The Design of the Syntax Definition Formalism SDF3 in Propositions

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Goals of SDF3 Design

Syntax definition

- Define concrete *and* abstract syntax of programming languages

Understandable

- Can be used as reference documentation

Executable

- Can be used to generate tools

Declarative

- No need to understand (parsing) algorithms

Multi-purpose

- Derive many/all syntactic services from single definition

A Work in Progress

SDF

- Heering, Hendriks, Klint, Rekers 1989
- Generalized-LR parsing

SDF2

- Visser 1997
- Scannerless Generalized-LR parsing
- Shallow priority conflicts in LR table

SDF3

- Amorim, Visser, and many others 2018
- Deep priority conflicts
- Layout-sensitive syntax
- Constructors, templates, completion, …

SDF3 in Propositions

Basic language design is simple

- Core = context-free grammars
- Boilerplate to define all aspects of language syntax

SDF3 provides high-level sugar

- Convenient, concise expression
- Abstracts from boilerplate

Hidden design

- Surface level is deceptively simple
- Mostly ‘does what you expect’

This talk: Explain these by means of propositions

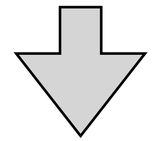
- E.g. “Syntax = Structure”

Structure

Syntax = Structure

```
module structure

imports Common

context-free start-symbols Exp

context-free syntax

  Exp.Var = ID

  Exp.Int = INT

  Exp.Add = Exp "+" Exp

  Exp.Fun = "function" "(" {ID ","}* ")" "{" Exp "}"

  Exp.App = Exp "(" {Exp ","}* ")"

  Exp.Let = "let" Bnd* "in" Exp "end"

  Bnd.Bnd = ID "=" Exp
```

```
let
  inc = function(x) { x + 1 }
 in
  inc(3)
end
```



```
Let(
  [ Bnd(
      "inc"
    , Fun(["x"], Add(Var("x"), Int("1")))
    )
  ]
, App(Var("inc"), [Int("3")])
)
```

Token = Character

```
module structure

imports Common

context-free start-symbols Exp

context-free syntax

  Exp.Var = ID

  Exp.Int = INT

  Exp.Add = Exp "+" Exp

  Exp.Fun = "function" "(" {ID ","}* ")" "{" Exp "}"

  Exp.App = Exp "(" {Exp ","}* ")"

  Exp.Let = "let" Bnd* "in" Exp "end"

  Bnd.Bnd = ID "=" Exp
```

```
let
  inc = function(x) { x + 1 }
 in
  inc(3)
end
```

```
module Common

lexical syntax

  ID  = [a-zA-Z] [a-zA-Z0-9]*

  INT = "-"? [0-9]+
```

Lexical Syntax = Context-Free Syntax
(But we don't care about structure of lexical syntax)

Literal = Non-Terminal

```
module structure

imports Common

context-free start-symbols Exp

context-free syntax

  Exp.Var = ID

  Exp.Int = INT

  Exp.Add = Exp "+" Exp

  Exp.Fun = "function" "(" {ID ","}* ")" "{" Exp "}"

  Exp.App = Exp "(" {Exp ","}* ")"

  Exp.Let = "let" Bnd* "in" Exp "end"

  Bnd.Bnd = ID "=" Exp
```

```
let
  inc = function(x) { x + 1 }
 in
  inc(3)
end
```

```
syntax

  "+"        = [\43]
  "function" = [\102] [\117] [\110] [\99] [\1
  "{"        = [\123]
  "}"        = [\125]
  "("        = [\40]
  ","        = [\44]
  ")"        = [\41]
  "let"      = [\108] [\101] [\116]
  "in"       = [\105] [\110]
  "end"      = [\101] [\110] [\100]
  "="        = [\61]
```

Layout = Whitespace & Comments

```
module Common

lexical syntax

  LAYOUT          = [\ \t\n\r]

  LAYOUT          = "/*" InsideComment* "*/"
  InsideComment   = ~[\*]
  InsideComment   = CommentChar
  CommentChar     = [\*]

  LAYOUT          = "//" ~[\n\r]* NewLineEOF
  NewLineEOF      = [\n\r]
  NewLineEOF      = EOF
```

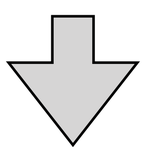
```
let
  inc = function(x) { x + 1 }
 in
  // function application
  inc /* function position */ (
    3 // argument list
  )
end
```

Layout = (Almost) Everywhere

```
module Common

lexical syntax

  LAYOUT          = [\ \t\n\r]

  LAYOUT          = "/*" InsideComment* "*/"
  InsideComment   = ~[\*]
  InsideComment   = CommentChar
  CommentChar     = [\*]

  LAYOUT          = "//" ~[\n\r]* NewLineEOF
  NewLineEOF      = [\n\r]
  NewLineEOF      = EOF
```

```
let
  inc = function(x) { x + 1 }
 in
  // function application
  inc /* function position */ (
    3 // argument list
  )
end
```

```
Exp.App = Exp "(" {Exp ","}* ")"
```



```
Exp-CF.App = Exp-CF LAYOUT?-CF "(" LAYOUT?-CF {Exp ","}*-CF LAYOUT?-CF ")"
```

Parsing = Formatting^{-1}

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Parsing = Formatting^{-1}

```
context-free syntax

  Exp.Var = <<ID>>

  Exp.Int = <<INT>>

  Exp.Add = <<Exp> + <Exp>>

  Exp.Fun = <
    function(<{ID ","}*>){
      <Exp>
    }
  >

  Exp.App = <<Exp>(<{Exp ","}*>)>

  Exp.Let = <
    let
      <Bnd*>
     in
      <Exp>
    end
  >

  Bnd.Bnd = <<ID> = <Exp>>
```

```
let
  inc = function(x) { x + 1 }
 in
  inc(3)
end
```

```
Let(
  [ Bnd(
      "inc"
    , Fun(["x"], Add(Var("x"), Int("1")))
    )
  ]
, App(Var("inc"), [Int("3")])
)
```

```
let
  inc = function(x){
    x + 1
  }
 in
  inc(3)
end
```

Completion = Rewrite(Incomplete Structure)

```
class A {

  public int m() {
    int x;
    x = $Exp;
    return
  }
}
```

+Add
+Sub
+Mul
+Lt
+VarRef

$Exp + $Exp

```
class A {

  public int m() {
    int x;
    x = $Exp + $Exp;
    retu
  }
}
```

+Add
+Sub
+Mul
+Lt
+VarRef

$Exp + $Exp

```
class A {

  public int m() {
    int x;
    x = 21 + $Exp;
    return x;
  }
}
```

+Add
+Sub
+Mul
+Lt
+VarRef

($Exp + $Exp)

```
class A {

  public int m() {
    int x;
    x = 21 + 21;
    return x;
  }
}
```

Extension

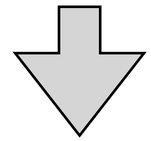
Language Extension => Grammar Extension

```
module extension
imports functional query
context-free start-symbols Exp
context-free syntax
  Exp = Query
  Cond = Exp
```

```
module functional
imports Common
context-free syntax
 Exp = <(<Exp>)> {bracket}
 …
```

```
module query
imports Common
context-free syntax
  Query.Query = <
    select <QID*> from <QID*> where <Cond>
  >
  Cond.And = <<Cond> and <Cond>> {left}
  Cond.Eq = <<Cond> == <Cond>> {non-assoc}
```

```
let
  fs = select f from A where test f == 1
 in
  print fs
```

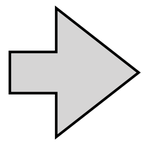


```
Let(
  [ Bnd(
      "fs"
    , Query(
        ["f"]
      , ["A"]
      , Eq(App(Var("test"), Var("f")), Int("1"))
      )
    )
  ]
, App(Var("print"), Var("fs"))
)
```

Disambiguation

Traditional: Ambiguity = Parse Table Conflict

```
context-free syntax

  Exp      = <(<Exp>)> {bracket}

  Exp.Int = INT
  Exp.Var = ID
  Exp.Add = <<Exp> + <Exp>>

  Exp.Fun = <function(<{ID ","}*>) <Exp>>
  Exp.App = <<Exp> <Exp>>

  Exp.Let = <let <Bnd*> in <Exp>>

  Bnd.Bnd = <<ID> = <Exp>>

  Exp.If     = <if(<Exp>) <Exp>>
  Exp.IfElse = <if(<Exp>) <Exp> else <Exp>>

  Exp.Match  = <match <Exp> with <Pat+>>
  Pat.Clause = [[ID] -> [Exp]]
```

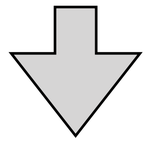


No can parse

Ambiguity = Multiple Possible Parses

```
context-free syntax

  Exp     = <(<Exp>)> {bracket}

  Exp.Int = INT
  Exp.Var = ID
  Exp.Add = <<Exp> + <Exp>>

  Exp.Fun = <function(<{ID ","}*>) <Exp>>
  Exp.App = <<Exp> <Exp>>

  Exp.Let = <let <Bnd*> in <Exp>>

  Bnd.Bnd = <<ID> = <Exp>>

  Exp.If     = <if(<Exp>) <Exp>>
  Exp.IfElse = <if(<Exp>) <Exp> else <Exp>>

  Exp.Match  = <match <Exp> with <Pat+>>
  Pat.Clause = [[ID] -> [Exp]]
```

```
a + b + c
```

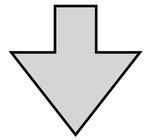


```
amb(
  [ Add(Var("a"), Add(Var("b"), Var("c")))
  , Add(Add(Var("a"), Var("b")), Var("c"))
  ]
)
```

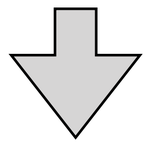
Disambiguation = Select(Structure)

```
context-free syntax

  Exp      = <(<Exp>)> {bracket}

  Exp.Int = INT
  Exp.Var = ID
  Exp.Add = <<Exp> + <Exp>>

  Exp.Fun = <function(<{ID ","}*>) <Exp>>
  Exp.App = <<Exp> <Exp>>

  Exp.Let = <let <Bnd*> in <Exp>>

  Bnd.Bnd = <<ID> = <Exp>>

  Exp.If     = <if(<Exp>) <Exp>>
  Exp.IfElse = <if(<Exp>) <Exp> else <Exp>>

  Exp.Match  = <match <Exp> with <Pat+>>
  Pat.Clause = [[ID] -> [Exp]]
```

```
a + b + c
```



```
amb(
  [ Add(Var("a"), Add(Var("b"), Var("c")))
  , Add(Add(Var("a"), Var("b")), Var("c"))
  ]
)
```

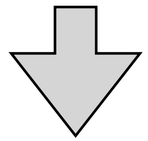


```
Add(Add(Var("a"), Var("b")), Var("c"))
```

Brackets = Explicit Disambiguation

```
context-free syntax

  Exp     = <(<Exp>)> {bracket}

  Exp.Int = INT
  Exp.Var = ID
  Exp.Add = <<Exp> + <Exp>>

  Exp.Fun = <function(<{ID ","}*>) <Exp>>
  Exp.App = <<Exp> <Exp>>

  Exp.Let = <let <Bnd*> in <Exp>>

  Bnd.Bnd = <<ID> = <Exp>>

  Exp.If     = <if(<Exp>) <Exp>>
  Exp.IfElse = <if(<Exp>) <Exp> else <Exp>>

  Exp.Match  = <match <Exp> with <Pat+>>
  Pat.Clause = [[ID] -> [Exp]]
```

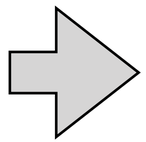
```
a + (b + c)
```



```
Add(Var("a"), Add(Var("b"), Var("c")))
```

Disambiguation by Manual Transformation = Bad

```
context-free syntax

  Exp     = <(<Exp>)> {bracket}

  Exp.Int = INT
  Exp.Var = ID
  Exp.Add = <<Exp> + <Exp>>

  Exp.Fun = <function(<{ID ","}*>) <Exp>>
  Exp.App = <<Exp> <Exp>>

  Exp.Let = <let <Bnd*> in <Exp>>

  Bnd.Bnd = <<ID> = <Exp>>

  Exp.If     = <if(<Exp>) <Exp>>
  Exp.IfElse = <if(<Exp>) <Exp> else <Exp>>

  Exp.Match  = <match <Exp> with <Pat+>>
  Pat.Clause = [[ID] -> [Exp]]
```



Big ugly grammar

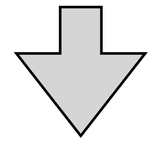
Declarative Disambiguation = Separate Concern

```
context-free syntax

  Exp     = <(<Exp>)> {bracket}

  Exp.Int = INT
  Exp.Var = ID
  Exp.Add = <<Exp> + <Exp>> {left}

  Exp.Fun = <function(<{ID ","}*>) <Exp>>
  Exp.App = <<Exp> <Exp>> {left}

  Exp.Let = <let <Bnd*> in <Exp>>

  Bnd.Bnd = <<ID> = <Exp>>

  Exp.If     = <if(<Exp>) <Exp>>
  Exp.IfElse = <if(<Exp>) <Exp> else <Exp>>

  Exp.Match  = <match <Exp> with <Pat+>> {longest-match}
  Pat.Clause = [[ID] -> [Exp]]

context-free priorities

  Exp.App > Exp.Add > Exp.IfElse > Exp.If > Exp.Match > Exp.Let > Exp.Fun
```

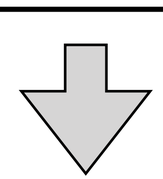
Associativity = Solve Intra Operator Ambiguity

```
context-free syntax

  Exp      = <(<Exp>)> {bracket}

  Exp.Int = INT
  Exp.Var = ID
  Exp.Add = <<Exp> + <Exp>> {left}

  Exp.Fun = <function(<{ID ","}*>) <Exp>>
  Exp.App = <<Exp> <Exp>> {left}

  Exp.Let = <let <Bnd*> in <Exp>>

  Bnd.Bnd = <<ID> = <Exp>>

  Exp.If     = <if(<Exp>) <Exp>>
  Exp.IfElse = <if(<Exp>) <Exp> else <Exp>>

  Exp.Match  = <match <Exp> with <Pat+>> {longest-match}
  Pat.Clause = [[ID] -> [Exp]]

context-free priorities

  Exp.App > Exp.Add > Exp.IfElse > Exp.If > Exp.Match > Exp.Let > Exp.Fun
```

```
a + b + c
```



```
amb(
  [ Add(Var("a"), Add(Var("b"), Var("c")))
  , Add(Add(Var("a"), Var("b")), Var("c"))
  ]
)
```

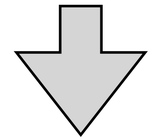


```
Add(Add(Var("a"), Var("b")), Var("c"))
```

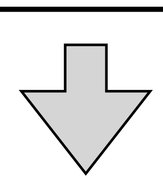
Priority = Solve Inter Operator Ambiguity

```
context-free syntax

  Exp      = <(<Exp>)> {bracket}

  Exp.Int = INT
  Exp.Var = ID
  Exp.Add = <<Exp> + <Exp>> {left}

  Exp.Fun = <function(<{ID ","}*>) <Exp>>
  Exp.App = <<Exp> <Exp>> {left}

  Exp.Let = <let <Bnd*> in <Exp>>

  Bnd.Bnd = <<ID> = <Exp>>

  Exp.If     = <if(<Exp>) <Exp>>
  Exp.IfElse = <if(<Exp>) <Exp> else <Exp>>

  Exp.Match  = <match <Exp> with <Pat+>> {longest-match}
  Pat.Clause = [[ID] -> [Exp]]

context-free priorities

  Exp.App > Exp.Add > Exp.IfElse > Exp.If > Exp.Match > Exp.Let > Exp.Fun
```

```
f a + b
```



```
amb(
  [ Add(App(Var("f"), Var("a")), Var("b"))
  , App(Var("f"), Add(Var("a"), Var("b")))
  ]
)
```

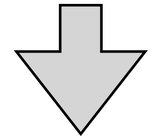


```
Add(App(Var("f"), Var("a")), Var("b"))
```

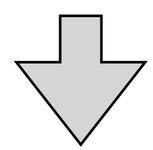
Dangling Else = Operators with Overlapping Prefix

```
context-free syntax

  Exp      = <(<Exp>)> {bracket}

  Exp.Int = INT
  Exp.Var = ID
  Exp.Add = <<Exp> + <Exp>> {left}

  Exp.Fun = <function(<{ID ","}*>) <Exp>>
  Exp.App = <<Exp> <Exp>> {left}

  Exp.Let = <let <Bnd*> in <Exp>>

  Bnd.Bnd = <<ID> = <Exp>>

  Exp.If     = <if(<Exp>) <Exp>>
  Exp.IfElse = <if(<Exp>) <Exp> else <Exp>>

  Exp.Match  = <match <Exp> with <Pat+>> {longest-match}
  Pat.Clause = [[ID] -> [Exp]]

context-free priorities

  Exp.App > Exp.Add > Exp.IfElse > Exp.If > Exp.Match
```

```
if(1) if(2) 3 else 4
```



```
amb(
  [ IfElse(
      Int("1")
    , If(Int("2"), Int("3"))
    , Int("4")
    )
  , If(
      Int("1")
    , IfElse(Int("2"), Int("3"), Int("4"))
    )
  ]
)
```

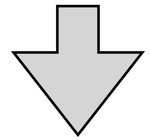


```
If(
  Int("1")
, IfElse(Int("2"), Int("3"), Int("4"))
)
```

Safe Disambiguation != Reject Unambiguous Sentences

```
context-free syntax

  Exp     = <(<Exp>)> {bracket}

  Exp.Int = INT
  Exp.Var = ID
  Exp.Add = <<Exp> + <Exp>>

  Exp.Fun = <function(<{ID ","}*>) <Exp>>
  Exp.App = <<Exp> <Exp>>

  Exp.Let = <let <Bnd*> in <Exp>>

  Bnd.Bnd = <<ID> = <Exp>>

  Exp.If     = <if(<Exp>) <Exp>>
  Exp.IfElse = <if(<Exp>) <Exp> else <Exp>>

  Exp.Match  = <match <Exp> with <Pat+>>
  Pat.Clause = [[ID] -> [Exp]]
```

```
4 + if(y) x
```

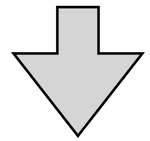


```
Add(Int("4"), If(Var("y"), Var("x")))
```

Safe Disambiguation != Reject Unambiguous Sentences

```
context-free syntax

  Exp      = <(<Exp>)> {bracket}

  Exp.Int = INT
  Exp.Var = ID
  Exp.Add = <<Exp> + <Exp>> {left}

  Exp.Fun = <function(<{ID ","}*>) <Exp>>
  Exp.App = <<Exp> <Exp>> {left}

  Exp.Let = <let <Bnd*> in <Exp>>

  Bnd.Bnd = <<ID> = <Exp>>

  Exp.If     = <if(<Exp>) <Exp>>
  Exp.IfElse = <if(<Exp>) <Exp> else <Exp>>

  Exp.Match  = <match <Exp> with <Pat+>> {longest-match}
  Pat.Clause = [[ID] -> [Exp]]

context-free priorities

  Exp.App > Exp.Add > Exp.IfElse > Exp.If > Exp.Match > Exp.Let > Exp.Fun
```

```
4 + if(y) x
```

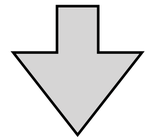


```
Add(Int("4"), If(Var("y"), Var("x")))
```

Deep Priority Conflict

```
context-free syntax

  Exp     = <(<Exp>)> {bracket}

  Exp.Int = INT
  Exp.Var = ID
  Exp.Add = <<Exp> + <Exp>>

  Exp.Fun = <function(<{ID ","}*>) <Exp>>
  Exp.App = <<Exp> <Exp>>

  Exp.Let = <let <Bnd*> in <Exp>>

  Bnd.Bnd = <<ID> = <Exp>>

  Exp.If     = <if(<Exp>) <Exp>>
  Exp.IfElse = <if(<Exp>) <Exp> else <Exp>>

  Exp.Match  = <match <Exp> with <Pat+>>
  Pat.Clause = [[ID] -> [Exp]]
```

```
4 + if(y) x + 3
```

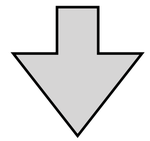


```
amb(
  [ Add(
      Int("4")
    , amb(
        [ Add(If(Var("y"), Var("x")), Int("3"))
        , If(Var("y"), Add(Var("x"), Int("3")))
        ]
      )
    )
  , Add(
      Add(Int("4"), If(Var("y"), Var("x")))
    , Int("3")
    )
  ]
)
```

Deep Priority Conflict (Solved)

```
context-free syntax

  Exp      = <(<Exp>)> {bracket}

  Exp.Int = INT
  Exp.Var = ID
  Exp.Add = <<Exp> + <Exp>> {left}

  Exp.Fun = <function(<{ID ","}*>) <Exp>>
  Exp.App = <<Exp> <Exp>> {left}

  Exp.Let = <let <Bnd*> in <Exp>>

  Bnd.Bnd = <<ID> = <Exp>>

  Exp.If     = <if(<Exp>) <Exp>>
  Exp.IfElse = <if(<Exp>) <Exp> else <Exp>>

  Exp.Match  = <match <Exp> with <Pat+>> {longest-match}
  Pat.Clause = [[ID] -> [Exp]]

context-free priorities

  Exp.App > Exp.Add > Exp.IfElse > Exp.If > Exp.Match > Exp.Let > Exp.Fun
```

```
4 + if(y) x + 3
```



```
Add(
  Int("4")
, If(Var("y"), Add(Var("x"), Int("3")))
)
```

Longest Match = Solve Repetition Ambiguity

```
context-free syntax

  Exp      = <(<Exp>)> {bracket}

  Exp.Int = INT
  Exp.Var = ID
  Exp.Add = <<Exp> + <Exp>> {left}

  Exp.Fun = <function(<{ID ","}*>) <Exp>>
  Exp.App = <<Exp> <Exp>> {left}

  Exp.Let = <let <Bnd*> in <Exp>>

  Bnd.Bnd = <<ID> = <Exp>>

  Exp.If     = <if(<Exp>) <Exp>>
  Exp.IfElse = <if(<Exp>) <Exp> else <Exp>>

  Exp.Match  = <match <Exp> with <Pat+>> {longest-mat
  Pat.Clause = [[ID] -> [Exp]]

context-free priorities

  Exp.App > Exp.Add > Exp.IfElse > Exp.If > Exp.Match > Exp.Let > Exp.Fun
```

```
match x with
  a -> match 5 with
         b -> 3
         c -> 4
```

```
Match(
  Var("x")
, amb(
    [ [ Clause(
          "a"
        , Match(Int("5"), [
            Clause("b", Int("3"))])
        )
      , Clause("c", Int("4"))
      ]
    , [ Clause(
          "a"
        , Match(
            Int("5")
          , [Clause("b", Int("3")),
             Clause("c", Int("4"))]
          ))]]))
```

Longest Match = Solve Repetition Ambiguity

```
context-free syntax

  Exp     = <(<Exp>)> {bracket}

  Exp.Int = INT
  Exp.Var = ID
  Exp.Add = <<Exp> + <Exp>> {left}

  Exp.Fun = <function(<{ID ","}*>) <Exp>>
  Exp.App = <<Exp> <Exp>> {left}

  Exp.Let = <let <Bnd*> in <Exp>>

  Bnd.Bnd = <<ID> = <Exp>>

  Exp.If     = <if(<Exp>) <Exp>>
  Exp.IfElse = <if(<Exp>) <Exp> else <Exp>>

  Exp.Match  = <match <Exp> with <Pat+>> {longest-match}
  Pat.Clause = [[ID] -> [Exp]]

context-free priorities

  Exp.App > Exp.Add > Exp.IfElse > Exp.If > Exp.Match > Exp.Let > Exp.Fun
```

```
match x with
  a -> match 5 with
         b -> 3
         c -> 4
```

```
Match(
  Var("x")
, [ Clause(
      "a"
    , Match(
        Int("5")
      , [Clause("b", Int("3")),
Clause("c", Int("4"))]
      )
    )
  ]
)
```

Wrap Up

Towards Systematic Design Space Exploration?

More propositions

- Parse Error Recovery = Parsing with Permissive Grammar
- Reserved words = reject
- Prefer longest match = follow restrictions
- Layout-sensitive syntax = context-free syntax + layout constraints
- Parenthesize = Disambiguate^{-1}
- …

Language design = Collection of propositions

- Make concepts and design choices explicit

Explore design space = Vary propositions

- Systematic?