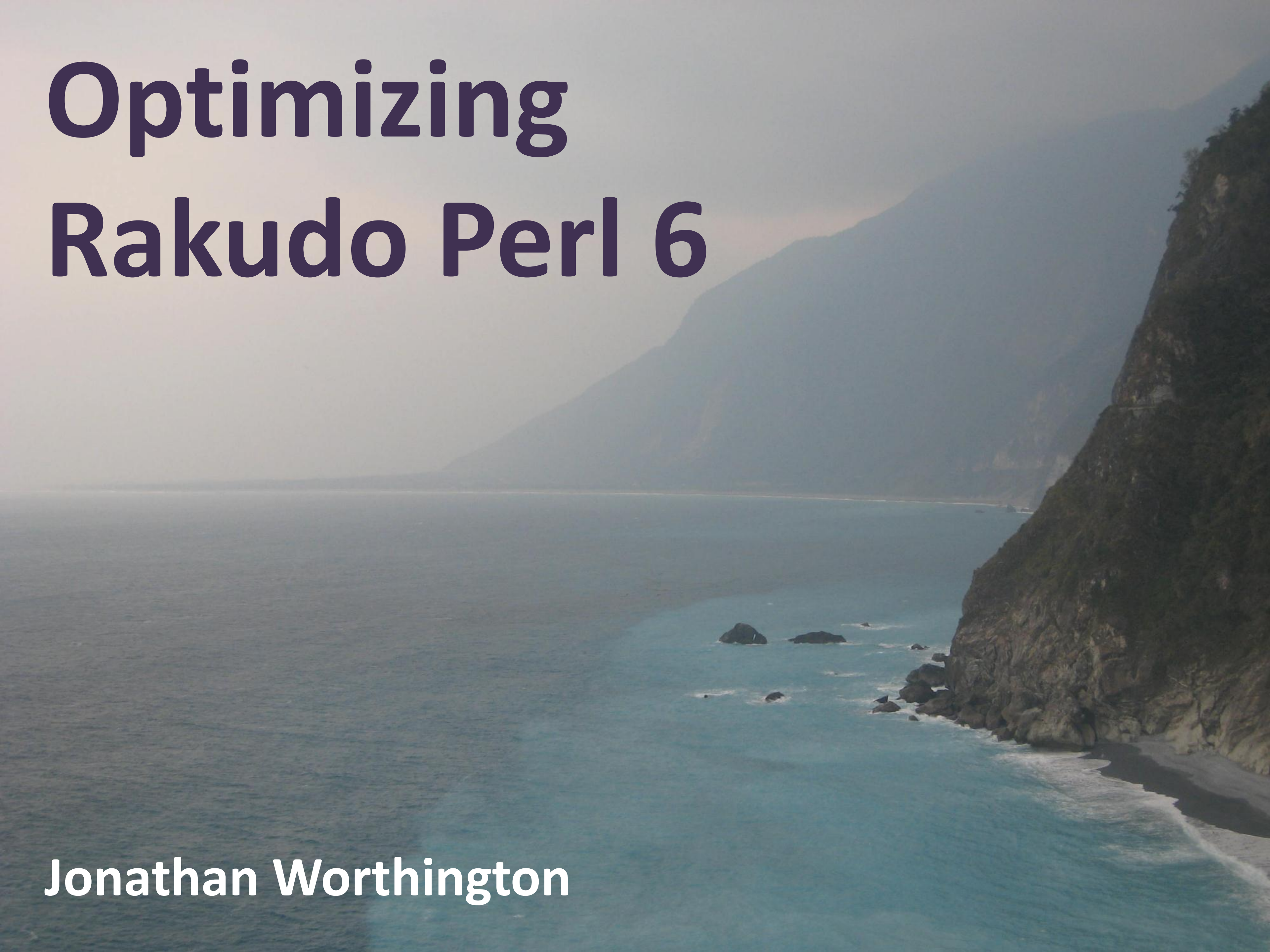
Optimizing Rakudo Perl 6



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OH HAI

Rakudo

What is Rakudo?

Unlike with Perl 5, Perl 6 refers to just the language, not any one implementation of it

Rakudo is a Perl 6 implementation

Supports a wide range of language features

Actively developed by many contributors (242 commits, 10 committers in October)

How Rakudo runs programs

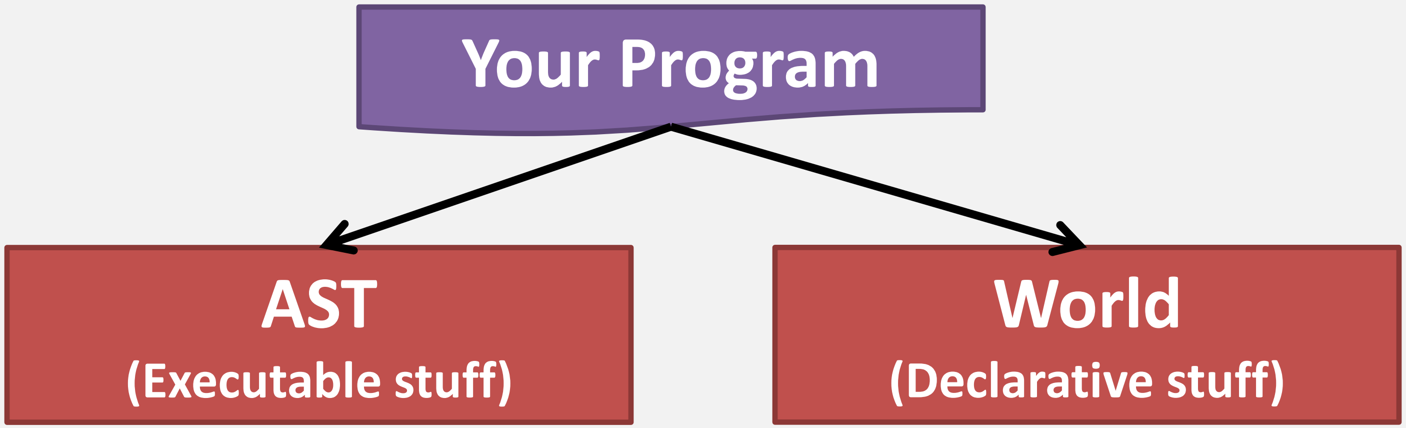
How Rakudo runs programs

You give Rakudo your program

Your Program

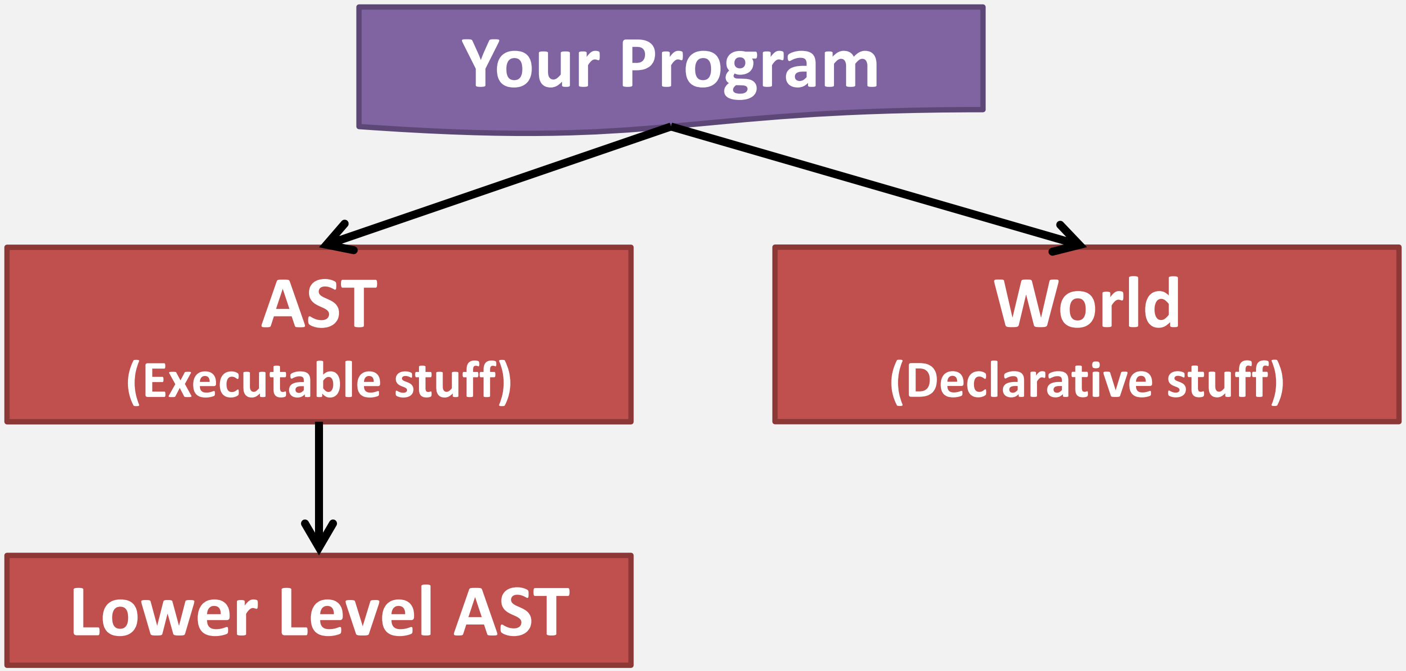
How Rakudo runs programs

It parses it and builds an AST and a world



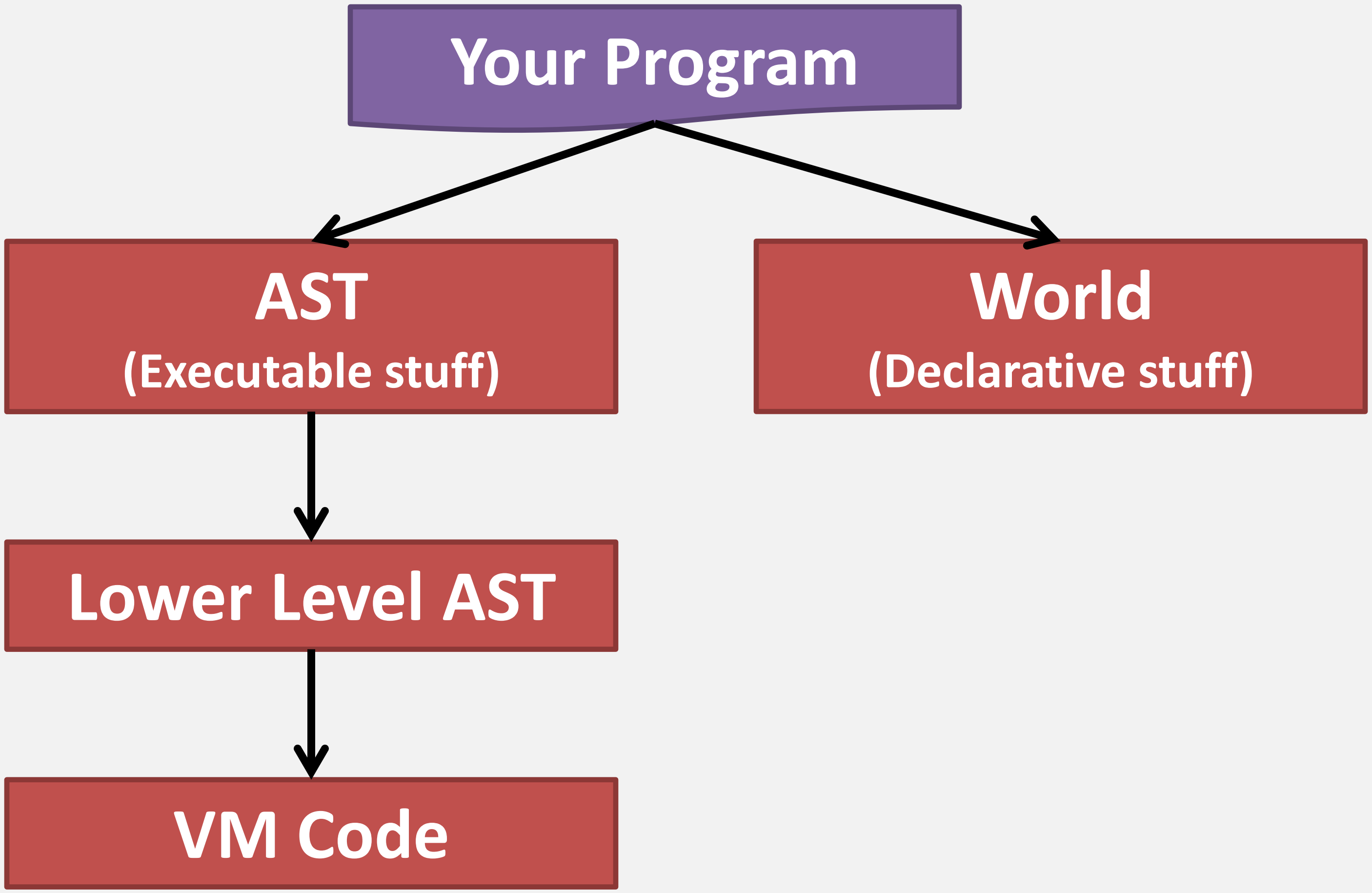
How Rakudo runs programs

The AST is turned into a VM-specific tree



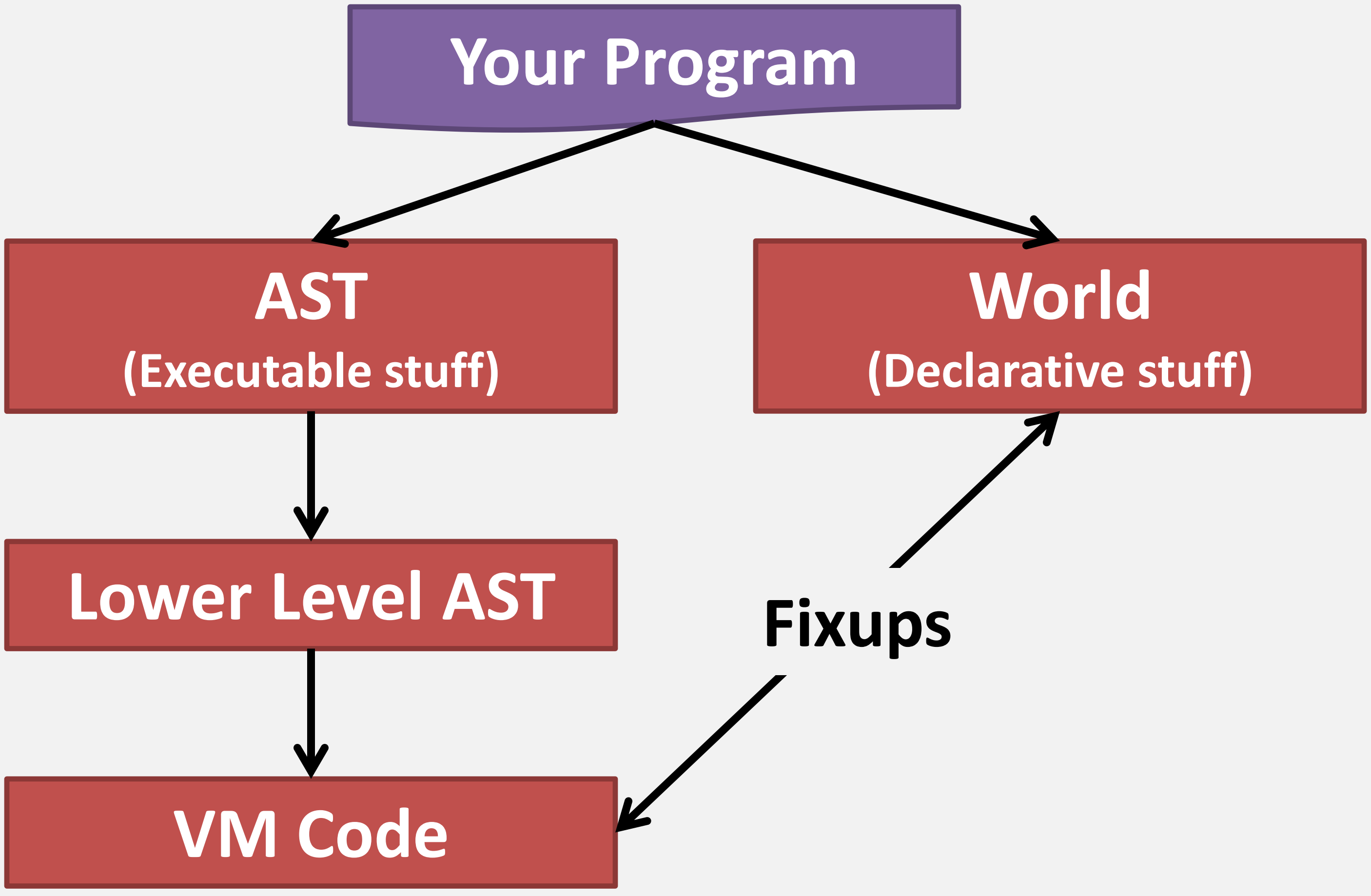
How Rakudo runs programs

Which finally becomes code for the VM



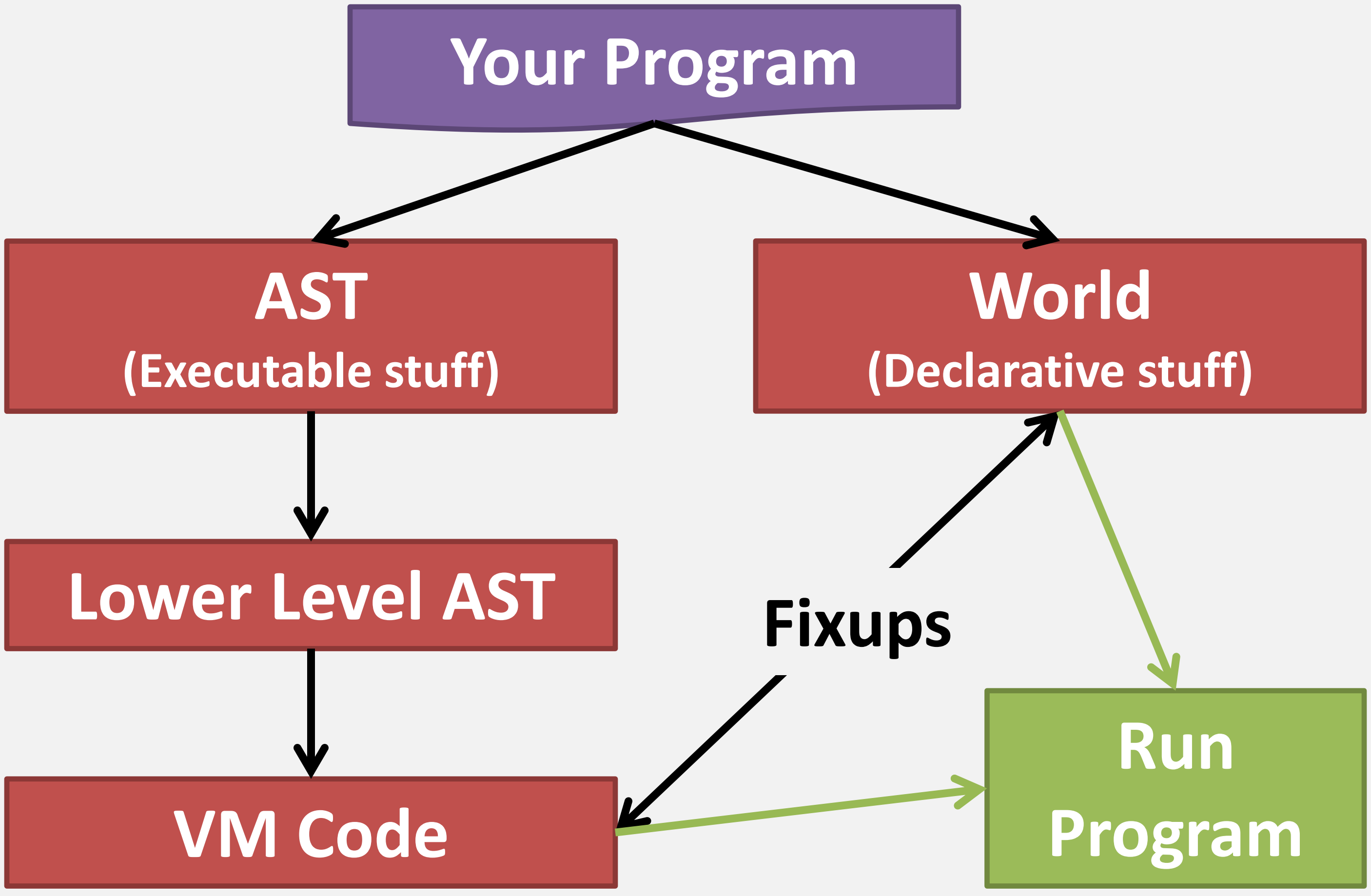
How Rakudo runs programs

We do a few fixups to the world…



How Rakudo runs programs

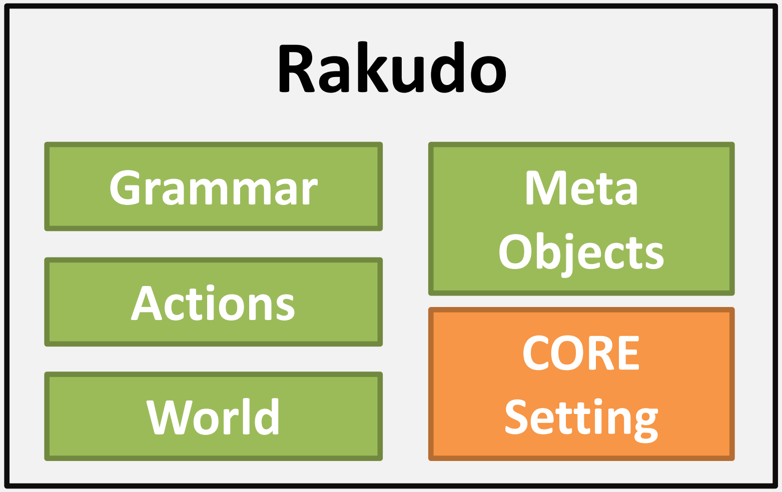
…and we're ready to run!



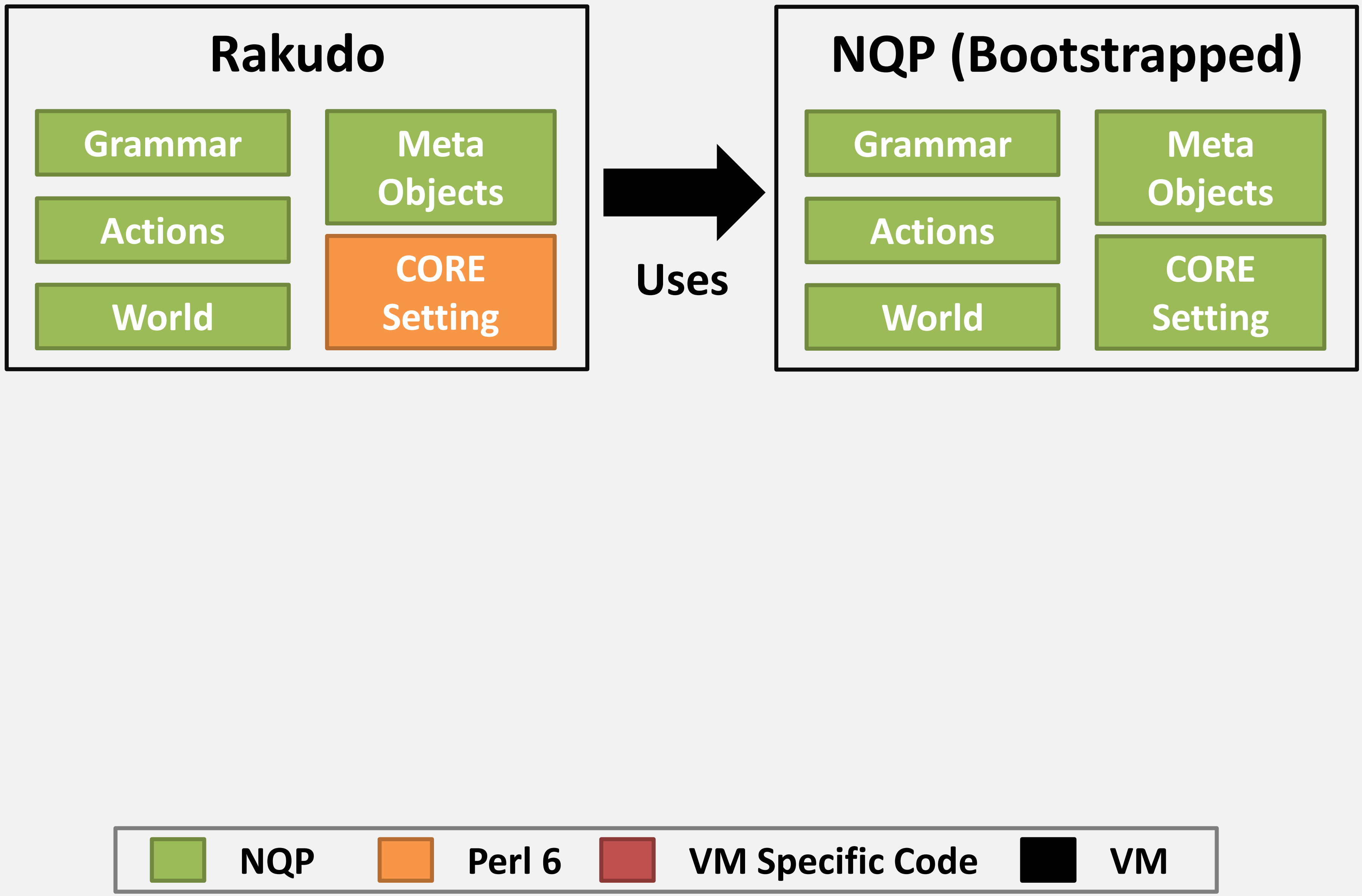
Rakudo Architecture

	NQP
	Perl 6
	VM Specific Code
	VM

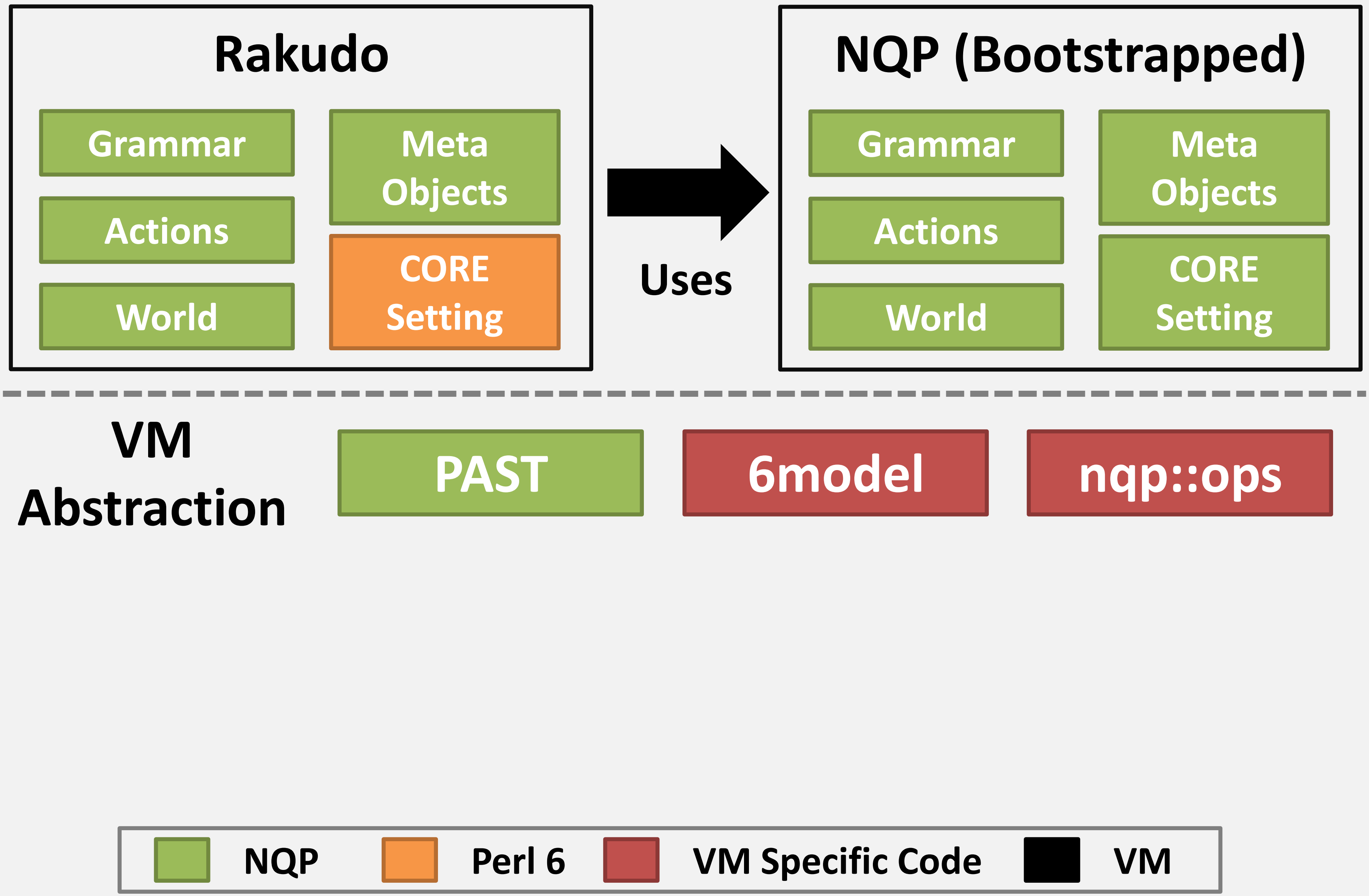
Rakudo Architecture



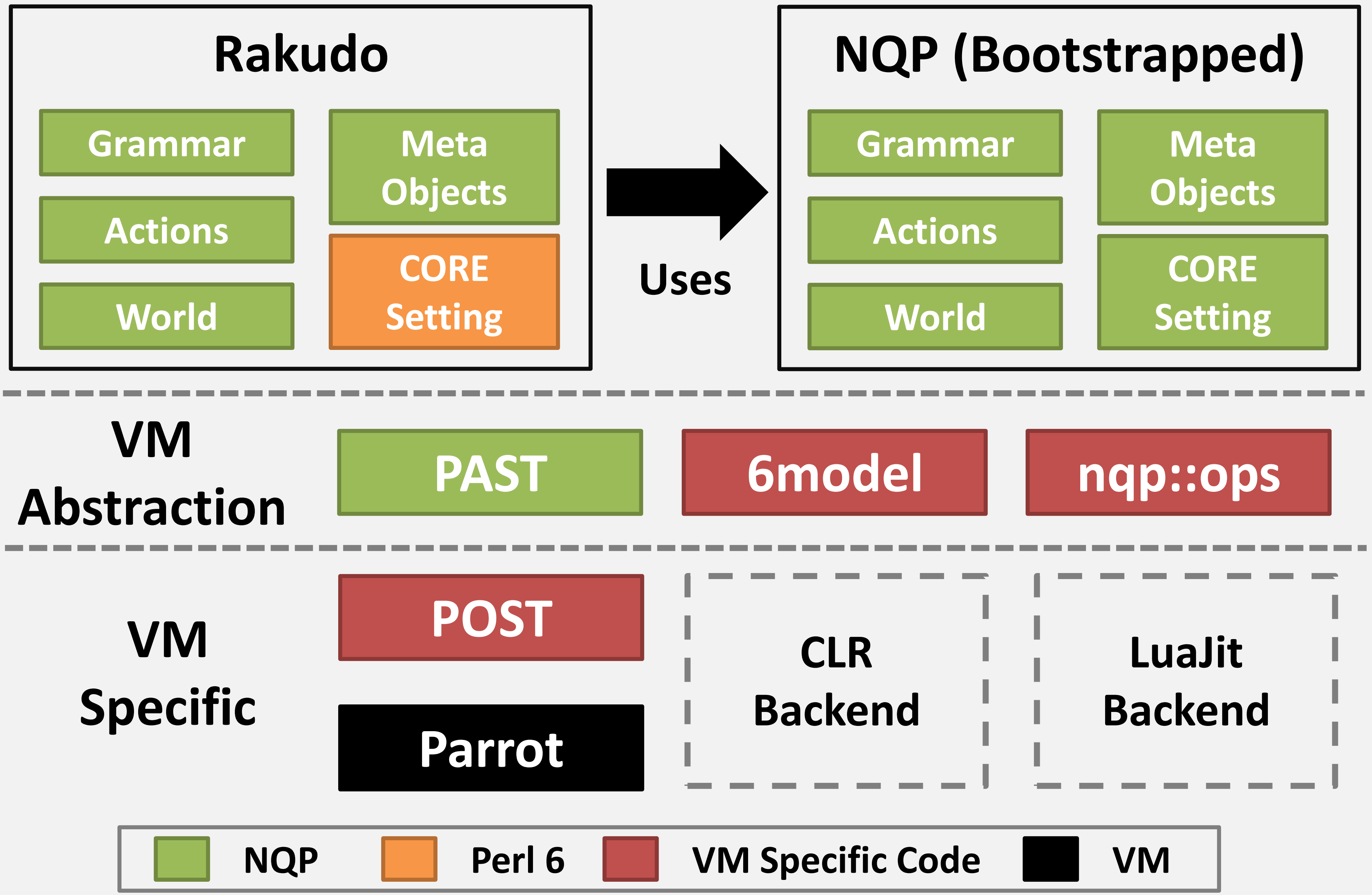
Rakudo Architecture



Rakudo Architecture



Rakudo Architecture



Where to optimize?

Optimize the Rakudo compiler

Optimize the setting (built ins)

Optimize NQP (which in turn helps Rakudo)

Optimize the lower level bits

Optimize the programs we're compiling

Which are we doing?

All of them! ☺

The first half of the this talk will focus on ways we optimize the compiler stack and the various built-ins

The second half will focus on the Rakudo optimizer, which produces better code from the input programs

Profile, don't guess!

Optimizations need to get targeted in order to really make a difference

Making something 2 times faster when it accounts for 0.5% of program runtime is not going to be very effective

Profilers tell us where we're spending time

VM-Level Profiling

What is it?

Profiling that lets us understand the low level parts of our implementation

May also involve profiling the VM itself
(we do this in the case of Parrot)

May involve profiling the layer on top of it
(this is the case for the CLR backend)

What it can tell us

Often, we find out a lot about the cost of primitive operations…

Signature binding
Object allocation
Lexical lookups
Invocation
Time spent doing GC

Example

We take our slowest running spectest and run it through the Visual Studio C profiler

Just from observation, we know that it spends a lot of time compiling the file

Once we get to running it, it’s all over within 2 seconds on modern hardware

Example

The output shows we spend 23% of the time in register allocation

perl6111101.vsp

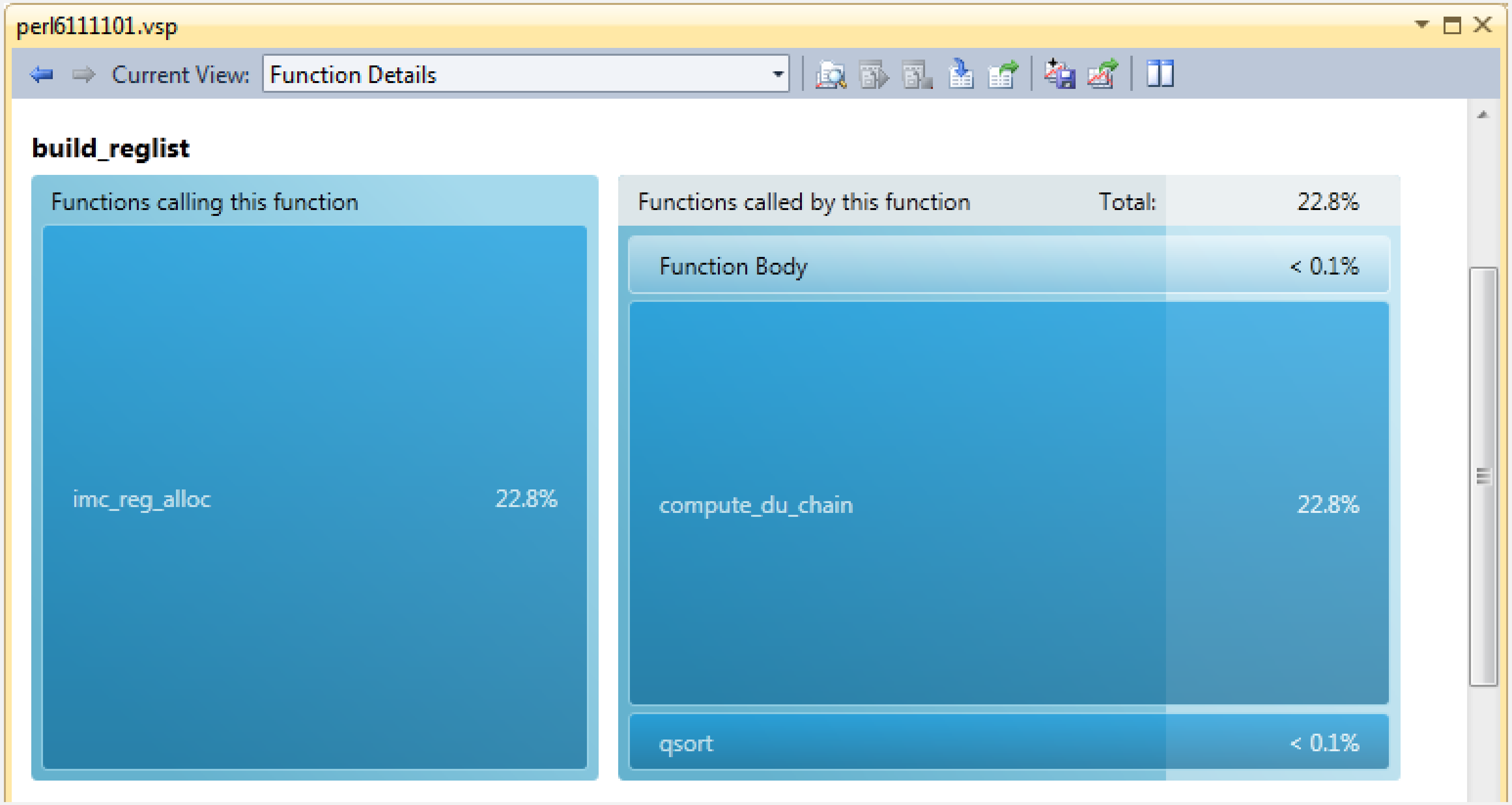
Current View: Functions

Function Name	Inclusive Samples	Exclusive Samples	Inclusive Samples %	Exclusive Samples %
imcc_run_compilation_internal	1,934	0	26.32	0.00
imcc_run_compilation_reentrant	1,934	0	26.32	0.00
imcc_compile_buffer_safe	1,933	0	26.31	0.00
imcc_run_compilation	1,932	0	26.29	0.00
Parrot_IMCCompiler_invoke	1,912	0	26.02	0.00
yyparse	1,905	15	25.93	0.20
imc_reg_alloc	1,717	0	23.37	0.00
build_reglist	1,676	0	22.81	0.00
compute_du_chain	1,675	160	22.80	2.18
get_new_pmc_header	1,630	37	22.18	0.50
Parrot_pmc_new	1,568	42	21.34	0.57
Parrot_callmethodcc_p_sc	1,317	37	17.92	0.50
Parrot_pcc_build_sig_object_from_op	1,242	100	16.90	1.36

This is decidedly abnormal

Example

We can further drill down to see where time is being spent



Example

While this does point to inefficiencies in the register allocator, it also suggests we should be generating better code

A quick look reveals that a couple of places generate code with an enormous number of registers used within a single block

Big pain point ➔ worth spending time on

Another story

Profiling compilation of the setting revealed that a huge amount of time (>20%) was taken by the GC to scan the system stack

This uncovered a very inefficient algorithm for pointer analysis that had terrible CPU cache characteristics

A 50ish line patch got a 20% improvement

Benefits and limits

We can find out what lower level operations are taking up time

However, at some level everything is made up of allocations, dispatches, etc.

We need to profile at a higher level in order to understand what those allocations and dispatches actually are

Perl 6 and NQP Profiling

What is it?

Enables us to find out what NQP and Perl 6 level routines we are spending time in

Parrot provides a sub-level profiler, which produces output that can be viewed using KCacheGrind

Can sometimes provide a very different view of where time is being spent

Example

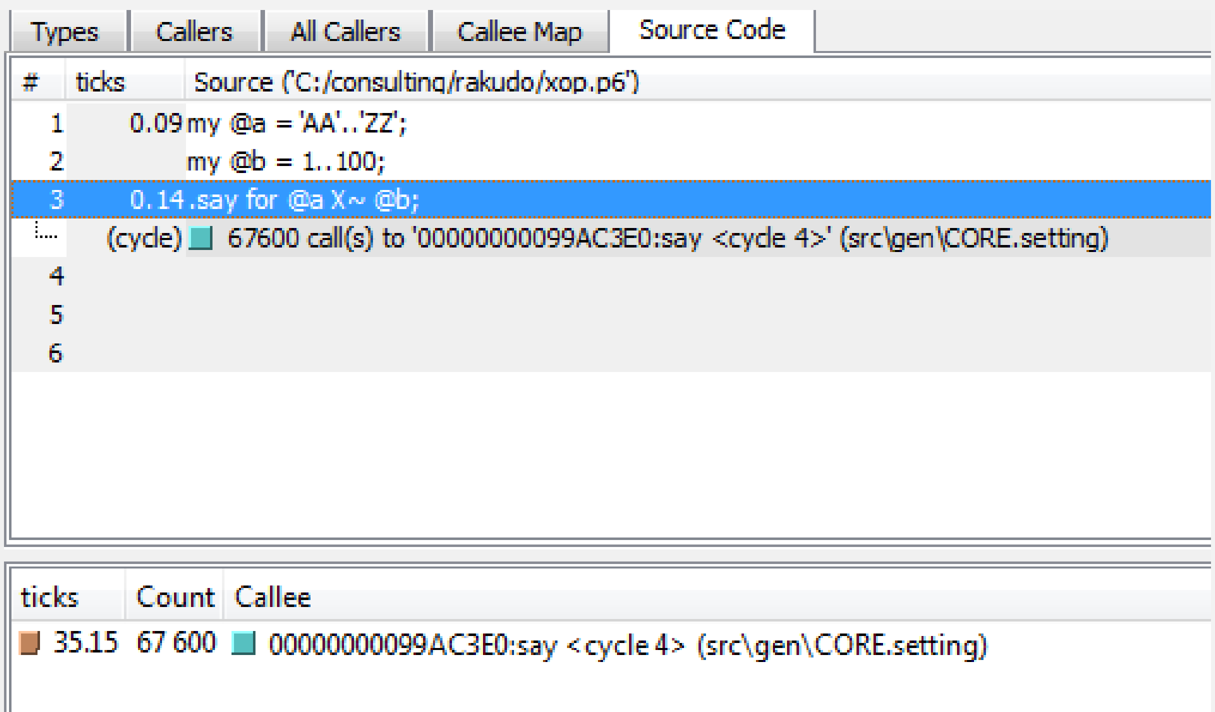
This program was found to run hideously slowly for some reason

```
my @a = 'AA'..'ZZ';
my @b = 1..100;
.say for @a X~ @b;
```

Let's take a look at it under the high level language profiler…

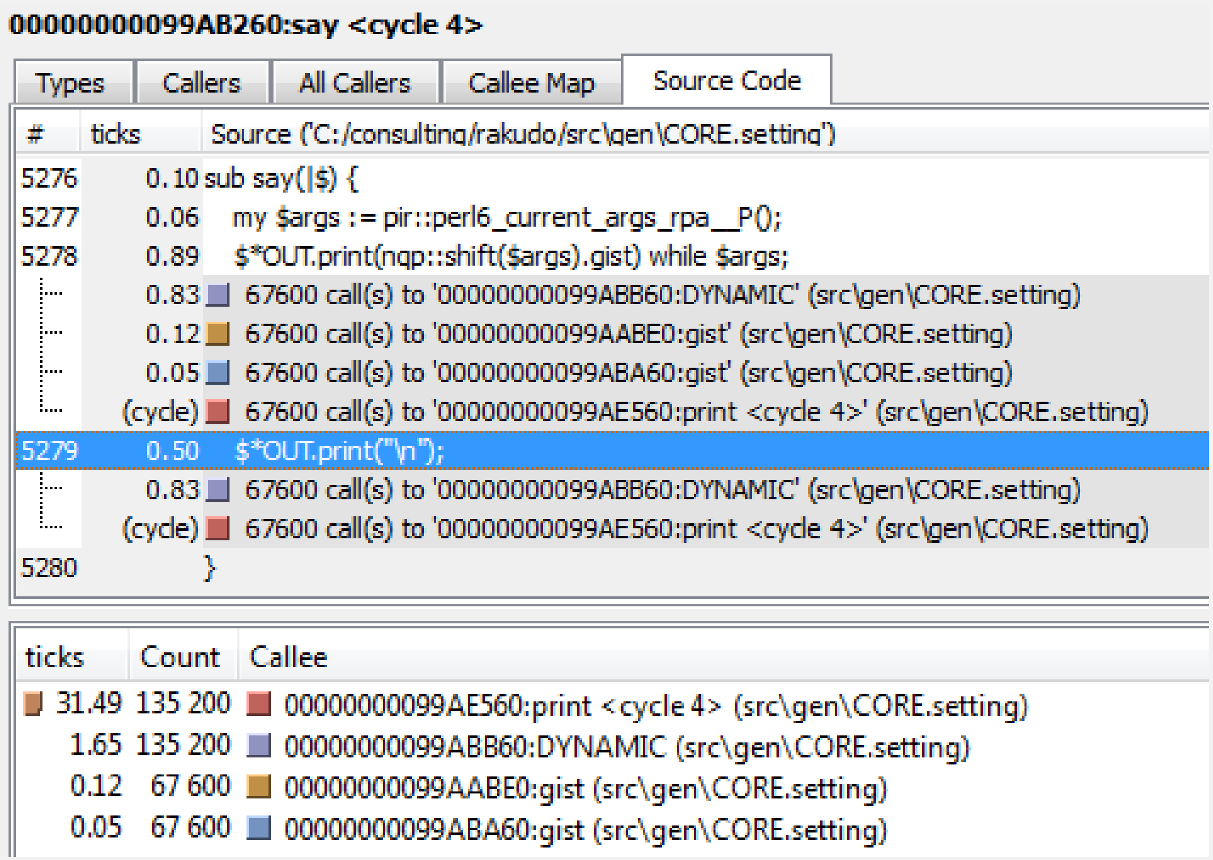
Example

Drilling down through the results, we discover that an awful lot of time is spent calling the say method (about 35%)



Example

Drilling down, say spends most of its time calling $*OUT.print(…)



Example

Looking at the code, we see that every call to IO.print assumes it is dealing with a list of possible things

```
method print(IO:D: *@list) {
    $!PIO.print(nqp::unbox_s(@list.shift.Str))
        while @list.gimme(1);
    Bool::True
}
```

That's a lot of work when we just have a single string to output!

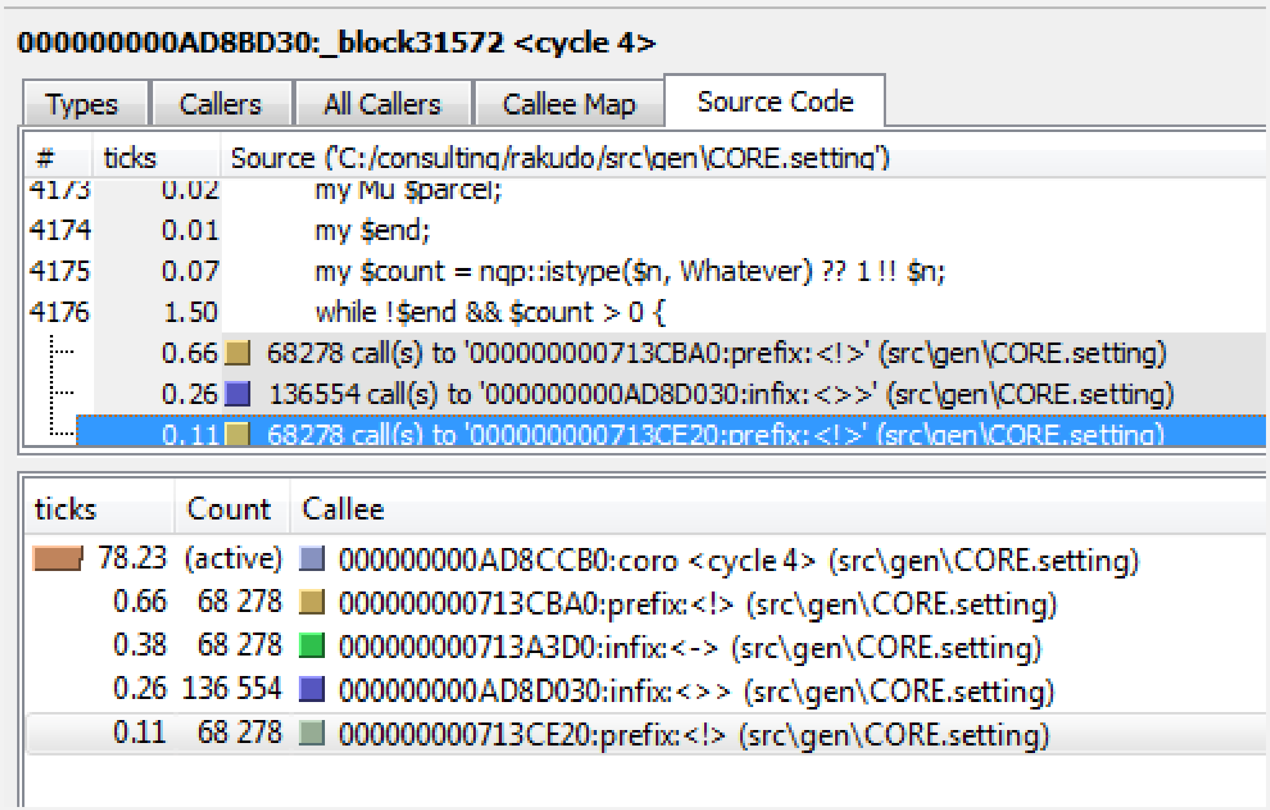
Example

Things are improved greatly by adding another multi candidate for the Str case

```
proto method print(|$) { * }
multi method print(IO:D: Str:D $value) {
    $!PIO.print(nqp::unbox_s($value));
    Bool::True
}
multi method print(IO:D: *@list) {
    $!PIO.print(nqp::unbox_s(@list.shift.Str))
        while @list.gimme(1);
    Bool::True
}
```

Example

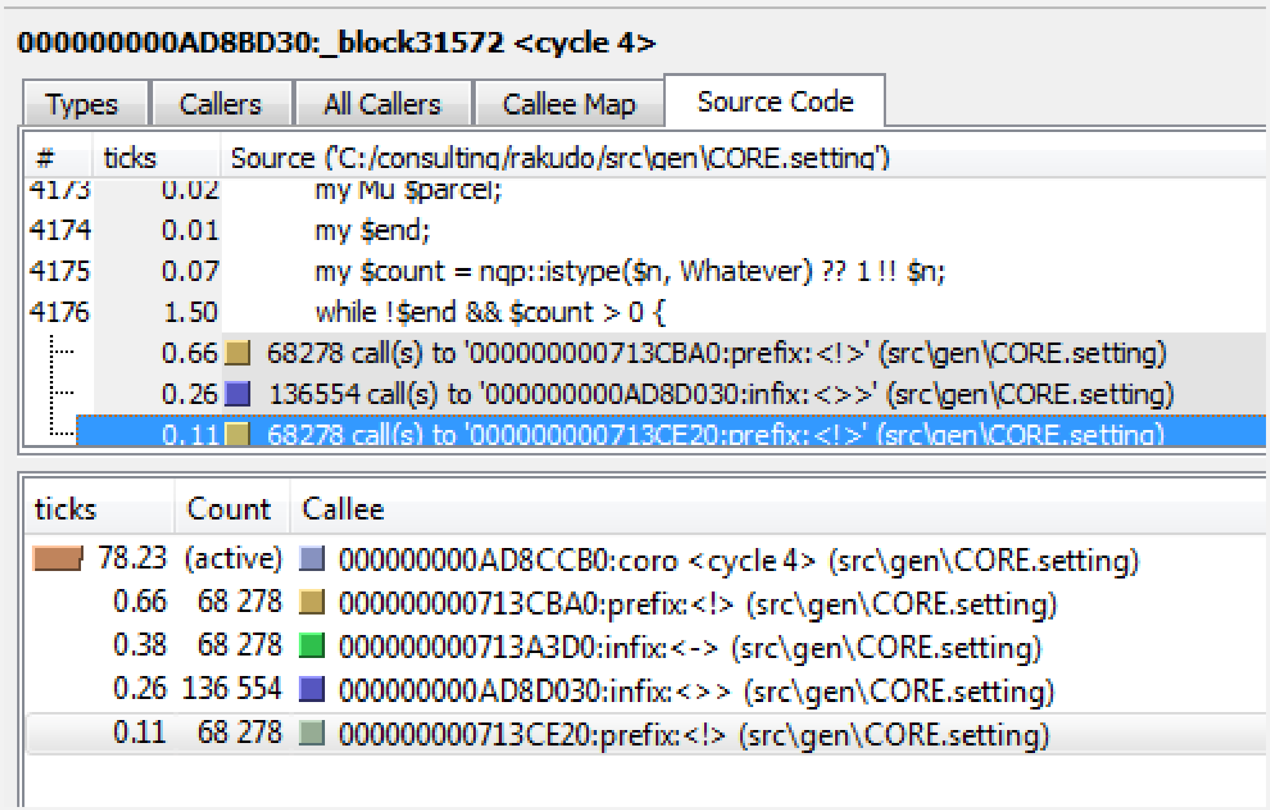
Continuing on, we end up in the iterator implementation, and spot something odd



We call two variants of the not operator – one more expensive than the other

Example

Continuing on, we end up in the iterator implementation, and spot something odd

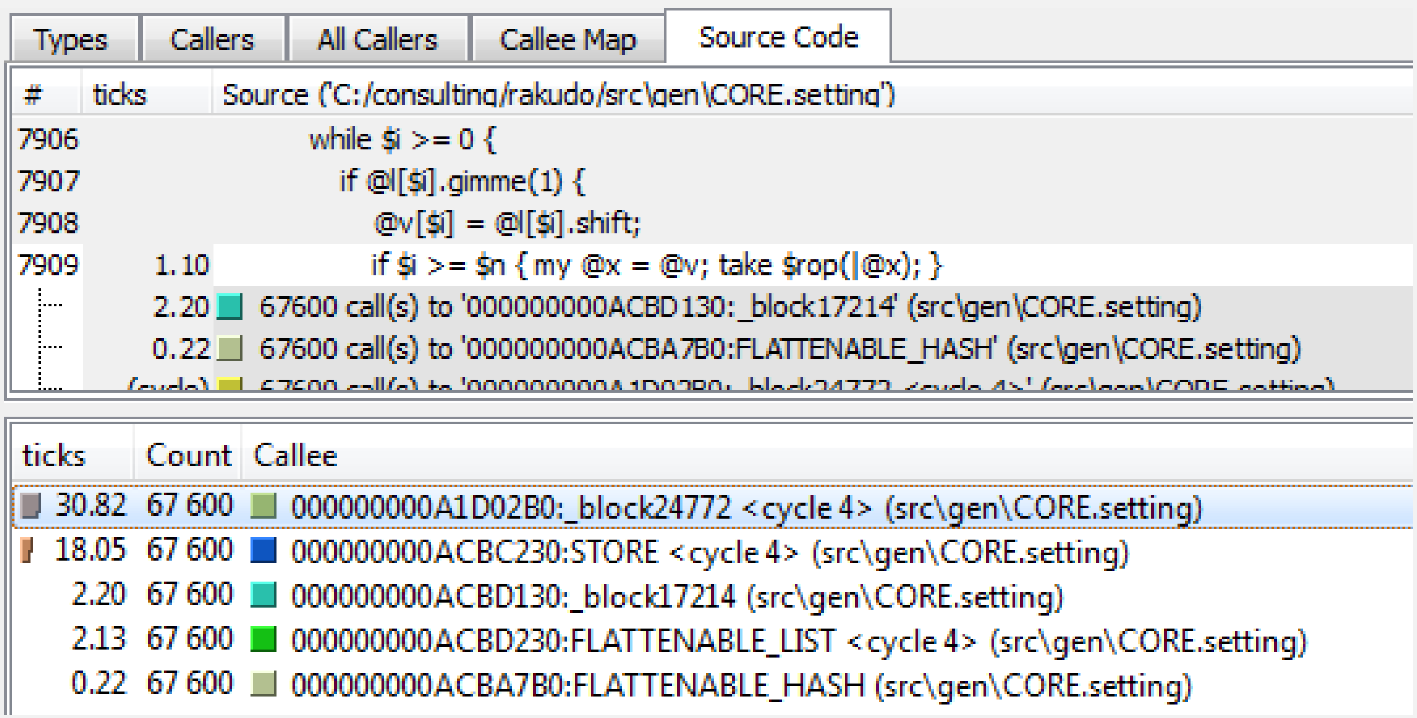


We call two variants of the not operator – one more expensive than the other

Fix by initializing $end to False!

Example

Going deeper, we find a real hot spot in the implementation of the X op - one line that accounts for over 50% of runtime



Example

Cross with an arity-2 op should be easy!

```
my $rop = METAOP_REDUCE($op);
# …
gather {
    while $i >= 0 {
        if @l[$i].gimme(1) {
            @v[$i] = @l[$i].shift;
            if $i >= $n { my @x = @v; take $rop(|@x); }
            else {
                $i = $i + 1;
                @l[$i] = (@lol[$i].flat,).list;
            }
        }
        else { $i = $i - 1; }
    }
}
```

This is overkill for the common case

Example

Cross with an arity-2 op should be easy!

```
my $rop = @lol.elems == 2 ?? $op !! METAOP_REDUCE($op);
# …
gather {
    while $i >= 0 {
        if @l[$i].gimme(1) {
            @v[$i] = @l[$i].shift;
            if $i >= $n { my @x = @v; take $rop(|@x); }
            else {
                $i = $i + 1;
                @l[$i] = (@lol[$i].flat,).list;
            }
        }
        else { $i = $i - 1; }
    }
}
```

This call took 30%; now it takes just 3%

Example

This was not a made up example; rather, it was a walk through of a process that resulted in commits to Rakudo

Just from these changes, the example program now ran in half the time

There’s plenty more improvements waiting to be discovered and implemented

Profiler win!

The profiler shows time spent across…

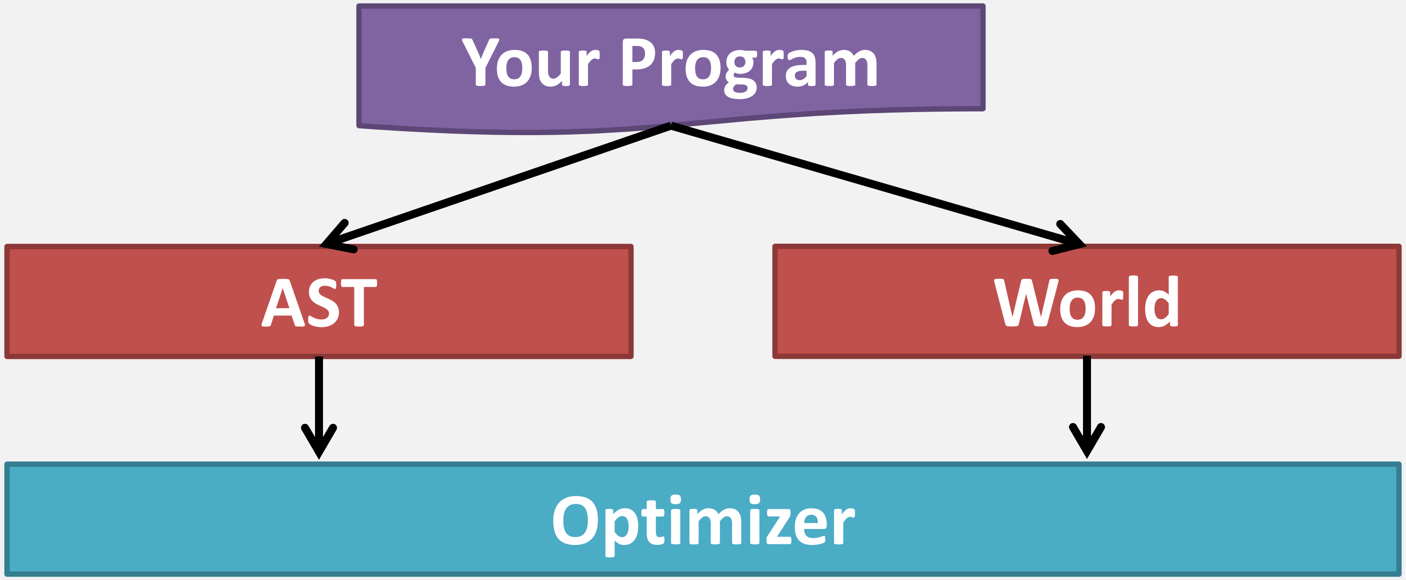
User code (Perl 6)
Built-ins in the setting (Perl 6)
The compiler implementation (NQP)

We can drill down between them (even seeing where the compiler calls a BEGIN block written in Perl 6!)

What is an optimizer?

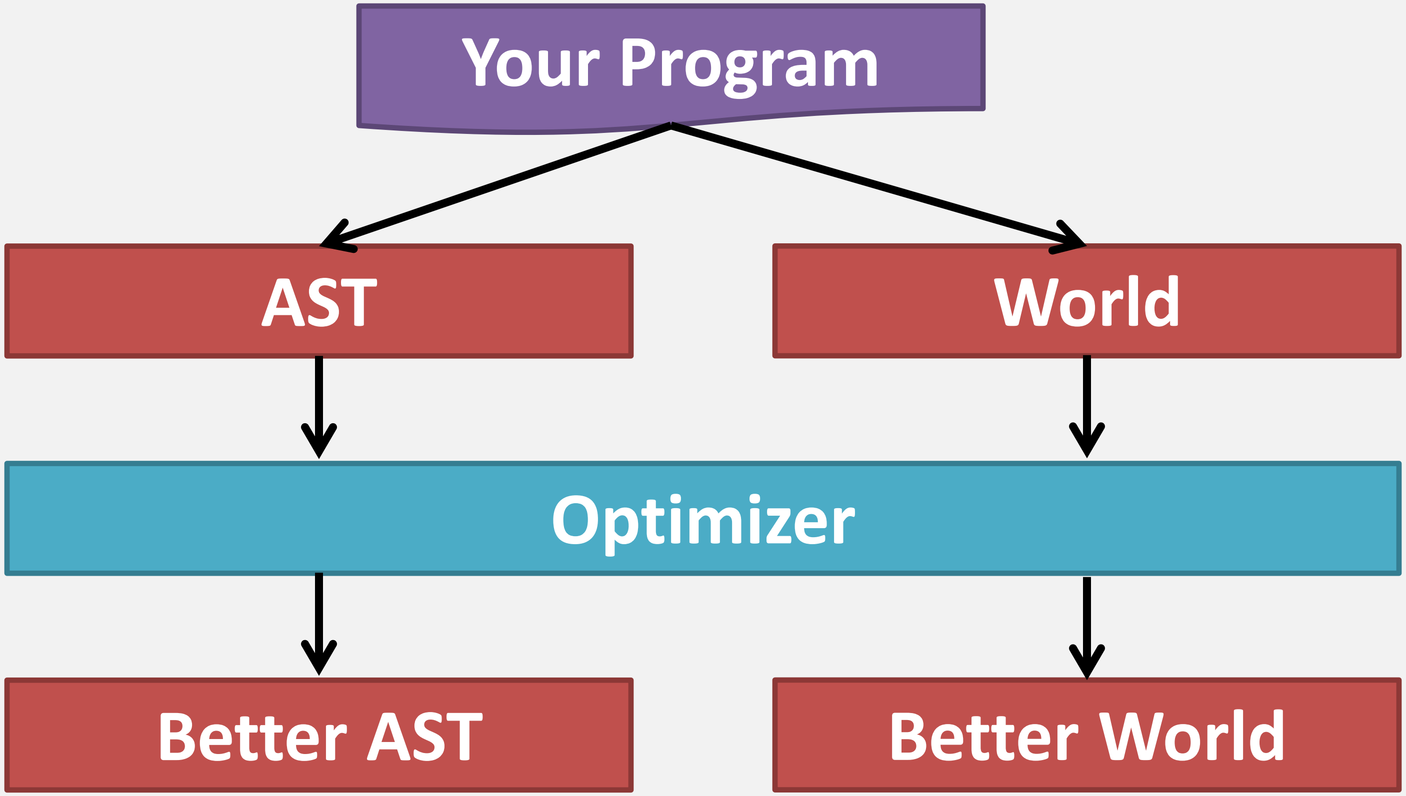
Where does an optimizer fit in?

The optimization phase comes after we have fully built the AST and the world



Where does an optimizer fit in?

It considers both, and then tries to improve them (mostly, it does changes “in place”)



Overall approach

An optimizer does everything in two steps

Analysis

What optimizations can I perform here? Is it really safe to do so?

Transformation

Given the analysis says “yes”, actually do the optimization

What’s the hard part?

The transformations tend to be relatively straightforward

All of the hard work takes place in the analysis phase

Doing a transformation where it’s not safe results in an “improved” program that is faster…and wronger!

The Rakudo Perl 6 Optimizer

Optimizations we do today

So far, the optimizer can do…

Inlining simple, declaration-free blocks
Compile-time sub call binding checks
Inlining of simple subs
Compile-time multi-dispatch resolution
Inlining of compile-time resolved multi candidates

It can also detect some cases where code could never possibly work – and alert you at compile time

Sample program

For this example, we'll consider a short program with a tight loop; the programmer gave us a little type information too

```
my int $i = 0;
while $i < 10000000 {
    $i = $i + 1;
}
say $i;
```

Without optimization (1)

```
  store_lex "$i", 0
loop1019_test:
  find_lex $I1013, "$i"
  perl6_box_int $P101, $I1013
  nqp_get_sc_object $P102, "1320268783", 10
  $P1012 = "&infix:<<>"($P101, $P102)
chain_end_15:
  unless $P1012, loop1019_done
  .const 'Sub' $P1015 = "11_1320268784.057"
  capture_lex $P1015
  $P1015()
  goto loop1019_test
loop1019_done:
  find_lex $I1020, "$i"
  perl6_box_int $P101, $I1020
  $P102 = "&say"($P101)
```

Unrequired boxing

Multi-dispatch to the < operator on a hot path

Inner block of the while loop is an invocation

Without optimization (2)

```
.sub "_block1014"  :anon
:subid("11_1320268784.057")
    .param pmc param_1017 :call_sig
    .lex "$_", $P1016
    .lex "call_sig", param_1017
    bind_signature
    find_lex $I1018, "$i"
    perl6_box_int $P103, $I1018
    nqp_get_sc_object $P104,
"1320268783.804", 11
    $I100 = "&infix:<+>"($P103, $P104)
    store_lex "$i", $I100
    perl6_box_int $P105, $I100
    .return ($P105)
.end
```

Unrequired boxing

Multi-dispatch to the + operator

Boxing again!

Simple block inlining

In Perl 6, every block is conceptually a new lexical scope and a closure

Analysis

Our block declares no lexical symbols, so it serves no operational purpose

Transformation

Flatten it in to the enclosing scope

After simple block inlining

```
  store_lex "$i", 0
loop1019_test:
  find_lex $I1013, "$i"
  perl6_box_int $P101, $I1013
  nqp_get_sc_object $P102, "1320268783.804", 10
  $P1012 = "&infix:<<>"($P101, $P102)
chain_end_15:
  unless $P1012, loop1019_done
  find_lex $P103, "$_"
  set pres_topic_1, $P103
  find_lex $I1016, "$i"
  perl6_box_int $P104, $I1016
  nqp_get_sc_object $P105, "1320271436.881", 11
  $I100 = "&infix:<+>"($P104, $P105)
  store_lex "$i", $I100
  perl6_box_int $P106, $I100
  store_lex "$_", pres_topic_1
  goto loop1019_test
loop1019_done:
  find_lex $I1020, "$i"
  perl6_box_int $P101, $I1020
  $P102 = "&say"($P101)
```

Blue

Original code in outer scope

Green

Inlined code from the inner block

Orange

Added “safety” code to preserve the $_ variable

Operators and multiple dispatch

In Perl 6, all operators are multiple dispatch lexical subroutines

This means that operator overloading just means declaring extra multi candidates

Changes are lexically scoped – that is, your operator changes are not global, and thus do not affect unrelated code

Performance consequences

The Perl 6 multiple dispatch algorithm can be implemented efficiently; Rakudo does rather well here

However, invocation overhead is still very high compared to just adding two numbers!

The good news: in a given scope we know all of the multi candidates that are possible

Compile time resolution

Knowing all possible candidates

+

Knowing the types of all arguments

=

Can (sometimes) decide which candidate is going to be called at compile time

\☺/

Compile time resolution

At compile time we know that...

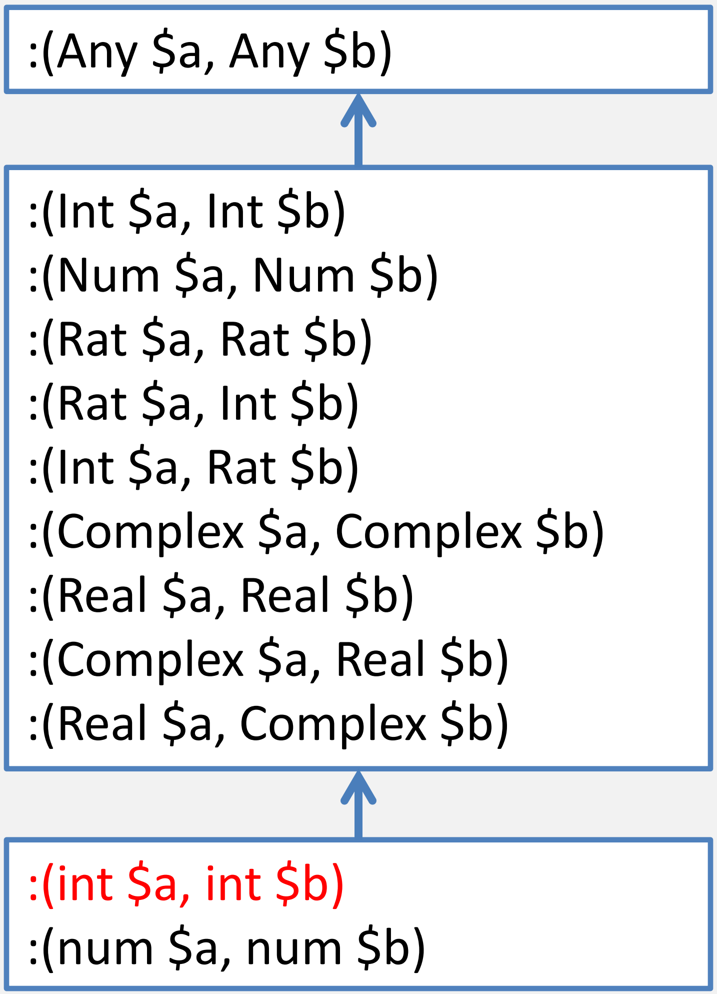
```
$i + 1
```

Will make a call &infix<+>(int, int)

Can we safely decide which multi candidate will be called based upon this information?

Compile time resolution

&infix<+>



We cannot go for a simple match – we have incomplete information in some cases

Just because we statically have Any does not mean we won't have types that pick a narrower candidate at runtime

However, always safe to pick from natives group or the one immediately above it

Inlining

Deciding which multi candidate to invoke helps a bit – but the decision making is actually dominated by the invocation

However, we have another option: some very simple subs can be inlined

This means their bodies are just copied to the place where the call would be

After inlining operator multis

```
  store_lex "$i", 0
loop1019_test:
  find_lex $I1014, "$i"
  islt $I100, $I1014, 10000000
  perl6_booleanize $P101, $I100
  perl6_decontainerize_return_value $P102, $P101
  unless $P1012, loop1019_done
  find_lex $P103, "$_"
  set pres_topic_1, $P103
  find_lex $I1015, "$i"
  add $I100, $I1015, 1
  store_lex "$i", $I100
  perl6_box_int $P103, $I100
  store_lex "$_", pres_topic_1
  goto loop1019_test
loop1019_done:
  find_lex $I1020, "$i"
  perl6_box_int $P101, $I1020
  $P102 = "&say"($P101)
```

Here, the < operator has been inlined

Here, the + operator has been inlined

Additionally, much boxing is now gone!

Result

The optimizations result in code that is much more "to the point", and that isn't paying invocation overhead all the time

Compared to the original program, this optimized version runs 23 times faster!

The code still isn't all that great – we can do somewhat better yet

That could never work!

While trying to resolve some dispatches at compile time, the optimizer may also be able to prove that it will never work

```
sub greet($name, $greeting) {
    say "$greeting, $name";
}
greet("Elena");
```

```
===SORRY!===
CHECK FAILED:
Calling 'greet' will never work with argument types (str)
(line 4)
    Expected: :(Any $name, Any $greeting)
```

Future Optimizer Work

Variable analysis

Currently, the optimizer does not analyse how variables are used in a program

Knowing when variables are read and/or written would allow for a range of optimizations and detection of program errors at compile time

This is the "next big task" for the optimizer

Method inlining

Methods calls are late bound, so we don’t tend to really know what to inline

However, we can make a good guess, then include both an inline and a guard type check, which falls back to a normal dispatch

Best when the call is in a hot loop, but the guard check can be moved outside of it

Type inference

Many variables keep the same type they start out with for their entire lifetime

May be able to infer this initial type, and then try to "prove" that it is preserved throughout the variable's life time

A way to make untyped programs faster

Looking Ahead

Faster!

The Rakudo of today tends to be faster – and is sometimes considerably faster – than the Rakudo of a year ago

Performance is one of the biggest adoption blockers, and is a big focus for us

Much more work to come – stay tuned, or come and join in the fun! ☺

all<Ďakujem Danke>

Questions?

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