Building a Parser II

CS164
3:30-5:00 TT
10 Evans

Administrativia

- PA2 assigned today
  - due in 12 days
- WA1 assigned today
  - due in a week
  - it's a practice for the exam
- First midterm
  - Oct 5
  - will contain some project-inspired questions

Overview

- Grammars
- derivations
- Recursive descent parser
- Eliminating left recursion

Grammars

- Programming language constructs have recursive structure.
  - which is why our hand-written parser had this structure, too
- An expression is either:
  - number, or
  - variable, or
  - expression + expression, or
  - expression - expression, or
  - (expression), or
  - ...

Context-free grammars (CFG)

- a natural notation for this recursive structure
- grammar for our balanced parens expressions:
  BalancedExpression → **a** | **(** BalancedExpression **)**
- describes (generates) strings of symbols:
  - a, (a), ((a)), (((a))), ...
- like regular expressions but can refer to
  - other expressions (here, BalancedExpression)
  - and do this recursively (giving is "non-finite state")

Example: arithmetic expressions

- Simple arithmetic expressions:
  E → n | id | (E) | E + E | E * E
- Some elements of this language:
  - id
  - n
  - (n)
  - n + id
  - id * (id + id)

Symbols: Terminals and Nonterminals

- grammars use two kinds of symbols
- terminals:
  - no rules for replacing them
  - once generated, terminals are permanent
  - these are tokens of our language
- nonterminals:
  - to be replaced (expanded)
  - in regular expression lingo, these serve as names of expressions
  - start non-terminal: the first symbol to be expanded

Notational Conventions

- In these lecture notes, let's adopt a notation:
  - Non-terminals are written upper-case
  - Terminals are written lower-case or as symbols, e.g., token LPAR is written as (
  - The start symbol is the left-hand side of the first production

Derivations

- This is how a grammar generates strings:
  - think of grammar rules (called productions) as rewrite rules
- Derivation: the process of generating a string
  1. begin with the start non-terminal
  2. rewrite the non-terminal with some of its productions
  3. select a non-terminal in your current string
     i. if no non-terminal left, done.
     ii. otherwise go to step 2.

Example: derivation

Grammar: E → n | id | (E) | E + E | E * E

- a derivation:

E	rewrite E with (E)
(E)	rewrite E with n
(n)	this is the final string of terminals

- another derivation (written more concisely):

E → (E) → (E * E) → (E + E * E) → (n + E * E) → (n + id * E) → (n + id * id)

So how do derivations help us in parsing?

- A program (a string of tokens) has no syntax error if it can be derived from the grammar.
  - but so far you only know how to derive some (any) string, not how to check if a given string is derivable
- So how to do parsing?
  - a naïve solution: derive all possible strings and check if your program is among them
  - not as bad as it sounds: there are parsers that do this, kind of. Coming soon.

Decaf Example

A fragment of Decaf:

```
STMT → while ( EXPR ) STMT
     | id ( EXPR ) ;

EXPR → EXPR + EXPR
     | EXPR - EXPR
     | EXPR < EXPR
     | ( EXPR )
     | id
```

Decaf Example (Cont.)

Some elements of the (fragment of) language:

```
id ( id ) ;
id ( ( ( ( id ) ) ) ) ;
while ( id < id ) id ( id ) ;
while ( while ( id ) ) id ( id ) ;
while ( id ) while ( id ) while ( id ) id ( id ) ;
```

Question: One of the strings is not from the language. Which one?

```
STMT  → while ( EXPR ) STMT
      | id ( EXPR ) ;
EXPR  → EXPR + EXPR | EXPR - EXPR
      | EXPR < EXPR | ( EXPR ) | id
```


CFGs (definition)

- A CFG consists of
  - A set of terminal symbols T
  - A set of non-terminal symbols N
  - A start symbol S (a non-terminal)
  - A set of productions:

  produtions are of two forms ($X \in N$)
  $X \rightarrow \varepsilon$, or
  $X \rightarrow Y_1 Y_2 \ldots Y_n$ where $Y_i \in N \cup T$

context-free grammars

- what is "context-free"?
  - means the grammar is not context-sensitive
- context-sensitive gramars
  - can describe more languages than CFGs
  - because their productions restrict when a non-terminal can be rewritten. An example production:
    d N → d A B c
  - meaning: N can be rewritten into ABc only when preceded by d
  - can be used to encode semantic checks, but parsing is hard

Now let's parse a string

- recursive descent parser derives all strings
  - until it matches derived string with the input string
  - or until it is sure there is a syntax error

Recursive Descent Parsing

- Consider the grammar
  $E \rightarrow T + E \mid T$
  $T \rightarrow \text{int} \mid \text{int} * T \mid (E)$
- Token stream is: $\text{int}_5 * \text{int}_2$
- Start with top-level non-terminal E

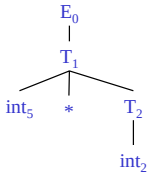
- Try the rules for E in order

Recursive Descent Parsing. Example (Cont.)

- Try $E_0 \rightarrow T_1 + E_2$
- Then try a rule for $T_1 \rightarrow (E_3)$
  - But (does not match input token int_5
- Try $T_1 \rightarrow \text{int}$. Token matches.
  - But + after T_1 does not match input token *
- Try $T_1 \rightarrow \text{int} * T_2$
  - This will match but + after T_1 will be unmatched
- Have exhausted the choices for T_1
  - Backtrack to choice for E_0

Recursive Descent Parsing. Example (Cont.)

- Try $E_0 \rightarrow T_1$
- Follow same steps as before for T_1
  - And succeed with $T_1 \rightarrow$ int * T_2 and $T_2 \rightarrow$ int
  - With the following parse tree



A Recursive Descent Parser (2)

- Define boolean functions that check the token string for a match of
  - A given token terminal
    bool term(TOKEN tok) { return in[next++] == tok; }
  - A given production of S (the n^{th})
    bool S_n() { … }
  - Any production of S:
    bool S() { … }
- These functions advance next

A Recursive Descent Parser (3)

- For production $E \rightarrow T + E$
  bool E_1() { return T() && term(PLUS) && E(); }
- For production $E \rightarrow T$
  bool E_2() { return T(); }
- For all productions of E (with backtracking)

```
bool E() {
  int save = next;
  return    (next = save, E1())
         || (next = save,  E2());   }
```


A Recursive Descent Parser (4)

- Functions for non-terminal T

```
bool T1() { return term(OPEN) && E() && term(CLOSE); }
bool T2() { return term(INT) && term(TIMES) && T(); }
bool T3() { return term(INT); }

bool T() {
  int save = next;
  return    (next = save, T1())
         || (next = save,  T2())
         || (next = save,  T3()); }
```


Recursive Descent Parsing. Notes.

- To start the parser
  - Initialize next to point to first token
  - Invoke E()
- Notice how this simulates our backtracking example from lecture
- Easy to implement by hand
- Predictive parsing is more efficient

Recursive Descent Parsing. Notes.

- Easy to implement by hand
  - An example implementation is provided as a supplement "Recursive Descent Parsing"
- But does not always work …

Recursive-Descent Parsing

- Parsing: given a string of tokens $t_1\ t_2\ \dots\ t_n$, find its parse tree
- Recursive-descent parsing: Try all the productions exhaustively
  - At a given moment the fringe of the parse tree is: $t_1\ t_2\ \dots\ t_k\ A\ \dots$
  - Try all the productions for A: if $A \rightarrow BC$ is a production, the new fringe is $t_1\ t_2\ \dots\ t_k\ B\ C\ \dots$
  - Backtrack when the fringe doesn't match the string
  - Stop when there are no more non-terminals

When Recursive Descent Does Not Work

- Consider a production $S \rightarrow S\ a$:
  - In the process of parsing S we try the above rule
  - What goes wrong?
- A left-recursive grammar has a non-terminal S
  $S \rightarrow^{+} S\alpha$ for some α
- Recursive descent does not work in such cases
  - It goes into an ∞ loop

Elimination of Left Recursion

- Consider the left-recursive grammar
  $S \rightarrow S\ \alpha \mid \beta$
- S generates all strings starting with a β and followed by a number of α
- Can rewrite using right-recursion
  $S \rightarrow \beta\ S'$
  $S' \rightarrow \alpha\ S' \mid \varepsilon$

Elimination of Left-Recursion. Example

- Consider the grammar
  $S \rightarrow 1 \mid S\ 0$ ($\beta = 1$ and $\alpha = 0$)

  can be rewritten as
  $S \rightarrow 1\ S'$
  $S' \rightarrow 0\ S' \mid \varepsilon$

More Elimination of Left-Recursion

- In general
  $S \rightarrow S\ \alpha_1 \mid \dots \mid S\ \alpha_n \mid \beta_1 \mid \dots \mid \beta_m$
- All strings derived from S start with one of $\beta_1,\dots,\beta_m$ and continue with several instances of $\alpha_1,\dots,\alpha_n$
- Rewrite as
  $S \rightarrow \beta_1\ S' \mid \dots \mid \beta_m\ S'$
  $S' \rightarrow \alpha_1\ S' \mid \dots \mid \alpha_n\ S' \mid \varepsilon$

General Left Recursion

- The grammar
  $S \rightarrow A\ \alpha \mid \delta$
  $A \rightarrow S\ \beta$
  is also left-recursive because
  $S \rightarrow^{+} S\ \beta\ \alpha$
- This left-recursion can also be eliminated
- See [ASU], Section 4.3 for general algorithm

Summary of Recursive Descent

- Simple and general parsing strategy
  - Left-recursion must be eliminated first
  - … but that can be done automatically
- Unpopular because of backtracking
  - Thought to be too inefficient
- In practice, backtracking is eliminated by restricting the grammar