Pushdown Automata - Simplifying the Grammar

Lecture 20 Section 2.2

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Fri, Oct 12, 2012

Outline

- Simplifying the Grammar Rules
 - The Simplification Rules
 - An Example
 - Another Example

Assignment

Outline

- Simplifying the Grammar Rules
 - The Simplification Rules
 - An Example
 - Another Example

2 Assignment

Example (Simplifying a grammar)

We will simplify the grammar

$$egin{align*} A_{pr} &
ightarrow A_{pp} A_{pr} \mid A_{pq} A_{qr} \mid A_{pr} A_{rr} \mid A_{qq} \ A_{pp} &
ightarrow arepsilon \ A_{pq} &
ightarrow A_{pp} A_{pq} \mid A_{pq} A_{qq} \ A_{qq} &
ightarrow \mathbf{a} A_{qq} \mathbf{b} \mid A_{qq} A_{qq} \mid arepsilon \ A_{qr} &
ightarrow A_{qq} A_{qr} \mid A_{qr} A_{rr} \ A_{rr} &
ightarrow arepsilon. \end{gathered}$$

Outline

- Simplifying the Grammar Rules
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2 Assignment

The Simplification Rules

- We may simplify these grammar rules considerably.
 - Eliminate any rule involving a variable that never appears on the left.
 - Eliminate any rule involving a variable, other than the start symbol, that never appears on the right.
 - Eliminate any rule involving a variable that is purely recursive.
 - Eliminate any unnecessary unit rules.
 - Use common sense to eliminate any other rules that are useless.

Outline

- Simplifying the Grammar Rules
 - The Simplification Rules
 - An Example
 - Another Example
- 2 Assignment

The Grammar Rules

Example (Simplifying a grammar)

• Apply Rule 3 (purely recursive variables).

$$egin{align*} A_{pr}
ightarrow A_{pp}A_{pr} \mid A_{pq}A_{qr} \mid A_{pr}A_{rr} \mid A_{qq} \ A_{pp}
ightarrow arepsilon \ A_{pq}
ightarrow A_{pp}A_{pq} \mid A_{pq}A_{qq} \ A_{qq}
ightarrow \mathbf{a}A_{qq}\mathbf{b} \mid A_{qq}A_{qq} \mid arepsilon \ A_{qr}
ightarrow A_{qq}A_{qr} \mid A_{qr}A_{rr} \ A_{rr}
ightarrow arepsilon. \end{gathered}$$

Example (Simplifying a grammar)

• The grammar rules are reduced to

$$egin{align*} A_{pr}
ightarrow A_{pp} A_{pr} \mid A_{pq} A_{qr} \mid A_{pr} A_{rr} \mid A_{qq} \ A_{pp}
ightarrow arepsilon \ A_{qq}
ightarrow \mathbf{a} A_{qq} \mathbf{b} \mid A_{qq} A_{qq} \mid arepsilon \ A_{rr}
ightarrow arepsilon. \end{gathered}$$

Example (Simplifying a grammar)

• Apply Rule 5 (common sense).

$$egin{align*} A_{pr}
ightarrow A_{pp} A_{pr} \mid A_{pq} A_{qr} \mid A_{pr} A_{rr} \mid A_{qq} \ A_{pp}
ightarrow arepsilon \ A_{qq}
ightarrow \mathbf{a} A_{qq} \mathbf{b} \mid A_{qq} A_{qq} \mid arepsilon \ A_{rr}
ightarrow arepsilon. \end{gathered}$$

• We should eliminate these rules and replace A_{pp} and A_{rr} with ε everywhere they occur.

Example (Simplifying a grammar)

• Now the grammar rules are reduced to

$$egin{aligned} A_{pr} &
ightarrow A_{pr} \mid A_{pq} A_{qr} \mid A_{pr} \mid A_{qq} \ A_{qq} &
ightarrow \mathbf{a} A_{qq} \mathbf{b} \mid A_{qq} A_{qq} \mid arepsilon. \end{aligned}$$

Example (Simplifying a grammar)

• Apply Rule 4 (useless unit rules).

$$egin{aligned} oldsymbol{A_{pr}} & oldsymbol{A_{pr}} & oldsymbol{A_{pr}} & oldsymbol{A_{pq}} & oldsymbol{a_$$

Example (Simplifying a grammar)

We now have

$$egin{aligned} A_{pr} &
ightarrow A_{pq} A_{qr} \mid A_{qq} \ A_{aq} &
ightarrow \mathbf{a} A_{aq} \mathbf{b} \mid A_{aq} A_{aq} \mid arepsilon. \end{aligned}$$

Example (Simplifying a grammar)

• Apply Rule 1 (variables never on the left).

$$egin{aligned} A_{pr} &
ightarrow A_{pq}A_{qr} \mid A_{qq} \ A_{aq} &
ightarrow \mathbf{a}A_{aq}\mathbf{b} \mid A_{aq}A_{aq} \mid arepsilon. \end{aligned}$$

Example (Simplifying a grammar)

We now have

$$egin{aligned} & {\cal A}_{pr}
ightarrow {\cal A}_{qq} \ & {\cal A}_{qq}
ightarrow {f a} {\cal A}_{qq} {f b} \mid {\cal A}_{qq} {\cal A}_{qq} \mid arepsilon. \end{aligned}$$

Example (Simplifying a grammar)

Apply Rule 4 (useless unit rules).

$$egin{aligned} oldsymbol{A_{pr}} & oldsymbol{A_{qq}} & oldsymbol{A_{qq}} & oldsymbol{a_{qq}} oldsymbol{b} \mid oldsymbol{A_{qq}} oldsymbol{A_{qq}} \mid arepsilon. \end{aligned}$$

• Eliminate A_{pr} , making A_{qq} the new start symbol.

Example (Simplifying a grammar)

We now have

$$A_{qq}
ightarrow \mathbf{a} A_{qq} \mathbf{b} \mid A_{qq} A_{qq} \mid \varepsilon.$$

or, more simply,

$$S \rightarrow aSb \mid SS \mid \epsilon$$

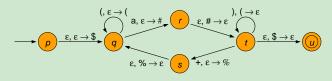
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2 Assignment

Example (Converting a PDA to a CFG and simplifying)

• Simplify the grammar for the language of the valid algebraic expressions over the alphabet $\Sigma = \{\mathbf{a}, +, (,)\}$.



Example (Converting a PDA to a CFG and simplifying)

Pushers	Poppers
$\delta(\pmb{p}, \varepsilon, \varepsilon) = (\pmb{q}, \$)$	$\delta(r,\varepsilon,\#)=(t,\varepsilon)$
$\delta(q, (\varepsilon)) = (q, (\varepsilon))$	$\delta(t,), () = (t, \varepsilon)$
$\delta(oldsymbol{q}, oldsymbol{a}, arepsilon) = (oldsymbol{r}, oldsymbol{\sharp})$	$\delta(oldsymbol{s},arepsilon,{lpha})=(oldsymbol{q},arepsilon)$
$\delta(t,+,arepsilon)=(oldsymbol{s}, \%)$	$\delta(t,\varepsilon,\$)=(u,\varepsilon)$

Example (Converting a PDA to a CFG and simplifying)

We found the grammar to be

$$\begin{array}{l} A_{pu} \rightarrow A_{pp}A_{pu} \mid A_{pq}A_{qu} \mid A_{pr}A_{ru} \mid A_{pt}A_{tu} \mid A_{ps}A_{su} \mid A_{pu}A_{uu} \mid A_{qt} \\ A_{pp} \rightarrow \varepsilon \\ A_{pq} \rightarrow A_{pp}A_{pq} \mid A_{pq}A_{qq} \mid A_{pr}A_{rq} \mid A_{pt}A_{tq} \mid A_{ps}A_{sq} \\ A_{pt} \rightarrow A_{pp}A_{pt} \mid A_{pq}A_{qt} \mid A_{pr}A_{rt} \mid A_{pt}A_{tt} \mid A_{ps}A_{st} \\ A_{qq} \rightarrow A_{qq}A_{qq} \mid A_{qr}A_{rq} \mid A_{qt}A_{tq} \mid A_{qs}A_{sq} \mid (A_{qs} \mid \mathbf{a}A_{rs} \mid \varepsilon \\ A_{qt} \rightarrow A_{qq}A_{qt} \mid A_{qr}A_{rt} \mid A_{qt}A_{tt} \mid A_{qs}A_{st} \mid (A_{qr} \mid (A_{qt}) \mid \mathbf{a}A_{rr} \mid \mathbf{a}A_{rt}) \\ A_{qu} \rightarrow A_{qq}A_{qu} \mid A_{qr}A_{ru} \mid A_{qt}A_{tu} \mid A_{qs}A_{su} \mid A_{qu}A_{uu} \\ A_{rr} \rightarrow \varepsilon \\ A_{tq} \rightarrow A_{tq}A_{qq} \mid A_{tr}A_{rq} \mid A_{tt}A_{tq} \mid A_{ts}A_{sq} \mid + A_{ss} \\ A_{tt} \rightarrow A_{tq}A_{qt} \mid A_{tr}A_{rt} \mid A_{tt}A_{tt} \mid A_{ts}A_{st} \mid + A_{sr} \mid + A_{st}) \mid \varepsilon \\ A_{tu} \rightarrow A_{tq}A_{qu} \mid A_{tr}A_{ru} \mid A_{tt}A_{tu} \mid A_{ts}A_{su} \mid A_{tu}A_{uu} \\ A_{ss} \rightarrow \varepsilon \\ A_{uu} \rightarrow \varepsilon \end{array}$$

Example (Converting a PDA to a CFG and simplifying)

Apply Rule 1.

```
A_{DU} \rightarrow A_{DD}A_{DU} \mid A_{Da}A_{au} \mid A_{Dr}A_{ru} \mid A_{Dt}A_{tu} \mid A_{Ds}A_{su} \mid A_{Du}A_{uu} \mid A_{at}
A_{nn} \rightarrow \varepsilon
A_{pq} \rightarrow A_{pp}A_{pq} \mid A_{pq}A_{qq} \mid A_{pr}A_{rq} \mid A_{pt}A_{tq} \mid A_{ps}A_{sq}
A_{pt} \rightarrow A_{pp}A_{pt} \mid A_{pq}A_{qt} \mid A_{pr}A_{rt} \mid A_{pt}A_{tt} \mid A_{ps}A_{st}
A_{qq} \rightarrow A_{qq} A_{qq} \mid A_{qr} A_{rq} \mid A_{qt} A_{tq} \mid A_{qs} A_{sq} \mid (A_{qs} \mid \mathbf{a} A_{rs} \mid \varepsilon)
A_{qt} \rightarrow A_{qq}A_{qt} \mid A_{qr}A_{rt} \mid A_{qt}A_{tt} \mid A_{qs}A_{st} \mid (A_{qr} \mid (A_{qt}) \mid \mathbf{a}A_{rr} \mid \mathbf{a}A_{rt})
A_{qu} \rightarrow A_{qq} A_{qu} \mid A_{qr} A_{ru} \mid A_{qt} A_{tu} \mid A_{qs} A_{su} \mid A_{qu} A_{uu}
 Arr -> E
A_{tq} \rightarrow A_{tq}A_{qq} \mid A_{tr}A_{rq} \mid A_{tt}A_{tq} \mid A_{ts}A_{sq} \mid + A_{ss}
 A_{tt} \rightarrow A_{ta}A_{at} \mid A_{tr}A_{rt} \mid A_{tt}A_{tt} \mid A_{ts}A_{st} \mid + A_{sr} \mid + A_{st} \mid \varepsilon
A_{tu} \rightarrow A_{ta}A_{au} \mid A_{tr}A_{ru} \mid A_{tt}A_{tu} \mid A_{ts}A_{su} \mid A_{tu}A_{uu}
A_{SS} \rightarrow \varepsilon
A_{IIII} \rightarrow \varepsilon
```

Example (Converting a PDA to a CFG and simplifying)

This leaves the rules

$$\begin{array}{l} A_{pu} \rightarrow A_{pp}A_{pu} \mid A_{pq}A_{qu} \mid A_{pt}A_{tu} \mid A_{pu}A_{uu} \mid A_{qt} \\ A_{pp} \rightarrow \varepsilon \\ A_{pq} \rightarrow A_{pp}A_{pq} \mid A_{pq}A_{qq} \mid A_{pt}A_{tq} \\ A_{pt} \rightarrow A_{pp}A_{pt} \mid A_{pq}A_{qt} \mid A_{pt}A_{tt} \\ A_{qq} \rightarrow A_{qq}A_{qq} \mid A_{qt}A_{tq} \mid \varepsilon \\ A_{qt} \rightarrow A_{qq}A_{qt} \mid A_{qt}A_{tt} \mid (A_{qt}) \mid \mathbf{a}A_{rr} \\ A_{qu} \rightarrow A_{qq}A_{qu} \mid A_{qt}A_{tu} \mid A_{qu}A_{uu} \\ A_{rr} \rightarrow \varepsilon \\ A_{tq} \rightarrow A_{tq}A_{qq} \mid A_{tt}A_{tq} \mid + A_{ss} \\ A_{tt} \rightarrow A_{tq}A_{qt} \mid A_{tt}A_{tt} \mid \varepsilon \\ A_{tu} \rightarrow A_{tq}A_{qu} \mid A_{tt}A_{tu} \mid A_{tu}A_{uu} \\ A_{ss} \rightarrow \varepsilon \\ A_{uu} \rightarrow \varepsilon \end{array}$$

Example (Converting a PDA to a CFG and simplifying)

Apply Rule 5.

$$\begin{array}{l} A_{pu} \rightarrow A_{pp}A_{pu} \mid A_{pq}A_{qu} \mid A_{pt}A_{tu} \mid A_{pu}A_{uu} \mid A_{qt} \\ A_{pp} \rightarrow \varepsilon \\ A_{pq} \rightarrow A_{pp}A_{pq} \mid A_{pq}A_{qq} \mid A_{pt}A_{tq} \\ A_{pt} \rightarrow A_{pp}A_{pq} \mid A_{pq}A_{qt} \mid A_{pt}A_{tt} \\ A_{qq} \rightarrow A_{qq}A_{qq} \mid A_{qt}A_{tq} \mid \varepsilon \\ A_{qt} \rightarrow A_{qq}A_{qt} \mid A_{qt}A_{tt} \mid (A_{qt}) \mid \mathbf{a}A_{rr} \\ A_{qu} \rightarrow A_{qq}A_{qu} \mid A_{qt}A_{tu} \mid A_{qu}A_{uu} \\ A_{rr} \rightarrow \varepsilon \\ A_{tq} \rightarrow A_{tq}A_{qq} \mid A_{tt}A_{tt} \mid \varepsilon \\ A_{tt} \rightarrow A_{tq}A_{qt} \mid A_{tt}A_{tt} \mid \varepsilon \\ A_{tu} \rightarrow A_{tq}A_{qu} \mid A_{tt}A_{tu} \mid A_{tu}A_{uu} \\ A_{ss} \rightarrow \varepsilon \\ A_{uu} \rightarrow \varepsilon \end{array}$$

Example (Converting a PDA to a CFG and simplifying)

This leaves the rules

$$A_{pu} \rightarrow A_{pu} \mid A_{pq}A_{qu} \mid A_{pt}A_{tu} \mid A_{pu} \mid A_{qt}$$

$$A_{pq} \rightarrow A_{pq} \mid A_{pq}A_{qq} \mid A_{pt}A_{tq}$$

$$A_{pt} \rightarrow A_{pt} \mid A_{pq}A_{qt} \mid A_{pt}A_{tt}$$

$$A_{qq} \rightarrow A_{qq}A_{qq} \mid A_{qt}A_{tq} \mid \varepsilon$$

$$A_{qt} \rightarrow A_{qq}A_{qt} \mid A_{qt}A_{tt} \mid (A_{qt}) \mid \mathbf{a}$$

$$A_{qu} \rightarrow A_{qq}A_{qu} \mid A_{qt}A_{tu} \mid A_{qu}A_{uu}$$

$$A_{tq} \rightarrow A_{tq}A_{qq} \mid A_{tt}A_{tq} \mid +$$

$$A_{tt} \rightarrow A_{tq}A_{qt} \mid A_{tt}A_{tt} \mid \varepsilon$$

$$A_{tu} \rightarrow A_{tq}A_{qu} \mid A_{tt}A_{tt} \mid \epsilon$$

$$A_{tu} \rightarrow A_{tq}A_{qu} \mid A_{tt}A_{tu} \mid A_{tu}$$

Example (Converting a PDA to a CFG and simplifying)

• Apply Rule 4.

```
\begin{array}{l} A_{pu} \rightarrow A_{pu} \mid A_{pq}A_{qu} \mid A_{pt}A_{tu} \mid A_{pu} \mid A_{qt} \\ A_{pq} \rightarrow A_{pq} \mid A_{pq}A_{qq} \mid A_{pt}A_{tq} \\ A_{pt} \rightarrow A_{pt} \mid A_{pq}A_{qt} \mid A_{pt}A_{tt} \\ A_{qq} \rightarrow A_{qq}A_{qq} \mid A_{qt}A_{tq} \mid \varepsilon \\ A_{qt} \rightarrow A_{qq}A_{qt} \mid A_{qt}A_{tt} \mid (A_{qt}) \mid \mathbf{a} \\ A_{qu} \rightarrow A_{qq}A_{qu} \mid A_{qt}A_{tu} \mid A_{qu}A_{uu} \\ A_{tq} \rightarrow A_{tq}A_{qq} \mid A_{tt}A_{tq} \mid + \\ A_{tt} \rightarrow A_{tq}A_{qt} \mid A_{tt}A_{tt} \mid \varepsilon \\ A_{tu} \rightarrow A_{tq}A_{qu} \mid A_{tt}A_{tu} \mid A_{tu} \end{array}
```

Example (Converting a PDA to a CFG and simplifying)

This leaves the rules

$$A_{pu} \rightarrow A_{pq}A_{qu} \mid A_{pt}A_{tu} \mid A_{qt}$$

$$A_{pq} \rightarrow A_{pq}A_{qq} \mid A_{pt}A_{tq}$$

$$A_{pt} \rightarrow A_{pq}A_{qt} \mid A_{pt}A_{tt}$$

$$A_{qq} \rightarrow A_{qq}A_{qq} \mid A_{qt}A_{tq} \mid \varepsilon$$

$$A_{qt} \rightarrow A_{qq}A_{qt} \mid A_{qt}A_{tt} \mid (A_{qt}) \mid \mathbf{a}$$

$$A_{qu} \rightarrow A_{qq}A_{qu} \mid A_{qt}A_{tu} \mid A_{qu}A_{uu}$$

$$A_{tq} \rightarrow A_{tq}A_{qq} \mid A_{tt}A_{tq} \mid +$$

$$A_{tt} \rightarrow A_{tq}A_{qt} \mid A_{tt}A_{tt} \mid \varepsilon$$

$$A_{tu} \rightarrow A_{tq}A_{qu} \mid A_{tt}A_{tu}$$

Example (Converting a PDA to a CFG and simplifying)

Apply Rule 3.

```
A_{pu} \rightarrow A_{pq}A_{qu} \mid A_{pt}A_{tu} \mid A_{qt}
A_{pq} \rightarrow A_{pq}A_{qq} \mid A_{pt}A_{tq}
A_{pt} \rightarrow A_{pq}A_{qt} \mid A_{pt}A_{tt}
A_{qq} \rightarrow A_{qq}A_{qq} \mid A_{qt}A_{tq} \mid \varepsilon
A_{qt} \rightarrow A_{qq}A_{qt} \mid A_{qt}A_{tt} \mid (A_{qt}) \mid \mathbf{a}
A_{qu} \rightarrow A_{qq}A_{qu} \mid A_{qt}A_{tu} \mid A_{qu}A_{uu}
A_{tq} \rightarrow A_{tq}A_{qq} \mid A_{tt}A_{tq} \mid +
A_{tt} \rightarrow A_{tq}A_{qt} \mid A_{tt}A_{tt} \mid \varepsilon
A_{tu} \rightarrow A_{tq}A_{qu} \mid A_{tt}A_{tu}
```

Example (Converting a PDA to a CFG and simplifying)

This leaves the rules

$$A_{pu}
ightarrow A_{pq}A_{qu} \mid A_{pt}A_{tu} \mid A_{qt}$$
 $A_{qq}
ightarrow A_{qq}A_{qq} \mid A_{qt}A_{tq} \mid \varepsilon$
 $A_{qt}
ightarrow A_{qq}A_{qt} \mid A_{qt}A_{tt} \mid (A_{qt}) \mid \mathbf{a}$
 $A_{tq}
ightarrow A_{tq}A_{qq} \mid A_{tt}A_{tq} \mid +$
 $A_{tt}
ightarrow A_{tq}A_{qt} \mid A_{tt}A_{tt} \mid \varepsilon$

Example (Converting a PDA to a CFG and simplifying)

Apply Rule 1.

```
A_{pu} \rightarrow A_{pq}A_{qu} \mid A_{pt}A_{tu} \mid A_{qt}
A_{qq} \rightarrow A_{qq}A_{qq} \mid A_{qt}A_{tq} \mid \varepsilon
A_{qt} \rightarrow A_{qq}A_{qt} \mid A_{qt}A_{tt} \mid (A_{qt}) \mid \mathbf{a}
A_{tq} \rightarrow A_{tq}A_{qq} \mid A_{tt}A_{tq} \mid +
A_{tt} \rightarrow A_{tq}A_{qt} \mid A_{tt}A_{tt} \mid \varepsilon
```

Example (Converting a PDA to a CFG and simplifying)

This leaves the rules

$$A_{pu}
ightarrow A_{qt}$$
 $A_{qq}
ightarrow A_{qq} A_{qq} \mid A_{qt} A_{tq} \mid \varepsilon$
 $A_{qt}
ightarrow A_{qq} A_{qt} \mid A_{qt} A_{tt} \mid (A_{qt}) \mid \mathbf{a}$
 $A_{tq}
ightarrow A_{tq} A_{qq} \mid A_{tt} A_{tq} \mid +$
 $A_{tt}
ightarrow A_{tq} A_{qt} \mid A_{tt} A_{tt} \mid \varepsilon$

Example (Converting a PDA to a CFG and simplifying)

Apply Rule 4.

$$A_{pu} \rightarrow A_{qt}$$

$$A_{qq} \rightarrow A_{qq}A_{qq} \mid A_{qt}A_{tq} \mid \varepsilon$$

$$A_{qt} \rightarrow A_{qq}A_{qt} \mid A_{qt}A_{tt} \mid (A_{qt}) \mid \mathbf{a}$$

$$A_{tq} \rightarrow A_{tq}A_{qq} \mid A_{tt}A_{tq} \mid +$$

$$A_{tt} \rightarrow A_{tq}A_{qt} \mid A_{tt}A_{tt} \mid \varepsilon$$

and make A_{at} the new start symbol.

Example (Converting a PDA to a CFG and simplifying)

This leaves the rules

$$A_{qt} \rightarrow A_{qq}A_{qt} \mid A_{qt}A_{tt} \mid (A_{qt}) \mid \mathbf{a}$$

$$A_{qq} \rightarrow A_{qq}A_{qq} \mid A_{qt}A_{tq} \mid \varepsilon$$

$$A_{tq} \rightarrow A_{tq}A_{qq} \mid A_{tt}A_{tq} \mid +$$

$$A_{tt} \rightarrow A_{tq}A_{qt} \mid A_{tt}A_{tt} \mid \varepsilon$$

Example (Converting a PDA to a CFG and simplifying)

• Now give them simpler names: $S = A_{qt}$, $A = A_{qq}$, $B = A_{tt}$, and $C = A_{tq}$.

$$S
ightarrow AS \mid SB \mid (S) \mid$$
 a
 $A
ightarrow AA \mid SC \mid \varepsilon$
 $C
ightarrow CA \mid BC \mid +$
 $B
ightarrow CS \mid BB \mid \varepsilon$

Example (Converting a PDA to a CFG and simplifying)

• Use the grammar to derive the string $(\mathbf{a} + \mathbf{a}) + \mathbf{a}$.

$$S
ightarrow AS \mid SB \mid (S) \mid$$
 a $A
ightarrow AA \mid SC \mid \varepsilon$ $B
ightarrow BB \mid CS \mid \varepsilon$ $C
ightarrow CA \mid BC \mid +$

Example (Converting a PDA to a CFG and simplifying)

• Use the grammar to derive the string $(\mathbf{a} + \mathbf{a}) + \mathbf{a}$.

$$S \Rightarrow SB$$

$$\Rightarrow (S)B$$

$$\Rightarrow (AS)B$$

$$\Rightarrow (SCS)B$$

$$\Rightarrow (SCS)CS$$

$$\Rightarrow (\mathbf{a} + \mathbf{a}) + \mathbf{a}$$

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- Simplifying the Grammar Rules
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 - An Example
 - Another Example

Assignment

Assignment

Assignment

- Read Section 2.2, pages 115 123.
- Simplify the grammar created in the previous homework problem, with PDA

