Signature Inference for Functional Property Discovery

or: How never to come up with tests manually anymore(*)

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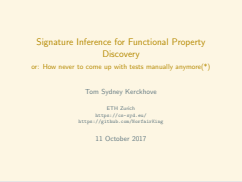

Motivation

Writing correct software is hard for humans.

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Unit Testing

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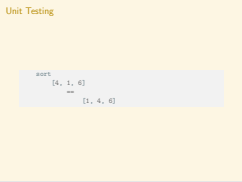

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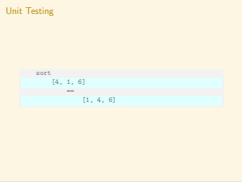

Property testing

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Property Discovery with QuickSpec

Example Code

```haskell
module MySort where

mySort :: Ord a => [a] -> [a]
mySort [] = []
mySort (x:xs) = insert (mySort xs)
  where
    insert [] = [x]
    insert (y:ys)
        | x <= y = x : y : ys
        | otherwise = y : insert ys

myIsSorted :: Ord a => [a] -> Bool
myIsSorted [] = True
myIsSorted [_] = True
myIsSorted (x:y:ls) = x <= y && myIsSorted (y : ls)
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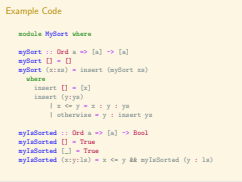

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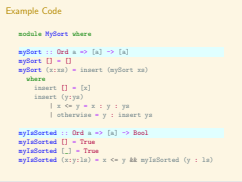

Property Discovery using QuickSpec

```
== Signature ==
     True :: Bool
     (<=) :: Ord a => a -> a -> Bool
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   mySort :: Ord a => [a] -> [a]
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== Laws ==
  1. y <= y = True
  2. y <= True = True
  3. True <= x = x
  4. myIsSorted (mySort xs) = True
  5. mySort (mySort xs) = mySort xs
  6. xs <= mySort xs = myIsSorted xs
  7. mySort xs <= xs = True
  8. myIsSorted (y : (y : xs)) = myIsSorted (y : xs)
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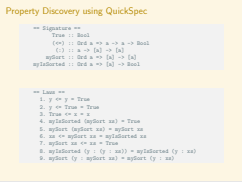

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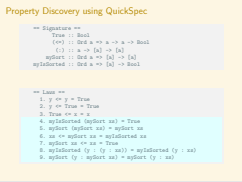

QuickSpec Code

```haskell
{-# LANGUAGE ScopedTypeVariables #-}
{-# LANGUAGE ConstraintKinds #-}
{-# LANGUAGE RankNTypes #-}
{-# LANGUAGE FlexibleContexts #-}

module MySortQuickSpec where

import Control.Monad
import MySort
import QuickSpec

main :: IO ()
main =
    void $
    quickSpec
        signature
        { constants =
              [ constant "True" (True :: Bool)
              , constant "<=" (mkDict (<=) :: Dict (Ord A) -> A -> A -> Bool)
              , constant ":" ((:) :: A -> [A] -> [A])
              , constant "mySort" (mkDict mySort :: Dict (Ord A) -> [A] -> [A])
              , constant
                    "myIsSorted"
                    (mkDict myIsSorted :: Dict (Ord A) -> [A] -> Bool)
              ]
        }

mkDict ::
       (c =>
            a)
    -> Dict c
    -> a
mkDict x Dict = x
```


Problems with QuickSpec: Monomorphisation

Only for monomorphic functions

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constant "filter"
  (filter :: (A -> B) -> [A] -> [B] -> Bool)
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Programmer has to write code for all functions of interest
15 lines of subject code.
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Problems with QuickSpec: Speed

Dumb version of the QuickSpec approach:

1. Generate all possible terms
2. Generate all possible equations (tuples) of terms
3. Type check them to make sure the equation makes sense
4. Check that the input can be generated and the output compared for equality
5. Run QuickCheck to see if the equation holds

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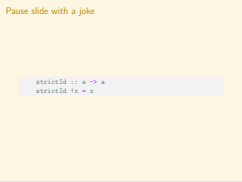
Pause slide with a joke

```
strictId :: a -> a
strictId !x = x
```

Property Discovery with EasySpec

Step 1: Automation

Signatures

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mkDict ::
       (c =>
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mkDict x Dict = x
```


A QuickSpec Signature

```haskell
data Signature =
  Signature {
    functions           :: [Function],
    [...]
    properties          :: [Prop],
  }
```

```haskell
quickSpec :: Signature -> IO Signature
```


Signature Expression Generation

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```
filter :: (a -> Bool) -> [a] -> [a]
```


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function "filter"
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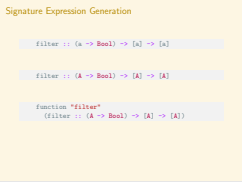

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```
function "filter"
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```
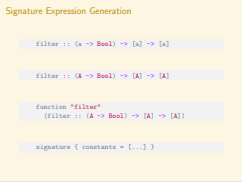
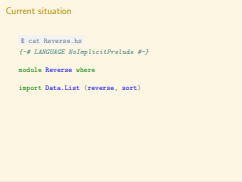

```
signature { constants = [...] }
```

Current situation

```
$ cat Reverse.hs
{-# LANGUAGE NoImplicitPrelude #-}

module Reverse where

import Data.List (reverse, sort)
```

Current situation

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$ cat Reverse.hs
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module Reverse where

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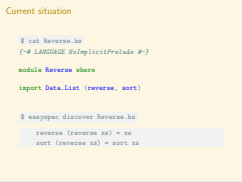
$ easyspec discover Reverse.hs

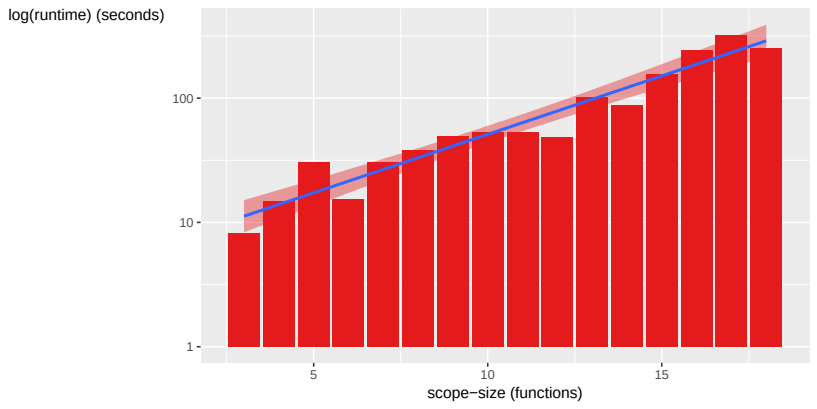
    reverse (reverse xs) = xs
    sort (reverse xs) = sort xs
```

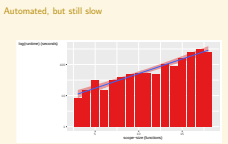



Pause slide with a joke

```
safePerformIO :: IO a -> IO a
safePerformIO ioa = ioa >>= return
```


Automated, but still slow





1. Now we have automated QuickSpec, but it still slow

Definitions

Definitions: Property

Example:

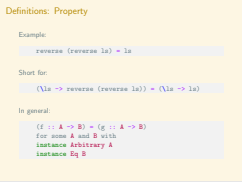
```
reverse (reverse ls) = ls
```

Short for:

```
(\ls -> reverse (reverse ls)) = (\ls -> ls)
```

In general:

```
(f :: A -> B) = (g :: A -> B)
for some A and B with
instance Arbitrary A
instance Eq B
```

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Idea

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Critical insight

We are not interested in the entire codebase.

We are interested in a relatively small amount of code.

1. This means that we have an entirely different goal than QuickSpec.
2. Comparisons with QuickSpec are not really fair, but we have nothing else to compare to.

Reducing the size of the signature

```
inferSignature
  :: [Function] -- Focus functions
  -> [Function] -- Functions in scope
  -> [Function] -- Chosen functions
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Full background and empty background

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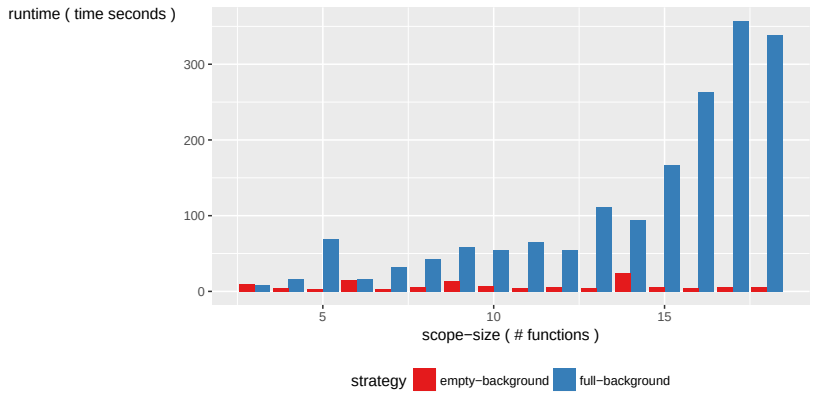

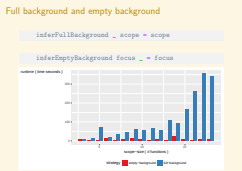

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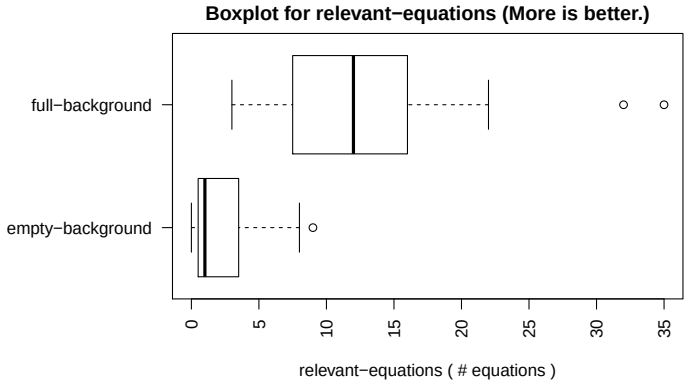
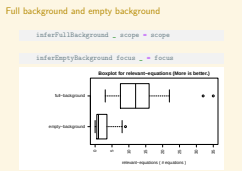


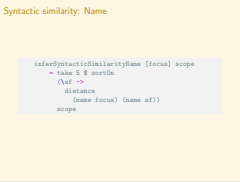


Pause slide with a joke

```
safeCoerce :: a ~ b => a -> b
safeCoerce x = x
```


Syntactic similarity: Name

```
inferSyntacticSimilarityName [focus] scope
    = take 5 $ sortOn
      (\sf ->
        distance
          (name focus) (name sf))
      scope
```

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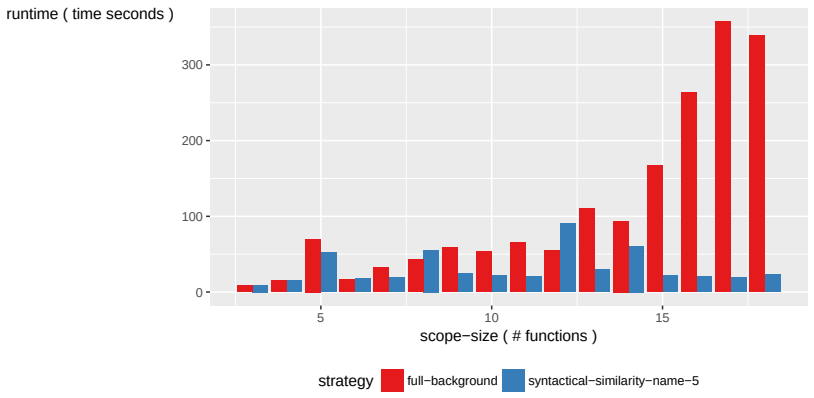

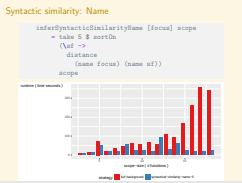

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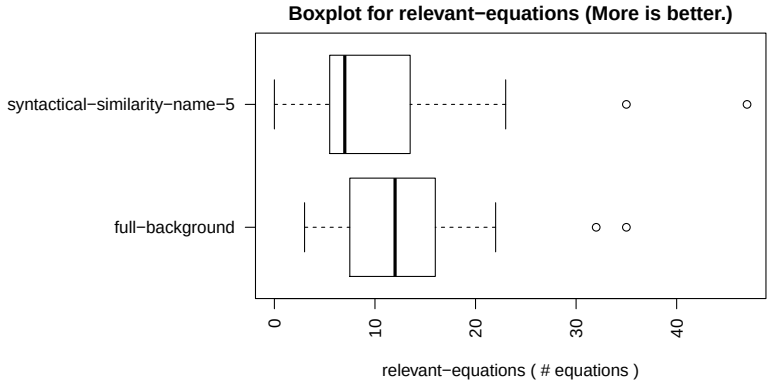

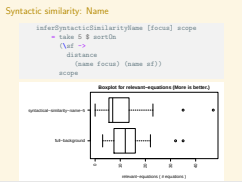

Syntactic similarity: Implementation

```
inferSyntacticSimilaritySymbols i [focus] scope
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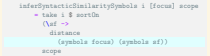
Syntactic similarity: Implementation



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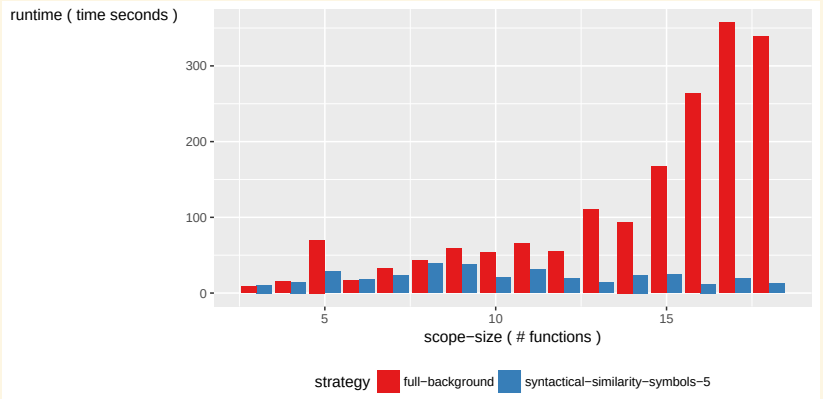

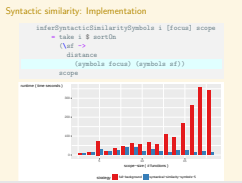

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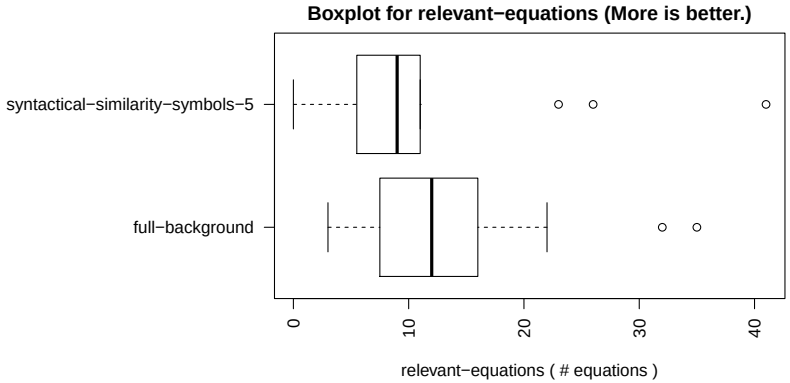

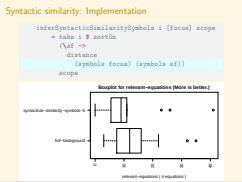

Syntactic similarity: Type

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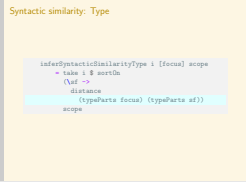

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      scope
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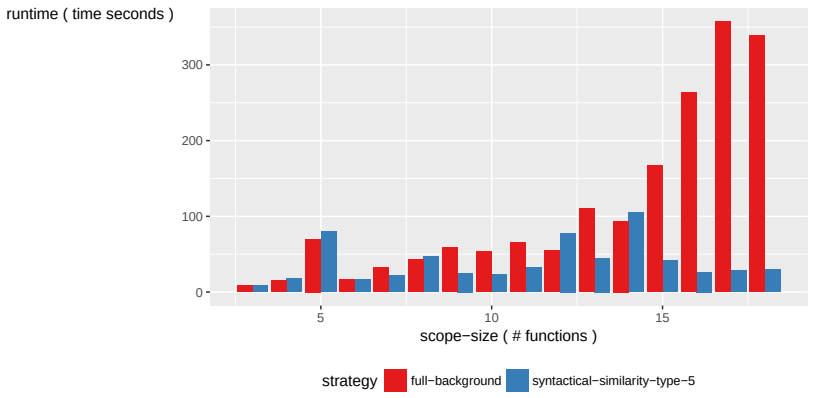
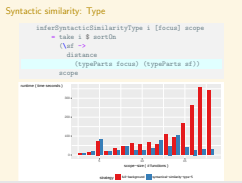
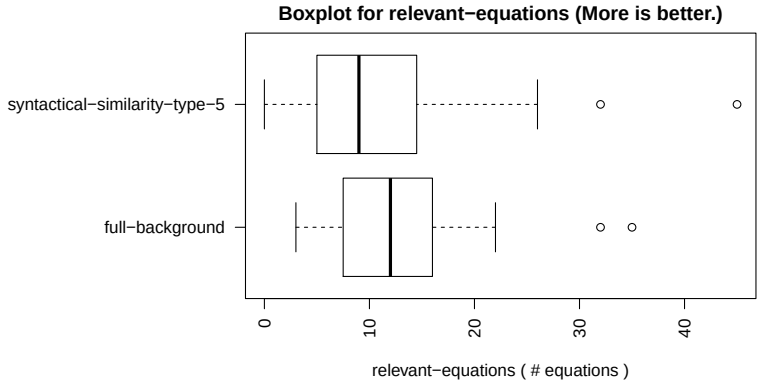
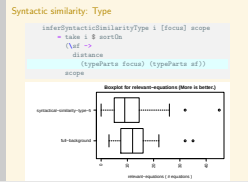




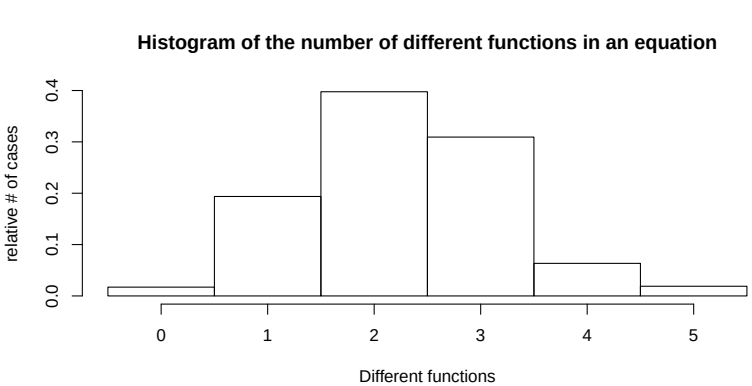
Syntactic similarity: Type

```
inferSyntacticSimilarityType i [focus] scope
    = take i $ sortOn
      (\sf ->
        distance
          (typeParts focus) (typeParts sf))
      scope
```





Breakthrough



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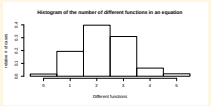

Idea

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We can run QuickSpec more than once!

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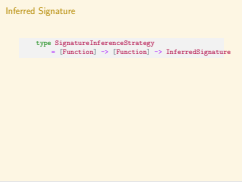
Inferred Signature

```
type SignatureInferenceStrategy
    = [Function] -> [Function] -> InferredSignature
```

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Combine the results of multiple runs:

```
type InferredSignature = [Signature]
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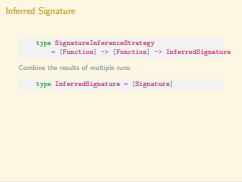

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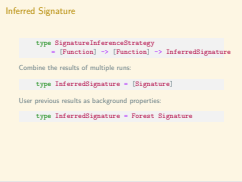
User previous results as background properties:

```
type InferredSignature = Forest Signature
```

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type InferredSignature = Forest Signature
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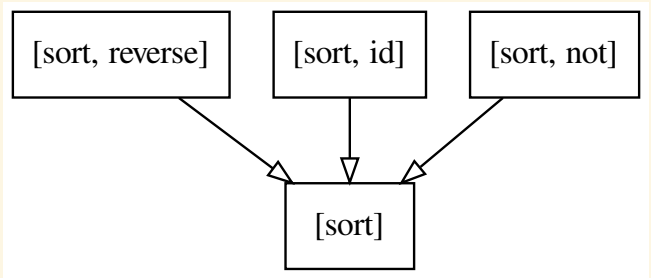
Share previous runs:

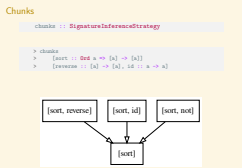
```
type InferredSignature = DAG Signature
```


Chunks

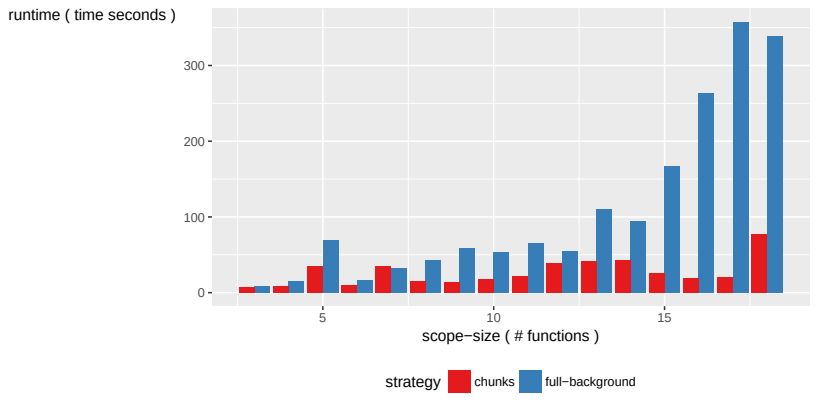
```
chunks :: SignatureInferenceStrategy
```

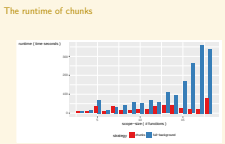
```
> chunks
>     [sort :: Ord a => [a] -> [a]]
>     [reverse :: [a] -> [a], id :: a -> a]
```



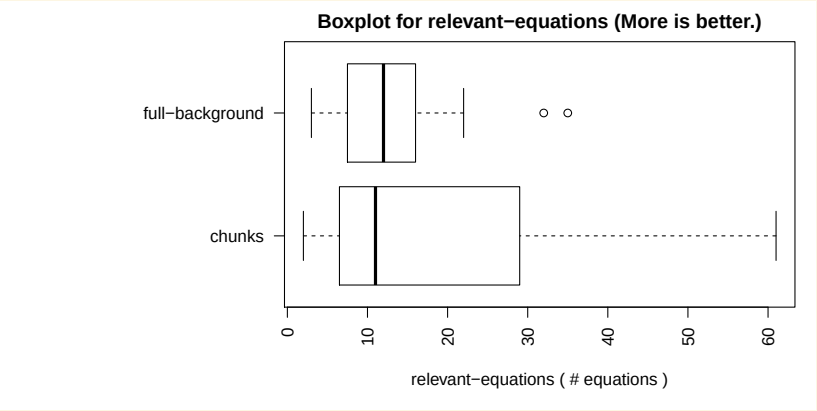


The runtime of chunks





The outcome of chunks: Relevant equations



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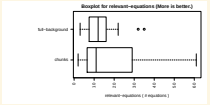

Inferred Signature

```
type SignatureInferenceStrategy
    = [Function] -> [Function] -> InferredSignature


type InferredSignature =
    DAG ([(Signature, [Equation])] -> Signature)
```


Inferred Signature

```haskell
type SignatureInferenceStrategy
    = [Function] -> [Function] -> InferM ()

data InferM a where
    InferPure :: a -> InferM a
    InferFmap :: (a -> b) -> InferM a -> InferM b
    InferApp :: InferM (a -> b) -> InferM a -> InferM b
    InferBind :: InferM a -> (a -> InferM b) -> InferM b

    InferFrom
        :: Signature
        -> [OptiToken]
        -> InferM (OptiToken, [Equation])
```


Inferred Signature

Chunks Plus

```
chunksPlus :: SignatureInferenceStrategy
```

```
> chunksPlus
>     [sort :: Ord a => [a] -> [a]]
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```
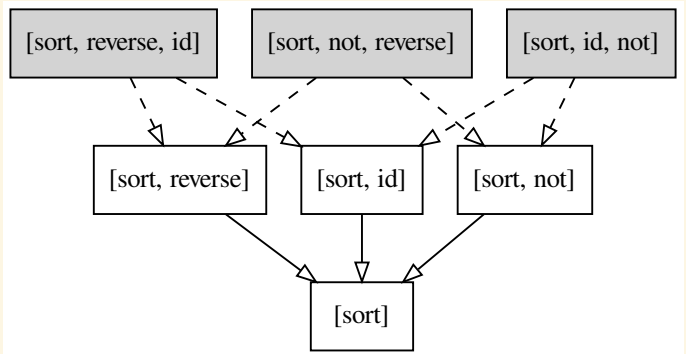
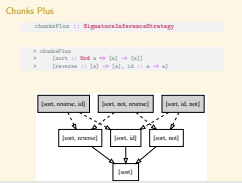
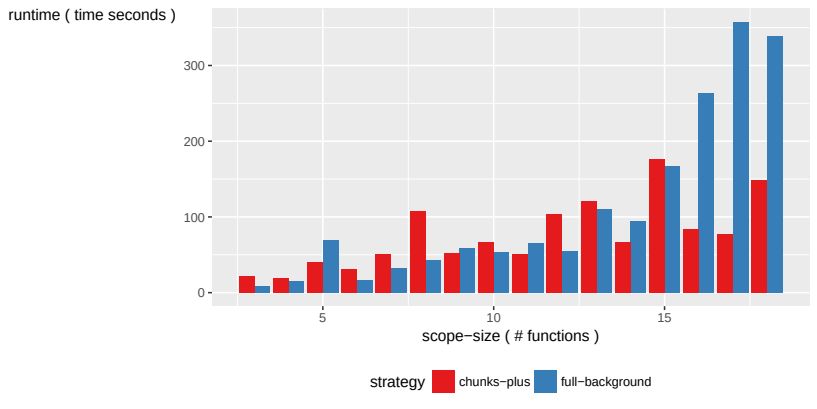
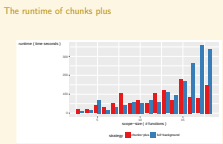



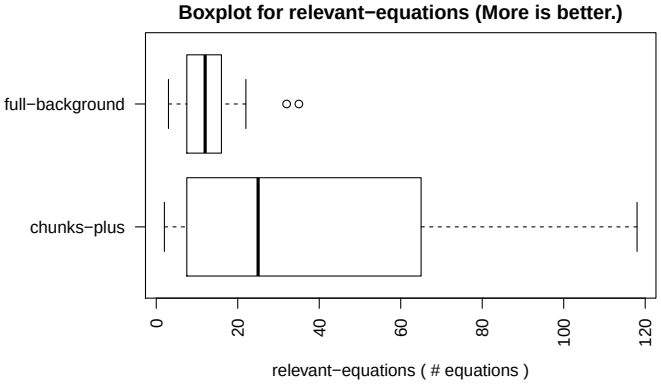


The runtime of chunks plus





The outcome of chunks plus: Relevant equations



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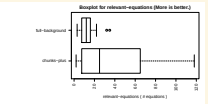

Neat

```
$ time stack exec easyspec \
      -- discover MySort.hs MySort.mySort

xs <= mySort xs = myIsSorted xs
mySort xs <= xs = True
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Call to action

Proofs of concept:

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```

Now we need to make it production ready!

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