Context-Sensitive Analysis

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Outline

1. Motivation
2. Attribute Grammar
Can CFG see what wrong is here?

```latex
m_A_member1 : Int ← "a_string";
```
Motivation

Recap

Can CFG see what wrong is here?

\[
m_{A\_member1} : \text{Int} \leftarrow "a\_string";
\]

Let us try...
Recap (Cont.)

Then which level does this problem exist?
- Lexcial?
- Syntax?
- Semantic?
Recap (Cont.)

Conclusion

- CFG cannot interpret what a parsing result (e.g. a parse tree) means.
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- CFG cannot interpret what a parsing result (e.g. a parse tree) means.
- Semantic analysis judges whether the syntax structure of a program makes sense in terms of its meaning.
What should we check in a semantic analysis? (not a thorough list)
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- Type.
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- Type.
- Scope.
Some typical semantic errors:
Recap (Cont.)

Some typical semantic errors:

- Type mismatch.
Recap (Cont.)

Some typical semantic errors:
- Type mismatch.
- Undeclared variable.
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- Type mismatch.
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- Reserved identifier misuse.
Recap (Cont.)

Some typical semantic errors:

- Type mismatch.
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- Multiple declaration of variable in a scope.
Recap (Cont.)

Some typical semantic errors:

- Type mismatch.
- Undeclared variable.
- Reserved identifier misuse.
- Multiple declaration of variable in a scope.
- Accessing an out of scope variable.
Recap (Cont.)

Some typical semantic errors:

- Type mismatch.
- Undeclared variable.
- Reserved identifier misuse.
- Multiple declaration of variable in a scope.
- Accessing an out of scope variable.
- Actual and formal parameter mismatch.
How do we do semantic analysis?
Question

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Answer

One way to do it is to utilize attribute grammars.
Attribute Grammar  An **attribute grammar** consists of a context-free grammar augmented by a set of rules that specify computations.
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Attribute Grammar

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**Synthesized Attribute** An attribute defined wholly in terms of the attributes of the node, its children, and constants. They are used or passing information downwards in the tree.

**Inherited Attribute** An attribute defined wholly in terms of the nodes own attributes and those of its siblings or its parent in the parse tree (plus constants). They are used to pass information upwards.
Ingredients

An attribute grammar consists of:

- A underlying context-free grammar.
- A description of which nonterminals have which attributes (synthesized or inherited).
- For each production, a description how to compute the inherited attributes of the non-terminals in the RHS.
- Synthesized attributes of the non-terminal at the LHS.
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  - Inherited attributes of the non-terminals in the RHS.
  - Synthesized attributes of the non-terminal at the LHS.
Examples

An example of synthesized attributes and how to do the evaluation:

```
<table>
<thead>
<tr>
<th>PRODUCTION</th>
<th>SEMANTIC RULE</th>
</tr>
</thead>
<tbody>
<tr>
<td>L → En</td>
<td>print(E.val)</td>
</tr>
<tr>
<td>E → E₁ + T</td>
<td>E.val := E₁.val + T.val</td>
</tr>
<tr>
<td>E → T</td>
<td>E.val := T.val</td>
</tr>
<tr>
<td>T → T₁ * F</td>
<td>T.val := T₁.val * F.val</td>
</tr>
<tr>
<td>T → F</td>
<td>T.val := F.val</td>
</tr>
<tr>
<td>F → (E)</td>
<td>F.val := E.val</td>
</tr>
<tr>
<td>F → digit</td>
<td>F.val := digit.lexval</td>
</tr>
</tbody>
</table>
```

Figure 1: $3 \times 5 + 4n$. 

E.val = 19
T.val = 15 + T.val
T.val = 15 * F.val
T.val = 3 * F.val
F.val = 5 digit.lexval = 4
digit.lexval = 3
An example of inherited attributes and how to do the evaluation:

<table>
<thead>
<tr>
<th>PRODUCTION</th>
<th>SEMANTIC RULE</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D \rightarrow TL$</td>
<td>$L.in := T.type$</td>
</tr>
<tr>
<td>$T \rightarrow int$</td>
<td>$T.type := integer$</td>
</tr>
<tr>
<td>$T \rightarrow real$</td>
<td>$T.type := real$</td>
</tr>
<tr>
<td>$L \rightarrow L_1, id$</td>
<td>$L_1.in := L.in; \ addtype(id.entry, L.in)$</td>
</tr>
<tr>
<td>$L \rightarrow id$</td>
<td>$addtype(id.entry, L.in)$</td>
</tr>
</tbody>
</table>

**Figure 2:** real $id_1$, $id_2$, $id_3$.```
Evaluation

Goal

Each attribute value must be available when a computation is performed.
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How?
Dependency graphs for representing attribute dependencies, and topological sort for obtaining the evaluation order.
Dependency Graph  A dependency graph shows the interdependencies among the attributes of the various nodes of a parse-tree.

- A node for each attribute.
- An attribute $b$ depending on another attribute $c$ is denoted by $b \leftarrow c$. 
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- An attribute \( b \) depending on another attribute \( c \) is denoted by \( b \leftarrow c \).

**Topological Sort** Any ordering \( s_1, \ldots, s_k \) such that if \( s_i \leftarrow s_j \) is a link in the dependency graph then \( s_i > s_j \).
Examples

Can you draw the dependency graphs for the previous two examples?
Evaluation (Cont.)

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Something Real

Let us check out a real example for our project.