Message in a Bottle

Sending Messages, Caches, PICs, and More

Pablo Tesone - 02/12/2020

Sending Messages

A bytecode view

```
sendingAMessage

    ^ 42 aMessage
```

Source Code

```
41 <20> pushConstant: 42
42 <81> send: aMessage
43 <5C> returnTop
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Bytecode

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Sending a message activates a method on a given receiver with the required parameters.

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Gotta Catch'Em All!

Sending Messages

Parameters & Receiver

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Sending Messages

Parameters & Receiver

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Bytecode

Receiver & Parameters are pushed to the Stack, just before the send message.

Sending Messages

Let’s find the method

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```

Bytecode

To get the method to activate, we need to do the lookup.

Sending Messages

Everything starts with a Selector

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Bytecode

We need to get the selector. How we know is this one?

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Bytecode

We need to get the selector. How we know is this one?

```
42 <81> send: aMessage
```

It is encoded (or kind of) in the bytecode

Sending Messages

The Bytecode is your friend

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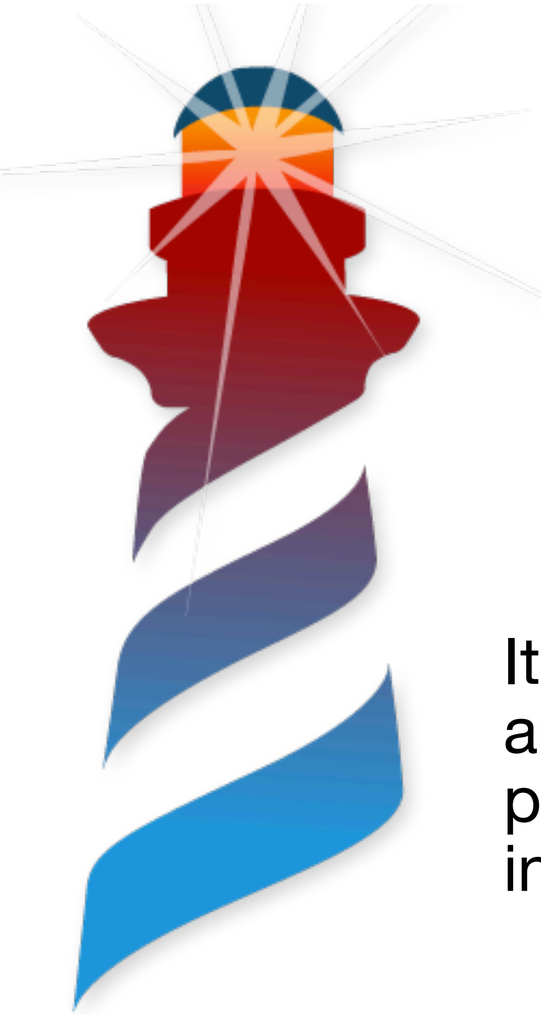
42 <81> send: aMessage
```

Our Bytecode



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#VMJitMethodTest->VMJitMethodTest
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Our Literals (zero-based)

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Our Literals (zero-based)

All Bytecodes

16r80	16r81	16r82	16r83	…
Send 0 args Literal 0	Send 0 args Literal 1	Send 0 args Literal 2	Send 0 args Literal 3	…
16r90	16r91	16r92	16r93	…
Send 1 args Literal 0	Send 1 args Literal 1	Send 1 args Literal 2	Send 1 args Literal 3	…
16rA0	16rA1	16rA2	16rA3	…
Send 2 args Literal 0	Send 2 args Literal 1	Send 2 args Literal 2	Send 2 args Literal 3	…

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Send 2 args Literal 0	Send 2 args Literal 1	Send 2 args Literal 2	Send 2 args Literal 3	…

Not all possible combinations…. We have an extended send message bytecode (16rEA)

Method Lookup

This one… I hope you know.

- We have:
  - The Receiver
  - The Selector

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Method Lookup

This one… I hope you know.

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  - The Receiver
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We need to get the Method.

Here the VM do the method lookup, as we now it.

Method Lookup

But… there is always a but

- Doing the lookup every time is expensive.
- The hierarchies can be deep!!!
- We need an improvement.

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Let’s add a cache!!

Method Lookup

But… there is always a but

- Let’s add a Global Method Cache
- We have a Hashed Map
- Key = ClassTag + Selector
- Value = CompiledMethod

Global Method Cache

ClassTag	Selector	CompiledMethod
ClassTag(X)	#aMessage	X >> #aMessage

Hash(X,aMessage)

1024 Entries

A Hash map, with the class and selector.

Global Method Cache

Handling collisions

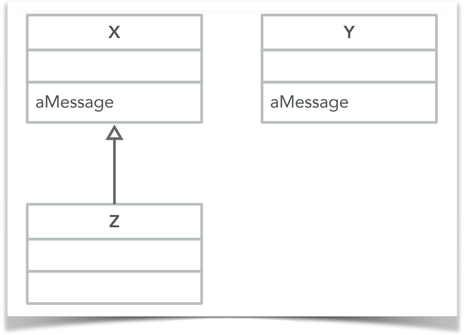
- We calculate a hash of ClassTag and Selector
- Collisions occurs (we only have 1024 slots)
- We do three probes (multiplying by 2 the hash)

“You have 3 questions”

What happens if there is Polymorphism?

	ClassTag	Selector	CompiledMethod
Hash(Y,aMessage)	ClassTag(Y)	#aMessage	Y >> #aMessage
Hash(X,aMessage)	ClassTag(X)	#aMessage	X >> #aMessage

1024 Entries



Our Classes

A new entry is added with the correct hash

What happens if there is inheritance?

	ClassTag	Selector	CompiledMethod
Hash(Y,aMessage)	ClassTag(Y)	#aMessage	Y >> #aMessage
Hash(X,aMessage)	ClassTag(X)	#aMessage	X >> #aMessage

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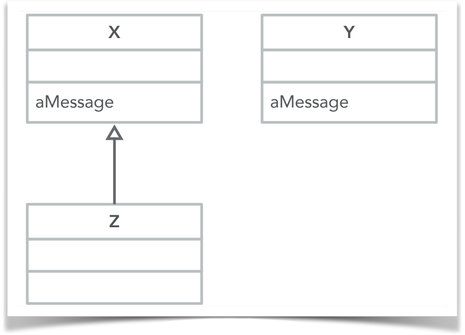
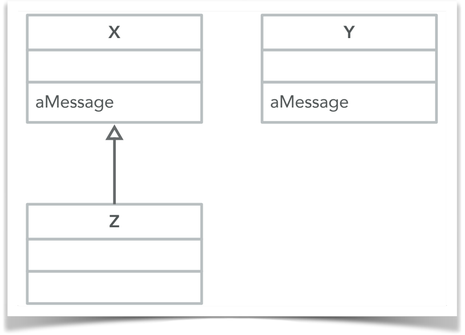


Our Classes

What happens if there is inheritance?

	ClassTag	Selector	CompiledMethod
Hash(Y,aMessage)	ClassTag(Y)	#aMessage	Y >> #aMessage
Hash(X,aMessage)	ClassTag(X)	#aMessage	X >> #aMessage
Hash(Z,aMessage)	ClassTag(Z)	#aMessage	X >> #aMessage

1024 Entries



Our Classes

The Hierarchy is flatten, but the compiled methods are shared.

A message is sent

Finally….

- With
  - Receiver
  - Arguments
  - Method

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We can finally activate the method!!

A message is sent

Finally….

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We can finally activate the method!!

And… if previously found in the cache, compile it to machine code

How is it compiled!!!

Shut-up and show me code!!!

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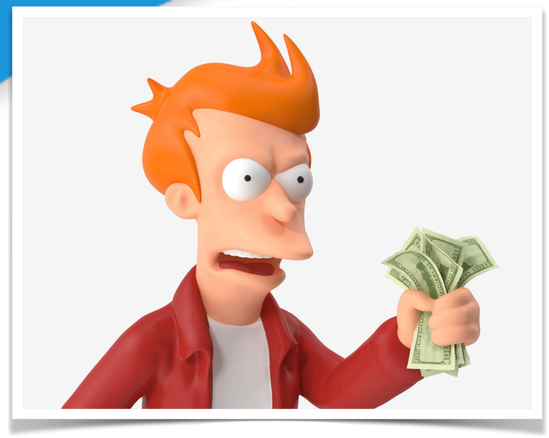
Bytecode



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Abort:
                    MoveCqR 0 ReceiverResultReg
                    PushR LinkReg
                    Call abortTrampoline
                    AlignmentNops 8
Entry:
                    AndCqRR 7 ReceiverResultReg
                    JumpNonZero Label2
                    MoveMwrR 0 ReceiverResultReg TempReg
                    AndCqR 16r3FFFFF TempReg
                    Nop
                    Nop
                    Nop
Label 2:
                    CmpRR ClassReg TempReg
                    JumpNonZero Abort
                    PushR ReceiverResultReg
Label 3:
                    PushR LinkReg
                    PushR FPReg
                    MoveRR SPReg FPReg
                    PushCw 16r1000430
                    MoveCqR 16r1016400 SendNumArgsReg
                    PushR SendNumArgsReg
                    PushR ReceiverResultReg

                    MoveAwR 16r7FFFFFFFFFFFFC88 TempReg
                    CmpRR TempReg SPReg
                    JumpBelow Abort

                    MoveCqR 16r151 ReceiverResultReg
                    MovePatcheableC32R 1 ClassReg
                    Call send0ArgTrampoline

                    MoveRR FPReg SPReg
                    PopR FPReg
                    PopR LinkReg
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How is it compiled!!!

Let it goes slowly

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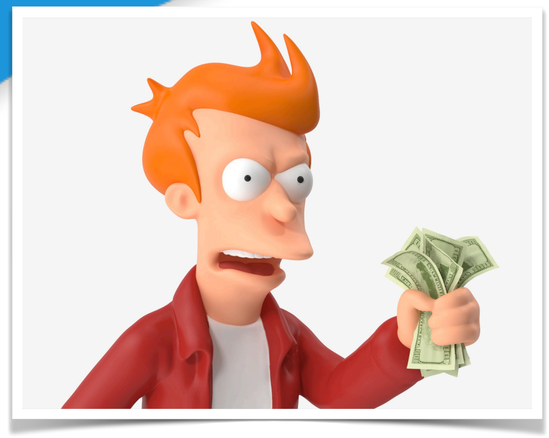

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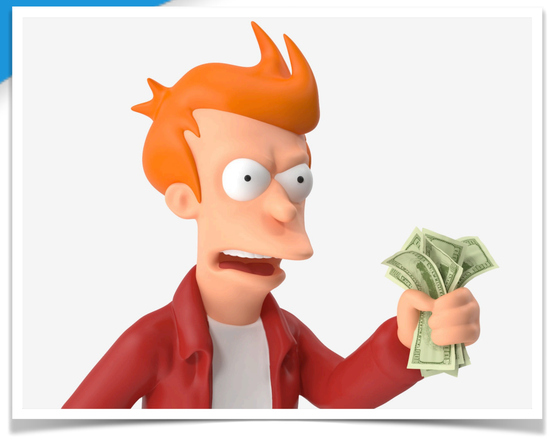

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Entry point & Type check

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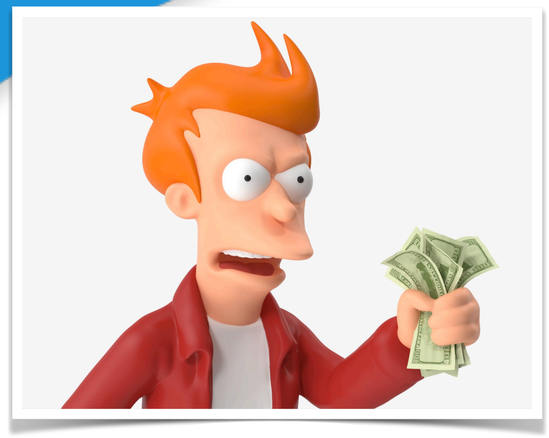

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Calling the Abort trampoline

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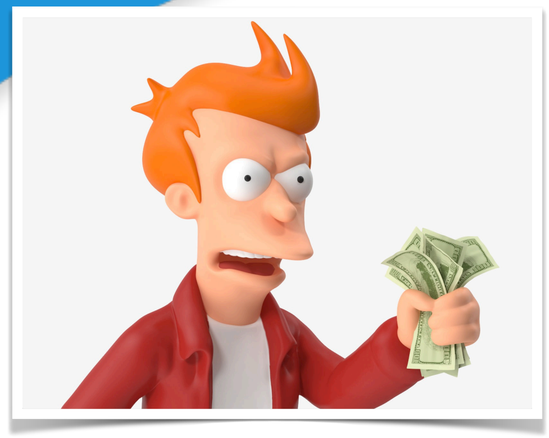

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Frame building

How is it compiled!!!

Let it goes slowly

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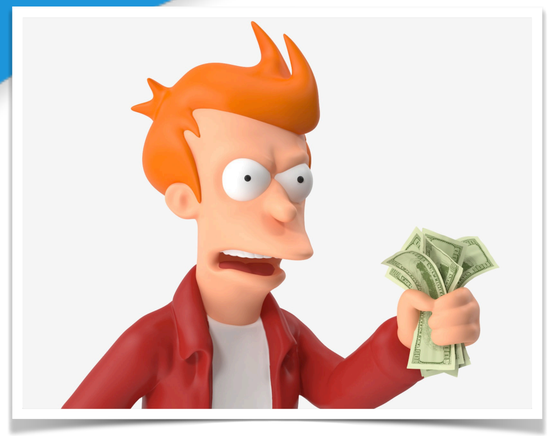

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Frame un-building & return

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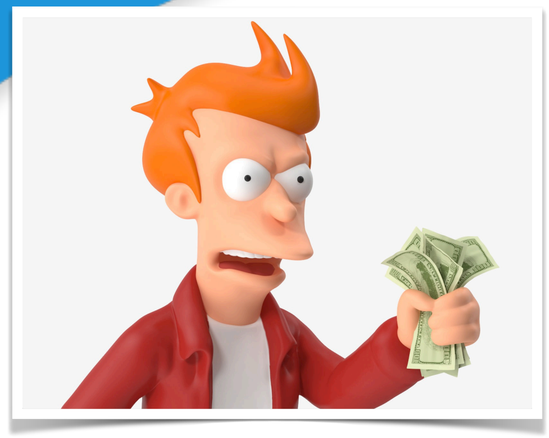

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```

Stack overflow check & maybe context switch

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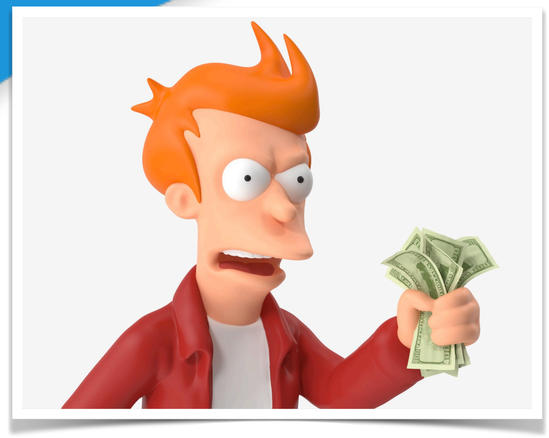

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Sending Message

I want a Zoom
Let’s Analyse it

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41 <20> pushConstant: 42

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Bytecode (friendly reminder)

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Bytecode (friendly reminder)

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MoveCqR 16r151 ReceiverResultReg
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Call send0ArgTrampoline
```

Move Receiver (42) to the ReceiverResultReg (42 as SmallInteger => 16r151)

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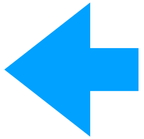

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MoveCqR 16r151 ReceiverResultReg
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Call send0ArgTrampoline
```

Move Selector Index to ClassReg

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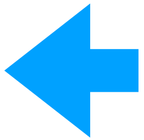

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MoveCqR 16r151 ReceiverResultReg
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Call send0ArgTrampoline
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We call the trampoline to do the send.

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MovePatcheableC32R 1 ClassReg
Call send0ArgTrampoline
```

41 <20> pushConstant: 42

42 <81> send: aMessage

43 <5C> returnTop

Bytecode (friendly reminder)

We call the trampoline to do the send.

We have specialised cases for 0, 1 & 2 arguments.

For 3 or more…. easy add a parameter

I want a Zoom
More arguments

- If the number of arguments is 1 or 2, they go in registers (Arg0Reg & Arg1Reg).
- If there are more arguments they go in the stack.
- If there are 3 or more arguments, the number of arguments go in the SendNumArgsReg register.

```
… Receiver & Args already in the stack …
MovePatcheableC32R 3 SendNumArgsReg
MovePatcheableC32R 1 ClassReg
Call sendNArgTrampoline
```

We can do it better…

Monomorphic Calls

- This solution is good but:
  - We are jumping to the interpreter in each message send.
  - We are doing a cache lookup every time, and maybe a full lookup.
  - The most probable case is that we are always activating the same compiled method.
  - If the target method is already compiled in machine code… why not call it directly?

What we want!

Monomorphic Calls

- Once we have found the method to execute, why not patch the message send to call the correct method directly.

```
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```
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Call 16rFF001122
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```

Entry address of the JITed method of `SmallInteger >> #aMessage`

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Bytecode (friendly reminder)

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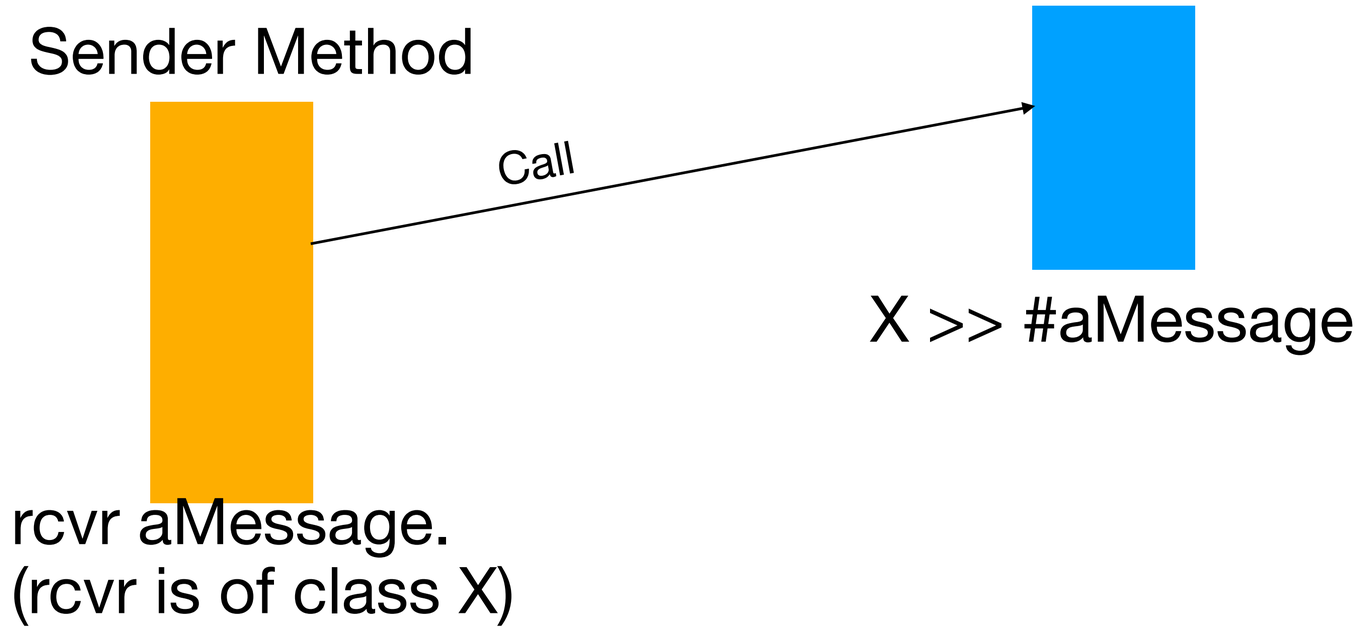
```

Expected Class Tag of the Receiver

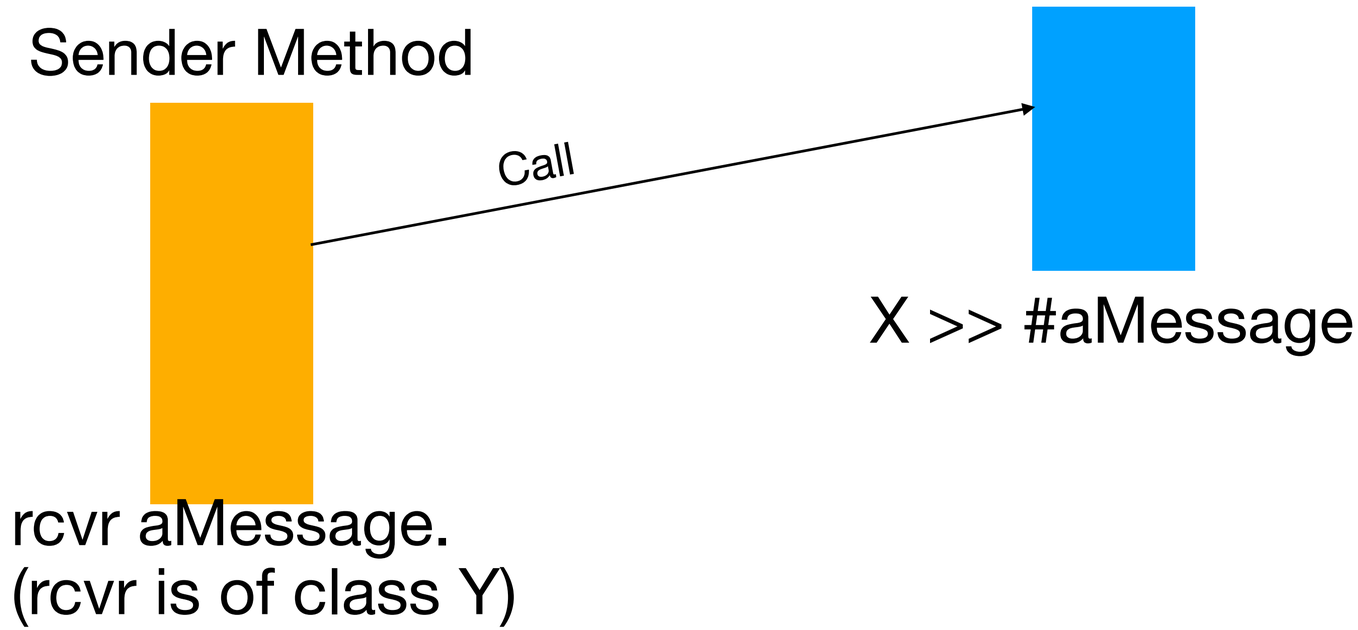
```
41 <20> pushConstant: 42
42 <81> send: aMessage
43 <5C> returnTop
```

Bytecode (friendly reminder)

Executing the call



If the receiver is not the expected of the class?



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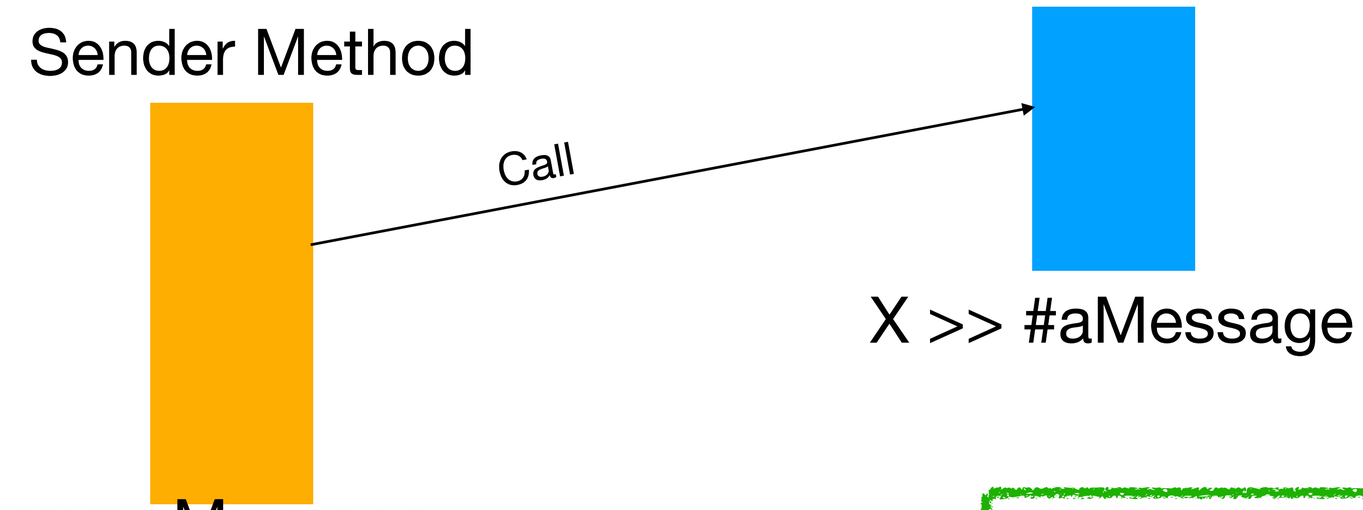
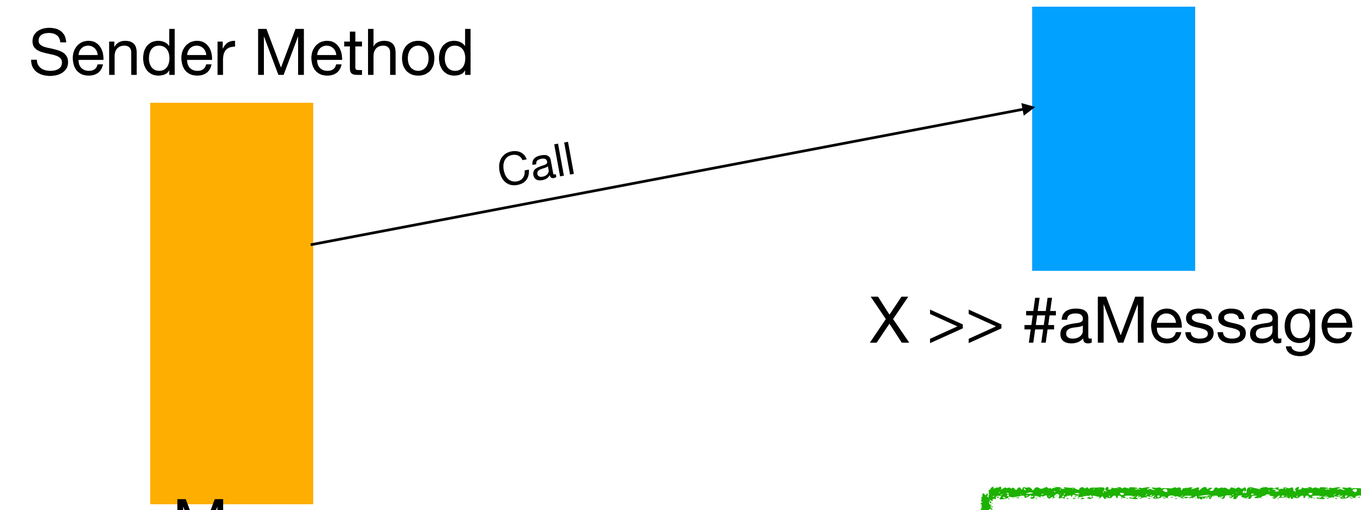
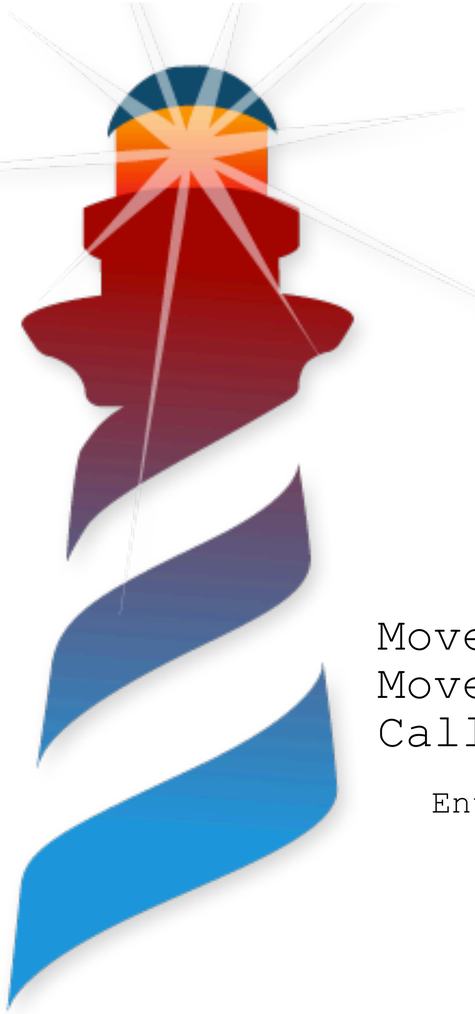


We should not execute
X >> #aMessage

If the receiver is not the expected of the class?



We need to validate this condition



Why Sending the Expected Class Tag?

Monomorphic Calls

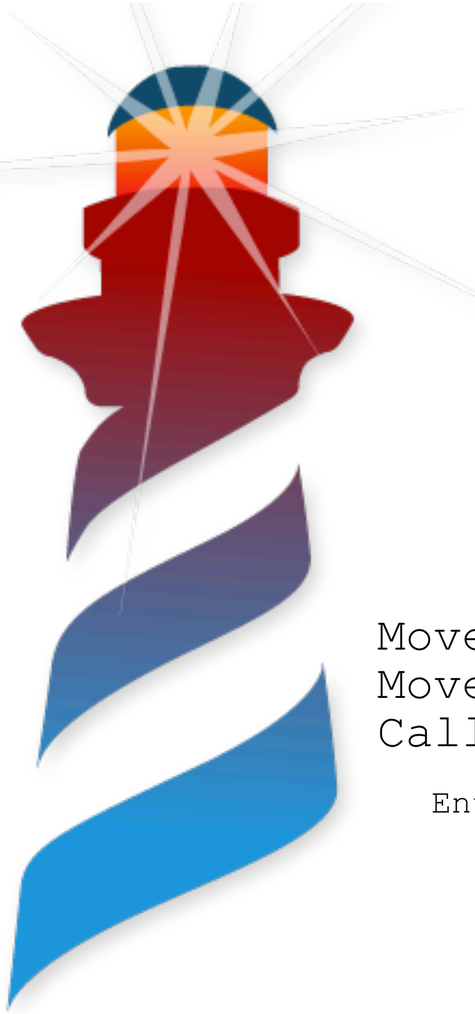
- So we can test if we are in the correct receiver. If not the abort trampoline is call.

```
MoveCqR 16r151 ReceiverResultReg
MovePatcheableC32R 1 ClassReg
Call send0ArgTrampoline
```

```
MoveCqR 16r151 ReceiverResultReg
MovePatcheableC32R 16r5588 ClassReg
Call 16rFF001122
```

```
Entry:
        AndCqRR 7 ReceiverResultReg TempReg
        JumpNonZero Label2
        MoveMwrR 0 ReceiverResultReg TempReg
        AndCqR 16r3FFFFF TempReg
        Nop
        Nop
        Nop

Label 2:
        CmpRR ClassReg TempReg
        JumpNonZero Abort
        PushR ReceiverResultReg
```



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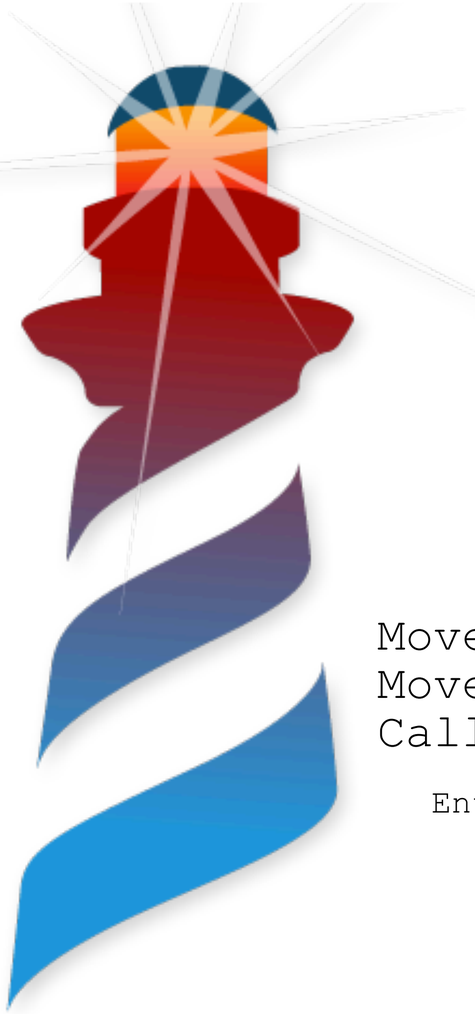
Extract the Class tag if it is an immediate



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Label 2:
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        JumpNonZero Abort
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```
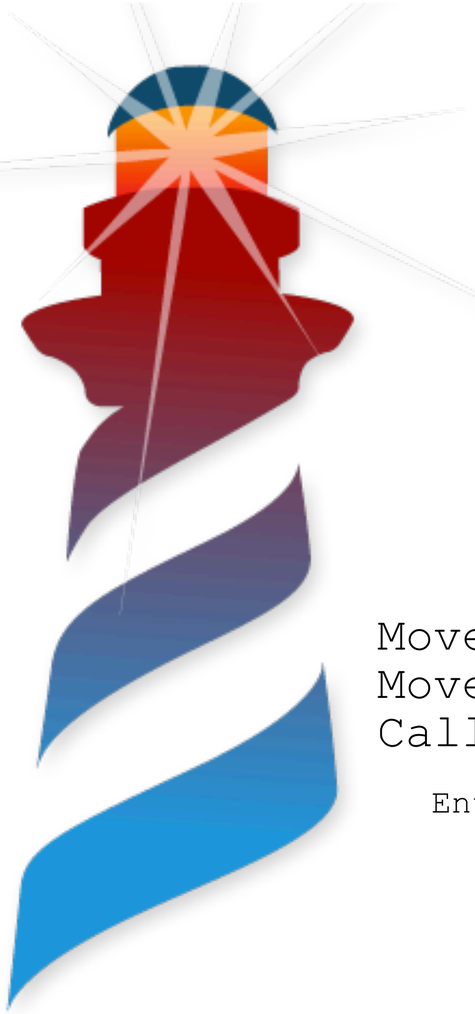

Extract the Class tag if non immediate.



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Label 2:
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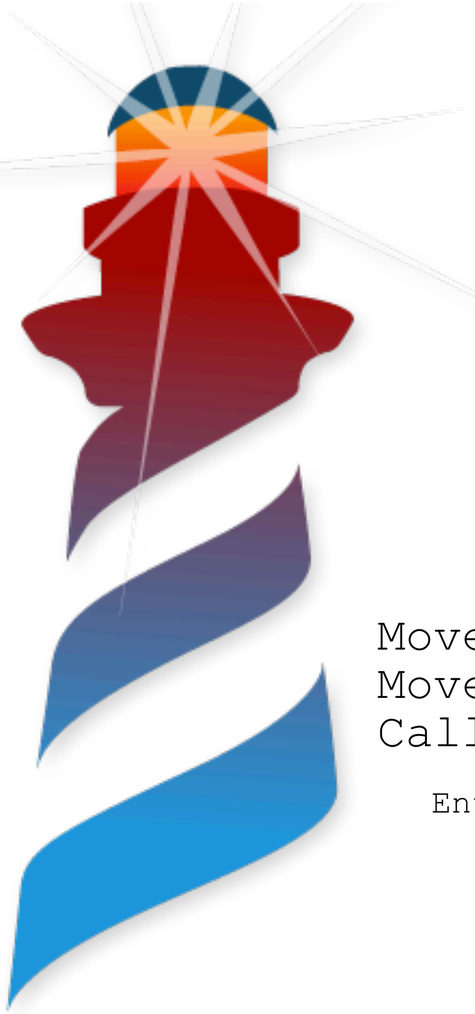
        PushR ReceiverResultReg
```

Compare the expected and the actual class tag. If it is the same… continue the method



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        Nop
        Nop
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Label 2:
        CmpRR ClassReg TempReg
        JumpNonZero Abort
        PushR ReceiverResultReg
```

If not the same… jump to the call to the abort trampoline

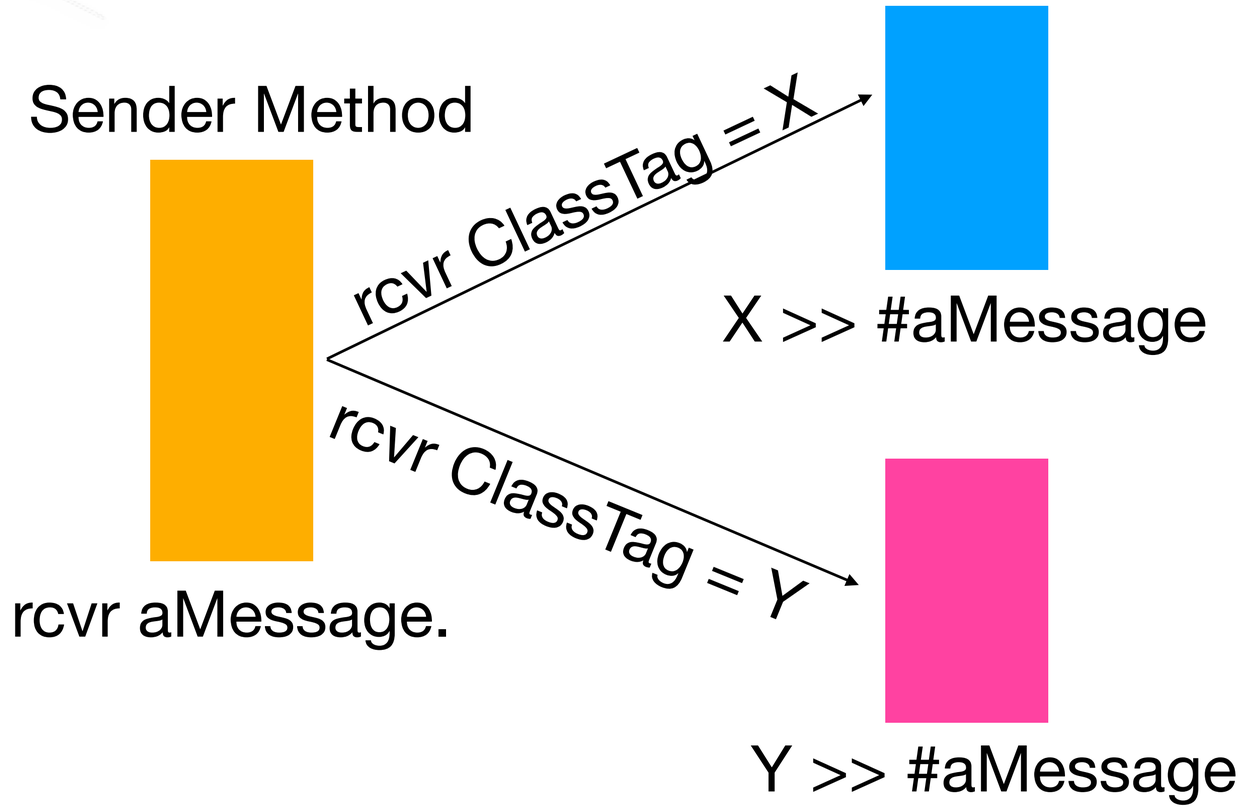
What the Abort Trampoline Do?

a.k.a Single-In-line Cache Miss

- Call #ceSICMiss: in the VM C Runtime with the receiver.
- We are expecting a single method to be activated here, but another appears. So we need to fix the patched sender.
- We have to extend the single-in-line cache with a polymorphic cache (or even a Megamorphic).

Polymorphic Calls

Welcome Polymorphism!



Polymorphic Calls

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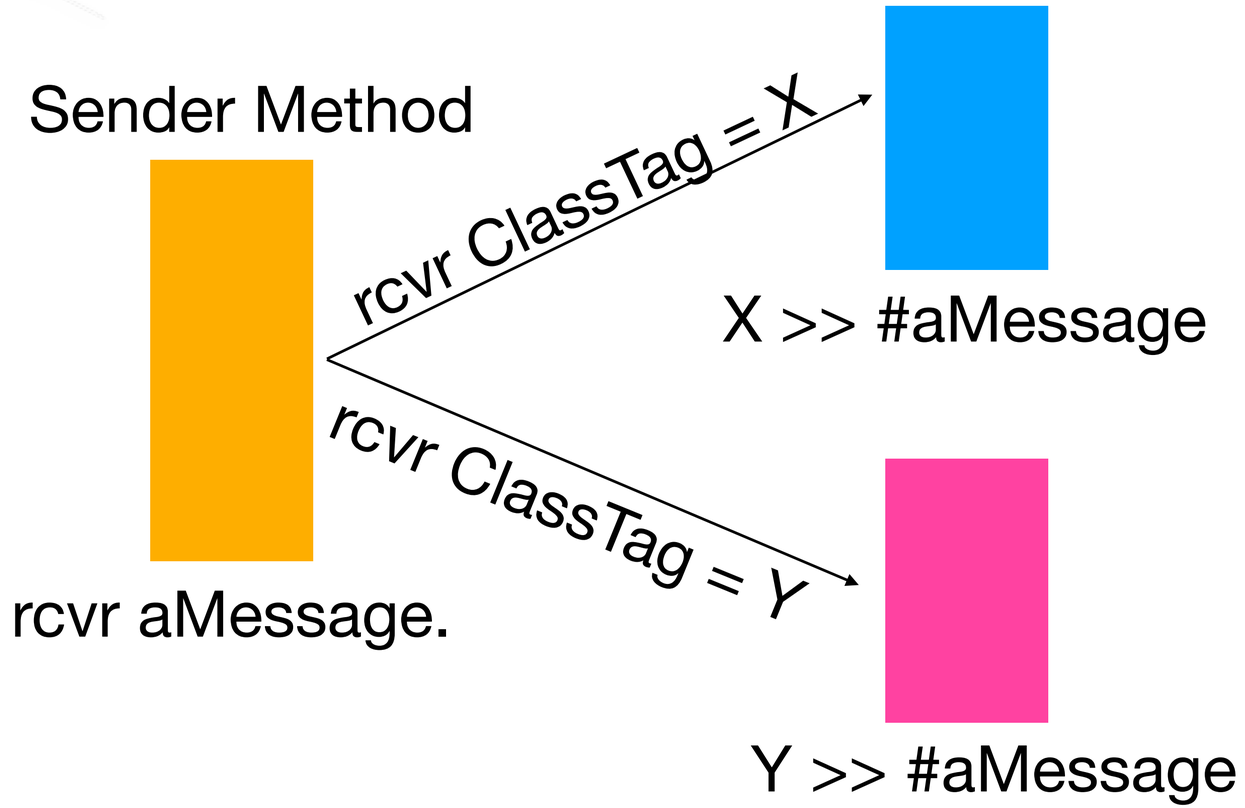
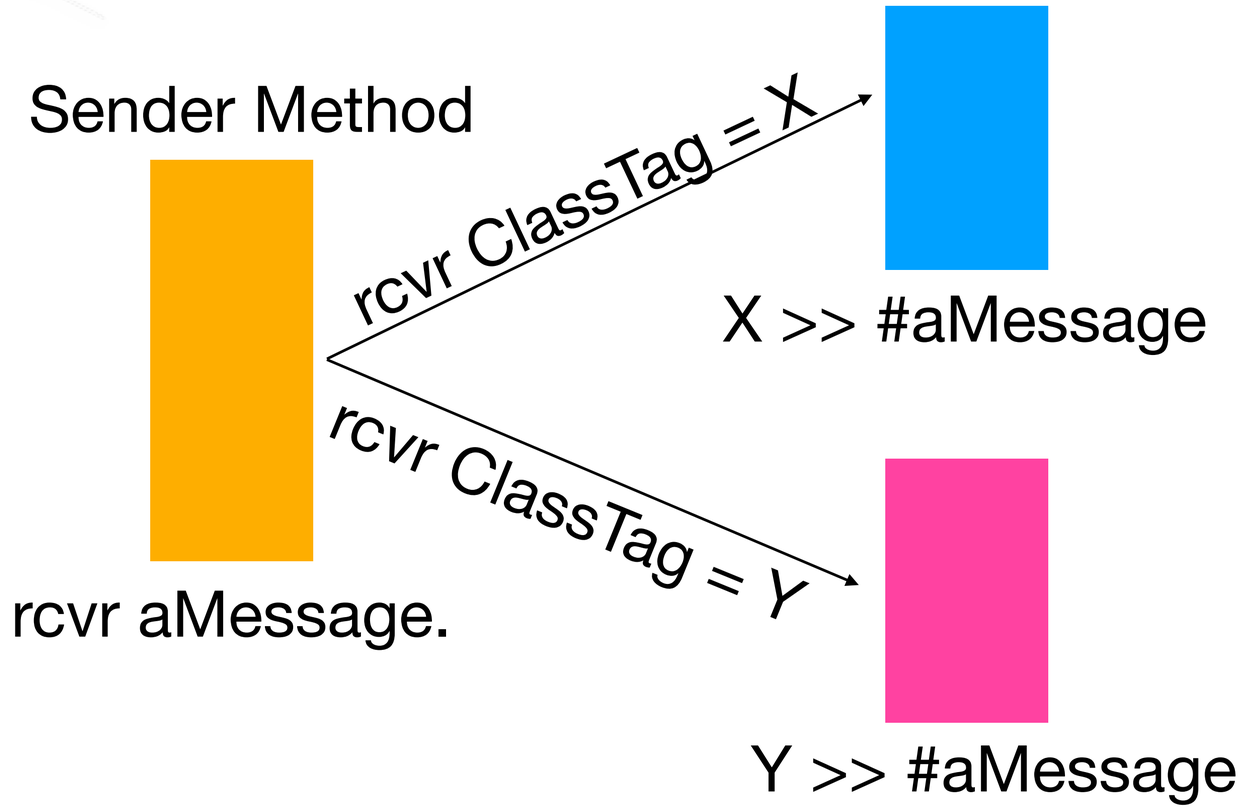


We want to put this decision logic somewhere!!!

Polymorphic Calls

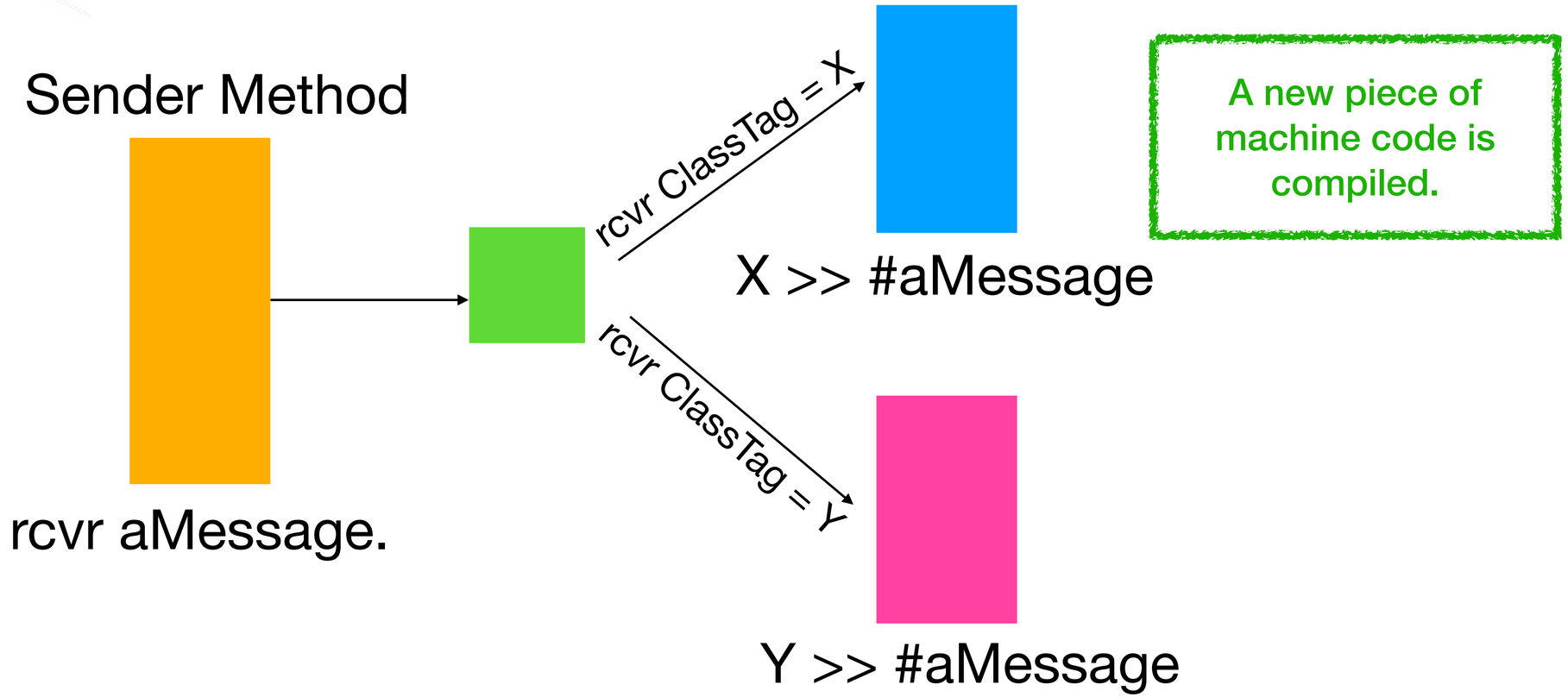
Welcome Polymorphism!



We cannot modify the existing method. So create something in the middle

Polymorphic Calls

Polymorphic-In-line-Cache, I choose you!



Polymorphic Calls

Polymorphic-In-line-Cache, I choose you!

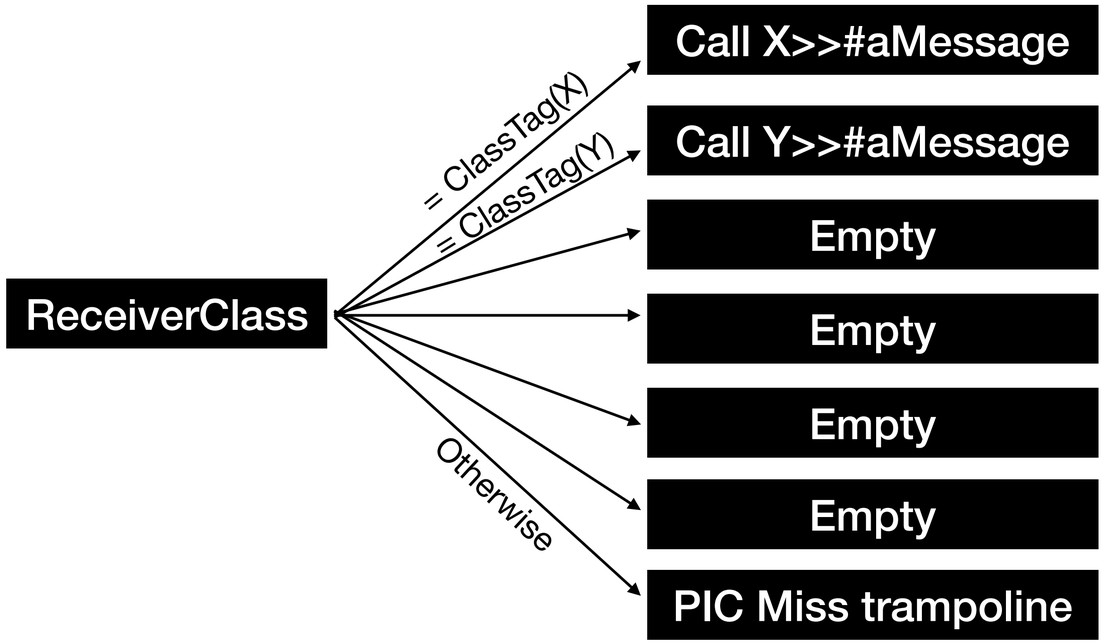
```
MoveCqR 16r151 ReceiverResultReg
MovePatcheableC32R 16r5588 ClassReg
Call 16rFF001122
```

```
MoveCqR 16r151 ReceiverResultReg
MovePatcheableC32R 16r5588 ClassReg
Call 16rFF998877
```

The sender is now patched to call the PIC.

Polymorphic Calls

PICs a.k.a a Nice Switch Case



Polymorphic Calls

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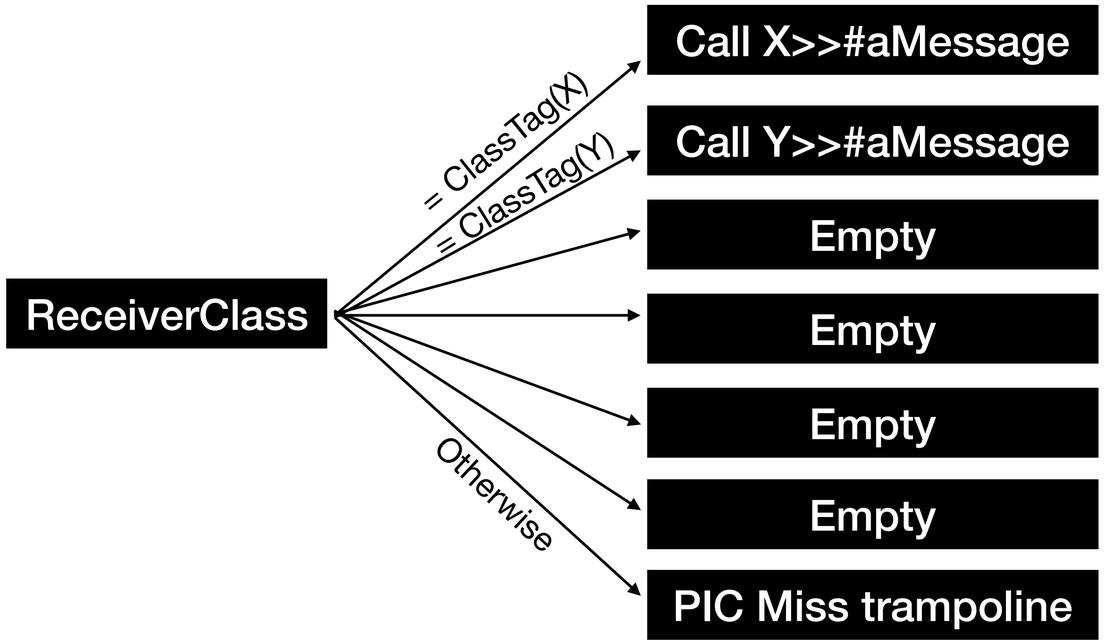


Starts with 2 Cases

A PIC is created by call site if needed.

6 Slots in total.

If one of the existing does not fit. PIC Miss Trampoline

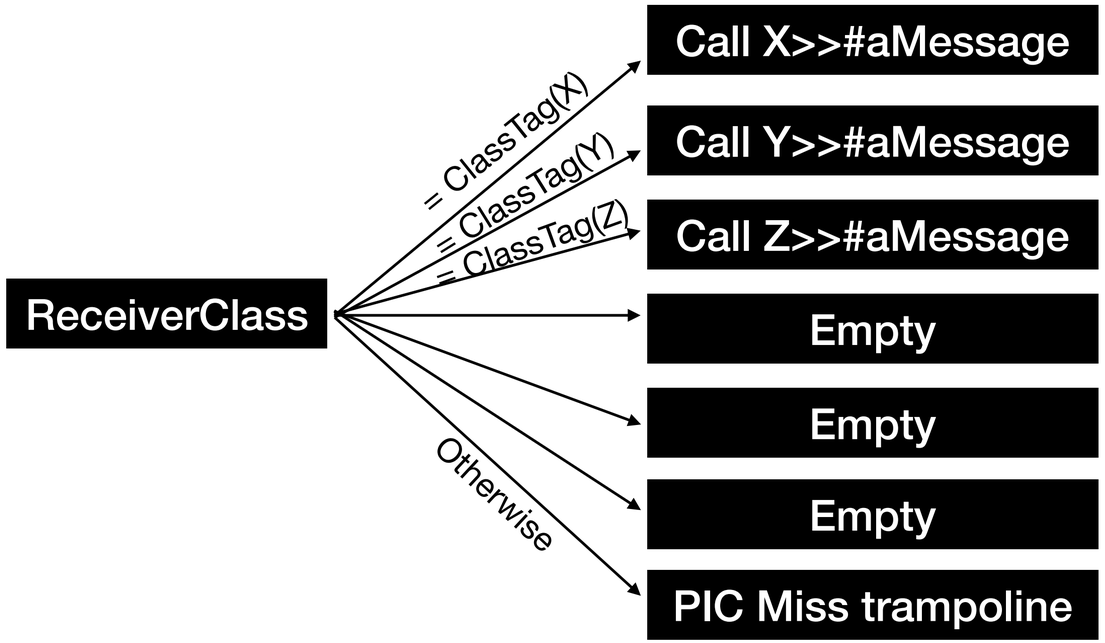
Polymorphic Calls

PIC Miss Trampoline

- This VM C runtime function is executed if a new method appear and it is not in the PIC.
- If there is a machine code method. Patch the PIC to include it.
- A new case is added to the PIC, and the new method is executed.

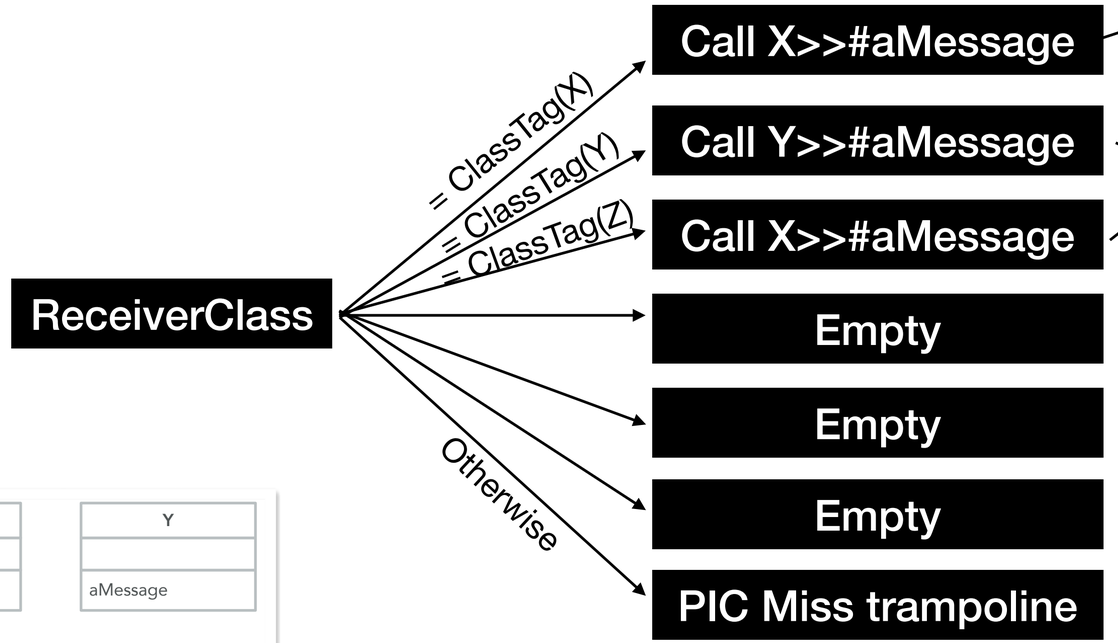
Polymorphic Calls

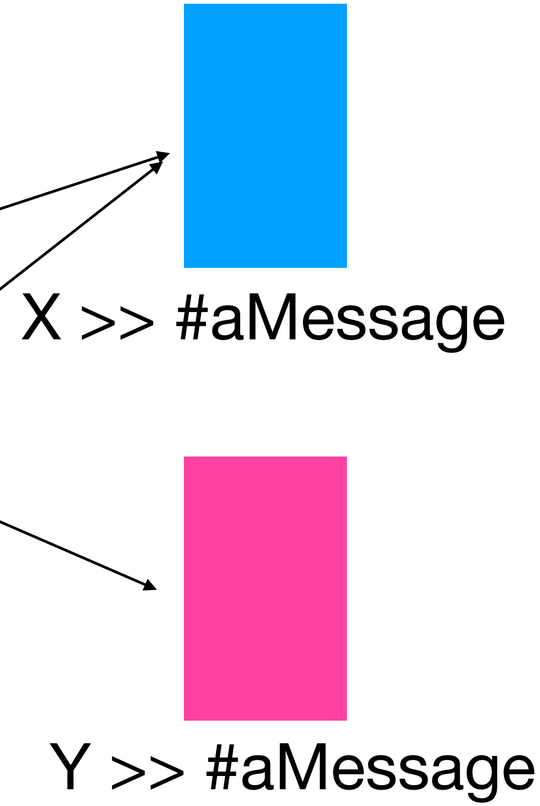
PICs a.k.a a Nice Switch Case

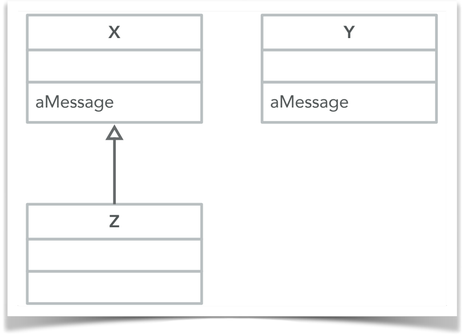


Polymorphic Calls

What with Inheritance



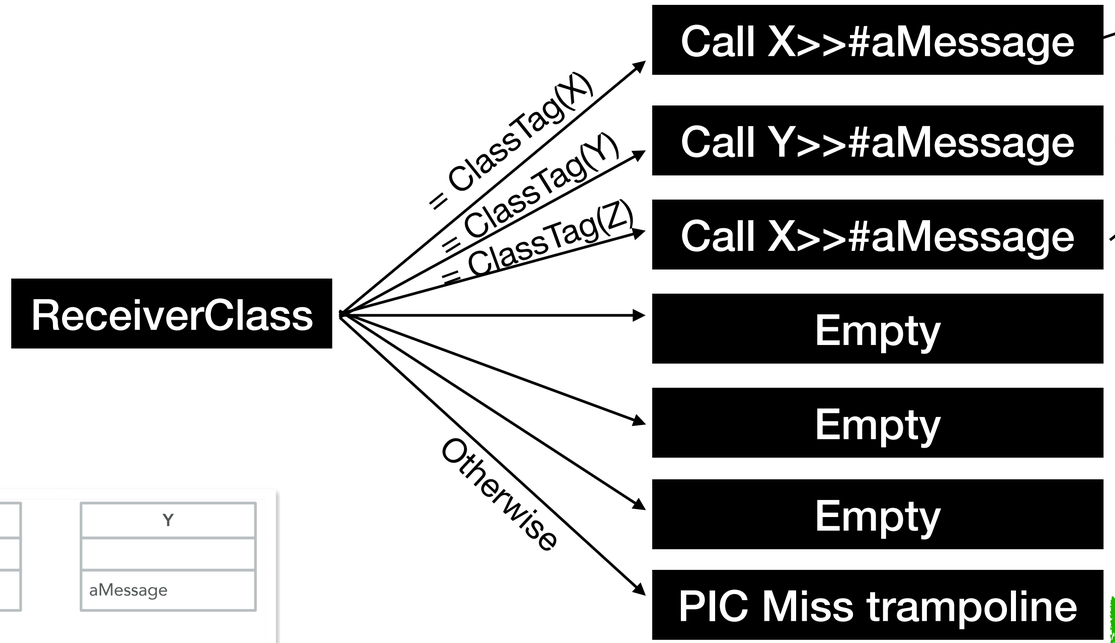


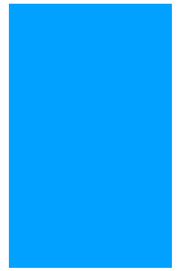


Our Classes

Polymorphic Calls

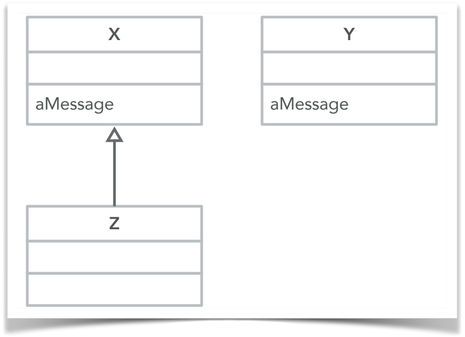
What with Inheritance





X >> #aMessage

Y >> #aMessage



Our Classes

If there is inheritance, and the message is sent. We have two entries: with different class tags, but same method

Megamorphic Calls

When a PIC is not enough

- If we have more a PIC that is full (all its slots are used by methods) and a new possible method is found for that class site.
- We have a Megamorphic call site.

Megamorphic Calls

What a Megamorphic-in-line-cache do?

- It is compiled in the method zone.
- There is one by selector (different call-sites uses the same one).
- It is compiled to do:
  - Search the pair <selector,classTag> in the method cache.
  - Search it 3 times.
  - If found, call it
  - If not found… call a trampoline to do the slow lookup and method activation.

What do we miss?

There is always more to learn…

- Super message sends
- MessageNotUnderstood handling
- Special selectors
- Young methods and early megamorphic promotion
- Optimizations / Implementation details
- ...

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Thanks!!!!

We are going to catch them all!!!