Giving MoarVM a new general dispatch mechanism to speed up various slow Raku constructs

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Edument

What is dispatch

and why does it matter?

How we approached dispatch thus far

and the shortcomings of past approaches

A new generalized approach

to implementing the many different kinds of dispatch

The current status

in terms of completion and performance

Future opportunities

for further improvements

What is dispatch

and why does it matter?

```
$store.get-product($id)
```


```
class Store {
    method get-product($id) {
        ...
    }
}
```

```
$x + $y
```


```
multi infix:<+>(Int $x, Int $y) {
    ...
}
```

Dispatch fills the places in-between the code we write

It's everywhere...

...but we'd like to see it nowhere

(especially not high on profiler output)

More generally, dispatch is any process where the **types or values** of arguments determine **what code we run**

Assignment is dispatch

```
# Just write to the Scalar $!value attribute
my $x = $v;
# Depends on the type of $v (write or error)
my Int $y = $v;
# Reset to the default value
$x = Nil;
# May need to vivify the hash value
%h<x> = $v;
```

An incomplete list of things that are essentially dispatch in Raku

Standard method calls ($o.m)

Maybe method calls ($o.?m)

Qualified method calls ($o.T::m)

Private method calls ($o!pm)

Qualified private method calls ($o!T::Pm)

Multiple dispatch

Invocation of an object (Code, CALL-ME)

callsame, nextwith, etc.

Anything that has been wrap'd

Coercion

Return type assertion

Binding type assertion

Assignment

Sinking

And many of these combine
(for example, a wrapped multi method)

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Maybe method calls ($o.?m)

Qualified method calls ($o.T::m)

Private method calls ($o!pm)

Qualified private method calls ($o!T::Pm)

Multiple dispatch

Invocation of an object (Code, CALL-ME)

callsame, nextwith, etc.

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Coercion

Return type assertion

Binding type assertion

Assignment

Sinking

How we approached dispatch thus far

and the shortcomings of past approaches

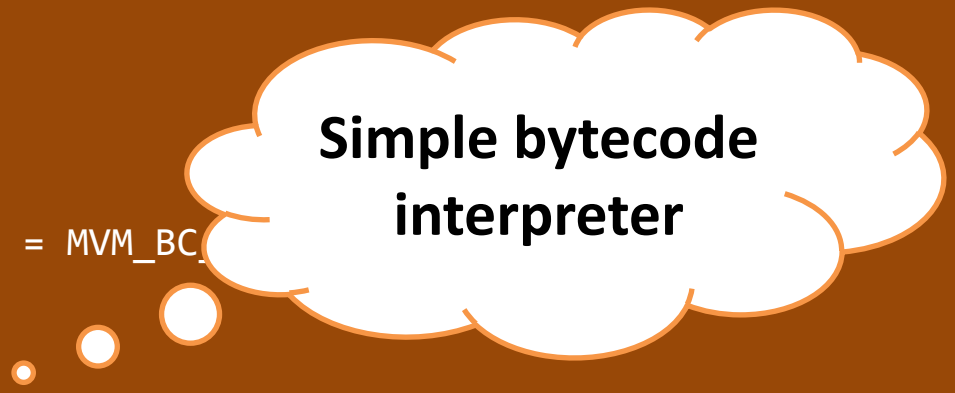
In the beginning...

In the beginning...

```
DISPATCH(NEXT_OP) {
    OP(no_op):
        goto NEXT;
    OP(const_i64):
        GET_REG(cur_op, 0).i64 = MVM_BC_get_I64(cur_op, 2);
        cur_op += 10;
        goto NEXT;
    OP(add_i):
        GET_REG(cur_op, 0).i64 = GET_REG(cur_op, 2).i64 + GET_REG(cur_op, 4).i64;
        cur_op += 6;
        goto NEXT;
    OP(if_i):
        if (GET_REG(cur_op, 0).i64)
            cur_op = bytecode_start + GET_UI32(cur_op, 2);
        else
            cur_op += 6;
        GC_SYNC_POINT(tc);
        goto NEXT;
    ...
```

In the beginning...

```
DISPATCH(NEXT_OP) {
    OP(no_op):
        goto NEXT;
    OP(const_i64):
        GET_REG(cur_op, 0).i64 = MVM_BC
        cur_op += 10;
        goto NEXT;
    OP(add_i):
        GET_REG(cur_op, 0).i64 = GET_REG(cur_op, 2).i64 + GET_REG(cur_op, 4).i64;
        cur_op += 6;
        goto NEXT;
    OP(if_i):
        if (GET_REG(cur_op, 0).i64)
            cur_op = bytecode_start + GET_UI32(cur_op, 2);
        else
            cur_op += 6;
        GC_SYNC_POINT(tc);
        goto NEXT;
    ...
```



Interpreting bytecode is rather slow...

...but C is pretty darn fast...

...so write the performance critical parts in C

Thus, complex ops...

```
 OP(findmeth): {
    /* Increment PC first, as we may make a method call. */
    MVMRegister *res  = &GET_REG(cur_op, 0);
    MVMObject   *obj  = GET_REG(cur_op, 2).o;
    MVMString   *name = MVM_cu_string(tc, cu, GET_UI32(cur_op, 4));
    cur_op += 8;
    MVM_6model_find_method(tc, obj, name, res, 1);
    goto NEXT;
}
```

Thus, complex ops...

```
OP(findmeth): {
    /* Increment PC first, as we may make a method call. */
    MVMRegister *res  = &GET_REG(cur_op, 0);
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    cur_op += 8;
    MVM_6model_find_method(tc, obj, name, res, 1);
    goto NEXT;
}
```

Look up in a cache...and if it's not found, call the `find_method` method on the meta-object to find it...

Thus

```
OP(findmeth): {
    /* Increment
    MVMRegister *res
    MVMObject   *obj  = GET_REG(cur_op
    MVMString   *name = MVM_cu_string(tc, cu, GET_UI32(cur_op, 4));
    cur_op += 8;
    MVM_6model_find_method(tc, obj, name, res, 1);
    goto NEXT;
}
```

Wait, but then I need to find the `find_method` method...it'd better be in the cache...

Look up in a cache...and if it's not found, call the `find_method` method on the meta-object to find it...

Thus

OP(fi

Wait, but then I need to find the

od...it'd

Oh, and the interpreter should not be recursively entered, so have to write the C code in continuation passing style!

```
_ui32(cur_op, 4));
MVM_6m        ,     ne, res, 1);
goto NEXT;
}
```

Look up in a cache...and if it's not found, call the `find_method` method on the meta-object to find it...

Here's another one

```
OP(if_o):
    GC_SYNC_POINT(tc);
    MVM_coerce_istrue(tc, GET_REG(cur_op, 0).o, NULL,
        bytecode_start + GET_UI32(cur_op, 2),
        cur_op + 6,
        0);
    goto NEXT;
```

The thing that underlies `if` statements on objects today

Here's another one

```
OP(if_o):
    GC_SYNC_POINT(tc);
    MVM_coerce_istrue(tc, GET_REG(cur_op, 0).o, NULL,
        bytecode_start + GET_UI32(cur_op, 2),
        cur_op + 6,
        0);
    goto NEXT;
```

Try to avoid making a method call to `Bool` when possible, because those were expensive

...and on the inside...

```
void MVM_coerce_istrue(MVMThreadContext *tc, MVMObject *obj,
        MVMRegister *res_reg, MVMuint8 *true_addr, MVMuint8 *false_addr,
        MVMuint8 flip) {
    MVMint64 result = 0;
    if (!MVM_is_null(tc, obj)) {
        MVMBoolificationSpec *bs = obj->st->boolification_spec;
        switch (bs == NULL ? MVM_BOOL_MODE_NOT_TYPE_OBJECT : bs->mode) {
            case MVM_BOOL_MODE_UNBOX_INT:
                result = !IS_CONCRETE(obj) || REPR(obj)->box_funcs.get_int(tc,
                    STABLE(obj), obj, OBJECT_BODY(obj)) == 0 ? 0 : 1;
                break;
            case MVM_BOOL_MODE_UNBOX_NUM:
                result = !IS_CONCRETE(obj) || REPR(obj)->box_funcs.get_num(tc,
                    STABLE(obj), obj, OBJECT_BODY(obj)) == 0.0 ? 0 : 1;
                break;
            ...
```

...and on the inside...

```
void MVM_coerce_istrue(MVMThreadContext *tc, MVMObject *obj,
        MVMRegister *res_reg, MVMuint8 *true_addr, MVMuint8 *false_addr,
        MVMuint8 flip) {
    MVMint64 result = 0;
    if (!MVM_is_null(tc, obj)) {
        MVMBoolificationSpec *bs = obj->st->boolification_spec;
        switch (bs == NULL ? MVM_BOOL_MODE_NOT_TYPE_OBJECT : bs->mode) {
            case MVM_BOOL_MODE_UNBOX_INT:
                result = !IS_CONCRETE(obj) || REPR(obj)->box_funcs.get_int(tc,
                    STABLE(obj), obj, OBJECT_BODY(obj)) == 0 ? 0 : 1;
                ...
```

Another `switch` statement to decide what to do...but it's C so it's fast? ☺

With time, the runtime started to learn the tricks of the trade...

Type specialization

Record what types actually show up, produce optimized bytecode for those

Deoptimization

If the types are wrong, fall back to the original code

Inlining

Copy small routines into the caller, saving call costs

JIT compilation

Produce machine code, avoiding interpreter overhead

And having these changes everything....

At first...	But now...
We only had a bytecode interpreter	We can JIT-compile hot bytecode into machine code
Lots of little method calls were prohibitively expensive	We can inline small method calls, so the calling cost is gone
Doing the hot-path decision making in C was a clear win	The C code is an opaque blob that we can't type specialize

Another issue: only the most common kinds of dispatch got special treatment in the VM


Hi! I'm a performance cliff!


Multi-dispatch on nominal types
Method calls
Boolification
Hi! I'm a performance cliff!


Multi-dispatch on nominal types
Method calls
Boolification
Hi! I'm a performance cliff!
Multi-dispatch with where clauses
Qualified method calls
callsame & co.
.?method calls

In general:

If it's a dispatch, but the runtime (and especially the optimizer) can't reason about it as one, it'll probably be *slow*

But why?

If we implement this:

```
my $result = $obj.?method($arg, $arg);
```

With a helper like this:

```
method dispatch:<.?>(Mu \SELF: Str() $name, |c) is raw {
    nqp::can(SELF,$name) ??
        SELF."$name"(|c) !!
        Nil
}
```

Mild polymorphism

```
my $result = $obj.?method($arg, $arg);
```

Becomes megamorphism

```
method dispatch:<.?>(Mu \SELF: Str() $name, |c) is raw {
    nqp::can(SELF,$name) ??
        SELF."$name"(|c) !!
        Nil
}
```

Mild polymorphism

```
my $result = $obj.?method($arg, $arg);
```

One name, probably a handful of types

Becomes megamorphism

```
method dispatch:<.?>(Mu \SELF: Str() $name, |c) is raw {
    nqp::can(SELF,$name) ??
        SELF."$name"(|c) !!
        Nil
}
```

Many names, many types

Optimization relies heavily on turning *potentially polymorphic* programs into *mostly monomorphic* programs

And to make matters even worse...

```
method dispatch:<.?>(Mu \SELF: Str() $name, |c) is raw {
    nqp::can(SELF,$name) ??
        SELF."$name"(|c) !!
        Nil
}
```

Slurp here...

...flatten here

And to make matters even worse...

```
method dispatch:<.?>(Mu \SELF: Str() $name, |c) is raw {
    nqp::can(SELF,$name) ??
        SELF."$name"(|c) !!
        Nil
}
```

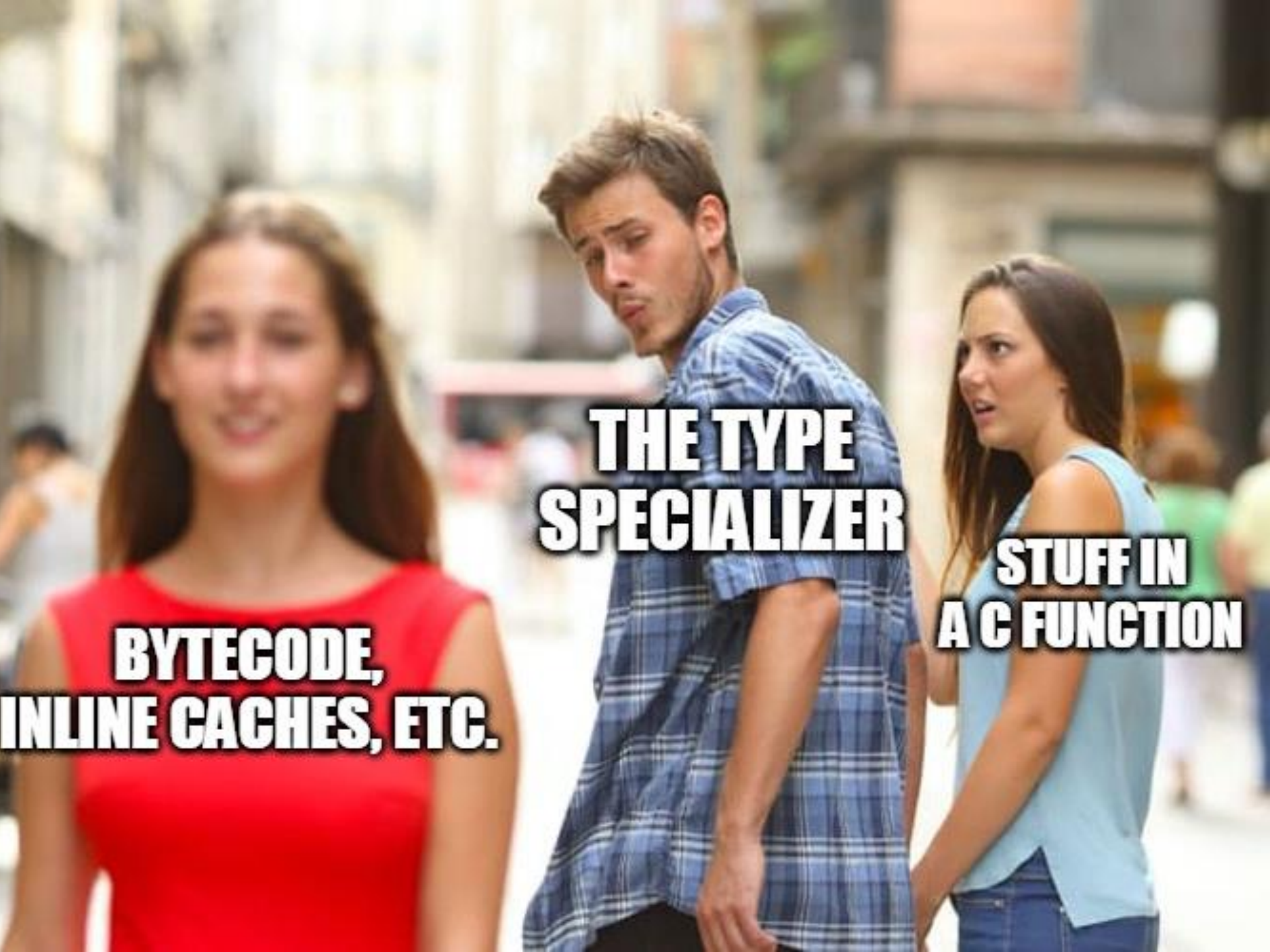
Slurp here...

...flatten here

Callsite shapes are keys to specializations and caches, but are lost too

So what can we do?

Teach the VM about more language features?


BYTECODE,
INLINE CACHES, ETC.
THE TYPE
SPECIALIZER
STUFF IN
A C FUNCTION


NOT HAVING
TO HUNT GC BUGS
ME
NEW
GC BUGS


NEW LANGUAGE FEATURES
PROGRAMMABLE DISPATCH MECHANISM
MODIFYING THE VM

A new generalized approach

to implementing the many different kinds of dispatch

One* new instruction

`dispatch`

*** Actually, it comes in 5 forms by return type:**
void, native int, native num, native str, and object

Exposed like other ops

```
nqp::dispatch(...)
```

```
say(nqp::dispatch('boot-value',    42));    # 42
say(nqp::dispatch('boot-constant', 101));   # 101
```

```
say(nqp::dispatch('boot-value',    42));    # 42
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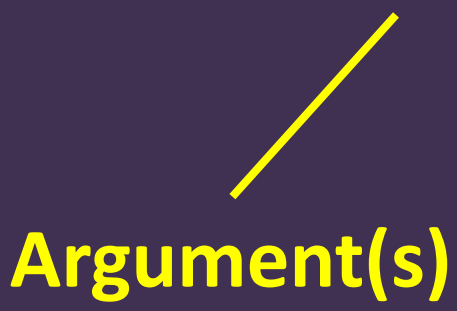
```

Dispatcher ID

```
say(nqp::dispatch('boot-value',    42));    # 42
say(nqp::dispatch('boot-constant', 101));   # 101
```



```
sub spot-the-difference($x) {
    say(nqp::dispatch('boot-value', $x) ~ ' ' ~
        nqp::dispatch('boot-constant', $x));
}

spot-the-difference(1);     # 1 1
spot-the-difference(2);     # 2 1
spot-the-difference(3);     # 3 1
```

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sub spot-the-difference($x) {
    say(nqp::dispatch('boot-value', $x) ~ ' ' ~
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}

spot-the-difference(1);     # 1 1
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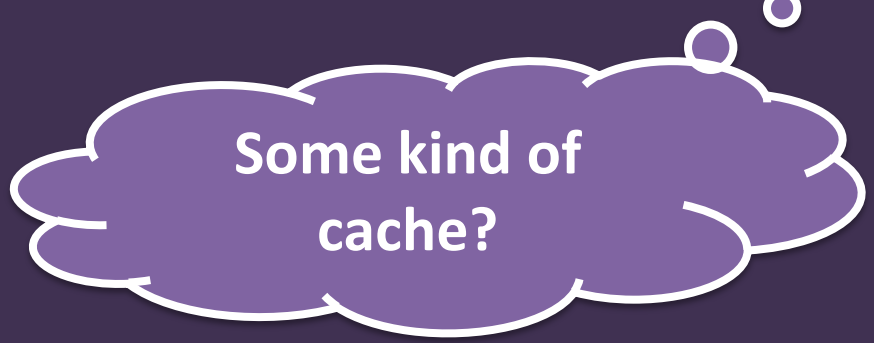

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sub spot-the-difference($x) {
    say(nqp::dispatch('boot-value', $x) ~ ' ' ~
        nqp::dispatch('boot-constant', $x));
}
```

```
00000      checkarity          1, 1
00001      param_rp_o          loc_0_obj, 0
00002      paramnamesused
    annotation: op.nqp:2
00003      getlex_no           loc_1_obj, '&say'
00004      dispatch_o          loc_2_obj, 'boot-value', Callsite_0, loc_0_obj
00005      decont              loc_2_obj, loc_2_obj
00006      dispatch_s          loc_3_str, 'nqp-stringify', Callsite_0, loc_2_obj
00007      const_s             loc_4_str, ' '
00008      concat_s            loc_4_str, loc_3_str, loc_4_str
00009      dispatch_o          loc_2_obj, 'boot-constant', Callsite_0, loc_0_obj
00010      dispatch_s          loc_3_str, 'nqp-stringify', Callsite_0, loc_2_obj
00011      concat_s            loc_3_str, loc_4_str, loc_3_str
00012      dispatch_o          loc_1_obj, 'lang-call', Callsite_1, loc_1_obj, loc_3_str
00013      return_o            loc_1_obj
```

```
sub spot-the-difference($x) {
    say(nqp::dispatch('boot-value', $x) ~ ' ' ~
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00002      paramnamesused
    annotation: op.nqp:2
00003      getlex_no           loc_1_obj, '&say'
00004      dispatch_o          loc_2_obj, 'boot-value', Callsite_0, loc_0_obj
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00006      dispatch_s          loc_3_str, 'nqp-stringify', Callsite_0, loc_2_obj
00007      const_s             loc_4_str, ' '
00008      concat_s            loc_4_str, loc_3_str, loc_4_str
00009      dispatch_o          loc_2_obj, 'boot-constant', Callsite_0, loc_0_obj
00010      dispatch_s          loc_3_str, 'nqp-stringify', Callsite_0, loc_2_obj
00011      concat_s            loc_3_str, loc_4_str, loc_3_str
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sub spot-the-difference($x) {
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00003      getlex_no           loc_1_obj, '&say'
00004      dispatch_o          loc_2_obj, 'boot-value', Callsite_0, loc_0_obj
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00007      const_s             loc_4_str, ' '
00008      concat_s            loc_4_str, loc_3_str, loc_4_str
00009      dispatch_o          loc_2_obj, 'boot-constant', Callsite_0, loc_0_obj
00010      dispatch_s          loc_3_str, 'nqp-stringify', Callsite_0, loc_2_obj
00011      concat_s            loc_3_str, loc_4_str, loc_3_str
00012      dispatch_o          loc_1_obj, 'lang-call', Callsite_1, loc_1_obj, loc_3_str
00013      return_o            loc_1_obj
```

```
sub spot-the-difference($x) {
    say(~nqp::dispatch('boot-value', $x) ~ ' ' ~
        ~nqp::dispatch('boot-constant', $x));
}
```

```
00000      checkarity          1, 1
00001      param_rp_o          loc_0_obj, 0
00002      paramnamesused
     annotation: op.nqp:2
00003      getlex_no           loc_1_obj, '&say'
00004      dispatch_o          loc_2_obj, 'boot-value', Callsite_0, loc_0_obj
00005      decont              loc_2_obj, loc_2_obj
00006      dispatch_s          loc_3_str, 'nqp-stringify', Callsite_0, loc_2_obj
00007      const_s             loc_4_str, ' '
00008      concat_s            loc_4_str, loc_3_str, loc_4_str
00009      dispatch_o          loc_2_obj, 'boot-constant', Callsite_0, loc_0_obj
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00011      concat_s            loc_3_str, loc_4_str, loc_3_str
00012      dispatch_o          loc_1_obj, 'lang-call', Callsite_1, loc_1_obj, loc_3_str
00013      return_o            loc_1_obj
```

On the first call, allocate 1 pointer of storage for each dispatch op...

```
00000      checkarity          1, 1
00001      param_rp_o          loc_0_obj, 0
00002      paramnamesused
     annotation: op.nqp:2
00003      getlex_no           loc_1_obj, '&say'
00004      dispatch_o          loc_2_obj, 'boot-value', Callsite_0, loc_0_obj
00005      decont              loc_2_obj, loc_2_obj
00006      dispatch_s          loc_3_str, 'nqp-stringify', Callsite_0, loc_2_obj
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00011      concat_s            loc_3_str, loc_4_str, loc_3_str
00012      dispatch_o          loc_1_obj, 'lang-call', Callsite_1, loc_1_obj, loc_3_str
00013      return_o            loc_1_obj
```

...and initialize all of them to a pointer to a singleton "unlinked" state

```
00000      checkarity          1, 1
00001      param_rp_o          loc_0_obj, 0
00002      paramnamesused
     annotation: op.nqp:2
00003      getlex_no           loc_1_obj, '&say'
00004      dispatch_o          loc_2_obj, 'boot-value', Callsite_0, loc_0_obj
00005      decont              loc_2_obj, loc_2_obj
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00007      const_s             loc_4_str, ' '
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00012      dispatch_o          loc_1_obj, 'lang-call', Callsite_1, loc_1_obj, loc_3_str
00013      return_o            loc_1_obj
```

Unlinked	Unlinked	Unlinked	Unlinked	Unlinked

What does dispatch do?

```
OP(dispatch_o): {
    MVMDispInlineCacheEntry **ice_ptr = MVM_disp_inline_cache_get(
            cur_op, bytecode_start, tc->cur_frame);
    MVMDispInlineCacheEntry *ice = *ice_ptr;
    MVMString *id = MVM_cu_string(tc, cu, GET_UI32(cur_op, 2));
    MVMCallsite *callsite = cu->body.callsites[GET_UI16(cur_op, 6)];
    MVMuint16 *args = (MVMuint16 *)(cur_op + 8);
    MVMuint32 bytecode_offset = cur_op - *tc->interp_bytecode_start - 2;
    tc->cur_frame->return_value = &GET_REG(cur_op, 0);
    tc->cur_frame->return_type  = MVM_RETURN_OBJ;
    cur_op += 8 + 2 * callsite->flag_count;
    tc->cur_frame->return_address = cur_op;
    ice->run_dispatch(tc, ice_ptr, ice, id, callsite, args,
            tc->cur_frame->work, tc->cur_frame->static_info,
            bytecode_offset);
    goto NEXT;
}
```

What does dispatch do?

```
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    MVMDispInlineCacheEntry **ice_ptr = MVM_disp_inline_cache_get(
            cur_op, bytecode_start, tc->cur_frame);
    MVMDispInlineCacheEntry *ice = *ice_ptr;
    MVMString *id = MVM_cu_string(tc, cu, GET_UI32(cur_op, 2));
    MVMCallsite *callsite = cu->body.callsites[GET_UI16(cur_op, 6)];
    MVMuint16 *args = (MVMuint16 *)(cur_op + 8);
    MVMuint32 bytecode_offset = cur_op - *tc->interp_bytecode_start - 2;
    tc->cur_frame->return_value = &GET_REG(cur_op, 0);
    tc->cur_frame->return_type  = MVM_RETURN_OBJ;
    cur_op += 8 + 2 * callsite->flag_count;
    tc->cur_frame->return_address = cur_op;
    ice->run_dispatch(tc, ice_ptr, ice, id, callsite, args,
            tc->cur_frame->work, tc->cur_frame->static_info,
            bytecode_offset);
    goto NEXT;
}
```

Find the address of the current state

What does dispatch do?

```
OP(dispatch_o): {
    MVMDispInlineCacheEntry **ice_ptr = MVM_disp_inline_cache_get(
            cur_op, bytecode_start, tc->cur_frame);
    MVMDispInlineCacheEntry *ice = *ice_ptr;
    MVMString *id = MVM_cu_string(tc, cu, GET_UI32(cur_op, 2));
    MVMCallsite *callsite = cu->body.callsites[GET_UI16(cur_op, 6)];
    MVMuint16 *args = (MVMuint16 *)(cur_op + 8);
    MVMuint32 bytecode_offset = cur_op - *tc->interp_bytecode_start - 2;
    tc->cur_frame->return_value = &GET_REG(cur_op, 0);
    tc->cur_frame->return_type  = MVM_RETURN_OBJ;
    cur_op += 8 + 2 * callsite->flag_count;
    tc->cur_frame->return_address = cur_op;
    ice->run_dispatch(tc, ice_ptr, ice, id, callsite, args,
            tc->cur_frame->work, tc->cur_frame->static_info,
            bytecode_offset);
    goto NEXT;
}
```

Dereference it to get the current state

What does dispatch do?

```
OP(dispatch_o): {
    MVMDispInlineCacheEntry **ice_ptr = MVM_disp_inline_cache_get(
            cur_op, bytecode_start, tc->cur_frame);
    MVMDispInlineCacheEntry *ice = *ice_ptr;
    MVMString *id = MVM_cu_string(tc, cu, GET_UI32(cur_op, 2));
    MVMCallsite *callsite = cu->body.callsites[GET_UI16(cur_op, 6)];
    MVMuint16 *args = (MVMuint16 *)(cur_op + 8);
    MVMuint32 bytecode_offset = cur_op - *tc->interp_bytecode_start - 2;
    tc->cur_frame->return_value = &GET_REG(cur_op, 0);
    tc->cur_frame->return_type  = MVM_RETURN_OBJ;
    cur_op += 8 + 2 * callsite->flag_count;
    tc->cur_frame->return_address = cur_op;
    ice->run_dispatch(tc, ice_ptr, ice, id, callsite, args,
            tc->cur_frame->work, tc->cur_frame->static_info,
            bytecode_offset);
    goto NEXT;
}
```

Look up the dispatcher ID and callsite shape

What does dispatch do?

```
OP(dispatch_o): {
    MVMDispInlineCacheEntry **ice_ptr = MVM_disp_inline_cache_get(
            cur_op, bytecode_start, tc->cur_frame);
    MVMDispInlineCacheEntry *ice = *ice_ptr;
    MVMString *id = MVM_cu_string(tc, cu, GET_UI32(cur_op, 2));
    MVMCallsite *callsite = cu->body.callsites[GET_UI16(cur_op, 6)];
    MVMuint16 *args = (MVMuint16 *)(cur_op + 8);
    MVMuint32 bytecode_offset = cur_op - *tc->interp_bytecode_start - 2;
    tc->cur_frame->return_value = &GET_REG(cur_op, 0);
    tc->cur_frame->return_type  = MVM_RETURN_OBJ;
    cur_op += 8 + 2 * callsite->flag_count;
    tc->cur_frame->return_address = cur_op;
    ice->run_dispatch(tc, ice_ptr, ice, id, callsite, args,
            tc->cur_frame->work, tc->cur_frame->static_info,
            bytecode_offset);
    goto NEXT;
}
```

Calculate the argument register list location

What does dispatch do?

```
OP(dispatch_o): {
    MVMDispInlineCacheEntry **ice_ptr = MVM_disp_inline_cache_get(
            cur_op, bytecode_start, tc->cur_frame);
    MVMDispInlineCacheEntry *ice = *ice_ptr;
    MVMString *id = MVM_cu_string(tc, cu, GET_UI32(cur_op, 2));
    MVMCallsite *callsite = cu->body.callsites[GET_UI16(cur_op, 6)];
    MVMuint16 *args = (MVMuint16 *)(cur_op + 8);
    MVMuint32 bytecode_offset = cur_op - *tc->interp_bytecode_start - 2;
    tc->cur_frame->return_value = &GET_REG(cur_op, 0);
    tc->cur_frame->return_type  = MVM_RETURN_OBJ;
    cur_op += 8 + 2 * callsite->flag_count;
    tc->cur_frame->return_address = cur_op;
    ice->run_dispatch(tc, ice_ptr, ice, id, callsite, args,
            tc->cur_frame->work, tc->cur_frame->static_info,
            bytecode_offset);
    goto NEXT;
}
```

Set the return value location and address

What does `dispatch` do?

```
OP(dispatch_o): {
    MVMDispInlineCacheEntry **ice_ptr = MVM_disp_inline_cache_get(
            cur_op, bytecode_start, tc->cur_frame);
    MVMDispInlineCacheEntry *ice = *ice_ptr;
    MVMString *id = MVM_cu_string(tc, cu, GET_UI32(cur_op, 2));
    MVMCallsite *callsite = cu->body.callsites[GET_UI16(cur_op, 6)];
    MVMuint16 *args = (MVMuint16 *)(cur_op + 8);
    MVMuint32 bytecode_offset = cur_op - *tc->interp_bytecode_start - 2;
    tc->cur_frame->return_value = &GET_REG(cur_op, 0);
    tc->cur_frame->return_type  = MVM_RETURN_OBJ;
    cur_op += 8 + 2 * callsite->flag_count;
    tc->cur_frame->return_address = cur_op;
    ice->run_dispatch(tc, ice_ptr, ice, id, callsite, args,
            tc->cur_frame->work, tc->cur_frame->static_info,
            bytecode_offset);
    goto NEXT;
}
```

Do the right thing for the current state

In the unlinked state, we record a *dispatch program*

```
sub spot-the-difference($x) {
    say(nqp::dispatch('boot-value', $x) ~ ' ' ~
        nqp::dispatch('boot-constant', $x));
}
```

```
Dispatch program 0x55f437d2b2b0 (1 temporaries)
   at op.nqp:2  (<ephemeral file>:spot-the-difference)
  Ops:
    Load argument 0 into temporary 0
    Set result object value from temporary 0
```

```
sub spot-the-difference($x) {
    say(nqp::dispatch('boot-value', $x) ~ ' ' ~
        nqp::dispatch('boot-constant', $x));
}
```

```
Dispatch program 0x55f437d2baa0 (1 temporaries)
   at op.nqp:3  (<ephemeral file>:spot-the-difference)
  Ops:
    Load collectable constant at index 0 into temporary 0
    Set result object value from temporary 0
```

`boot-constant` and `boot-value` are two of the *dispatch terminals* - things that produce a final outcome

boot-code

```
# Run bytecode with some arguments (works only
# in NQP since this is a raw bytecode handle,
# not a Code object as in Raku)
my $code := -> $x, $y { say($x + $y) };
nqp::dispatch('boot-code', $code, 40, 2); # 42
```

boot-syscall

```
# Calls VM-provided functionality
my @arr := [1,2,3];
say(nqp::dispatch('boot-syscall', 'elems', # 3
                  @arr));
```

That's all we need.

(Because everything else can be exposed in terms of `boot-syscall`.)

Userspace dispatchers

Additional dispatchers can be registered using a syscall

```
nqp::dispatch('boot-syscall', 'dispatcher-register', 'identity',
    # Invoked with the argument capture
    -> $capture {
        ...
    });
```

Delegation

User-defined dispatchers always delegate to some other dispatcher

```
nqp::dispatch('boot-syscall', 'dispatcher-register', 'identity',
    # Invoked with the argument capture
    -> $capture {
        # Must delegate, ultimately to a terminal
        nqp::dispatch('boot-syscall', 'dispatcher-delegate',
            'boot-value', $capture);
    });
```

Usage

They show up in the bytecode just like any built-in dispatcher

```
nqp::dispatch('boot-syscall', 'dispatcher-register', 'identity',
    # Invoked with the argument capture
    -> $capture {
        # Must delegate, ultimately to a terminal
        nqp::dispatch('boot-syscall', 'dispatcher-delegate',
            'boot-value', $capture);
    });

say(nqp::dispatch('identity', 'function')); # function
```

Capture transforms

Insert argument
Drop argument

```
nqp::dispatch('boot-syscall', 'dispatcher-register', 'drop-first',
    -> $capture {
        my $shorter := nqp::dispatch('boot-syscall',
            'dispatcher-drop-arg', $capture, 1);
        nqp::dispatch('boot-syscall', 'dispatcher-delegate',
            'boot-code', $shorter);
    });

my $code := -> $a { $a }
say(nqp::dispatch('drop-first', $code, 1, 2));  # 2
```

What about this one?

```
nqp::dispatch('boot-syscall', 'dispatcher-register', 'type-name',
    -> $capture {
        # Get the type name.
        my $arg := nqp::captureposarg($capture, 0);
        my str $name := $arg.HOW.name($arg);
        # Evaluate to the type name.
        my $outcome := nqp::dispatch('boot-syscall',
            'dispatcher-insert-arg-literal-str',
            $capture, 0, $name);
        nqp::dispatch('boot-syscall', 'dispatcher-delegate',
            'boot-constant', $outcome);
    });
```

Oops!

```
class Badger {}
class Mushroom {}
sub try-it($obj) {
    nqp::dispatch('type-name', $obj)
}
say(try-it(Badger));   # Badger
say(try-it(Badger));   # Badger
say(try-it(Badger));   # Badger
say(try-it(Badger));   # Badger
say(try-it(Mushroom)); # Badger
say(try-it(Mushroom)); # Badger
```

Need to add a guard

```
nqp::dispatch('boot-syscall', 'dispatcher-register', 'type-name',
    -> $capture {
        # Get the type name.
        my $arg := nqp::captureposarg($capture, 0);
        my str $name := $arg.HOW.name($arg);
        # Guard by type.
        my $track-arg := nqp::dispatch('boot-syscall',
            'dispatcher-track-arg', $capture, 0);
        nqp::dispatch('boot-syscall', 'dispatcher-guard-type',
            $track-arg);
        # Evaluate to the type name.
        my $outcome := nqp::dispatch('boot-syscall',
            'dispatcher-insert-arg-literal-str',
            $capture, 0, $name);
        nqp::dispatch('boot-syscall', 'dispatcher-delegate',
            'boot-constant', $outcome);
    });
```

Better!

```
class Badger {}
class Mushroom {}
sub try-it($obj) {
    nqp::dispatch('type-name', $obj)
}
say(try-it(Badger));   # Badger
say(try-it(Badger));   # Badger
say(try-it(Badger));   # Badger
say(try-it(Badger));   # Badger
say(try-it(Mushroom)); # Mushroom
say(try-it(Mushroom)); # Mushroom
```

Something neat

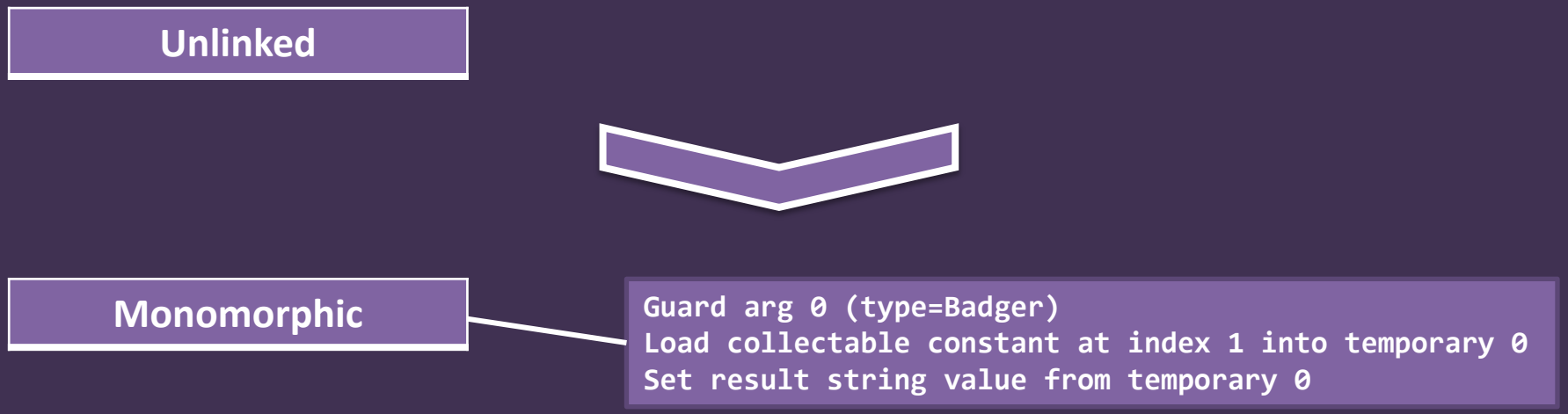
Dispatch programs erase all delegation, all intermediate captures, and duplicate guards!

```
Dispatch program 0x559750f6d000 (1 temporaries)
   at op.nqp:21  (<ephemeral file>:try-it)
  Ops:
    Guard arg 0 (type=Badger)
    Load collectable constant at index 1 into temporary 0
    Set result string value from temporary 0
```

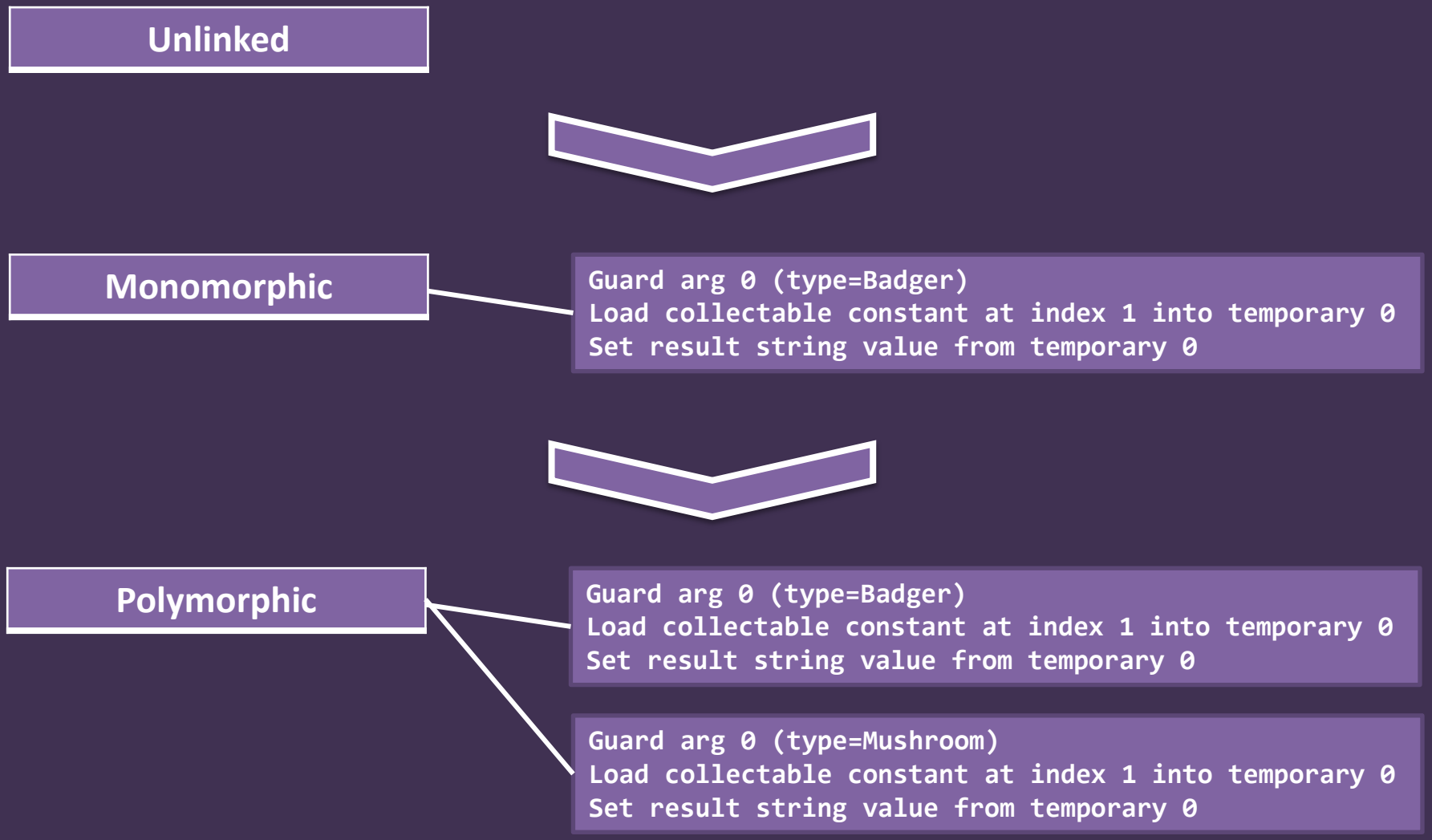
Callsite transitions

Unlinked

Callsite transitions



Callsite transitions



A real example

```
nqp::dispatch('boot-syscall', 'dispatcher-register', 'nqp-meth-call', -> $capture {
    # Try to find the method; complain if there's none found.
    my $obj := nqp::captureposarg($capture, 0);
    my str $name := nqp::captureposarg_s($capture, 1);
    my $meth := $obj.HOW.find_method($obj, $name);
    if nqp::isconcrete($meth) {
        # Establish a guard on the invocant type and method name (however the name
        # may well be a literal, in which case this is free).
        nqp::dispatch('boot-syscall', 'dispatcher-guard-type',
            nqp::dispatch('boot-syscall', 'dispatcher-track-arg', $capture, 0));
        nqp::dispatch('boot-syscall', 'dispatcher-guard-literal',
            nqp::dispatch('boot-syscall', 'dispatcher-track-arg', $capture, 1));

        # Drop the first two arguments, which are the decontainerized invocant
        # and the method name. Then insert the resolved method and delegate to
        # lang-call to invoke it (we may have other languages mixing into NQP
        # types and adding their methods).
        my $args := nqp::dispatch('boot-syscall', 'dispatcher-drop-arg',
            nqp::dispatch('boot-syscall', 'dispatcher-drop-arg', $capture, 0),
            0);
        my $delegate := nqp::dispatch('boot-syscall', 'dispatcher-insert-arg-literal-obj',
            $args, 0, $meth);
        nqp::dispatch('boot-syscall', 'dispatcher-delegate', 'lang-call', $delegate);
    }
    else {
        nqp::dispatch('boot-syscall', 'dispatcher-delegate', 'lang-meth-not-found', $capture);
    }
});
```

A real example

```
nqp::dispatch('boot-syscall', 'dispatcher-register', 'nqp-meth-call', -> $capture {
    # Try to find the method.
    my $obj := nqp::captureposarg($capture, 0);
    my str $name := nqp::captureposarg_s($capture, 1);
    my $meth := $obj.HOW.find_method($obj, $name);
    if nqp::isconcrete($meth) {
        # Establish a guard on the invocant type and method name (however the name
        # may well be a literal, in which case this is free).
        nqp::dispatch('boot-syscall', 'dispatcher-guard-type',
            nqp::dispatch('boot-syscall', 'dispatcher-track-arg', $capture, 0));
        nqp::dispatch('boot-syscall', 'dispatcher-guard-literal',
            nqp::dispatch('boot-syscall', 'dispatcher-track-arg', $capture, 1));

        # Drop the first two arguments, which are the decontainerized invocant
        # and the method name. Then insert the resolved method and delegate to
        # lang-call to invoke it (we may have other languages mixing into NQP
        # types and adding their methods).
        my $args := nqp::dispatch('boot-syscall', 'dispatcher-drop-arg',
            nqp::dispatch('boot-syscall', 'dispatcher-drop-arg', $capture, 0),
            0);
        my $delegate := nqp::dispatch('boot-syscall', 'dispatcher-insert-arg-literal-obj',
            $args, 0, $meth);
        nqp::dispatch('boot-syscall', 'dispatcher-delegate', 'lang-call', $delegate);
    }
    else {
        nqp::dispatch('boot-syscall', 'dispatcher-delegate', 'lang-meth-not-found', $capture);
    }
});
```

nqp-meth-call

A real example

```
nqp::dispatch('boot-syscall', 'dispatcher-register', 'nqp-meth-call', -> $capture {
    # Try to find the method.
    my $obj := nqp::captureposarg($capture, 0);
    my str $name := nqp::captureposarg_s($capture, 1);
    my $meth := $obj.HOW.find_method($obj, $name);
    if nqp::isconcrete($meth) {
        # Establish a guard on th          t type and method name (however the name
        # may well be a literal, i                 is free).
        nqp::dispatch(
            nqp::dispa
        nqp::dispatch(
            nqp::dispa

        # Drop the fir
        # and the meth
        # lang-call to invoke it (we may have other languages mixing into NQP
        # types and adding their methods).
        my $args := nqp::dispatch('boot-syscall', 'dispatcher-drop-arg',
            nqp::dispatch('boot-syscall', 'dispatcher-drop-arg', $capture, 0),
            0);
        my $delegate := nqp::dispatch('boot-syscall', 'dispatcher-insert-arg-literal-obj',
            $args, 0, $meth);
        nqp::dispatch('boot-syscall', 'dispatcher-delegate', 'lang-call', $delegate);
    }
    else {
        nqp::dispatch('boot-syscall', 'dispatcher-delegate', 'lang-meth-not-found', $capture);
    }
});
```


```
# Try to find the method.
my $obj := nqp::captureposarg($capture, 0);
my str $name := nqp::captureposarg_s($capture, 1);
my $meth := $obj.HOW.find_method($obj, $name);
```

A real example

```
nqp::dispatch('boot-syscall', 'dispatcher-register', 'nqp-meth-call', -> $capture {
    # Try to find the method.
    my $obj := nqp::captureposarg($capture, 0);
    my str $name := nqp::captureposarg_s($capture, 1);
    my $meth := $obj.HOW.find_method($obj, $name);
    if nqp::isconcrete($meth) {
        # Establish a guard on the invocant type and method name (however the name
        # may well be a literal, in which case this is free).
        nqp::dispatch('boot-syscall', 'dispatcher-guard-type',
            nqp::dispatch('boot-syscall', 'dispatcher-track-arg', $capture, 0));
        nqp::dispatch('boot-syscall', 'dispatcher-guard-literal',
            nqp::dispatch('boot-syscall', 'dispatcher-track-arg', $capture, 1));

        # Drop the fi                    which are the decontainerized invocant
```

```
# Establish a guard on the invocant type and method name
# (however the name may well be a literal, in which case this
# is free).
nqp::dispatch('boot-syscall', 'dispatcher-guard-type',
    nqp::dispatch('boot-syscall', 'dispatcher-track-arg',
        $capture, 0));
nqp::dispatch('boot-syscall', 'dispatcher-guard-literal',
    nqp::dispatch('boot-syscall', 'dispatcher-track-arg',
        $capture, 1));
```

```
});
```

A real example

```
my $args := nqp::dispatch('boot-syscall', 'dispatcher-drop-arg',
    nqp::dispatch('boot-syscall', 'dispatcher-drop-arg',
        $capture, 0),
    0);
my $delegate := nqp::dispatch('boot-syscall',
    'dispatcher-insert-arg-literal-obj',
    $args, 0, $meth);
nqp::dispatch('boot-syscall', 'dispatcher-delegate', 'lang-call',
    $delegate);
```

```
        # and the method ...                    the resolved method and delegate to
        # lang-call to invoke it ...            ve other languages mixing into NQP
        # types and adding their methods).
        my $args := nqp::dispatch('boot-syscall', 'dispatcher-drop-arg',
            nqp::dispatch('boot-syscall', 'dispatcher-drop-arg', $capture, 0),
            0);
        my $delegate := nqp::dispatch('boot-syscall', 'dispatcher-insert-arg-literal-obj',
            $args, 0, $meth);
        nqp::dispatch('boot-syscall', 'dispatcher-delegate', 'lang-call', $delegate);
    }
    else {
        nqp::dispatch('boot-syscall', 'dispatcher-delegate', 'lang-meth-not-found', $capture);
    }
});
```

Resumption

Dispatchers also support saving state - in the best case at zero runtime cost - in case a dispatch is resumed

Used for `callsame`, `nextwith`, etc.

Also used for `multis` with `where` clauses, unpacking, etc.

And then...

Dispatch programs in hot code are translated into ops by the optimizer

Then we optimize: inlining, larger scale guard elimination, etc.

JIT compilation of what remains, removing interpretation overhead

The current status

in terms of completion and performance

Currently passing

99.6%

of specification tests

Issues remain with

< 40

ecosystem modules

"Make it work,
then make it fast"

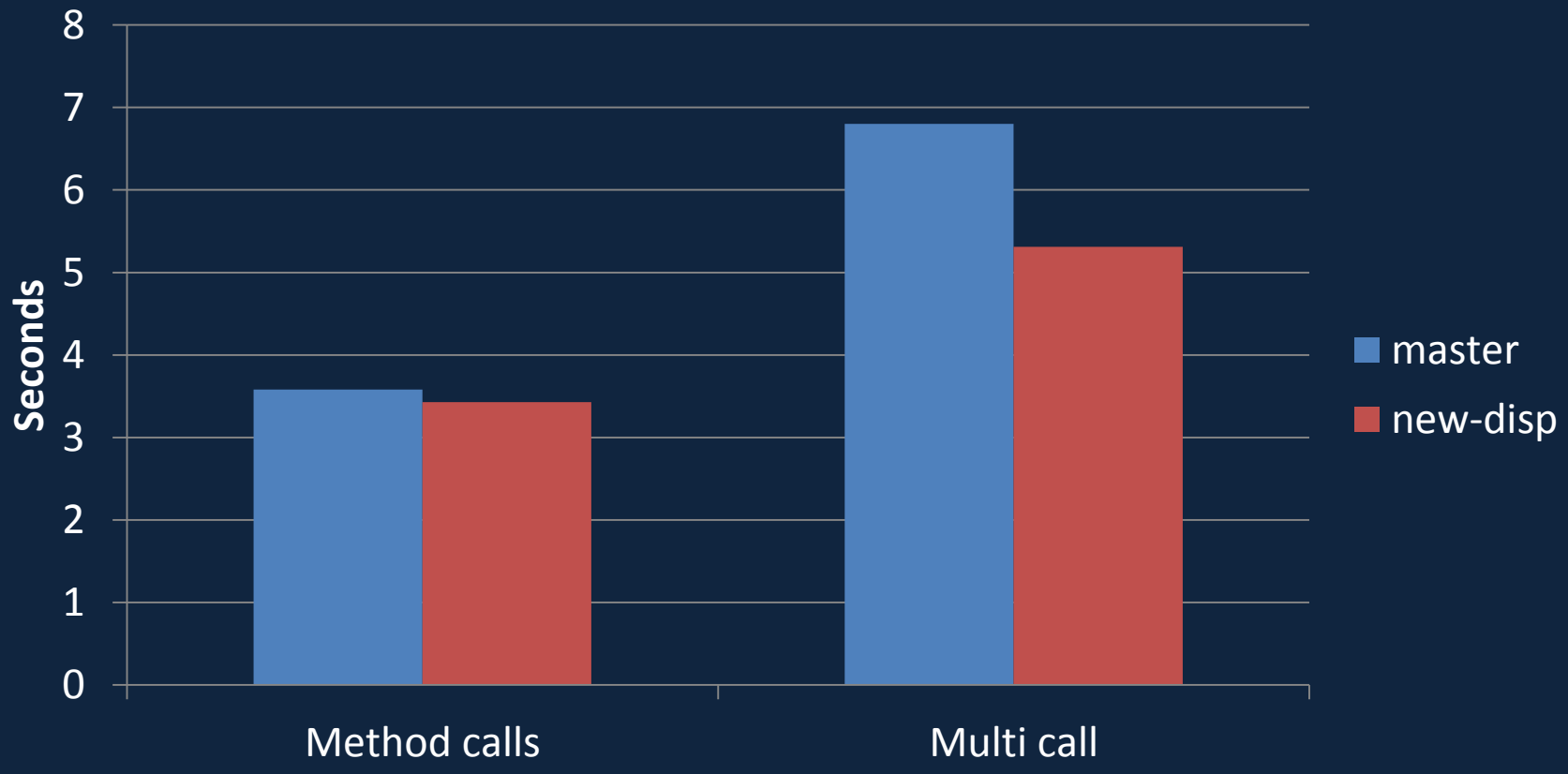
Still need to re-enable some really important optimizations

Without them, we will obviously do poorly at basic cases of method dispatch and multiple dispatch

They've had so much attention in the current implementation

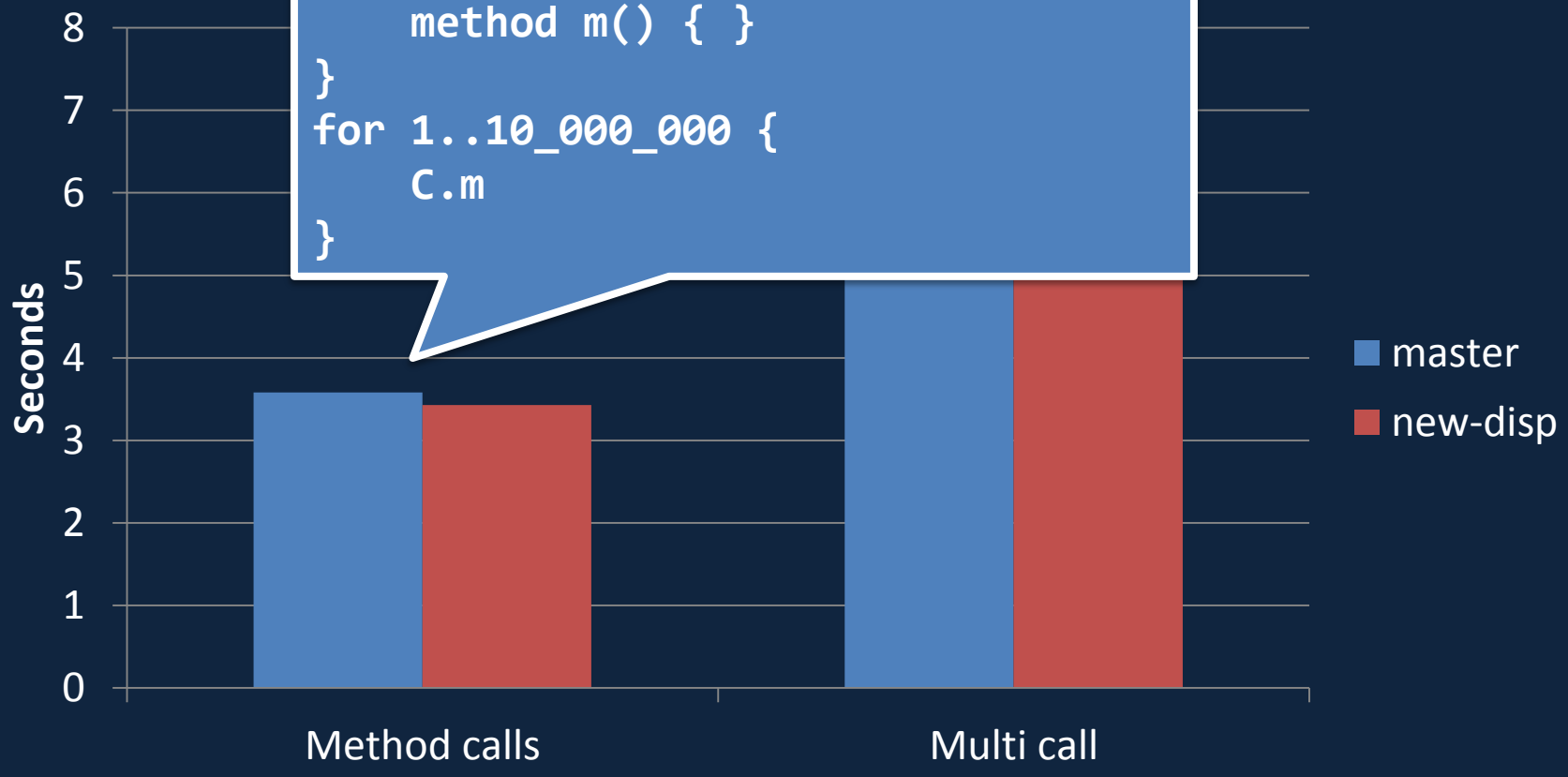
But we can find some things to measure...

Baseline performance
(master vs. new-disp, optimizer disabled)

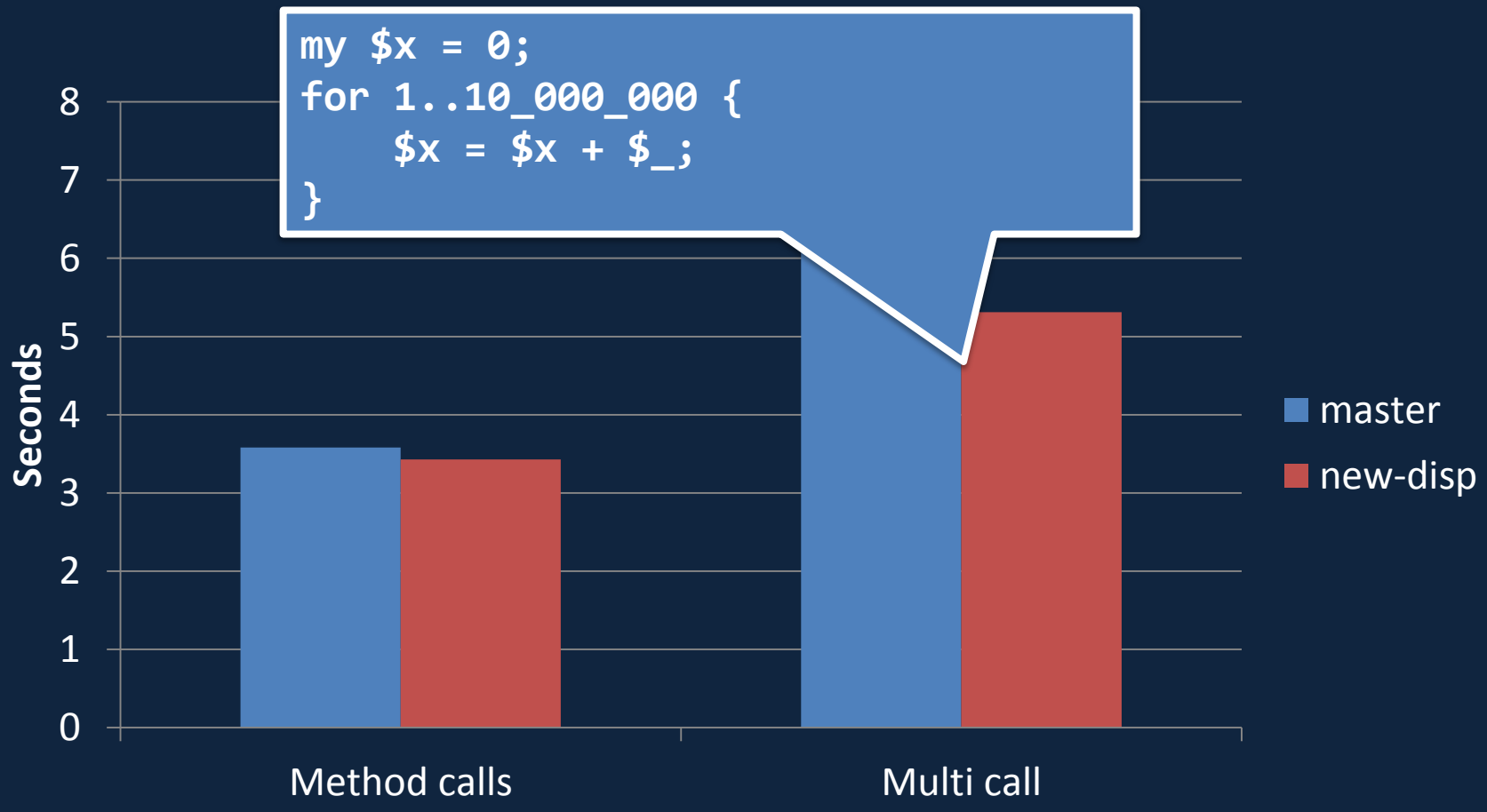


Baseline performance
(master vs. new-disp, optimizer disabled)

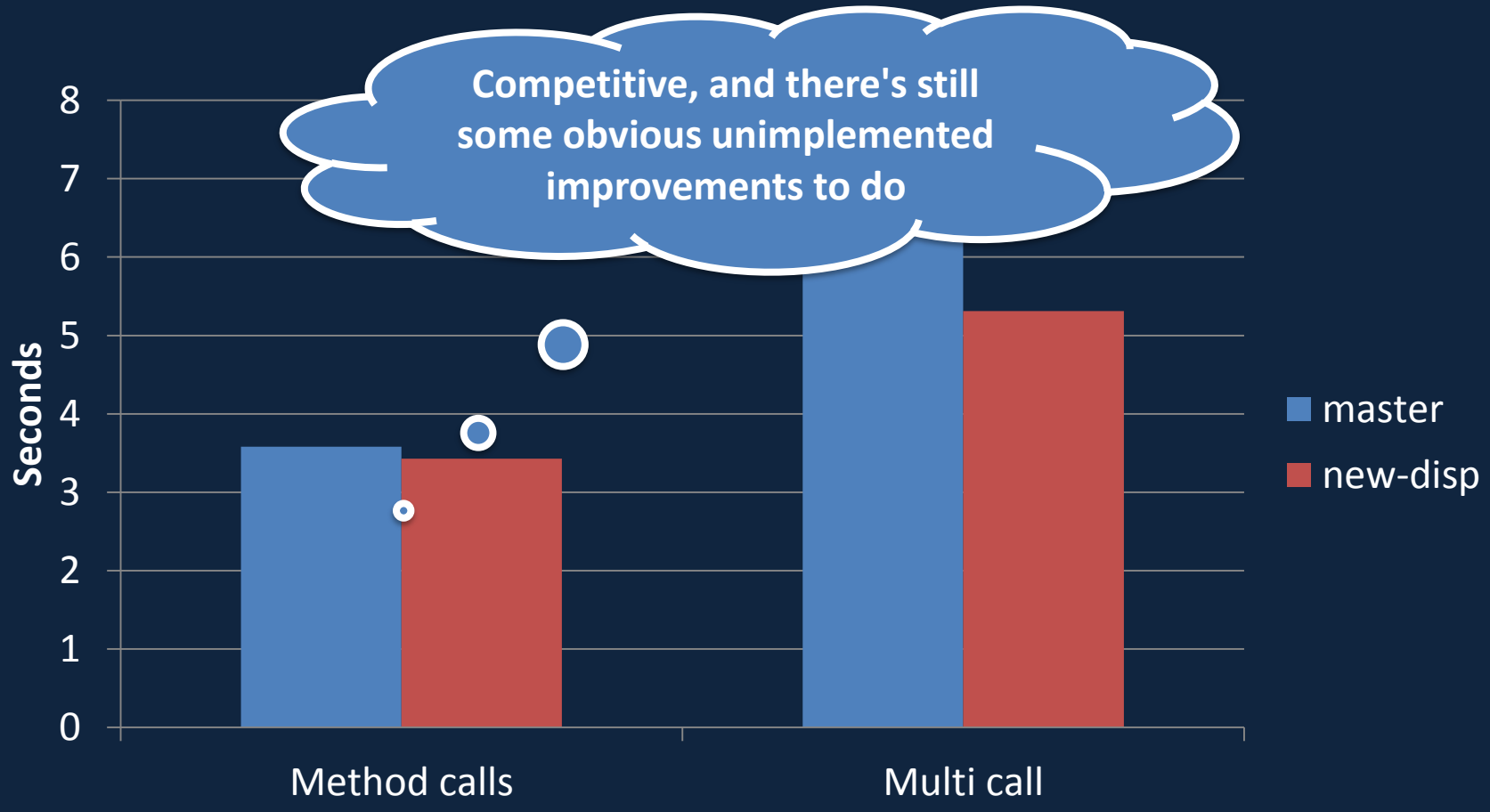
```
class C {
    method m() { }
}
for 1..10_000_000 {
    C.m
}
```



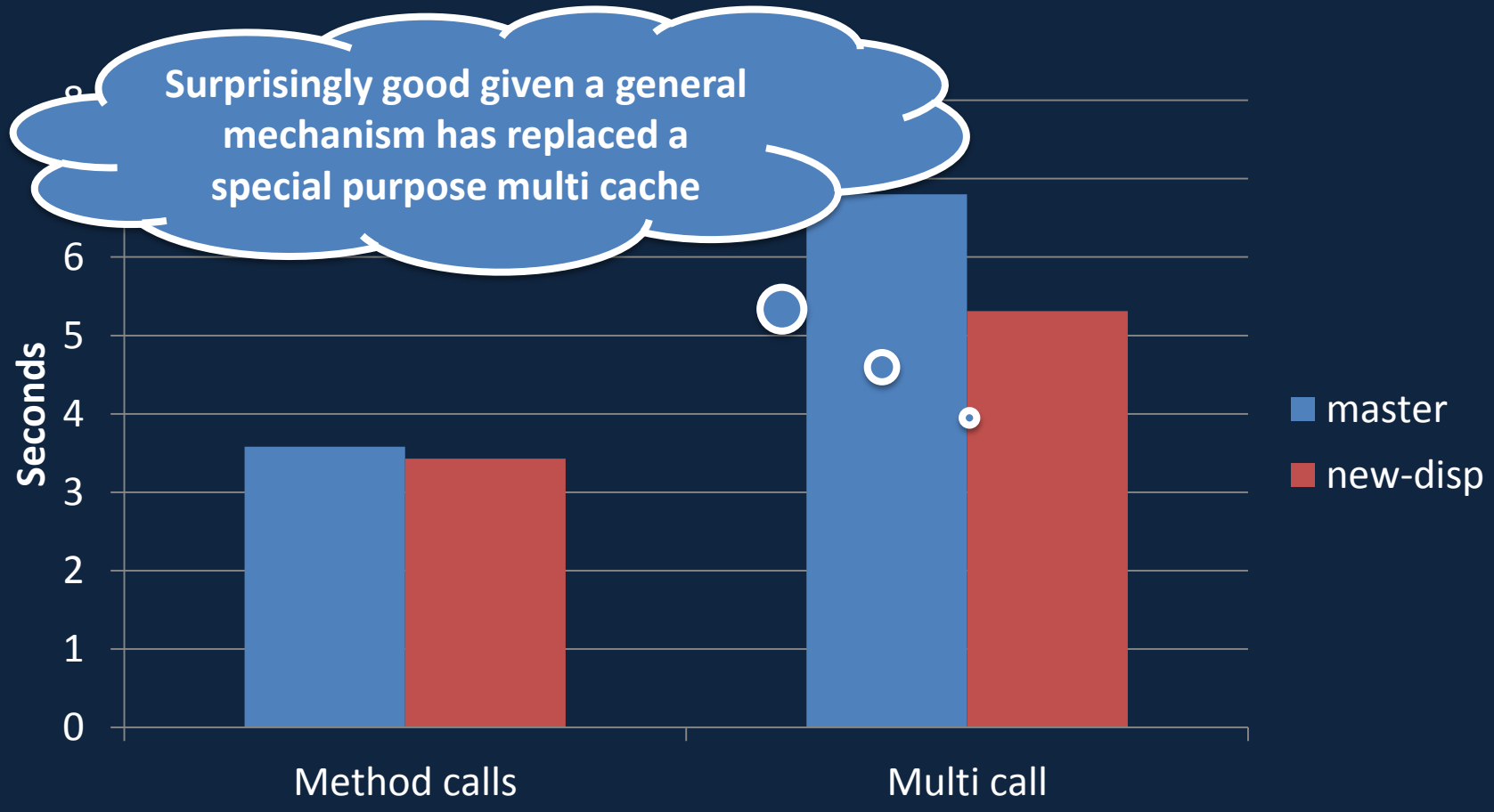
Baseline performance
(master vs. new-disp, optimizer disabled)



Baseline performance
(master vs. new-disp, optimizer disabled)



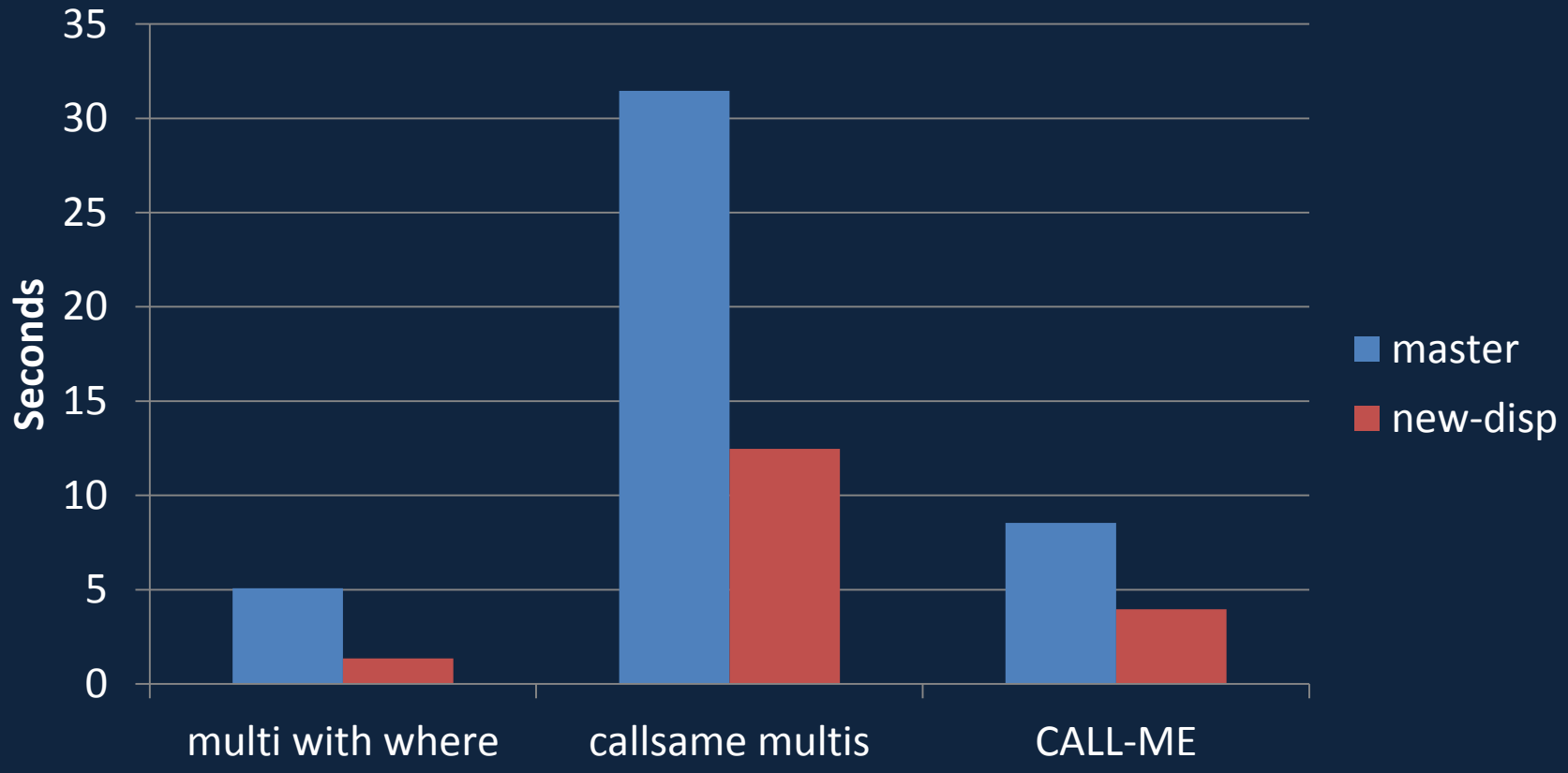
Baseline performance
(master vs. new-disp, optimizer disabled)



What about the features that have especially weak performance on master?

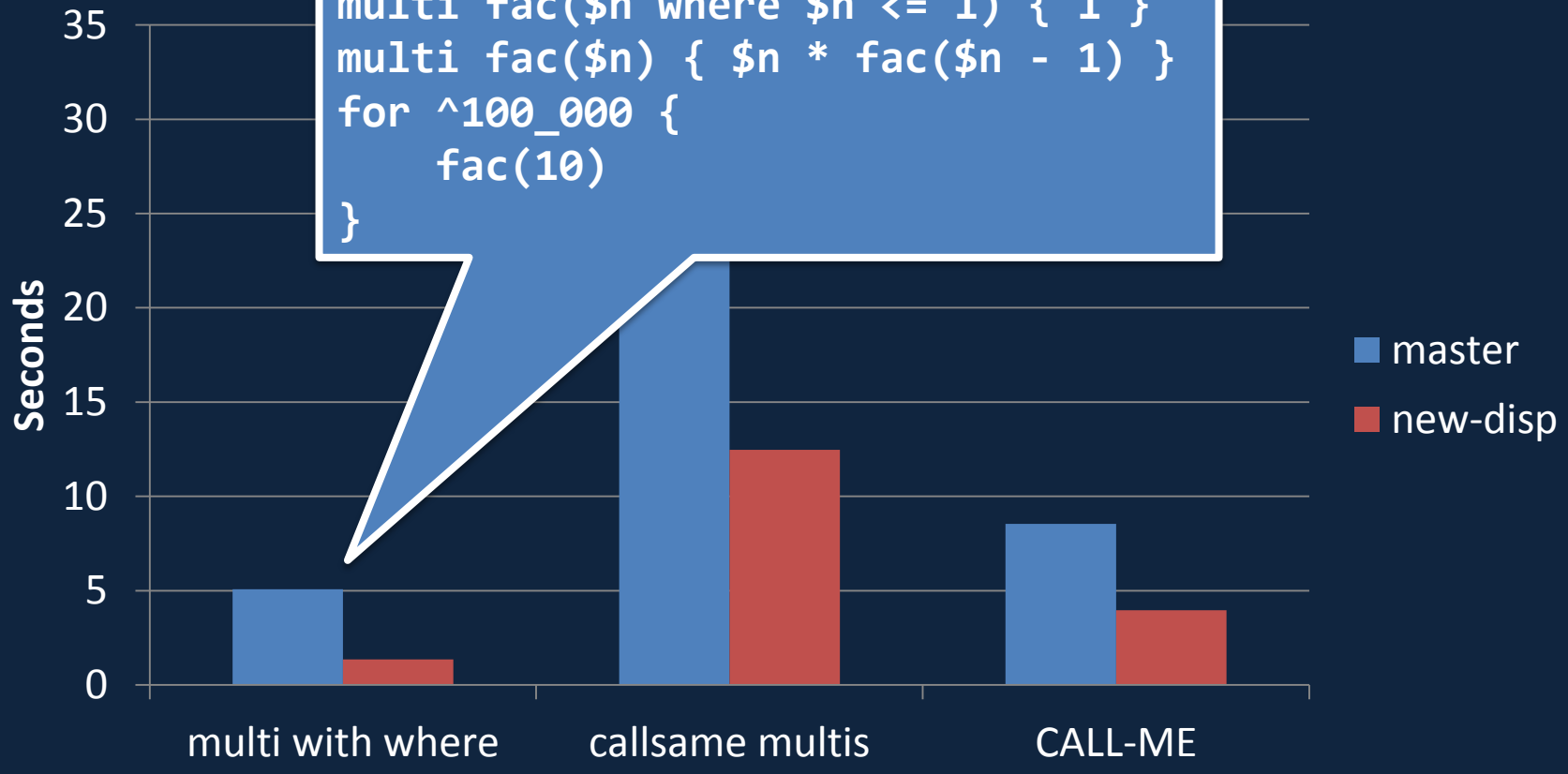
Is the design improvement on `new-disp` enough to come out ahead, *even with the optimizer integration incomplete*?

Currently slow dispatches
(master vs. new-disp)



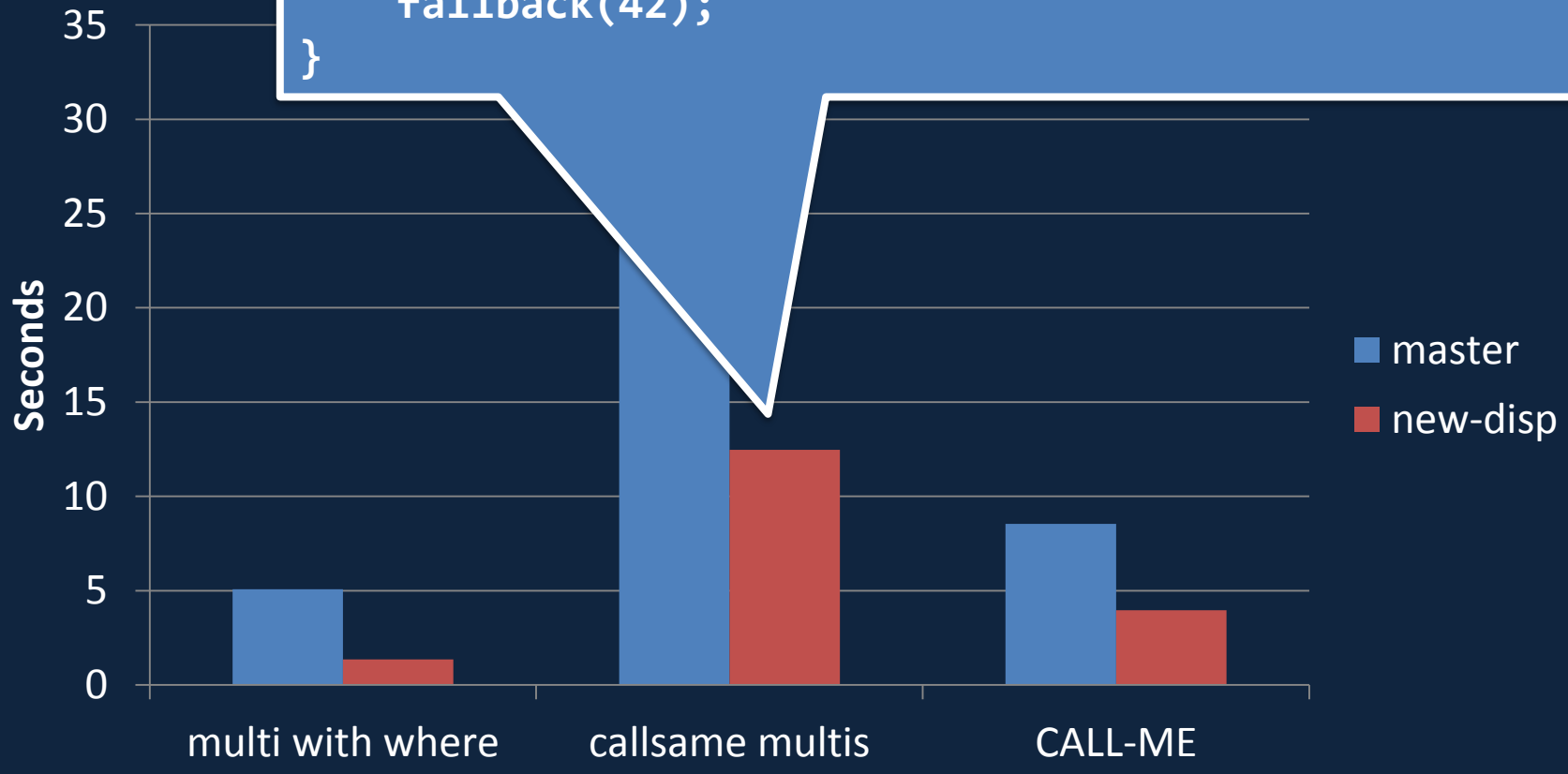
Currently slow dispatches
(master vs. new-disp)

```
multi fac($n where $n <= 1) { 1 }
multi fac($n) { $n * fac($n - 1) }
for ^100_000 {
    fac(10)
}
```

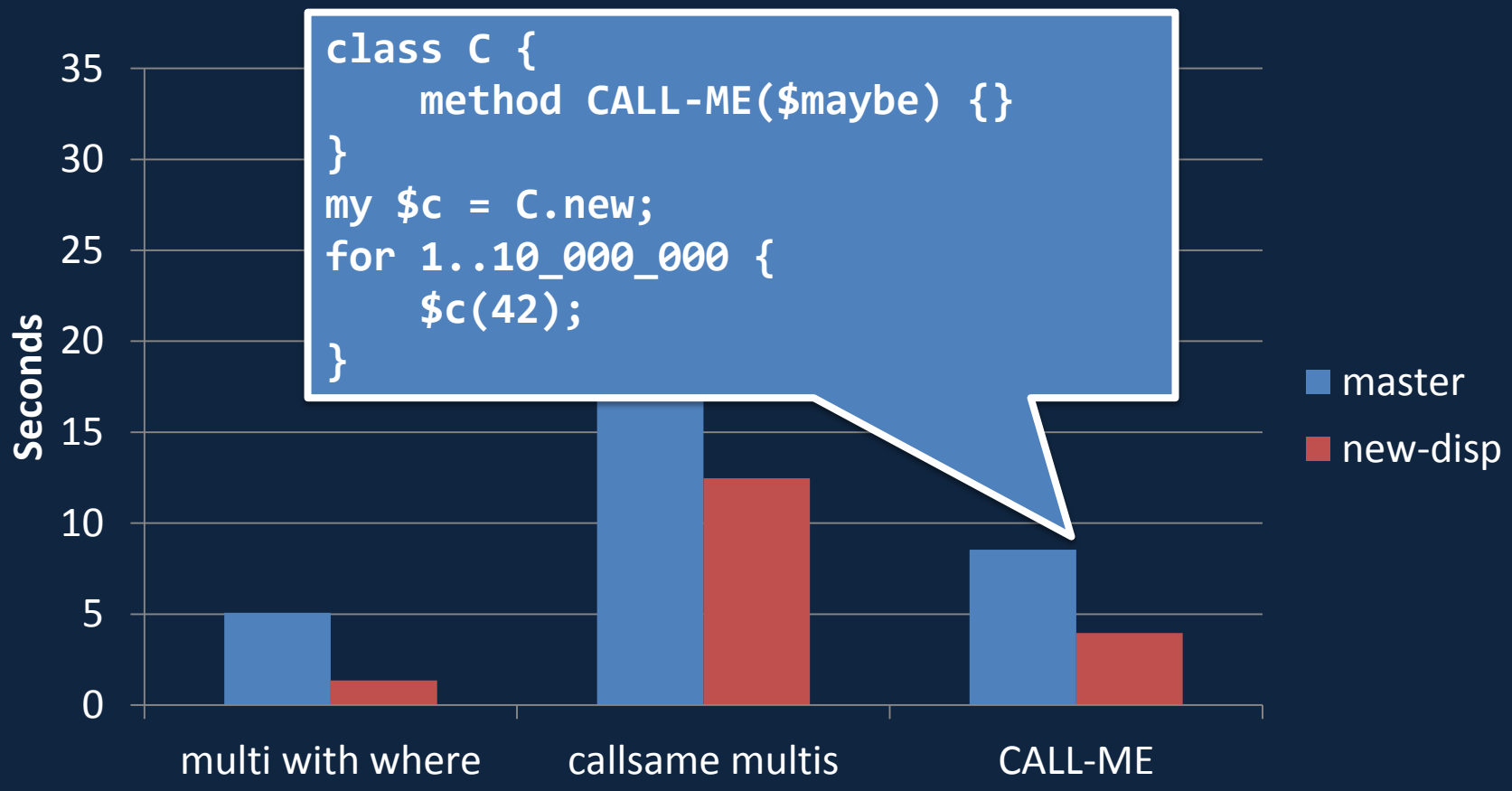


Cu

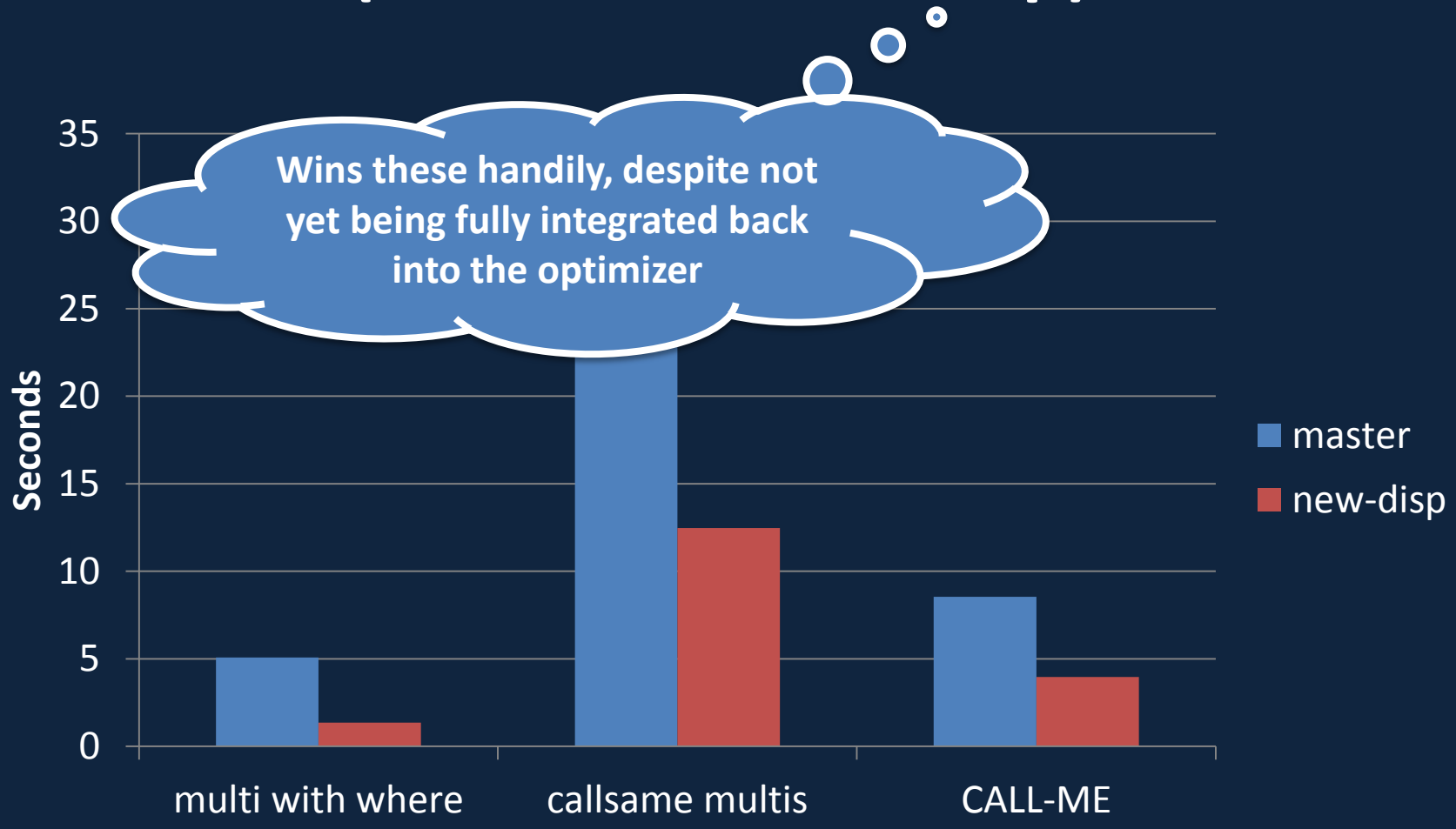
```
multi fallback(Any $x) { "a$x" }
multi fallback(Numeric $x) { "n" ~ callsame }
multi fallback(Real $x) { "r" ~ callsame }
multi fallback(Int $x) { "i" ~ callsame }
for ^1_000_000 {
    fallback(4+2i);
    fallback(4.2);
    fallback(42);
}
```



Currently slow dispatches
(master vs. new-disp)



Currently slow dispatches
(master vs. new-disp)



Future opportunities

for further improvements

First, get it good enough to merge

- ✓Final few spectests fixed
- ✓Minimize ecosystem regressions
- ✓Fully re-integrated into optimizer
- ✓Minimize significant performance regressions

Optimization of dispatch resumptions

Inline small targets of a callsame

Make `where` clauses much more competitive with conditionals

Faster native calls

We could treat them as another kind of dispatch terminal

Argument marshalling could be largely done in dispatch programs

Potential for vast improvement on today, especially when JIT is involved

And much more...

Faster calls on role puns

Faster delegation (`handles`)

Faster FALLBACK method handling

A safe "call if it binds" mechanism
(faster Cro request routing)

Thank you!

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