G52MAL
Machines and Their Languages
Lecture 15
Recursive-Descent Parsing: Introduction

Henrik Nilsson

University of Nottingham, UK

This Lecture

- What is Parsing?
- Recursive-Descent Parsing Fundamentals
- Handling Choice

What is Parsing? (1)

What is Parsing? (1)

- According to Merriam-Webster OnLine (www.webster.com), ***parse*** means:

  to resolve (as a sentence) into component parts of speech and describe them grammatically

What is Parsing? (1)

- According to Merriam-Webster OnLine (www.webster.com), ***parse*** means:

  to resolve (as a sentence) into component parts of speech and describe them grammatically

- In CS, we take this to mean answering

  $$w \in L(G)?$$

  for a CFG G by analysing the structure of w according to G; i.e. to ***recognize*** the language generated by a grammar G.

What is Parsing? (2)

- A ***parser*** is a program that carries out parsing; i.e., essentially (for CFGs) a realization of a PDA.

What is Parsing? (2)

- A ***parser*** is a program that carries out parsing; i.e., essentially (for CFGs) a realization of a PDA.
- For most practical applications, a parser will also return a structured representation of a word $w \in L(G)$: its ***derivation*** or ***parse tree*** (although usually a simplified version, an ***Abstract Syntax Tree***).

Parsing Strategies

There are two basic strategies for parsing: ***top-down*** and ***bottom up***.

Parsing Strategies

There are two basic strategies for parsing: ***top-down*** and ***bottom up***.

- A top-down parser attempts to carry out a derivation matching the input starting from the start symbol; i.e., it constructs the parse tree for the input ***from the root downwards*** in preorder.

Parsing Strategies

There are two basic strategies for parsing: ***top-down*** and ***bottom up***.

- A top-down parser attempts to carry out a derivation matching the input starting from the start symbol; i.e., it constructs the parse tree for the input ***from the root downwards*** in preorder.
- A bottom-up parser tries to construct the parse tree ***from the leaves upwards*** by using the productions “backwards”.

Recursive-Descent Parsing (1)

Recursive-descent parsing is a way to implement top-down parsing.

We are just going to focus on the language recognition problem:

$$w \in L(G)?$$

Recursive-Descent Parsing (1)

Recursive-descent parsing is a way to implement top-down parsing.

We are just going to focus on the language recognition problem:

$$w \in L(G)?$$

This suggests the following type for the parser:

```
parser :: [Token] -> Bool
```

Token is “compiler speak” for (input) symbol.

Recursive-Descent Parsing (2)

Consider a typical production in some grammar G:

$$S \to AB$$

Let $L(X)$ be the language $\{w \in T^* \mid X \overset{*}{\underset{G}{\Rightarrow}} w\}$.

Note that

$$\begin{aligned} w \in L(S) \Leftarrow \exists w_1, w_2 \ . \quad & w = w_1 w_2 \\ & \wedge\, w_1 \in L(A) \\ & \wedge\, w_2 \in L(B) \end{aligned}$$

Recursive-Descent Parsing (2)

Consider a typical production in some grammar G:

$$S \to AB$$

Let $L(X)$ be the language $\{w \in T^* \mid X \overset{*}{\underset{G}{\Rightarrow}} w\}$.

Note that

$$\begin{aligned} w \in L(S) \Leftarrow \exists w_1, w_2 \,.\; & w = w_1 w_2 \\ & \wedge\, w_1 \in L(A) \\ & \wedge\, w_2 \in L(B) \end{aligned}$$

I.e., given a parser for $L(A)$ and a parser for $L(B)$, we can construct a parser for $L(S)$.

Recursive-Descent Parsing (3)

But we need a way to divide the input word w!

Recursive-Descent Parsing (3)

But we need a way to divide the input word w!

Idea!

Each parser

- tries to derive a ***prefix*** of the input according to the productions for the nonterminal
- returns the remaining ***suffix*** if successful.

Recursive-Descent Parsing (3)

But we need a way to divide the input word w!

Idea!

Each parser

- tries to derive a ***prefix*** of the input according to the productions for the nonterminal
- returns the remaining ***suffix*** if successful.

New type:

```
parseX :: [Token] -> Maybe [Token]
```

(Recall: `data Maybe a = Nothing | Just a`)

Recursive-Descent Parsing (4)

Now we can construct a parser for $L(S)$

$$S \to AB$$

in terms of parsers for $L(A)$ and $L(B)$:

```
parseS :: [Token] -> Maybe [Token]
parseS ts =
     case parseA ts of
          Nothing  -> Nothing
          Just ts' ->
               case parseB ts' of
                    Nothing    -> Nothing
                    Just ts'' -> Just ts''
```

Recursive-Descent Parsing (5)

Or we can simplify to just

```
parseS :: [Token] -> Maybe [Token]
parseS ts =
    case parseA ts of
        Nothing  -> Nothing
        Just ts’ -> parseB ts’
```

This is called recursive-descent parsing because the parse functions (usually) end up being (mutually) recursive.

Exercise

Suppose `type Token = Char` and

```
parseA :: [Token] -> Maybe [Token]
parseA ('a' : ts) = Just ts
parseA _          = Nothing

parseB :: [Token] -> Maybe [Token]
parseB ('b' : ts) = Just ts
parseB _          = Nothing
```

- Evaluate `parseA`, `parseB`, and `parseS` on "`abcd`".
- What are the productions for A and B?

Recursive-Descent Parsers and PDAs

- Fundamental to the implementation of a recursive computation is a ***stack*** that
  - keeps track of the ***state*** of the computation
  - allows for ***subcomputations*** (to any depth).

Recursive-Descent Parsers and PDAs

- Fundamental to the implementation of a recursive computation is a ***stack*** that
  - keeps track of the ***state*** of the computation
  - allows for ***subcomputations*** (to any depth).
- In a language that supports recursive functions and procedures, the stack isn't explicitly visible. But internally, it is the central datastructure.

Recursive-Descent Parsers and PDAs

- Fundamental to the implementation of a recursive computation is a ***stack*** that
  - keeps track of the ***state*** of the computation
  - allows for ***subcomputations*** (to any depth).
- In a language that supports recursive functions and procedures, the stack isn't explicitly visible. But internally, it is the central datastructure.
- Thus, a recursive-descent parser is a kind of PDA.

Recursive-Descent Parsing (6)

We also need a way to handle ***choice***, as in

$$S \to AB \mid CD$$

Recursive-Descent Parsing (6)

We also need a way to handle ***choice***, as in

$$S \to AB \mid CD$$

We are first going to consider the case when the choice is obvious, as in

$$S \to aAB \mid cCD$$

I.e. we assume it is manifest from the grammar that we can choose between productions with a one-symbol ***lookahead***.

A Simple Recursive-Descent Parser (1)

Consider:

$$\begin{array}{rcl} S & \rightarrow & aA \mid bBA \\ A & \rightarrow & aA \mid \epsilon \\ B & \rightarrow & bB \mid \epsilon \end{array}$$

A Simple Recursive-Descent Parser (1)

Consider:

$$\begin{array}{lcl} S & \rightarrow & aA \mid bBA \\ A & \rightarrow & aA \mid \epsilon \\ B & \rightarrow & bB \mid \epsilon \end{array}$$

We are going to need one parsing function for each non-terminal:

- `parseS :: [Token] -> Maybe [Token]`
- `parseA :: [Token] -> Maybe [Token]`
- `parseB :: [Token] -> Maybe [Token]`

A Simple Recursive-Descent Parser (2)

Production: $S \rightarrow aA \mid bBA$

```
type Token = Char

parseS :: [Token] -> Maybe [Token]
parseS ('a' : ts) =
     parseA ts
parseS ('b' : ts) =
     case parseB ts of
          Nothing  -> Nothing
          Just ts' -> parseA ts'
parseS _ = Nothing
```

A Simple Recursive-Descent Parser (3)

Production: $A \rightarrow aA \mid \epsilon$

```
parseA :: [Token] -> Maybe [Token]
parseA ('a' : ts) = parseA ts
parseA ts         = Just ts
```

Production: $B \rightarrow bB \mid \epsilon$

```
parseB :: [Token] -> Maybe [Token]
parseB ('b' : ts) = parseB ts
parseB ts         = Just ts
```

Note: Since $A \Rightarrow \epsilon$ and $B \Rightarrow \epsilon$, it is ***not*** a syntax error if the next token is not, respectively, a and b.

Choice (1)

Now consider:

$$\begin{array}{rcl} S & \rightarrow & aA \mid aBA \\ A & \rightarrow & aA \mid \epsilon \\ B & \rightarrow & bB \mid \epsilon \end{array}$$

Choice (1)

Now consider:

$$\begin{aligned} S &\rightarrow aA \mid aBA \\ A &\rightarrow aA \mid \epsilon \\ B &\rightarrow bB \mid \epsilon \end{aligned}$$

In `parseS`, should `parseA` or `parseB` be called once a has been read?

Choice (2)

We could try the alternatives in order; i.e., a limited form of ***backtracking***:

Production: $S \to aA \mid aBA$

```
parseS ('a' : ts) =
    case parseA ts of
        Just ts' -> Just ts'
        Nothing ->
            case parseB ts of
                Nothing  -> Nothing
                Just ts' -> parseA ts'
```

Choice (3)

Similarly, to handle ϵ-productions (as we already did):

Production: $A \;\rightarrow\; aA \mid \epsilon$

```
parseA :: [Token] -> Maybe [Token]
parseA ('a' : ts) = parseA ts
parseA ts         = Just ts
```

Choice (3)

Similarly, to handle ϵ-productions (as we already did):

Production: $A \rightarrow aA \mid \epsilon$

```
parseA :: [Token] -> Maybe [Token]
parseA ('a' : ts) = parseA ts
parseA ts         = Just ts
```

If the present input starts with an a, consume it and continue. Only if this fails will the always successful ϵ-rule be used! The opposite order would not be very useful.

Choice (4)

Limited backtracking is ***not*** an exhaustive search: liable to get stuck in “blind alleys”.

Consider:

$$\begin{array}{rcl} S & \rightarrow & AB \\ A & \rightarrow & aA \mid \epsilon \\ B & \rightarrow & ab \end{array}$$

Choice (5)

Parsing functions:

```
parseA ('a' : ts) = parseA ts
parseA ts         = Just ts

parseB ('a' : 'b' : ts) = Just ts
parseB ts               = Nothing

parseS ts =
    case parseA ts of
        Nothing  -> Nothing
        Just ts' -> parseB ts'
```

Choice (6)

Will it work? Consider parsing ab. Clearly derivable from the grammar!

Choice (6)

Will it work? Consider parsing ab. Clearly derivable from the grammar!

But:

```
parseS "ab" = Nothing
```

Choice (6)

Will it work? Consider parsing ab. Clearly derivable from the grammar!

But:

```
parseS "ab" = Nothing
```

Why? Because

```
parseA "ab" = Just "b"
```

I.e., committed to the choice $A \to a$, and will never try $A \to \epsilon$: ***a "blind alley"***.

Choice (6)

Will it work? Consider parsing ab. Clearly derivable from the grammar!

But:

```
parseS "ab" = Nothing
```

Why? Because

```
parseA "ab" = Just "b"
```

I.e., committed to the choice $A \rightarrow a$, and will never try $A \rightarrow \epsilon$: ***a "blind alley"***.

Changing order may solve this, but will cause other problems.

Choice (7)

One principled approach is to try ***all*** alternatives; i.e., ***full backtracking*** (aka ***list of successes***):

Choice (7)

One principled approach is to try ***all*** alternatives; i.e., ***full backtracking*** (aka ***list of successes***):

- Each parsing function returns a ***list*** of ***all*** possible suffixes. Type:

```
parseX :: [Token] -> [[Token]]
```

Choice (7)

One principled approach is to try ***all*** alternatives; i.e., ***full backtracking*** (aka ***list of successes***):

- Each parsing function returns a ***list*** of ***all*** possible suffixes. Type:

```
parseX :: [Token] -> [[Token]]
```

- Translate $A \rightarrow \alpha \mid \beta$ into

```
parseA ts = parseAlpha ts ++ parseBeta ts
```

Choice (7)

One principled approach is to try ***all*** alternatives; i.e., ***full backtracking*** (aka ***list of successes***):

- Each parsing function returns a ***list*** of ***all*** possible suffixes. Type:

```
parseX :: [Token] -> [[Token]]
```

- Translate $A \rightarrow \alpha \mid \beta$ into

```
parseA ts = parseAlpha ts ++ parseBeta ts
```

- An empty list indicates no possible parsing.

Choice (8)

However:

- backtracking is computationally expensive
- issues with error reporting: where exactly lies the problem if it only ***after*** an exhaustive search becomes apparent that there is no possible way to parse a word?

We are going to look at another principled approach that avoids backtracking: ***predictive parsing***. (But the grammar must satisfy certain conditions.)