RegExps & DFAs

CS 536

Pre-class warm up

Write the regexp for Fortran real literals

An optional sign ('+' or '-')

An integer or:

1 or more digits followed by a '.' followed by 0 or more digits

or: A '.' followed by one or more digits

```
('+'|'-'|ε) (digit+('.'|ε) | (digit*'.'digit+))
```

Last time

Explored NFAs

- for every NFA there is an equivalent DFA
- epsilon edges add no expressive power

Introduce regular languages / expressions

Today

Convert regexps to DFAs

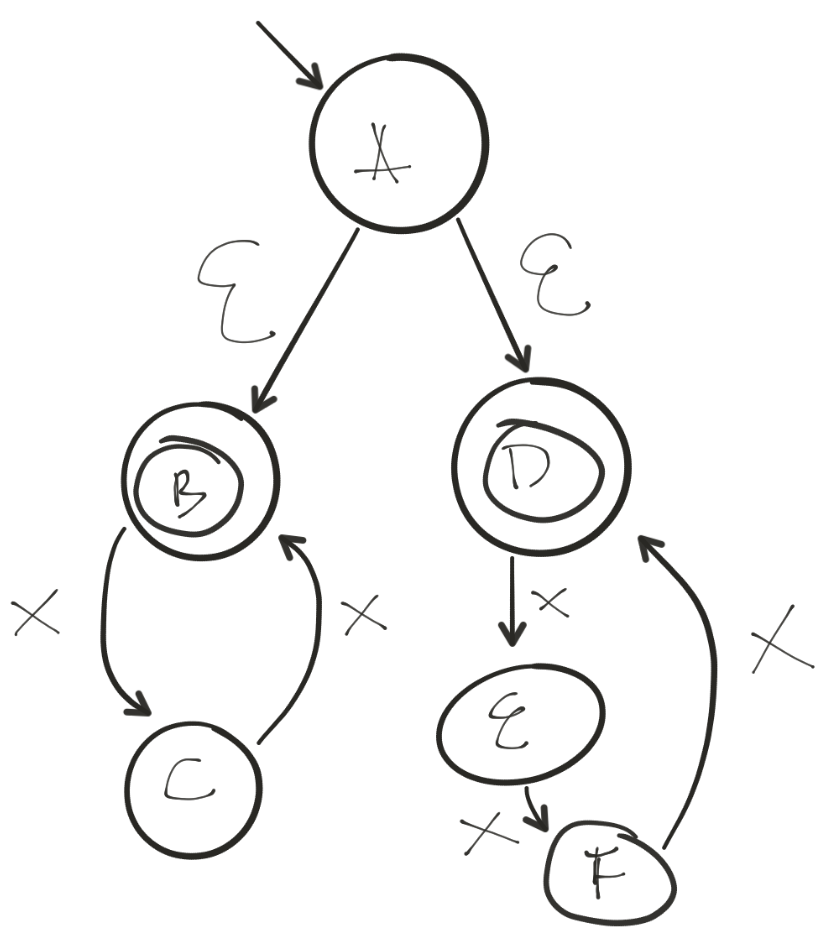
From language recognizers to tokenizers

Regexp to NFAs

Literals/epsilon correspond to simple DFAs

Operators correspond to methods of joining DFAs

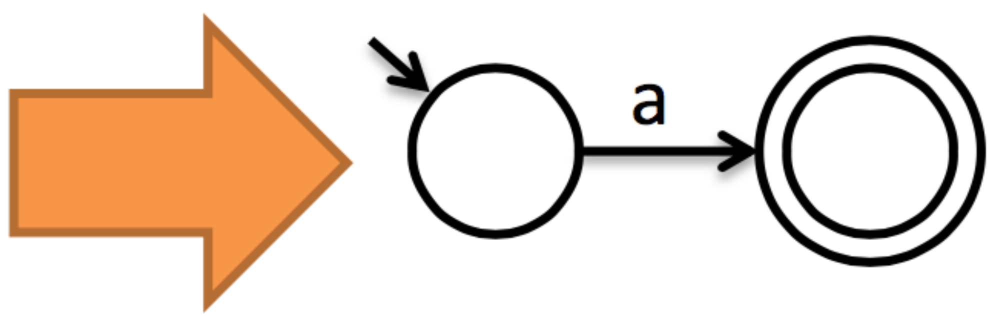
x^n, where n is even **or** divisible by 3



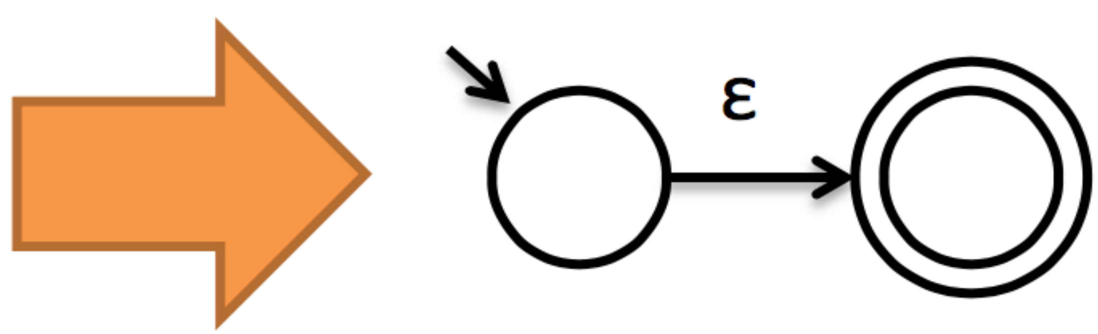
Regexp to NFA rules

Rules for operands

Literal ‘a’

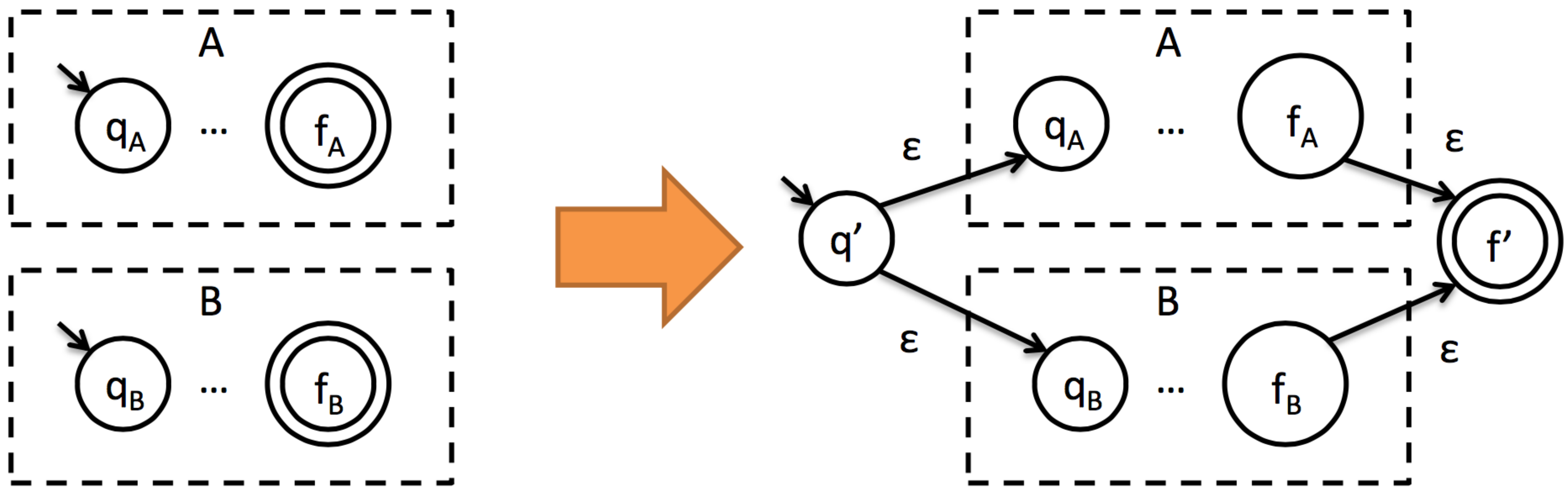


ε



Regexp to NFA rules

Rules for alternation A|B



Make new start state q' and new final state f'

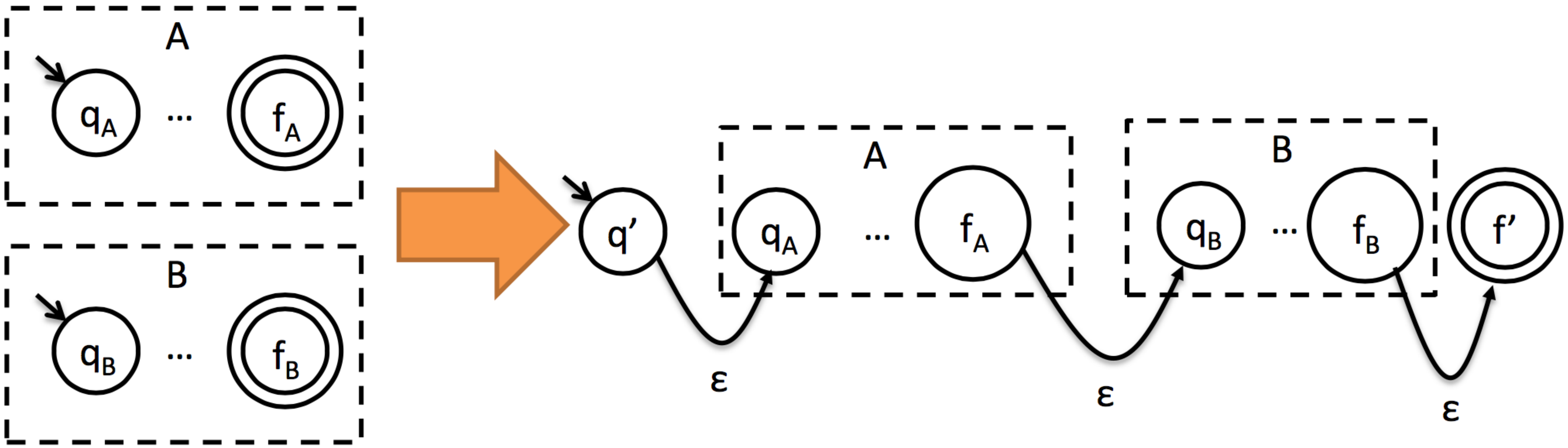
Make original final states non-final

Add to δ:

$q', \varepsilon \rightarrow q_A$
$q', \varepsilon \rightarrow q_B$
$F_a, \varepsilon \rightarrow f'$
$F_b, \varepsilon \rightarrow f'$

Regexp to NFA rules

Rule for catenation A.B



Make new start state q' and new final state f'

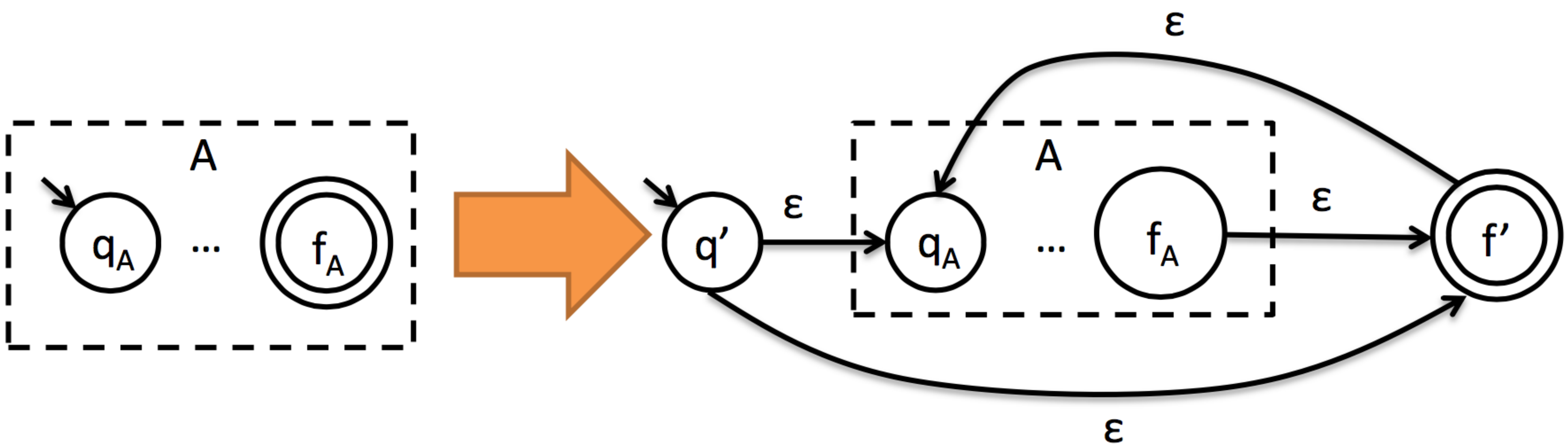
Make original final states non-final

Add to δ:

$q', \varepsilon \rightarrow q_A$
$f_A, \varepsilon \rightarrow q_B$
$f_b, \varepsilon \rightarrow f'$

Regexp to NFA rules

Rule for iteration A*



Make new start state q' and new final state f'

Make original final states non-final

Add to δ:

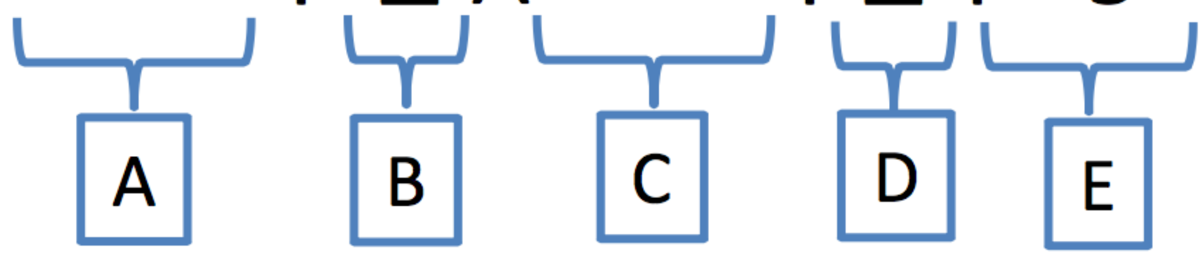
$q', \varepsilon \rightarrow q_A$
$q', \varepsilon \rightarrow f'$
$f', \varepsilon \rightarrow q_A$

Regexp operator precedence

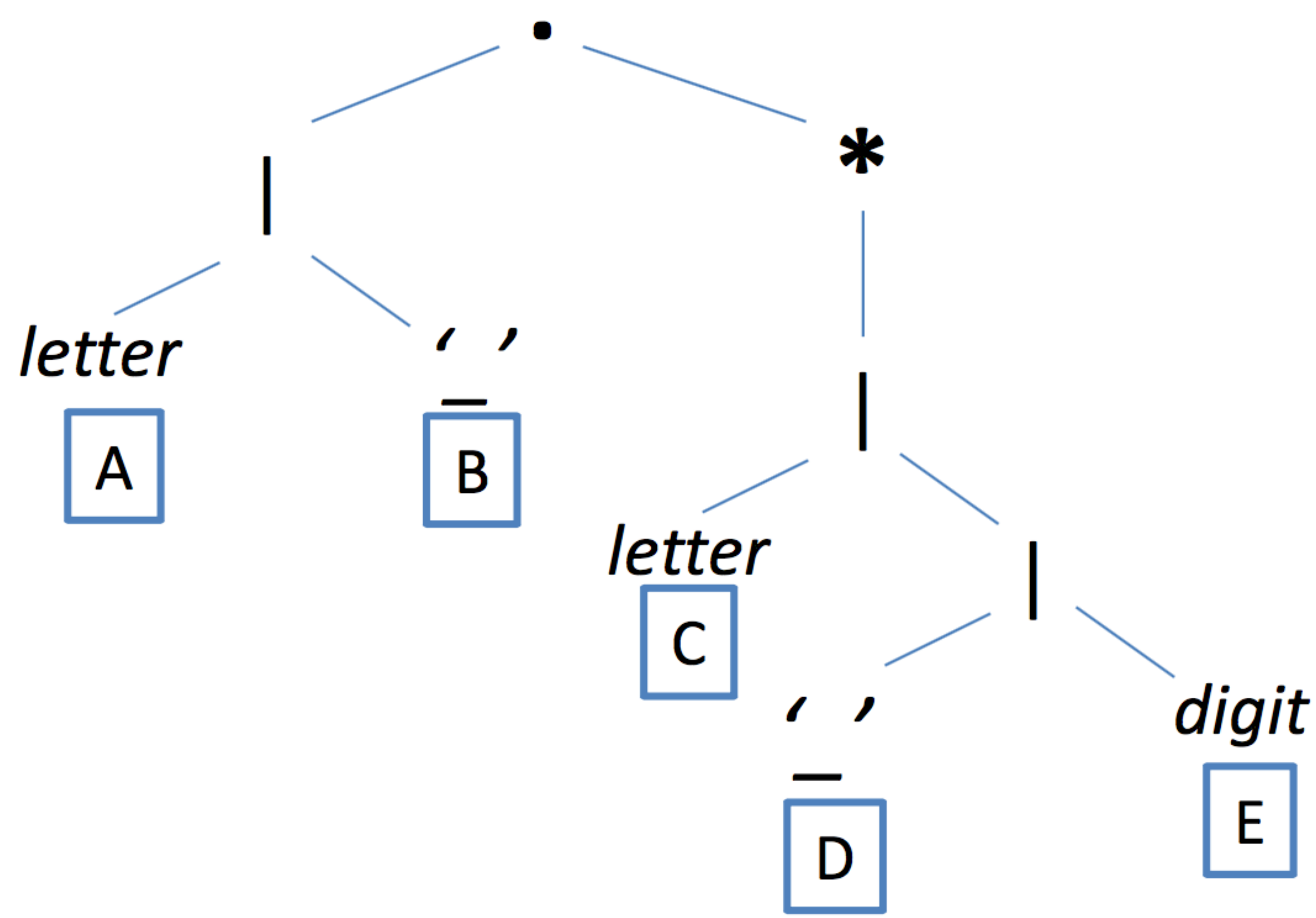
Operator	Precedence	Analogous math operator
|	low	addition
.	medium	multiplication
*	high	exponentiation

Tree representation of a regexp

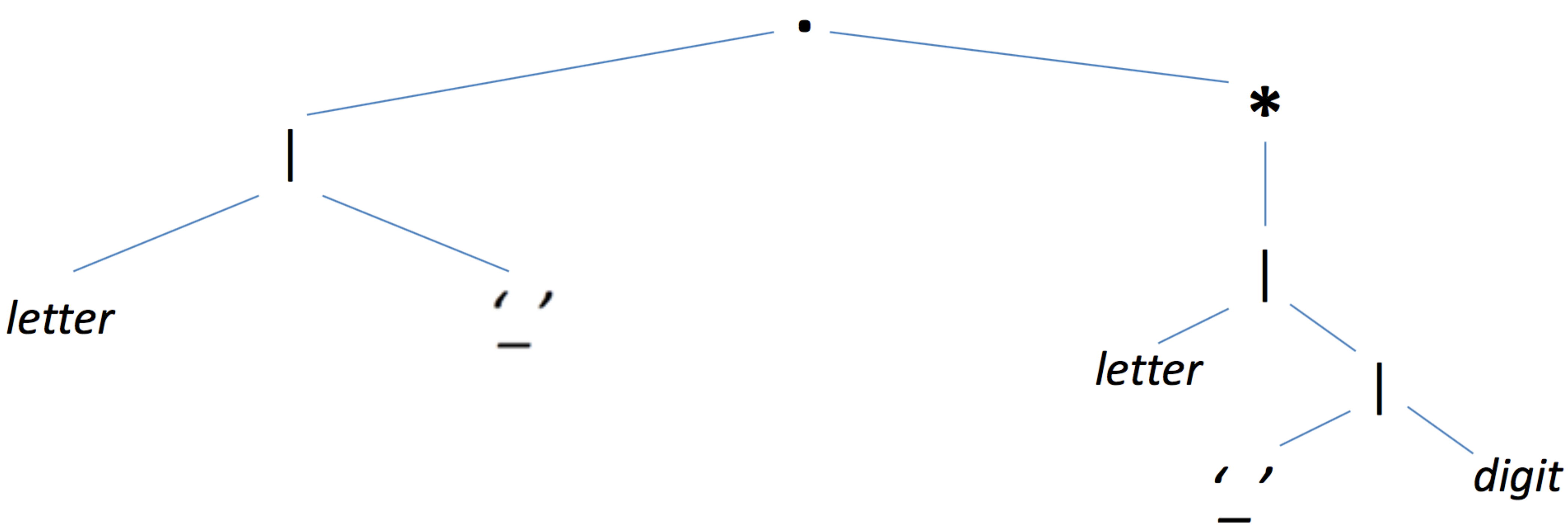
(letter | '_')(*letter*|'_'|*digit*)*



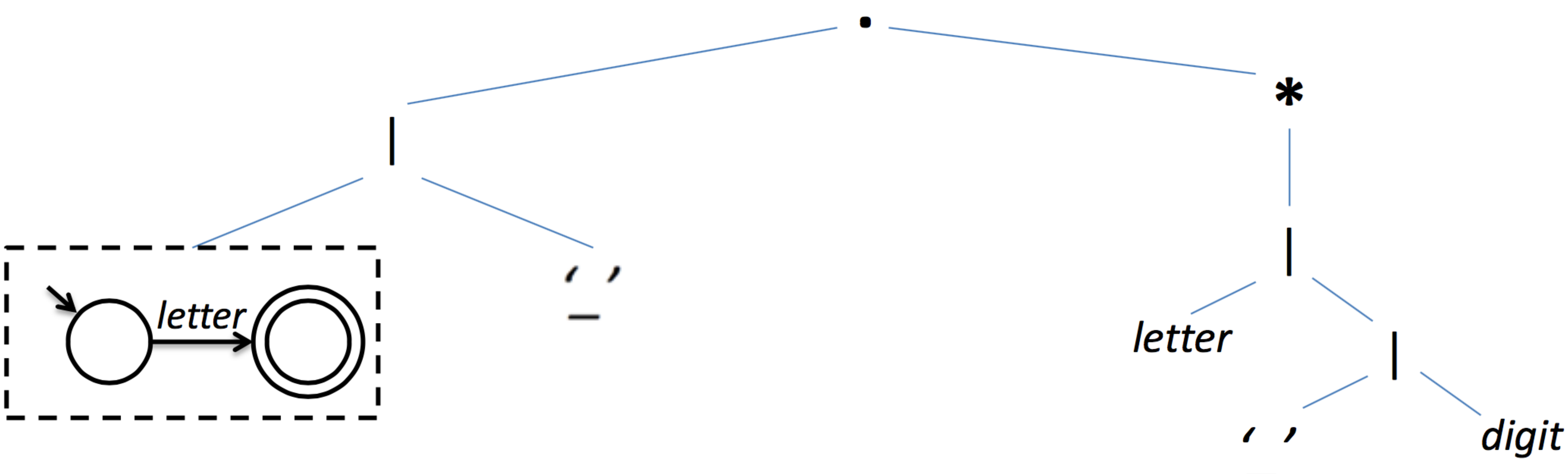
<table>
<tr><th>Operator</th><th>Precedence</th></tr>
<tr><td>|</td><td>low</td></tr>
<tr><td>.</td><td>medium</td></tr>
<tr><td>*</td><td>high</td></tr>
</table>



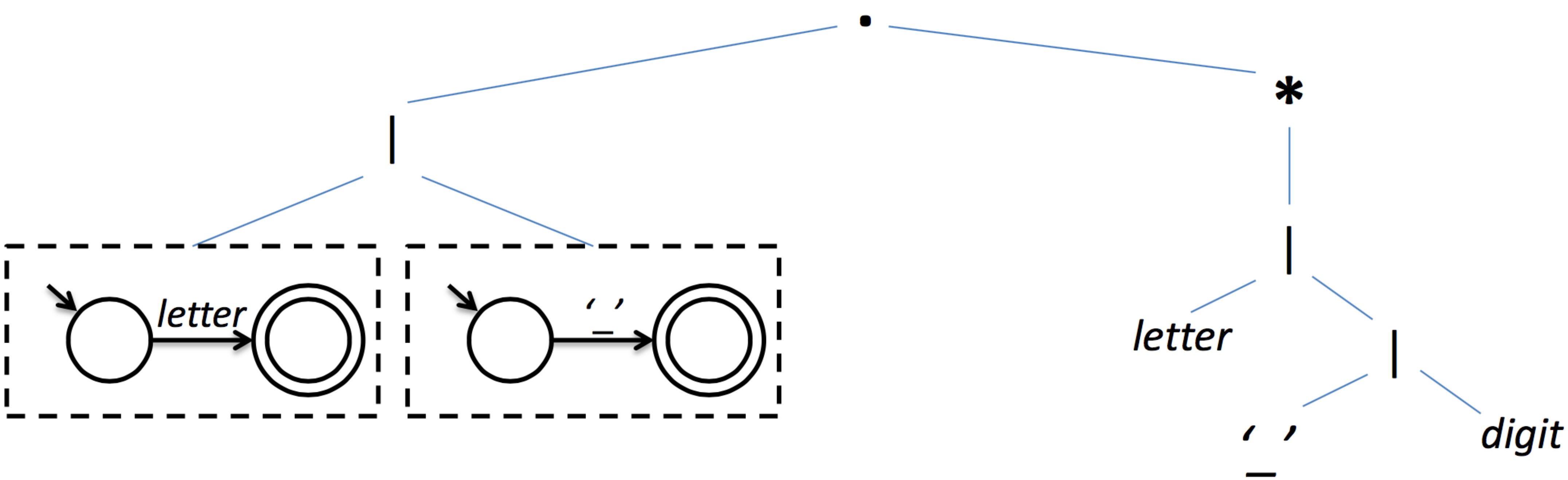
Bottom-up conversion



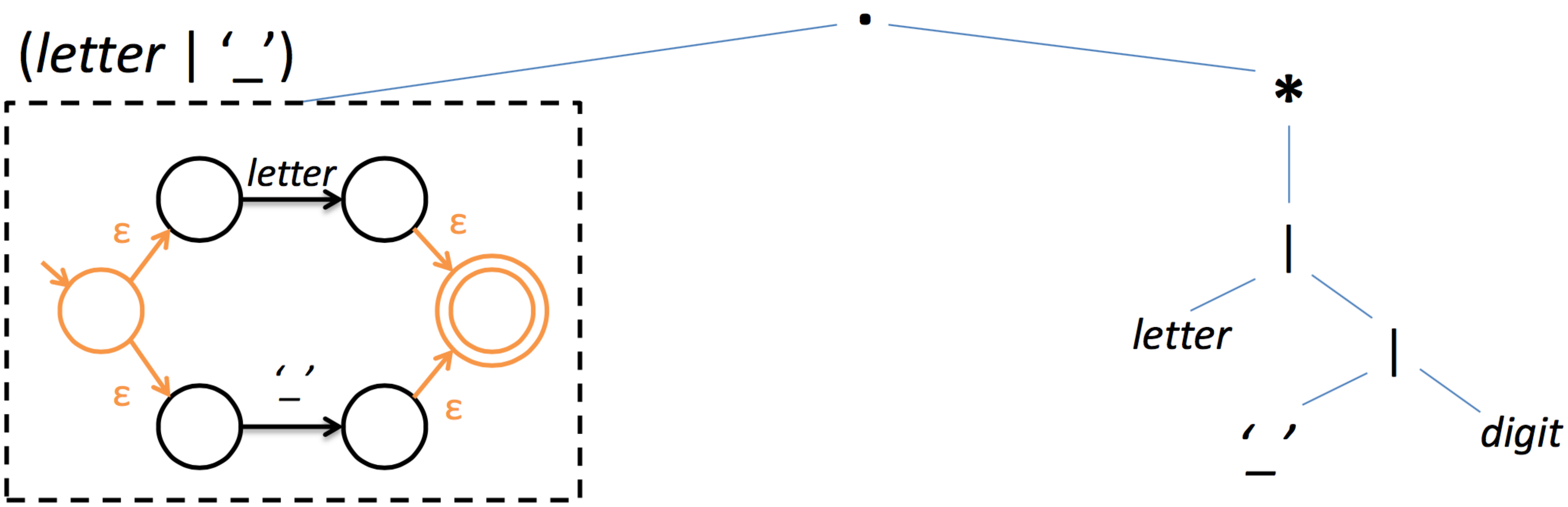
Bottom-up conversion



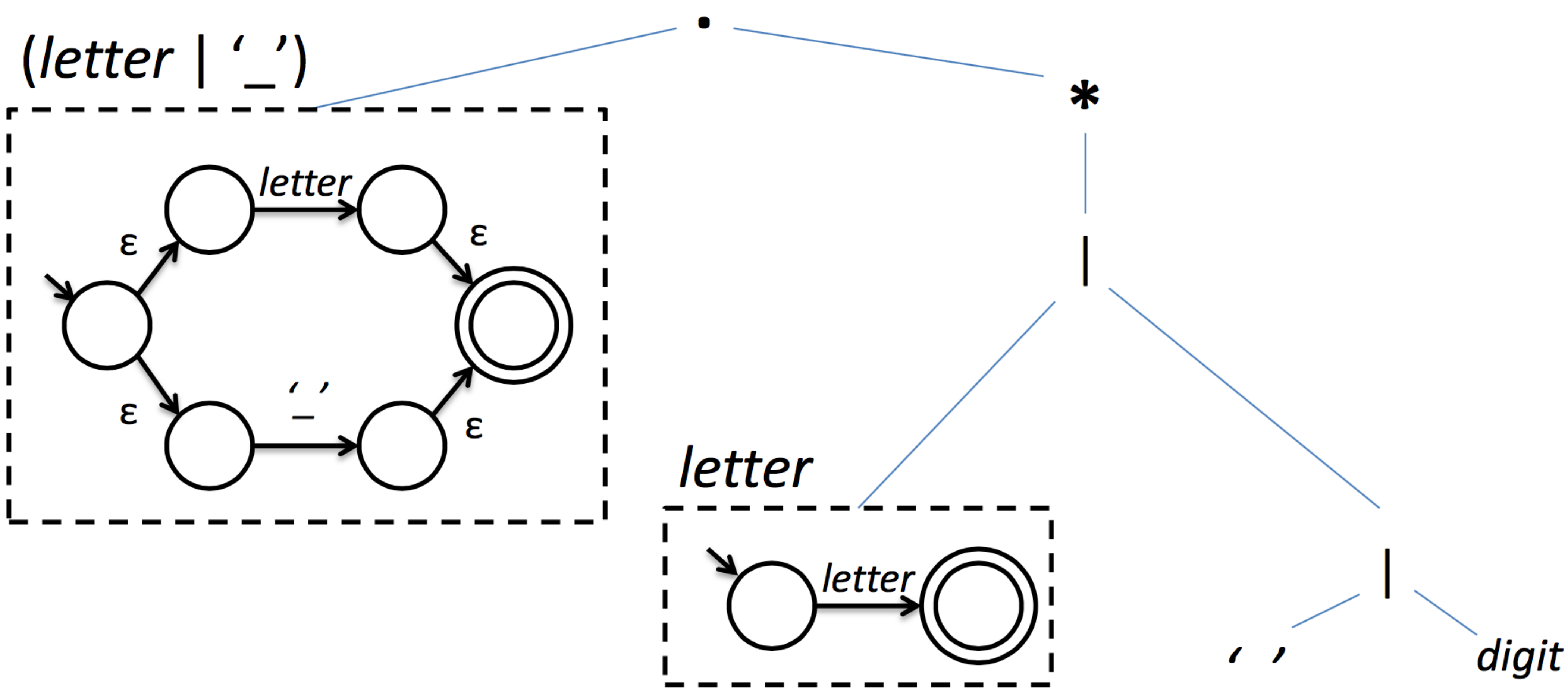
Bottom-up conversion



Bottom-up conversion



Bottom-up conversion



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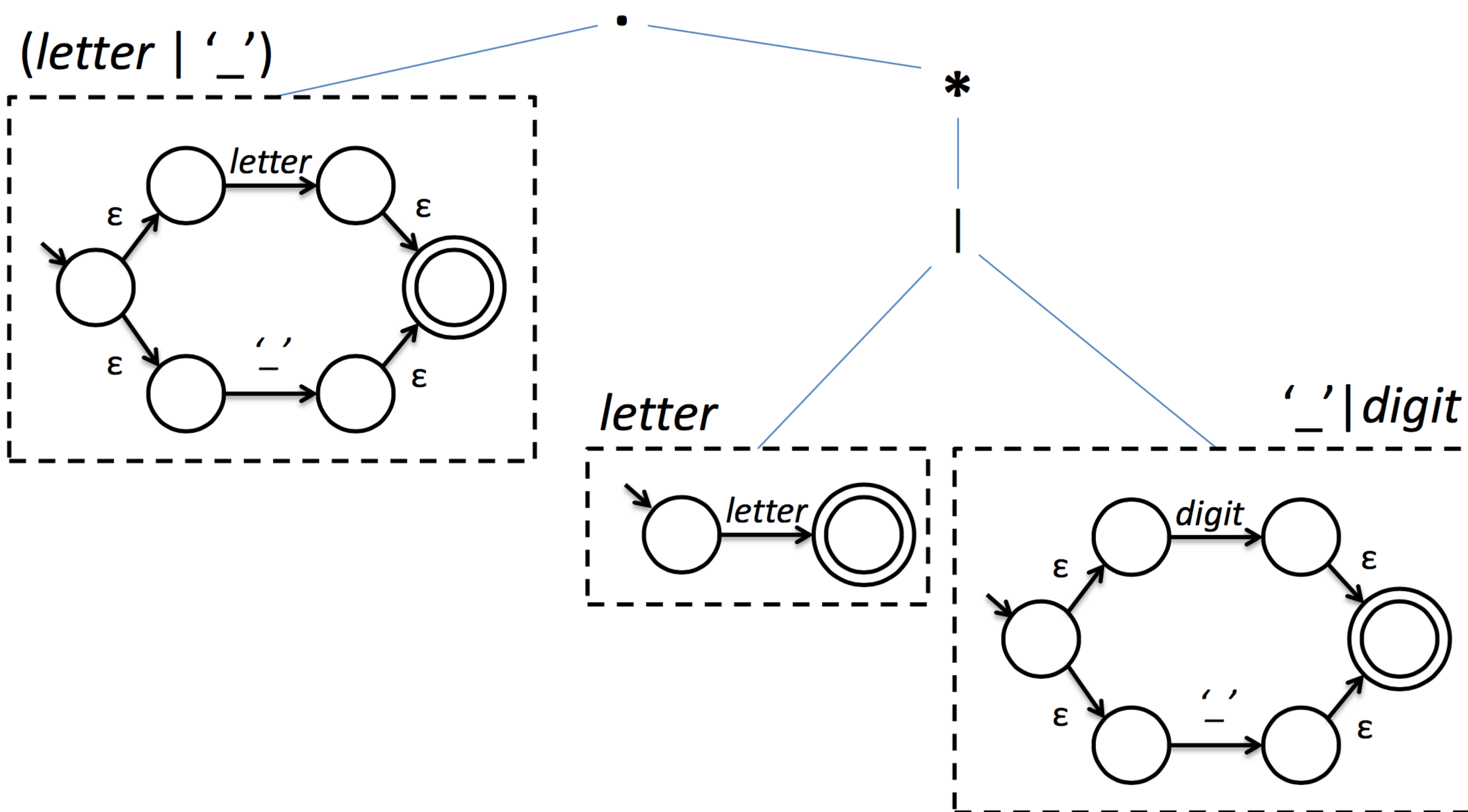
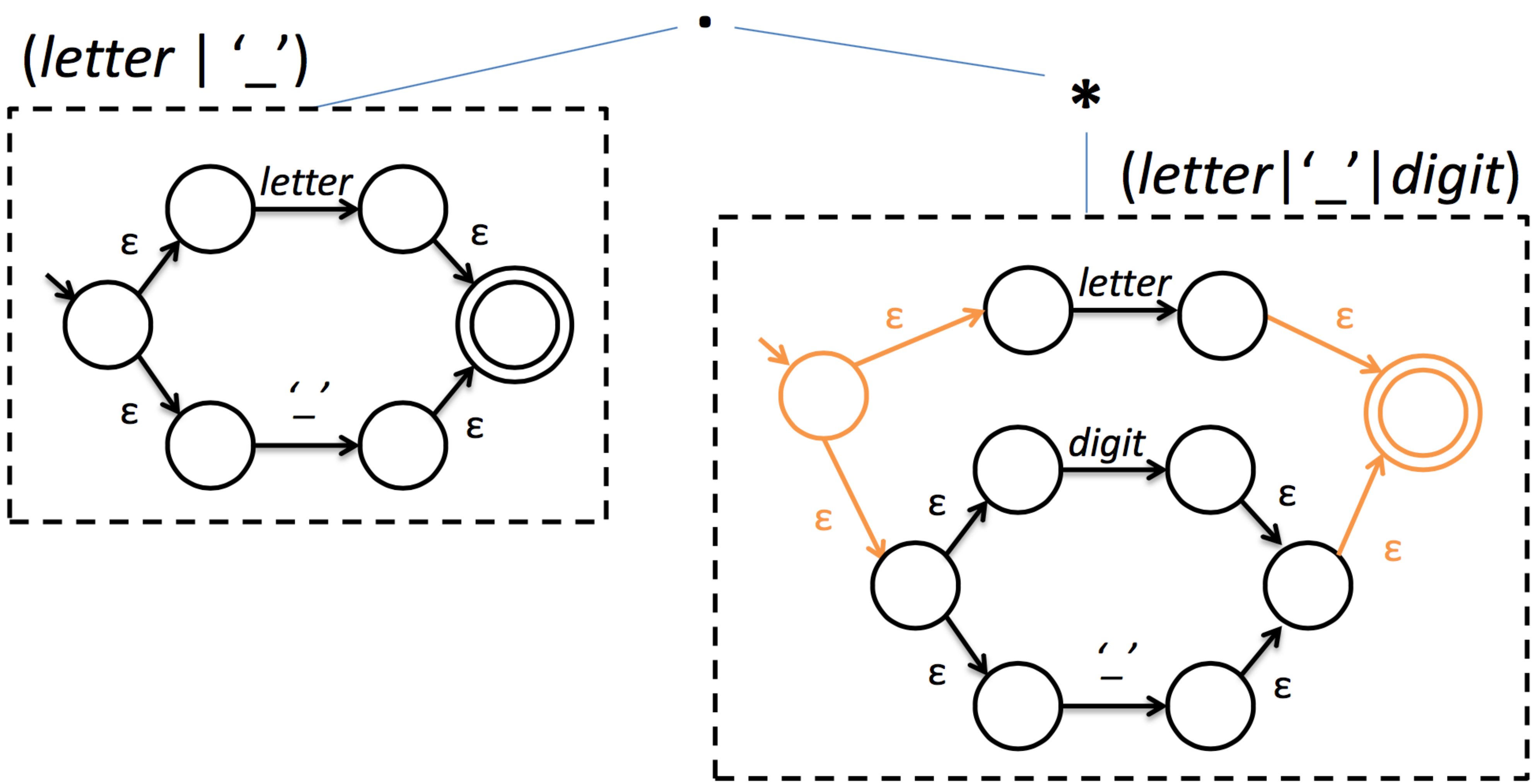
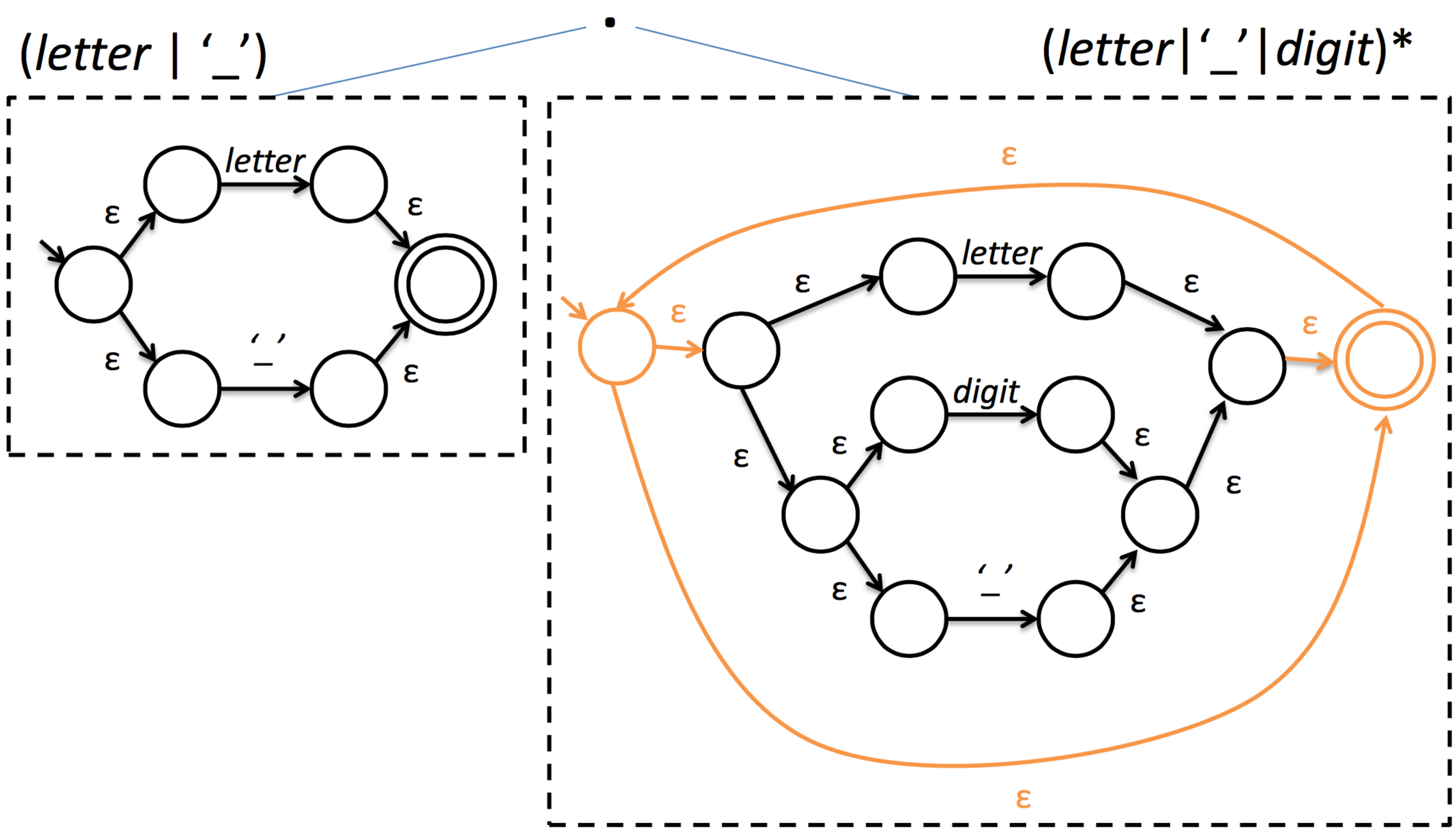


Bottom-up conversion

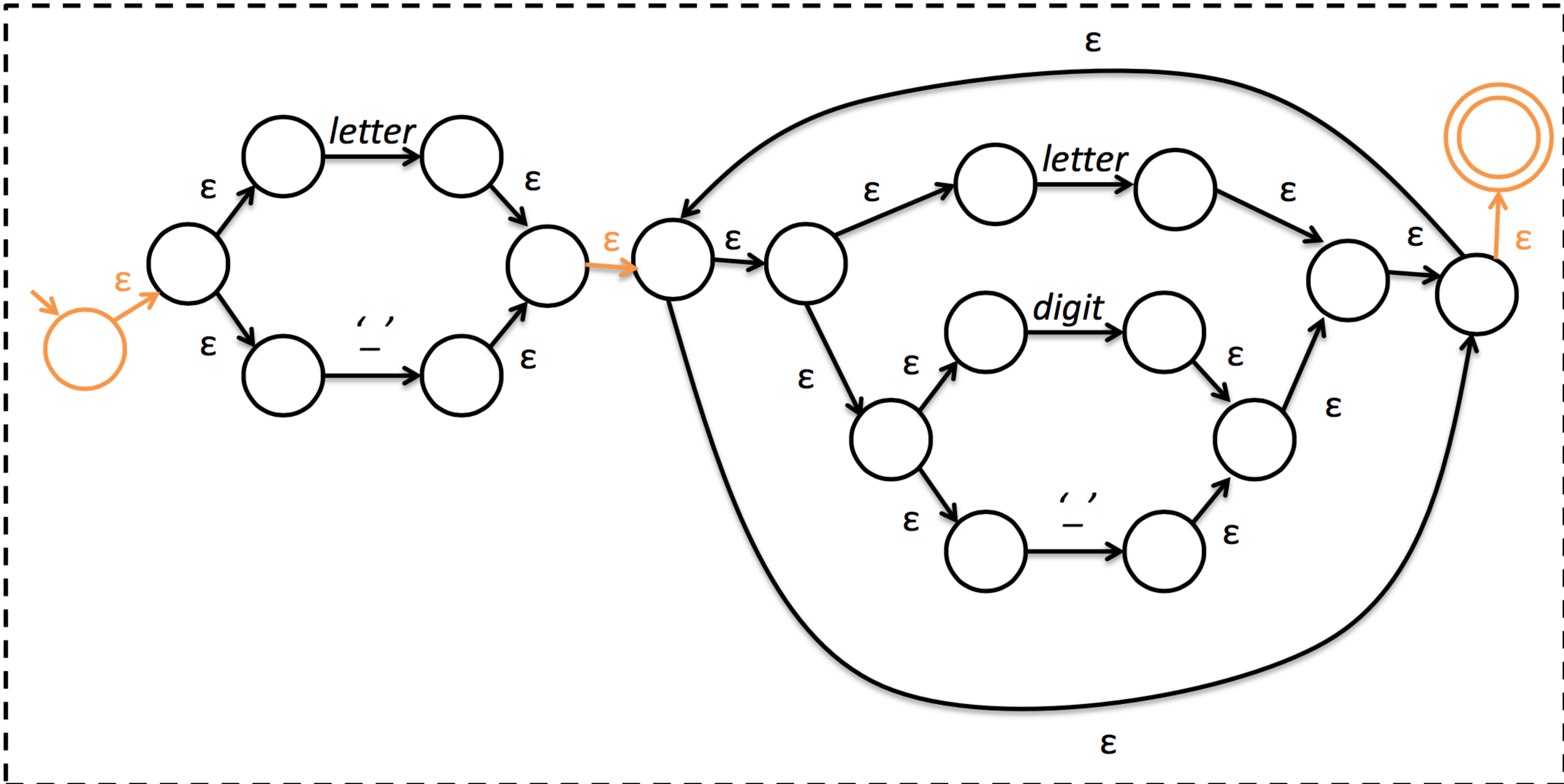


Bottom-up conversion



Bottom-up conversion

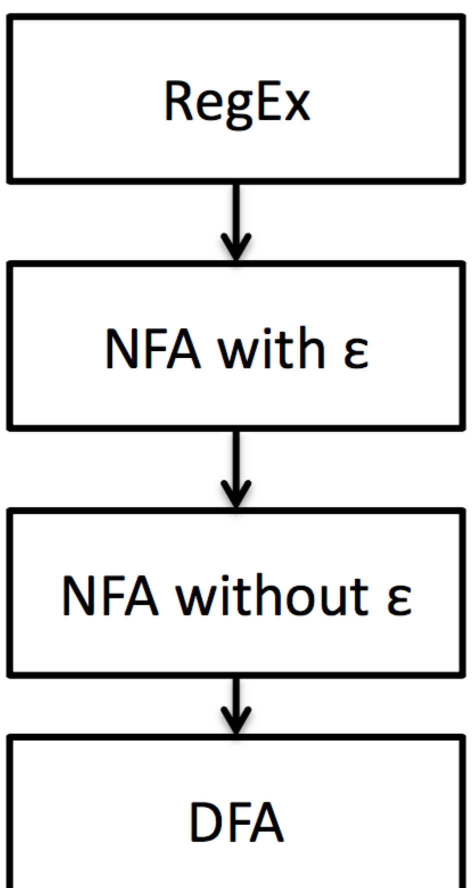
(*letter* | '_')(*letter*|'_'|*digit*)*



Regexp to DFAs

We now have an NFA

We need to go to DFA

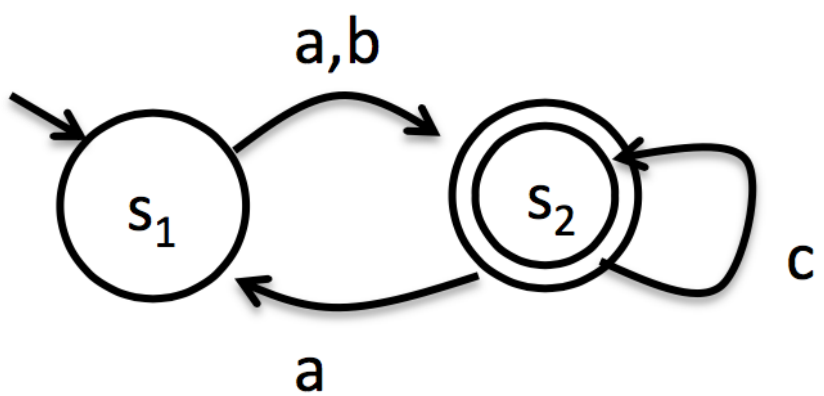


But what's so great about DFAs?

Table-driven DFAs

Recall that δ can be expressed as a table

This leads to a very efficient array representation



	a	b	c
s_1	s_2	s_2	
s_2	s_1		s_2

```
s = start state
while (more input){
  c = read char
  s = table[s][c]
}
if s is final, accept
```

FSMs for tokenization

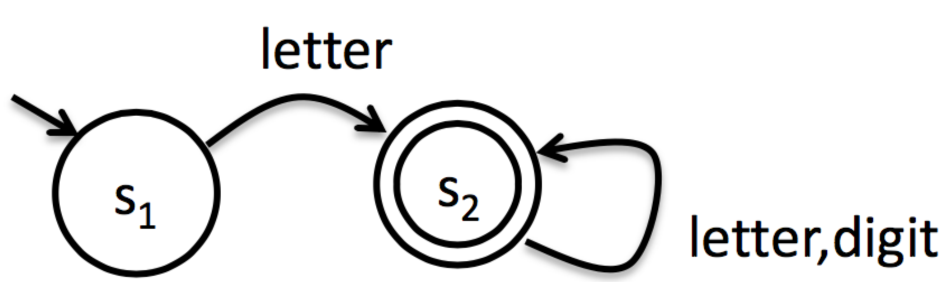
FSMs only check for language membership of a string

- the scanner needs to recognize a stream of many different tokens using the longest match
- the scanner needs to know what was matched

Idea: imbue states with actions that will fire when state is reached

A first cut at actions

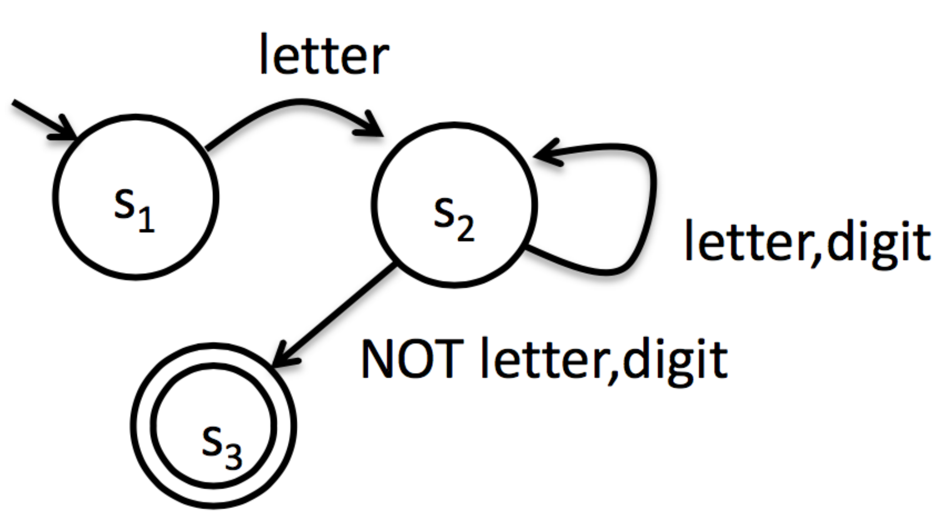
Consider the language of Pascal identifiers



State	Actions
s_2	return ID

BAD: not longest match

Accounting for longest matches

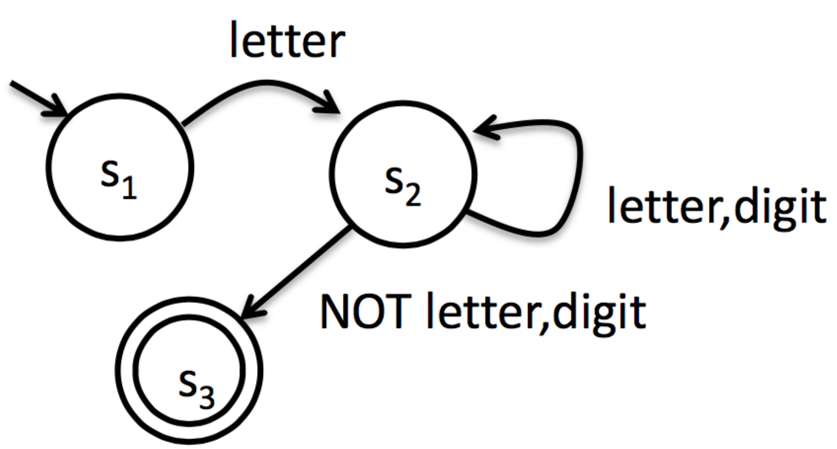


State	Actions
s_3	return ID

BAD: maybe we needed that character

A second take at actions

Give our FSMs ability to put chars back



State	Actions
s_3	Put 1 char back, return ID

Our first scanner

Consider a language with two statements

assignments: `ID = expr`

increments: `ID += expr`

where `expr` is of the form

`ID + ID`

`ID ^ ID`

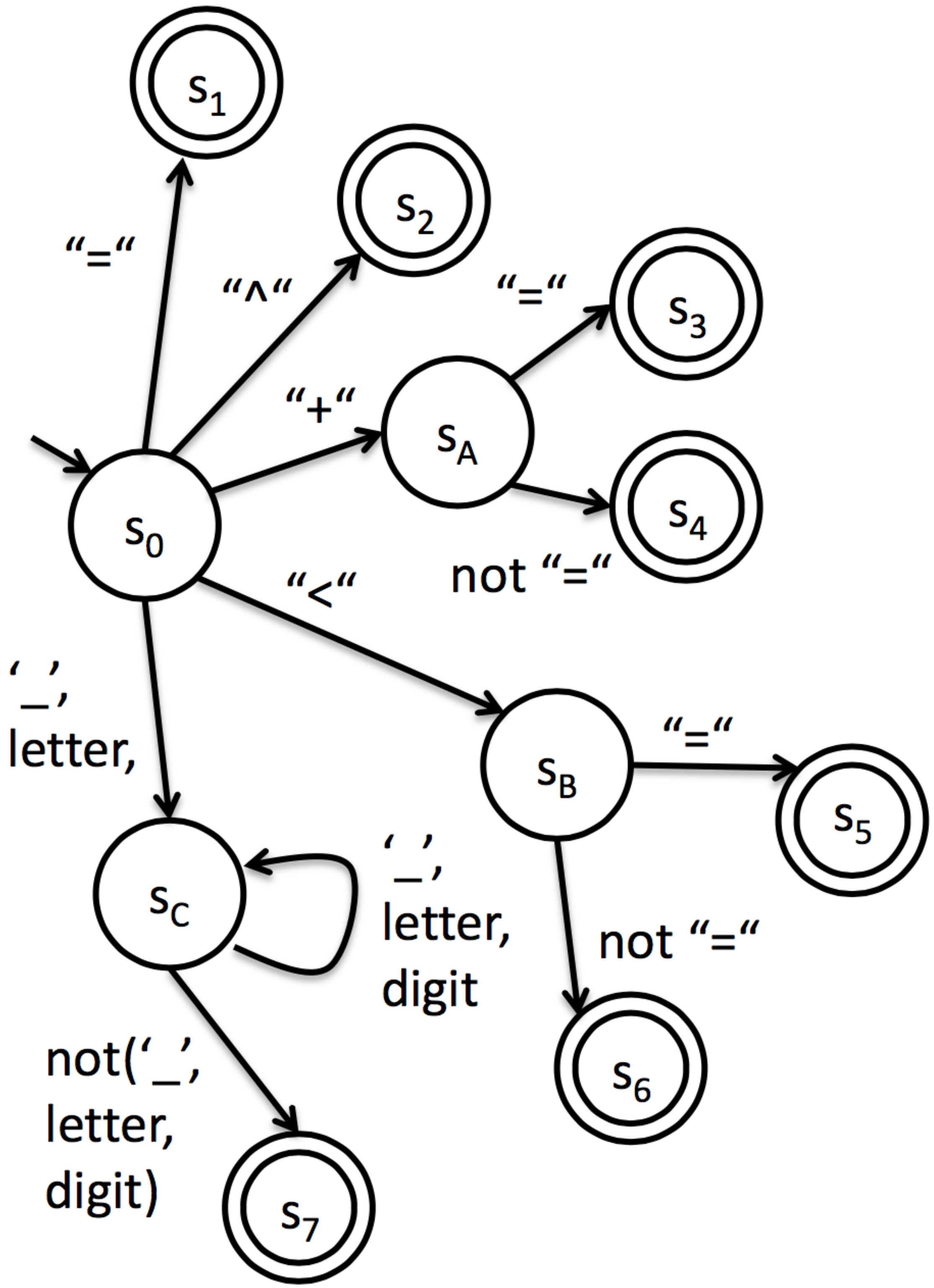
`ID < ID`

`ID <= ID`

Identifiers ID follow C conventions

Token name	Regular Expression
ASSIGN	“=“
INC	“+=“
PLUS	“+”
EXP	“^”
LT	“<“
LEQ	“<=“
ID	(*letter*|_)(*letter*|*digit*|_)*

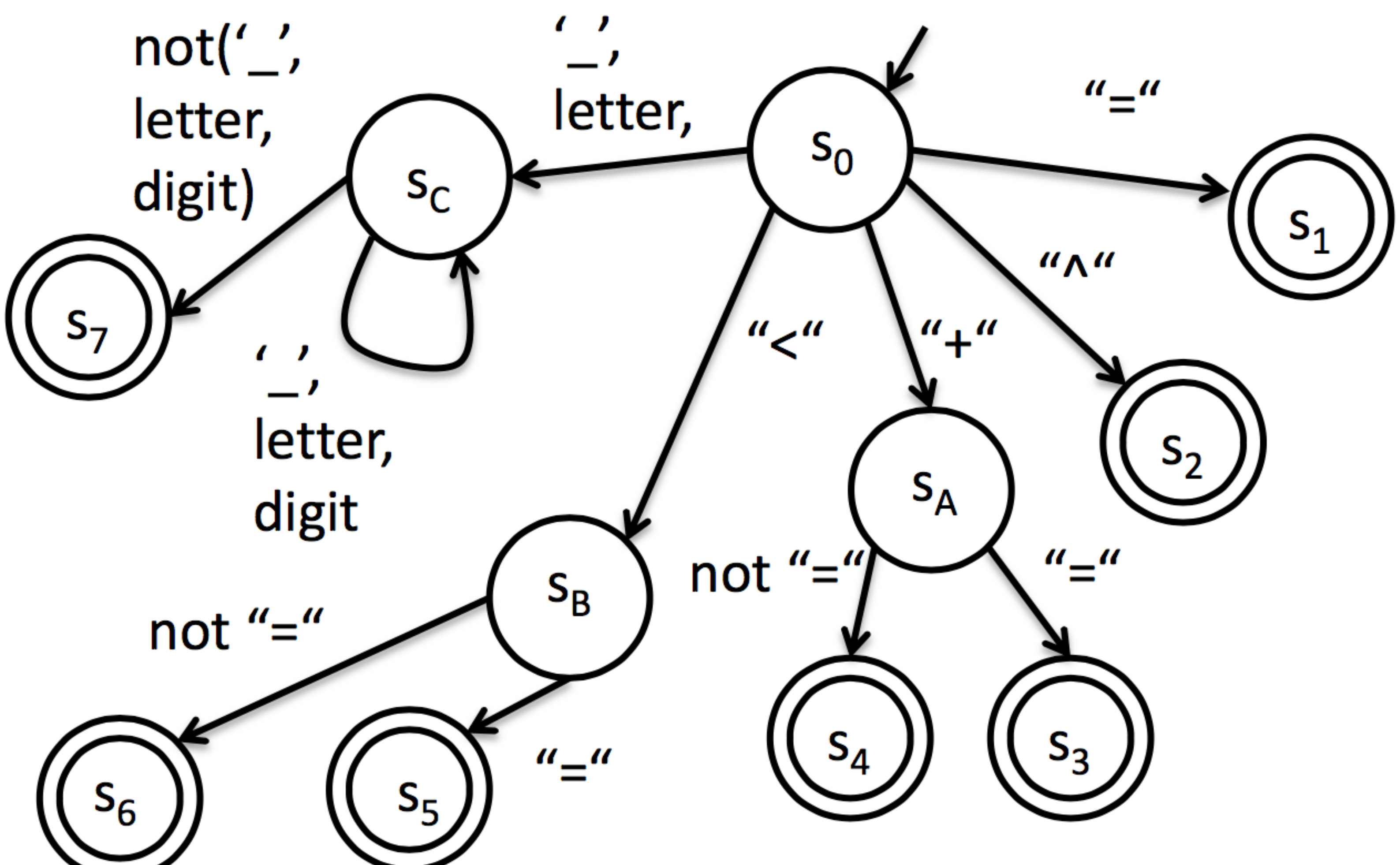
Combined DFA



Token name	Regular Expression
ASSIGN	“=“
INC	“+=“
PLUS	“+”
EXP	“^”
LT	“<“
LEQ	“<=“
ID	(*letter*|_)(*letter*|*digit*|_)*

State	Action
S1	return ASSIGN
S2	return EXP
S3	return INC
S4	put back 1 char, return PLUS
S5	Return LEQ
S6	put back 1 char, return LT
S7	put back 1 char, return ID

	=	+	^	<	_	letter	digit	EOF	none
S_0	Ret ASSIGN	S_A	Ret EXP	S_B	S_C	S_C		Ret EOF	
S_A	Ret INC	Back 1, Ret PLUS	Back 1, Ret PLUS	Back 1, Ret PLUS	Back 1, Ret PLUS	Back 1, Ret PLUS	Back 1, Ret PLUS	Back 1, Ret PLUS	Back 1, Ret PLUS
S_B	Ret LEQ	Back 1, Ret LT	Back1, Ret LT	Back 1, Ret LT	Back 1, Ret LT	Back 1, Ret LT	Back 1, Ret LT	Back 1, Ret LT	Back 1, Ret LT
S_C	Back 1, Ret ID	Back 1 Ret ID	Back 1, Ret ID	Back 1, Ret ID	S_C	S_C	S_C	Back 1, Ret ID	Back 1, Ret ID



	=	+	^	<	_	letter	digit	EOF	none
S_0	Ret ASSIGN	S_A	Ret EXP	S_B	S_C	S_C		Ret EOF	
S_A	Ret INC	Back 1, Ret PLUS	Back 1, Ret PLUS	Back 1, Ret PLUS	Back 1, Ret PLUS	Back 1, Ret PLUS	Back 1, Ret PLUS	Back 1, Ret PLUS	Back 1, Ret PLUS
S_B	Ret LEQ	Back 1, Ret LT	Back1, Ret LT	Back 1, Ret LT	Back 1, Ret LT	Back 1, Ret LT	Back 1, Ret LT	Back 1, Ret LT	Back 1, Ret LT
S_C	Back 1, Ret ID	Back 1 Ret ID	Back 1, Ret ID	Back 1, Ret ID	S_C	S_C	S_C	Back 1, Ret ID	Back 1, Ret ID

```
do{
  read char
  perform action / update state
if (action was to return a token){
          start again in start state
  }
} (while not EOF or stuck);
```

Lexical analyzer generators

aka scanner generators

The transformation from regexp to scanner is formally defined

Can write tools to synthesize a lexer automatically

- Lex: unix scanner generator
- Flex: fast lex
- JLex: Java version of Lex

JLex

Declarative specification

tell it what you want scanned, it will figure out the rest

Input: set of regexps + associated actions

`xyz.jlex` file

Output: Java source code for a scanner

`xyz.jlex.java` source code of scanner

jlex format

3 sections separated by %%

- user code section
- directives
- regular expressions + actions

```
//User Code Section (uninterpreted  java code)

%%

//Directives Section

DIGIT = [0-9]
LETTER = [a-zA-Z]                 Macro definitions
WHITESPACE = [\040\t\n]

%state SPECIALINTSTATE            State declaration

//Configure for use with java CUP (Parser generator)
%implements java_cup.runtime.Scanner
%function next_token
%type java_cup.runtime.Symbol

//End of file behavior
%eofval{
System.out.println("All done");
return null;
%eofval}

//Turn on line counting
%line

%%

//Regular Expression rules
```

Rules section

Format is <regex>{code} where regex is a regular expression for a single token

- can use macros from the directive sections in regex, surround with curly braces

Conventions

- chars represent themselves (except special characters)
- chars inside “” represent themselves (except \)

Regexp operators

- | * + ? () .

Character class operators

- \- range
- ^ not
- \ escape

```
“=“                 { System.out.println(yyline + 1 + “: ASSIGN”); }
“+”                 { System.out.println(yyline + 1 + “: PLUS”); }
“^”                 { System.out.println(yyline + 1 + “: EXP”); }
“<”                 { System.out.println(yyline + 1 + “: LT”); }
“+=”                 { System.out.println(yyline + 1 + “: INC”); }
“<=”                 { System.out.println(yyline + 1 + “: LEQ”); }
{WHITESPACE}        { }
({LETTER}|”_”)({DIGIT}|{LETTER}|”_”)* {
                    System.out.println(yyline+1 + “: ID “ + yytext());}
.                   { System.out.println(yyline + 1 + “: badchar”); }
```