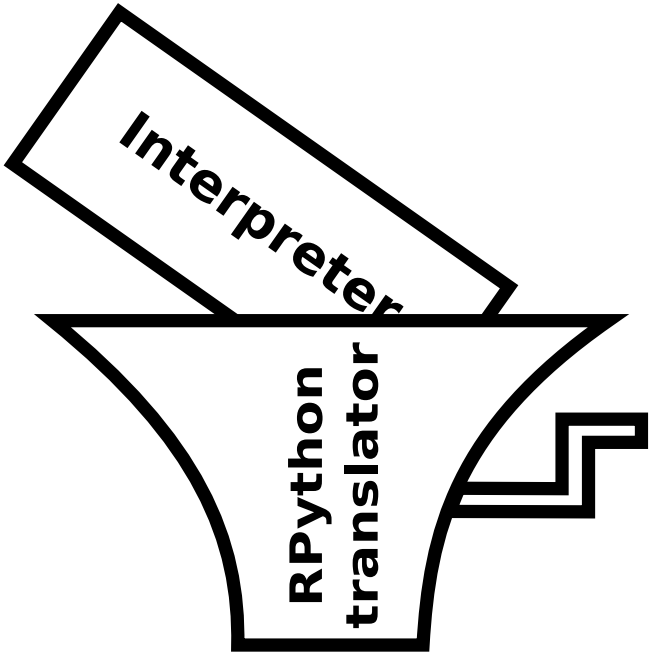
Runtime composition

Runtime composition

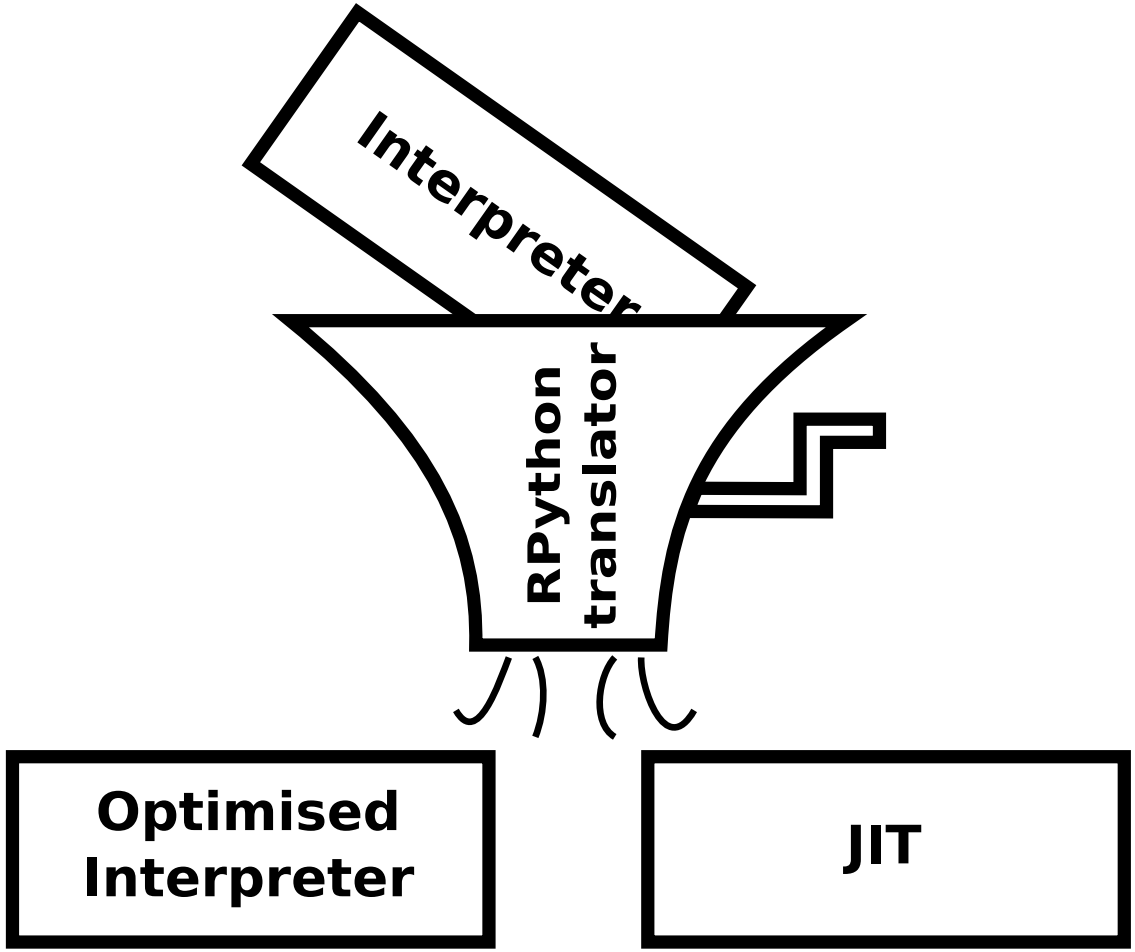



Interpreter

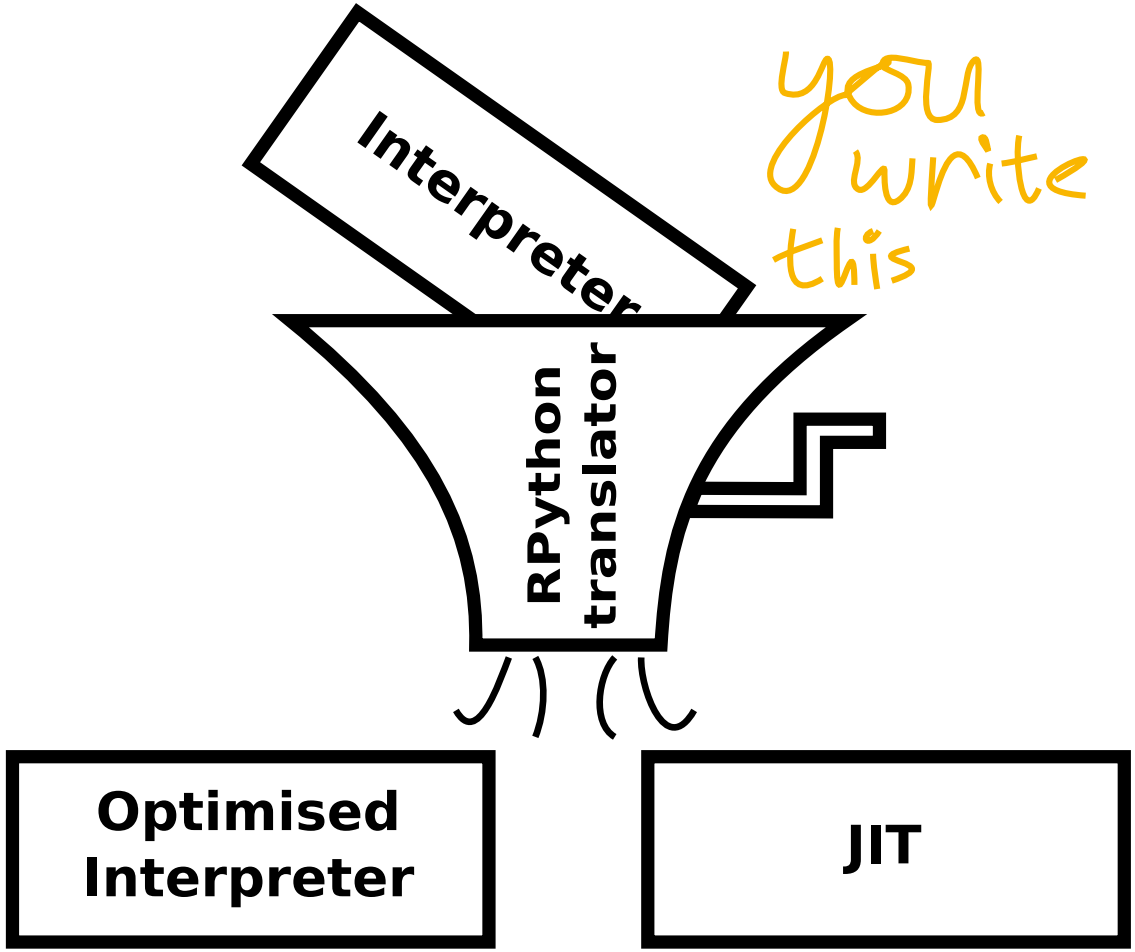
Meta-tracing translation with RPython



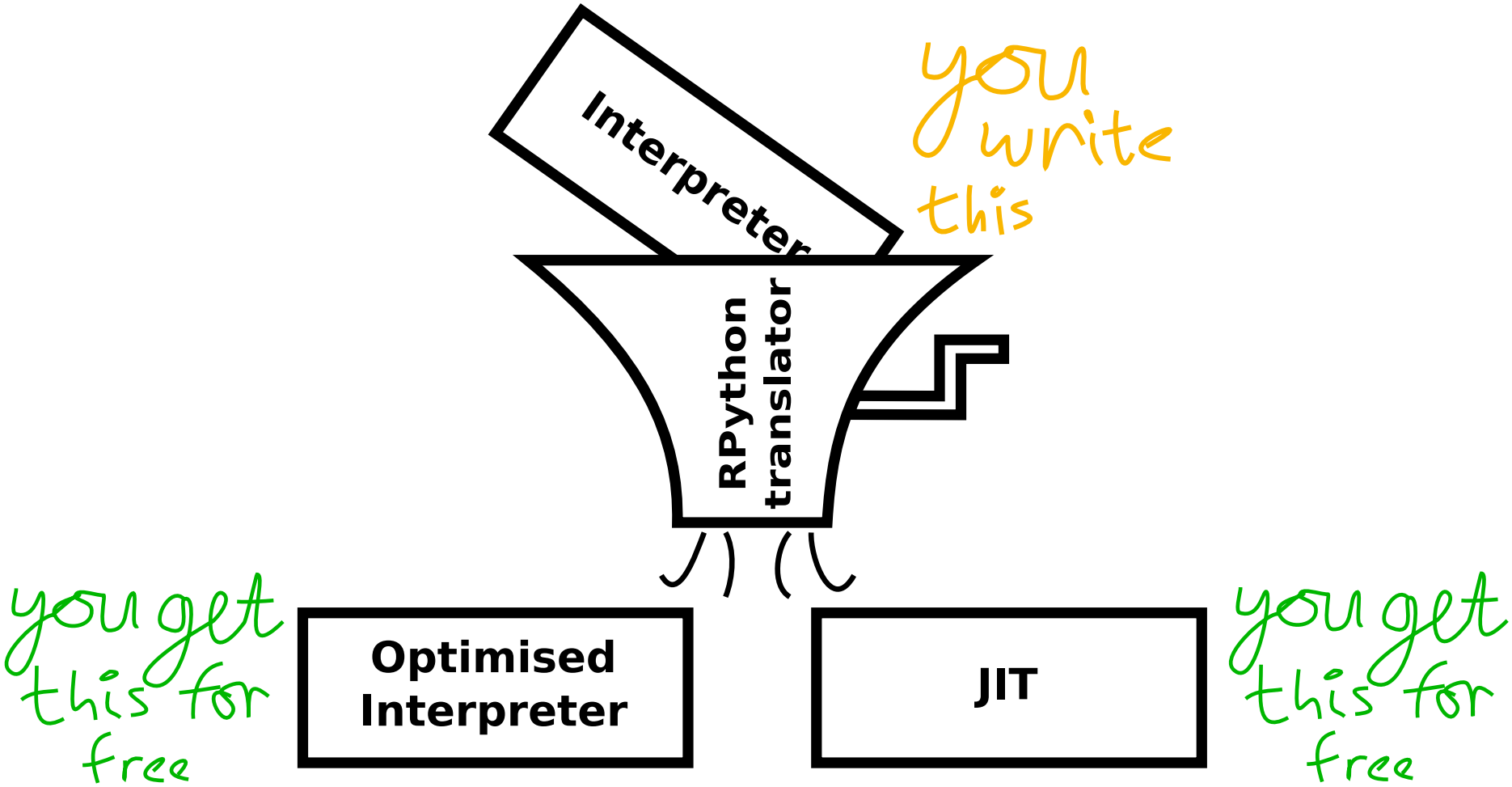
Meta-tracing translation with RPython



Meta-tracing translation with RPython



Meta-tracing translation with RPython



Adding a JIT 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 ...:
        ...
```

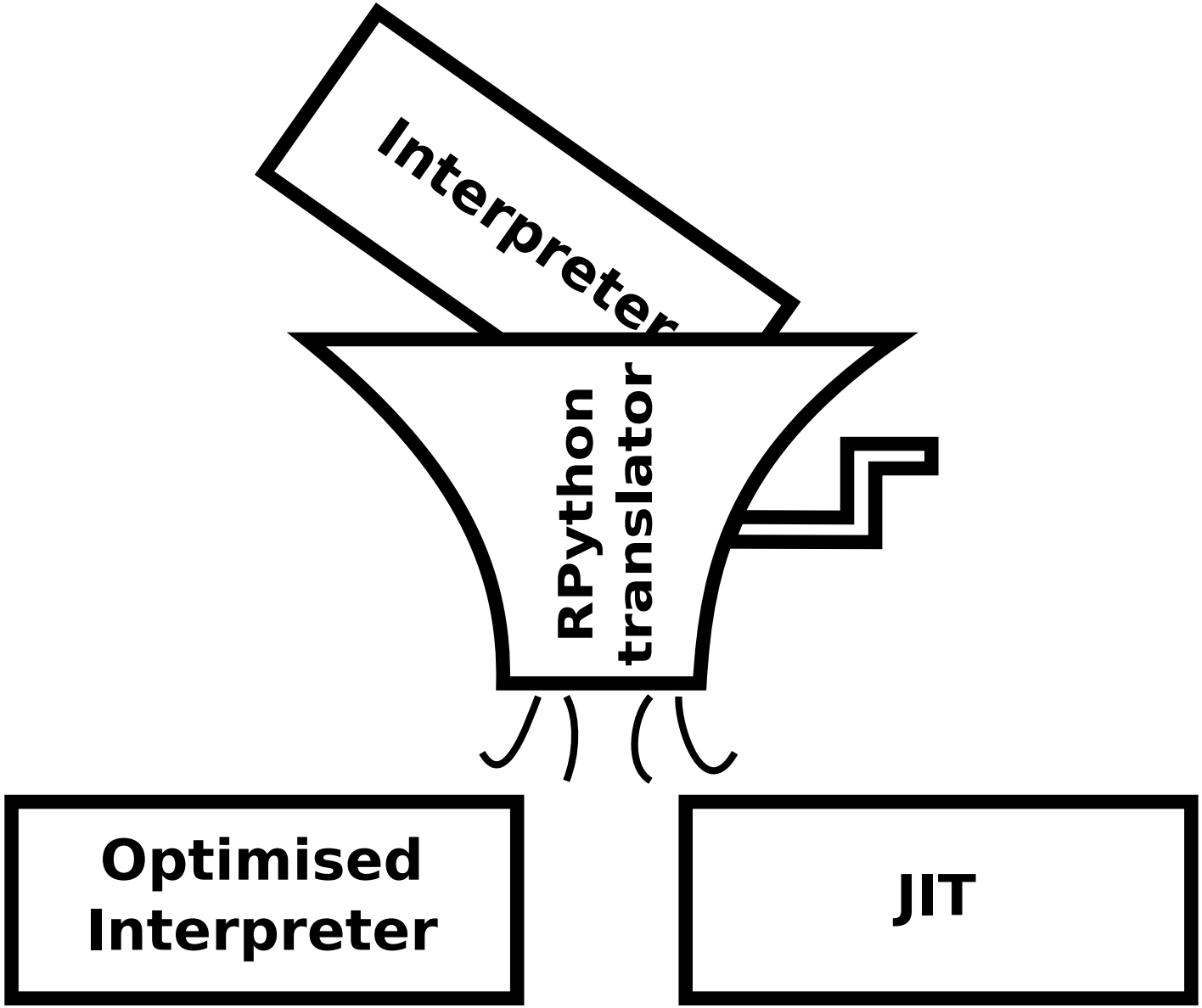
Observation: interpreters are big loops.

Adding a JIT to an RPython interpreter

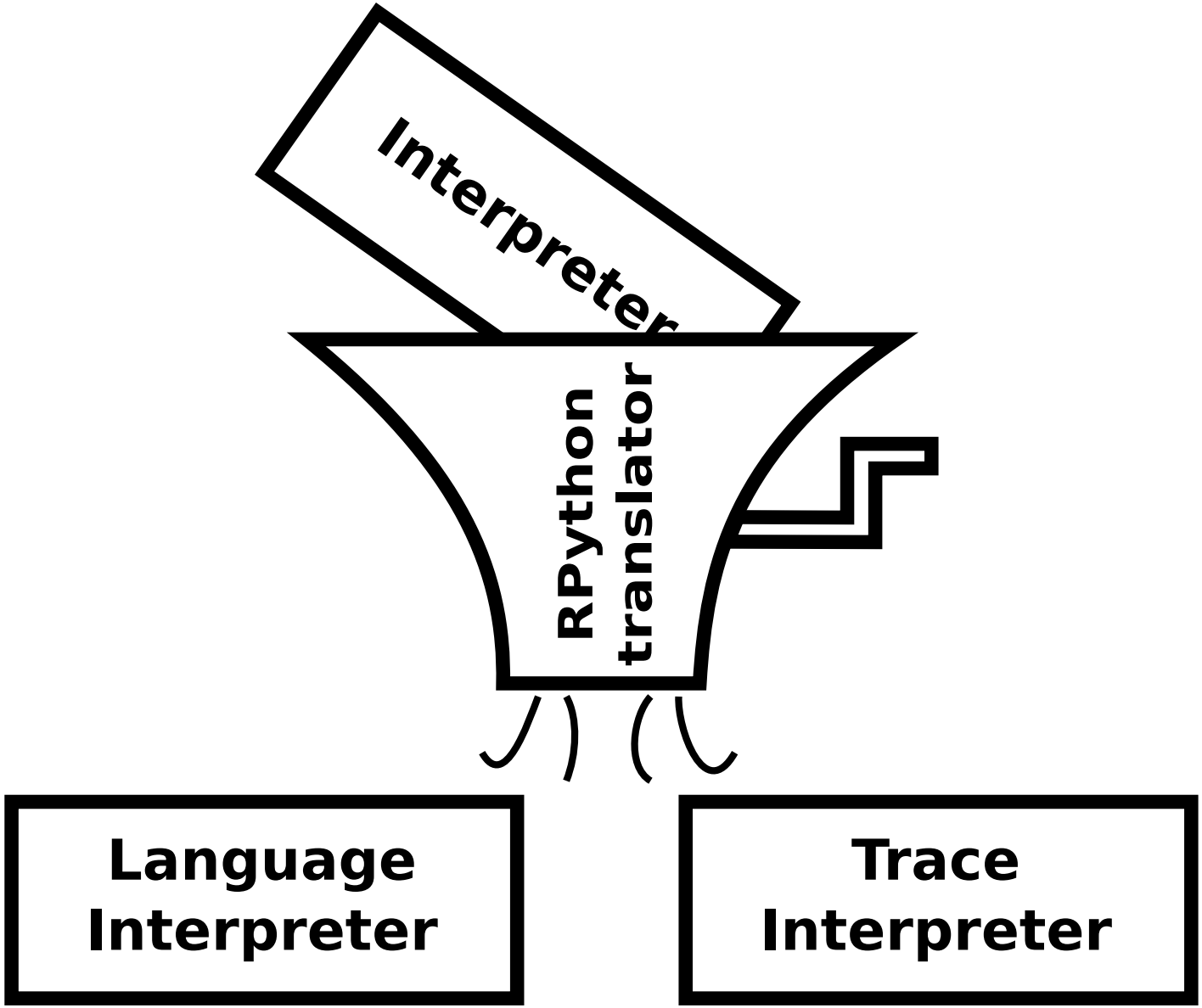
```
...
pc := 0
while 1:
    jit_merge_point(pc)
    instr := load_next_instruction(pc)
    if instr == POP:
        stack.pop()
        pc += 1
    elif instr == BRANCH:
        off = load_branch_jump(pc)
        if off < 0: can_enter_jit(pc)
        pc += off
    elif ...:
        ...
```

Observation: interpreters are big loops.

RPython translation



RPython translation



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

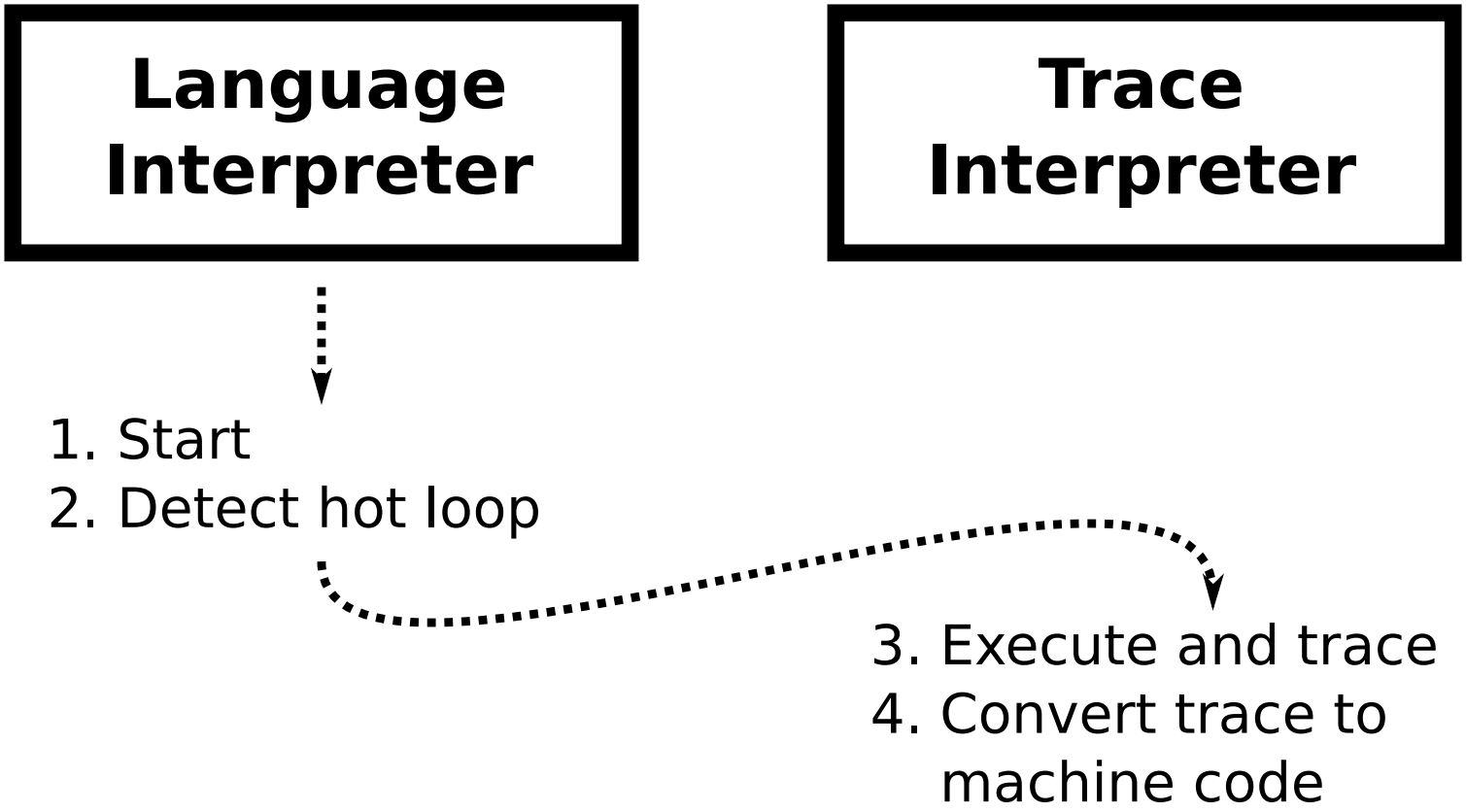
`if x < 0:`
`  x = x + 1`
`else:`
`  x = x + 2`
`x = x + 3`
	`guard_type(x, int)`
	`guard_not_less_than(x, 0)`
	`guard_type(x, int)`
	`x = int_add(x, 2)`
	`guard_type(x, int)`
	`x = int_add(x, 3)`

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
```

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
```

User program (lang *FL*)

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

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
```

Initial trace

```
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)
```

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

```
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)
```

Dict 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)
guard_type(v23, int)
v36 = add(v23, 3)
dict_set(v2, "x", v36)
```

Optimisation #4 & #5

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

```
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)
```

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, 5)
dict_set(v2, "x", v23)
```

Optimisation #4 & #5

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)
```

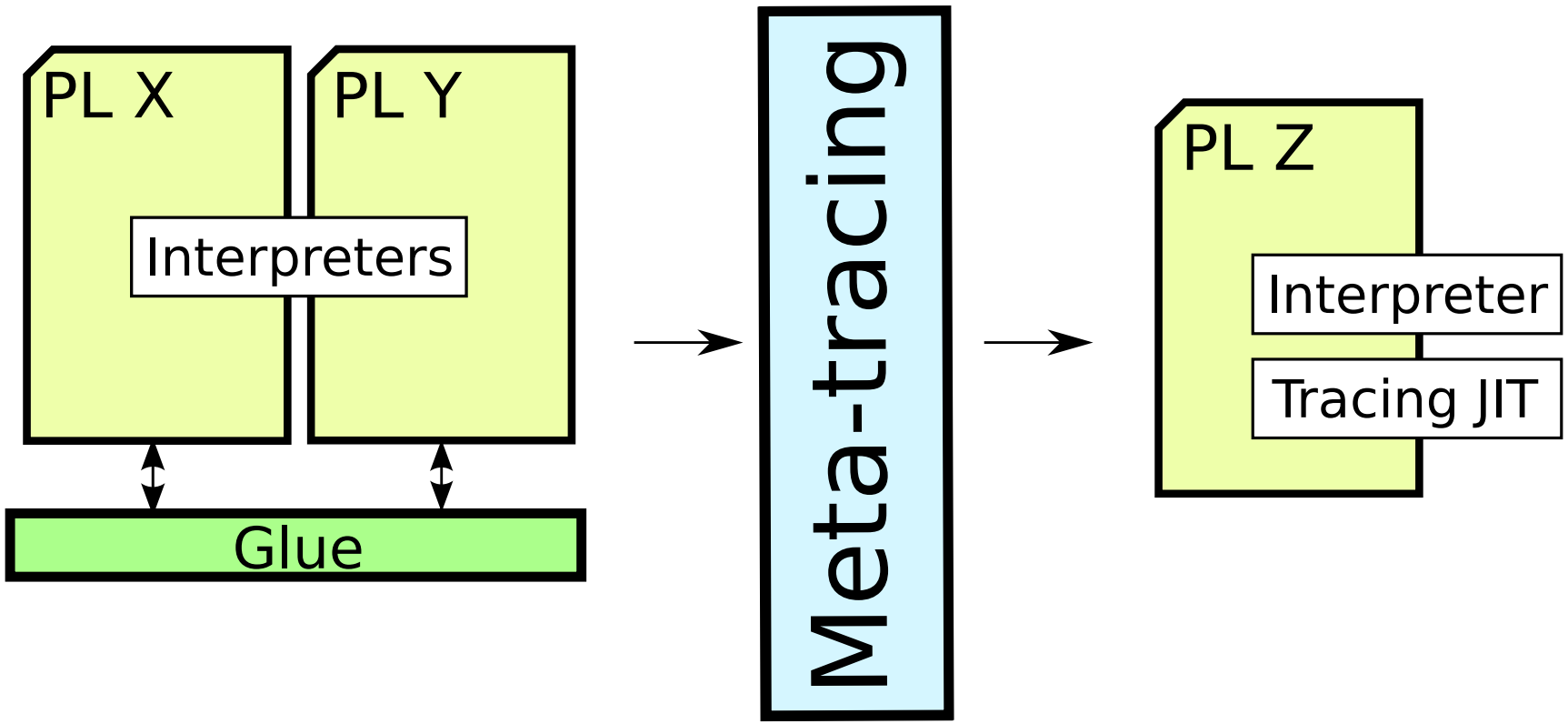
Arithmetic folded trace

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

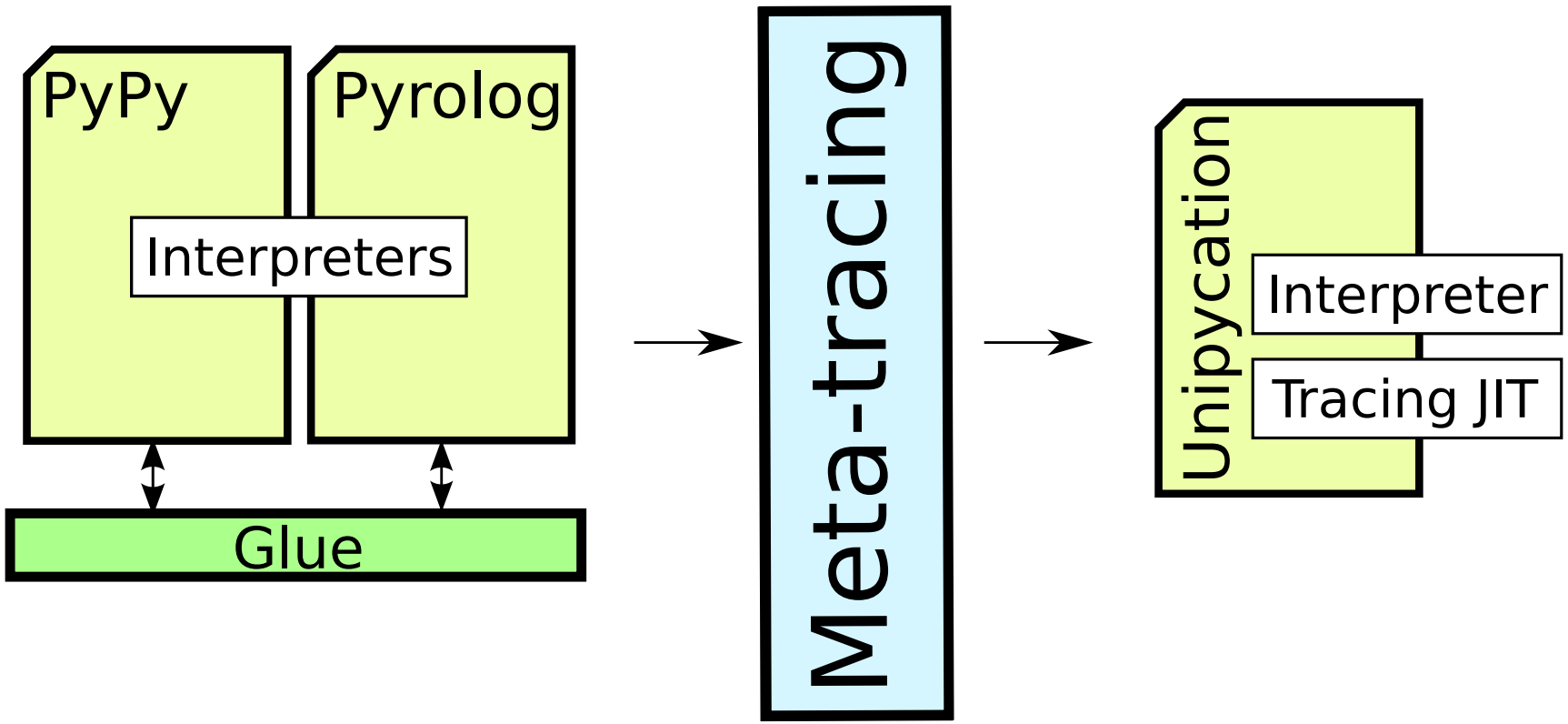
Trace optimisation: from 72 trace elements to 7.

Runtime composition recap

Runtime composition recap



Runtime composition recap



Unipycation demo

Benchmarking VM composition

Warning: draft numbers ahead

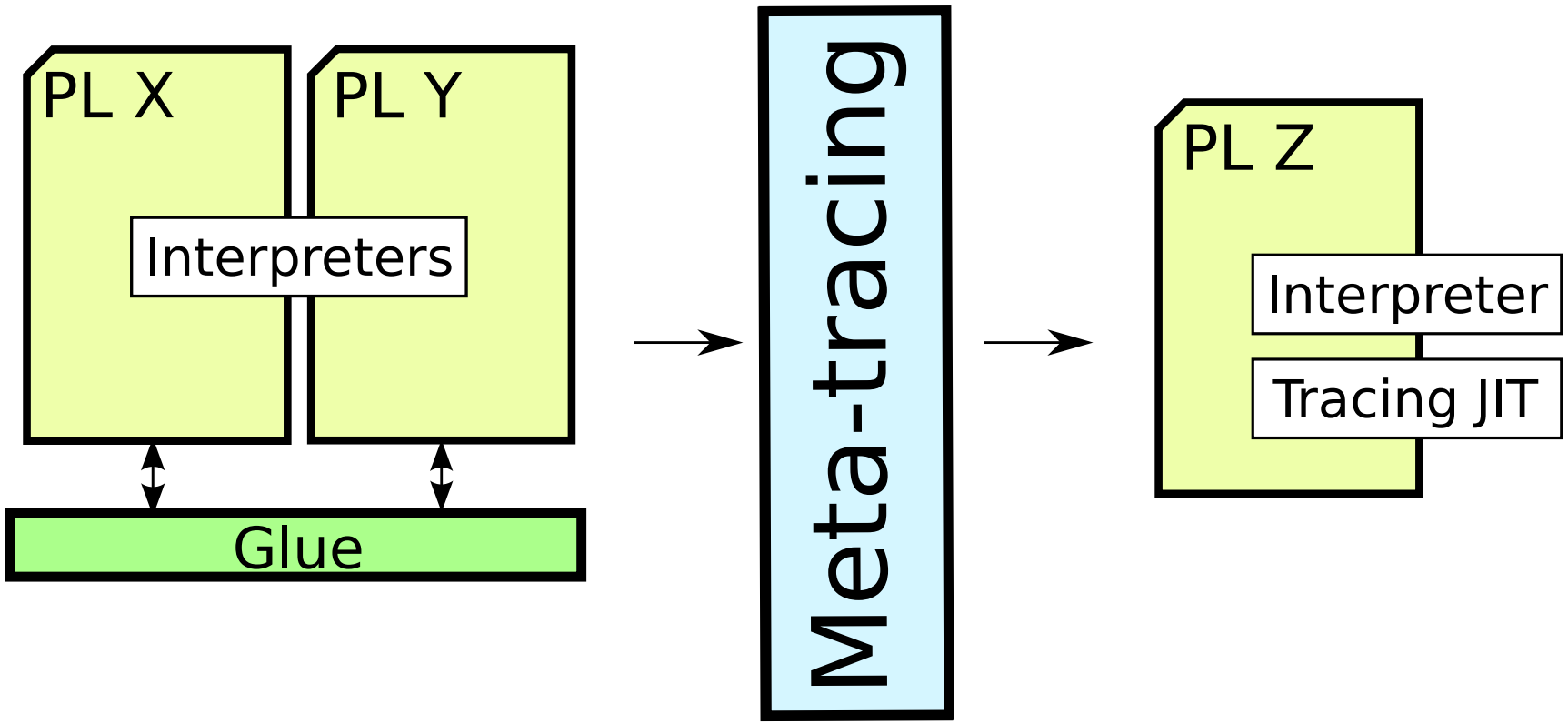
Absolute timing comparison

VM	Benchmark	*Python*		*Prolog*		*Python → Prolog*	
CPython-SWI	SmallFunc	0.125s	±0.006	0.257s	±0.001	28.893s	±0.175
	Loop1Arg0Result	2.924s	±0.215	7.352s	±0.037	9.310s	±0.065
	Loop1Arg1Result	4.184s	±0.028	18.890s	±0.082	20.865s	±0.050
	NondetLoop1Arg1Result	7.531s	±0.065	18.643s	±0.159	667.682s	±5.594
	TermConstruction	264.415s	±1.815	48.819s	±0.208	2185.150s	±14.251
	Lists	9.374s	±0.046	25.148s	±0.182	2207.304s	±12.344
Unipycation	SmallFunc	0.001s	±0.000	0.006s	±0.001	0.001s	±0.000
	Loop1Arg0Result	0.085s	±0.000	0.086s	±0.000	0.087s	±0.000
	Loop1Arg1Result	0.112s	±0.000	0.114s	±0.000	0.115s	±0.000
	NondetLoop1Arg1Result	0.500s	±0.002	0.548s	±0.064	2.674s	±0.010
	TermConstruction	6.053s	±0.218	2.444s	±0.002	36.069s	±0.171
	Lists	0.845s	±0.002	1.416s	±0.003	5.056s	±0.026
Jython-tuProlog	SmallFunc	0.088s	±0.002	3.050s	±0.036	52.294s	±0.371
	Loop1Arg0Result	1.078s	±0.007	206.590s	±2.884	199.963s	±1.784
	Loop1Arg1Result	2.145s	±0.175	293.311s	±4.270	294.781s	±4.746
	NondetLoop1Arg1Result	7.939s	±0.341	timeout		timeout	
	TermConstruction	timeout		timeout		timeout	
	Lists	timeout		timeout		timeout	

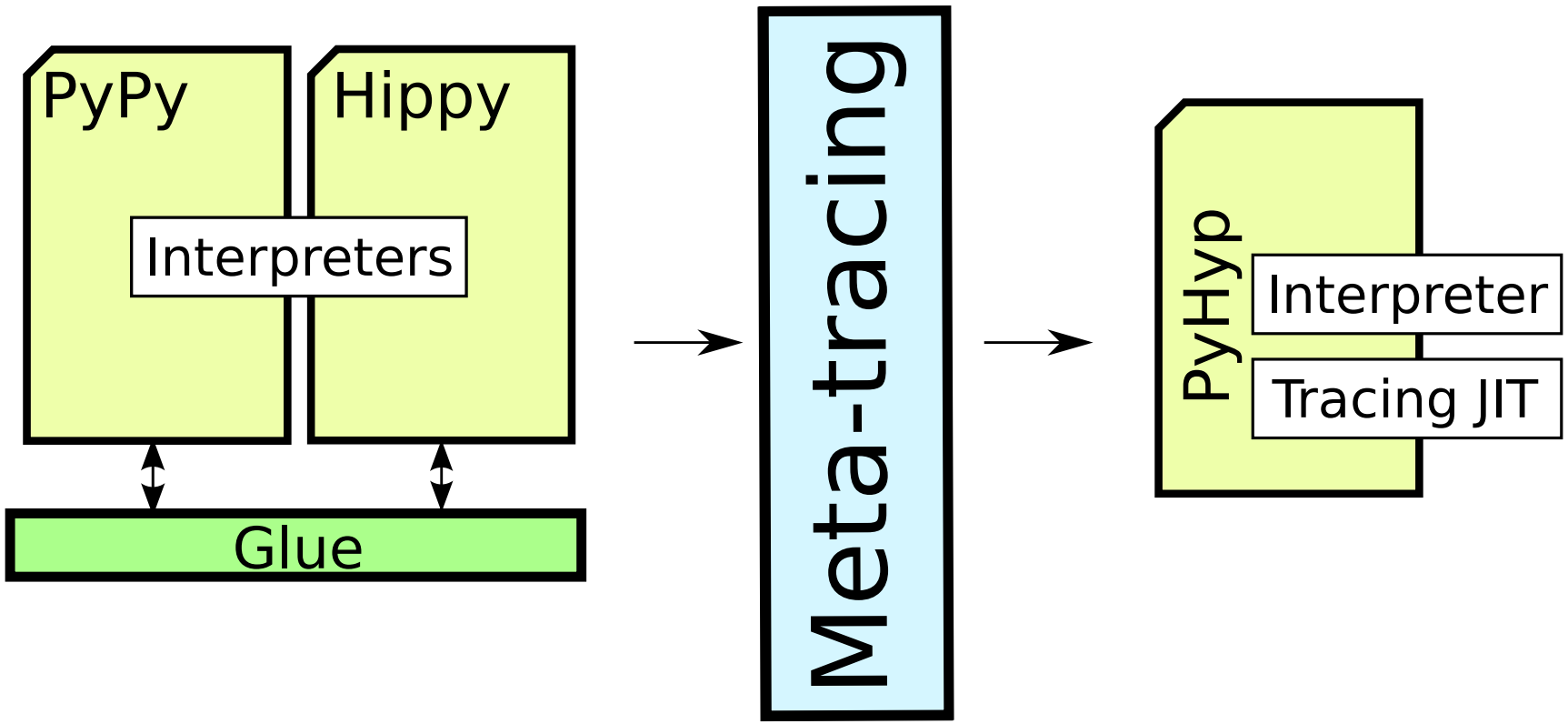
Relative timing comparison

VM	Benchmark	$\frac{Python \to Prolog}{Python}$		$\frac{Python \to Prolog}{Prolog}$		$\frac{Python \to Prolog}{\text{Unipycation}}$	
CPython-SWI	SmallFunc	231.770×	±10.154	112.567×	±0.934	27821.079×	±1896.725
	Loop1Arg0Result	3.184×	±0.232	1.266×	±0.011	107.591×	±0.779
	Loop1Arg1Result	4.987×	±0.039	1.105×	±0.006	181.899×	±0.444
	NondetLoop1Arg1Result	88.654×	±1.026	35.814×	±0.389	249.737×	±2.244
	TermConstruction	8.264×	±0.081	44.760×	±0.348	60.583×	±0.487
	Lists	235.459×	±1.742	87.772×	±0.789	436.609×	±3.494
Unipycation	SmallFunc	1.295×	±0.086	0.182×	±0.036	1.000×	
	Loop1Arg0Result	1.020×	±0.001	1.012×	±0.002	1.000×	
	Loop1Arg1Result	1.025×	±0.002	1.002×	±0.002	1.000×	
	NondetLoop1Arg1Result	5.349×	±0.035	4.879×	±0.631	1.000×	
	TermConstruction	5.959×	±0.224	14.756×	±0.069	1.000×	
	Lists	5.982×	±0.034	3.569×	±0.019	1.000×	
Jython-tuProlog	SmallFunc	592.904×	±14.602	17.143×	±0.259	50354.204×	±3330.993
	Loop1Arg0Result	185.460×	±2.182	0.968×	±0.017	2310.844×	±21.996
	Loop1Arg1Result	137.427×	±11.805	1.005×	±0.022	2569.873×	±41.331
	NondetLoop1Arg1Result	timeout		timeout		timeout	
	TermConstruction	timeout		timeout		timeout	
	Lists	timeout		timeout		timeout	

PyHyp


PL X
PL Y
Interpreters
Glue
Meta-tracing
PL Z
Interpreter
Tracing JIT

PyHyp


PyPy
Hippy
Interpreters
Glue
Meta-tracing
PyHyp
Interpreter
Tracing JIT

PyHyp demo

Composed Richards vs. other VMs

Warning: even draftier numbers ahead!

Composed Richards vs. other VMs

Type	VM	
Mono	PyPy 2.4.0	0.370 ± 0.000
	Hippy	0.553 ± 0.008
	PyHyp	0.556 ± 0.006
	HHVM 3.2.0	5.353 ± 0.262
	ZEND 5.4.4	10.406 ± 0.106

Composed Richards vs. other VMs

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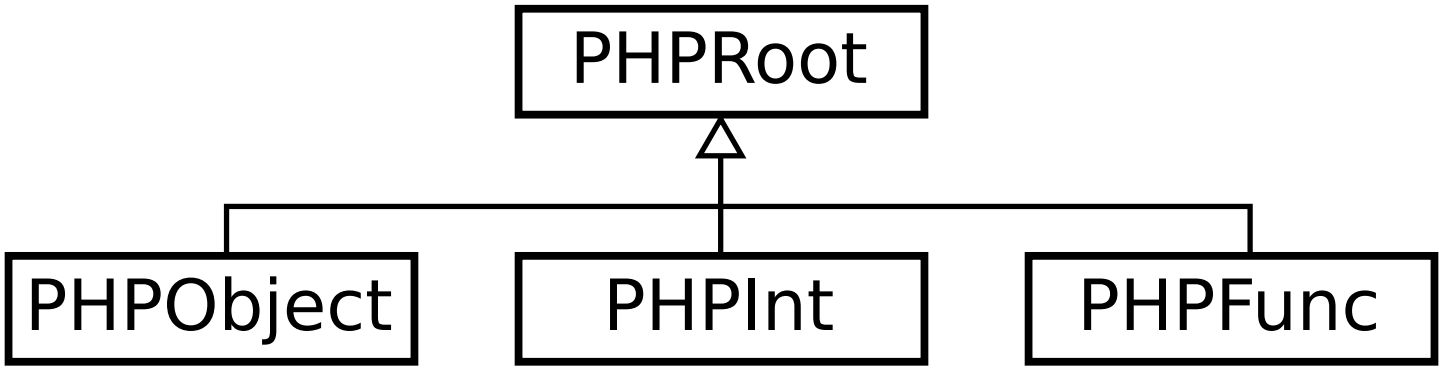
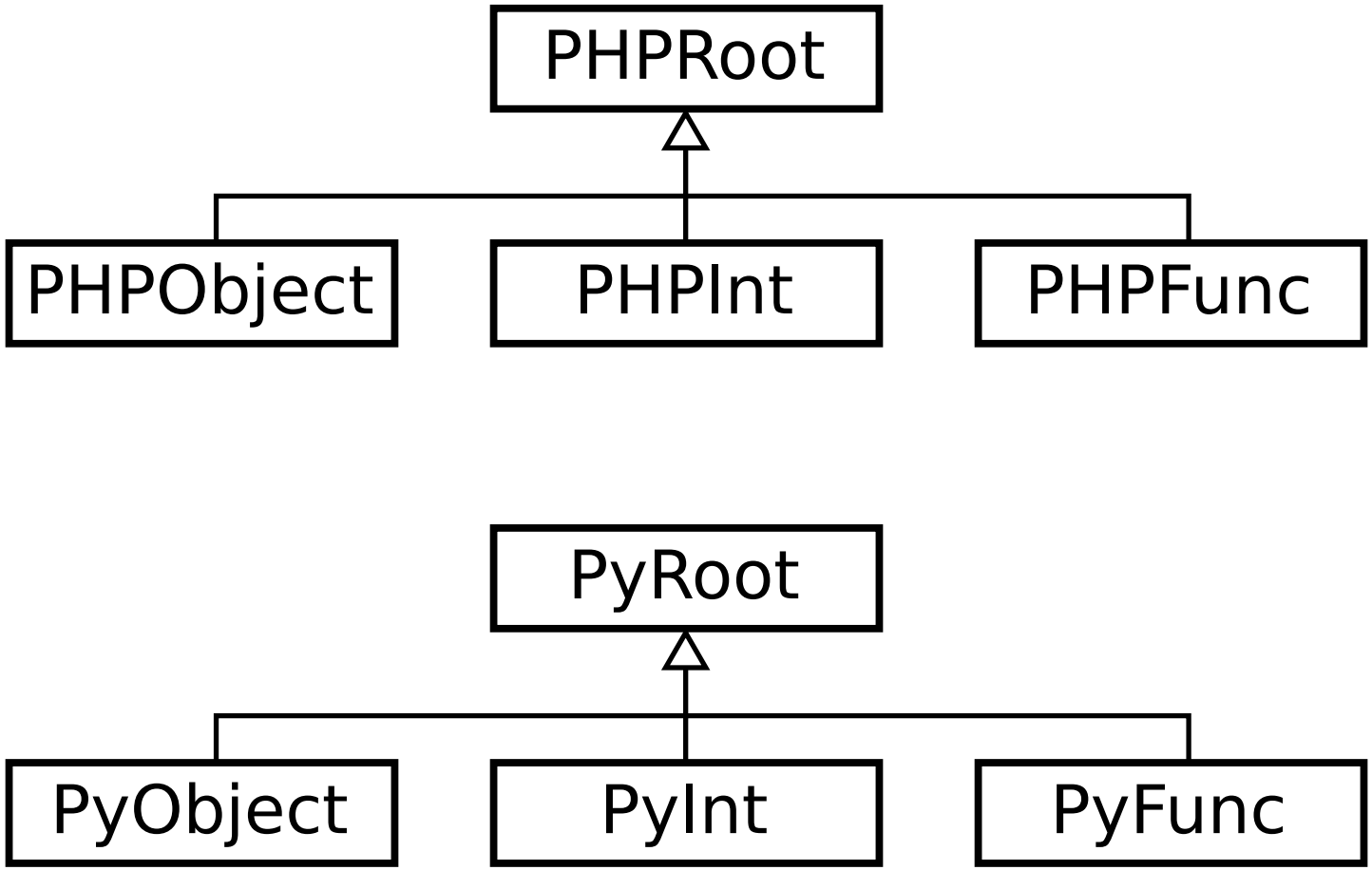
Composed	PyHyp	0.936 ± 0.038

Datatype conversion



Datatype conversion

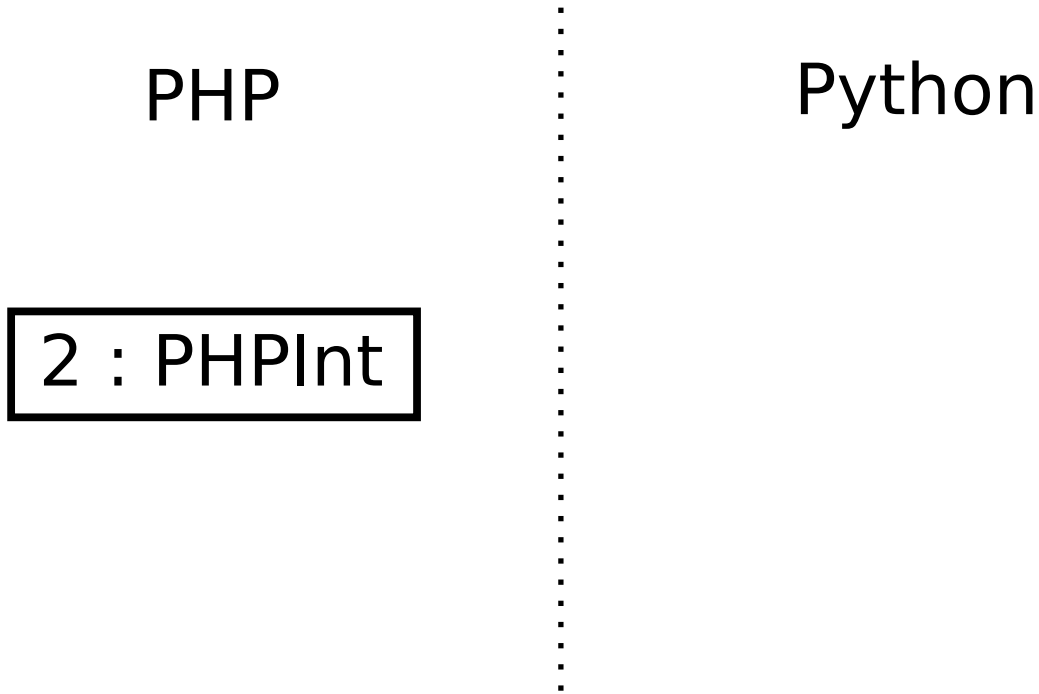


Datatype conversion: primitive types

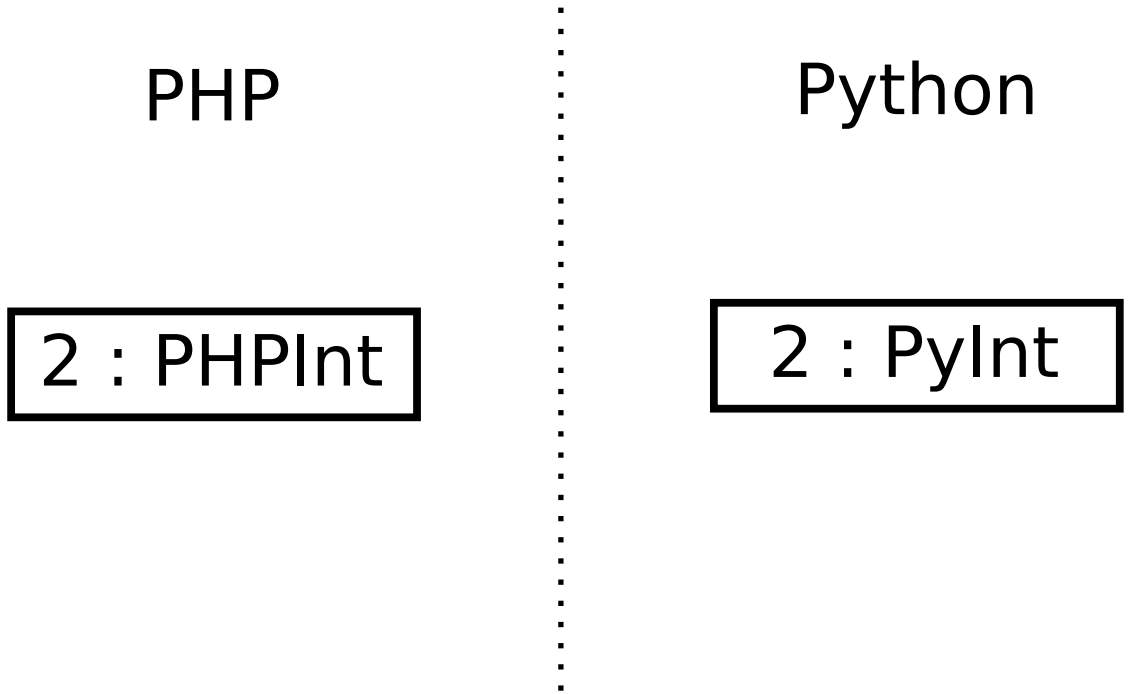
PHP

Python

Datatype conversion: primitive types



Datatype conversion: primitive types

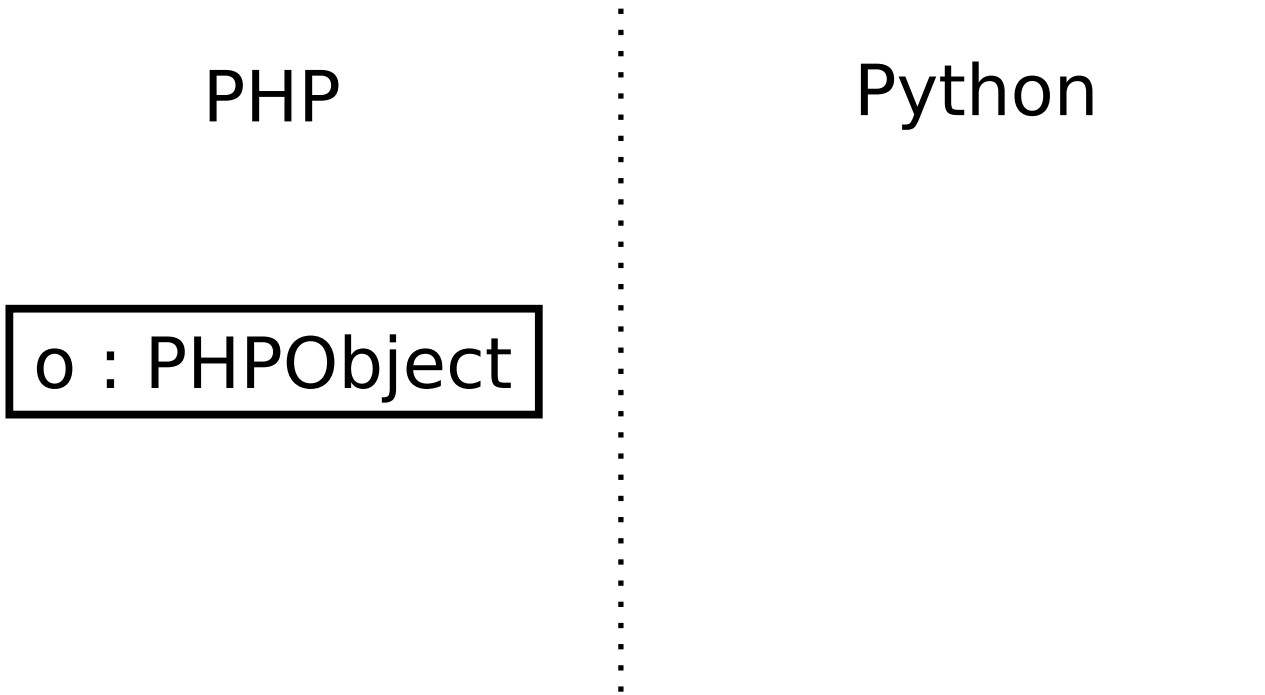


Datatype conversion: user types

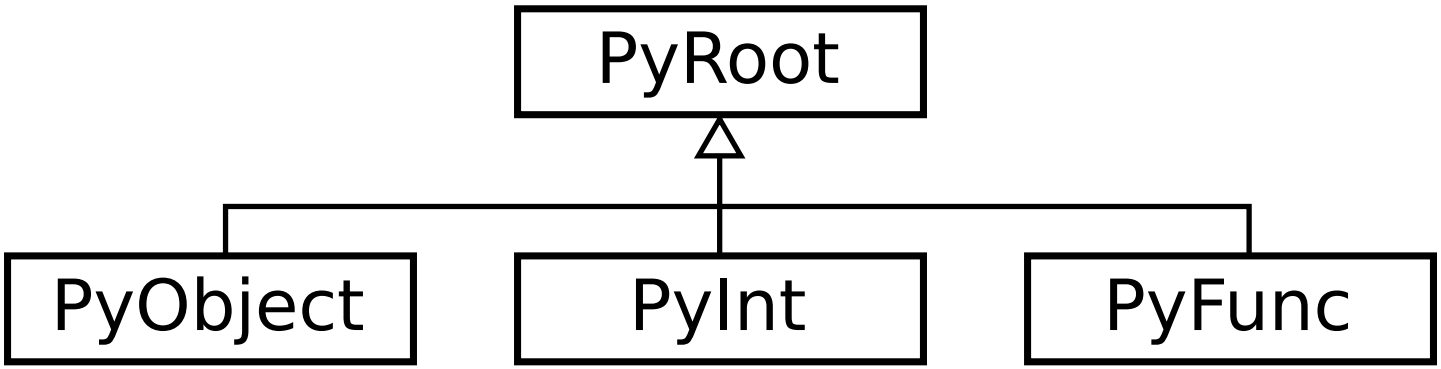
PHP

Python

Datatype conversion: user types



Datatype conversion: user types



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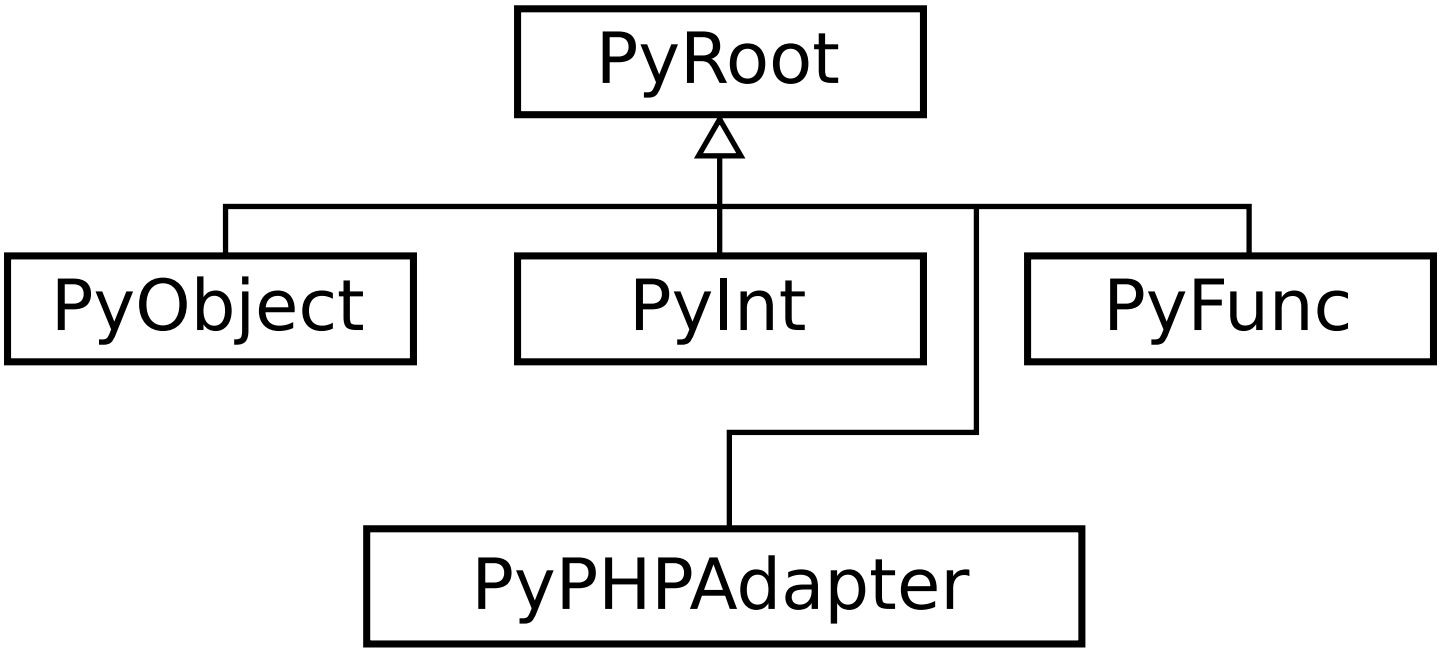
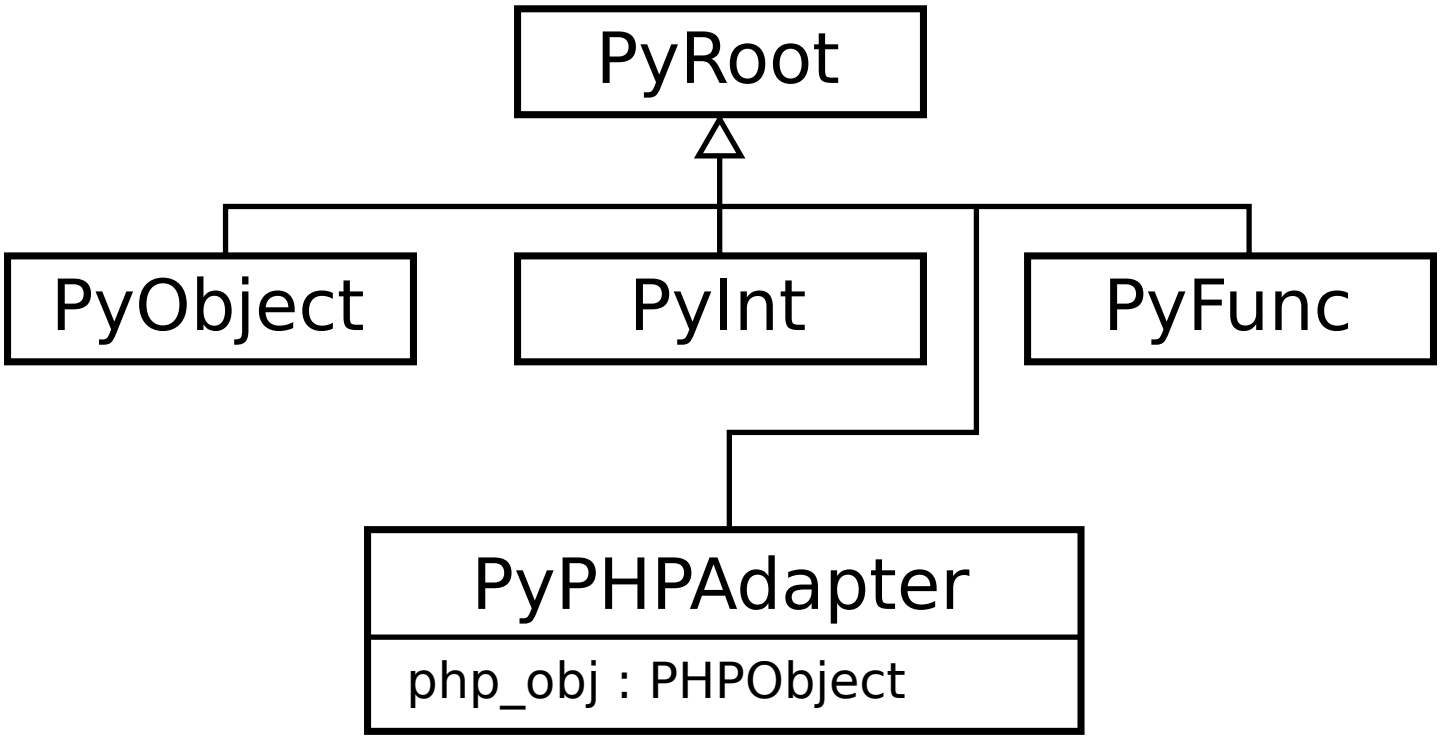
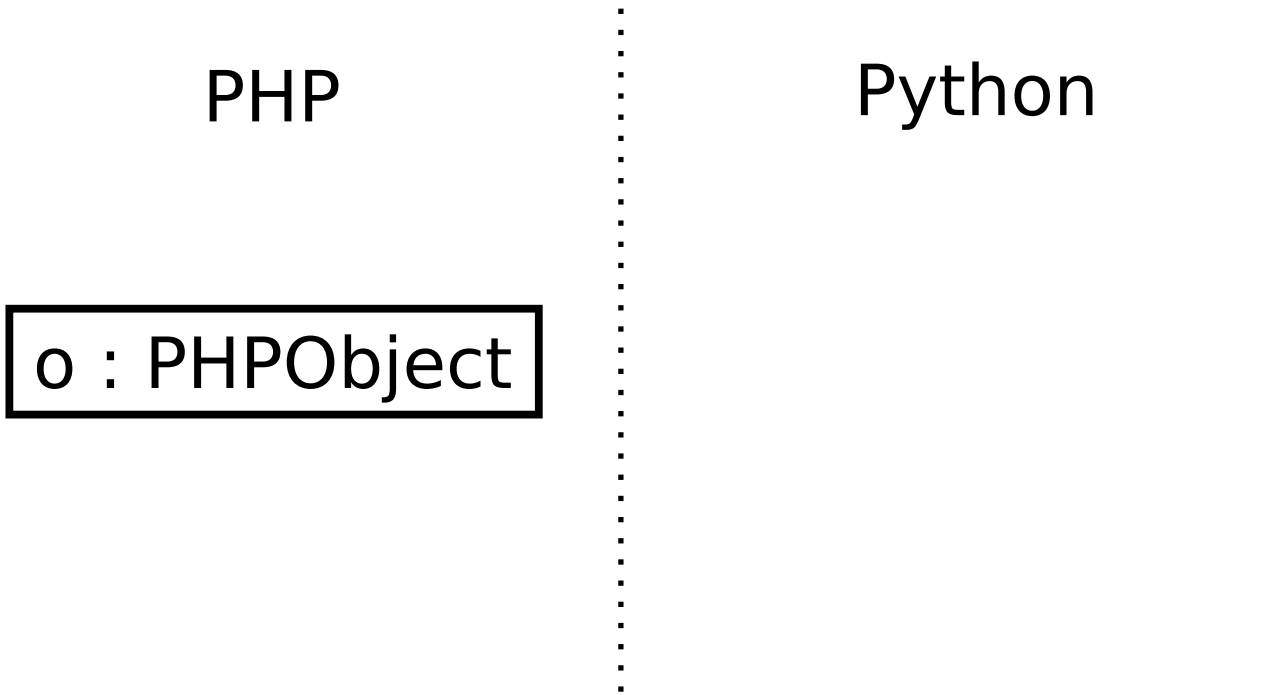


Datatype conversion: user types



Datatype conversion: user types



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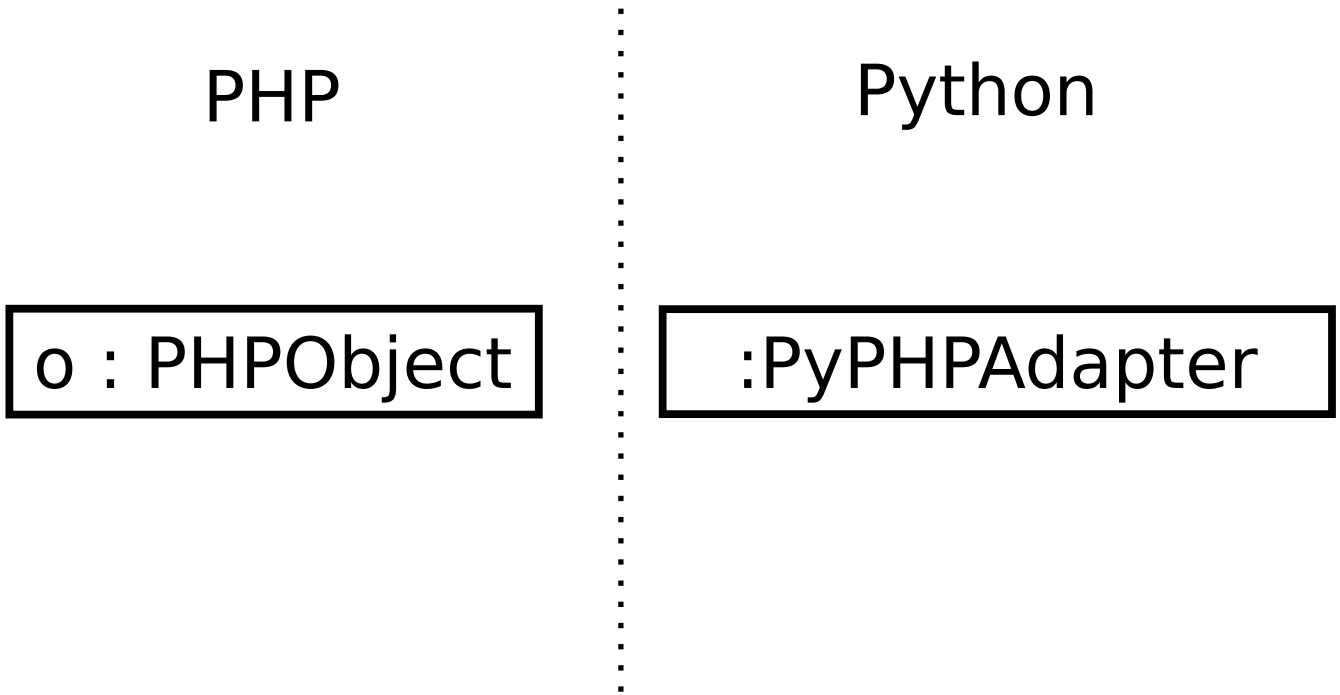
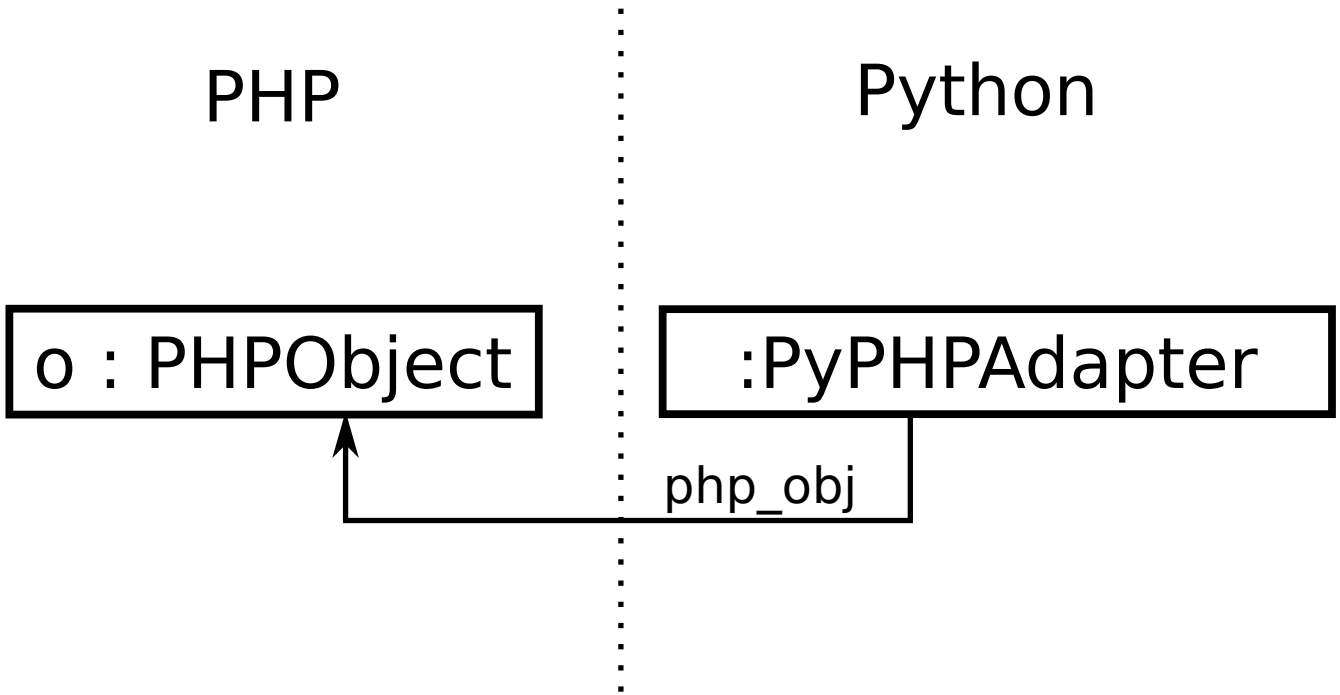
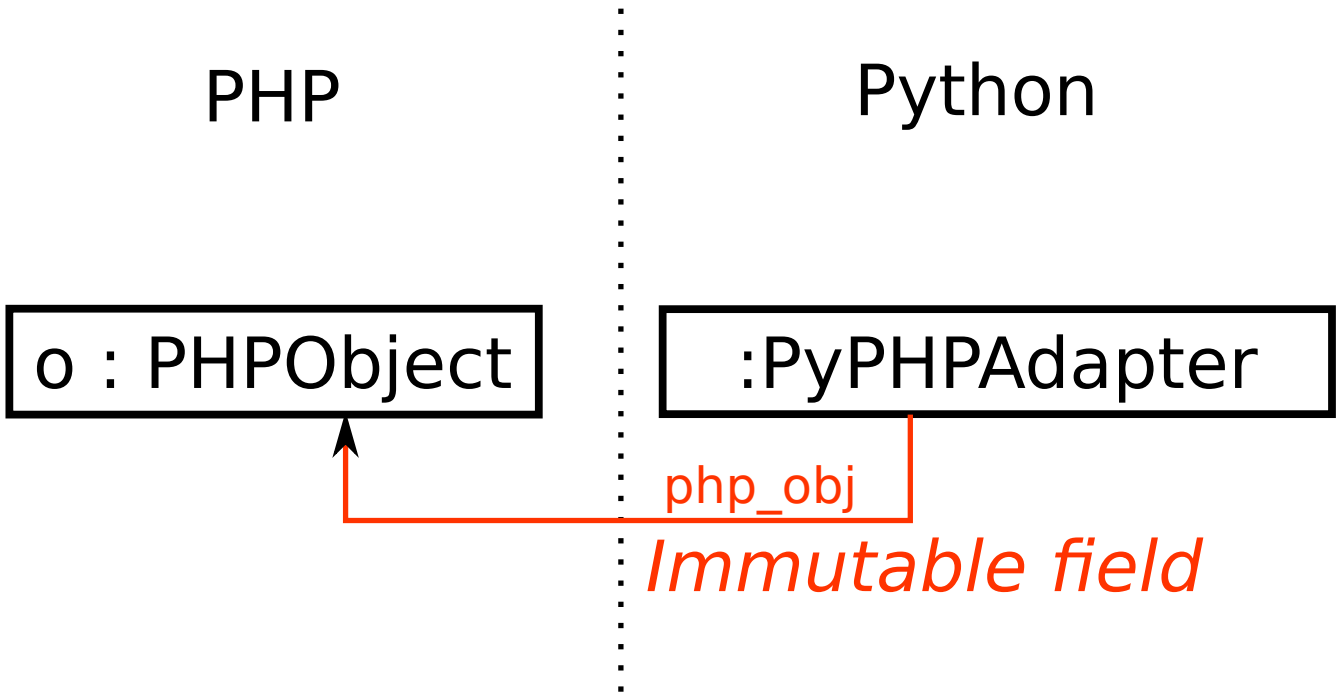


Datatype conversion: user types



Datatype conversion: user types



Some thoughts

- Critical: single meta-language (e.g. RPython / Truffle).

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- Critical: single meta-language (e.g. RPython / Truffle).
- Simplicity: good performance, yet understandable.
- Immutable adapters give near-native performance.
- **Whole new world of challenges for language designers & formalisers.**

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.

Summary

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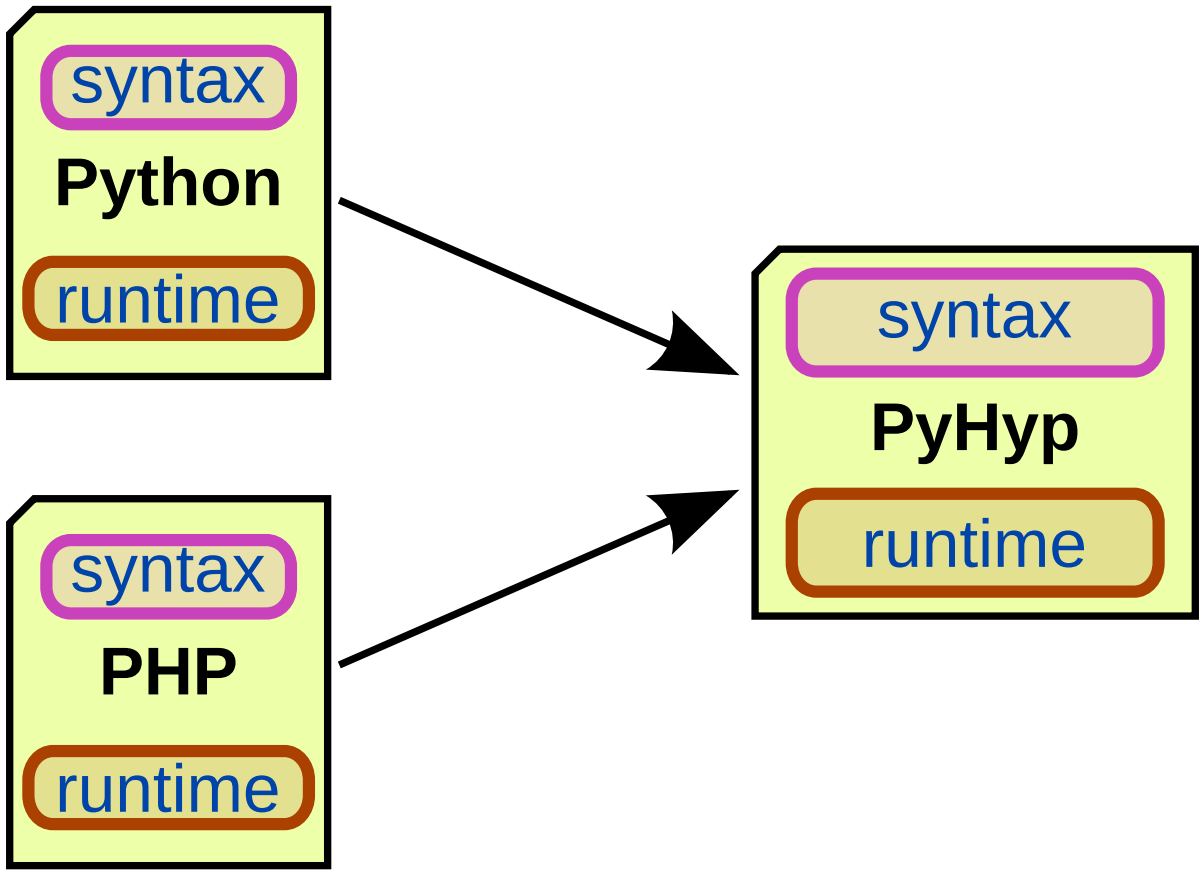
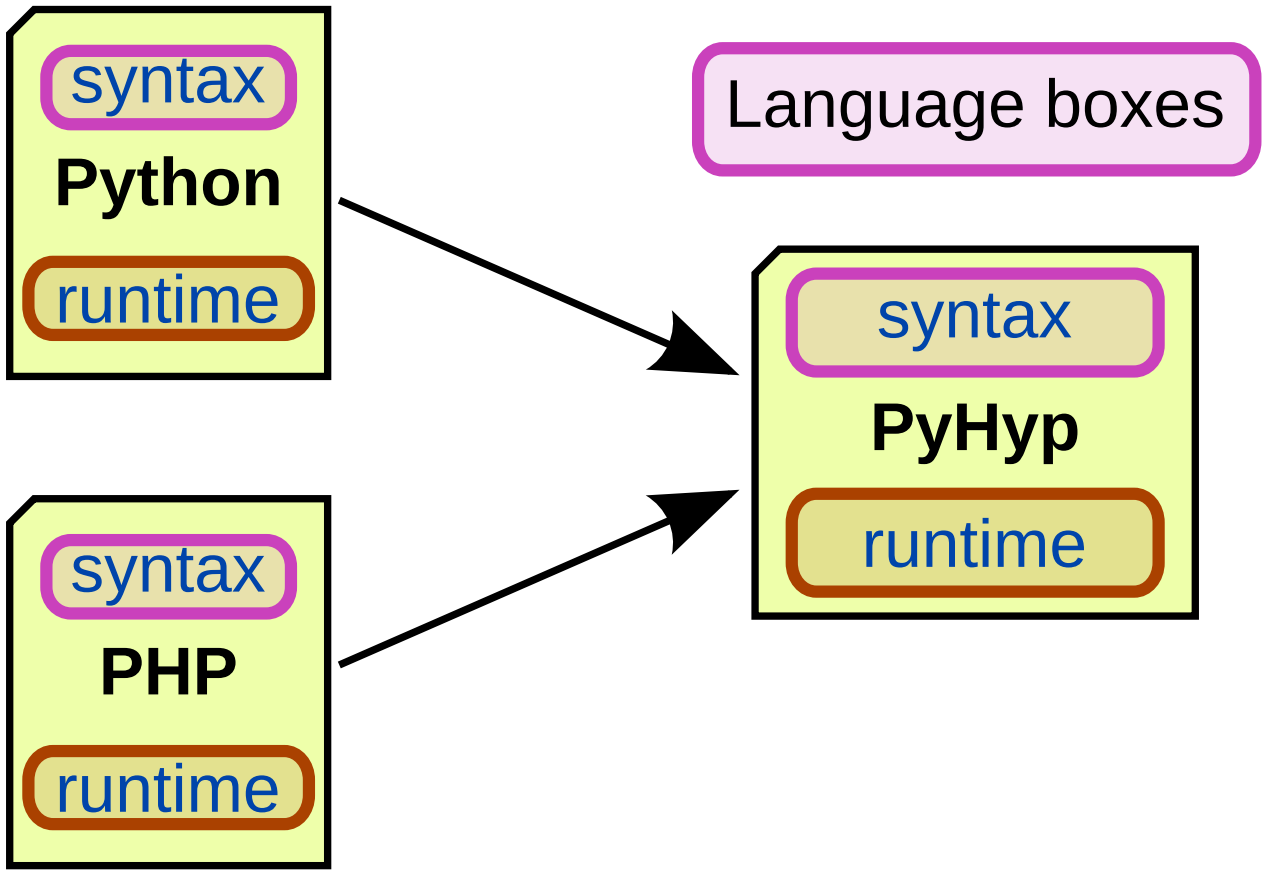

syntax
Python
runtime
syntax
PHP
runtime
syntax
PyHyp
runtime

Summary


syntax
Python
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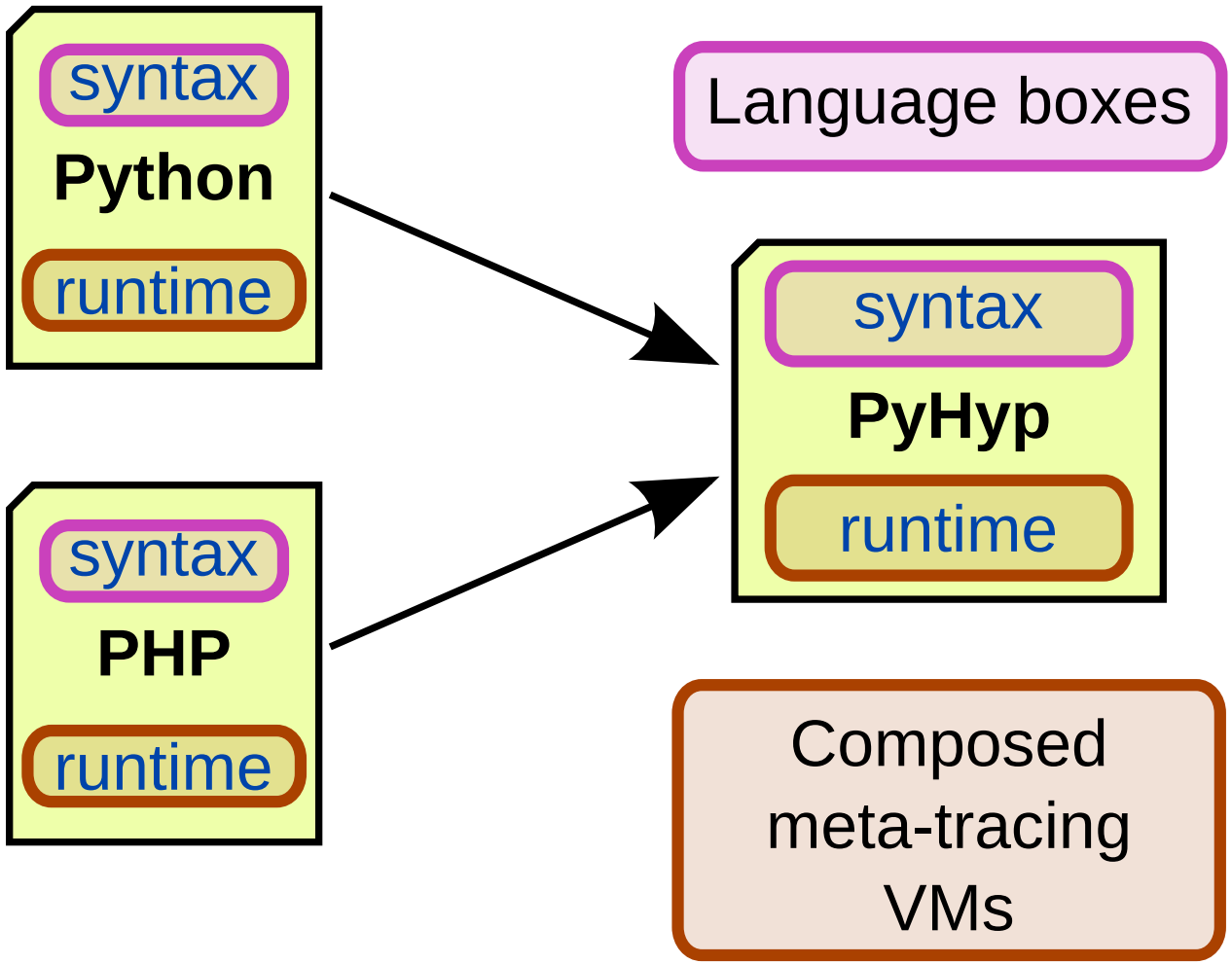
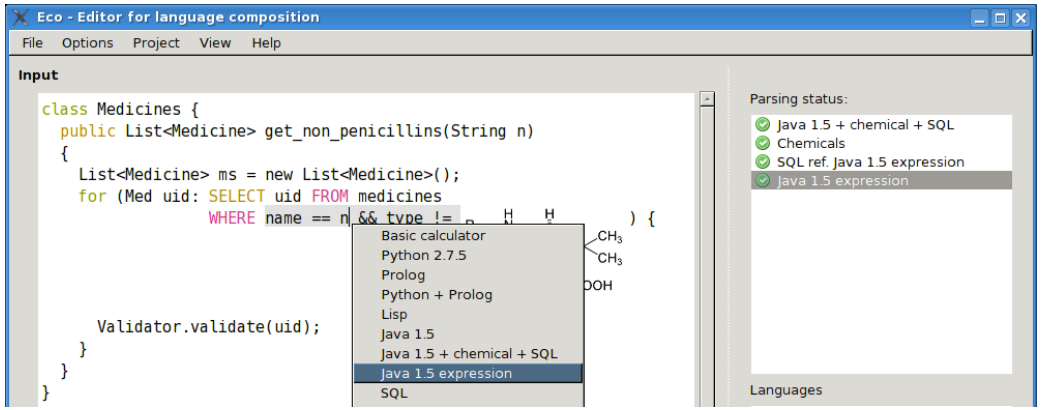
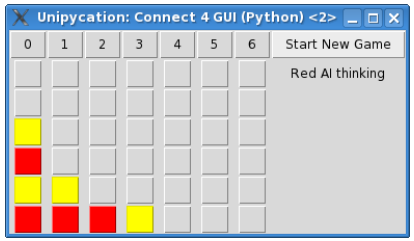
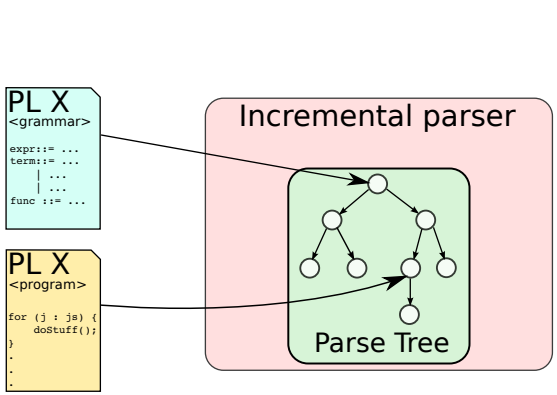
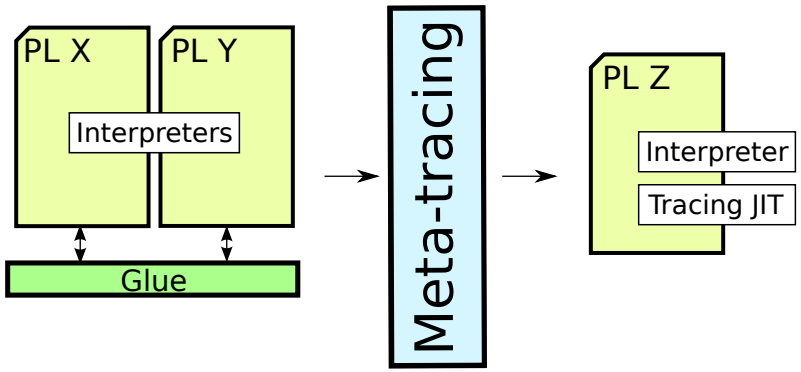

syntax
Python
runtime
syntax
PHP
runtime
Language boxes
syntax
PyHyp
runtime
Composed
meta-tracing
VMs

Thanks for listening









http://soft-dev.org/