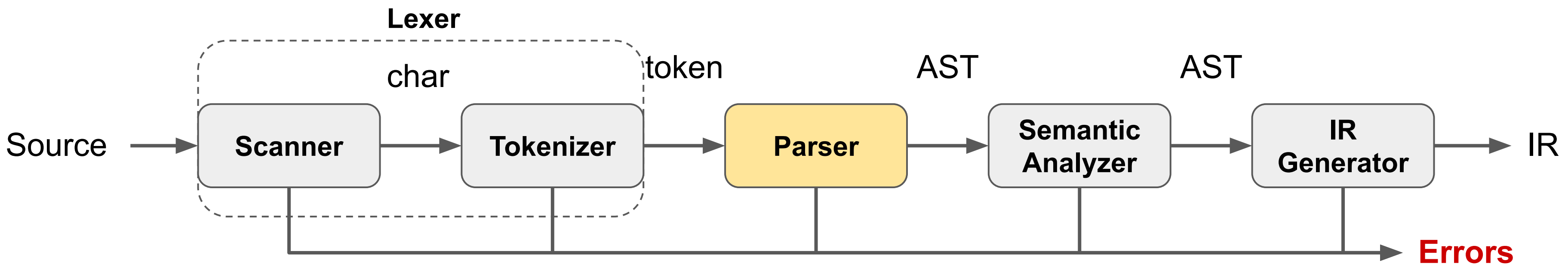
Compiling Techniques

Lecture 8: Abstract Syntax

Where are we?



A parser does more than simply recognize syntax.

In a multi-pass compiler, the parser builds a **syntax tree**, that can either be:

- a concrete syntax tree (aka parser tree) that directly corresponds to the parsers context-free grammar;
- a simplified abstract syntax tree (AST) that abstract some details away.

Example: Concrete Syntax Tree (Parse Tree)

Example: Grammar for arithmetic expressions in EBNF form

```
Expr   ::= Term ( (‘+’ | ‘-’) Term)*
Term   ::= Factor ( (‘*’ | ‘/’) Factor)*
Factor ::= number | ‘(‘ Expr ‘)’
```

Removing EBNF syntax

```
Expr    ::= Term Terms
Terms   ::= (‘+’ | ‘-’) Term Terms | ε
Term    ::= Factor Factors
Factors ::= (‘*’ | ‘/’) Factor Factors | ε
Factor  ::= number | ‘(‘ Expr ‘)’
```

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Expr   ::= Term ( (‘+’ | ‘-’) Term)*
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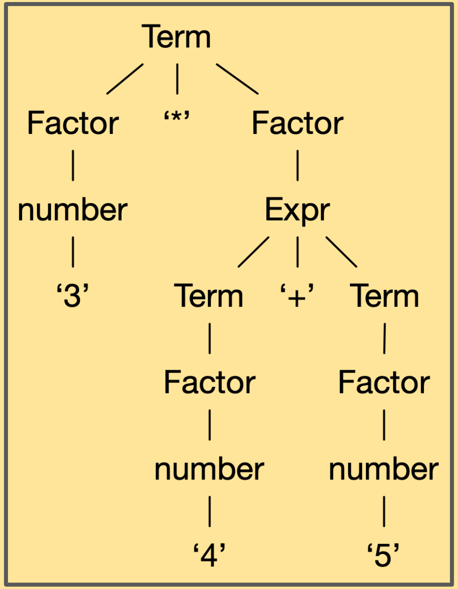
Removing EBNF syntax + simplifications

```
Expr    ::= Term ((‘+’ | ‘-’) Expr | ε)
Term    ::= Factor ((‘*’ | ‘/’) Term | ε)
Factor  ::= number | ‘(‘ Expr ‘)’
```

Example: Concrete Syntax Tree (Parse Tree)

Concrete Syntax Tree for
3 * (4 + 5)



Grammar for arithmetic expression

```
Expr    ::= Term ((‘+’ | ‘-’) Expr | ε)
Term    ::= Factor ((‘*’ | ‘/’) Term | ε)
Factor  ::= number | ‘(‘ Expr ‘)’
```

The concrete syntax tree contains a lot of unnecessary information!

It is possible to simplify the tree by removing redundant information.

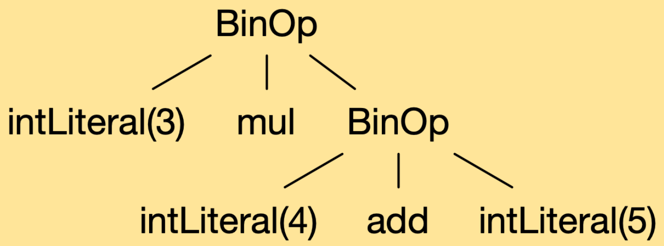
Abstract Grammar

The simplifications lead to a new simpler context-free grammar called Abstract Grammar

Example: Abstract grammar for arithmetic expressions

```
Expr   ::= BinOp | intLiteral
BinOp  ::= Expr Op Expr
Op     ::= add | sub | mul | div
```

***Abstract Syntax Tree* `for 3 * (4 + 5):`**



Choice of Abstract Grammar

For a given concrete grammar, there exists numerous abstract grammars.

We pick the most suitable grammar for the compiler.

Example: Abstract grammar for arithmetic expressions

```
Expr   ::= BinOp | intLiteral
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Op     ::= add | sub | mul | div
```

Alternative abstract grammar for arithmetic expressions

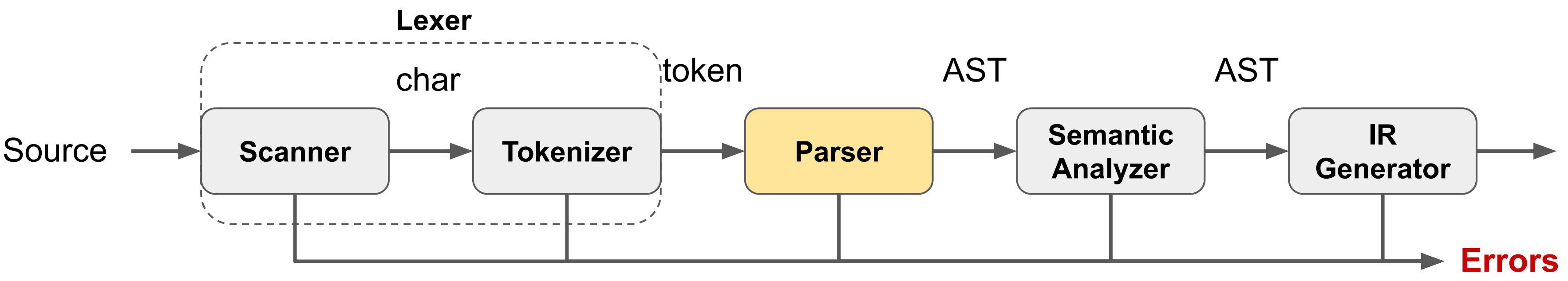
```
Expr   ::= AddOp | SubOp | MulOp | DivOp | intLiteral
AddOp  ::= Expr add Expr
SubOp  ::= Expr add Expr
MulOp  ::= Expr add Expr
DivOp  ::= Expr add Expr
```

Abstract Syntax Tree

The Abstract Syntax Tree (AST) forms the main intermediate representation of the compiler's front-end.

We will perform Semantic Analysis on this representation, that is:

- Name analysis (are all names declared before they are used?)
- Type checking



Implementation of the AST

The AST can be implemented like any other tree data structure

```
class Expr(ABC):
    pass

@dataclass
class BinOp(Expr):
    lhs: Expr
    op: str
    rhs: Expr

@dataclass
class IntLiteral(Expr):
    value: int
```

Abstract grammar

```
Expr    ::= BinOp | intLiteral
BinOp   ::= Expr Op Expr
Op      ::= add | sub | mul | div
```

Op should better be implemented as an `Enum`

```
BinOp(IntLiteral(3), "*", BinOp(IntLiteral(4), "+", IntLiteral(5)))
```

xDSL and MLIR

In this class, we use a framework to help us to implement our compiler.

This framework is called `xDSL`. It implements the same concepts that are found in the **MLIR - Multi-Level IR Compiler Framework** that is used in industry.

We will introduce new concepts of the framework as we go along.

Today we discuss how to represent ASTs with xDSL.

https://github.com/xdslproject/xdsl/ https://mlir.llvm.org/

Implementation of the AST with xDSL

`xDSL` helps us to easily define intermediate representations (such as our AST).

Here is the definition of our small AST.

```
@irdl_op_definition
class BinOp(Operation):
    name = "BinOp"
    op: OpAttr[StringAttr]
    lhs: SingleBlockRegion
    rhs: SingleBlockRegion

@irdl_op_definition
class IntLiteral(Operation):
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A `region` represents nested structure, such as the children of a node in the AST

A *macro* generates helpful boilerplate code to make printing, testing, etc. easy

Creating Operations with xDSL

xDSL provides a generic and flexible (but verbose) interface to create Operations:

```
node = Op.create(attributes={"key": value}, regions=[...])
```

We can easily hide the boilerplate, for example for `IntLiteral`:

```
class IntLiteral(Operation):
    @staticmethod
    def get(value: int) -> IntLiteral:
        return IntLiteral.create(attributes={
            "value": IntegerAttr.from_int_and_width(value, 32)})
```

This allows us to write:

```
BinOp.get(IntLiteral.get(3), "*",
          BinOp.get(IntLiteral.get(4), "+", IntLiteral.get(5)))
```

First Benefits of using xDSL

Using a framework like xDSL has many benefits.
For example, can we easily debug and print our created AST:

```
>>> xdsl.printer.Printer().print_op(
     BinOp.get(IntLiteral.get(3), "*",
               BinOp.get(IntLiteral.get(4), "+", IntLiteral.get(5))) )

BinOp() ["op" = "*"] {
  IntLiteral() ["value" = 3 : !i32]
} {
  BinOp() ["op" = "+"] {
     IntLiteral() ["value" = 4 : !i32]
  } {
     IntLiteral() ["value" = 5 : !i32]
  }
}
```

ChocoPy AST in xDSL – `Operations`

The CW1 template provides an implementation of the ChocoPy AST in xDSL which defines the following 22 `Operations`:

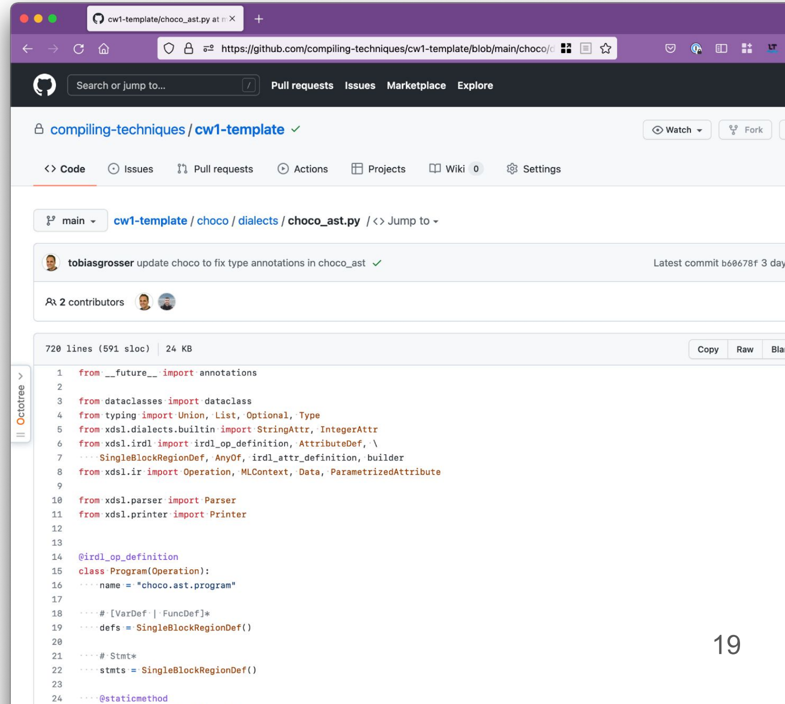
```
Program

TypeName, ListType, TypedVar

FuncDef, GlobalDecl, NonLocalDecl, VarDef

If, While, For, Pass, Return, Assign

Literal, ExprName, UnaryExpr, BinaryExpr,
IfExpr, ListExpr, CallExpr, IndexExpr
```



ChocoPy AST in xDSL – `Attributes`

An **`Attribute`** represents some compile-time metadata of an `Operation`

Examples of `Attributes` in the ChocoPy AST are:

- Names, such as the names of functions, variables, or types
- Literal values, e.g. `4`, “`Hello`”, or `True`
- Operator of binary and unary operations, e.g. `+`, `-`, `/`, `==`, `!=`, …

To represent this different metadata, we use these 4 types of Attributes:

`StringAttr, IntegerAttr, BoolAttr, NoneAttr`

The `NoneAttr` represents the **`None`** value of ChocoPy.

ChocoPy AST in xDSL – `Regions`

We use **`Regions`** to represent nesting.

E.g. `BinaryExpr` has two regions, one for each Operand:

```
BinaryExpr() ["op" = "+"] {
    Literal() ["value" = 4 : !i32]
} {
    Literal() ["value" = 5 : !i32]
}
```

Regions can have more than one `Operation` in them!

Consider for example the `If` Statement:

```
If() {
  Literal() ["value" = !bool<True>]
} {
  Literal() ["value" = 4 : !i32]
  Literal() ["value" = 8 : !i32]
} {
  Literal() ["value" = 15 : !i32]
  Literal() ["value" = 16 : !i32]
}
```

The second region represents the `then`-block, the third region the `else`-block.