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Programming Languages & Paradigms
PROP HT 2011

Lecture 2

Parsing, Names, Binding, Scope

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Why is it important to know how compilers work?

- To enhance understanding of programming languages
- To write better (more efficient) code in a high-level languages
- To learn techniques that can be useful also in other situations

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Different Approaches

- Compiled
- Interpreted
- Hybrid
- JIT-compiled
- Line-By-Line
- …

All of the above still need lexical analysis and syntactical analysis

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Semantics

Static Semantics (?)

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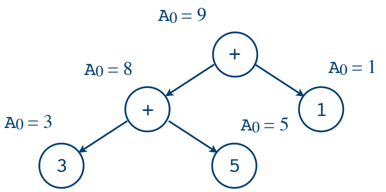
- Static semantics is used to describe properties that syntactically valid programs also must have to be semantically valid, e.g. that they are type correct
  - really more related to legal forms of programs rather than meaning
  - some cannot be described by BNF, some just very verbose
  - attribute grammars -- add to CFG by carrying some semantic information along inside parse tree nodes

`Attribute tree:`



Dynamic Semantics

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- Dynamic semantics is used to describe how the meaning of valid programs should be interpreted
- No single widely acceptable notation or formalism
- Three common (but not the only) approaches:
  - Operational
  - Denotational
  - Axiomatic

Dynamic Semantics - Operational

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- Operational semantics
  - The meaning of a statement defined by describing the effect of running it on a machine
  - Change in the state of the machine defines the meaning of the statement
  - $\langle e, \sigma \rangle \rightarrow v$ if the expression *e* is evaluated or executed starting in the state σ, the resulting computation terminates and yields the result v

    $a ::= n \mid X \mid a_0 + a_1 \mid a_0 - a_1 \mid a_0 * a_1$

$$\frac{\langle a_0, \sigma \rangle \rightarrow n_0 \quad \langle a_1, \sigma \rangle \rightarrow n_1}{\langle a_0 + a_1, \sigma \rangle \rightarrow n}$$

where n is the sum of n_0 and n_1

Dynamic Semantics - Operational

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- Advantages:
  - May be simple, intuitive for small examples
  - Good if used informally
  - Useful for implementation
- Disadvantages
  - Very complex for large programs
  - Lacks mathematical rigour
- Uses:
  - Compiler work

Dynamic Semantics - Denotational

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- Denotational semantics
  - Mathematical denotation of the meaning of the program (typically, a function)
  - The most abstract semantics description method
  - Define a function that maps a program (a syntactic object) to its meaning (a semantic object)
  - Facilitates reasoning about the program, but not always easy to find suitable semantic domains

$$[[e]] : \text{States} \rightarrow Values \quad [[e]](\sigma) = v$$
$$A[[a]]: \Sigma \rightarrow N$$

$$[[n]] = \{(\sigma, n) | \sigma \in \Sigma\}$$
$$[[X]] = \{(\sigma, \sigma(X)) | \sigma \in \Sigma\}$$
$$[[a_0 + a_1]] = \{(\sigma, n_0 + n_1) | (\sigma, n_0) \in A[[a_0]] \& (\sigma, n_1) \in A[[a_1]]$$

Ada

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Denotational vs. Operational

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- Denotational semantics is similar to high-level operational semantics, except:
  - Machine is gone
  - Language is mathematics (lambda calculus)

- The difference between denotational and operational semantics:
  - In operational semantics, the state changes are defined by coded algorithms for a virtual machine
  - In denotational semantics, they are defined by rigorous mathematical functions

Dynamic Semantics - Denotational

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- Advantages:
  - Compact & precise, with solid mathematical foundation
  - Can be used to prove the correctness of programs
  - Can be an aid to language design
- Disadvantages
  - Requires mathematical sophistication
  - Hard for programmer to use
- Uses
  - Compiler generation and optimization

Dynamic Semantics - Axiomatic

- Axiomatic semantics
  - Based on formal logic
  - Originally used for formal program verification
  - Define axioms or inference rules for each statement type in the language
  - The inference rules allows transformation of expressions to other expressions
  - The expressions (assertions) state the relationships and constraints among variables that are true at a specific point in execution

Dynamic Semantics

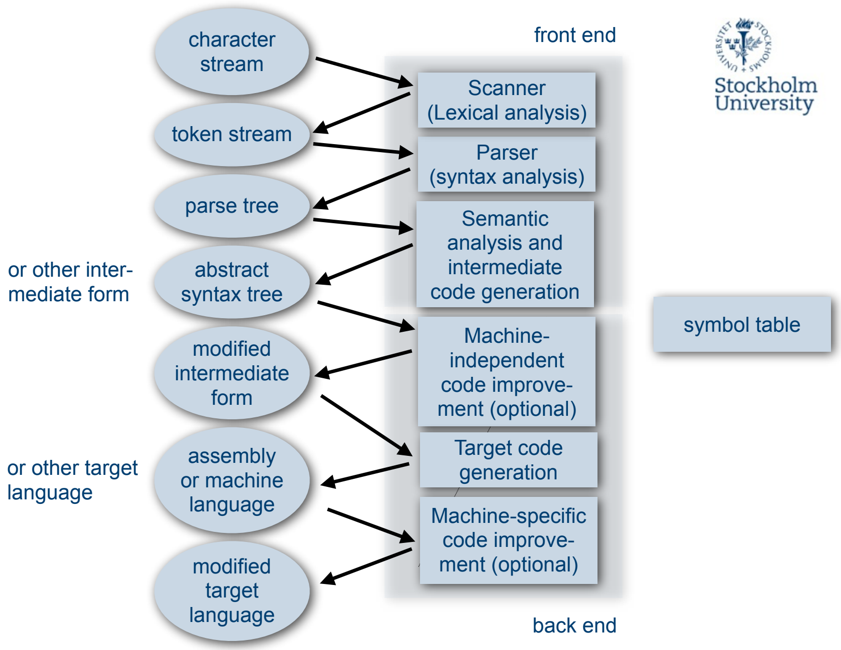
- Each form of semantic description has its place:

- Operational
  - Informal descriptions
  - Compiler work
- Denotational
  - Formal definitions
  - Provably correct implementations
- Axiomatic
  - Reasoning about particular properties
  - Proofs of correctness

Dynamic Semantics - Axiomatic

- Advantages
  - May be useful in proofs of correctness
  - Solid theoretical foundations
- Disadvantages
  - Predicate transformers are hard to define
  - Hard to give complete meaning
  - Does not suggest implementation
- Uses of Axiomatic Semantics
  - Reasoning about correctness

Back to "Reality"



Parsing (Syntactical Analysis)

Parsing

- What is parsing?
  - Check if the input program is correct
  - Produce parse tree or error messages
- Two major approaches
  - Top-down parsing
  - Bottom-up parsing
- Won't work on all context-free grammars
  - Properties of grammar determine parse-ability
  - We may be able to transform a grammar

Top-Down Parsing

Top-Down Parsers -- LL(1), recursive descent

- Start with the root of the parse tree grow toward leaves
  - Root of the tree: node labeled with the start symbol
- Algorithm:
  - Repeat until the fringe of the parse tree matches input string
  - At a node A, select a production for A
    - Add a child node for each symbol on rhs
  - If a terminal symbol is added that doesn't match, backtrack
  - Find the next node to be expanded (a non-terminal)
- Done when:
  - Leaves of parse tree match input string (success)
  - All productions exhausted in backtracking (failure)

Algol family


```
Grammar:
S   ::= abc | aSQ
bQc ::= bbcc
cQ  ::= Qc
```

```
Input string:
aabbcc
```


```
Grammar:
S   ::= abc | aSQ
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Input string:
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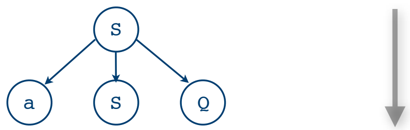

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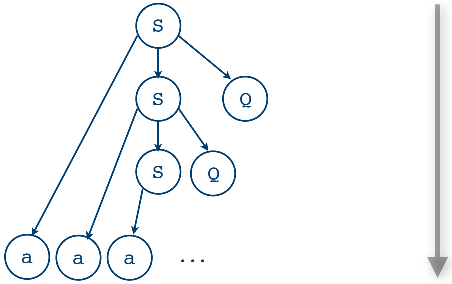

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Grammar:

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Input string:

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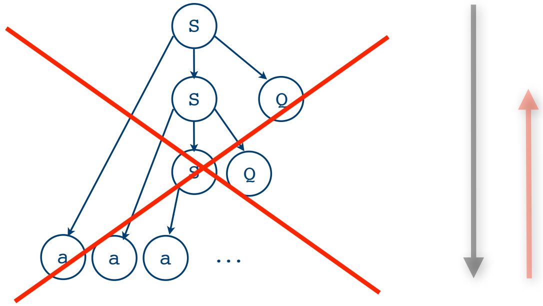

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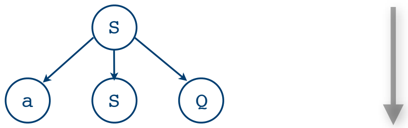

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Grammar:

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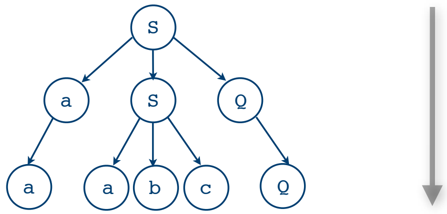
Input string:

aabbcc



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Input string:

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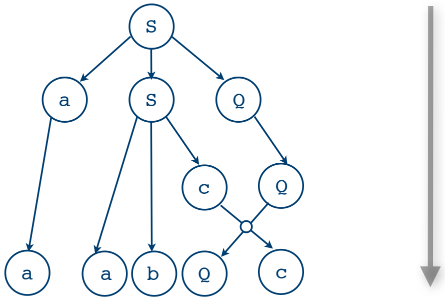


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S   ::= abc | aSQ
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Input string:

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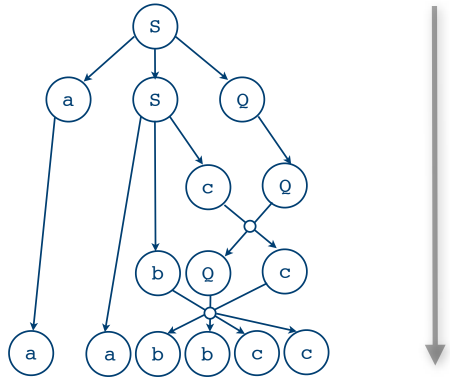
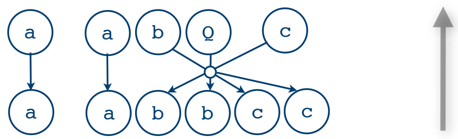


Bottom-Up Parsing


```
Grammar:
S   ::= abc | aSQ
bQc ::= bbcc
cQ  ::= Qc
```

Input string:

aabbcc

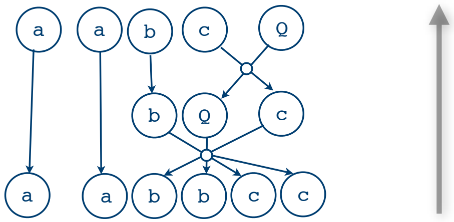


Grammar:

```
S   ::= abc | aSQ
bQc ::= bbcc
cQ  ::= Qc
```

Input string:

aabbcc



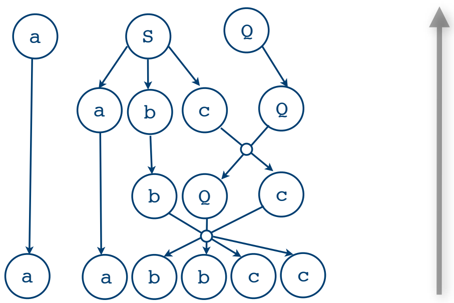
Assembler

Grammar:

```
S   ::= abc | aSQ
bQc ::= bbcc
cQ  ::= Qc
```

Input string:

aabbcc



Grammar:

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S   ::= abc | aSQ
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cQ  ::= Qc
```
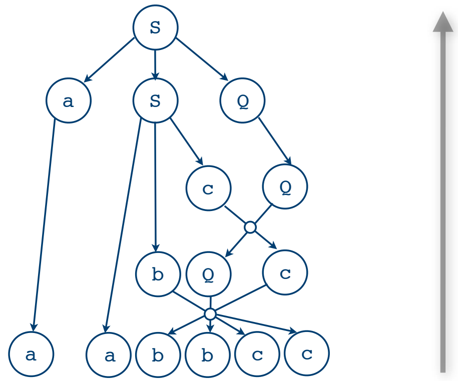

Input string:

aabbcc



Recursive-Descent Parsing

Recursive-Descent Parsing

- There is a subprogram for each nonterminal in the grammar, which can parse sentences that can be generated by that nonterminal
- EBNF is ideally suited for being the basis for a recursive-descent parser, because EBNF minimizes the number of nonterminals

- Assume we have a lexical analyzer named lex, which puts the next token code in nextToken
- The coding process when there is only one RHS:
  - For each terminal symbol in the RHS, compare it with the next input token; if they match, continue, else there is an error
  - For each nonterminal symbol in the RHS, call its associated parsing subprogram

Recursive-Descent Parsing, cont’d

- A nonterminal that has more than one RHS requires an initial process to determine which RHS it is to parse
  - The correct RHS is chosen on the basis of the next token of input (the lookahead)
  - The next token is compared with the first token that can be generated by each RHS until a match is found
  - If no match is found, it is a syntax error

- Left Recursion Problem
- Pairwise Disjointness

Lex, Yacc, Antlr

Names and Binding, Scope

Name, Binding and Scope

- A **name** is a term used for identification
- Most names are identifiers
- Symbols (like '+') can also be names

- A **binding** is an association between two things, such as a name and the thing it names
  – the association of values with identifiers

- The **scope** of a binding is the part of the program (textually) in which the binding is active

Binding Time

- When the “binding” is created or, more generally, the point at which any implementation decision is made
  – language design time, e.g. operator symbols to operations
  – language implementation time, e.g. data type to the range of possible values
  – program writing time, e.g. choose algorithms, data structures and names
  – compile time, e.g. bind a variable to a data type
  – link time, e.g. bind a library call to the subprogram code
  – load time, e.g. bind a static variable to a memory cell
  – run time, e.g. bind a non-static local variable to a memory cell

Static vs Dynamic

- A binding is static if it occurs before run time and remains unchanged throughout program execution
- A binding is dynamic if it occurs during run time and/or can change during execution of the program

Static Type Binding

- Explicit, implicit, inferred
- Advantages
- Disadvantages

Dynamic Type Binding

- Dynamic languages have **no** types bound to identifiers

- Advantages -- there are advantages!
- Disadvantages
  - error detection
  - documentation
  - cost

Thursday, November 3, 11

C and C++

Thursday, November 3, 11

Storage Binding and Lifetime

- Allocation - getting a cell from some pool of available cells
- Deallocation - putting a cell back into the pool

- The lifetime of a variable is the time during which it is bound to a particular memory cell

- **Static** - bound to memory cells before execution begins and remains bound to the same memory cell throughout execution
- **Stack-dynamic** - Storage bindings are created for variables when their declaration statements are elaborated
- **Explicit heap-dynamic** - Allocated and deallocated by explicit directives, specified by the programmer, which take effect during execution. Referenced only through pointers or references
- **Implicit heap-dynamic** - Allocation and deallocation caused by assignment statements

Thursday, November 3, 11

Scope

- The scope of a variable is the range of statements over which it is visible.
- The nonlocal variables of a program unit are those that are visible but not declared there.
- The scope rules of a language determine how references to names are associated with variables

Scope

- Static scope - with or without nested subprograms
- Blocks - block-structured language
- Declaration order - declarations first (before any code) or anywhere, declarations before use or not
- Global, hiding

- Dynamic Scoping - following execution path

- Advantages Static and Dynamic
- Disadvantages Static and Dynamic

- Scope and Lifetime

Scoping Example

```
 MAIN
- declaration of x
  SUB1
    - declaration of x
    ...
    call SUB2
    ...

  SUB 2
    ...
    - reference to x
    ...
...
call SUB1
...
```

MAIN calls SUB1

SUB1 calls SUB2

SUB2 uses x

Static scoping - reference to x is to MAIN's x

Dynamic scoping - reference to x is to SUB1's

The End

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