

Semantic Analysis Phases of Compilation

- Build an Abstract Syntax Tree (AST) while parsing
- Decorate the AST with type information (type checking/inference)
- Generate intermediate code from AST
- Optimize intermediate code
- Generate final code

Abstract Syntax Tree (AST)

Represents the syntactic structure of the input program, independent of peculiarities in the grammar.

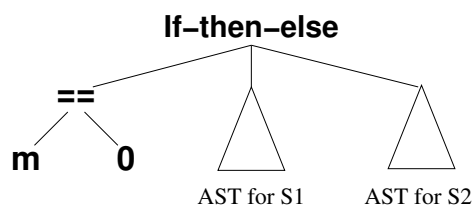
An Example:

Consider a statement of the form:

“if (m == 0) S1 else S2”

where S1 and S2 stand for some block of statements.

A possible AST for this statement is:

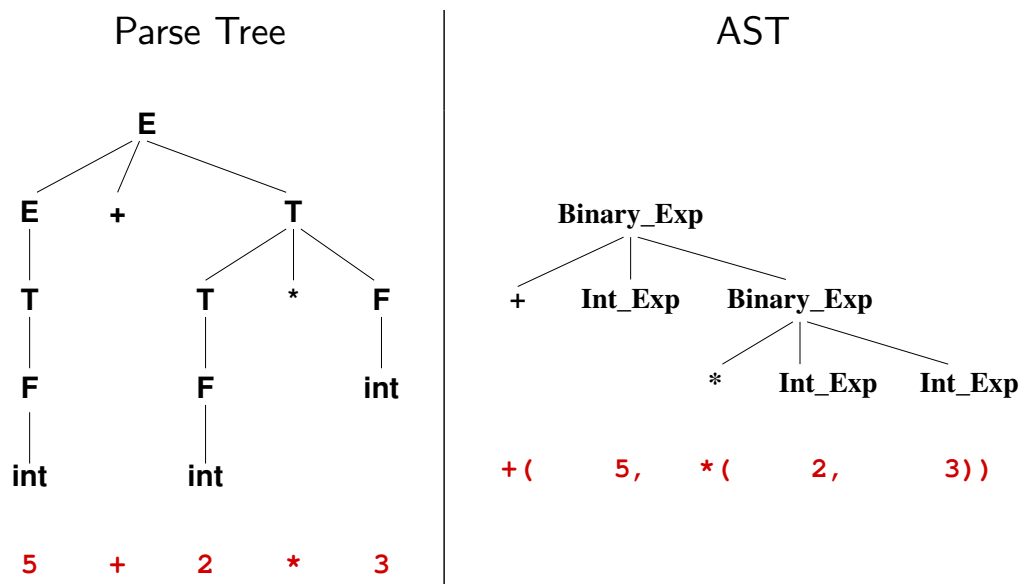


Construction of Abstract Syntax Trees

Typically done simultaneously with parsing

- ... as another instance of syntax-directed translation
- ... for translating *concrete* syntax (the parse tree) to *abstract* syntax (AST).
- ... with AST as a *synthesized attribute* of each grammar symbol.

Abstract Syntax Trees



Trees & Tree Grammars

Tree grammars can be used to specify a set of **trees**.

Example 1: The set of trees $\{a, f(a), f(f(a)), f(f(f(a))), \dots\}$ can be represented by the grammar:

$$\begin{aligned} T &\longrightarrow a \\ T &\longrightarrow f(T) \end{aligned}$$

Example 2: The set of trees $\{b, g(b, b), g(g(b, b), b), g(b, g(b, b)), \dots\}$ can be represented by:

$$\begin{aligned} S &\longrightarrow b \\ S &\longrightarrow g(S, S) \end{aligned}$$

AST & Tree Grammars

The set of AST's that represent the set of (syntactically correct) programs can be described by tree grammars.

```
Expression  ::  INT_EXPR(Int_val)
              |  FLOAT_EXPR(float_val)
              |  :
              |  METHOD_EXPR(Expression, Expression*)
              |  ARRAY_EXPR(Expression, Expression)
              |  FIELD_EXPR(Expression, Name)
              |  BINARY_EXPR(BinaryOp, Expression, Expression)
              |  UNARY_EXPR(UnaryOp, Expression)
              |  :
```

Actions and AST

$$\begin{array}{lll} E & \longrightarrow & E_1 + T \quad \{ E.\text{ast} = \text{BINARY_EXPR}(\text{PLUS}, E_1.\text{ast}, T.\text{ast}) \} \\ E & \longrightarrow & T \quad \{ E.\text{ast} = T.\text{ast}; \} \\ & \vdots & \\ F & \longrightarrow & (E) \quad \{ F.\text{ast} = E.\text{ast}; \} \\ F & \longrightarrow & \text{int} \quad \{ F.\text{ast} = \text{INT_EXPR}(\text{int.val}; \} \end{array}$$

Actions and AST: Another Example

$$\begin{array}{lll} S & \longrightarrow & \text{if } E \text{ } S_1 \text{ else } S_2 \\ & & \{ S.\text{ast} = \text{IF_STMT}(E.\text{ast}, S_1.\text{ast}, S_2.\text{ast}) \} \\ S & \longrightarrow & \text{return } E \quad \{ S.\text{ast} = \text{RETURN_STMT}(E.\text{ast}) \} \end{array}$$

Physical Representation of Trees

In C, trees can be built using *variant records* (e.g., structs and unions).

Example: The set of trees described by

$$S \longrightarrow g(S, S)$$
$$S \longrightarrow h(T)$$

can be implemented as:

```
typedef enum { G, H} S_node_kind;
struct S_node {
    S_node_kind kind;
    union {
        struct S_g {
            struct S_node *g_child1;
            struct S_node *g_child2;
        } g;
        struct T_node *h_child;
    } children;
};
```

C Implementation of AST Construction

$$\begin{aligned} S &\longrightarrow \text{if } E \text{ } S_1 \text{ else } S_2 && \{ S.\text{ast} = \text{IF_STMT}(E.\text{ast}, S_1.\text{ast}, S_2.\text{ast}) \} \\ S &\longrightarrow \text{return } E && \{ S.\text{ast} = \text{RETURN_STMT}(E.\text{ast}) \} \end{aligned}$$

$$\begin{aligned} S &\longrightarrow \text{if } E \text{ } S_1 \text{ else } S_2 && \{ S.\text{ast} = \text{malloc}(\text{sizeof}(\text{struct Statement})); \\ &&& \quad S.\text{ast}.\text{stmt}.\text{kind} = \text{IF}; \\ &&& \quad S.\text{ast}.\text{stmt}.\text{ifstmt}.\text{expr} = E.\text{ast}; \\ &&& \quad S.\text{ast}.\text{stmt}.\text{ifstmt}.\text{then} = S_1.\text{ast}; \\ &&& \quad S.\text{ast}.\text{stmt}.\text{ifstmt}.\text{else} = S_2.\text{ast}; \} \\ S &\longrightarrow \text{return } E && \{ S.\text{ast} = \text{new_ast_node}(\text{Statement}); \\ &&& \quad S.\text{ast}.\text{stmt}.\text{kind} = \text{RETURN}; \\ &&& \quad S.\text{ast}.\text{stmt}.\text{return}.\text{expr} = E.\text{ast} \} \end{aligned}$$

Tree Data Structures in OOP languages

The tree will be a base class, and each tree constructor will be a derived class.

$S \longrightarrow b$		class S {...}; // abstract base class
$S \longrightarrow g(S, S)$		class S_b: public S {...}; //derived classes
$S \longrightarrow h(T)$		class S_g: public S {
		public:
		S *g_1;
		S *g_2;
		...
		}
		class S_h: public S {
		public:
		T *h;
		...
		}

C++ Implementation of AST Construction

$S \longrightarrow$	if E S_1 else S_2
	{ $S.ast = IF_STMT(E.ast, S_1.ast, S_2.ast) \}$
$S \longrightarrow$	return E
	{ $S.ast = RETURN_STMT(E.ast) \}$

$S \longrightarrow$	if E S_1 else S_2
	{ $S.ast = new IF_Statement(E.ast, S_1.ast, S_2.ast); \}$
	// In constructor for IF_Statement(e, s1, s2):
	// where e, s1, s2 are all of type AST*
	// this.expr = e1;
	// this.then_part = s1; this.else_part = s2;
$S \longrightarrow$	return E
	{ $S.ast = new RETURN_Statement(E.ast); \}$