Disambiguation and Layout-Sensitive Syntax

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Disambiguation and Layout-Sensitive Syntax

Syntax Definition Summary

Derivations

- Generating sentences and trees from context-free grammars

Ambiguity

Declarative Disambiguation Rules

- Associativity and priority

Grammar Transformations

- Eliminating ambiguity by transformation

Layout-Sensitive Syntax

- Disambiguation using layout constraints

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]
               [\116] [\105] [\111] [\110]
  "{"        = [\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 ")"
```

Extension

Language Composition ⇒ Grammar Composition

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

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

Parsing = Formatting^{-1}

Parsing = Formatting^{-1}

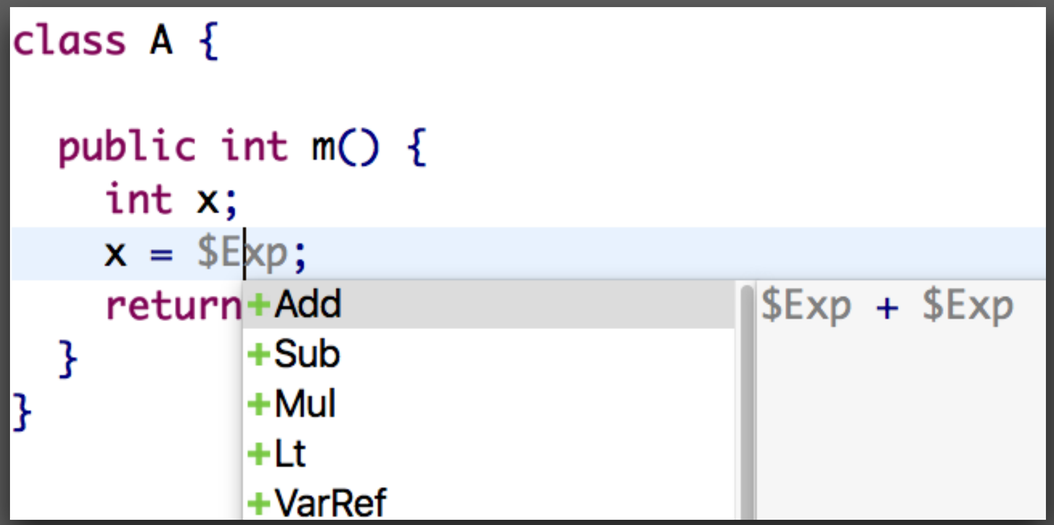
```
context-free syntax

  Exp.Var = <<ID>>

  Exp.Int = <<INT>>

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

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

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

  Exp.Let = <
    let
      <{Bnd "\n"}*>
     in
      <Exp>
    end
  >

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

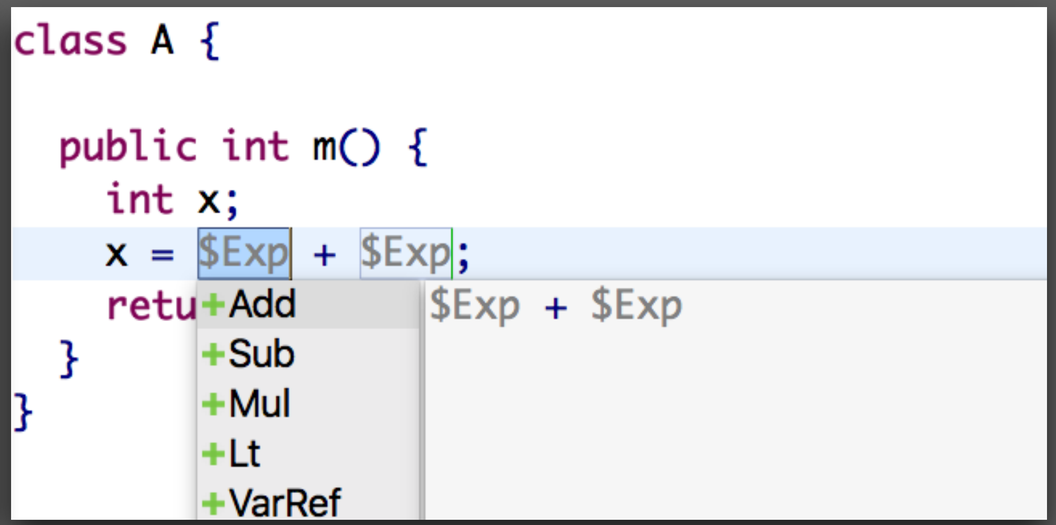
```
let
  inc = function(x) { x + 1 }
 in
  inc(3)
end
```

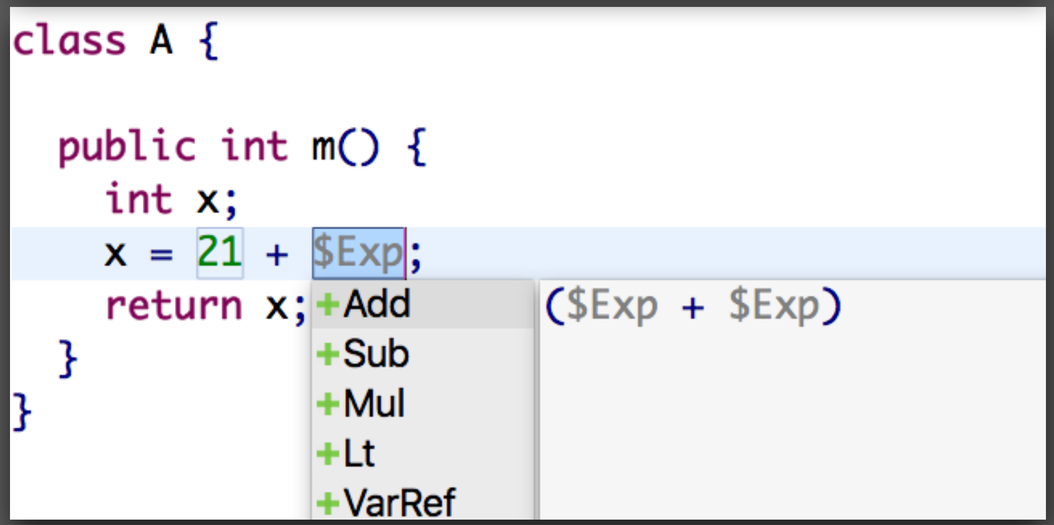
```
Let(
  [ Bnd(
      "inc"
    , Fun(["x"], Add(Var("x"), Int("1")))
    )
  ]
, App(Var("inc"), [Int("3")])
)
```

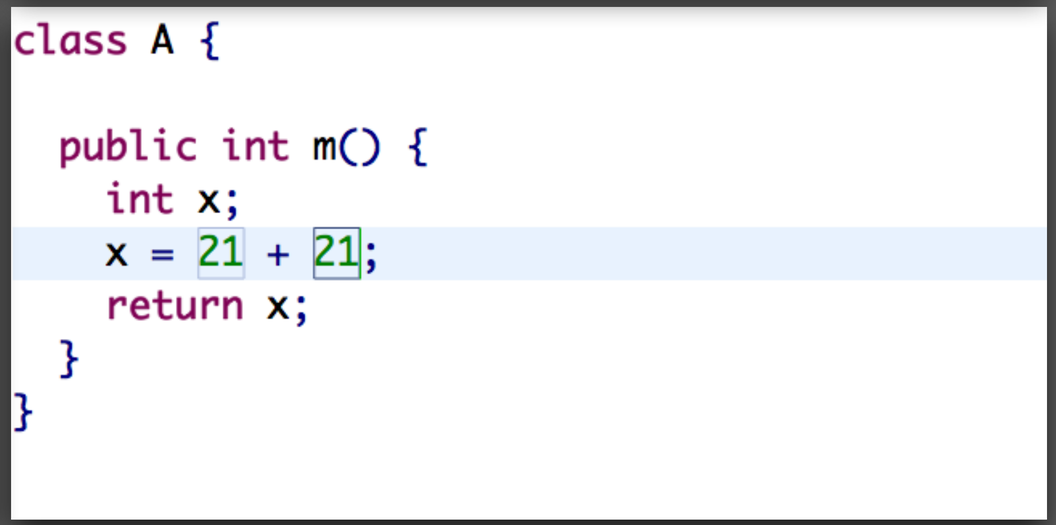
```
let
  inc = function(x){
    x + 1
  }
 in
  inc(3)
end
```

Completion = Rewrite(Incomplete Structure)









Context-Free Grammars

Context-Free Grammars

Terminals

- Basic symbols from which strings are formed

Nonterminals

- Syntactic variables that denote sets of strings

Start Symbol

- Denotes the nonterminal that generates strings of the languages

Productions

- A = X … X
- Head/left side (A) is a nonterminal
- Body/right side (X … X) zero or more terminals and nonterminals

Example Context-Free Grammar

```
grammar
  start S
  non-terminals E T F
  terminals "+" "*" "(" ")" ID
  productions
    S = E
    E = E "+" T
    E = T
    T = T "*" F
    T = F
    F = "(" E ")"
    F = ID
```

Abbreviated Grammar

```
grammar
  start S
  non-terminals E T F
  terminals "+" "*" "(" ")" ID
  productions
    S = E
    E = E "+" T
    E = T
    T = T "*" F
    T = F
    F = "(" E ")"
    F = ID
```

```
grammar
  productions
    S = E
    E = E "+" T
    E = T
    T = T "*" F
    T = F
    F = "(" E ")"
    F = ID
```

Nonterminals, terminals can be derived from productions

First production defines start symbol

Notation

```
A, B, C: non-terminals
l: terminals
a, b, c: strings of non-terminals and terminals
    (alpha, beta, gamma in math)
w, v: strings of terminal symbols
```

Meta: Syntax of Grammars

```
context-free syntax // grammars

  Grammar.Grammar = <
    grammar
      <Start?>
      <Sorts?>
      <Terminals?>
      <Productions>
  >
```

```
context-free syntax

  Production.Prod = <
    <Symbol><Constructor?> = <Symbol*>
  >

  Symbol.NT = <<ID>>
  Symbol.T  = <<STRING>>
  Symbol.L  = <<LCID>>

  Constructor.Con = <.<ID>>
```

```
context-free syntax

  Start.Start = <
    start <ID>
  >

  Sorts.Sorts = <
    sorts <ID*>
  >

  Sorts.NonTerminals = <
    non-terminals <ID*>
  >

  Terminals.Terminals = <
    terminals <Symbol*>
  >

  Productions.Productions = <
    productions
      <Production*>
  >
```

Derivations: Generating Sentences from Symbols

Derivations

```
grammar
  productions
    E = E "+" E
    E = E "*" E
    E = "-" E
    E = "(" E ")"
    E = ID
```

```
// derivation step: replace symbol by rhs of production
// E = E "+" E
// replace E by E "+" E
//
// derivation:
// repeatedly apply derivations
```

```
derivation
  E
  ⇒ "-" E
  ⇒ "-" "(" E ")"
  ⇒ "-" "(" ID ")"
```

```
derivation // derives in zero or more steps
  E ⇒* "-" "(" ID "+" ID ")"
```

Meta: Syntax of Derivations

```
context-free syntax // derivations

  Derivation.Derivation = <
    derivation
      <Symbol> <Step*>
  >

  Step.Step   = [⇒ [Symbol*]]
  Step.Steps  = [⇒* [Symbol*]]
  Step.Steps1 = [⇒+ [Symbol*]]
```

Left-Most Derivation

```
grammar
  productions
    E = E "+" E
    E = E "*" E
    E = "-" E
    E = "(" E ")"
    E = ID
```

```
derivation // left-most derivation
  E
  ⇒ "-" E
  ⇒ "-" "(" E ")"
  ⇒ "-" "(" E "+" E ")"
  ⇒ "-" "(" ID "+" E ")"
  ⇒ "-" "(" ID "+" ID ")"
```

Left-most derivation: Expand left-most non-terminal at each step

Right-Most Derivation

```
grammar
  productions
    E = E "+" E
    E = E "*" E
    E = "-" E
    E = "(" E ")"
    E = ID
```

```
derivation // left-most derivation
  E
  ⇒ "-" E
  ⇒ "-" "(" E ")"
  ⇒ "-" "(" E "+" E ")"
  ⇒ "-" "(" ID "+" E ")"
  ⇒ "-" "(" ID "+" ID ")"
```

```
derivation // right-most derivation
  E
  ⇒ "-" E
  ⇒ "-" "(" E ")"
  ⇒ "-" "(" E "+" E ")"
  ⇒ "-" "(" E "+" ID ")"
  ⇒ "-" "(" ID "+" ID ")"
```

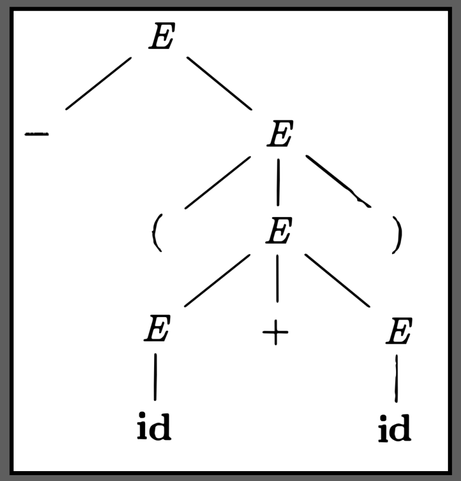
Right-most derivation: Expand right-most non-terminal at each step

Meta: Tree Derivations

```
context-free syntax // tree derivations

  Derivation.TreeDerivation = <
    tree derivation
      <Symbol> <PStep*>
  >

  PStep.Step   = [⇒ [PT*]]
  PStep.Steps  = [⇒* [PT*]]
  PStep.Steps1 = [⇒+ [PT*]]

  PT.App = <<Symbol>[<PT*>]>
  PT.Str = <<STRING>>
  PT.Sym = <<Symbol>>
```

Left-Most Tree Derivation

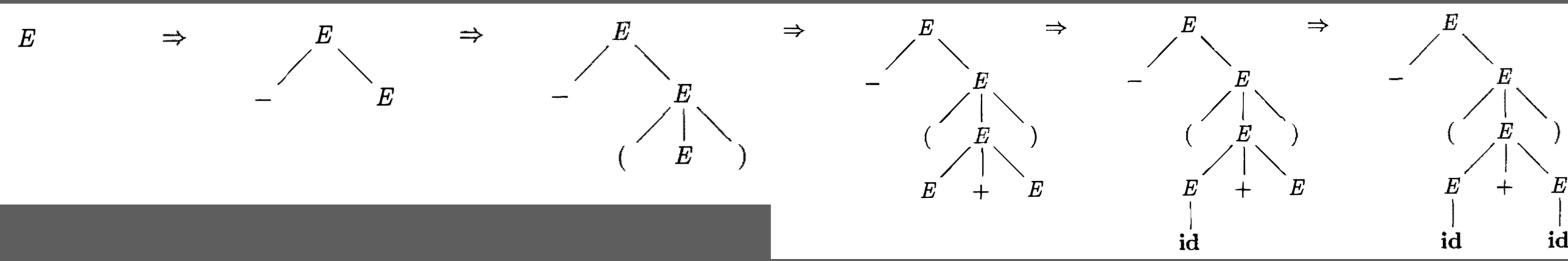
```
grammar
  productions
    E.A = E "+" E
    E.T = E "*" E
    E.N = "-" E
    E.P = "(" E ")"
    E.V = ID
```




```
derivation // left-most derivation
  E
  ⇒ "-" E
  ⇒ "-" "(" E ")"
  ⇒ "-" "(" E "+" E ")"
  ⇒ "-" "(" ID "+" E ")"
  ⇒ "-" "(" ID "+" ID ")"
```

```
tree derivation // left-most
  E
  ⇒ E["-" E]
  ⇒ E["-" E["(" E ")"]]
  ⇒ E["-" E["(" E[E "+" E] ")"]]
  ⇒ E["-" E["(" E[E[ID] "+" E] ")"]]
  ⇒ E["-" E["(" E[E[ID] "+" E[ID]] ")"]]
```

Left-Most Tree Derivation



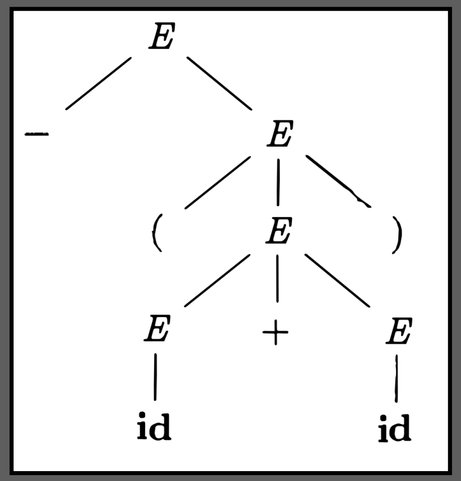

```
tree derivation // left-most
  E
  ⇒ E["-" E]
  ⇒ E["-" E["(" E ")"]]
  ⇒ E["-" E["(" E[E "+" E] ")"]]
  ⇒ E["-" E["(" E[E[ID] "+" E] ")"]]
  ⇒ E["-" E["(" E[E[ID] "+" E[ID]] ")"]]
```

Meta: Term Derivations

```
context-free syntax // term derivations

  Derivation.TermDerivation = <
    term derivation
      <Symbol> <TStep*>
  >

  TStep.Step   = [⇒ [Term*]]
  TStep.Steps  = [⇒* [Term*]]
  TStep.Steps1 = [⇒+ [Term*]]

  Term.App = <<ID>(<{Term ","}*>)>
  Term.Str = <<STRING>>
  Term.Sym = <<Symbol>>
```

Left-Most Term Derivation

```
grammar
  productions
    E.A = E "+" E
    E.T = E "*" E
    E.N = "-" E
    E.P = "(" E ")"
    E.V = ID
```




```
derivation // left-most derivation
  E
  ⇒ "-" E
  ⇒ "-" "(" E ")"
  ⇒ "-" "(" E "+" E ")"
  ⇒ "-" "(" ID "+" E ")"
  ⇒ "-" "(" ID "+" ID ")"
```

```
term derivation // left-most
  E
  ⇒ N(E)
  ⇒ N(P(E))
  ⇒ N(P(A(E, E))
  ⇒ N(P(A(V(ID), E))
  ⇒ N(P(A(V(ID), V(ID)))
```

Parse Trees Represent Derivations

```
List<String> YIELD(T : Tree) {
  T match {
    [A = Ts] ⇒ YIELDs(Ts);
    Str ⇒ [Str];
  };
}

List<String> YIELDs(Ts : List<Tree>) {
  Ts match {
    [] ⇒ "";
    [T | Ts] ⇒ YIELD(T) ++ YIELDs(Ts);
  };
}
```

$$S \Rightarrow^* PT$$

iff

$$S \Rightarrow^* \mathrm{YIELD}(PT)$$

Language Defined by a Grammar

$$L(G) = \{ w \mid S \Rightarrow^* w \}$$

Language: sentences

$$T(G) = \{ T \mid S \Rightarrow^* T \}$$

Language: trees

$$L(G) = \text{YIELD}(T(G))$$

Ambiguity

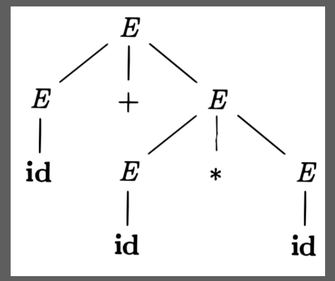
Ambiguity: Deriving Multiple Parse Trees

```
grammar
  productions
    E.A = E "+" E
    E.T = E "*" E
    E.N = "-" E
    E.P = "(" E ")"
    E.V = ID
```

```
derivation
  E ⇒* ID "+" ID "*" ID
```

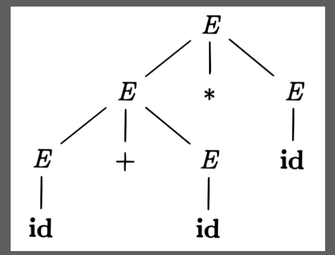
```
derivation
  E
  ⇒ E "+" E
  ⇒ ID "+" E
  ⇒ ID "+" E "*" E
  ⇒ ID "+" ID "*" E
  ⇒ ID "+" ID "*" ID
```

```
tree derivation
  E ⇒* E[E[ID] "+" E[E[ID] "*" E[ID]]]
```




```
derivation
  E
  ⇒ E "*" E
  ⇒ E "+" E "*" E
  ⇒ ID "+" E "*" E
  ⇒ ID "+" ID "*" E
  ⇒ ID "+" ID "*" ID
```

```
tree derivation
  E ⇒* E[E[E[ID] "+" E[ID]] "*" E[ID]]
```



Ambiguous grammar: produces >1 parse tree for a sentence

Ambiguity: Deriving Abstract Syntax Terms

```
grammar
  productions
    E.A = E "+" E
    E.T = E "*" E
    E.N = "-" E
    E.P = "(" E ")"
    E.V = ID
```

```
derivation
  E ⇒* ID "+" ID "*" ID
```

```
derivation
  E
  ⇒ E "+" E
  ⇒ ID "+" E
  ⇒ ID "+" E "*" E
  ⇒ ID "+" ID "*" E
  ⇒ ID "+" ID "*" ID
```

```
term derivation
  E
  ⇒ A(E, E)
  ⇒ A(V(ID), E)
  ⇒ A(V(ID), T(E, E))
  ⇒ A(V(ID), T(V(ID), E))
  ⇒ A(V(ID), T(V(ID), V(ID)))
```

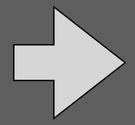
```
derivation
  E
  ⇒ E "*" E
  ⇒ E "+" E "*" E
  ⇒ ID "+" E "*" E
  ⇒ ID "+" ID "*" E
  ⇒ ID "+" ID "*" ID
```

```
term derivation
  E
  ⇒ T(E, E)
  ⇒ T(A(E, E), E)
  ⇒ T(A(V(ID), E), E)
  ⇒ T(A(V(ID), V(ID)), E)
  ⇒ T(A(V(ID), V(ID)), V(ID))
```

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 <{Case "|"}+>>
  Case.Case   = [[Pat] → [Exp]]

  Pat.PVar    = ID
  Pat.PApp    = <<Pat> <Pat>>
```



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 <{Case "|"}+>>
  Case.Case   = [[Pat] → [Exp]]

  Pat.PVar    = ID
  Pat.PApp    = <<Pat> <Pat>>
```

```
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 <{Case "|"}+>>
  Case.Case   = [[Pat] → [Exp]]

  Pat.PVar    = ID
  Pat.PApp    = <<Pat> <Pat>>
```

```
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

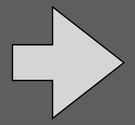
```
context-free syntax
  Exp         = <(<Exp>)> {bracket}

  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 <{Case "|"}+>>
  Case.Case   = [[Pat] → [Exp]]

  Pat.PVar    = ID
  Pat.PApp    = <<Pat> <Pat>>
```

```
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 <{Case "|"}+>>
  Case.Case   = [[Pat] → [Exp]]

  Pat.PVar    = ID
  Pat.PApp    = <<Pat> <Pat>>
```



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 <{Case "|"}+>>
                {longest-match}
  Case.Case   = [[Pat] → [Exp]]

  Pat.PVar    = ID
  Pat.PApp    = <<Pat> <Pat>> {left}
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 <{Case "|"}+>>
                {longest-match}
  Case.Case   = [[Pat] → [Exp]]

  Pat.PVar    = ID
  Pat.PApp    = <<Pat> <Pat>> {left}
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 <{Case "|"}+>>
                {longest-match}
  Case.Case   = [[Pat] → [Exp]]

  Pat.PVar    = ID
  Pat.PApp    = <<Pat> <Pat>> {left}
context-free priorities
  Exp.App > Exp.Add > Exp.IfElse > Exp.If
  > Exp.Match > Exp.Let > Exp.Fun
```

```
f a + b
```

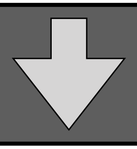
```
amb(
  [ Add(App(Var("f"), Var("a")), Var("b"))
  , App(Var("f"), Add(Var("a"), Var("b")))
  ]
)
```

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

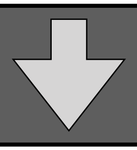
Dangling Else = Operators with Overlapping Prefix

```
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 <{Case "|"}+>>
                {longest-match}
  Case.Case   = [[Pat] → [Exp]]

  Pat.PVar    = ID
  Pat.PApp    = <<Pat> <Pat>> {left}
context-free priorities
  Exp.App > Exp.Add > Exp.IfElse > Exp.If
  > Exp.Match > Exp.Let > Exp.Fun
```

```
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 = Do Not 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 <{Case "|"}+>>
                {longest-match}
  Case.Case   = [[Pat] → [Exp]]

  Pat.PVar    = ID
  Pat.PApp    = <<Pat> <Pat>> {left}
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>> {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 <{Case "|"}+>>
                {longest-match}
  Case.Case   = [[Pat] → [Exp]]

  Pat.PVar    = ID
  Pat.PApp    = <<Pat> <Pat>> {left}
context-free priorities
  Exp.App > Exp.Add > Exp.IfElse > Exp.If
  > Exp.Match > Exp.Let > Exp.Fun
```

```
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 <{Case "|"}+>>
                {longest-match}
  Case.Case   = [[Pat] → [Exp]]

  Pat.PVar    = ID
  Pat.PApp    = <<Pat> <Pat>> {left}
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 <{Case "|"}+>>
                {longest-match}
  Case.Case   = [[Pat] → [Exp]]

  Pat.PVar    = ID
  Pat.PApp    = <<Pat> <Pat>> {left}
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(
    [ [ Case(
          PVar("a")
        , Match(
            Int("5")
          , [Case(PVar("b"), Int("3"))]
          )
        )
      , Case(PVar("c"), Int("4"))
      ]
    , [ Case(
          PVar("a")
        , Match(
            Int("5")
          , [ Case(PVar("b"), Int("3"))
            , Case(PVar("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 <{Case "|"}+>>
                {longest-match}
  Case.Case   = [[Pat] → [Exp]]

  Pat.PVar    = ID
  Pat.PApp    = <<Pat> <Pat>> {left}
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")
, [ Case(
      PVar("a")
    , Match(
        Int("5")
      , [ Case(PVar("b"), Int("3"))
        , Case(PVar("c"), Int("4"))
        ]
      )
    )
  ]
)
```

Parenthesize

Parenthesize = Disambiguate^{-1} (Insert Necessary Parentheses)

```
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 <{Case "|"}+>>
                {longest-match}
  Case.Case   = [[Pat] → [Exp]]

  Pat.PVar    = ID
  Pat.PApp    = <<Pat> <Pat>> {left}
context-free priorities
  Exp.App > Exp.Add > Exp.IfElse > Exp.If
  > Exp.Match > Exp.Let > Exp.Fun
```

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

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

```
a + b + c
```

Parenthesize = Disambiguate^{-1} (Insert Necessary Parentheses)

```
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 <{Case "|"}+>>
                {longest-match}
  Case.Case   = [[Pat] → [Exp]]

  Pat.PVar    = ID
  Pat.PApp    = <<Pat> <Pat>> {left}
context-free priorities
  Exp.App > Exp.Add > Exp.IfElse > Exp.If
  > Exp.Match > Exp.Let > Exp.Fun
```

```
a + (let x = b in (c + d))
```

```
Add(
  Var("a")
, Let(
    [Bnd("x", Var("b"))]
  , Add(Var("c"), Var("d"))
  )
)
```

```
a + let
  x = b
in
  c + d
```

Parenthesize = Disambiguate^{-1} (Insert Necessary Parentheses)

```
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 <{Case "|"}+>>
                {longest-match}
  Case.Case   = [[Pat] → [Exp]]

  Pat.PVar    = ID
  Pat.PApp    = <<Pat> <Pat>> {left}
context-free priorities
  Exp.App > Exp.Add > Exp.IfElse > Exp.If
  > Exp.Match > Exp.Let > Exp.Fun
```

```
(a + (let x = b in c)) + d
```

```
Add(
  Add(
    Var("a")
  , Let([Bnd("x", Var("b"))], Var("c"))
  )
, Var("d")
)
```

```
a + (let
  x = b
in
  c) + d
```

Parenthesize = Disambiguate^{-1} (Insert Necessary Parentheses)

```
context-free syntax
  Exp         = <(<Exp>)> {bracket}

  Exp.Int     = INT
  Exp.Var     = ID
  Exp.Add     = <<Exp> + <Exp>> {left}
  Exp.Sub     = <<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 <{Case "|"}+>>
                {longest-match}
  Case.Case   = [[Pat] → [Exp]]

  Pat.PVar    = ID
  Pat.PApp    = <<Pat> <Pat>> {left}
context-free priorities
  {left: Exp.Sub Exp.App} > Exp.Add > Exp.IfElse >
Exp.If
  > Exp.Match > Exp.Let > Exp.Fun
```

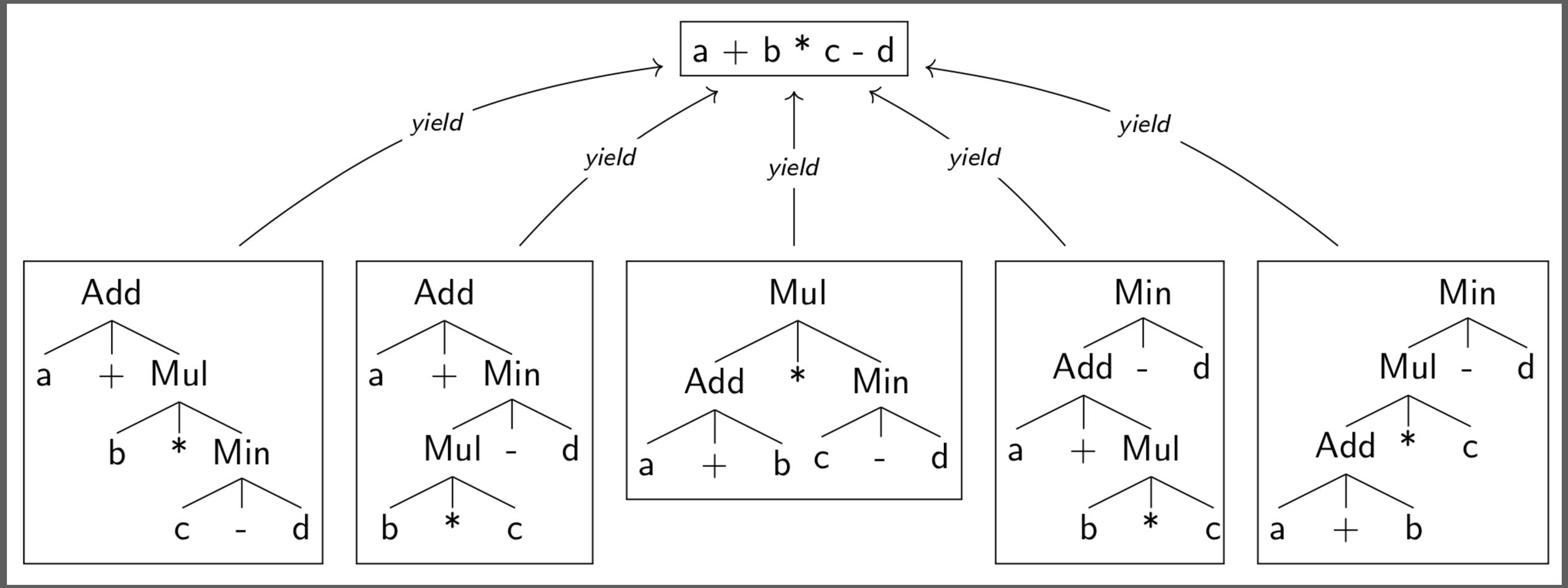
```
(a + (let x = b in c)) + d
```

```
Add(
  Add(
    Var("a")
  , Let([Bnd("x", Var("b"))], Var("c"))
  )
, Var("d")
)
```

```
a + (let
  x = b
in
  c) + d
```

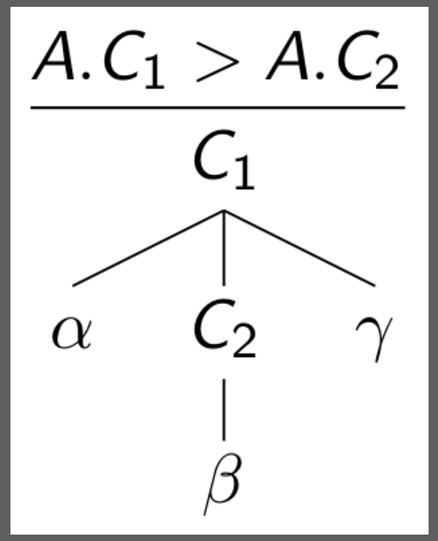
Semantics of Associativity and Priority

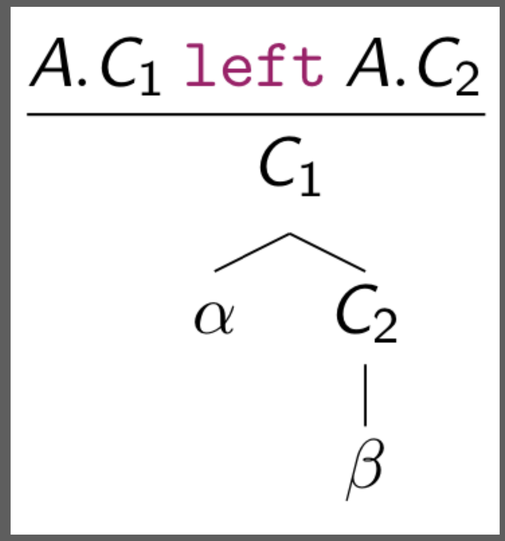
Ambiguous Sentence has Multiple Parse Trees

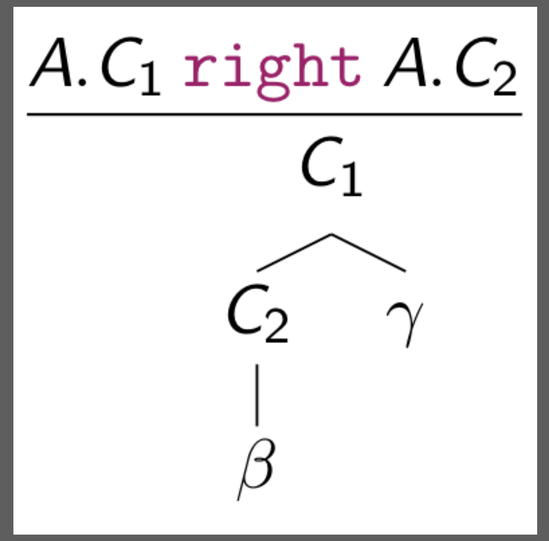


Associativity and Priority as Subtree Exclusion Rules [SDF2 (1997)]

Rules

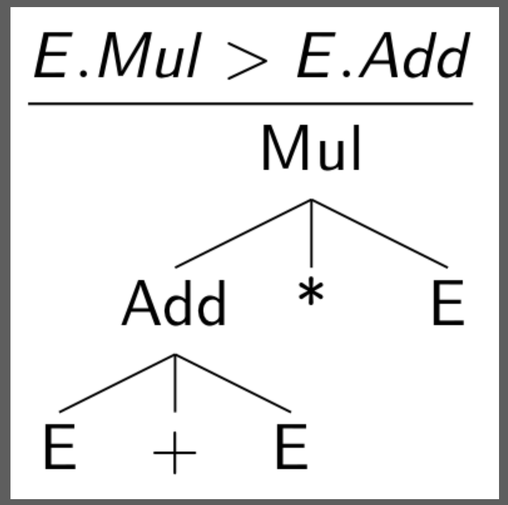


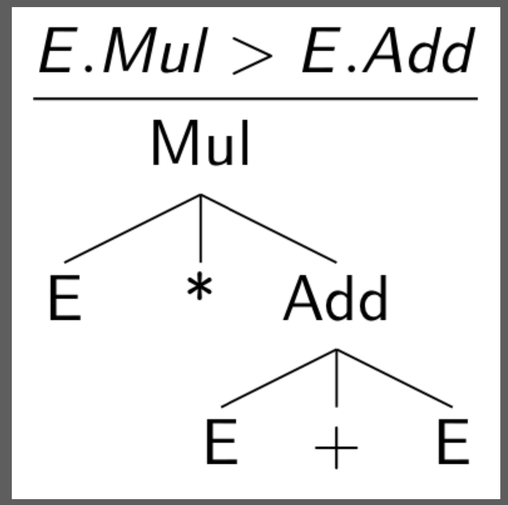


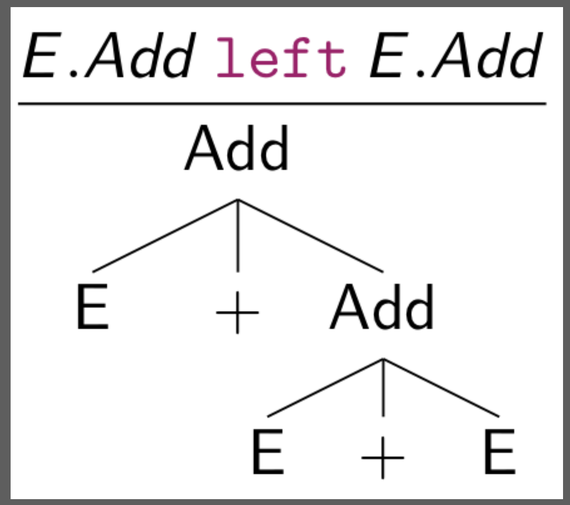


Disambiguation rules generate subtree exclusion patterns (aka conflict patterns)

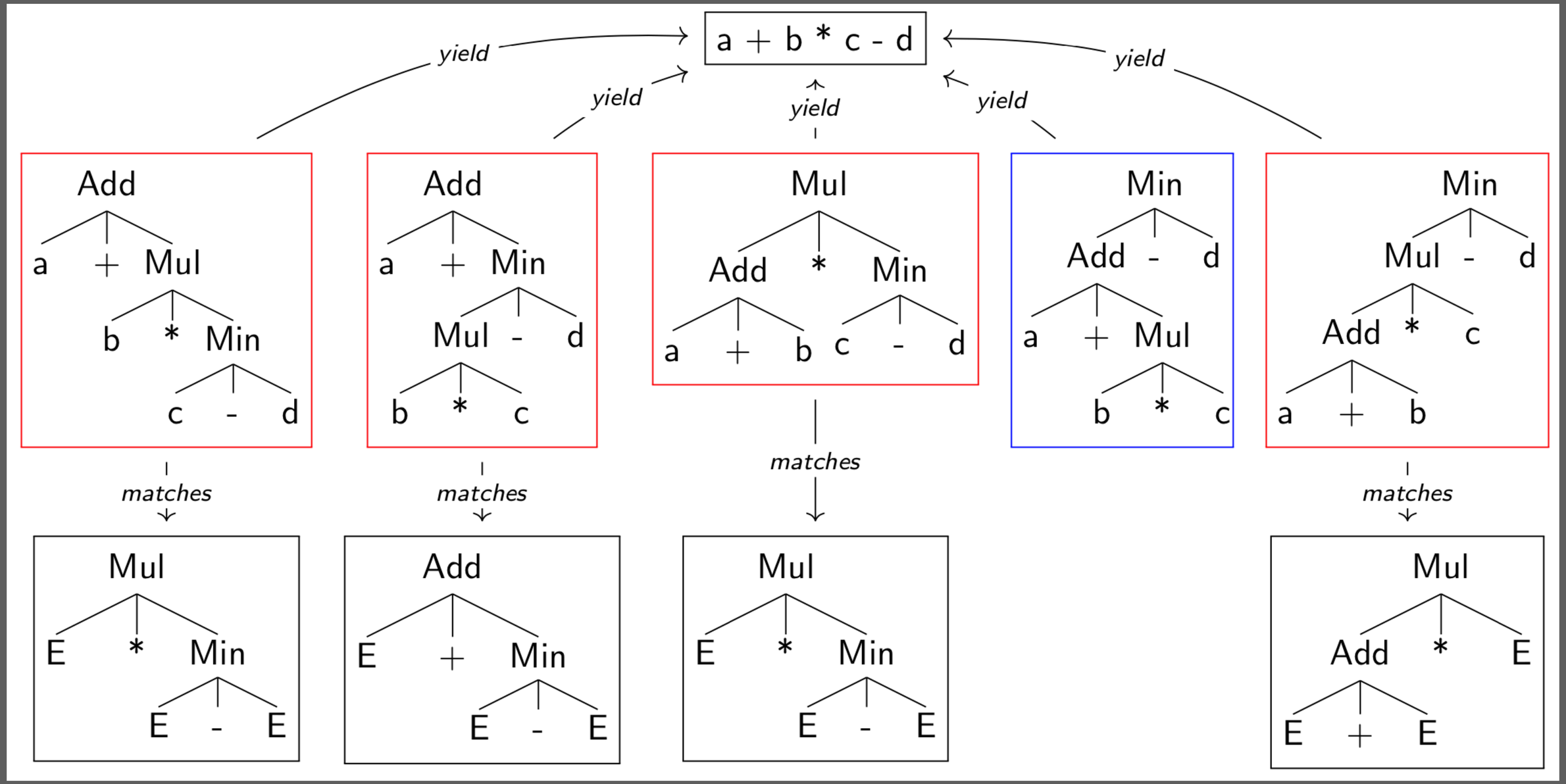
Instances





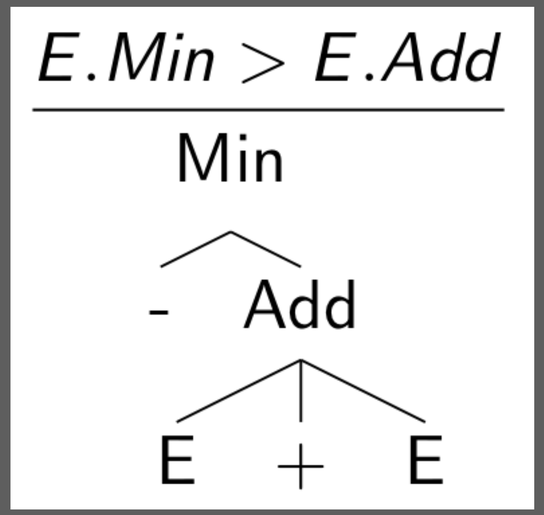


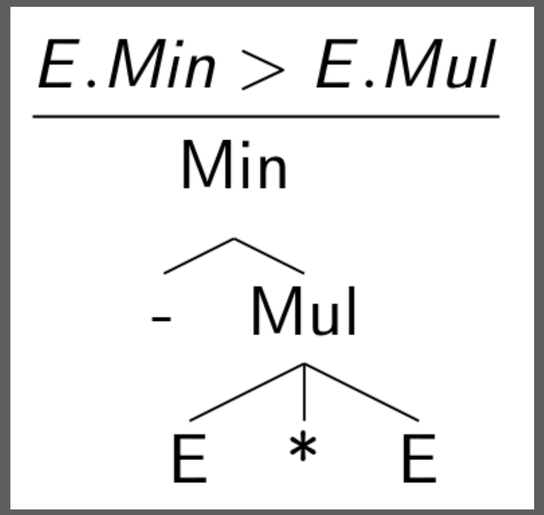
Disambiguation by Subtree Exclusion



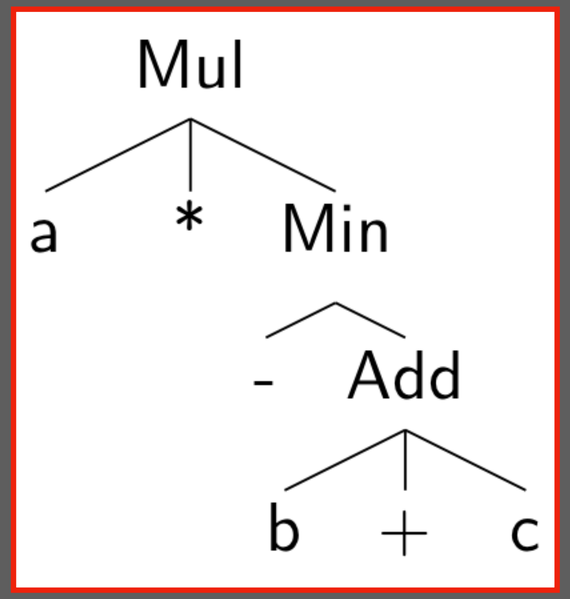
Safe for High Priority Prefix Operators

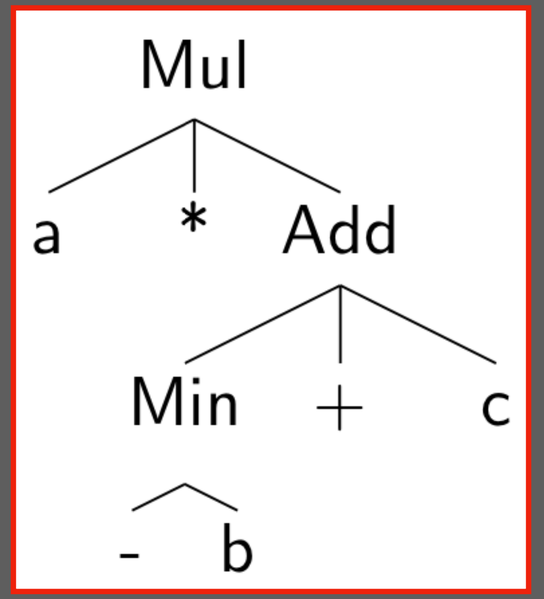
Conflict Patterns

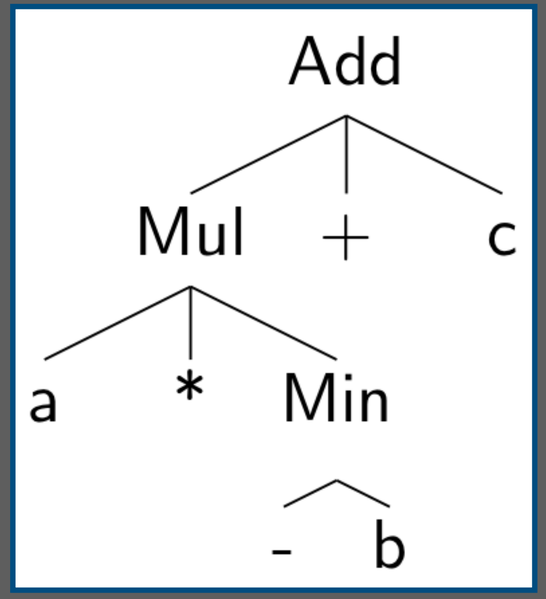




Trees

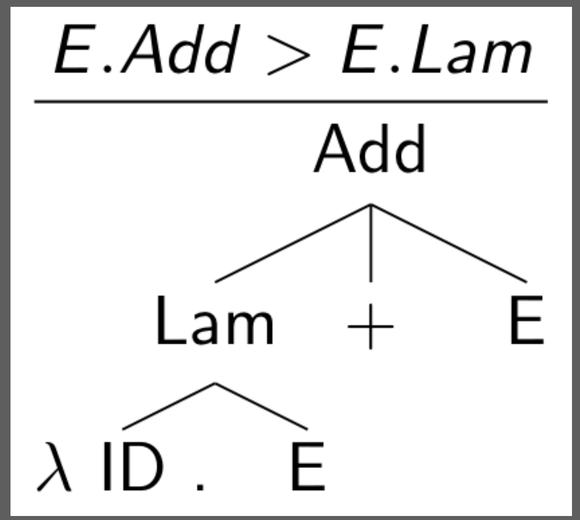


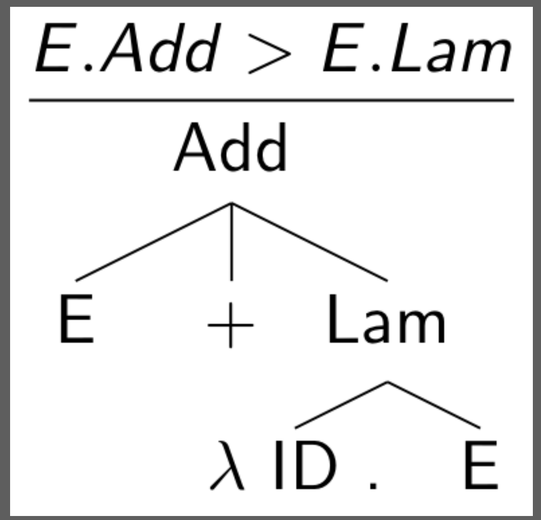




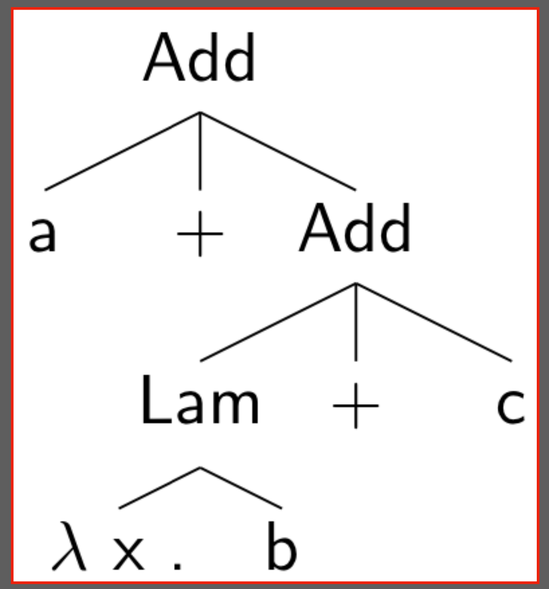
Unsafe for Low Priority Prefix Operators [SDF2]

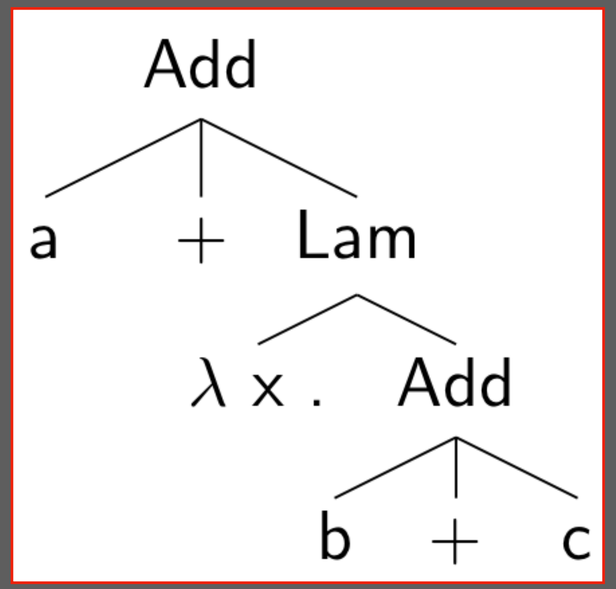
Conflict Patterns

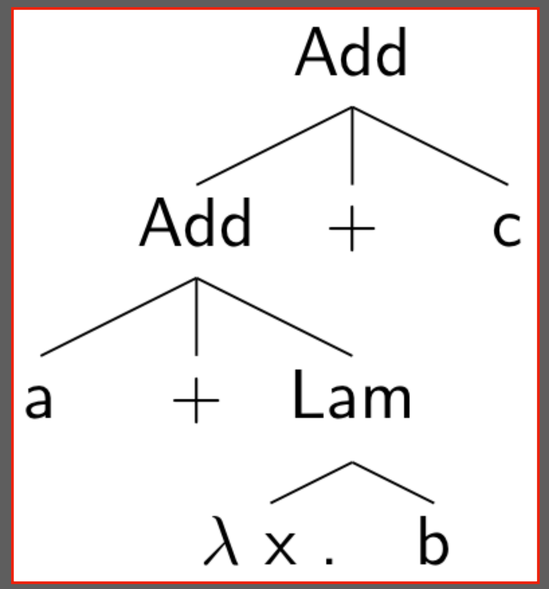




Trees

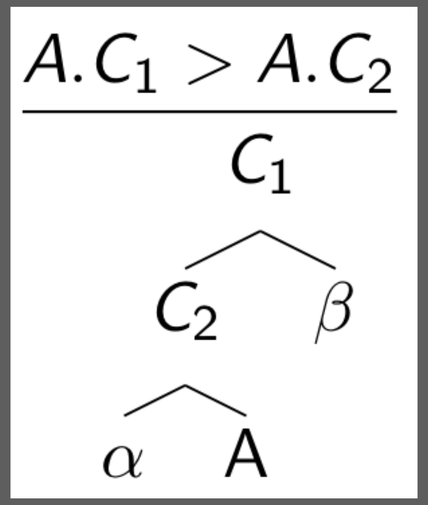




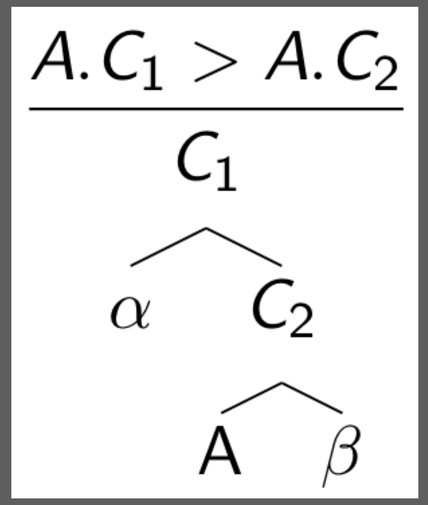


Safe Subtree Exclusion Rules [SDF3 (2019)]

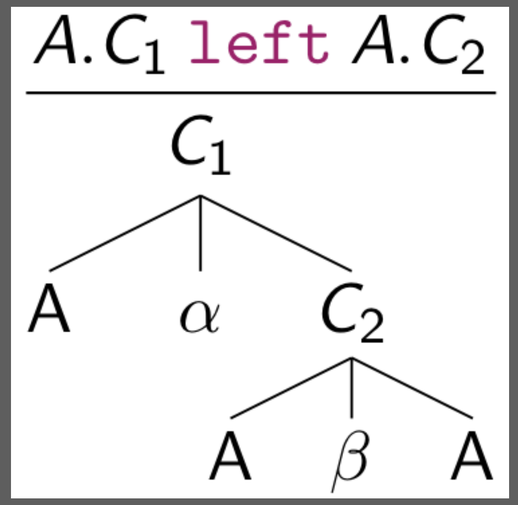
Rules

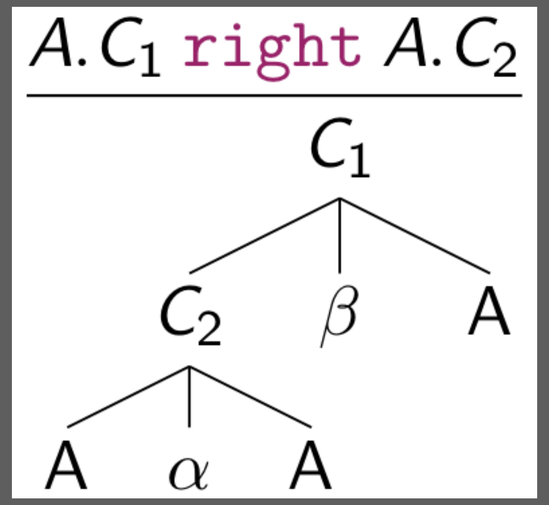


Right Recursive in
Left Recursive Position



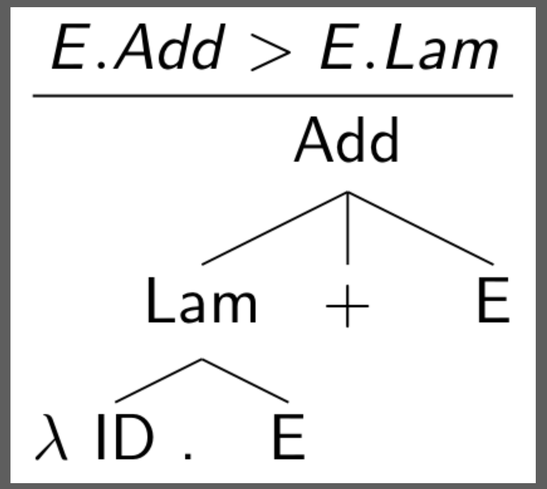
Left Recursive in
Right Recursive Position



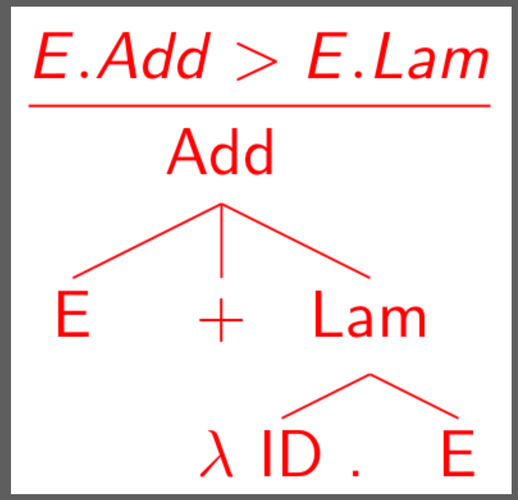


Associativity

Conflict Patterns



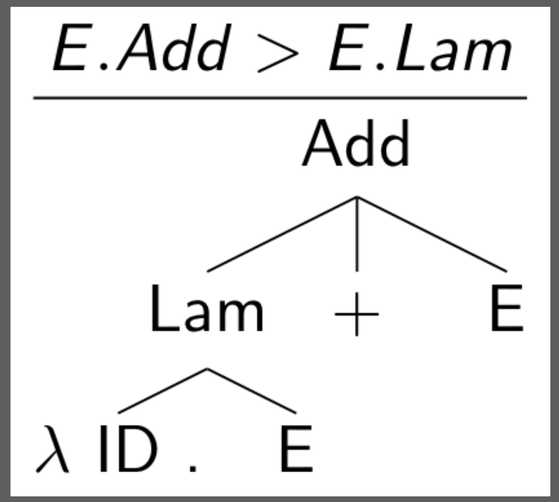
conflict pattern:
\ right recursive

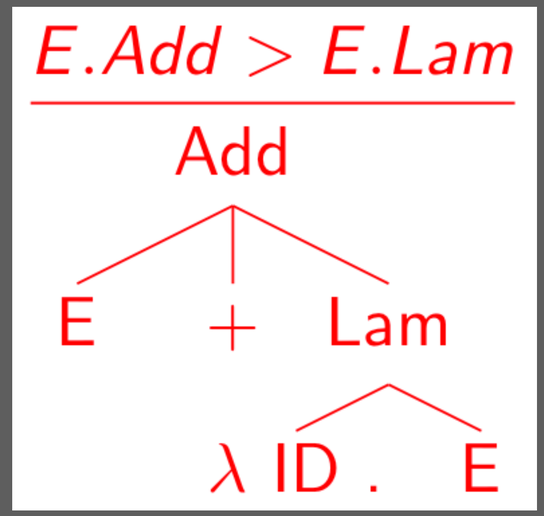


not a conflict pattern:
\ not left recursive

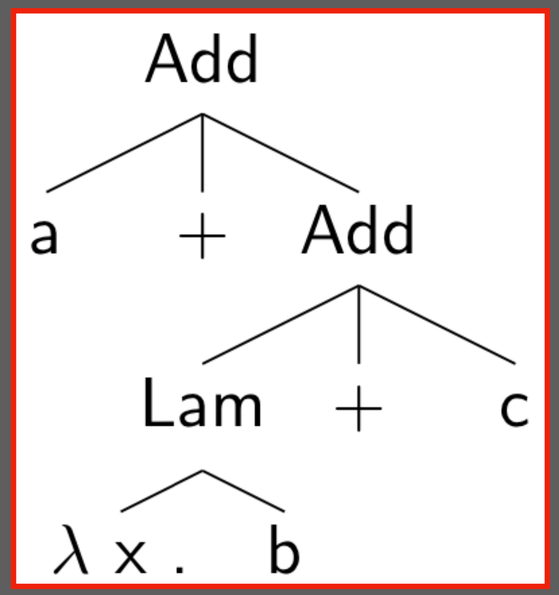
Shallow Interpretation: Safe for Low Priority Prefix Operators

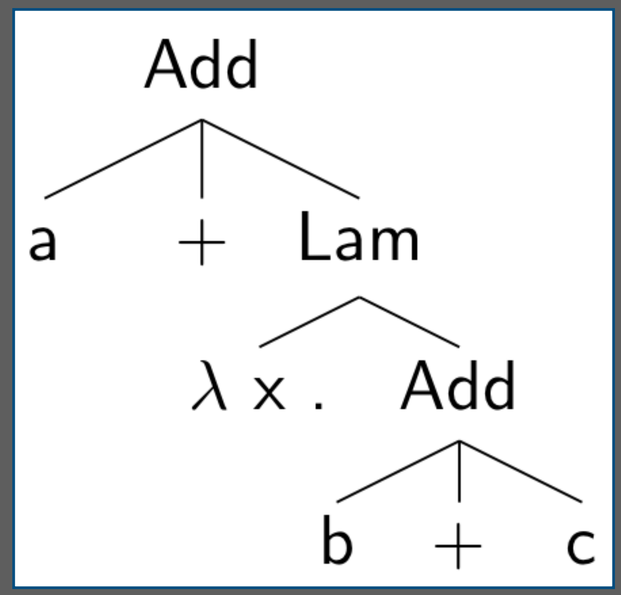
Conflict Patterns

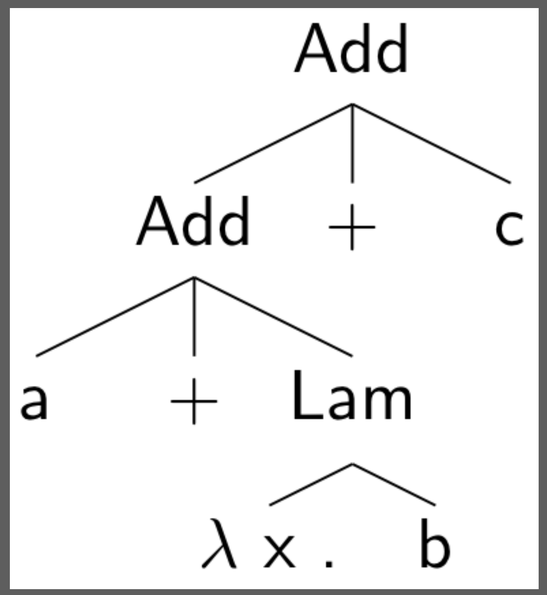




Trees

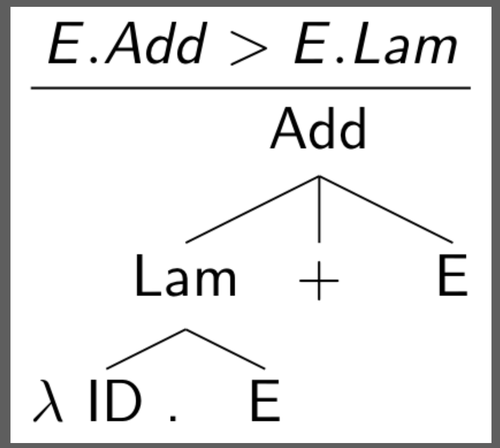


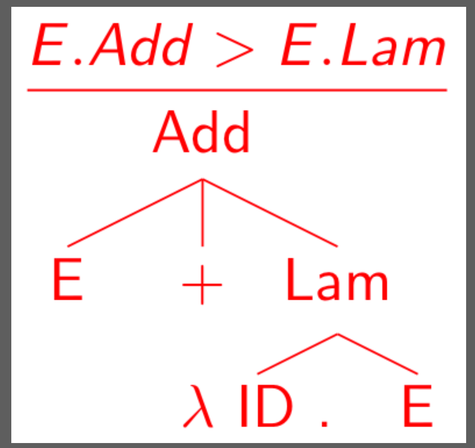


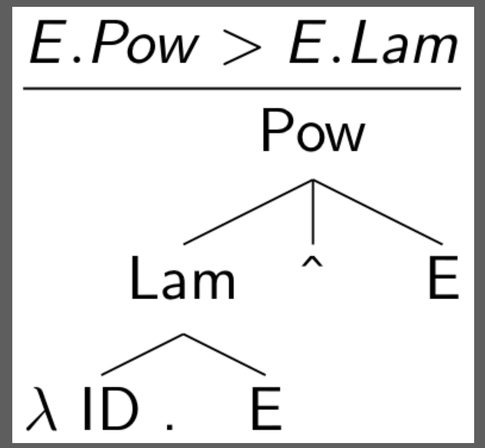


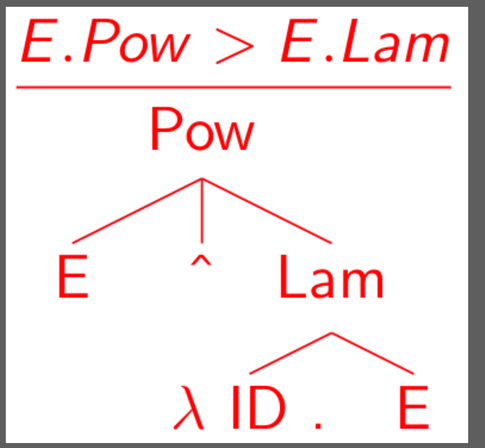
Shallow Interpretation: Incomplete for Low Priority Prefix Operators

Conflict Patterns



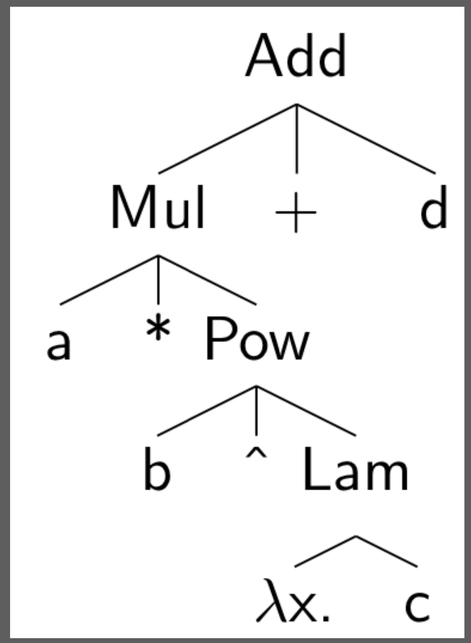


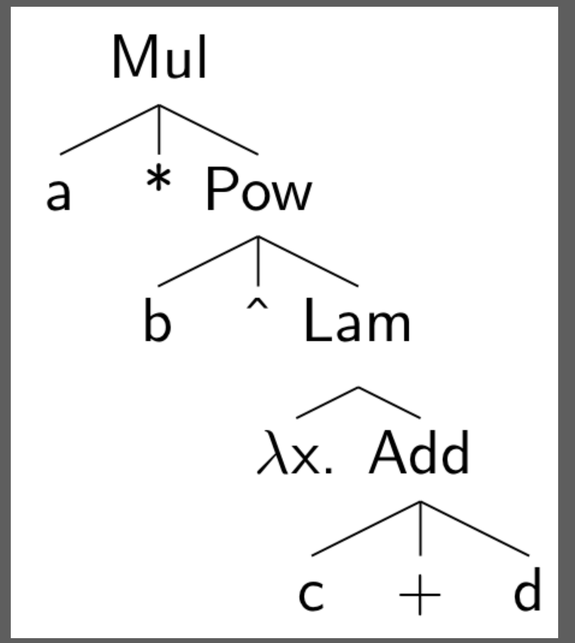




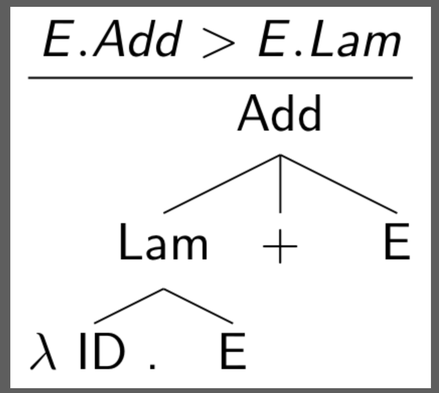
Trees

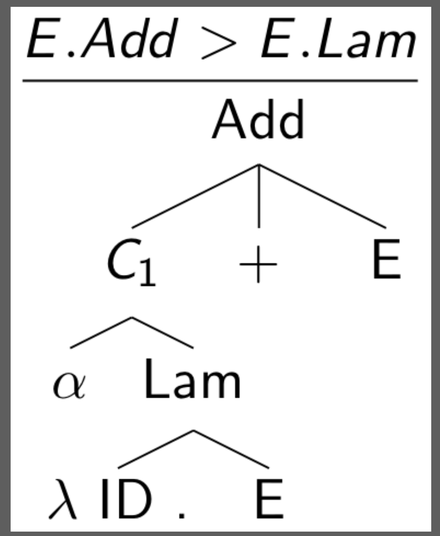
a * b ^ λ x. c + d

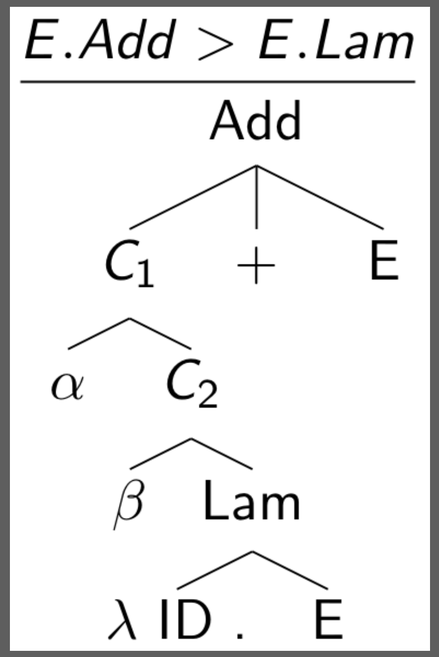




Deep Priority Conflicts: Match Subpattern in Right-Most Subtree

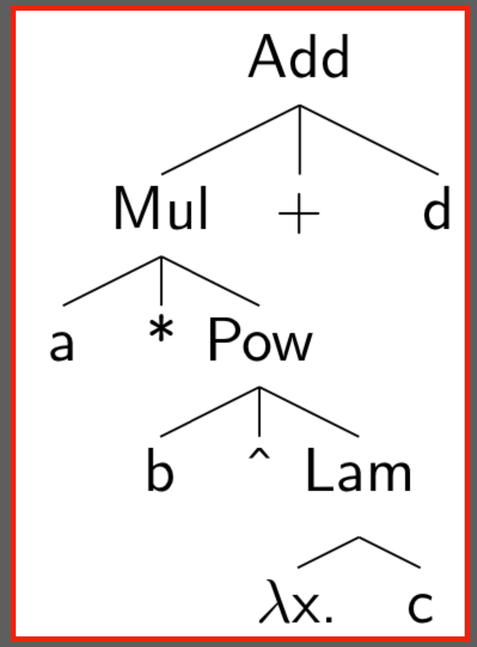


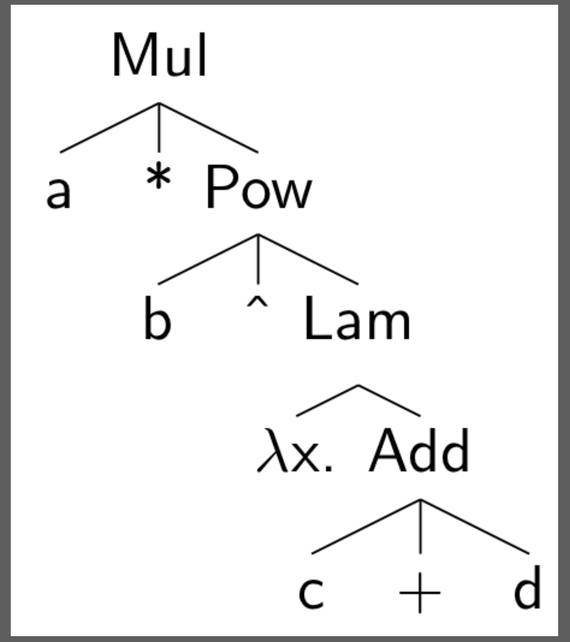




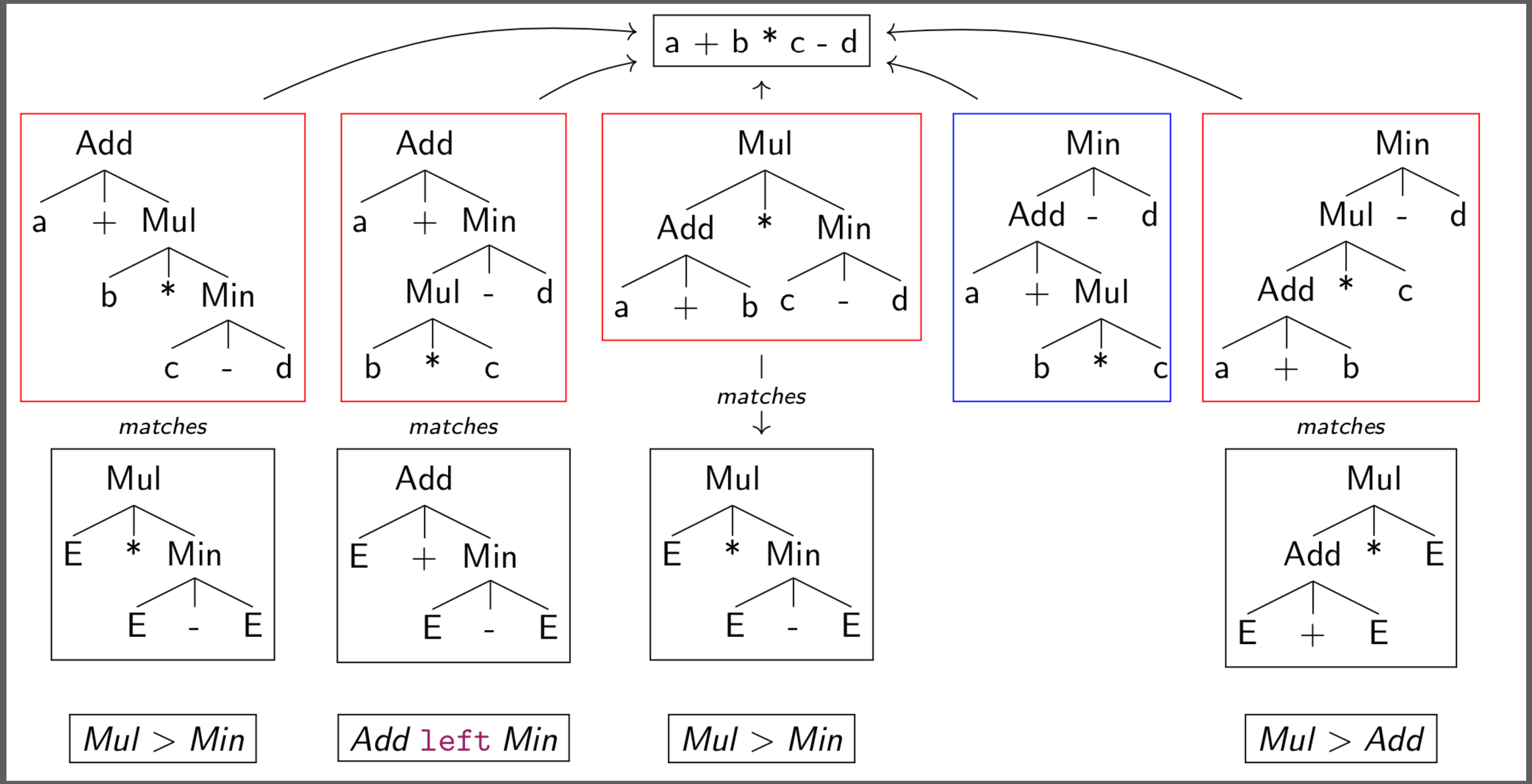
...

Infinite set of conflict patterns

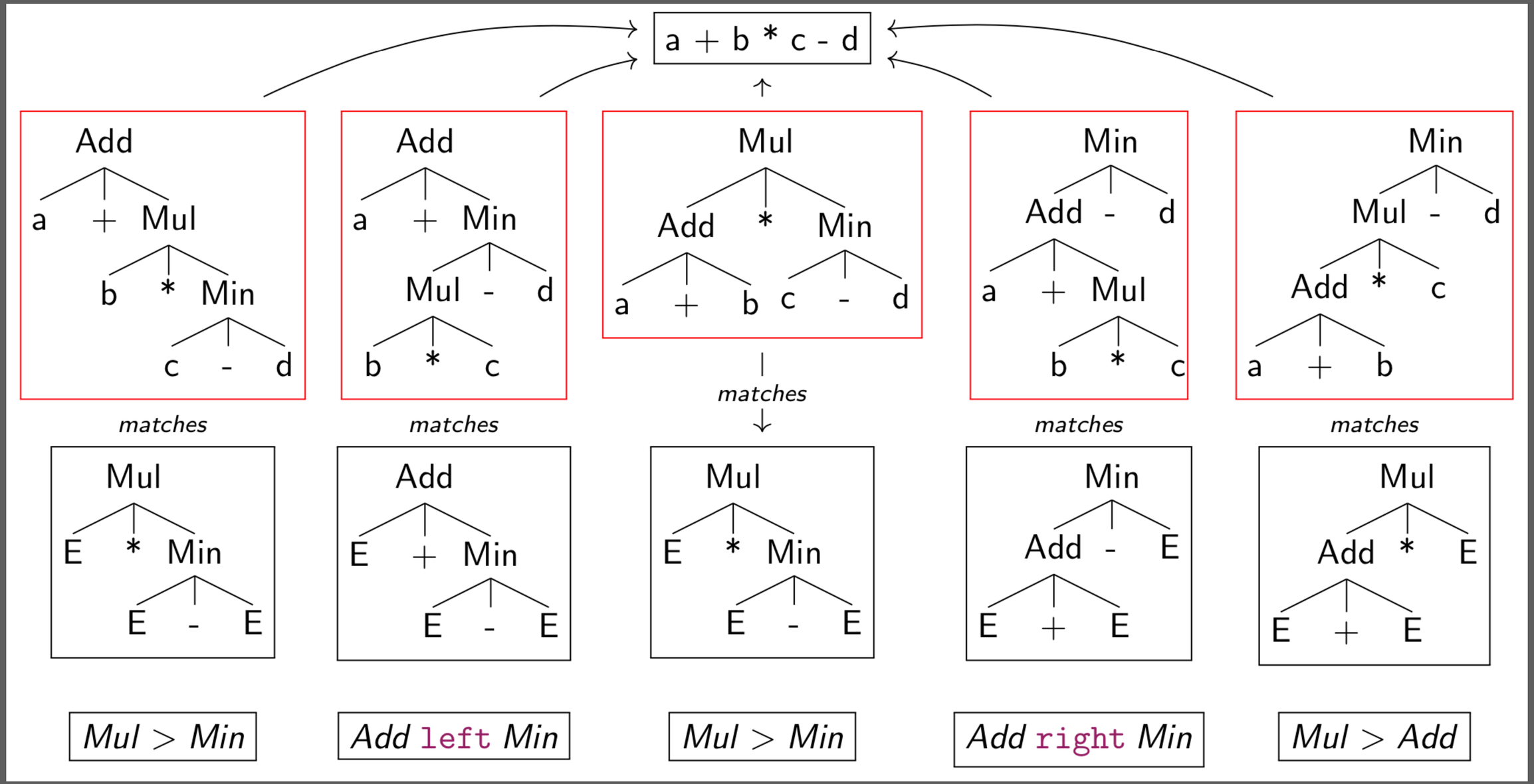




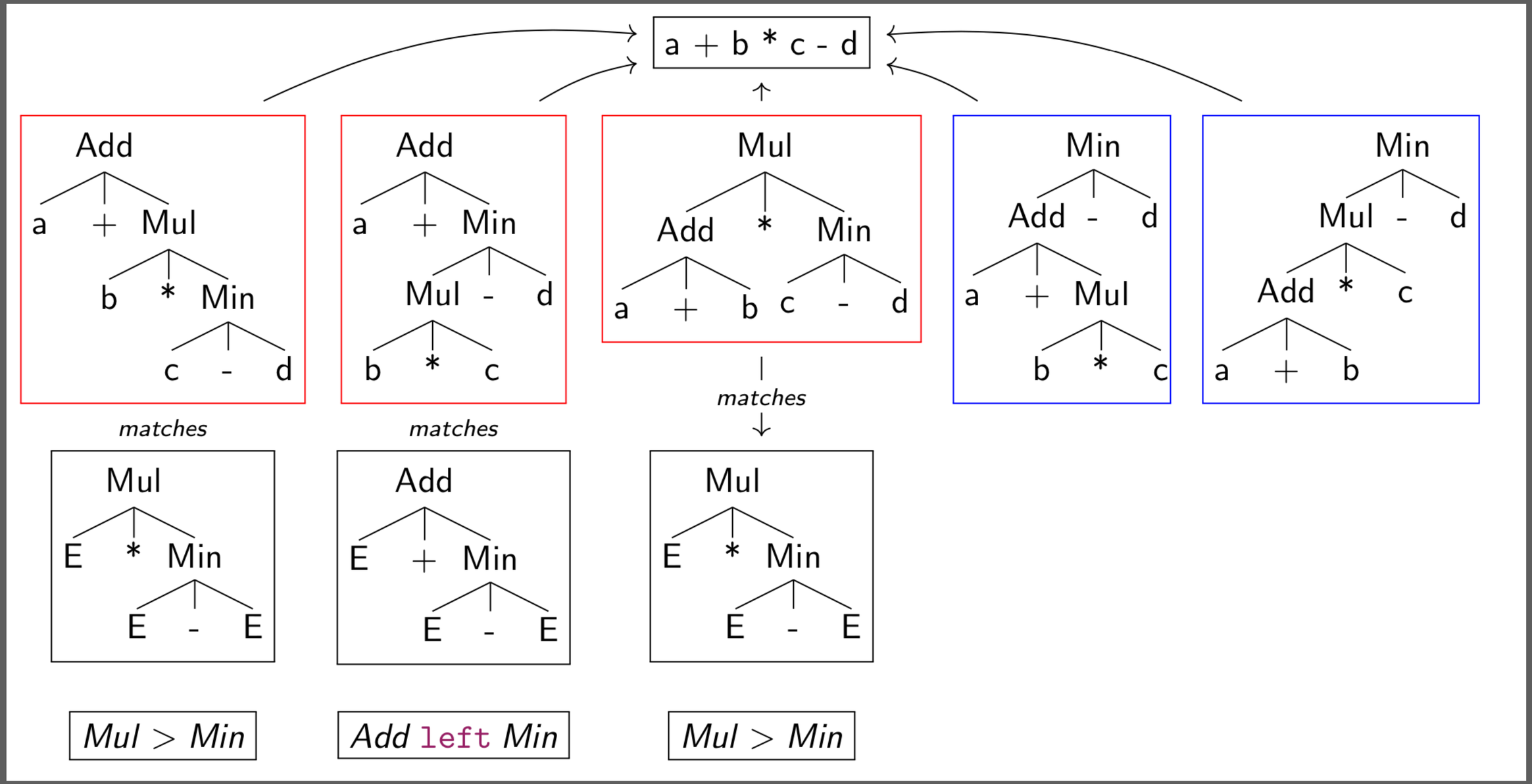
Safe and Complete Disambiguation Rules



Unsafe: Too Many Disambiguation Rules



Incomplete: Too Few Disambiguation Rules



Semantics of Associativity and Priority

What is the semantics of associativity and priority rules?

- subtree exclusion: tree patterns that are forbidden

Is a set of disambiguation rules safe?

- At most one rule for each pair of productions
- + some well-formedness criteria

Is a set of disambiguation rules complete?

- At least one rule for each pair of productions
- + some well-formedness criteria

How to implement?

Grammar Transformations

Grammar Transformations

Why?

- Disambiguation
- For use by a particular parsing algorithm

Transformations

- Eliminating ambiguities
- Eliminating left recursion
- Left factoring

Properties

- Does transformation preserve the language (set of strings, trees)?
- Does transformation preserve the structure of trees?

Ambiguous Expression Grammar

```
grammar
  productions
    E.A = E "+" E
    E.T = E "*" E
    E.M = "-" E
    E.B = "(" E ")"
    E.V = ID
```

```
derivation
  E ⇒* ID "*" ID "+" ID
```

```
term derivation
  E
  ⇒ A(E, E)
  ⇒ A(T(E, E), E)
  ⇒ A(T(E, E), E)
  ⇒ A(T(V(ID), E), E)
  ⇒ A(T(V(ID), V(ID)), E)
  ⇒ A(T(V(ID), V(ID)), V(ID))
```

```
term derivation
  E
  ⇒ T(E, E)
  ⇒ T(E, E)
  ⇒ T(V(ID), E)
  ⇒ T(V(ID), A(E, E))
  ⇒ T(V(ID), A(V(ID), E))
  ⇒ T(V(ID), A(V(ID), V(ID)))
```

Associativity and Priority Filter Ambiguities

```
grammar
  productions
    E.A = E "+" E
    E.T = E "*" E
    E.M = "-" E
    E.B = "(" E ")"
    E.V = ID
```

```
grammar
  productions
    E.A = E "+" E {left}
    E.T = E "*" E {left}
    E.M = "-" E
    E.B = "(" E ")"
    E.V = ID
  priorities
    E.M > E. T > E.A
```

```
derivation
  E ⇒* ID "*" ID "+" ID
```

```
term derivation
  E
  ⇒ A(E, E)
  ⇒ A(T(E, E), E)
  ⇒ A(T(E, E), E)
  ⇒ A(T(V(ID), E), E)
  ⇒ A(T(V(ID), V(ID)), E)
  ⇒ A(T(V(ID), V(ID)), V(ID))
```

```
term derivation
  E
  ⇒ T(E, E)
  ⇒ T(E, E)
  ⇒ T(V(ID), E)
  ⇒ T(V(ID), A(E, E))
  ⇒ T(V(ID), A(V(ID), E))
  ⇒ T(V(ID), A(V(ID), V(ID)))
```

Define Associativity and Priority by Transformation

```
grammar
  productions
    E.A = E "+" E {left}
    E.T = E "*" E {left}
    E.M = "-" E
    E.B = "(" E ")"
    E.V = ID
  priorities
    E.M > E. T > E.A
```

```
grammar
  productions
    E.A = E "+" T
    E   = T
    T.T = T "*" F
    T   = F
    F.V = ID
    F.B = "(" E ")"
```

```
derivation
  E ⇒* ID "*" ID "+" ID
```

```
term derivation
  E
  ⇒ A(E, E)
  ⇒ A(T(E, E), E)
  ⇒ A(T(E, E), E)
  ⇒ A(T(V(ID), E), E)
  ⇒ A(T(V(ID), V(ID)), E)
  ⇒ A(T(V(ID), V(ID)), V(ID))
```

~~
```
term derivation
  E
  ⇒ T(E, E)
  ⇒ T(E, E)
  ⇒ T(V(ID), E)
  ⇒ T(V(ID), A(E, E))
  ⇒ T(V(ID), A(V(ID), E))
  ⇒ T(V(ID), A(V(ID), V(ID)))
```
~~

Define Associativity and Priority by Transformation

```
grammar
  productions
    E.A = E "+" E {left}
    E.T = E "*" E {left}
    E.M = "-" E
    E.B = "(" E ")"
    E.V = ID
  priorities
    E.M > E. T > E.A
```

```
grammar
  productions
    E.A = E "+" T
    E   = T
    T.T = T "*" F
    T   = F
    F.V = ID
    F.M = "-" F
    F.B = "(" E ")"
```

```
Define new non-terminal for each
priority level:
   E, T, F
```

```
Add ‘injection’ productions to
include priority level n+1 in n:
  E = T
  T = F
```

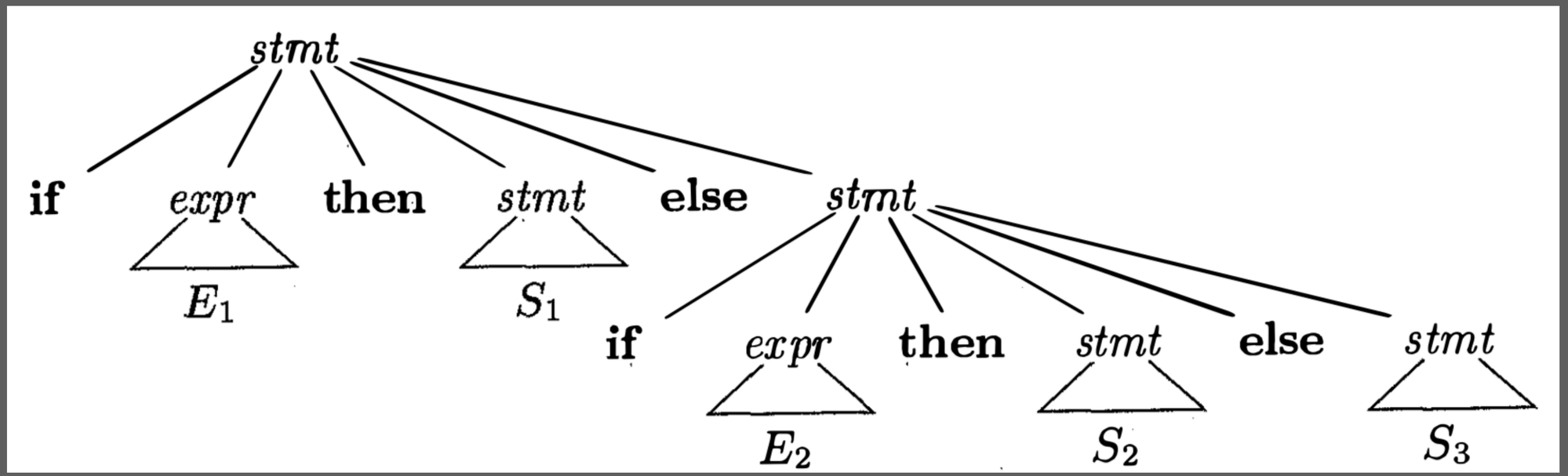
```
Change head of production to reflect
priority level
  T = T “*” F
```

```
Transform productions
  Left:  E = E “+” T
  Right: E = T “+” E
```

Dangling Else Grammar

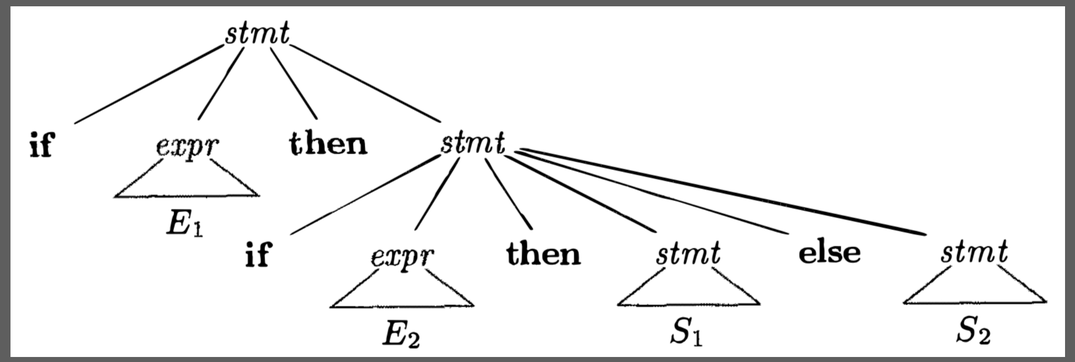
```
grammar
  sorts S E
  productions
    S.If  = if E then S
    S.IfE = if E then S else S
    S     = other
```

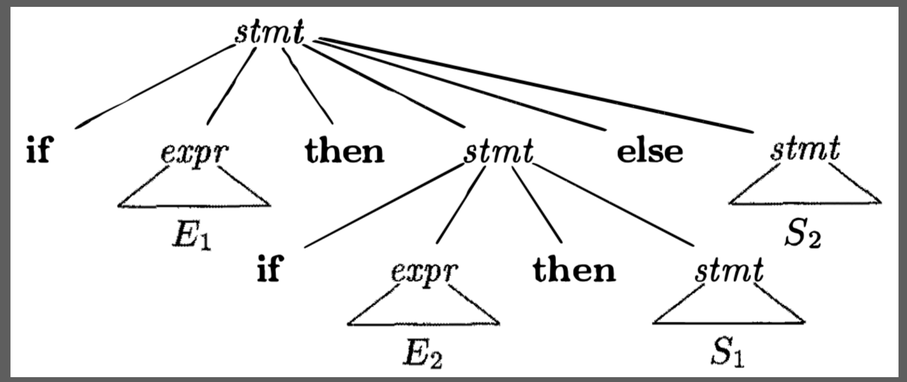
```
derivation
  S ⇒* if E1 then S1 else if E2 then S2 else S3

term derivation
  S ⇒* IfE(E1, S1, IfE(E2, S2, S3))

term derivation
  S
  ⇒ IfE(E1, S1, S)
  ⇒ IfE(E1, S1, IfE(E2, S2, S3))
```



Dangling Else Grammar is Ambiguous

```
grammar
  sorts S E
  productions
    S.If  = if E then S
    S.IfE = if E then S else S
    S     = other
```






```
derivation
  S ⇒* if E1 then if E2 then S1 else S2
```

```
term derivation
  S
  ⇒ If(E1, S)
  ⇒ If(E1, IfE(E2, S1, S2))

derivation
  S
  ⇒ if E1 then S
  ⇒ if E1 then if E2 then S1 else S2
```

```
term derivation
  S
  ⇒ IfE(E1, S, S2)
  ⇒ IfE(E1, If(E2, S1), S2)

derivation
  S
  ⇒ if E1 then S else S2
  ⇒ if E1 then if E2 then S1 else S2
```

Eliminating Dangling Else Ambiguity

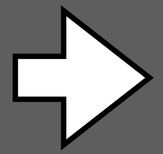
```
grammar
  sorts S E
  productions
    S.If  = if E then S
    S.IfE = if E then S else S
    S     = other
```

```
grammar
  productions
    S.If   = if E then S
    S.IfE  = if E then SE else S
    S      = other
    SE.IfE = if E then SE else SE
    SE     = other
```

Generalization of this transformation: contextual grammars

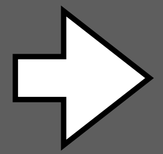
Eliminating Left Recursion

```
grammar
  productions
    E = E "+" T
    E = T
    T = T "*" F
    T = F
    F = "(" E ")"
    F = ID
```



```
grammar
  productions
    E  = T E'
    E' = "+" T E'
    E' =
    T  = F T'
    T' = "*" F T'
    T' =
    F  = "(" E ")"
    F  = ID
```

```
grammar
 productions
    A = A a
    A = b
```

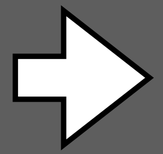


```
grammar
  productions
    A  = b A'
    A' = a A'
    A' = // empty
```

// b followed by a list of as

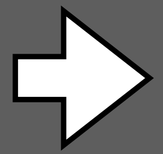
Eliminating Left Recursion using Regular Expressions

```
grammar
  productions
    E = E "+" T
    E = T
    T = T "*" F
    T = F
    F = "(" E ")"
    F = ID
```



```
grammar
  productions
    E  = T ("+" T)*
    T  = F ("*" F)*
    F  = "(" E ")"
    F  = ID
```

```
grammar
 productions
    A = A a
    A = b
```

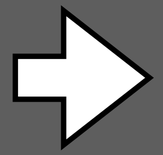


```
grammar
  productions
    A = b a*
```

```
// b followed by a list of as
```

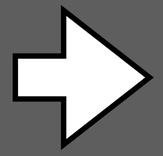
Left Factoring

```
grammar
  productions
    S.If  = if E then S
    S.IfE = if E then S else S
    S     = other
```



```
grammar
  sorts S E
  productions
    S.If      = if E then S S'
    S'.Else   = else S
    S'.NoElse = // empty
    S         = other
```

```
grammar
  productions
    A = a b1
    A = a b2
    A = c
```



```
grammar
  productions
    A  = a A'
    A' = b1
    A' = b2
    A  = c
```

Properties of Grammar Transformations

Preservation

- Preserves set of sentences
- Preserves set of trees
- Preserves tree structure

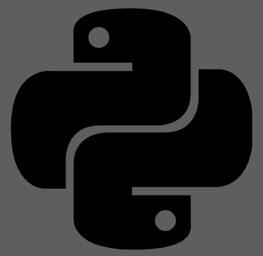
Systematic

- Algorithmic
- Heuristic

Layout-Sensitive Syntax

Layout-Sensitive Syntax

```python
if x ≠ y:
  if x > 0:
    y = x
else:
  y = -x
```



```haskell
guessValue x = do
  putStrLn "Enter your guess:"
  guess ← getLine
  case compare (read guess) x of
    EQ → putStrLn "You won!"
    _  → do putStrLn "Keep guessing."
            guessValue x
```

Disambiguation with Indentation Sensitive Context-free Grammars

```
case → 'case'> exp= 'of'> altBlock=
-- Reset indentation for delimited blocks

altBlock  → '{'> alts⊛ close⊛
close     → '}'>
-- Increase indentation for non-delimited blocks

altBlock  → altLayout>
altLayout → |alts⊨ altLayout=
altLayout → |alts⊨
-- Clause sequences

alts → alt=
alts → alt= ';'> alts=
```

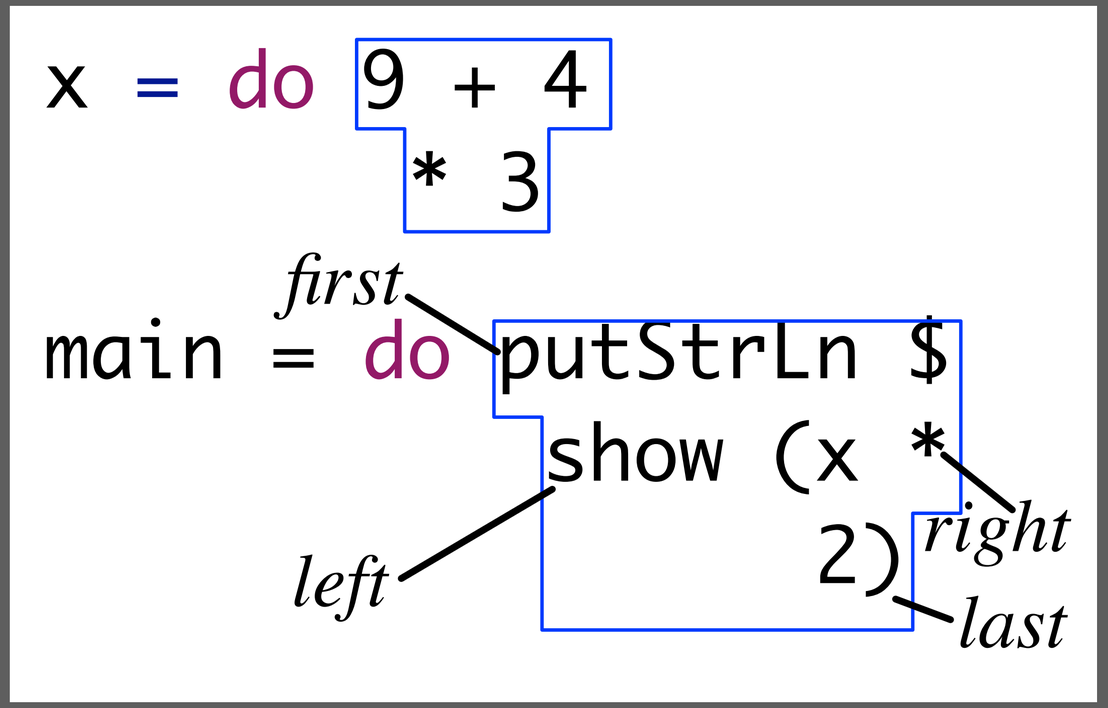
Michael Adams. Principled Parsing for Indentation-Sensitive Languages: Revisiting Landin's Offside Rule. In POPL'13.

SDF3: Disambiguation with Layout Constraints

```
context-free syntax

  Impl           = Stm {layout(1.first.col < 1.left.col)}

  Impls.StmSeq   = Impl Impls {layout(1.first.col == 2.first.col)}

  Impls          = Impl
  Expls          = Stm
  Expls.StmtSeq  = Stm ";" Expls
  Stms.Stms      = Impls

  Stms.Stms      = "{" Expls "}" {ignore-layout}
```

Sebastian Erdweg, Tillmann Rendel, Christian Kästner, and Klaus Ostermann.
Layout-Sensitive Generalized Parsing. In SLE'12.

Layout Constraints:Token Selectors

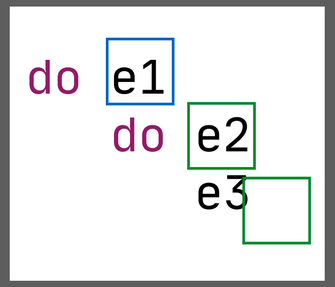


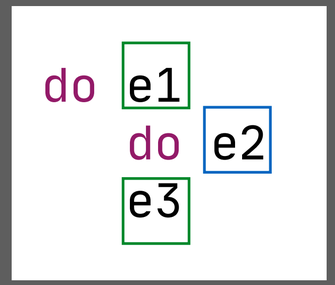

```
lComp = do
  x <- xRange
  return $ do
    y <- yRange
    return (x, y)
```

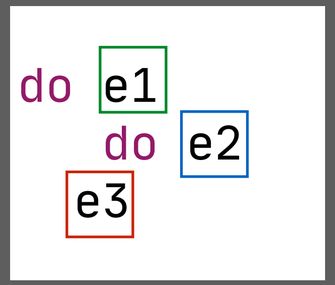
Interpret indentation using shapes around the tokens that belong to a subtree.

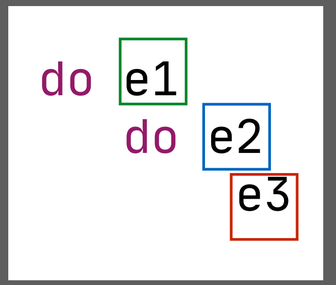
Layout Constraints: Encoding Alignment

```
context-free syntax

  Exp.Do       = "do" ExpList
  ExpList.Cns = Exp
  ExpList.Lst = ExpList Exp {layout(1.first.col == 2.first.col)}
  Exp.Id       = ID
```









Layout Constraints: Encoding Indentation

```
Exp.IfElse = "if" Exp "then" Exp "else" Exp
  {layout(4.first.line > 1.last.line && // then clause in next line
          4.first.col > 1.first.col &&  // and indented
          1.first.col == 5.first.col && // "if" and "else" aligned
          4.first.col == 6.first.col)}  // then and else clauses aligned
```

```
if e1 then
  if e2 then
    e3
  else
    e4
else
  e5
```

Low-level declarations

Layout Declarations

Tree Selectors

```
context-free syntax
  Exp.Do      = "do" ExpList
  ExpList.Cns = Exp
  ExpList.Lst = ExpList Exp {layout(1.first.col == 2.first.col)}
  Exp.Id      = ID
```

```
context-free syntax
  Exp.Do      = "do" ExpList
  ExpList.Cns = Exp
  ExpList.Lst = exps:ExpList exp:Exp {layout(... exps exp)}
  Exp.Id      = ID
```

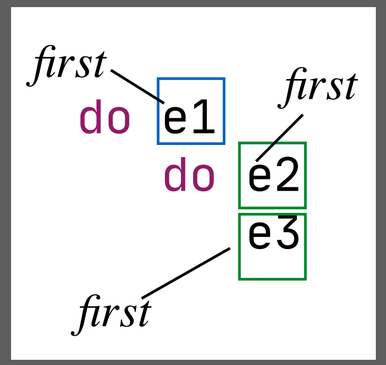
Tree Selectors

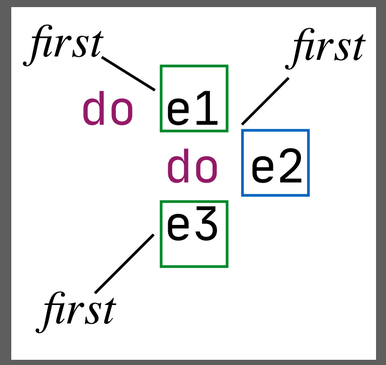
```
context-free syntax
  Exp.Do       = "do" ExpList {layout(2.first.col > 1.first.col)}
  ExpList.Cns = Exp
  ExpList.Lst = ExpList Exp {layout(1.first.col == 2.first.col)}
  Exp.Id       = ID
```

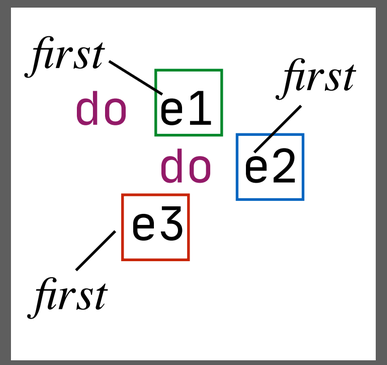
```
context-free syntax
  Exp.Do       = "do" ExpList {layout(... "do" 1)}
  ExpList.Cns = Exp
  ExpList.Lst = exps:ExpList exp:Exp {layout(... exps exp)}
  Exp.Id       = ID
```

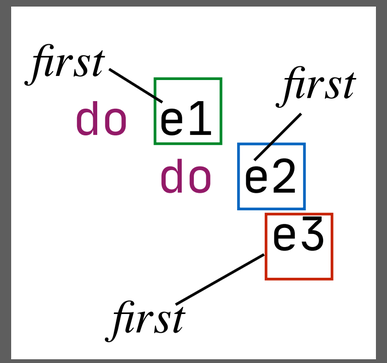
Alignment with Layout Constraints

```
context-free syntax
  Exp.Do       = "do" ExpList
  ExpList.Cns = Exp
  ExpList.Lst = ExpList Exp {layout(1.first.col == 2.first.col)}
  Exp.Id       = ID
```



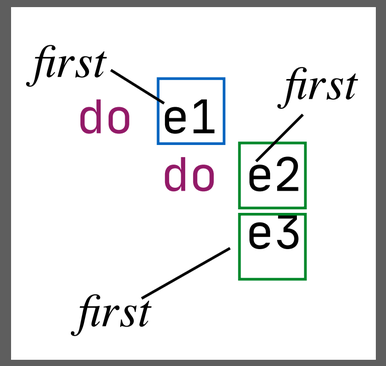


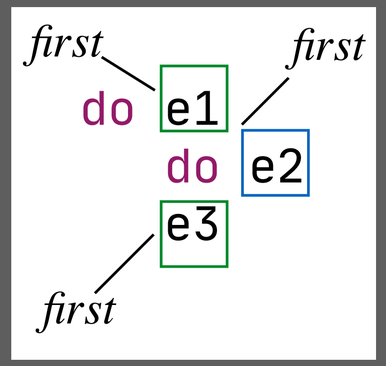


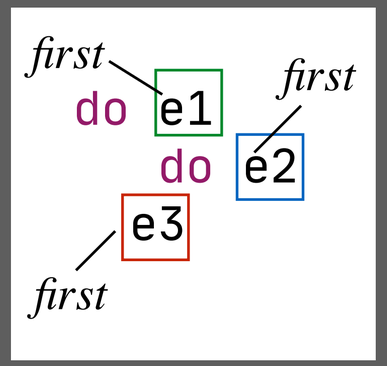


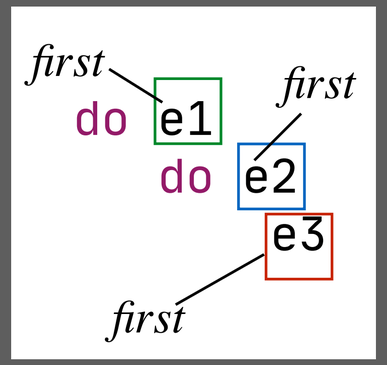
Alignment Declaration

```
context-free syntax
  Exp.Do       = "do" ExpList
  ExpList.Cns = Exp
  ExpList.Lst = exps:ExpList exp:Exp {layout(align exps exp)}
  Exp.Id       = ID
```







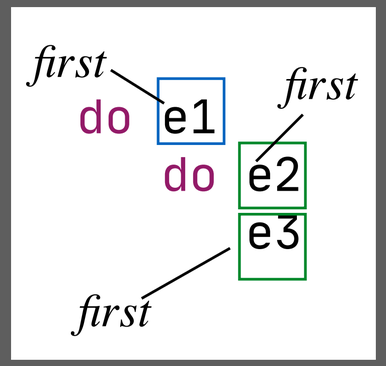


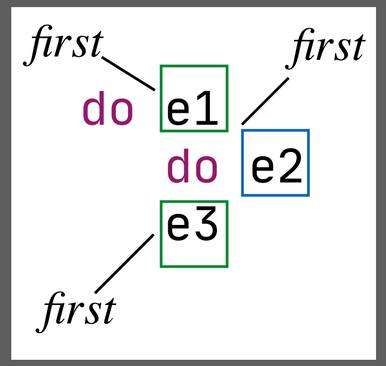
Semantics

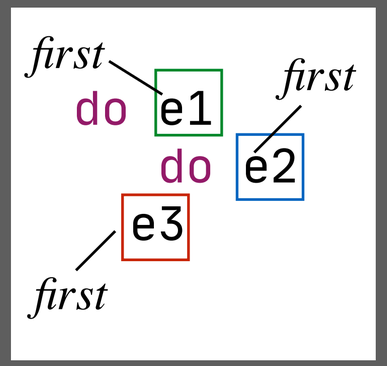
$$\frac{\texttt{x.first.col} = \texttt{y.first.col}}{\texttt{align x y}}$$

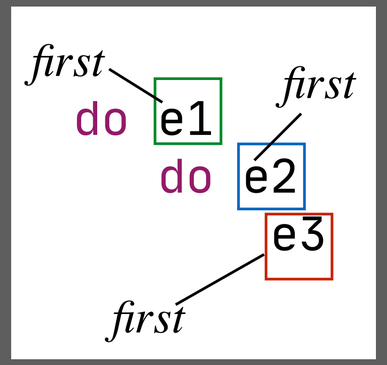
List Alignment Declaration

```
context-free syntax
  Exp.Do  = "do" exps:Exp+ {layout(align-list exps)}
  Exp.Id  = ID
  Exp+    = Exp+ Exp // normalized
  Exp+    = Exp      // productions
```





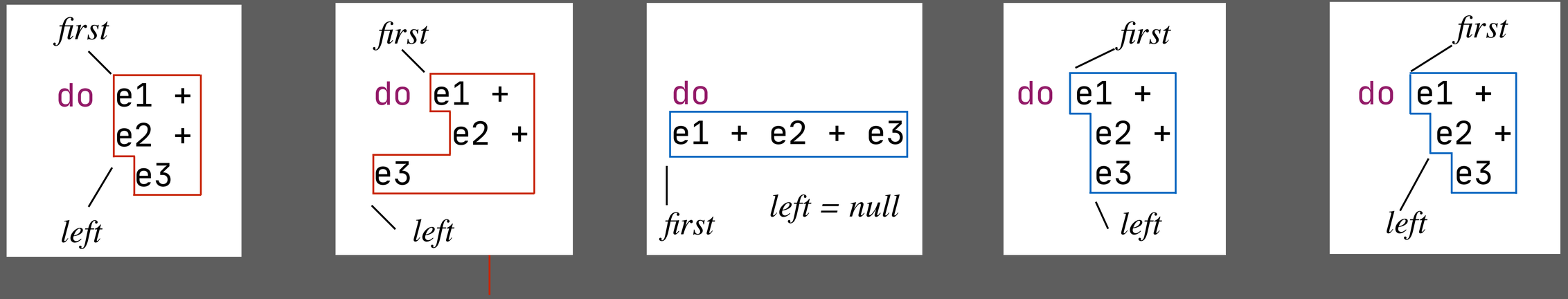




Semantics

$$\frac{\texttt{A+ = A+ A layout(1.first.col == 2.first.col)}}{\texttt{align-list x}}$$

Offside Rule

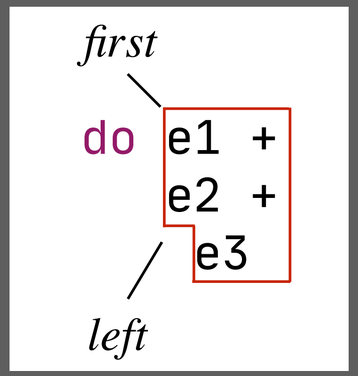


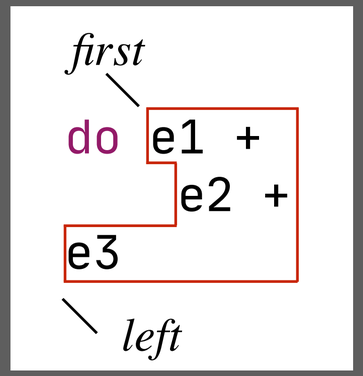
"The offside rule prescribes that all non-whitespace tokens of a structure must be further to the right than the token that starts the structure."

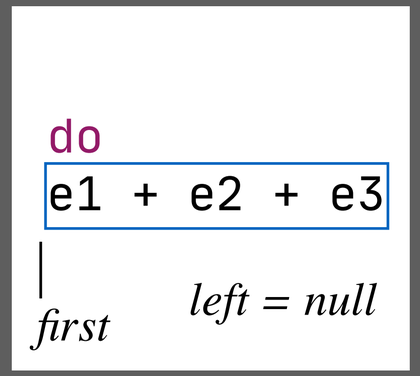
Erdweg et. al.. Layout-Sensitive Generalized Parsing. In SLE'12.

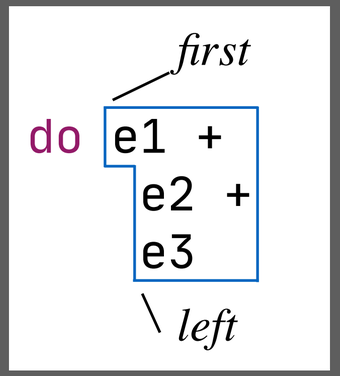
Offside with Layout Constraints

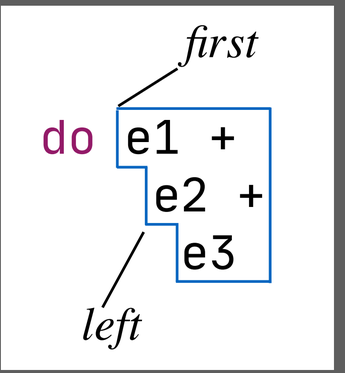
```
context-free syntax
  Exp.Do  = "do" Exp {layout(2.left.col > 2.first.col)}
  Exp.Add = Exp "+" Exp {left}
  Exp.Id  = ID
```





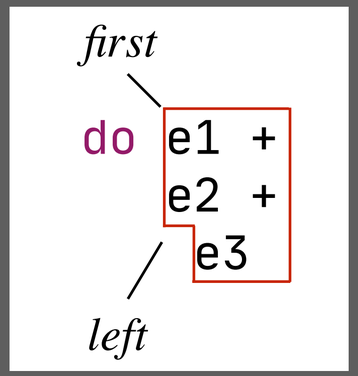


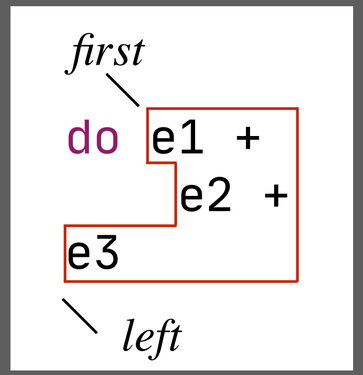


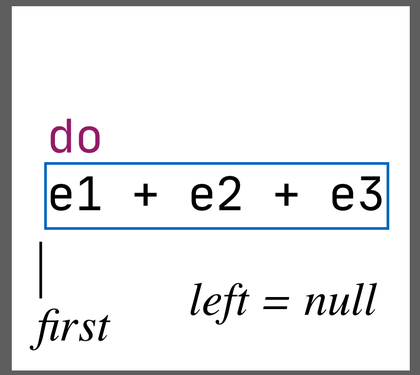


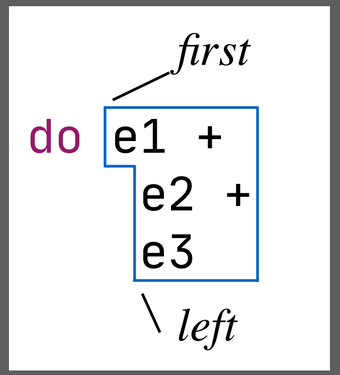
Offside

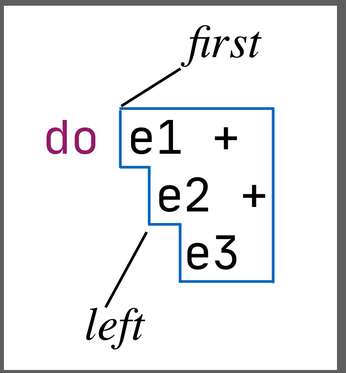
```
context-free syntax
  Exp.Do  = "do" exp:Exp {layout(offside exp)}
  Exp.Add = Exp "+" Exp {left}
  Exp.Id  = ID
```









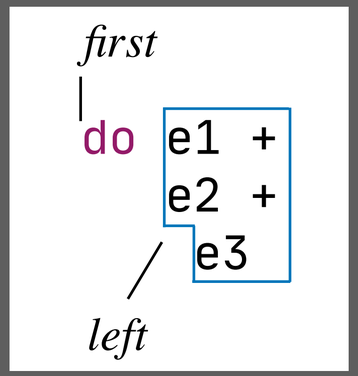


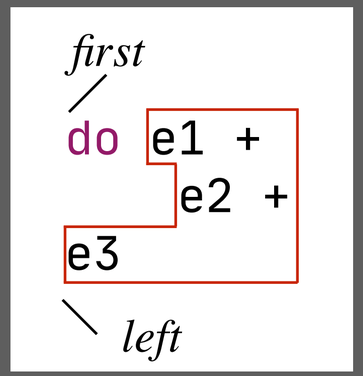
Semantics

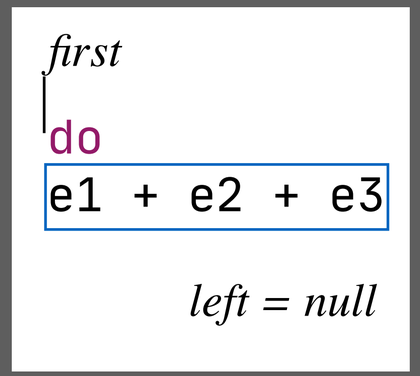
```
x.left.col > x.first.col
-------------------------
      offside x
```

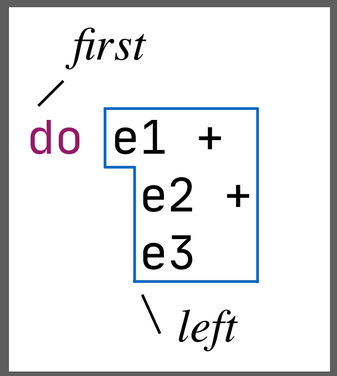
Relative Offside

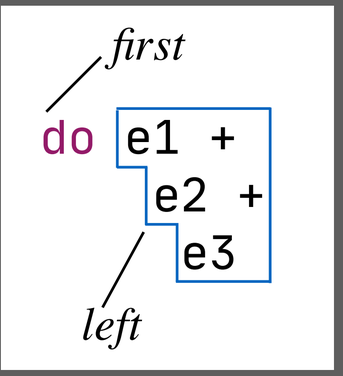
```
context-free syntax
  Exp.Do  = "do" exp:Exp {layout(offside "do" exp)}
  Exp.Add = Exp "+" Exp {left}
  Exp.Id  = ID
```









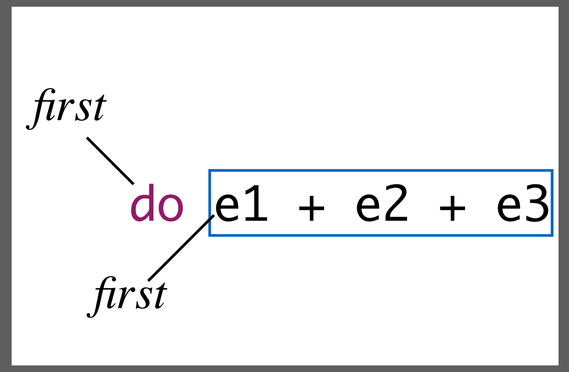


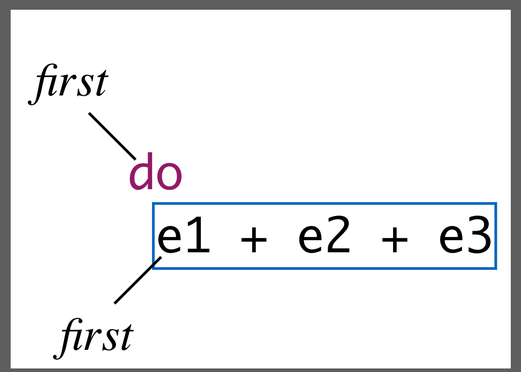
Semantics

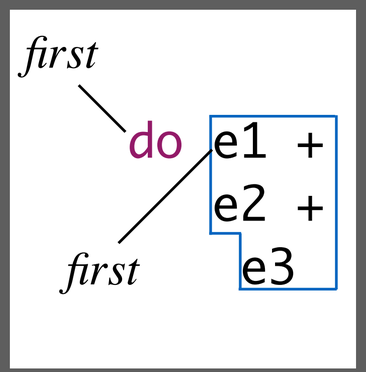
$$\frac{\texttt{y.left.col} > \texttt{x.first.col}}{\texttt{offside x y}}$$

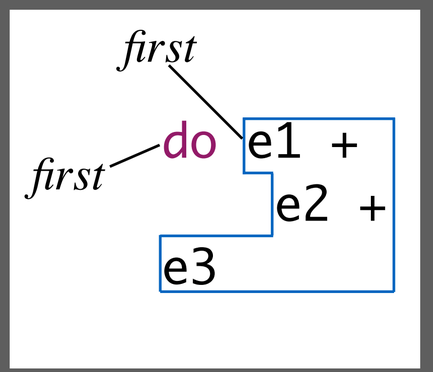
Indentation

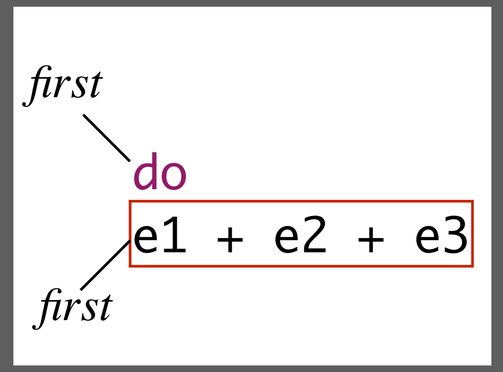
```
context-free syntax
  Exp.Do  = "do" exp:Exp {layout(indent "do" exp)}
  Exp.Add = Exp "+" Exp {left}
  Exp.Id  = ID
```









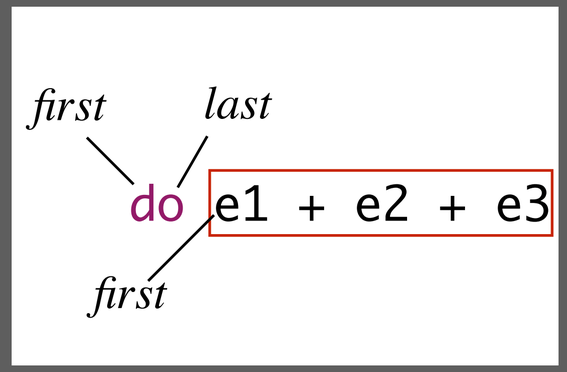


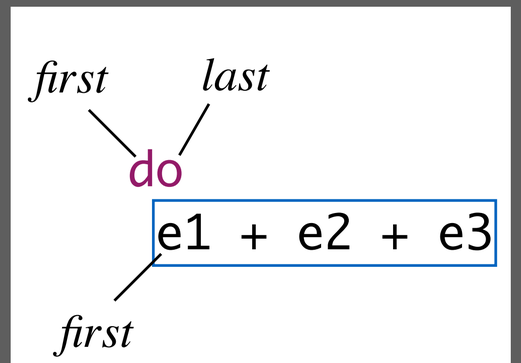
Semantics

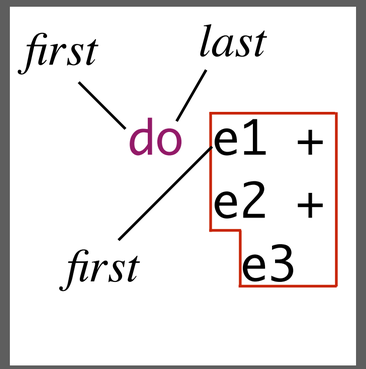
$$\frac{\texttt{y.first.col} > \texttt{x.first.col}}{\texttt{indent x y}}$$

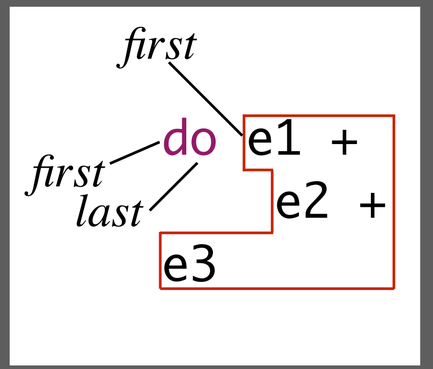
Newline + Indentation

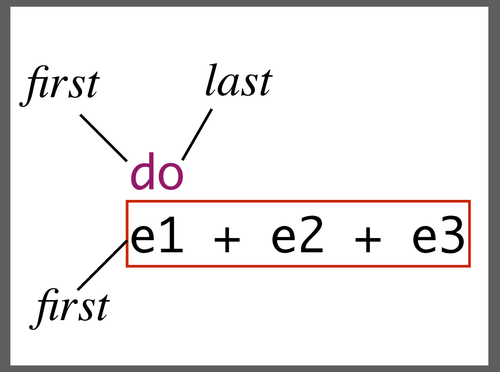
```
context-free syntax
 Exp.Do  = "do" exp:Exp {layout(newline-indent "do" exp)}
  Exp.Add = Exp "+" Exp {left}
  Exp.Id  = ID
```







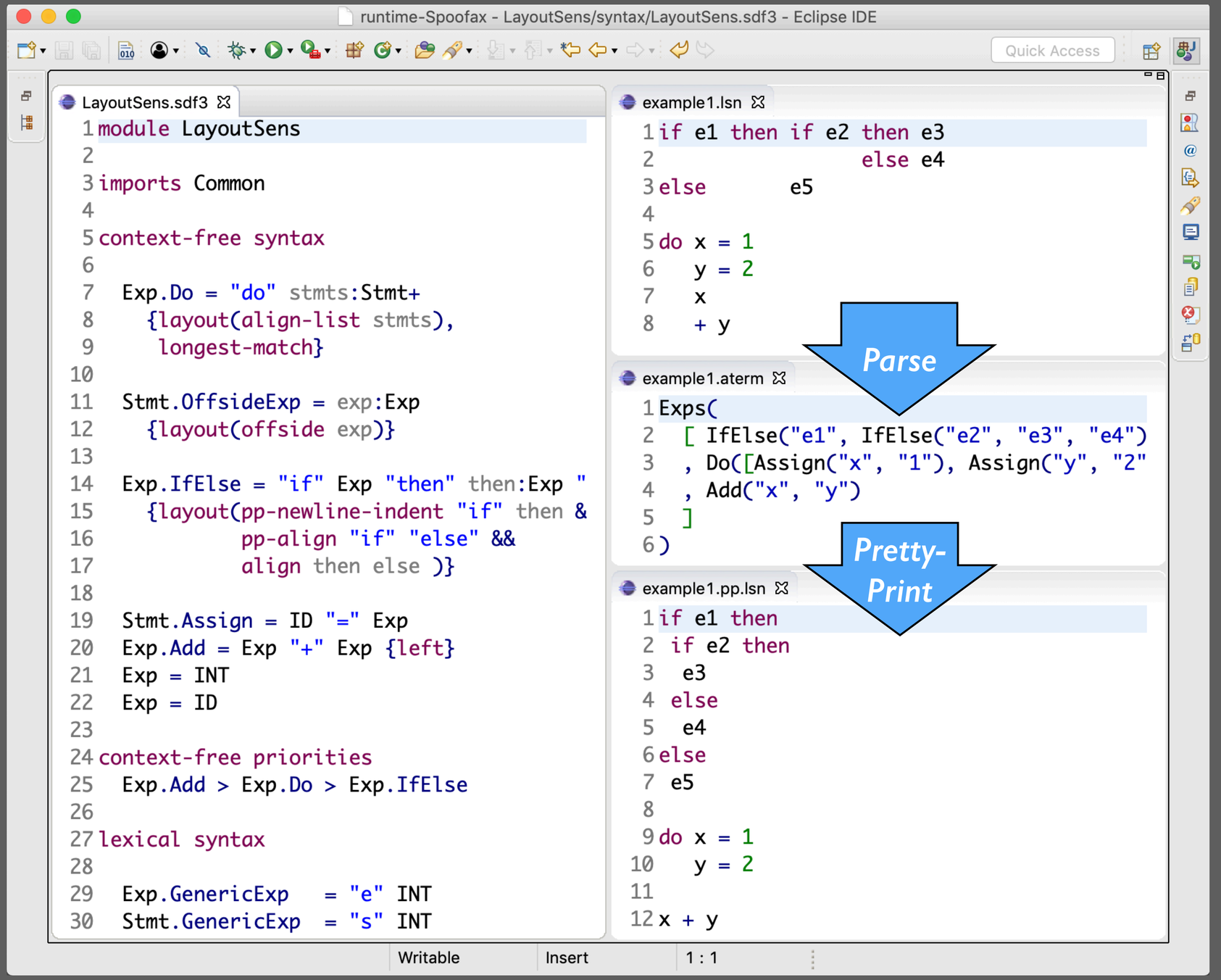




Semantics

$$\frac{\texttt{y.first.col} > \texttt{x.first.col} \;\&\&\; \texttt{y.first.line} > \texttt{x.last.line}}{\texttt{newline-indent x y}}$$

Parsing and Pretty-Printing


runtime-Spoofax - LayoutSens/syntax/LayoutSens.sdf3 - Eclipse IDE
Quick Access
LayoutSens.sdf3
module LayoutSens
imports Common
context-free syntax
Exp.Do = "do" stmts:Stmt+
{layout(align-list stmts),
longest-match}
Stmt.OffsideExp = exp:Exp
{layout(offside exp)}
Stmt.IfElse = "if" Exp "then" then:Exp "
{layout(pp-newline-indent "if" then &
pp-align "if" "else" &&
align then else)}
Stmt.Assign = ID "=" Exp
Exp.Add = Exp "+" Exp {left}
Exp = INT
Exp = ID
context-free priorities
Exp.Add > Exp.Do > Exp.IfElse
lexical syntax
Exp.GenericExp = "e" INT
Stmt.GenericExp = "s" INT
example1.lsn
if e1 then if e2 then e3
else e4
else e5
do x = 1
y = 2
x
+ y
Parse
example1.aterm
Exps(
[IfElse("e1", IfElse("e2", "e3", "e4")
, Do([Assign("x", "1"), Assign("y", "2"
, Add("x", "y")
]
)
Pretty-Print
example1.pp.lsn
if e1 then
if e2 then
e3
else
e4
else
e5
do x = 1
y = 2
x + y
Writable
Insert
1 : 1

{S} spoofax

Reading Material

Introduces layout constraints

https://doi.org/10.1007/978-3-642-36089-3_14

Layout-Sensitive Generalized Parsing

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Abstract. The theory of context-free languages is well-understood and context-free parsers can be used as off-the-shelf tools in practice. In particular, to use a context-free parser framework, a user does not need to understand its internals but can specify a language *declaratively* as a grammar. However, many languages in practice are not context-free. One particularly important class of such languages is layout-sensitive languages, in which the structure of code depends on indentation and whitespace. For example, Python, Haskell, F#, and Markdown use indentation instead of curly braces to determine the block structure of code. Their parsers (and lexers) are not declaratively specified but hand-tuned to account for layout-sensitivity.

To support *declarative* specifications of layout-sensitive languages, we propose a parsing framework in which a user can annotate layout in a grammar. Annotations take the form of constraints on the relative positioning of tokens in the parsed subtrees. For example, a user can declare that a block consists of statements that all start on the same column. We have integrated layout constraints into SDF and implemented a layout-sensitive generalized parser as an extension of generalized LR parsing. We evaluate the correctness and performance of our parser by parsing 33 290 open-source Haskell files. Layout-sensitive generalized parsing is easy to use, and its performance overhead compared to layout-insensitive parsing is small enough for practical application.

1 Introduction

Most computer languages prescribe a textual syntax. A parser translates from such textual representation into a structured one and constitutes the first step in processing a document. Due to the development of parser frameworks such as lex/yacc [15], ANTLR [18,17], PEGs [6,7], parsec [13], or SDF [8], parsers can be considered off-the-shelf tools nowadays: Non-experts can use parsers, because language specifications are declarative. Although many parser frameworks support some form of context-sensitive parsing (such as via semantic predicates in ANTLR [18]), one particularly relevant class of languages is not supported declaratively by any existing parser framework: layout-sensitive languages.

Layout-sensitive languages were proposed by Landin in 1966 [12]. In layout-sensitive languages, the translation from a textual representation to a structural one depends on the code's layout and its indentation. Most prominently, the *off-side rule* prescribes that all non-whitespace tokens of a structure must be further to the right than the token that starts the structure. In other words, a token

K. Czarnecki and G. Hedin (Eds.): SLE 2012, LNCS 7745, pp. 244–263, 2013.

Introduces layout declarations to abstract from low-level layout constraints and pretty-printing based on layout declarations/constraints.

Includes summary of layout constraints

Won distinguished paper award at SLE'18.

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Declarative Specification of Indentation Rules

A Tooling Perspective on Parsing and Pretty-Printing Layout-Sensitive Languages

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Abstract

In layout-sensitive languages, the indentation of an expression or statement can influence how a program is parsed. While some of these languages (e.g., Haskell and Python) have been widely adopted, there is little support for software language engineers in building tools for layout-sensitive languages. As a result, parsers, pretty-printers, program analyses, and refactoring tools often need to be handwritten, which decreases the maintainability and extensibility of these tools. Even state-of-the-art language workbenches have little support for layout-sensitive languages, restricting the development and prototyping of such languages.

In this paper, we introduce a novel approach to declarative specification of layout-sensitive languages using *layout declarations*. Layout declarations are high-level specifications of indentation rules that abstract from low-level technicalities. We show how to derive an efficient layout-sensitive generalized parser and a corresponding pretty-printer automatically from a language specification with layout declarations. We validate our approach in a case-study using a syntax definition for the Haskell programming language, investigating the performance of the generated parser and the correctness of the generated pretty-printer against 22191 Haskell files.

CCS Concepts • **Software and its engineering → Syntax**; *Parsers*;

Keywords parsing, pretty-printing, layout-sensitivity

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1 Introduction

Layout-sensitive (also known as indentation-sensitive) languages were introduced by Landin [17]. The term characterizes languages that must obey certain *indentation rules*, i.e., languages in which the indentation of the code influences how the program should be parsed. In layout-sensitive languages, alignment and indentation are essential to correctly identify the structures of a program. Many modern programming languages including Haskell [11], Python [23], Markdown [14] and YAML [4] are layout-sensitive. To illustrate how layout can influence parsing programs in such languages, consider the Haskell program in Figure 1, which contains multiple *do*-expressions:

```
1 guessValue x = do
2   putStrLn "Enter your guess:"
3   guess <- getLine
4   case compare (read guess) x of
5     EQ -> putStrLn "You won!"
6     _  -> do putStrLn "Keep guessing."
7              guessValue x
```

Figure 1. *Do*-expressions in Haskell.

In Haskell, all statements inside a *do*-block should be aligned (i.e., should start at the same column). In Figure 1, we know that the statement on line 7 (`guessValue x`) belongs to the inner *do*-block solely because of its indentation. If we modify the indentation of this statement, aligning it with the statements in the outer *do*-block, the program would have a different interpretation, looping indefinitely.

Next: Static Analysis and Type Checking