Today's Topics

Last Time

- Top-down parsers - predictive parsing, backtracking, recursive descent, LL parsers, relation to S/SL

This Time

- Constructing parsers in SL
- Syntax error recovery and repair

Parsing Using SL

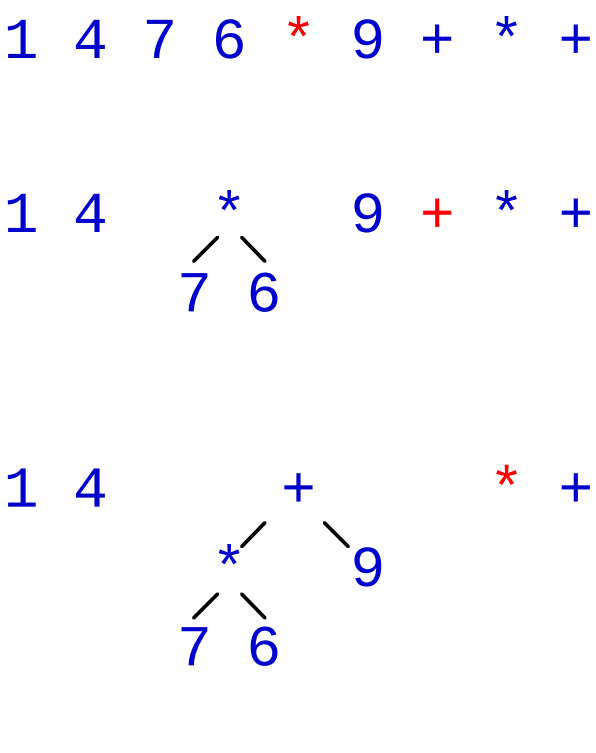
- As we have observed, an SL program (an S/SL program with no semantic mechanisms) is a context-free parser
- The output of an SL parser is a stream of *semantic tokens* - that is, input tokens for the semantic analyzer
- Expressions are translated by the parser to *postfix* notation using SL rules, one for each level of precedence

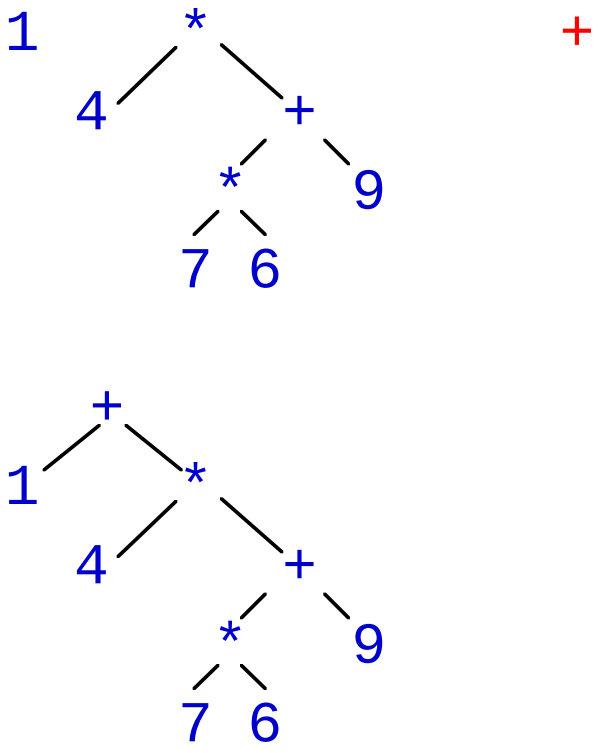
```
1+4*(7*6+9)  →  1 4 7 6 * 9 + * +
```

- Postfix is a convenient linear notation for the output *parse tree* - all precedences have been resolved, and the order of operations has been determined and is represented directly
- Subsequent phases (semantic analysis, code generation) need not be bothered with precedence or associativity

Understanding Postfix

- Postfix is simply a convenient linear notation for a parse tree
- Constructing the represented parse tree consists of reading from left to right, rotating the operators above the previous two items
- Example:





SL Parsing - Expressions

- For precedences: (C, Java, Pascal)

1. unary – *highest (most binding)*
2. * /
3. + – *lowest (least binding)*

```
Expn:
   @Term
   {[
      |'+':
         @Term
         .sAdd
      |'-':
         @Term
         .sSubtract
      | *:
         >
   ]};
```

```
Term:
   @Factor
   {[
      |'*':
         @Factor
         .sMult
      |'/':
         @Factor
         .sDivide
      | *:
         >
   ]};
```

```
Factor:
   [
      |'-':
         @Factor
         .sMinus
      | pIdentifier:
         .sIdentifier
         @Subscripts
      | pInteger:
         .sInteger
   ];
```

- Example:

```
1+-3*2  →  1 3 sMinus 2 sMult sAdd
```

SL Parsing - Expressions

- For precedences:

1. * /
2. unary –
3. + –

```
Expn:
    @Term
    {[
        |'+':
            @Term
            .sAdd
        |'-':
            @Term
            .sSubtract
        | *:
            >
    ]};
```

```
Term:
    [
        |'-':
            @Term
            .sMinus
        | *:
            @SubTerm
    ];
```

```
SubTerm:
    @Factor
    {[
        |'*':
            @Factor
            .sMult
        |'/':
            @Factor
            .sDivide
        | *:
            >
    ]};

Factor:
    [
        | pIdentifier:
            .sIdentifier
            @Subscripts
        | pInteger:
            .sInteger
    ];
```

- Example:

```
1+-3*2  →  1 3 2 sMult sMinus sAdd
```

Role of the SL Parser

- The Parser's job is to:
  (1) check syntax to see that it is valid,
  (2) resolve precedence and order of operations (associativity),
  (3) recognize and explicitly relate structure of statements, blocks and scopes
- Each kind of Parser achieves these aims in different ways
- The SL Parser does the first of these automatically using S/SL syntax error detection (more on this later)
- It does the second by converting expressions to their parse tree in postfix form
- It does the third by recognizing structural relationships and explicitly marking them using semantic tokens

Syntax Error Recovery

- A Parser must *detect* syntax errors - but it must also:
  - *Isolate* them, so that the user knows where the mistake is, and
  - *Recover* from them, so that it can continue parsing and check the rest of the program
- Parsing methods vary in their ability to do each of these well - all methods can *detect* syntax errors (otherwise they wouldn't be parsers)
- *Isolating* them (pointing out where the actual fault is) is more difficult, and *recovering* from them without causing more (phantom) errors is even more difficult

Syntax Error Recovery

- Most parsing algorithms provide some general *recovery strategy*
- Basic problem:
  - When syntax error is detected,
    (a mismatch between the next input token and what's
    expected by the grammar),
  - *Resynchronize* the state of the parse and the next input token
    with a minimum number of actions and the minimum probability
    of further errors
- Effective syntax error recovery and repair is a big area of research,
  with many complex algorithms
- Varying degrees of success, ranging from virtually useless
  (with many cascading "phantom" errors), to virtually perfect,
  with little or no cascading
- Success varies depending on the particular error - most recovery
  algorithms have one or more "pathological cases", where they do
  very badly

SL Syntax Error Recovery

- The built-in syntax error recovery used by SL (by Barnard, 1981) is based on using end-of-statement markers (e.g. ‘**;**’) as synchronization points for the parse

- This is a common idea in many syntactic error recovery strategies - e.g. COBOL compilers typically skip to the next statement keyword that starts a statement

SL Syntax Error Recovery

- In SL, a syntax error is detected when the expected input token (in either an explicit input token action or an input choice action) does not match the next input token

- The steps in recovery are:

  1. Suspend input token acceptance (enter *recovery state*)

  2. In recovery state, continue to walk S/SL table, *pretending* all expected input tokens are matched but *accepting none*, until we expect an end-of-statement token

  3. Flush (discard) tokens from input until an end-of-statement token

  4. Exit recovery state and continue as if nothing had happened

SL Syntax Error Recovery - Example

```
VarDeclaration:
   pIdentifier
   .sIdentifier
   ':'
   @TypeBody
   ';';

TypeBody:
   [
      | 'array':
      | 'file':
      | 'integer':
      | *:
        @SimpleType
   ];
```

```
SimpleType:
   [
      | pIdentifier:
      | *:
        @Constant
        '..' .sRange
        @Constant
   ];

Constant:
   pInteger
   .sIntegerliteral;
```

Input: `var x = integer;`

Recovery/repair: `var x : 1..1 ;`

SL Syntax Error Recovery - Input Choices

- If the error occurs during an input choice (i.e. the next input token does not match any alternative, and the choice has no default) then SL treats it as a mismatch of the first alternative
- So for recovery purposes (only),

```
Constant:
  [
    | pIdentifier:
      .sIdentifier
    | pInteger:
      .sInteger
  ];
```

- Acts like:

```
Constant:
  [
    | pInteger:
      .sInteger
    | *:
      pIdentifier
      .sIdentifier
  ];
```

- In other words, the error is treated as a mismatch of the first alternative, and then recovery proceeds as usual
- And if we are *in* recovery state, the first alternative is always taken

Recovery Loops

- SL recovery state walks the SL program looking for an expected end-of-statement token, *pretending* all input is matched
- When coding SL we have to be aware of the possibility of recovery - otherwise the path followed in recovery state may never reach and expected end-of-statement, and we have an infinite loop!

```
ConstantList:
  '('
  @Constant
  {[
    | ')':
      >
    | *:
      ',' @Constant
  ]};
```

- If input is `(1, 3; 2)`

  → infinite loop

- Each time around the loop, the default (|*:)is taken
- Must structure SL rules such that recovery will always terminate

Recovery Loop Resolution

- A simple rule-of-thumb makes it easy to be sure recovery will always terminate
- Always make the exiting alternative of an SL loop either:
  (a) the *default* (otherwise) alternative, or
  (b) the *first* alternative of a choice without a *default*

```
ConstantList:
  '('
  @Constant
  {[
    | ',':
      @Constant
    | *:
      >
  ]}
  ')';
```

```
ConstantList:
  '('
  @Constant
  {[
    | ')':
      >
    | ',':
      @Constant
  ]};
```

- If input is `(1, 3; 2)`

  → exits the loop as soon as enters recovery state

What if no Semicolons?

- Easier syntax error recovery was one of the original motivating factors behind the use of semicolons in programming languages
- Some languages, such as Euclid and Turing, do not have semicolons or other any other end-of-statement tokens (but are still free-format, that is, end-of-lines are not required)
- So how can the SL parser resynchronize after a syntax error?
- Observation: Programmers do not format their code in arbitrary ways - newlines (return or enter keys) tend to be typed at the ends of expressions and statements - therefore we can use the actual newline characters as synchronization points
- Of course this will not always work perfectly - but quite often in Computer Science we tend to overgeneralize and worry about the worst case when it's not reasonable - in 99% of cases this works
- If there happens to be a misplaced newline in the middle of a statement and there is an error, the only penalty will be a single extra "cascaded" syntax error

SL Syntax Error Recovery - No Semicolons

- Insert special *new line* ('<nl>') tokens into the grammar at ends of statements and other forms where semicolons "would be"
- Example:

```
VarDeclarations:
   pIdentifier
   .sIdentifier
   ':'
   @TypeBody
   '<nl>';
```

```
var x: int
var x: string
```

- SL Parser modifications to handle this :
  1. Mismatches between *expected* newline tokens and input tokens are ignored (not syntax errors because newlines not required in the language)
  2. Newline tokens are used as synchronization points :
     (a) Recovery state walks to the next expected newline token
     (b) Input is flushed to the next newline in the input

Summary

SL Parsers

- Parsers in SL output a postfix token stream which represents a parse tree in linear form
- SL parsers encode precedence and associativity using cascaded nonterminals as in BNF
- Syntax error recovery is an important and difficult problem
- SL has a simple built-in syntax error recovery strategy based on end-of-statement markers such as semicolon
- SL parsers must be coded to take into account the recovery strategy in order to avoid "recovery loops"

Next Week

- Programming language semantics
- Runtime model of execution

- Assignment #1 DUE - Wednesday, Feb 6, 4:30 pm
  (i.e., before next class)