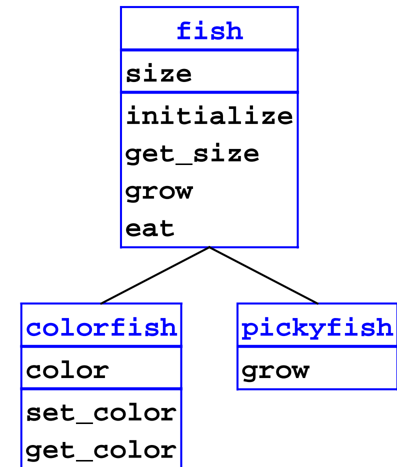
Outline

- More optimizations for our interpreter
- Types for objects

Optimization

Eliminate tree walks: object creation, method calls



Object Creation

Current interpreter:

1. Find class
2. Get field list (walk tree)
3. Allocate field array and object

To eliminate tree walks:

2. Extract flat field list from class

Method Calls

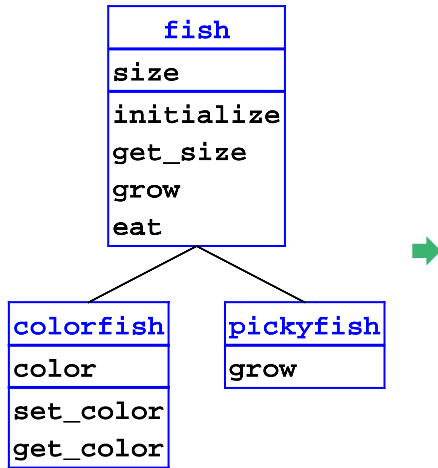
After object and arguments are determined:

1. Lookup object class
2. Find class containing method (walk tree)
3. Get variables for class (walk tree)
4. Create environment: fields + `%super` + `self` + args
5. Evaluate method body

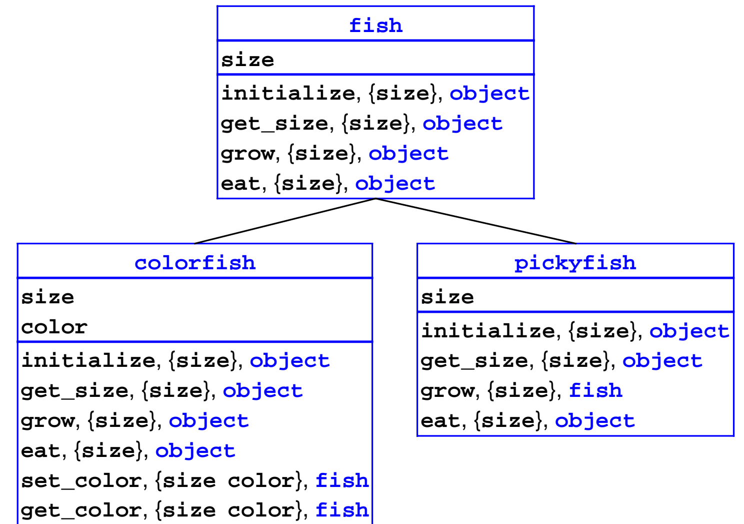
To eliminate tree walks:

2 & 3. Find method in current class, extract variable list

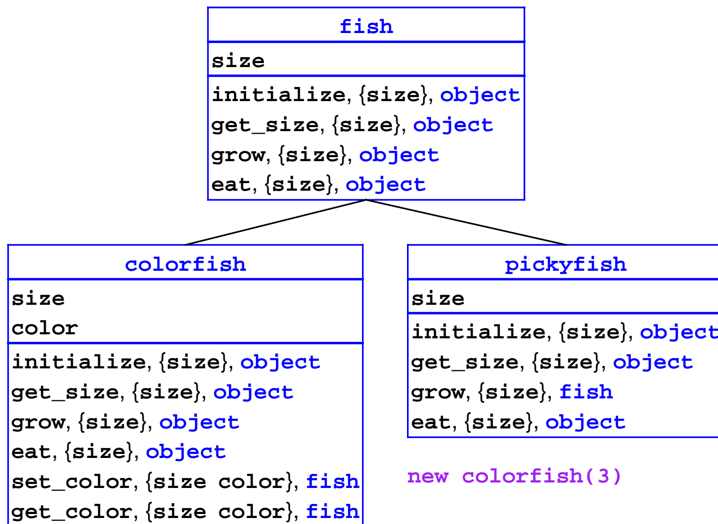
Class Elaboration



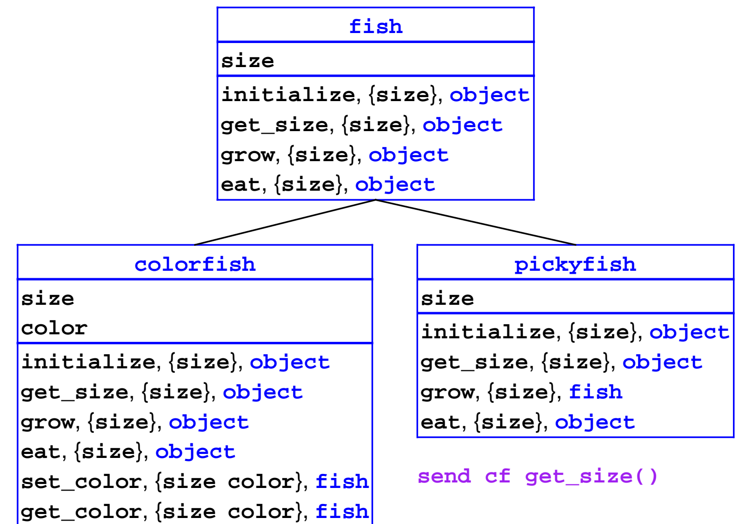
Class Elaboration



Class Elaboration



Class Elaboration



Implementation

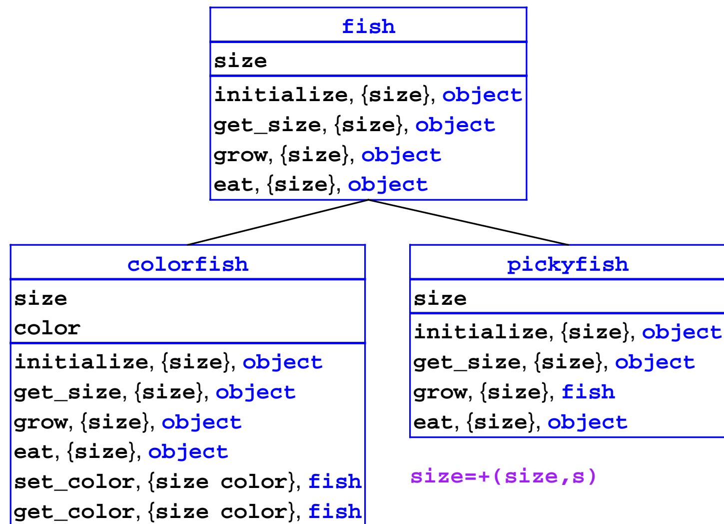
See the book and web page:

- Change **`elaborate-class-decls!`** to build annotated tree
- Change **`new-object`** to use class's immediate field list
- Change **`apply-method`** to work with annotated methods

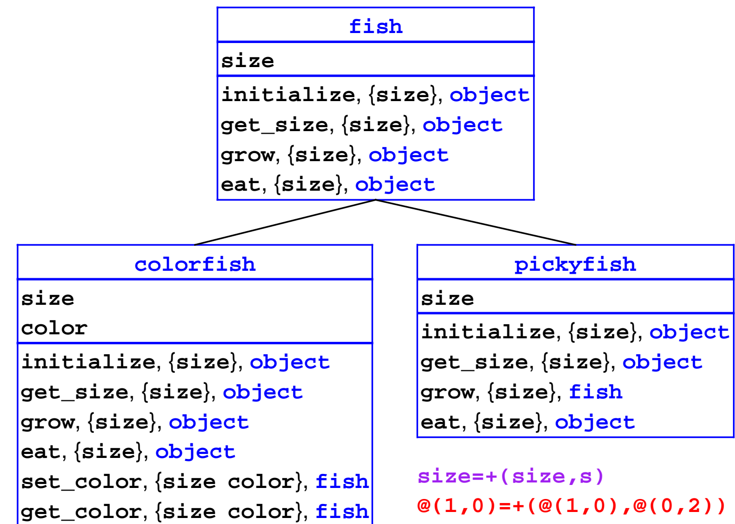
More Optimization

- Still have list walks: variable lookup, method lookup
  - Can eliminate many with lexical addresses
  - Can eliminate some by pre-computing method positions
  - Need type information to eliminate others

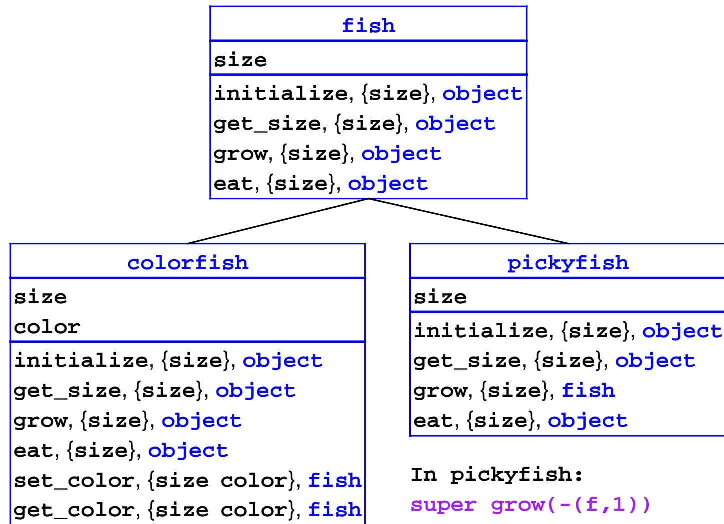
More Optimization: List Walks



More Optimization: List Walks



More Optimization: List Walks



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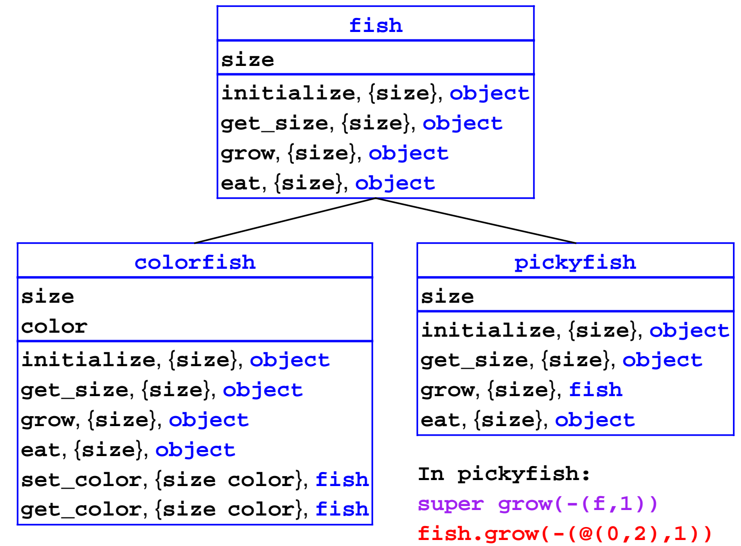

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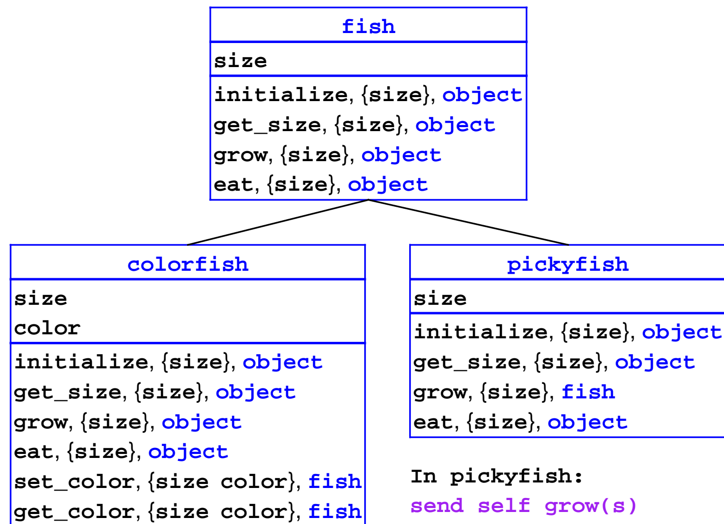
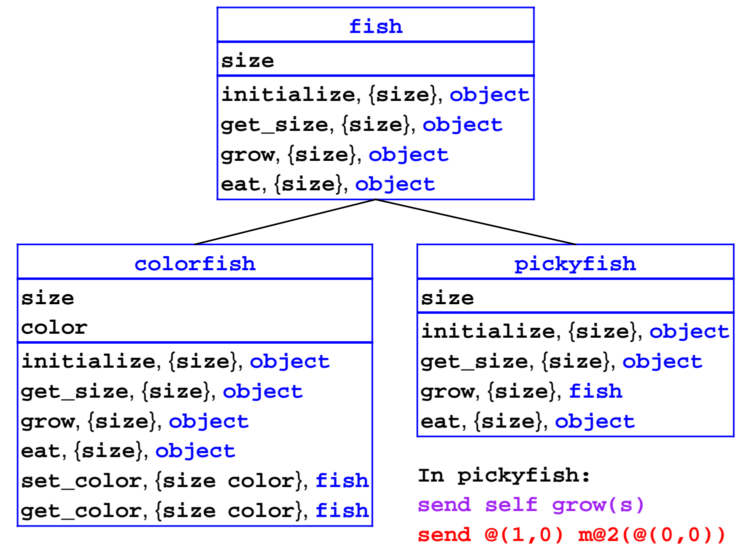


More Optimization: List Walks



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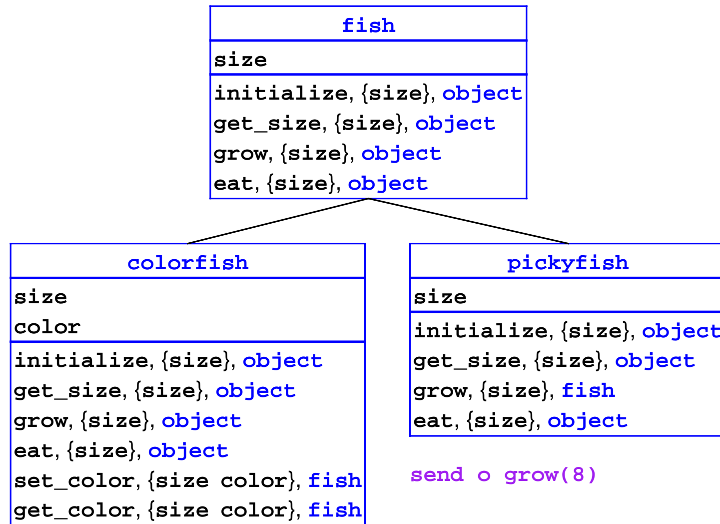
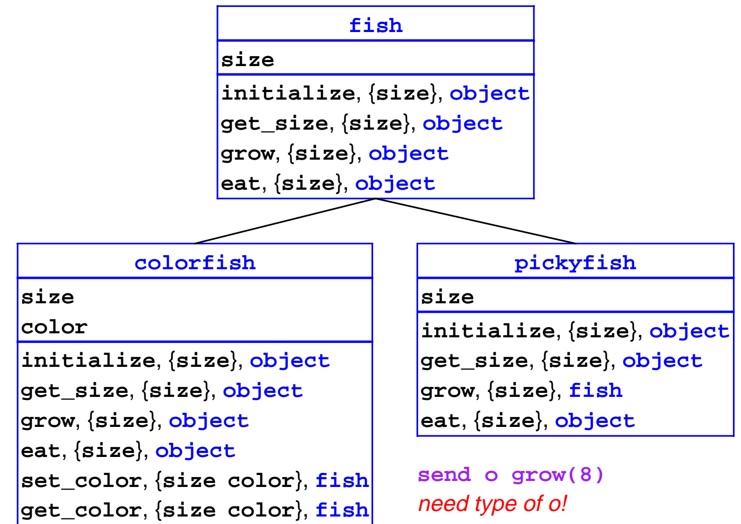


More Optimization: List Walks



Object Types

```
new c1()
c1
```

... *if* `c1` has an **`initialize`** method that takes no arguments

```
class c1 extends ...
 method void initialize() ...
```

Object Types

```
new c1(5)
       int
c1
```

... if `c1` has an **`initialize`** method that takes one integer

```
class c1 extends ...
 method void initialize(int v) ...
```

Object Types

```
send new c1() m(false)
```

c1, bool → int

... if `c1` has an `m` method that takes `bool` and returns `int`

```
class c1 extends ...
 method void initialize() ...
 method int m(bool v) ...
```

Object Types

```
class fish extends object
  field int size
  method void initialize (int s) ...
  method void eat(fish other) ...
class colorfish extends fish
  ...
```

```
send new fish(8) eat(new colorfish(1))
```

fish, colorfish

`colorfish` ***doesn't match*** `fish`

Subtyping

- ***Subtype:*** An instance of class `C` can be used as an instance of class `C'` if `C` is derived from `C'`

  `C <: C'`

- Subtype rule:

  If `e : T` and `T <: T'` , then `e : T'`

Object Types

```
class fish extends object
  field int size
  method void initialize (int s) ...
  method void eat(fish other) ...
class colorfish extends fish
  ...
```

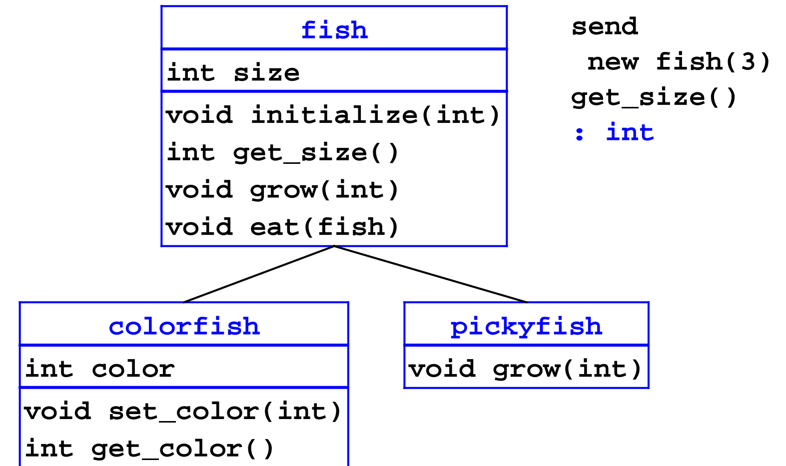
```
send new fish(8) eat(new colorfish(1))
```

fish, colorfish `<:` fish → void

Language Changes

- Add types to field declarations
- Add types to method arguments and result
- Add `abstract class` and `abstractmethod`
- Add `instanceof`
- Add `cast`

Program Checking



Things to Check

`cast` and `instanceof`:

- Operand has an object type (for any class)
- Target class exists

```
cast o c1        instanceof o c7
```

Things to Check

`cast` and `instanceof`:

- Operand has an object type (for any class)
- Target class exists

`cast` only:

- Class for operand and target are comparable
  - Otherwise, cast cannot possibly succeed

```
class c1 extends object ...
class c2 extends object ...
cast new c1() c2
```

Things to Check

Object creation:

- Class exists, and is not abstract
- Class has an **`initialize`** method
- **`initialize`**'s argument types match the operand types

```
class c1 extends object
  method void initialize(int x, bool y)
   ...

new c1(1, false)
```

Things to Check

Method calls:

- Receiver expression is an object
- Method is in the object-type's class
  - Except **`initialize`**...
- Method's argument types match the operand types

```
class c1 extends object
  method void initialize() ...
  method void m(int x, bool y)
   ...
let o1 = new c1()
in send o1 m(1, false)
```

Things to Check

`super` calls:

- Expression is within a method
- Method is in the superclass, and not abstract
- Method's argument types match the operand types

```
class c1 extends object
  method void m(int x, bool y)
    ...

class c2 extends c1
  method void n()
    super m(1, false)
  ...
```

Things to Check

`class` declarations:

- Superclass exists, and no cyclic inheritance
- Methods bodies ok
  - Use host class for type of **`self`**
- Overriding method signatures the same as in superclass
  - Except for **`initialize`**

```
class c2 extends c1
  method void m(int x, bool y)
   if y then +(2, x) else send self w()
```

The Initialize Method

```
class c1 extends obj
 field int x
 method void initialize()
  set x = 3
 method int m()
  send self initialize()

class c2 extends c1
 field int y
 method void initialize(int v)
   set y = v
   super initialize()
 ...
```

- Derived class needs different signature for `initialize`

The Initialize Method

```
class c1 extends obj
 field int x
 method void initialize()
  set x = 3
 method int m()
  send self initialize()

class c2 extends c1
 field int y
 method void initialize(int v)
   set y = v
   super initialize()
 ...
```

- Disallow `send` to `initialize`

The Initialize Method

```
class c1 extends obj
 field int x
 method void initialize()
  set x = 3
 method int m()
  send self initialize()

class c2 extends c1
 field int y
 method void initialize(int v)
   set y = v
   super initialize()
 ...
```

- `super` call to `initialize` is ok

Field Initializations

Not checked: field initializations

```
class interior_node extends tree
 field tree left
 field tree right
 method void initialize(tree l, tree r)
  begin
   send left sum();
   ...
  end
```

- Can get "bad object 0 for method call"
- This is analogous to the `null` error in Java

Type Checking and Errors

Disallowed errors:

- Object has no such method, or Super method not found
- Can't call method of non-object, non-0
- No such field, no such variable
- Illegal primitive argument (except car of empty)

Allowed errors:

- Can't call method of 0
- Cast failed
- Car of empty

Implementation

See the book and web page

Mixing Subtyping and Procedures

Our language still has procedures:

```
let feed = proc(colorfish f)
             send f grow(10)
    o1 = new colorfish(0)
 in
   (feed o1)
```

Mixing Subtyping and Procedures

And higher-order procedures:

```
let feed = proc(colorfish f)
             send f grow(10)
    o1 = new colorfish(0)
    o2 = new colorfish(1)
 in let toboth = proc((colorfish -> void) p)
                  begin
                    (p o1);
                    (p o2)
                  end
     in (toboth feed)
```

Mixing Subtyping and Procedures

Subtyping on procedure arguments:

```
let feed = proc(fish f)
             send f grow(10)
    o1 = new colorfish(0)
 in
   (feed o1)
```

- This works, and is allowed by our subtyping rule

Mixing Subtyping and Procedures

Subtyping on procedure arguments:

```
let feed = proc(fish f)
             send f grow(10)
    o1 = new colorfish(0)
    o2 = new colorfish(1)
 in let toboth = proc((colorfish -> void) p)
                  begin
                    (p o1);
                    (p o2)
                  end
     in (toboth feed)
```

- This works, but is ***not*** allowed by our subtyping rule

  `(fish -> void)` versus `(colorfish -> void)`

Procedure Subtyping Rule

If `T1 <: T1'` and `T2 <: T2'`

then `(T1' -> T2) <: (T1 -> T2')`

Another example:

- `dog <: animal`
  - a dog can go anywhere an animal can go
- `(animal -> hairstyle) <: (dog -> hairstyle)`
  - a groomer for all animals can groom a dog
  - a groomer who only works with dogs doesn't work for all animals

Procedure Subtyping Rule

If `T1 <: T1'` and `T2 <: T2'`

then `(T1' -> T2) <: (T1 -> T2')`

General intuition:

- `T1 <: T1'` means `T1'` is more general than `T1`

- A function that is willing to accept a more general argument is itself more specific

Procedure Subtyping Rule

If `T1 <: T1'` and `T2 <: T2'`

then `(T1' -> T2) <: (T1 -> T2')`

- Procedure types are ***contravariant*** with respect to their argument types
- Procedure types are ***covariant*** with respect to their result types