Lexical Analysis
Programming Languages

Sujit Kumar Chakrabarti

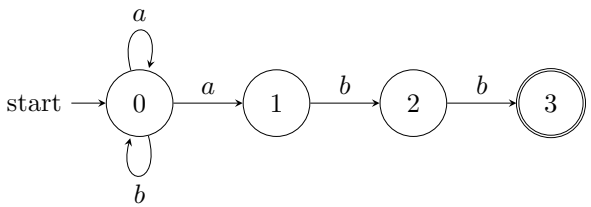
IIITB

Finite State Automata (FSA)

1. Non-deterministic FSA
2. Deterministic FSA

Non-Deterministic FSA (NFA)

Example 1



Language: $(a|b) \star abb$

Non-Deterministic FSA (NFA)

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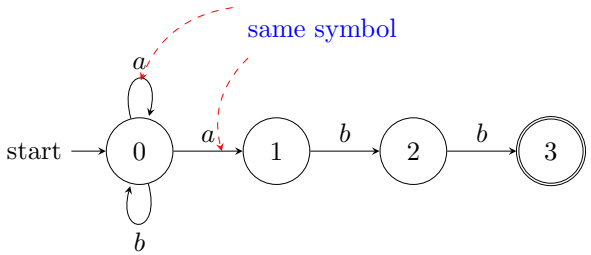

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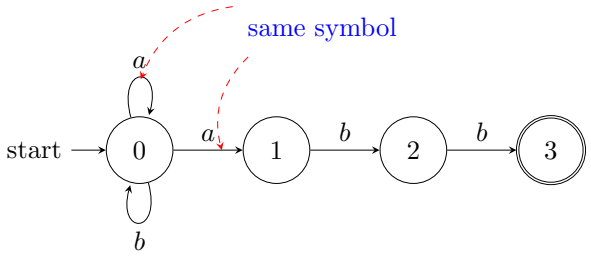

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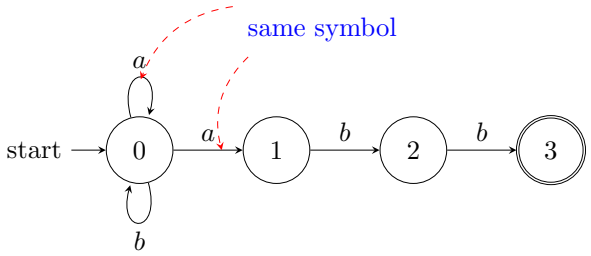

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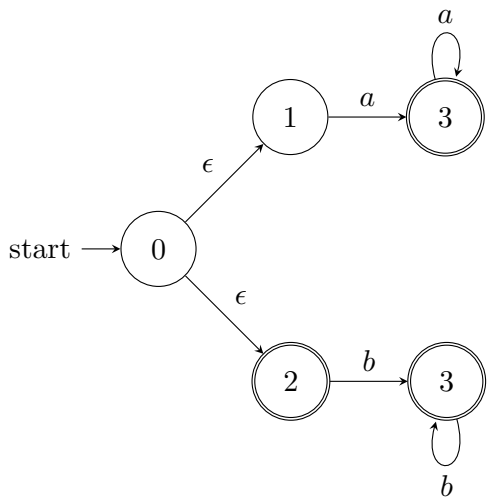
Non-Deterministic FSA (NFA)

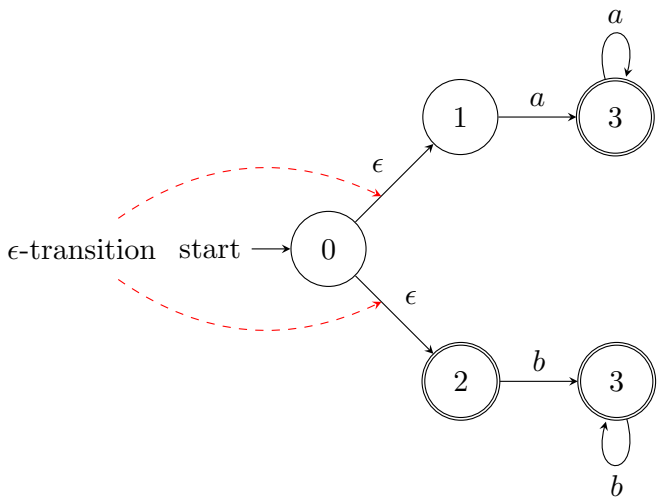
Example 2



Language: $aa\star|bb\star$

Non-Deterministic FSA (NFA)

Example 2



Language: $aa\star|bb\star$

Non-Deterministic FSA (NFA)

- Finite set of states – (S)
- Alphabet - $(\sum)$
- Transition function $(T : S \times \sum \rightarrow 2^S)$
- Initial state (S_0)
- Final/accepting states $(F \subseteq S)$

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Specific Properties

- The same state can transition to more than one states on the same symbol
- ϵ-transitions

Deterministic FSA (DFA)

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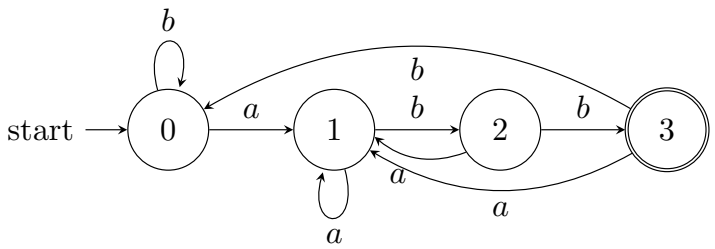
Specific Properties

- Only one next-state on the same symbol
- No ϵ-transitions

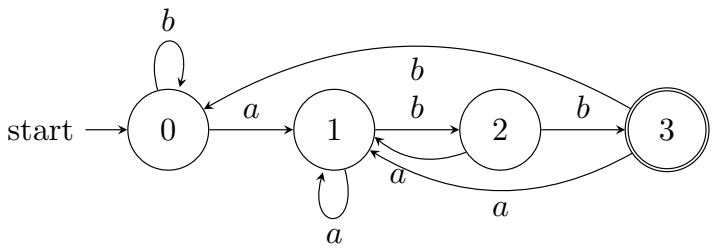
Deterministic FSA (DFA)

Example 1



Deterministic FSA (DFA)

Example 1



Language:

Deterministic FSA (DFA)

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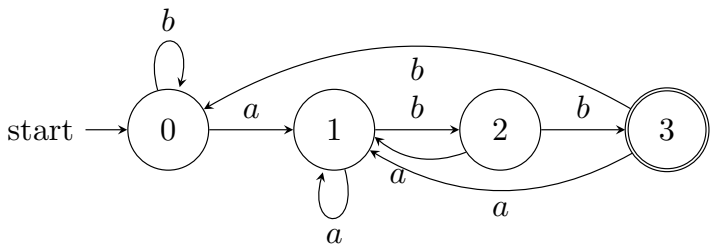

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NFA and DFA

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- NFAs: Often more readable
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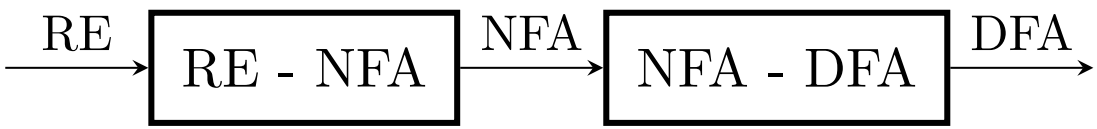
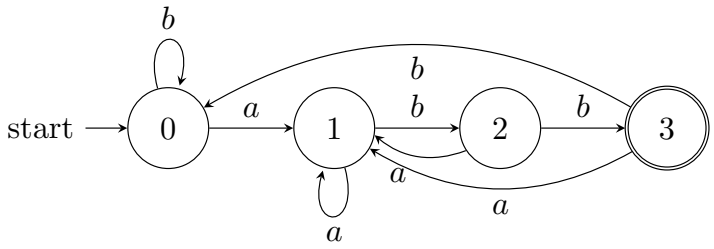
- DFAs: Less readable
- DFAs: Larger number of states
- DFAs: Faster to simulate
- Equally expressive $\equiv$ Regular expressions (Regular languages)

Lexical Analysis Process



Simulating FSAs

Representating transition function using transition tables



Transition Table:

State	a	b
0		
1		
2		
3		

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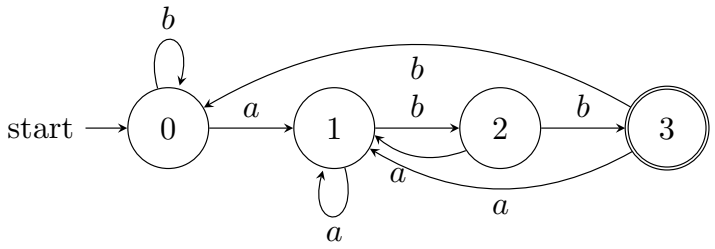

Transition Table:

State	a	b
0	1	0
1	1	2
2	1	3
3	1	0

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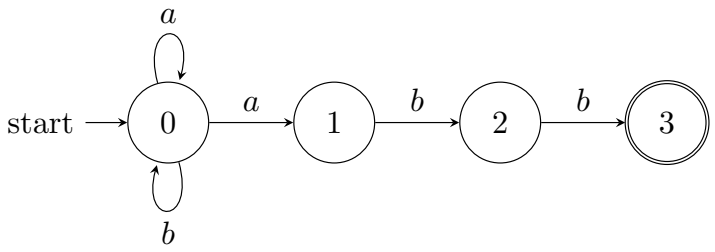

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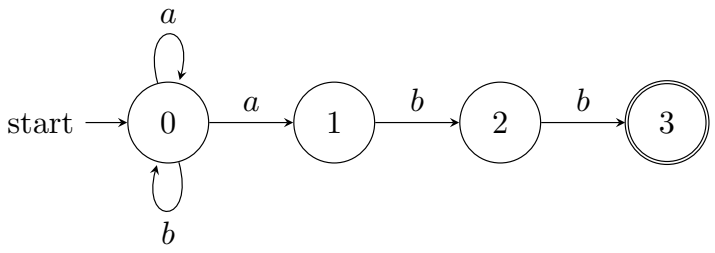


Transition Table:

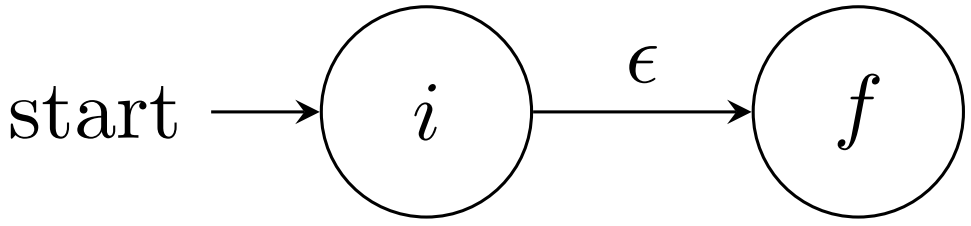
State	a	b
0	{0, 1}	{0}
1	{}	{2}
2	{}	{3}
3	{}	{}

NFA from Regular Expressions

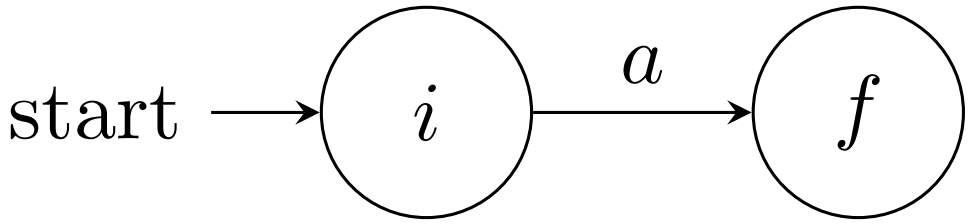
McNaughton-Yamada-Thompson Algorithm

Basis

ϵ



$a \in \sum$



Simulation of DFA

procedure SIMDFA(D, inp)

Simulation of DFA

```
procedure simDFA(D, inp)
    s ← D.s0
    while there is input left do
        c ← nextChar
        s ← D.move(s, c)
        if s = nil then
            break
        end if
    end while
    if s ∈ D.F then
        return true
    else
        return false
    end if
end procedure
```

Simulation of NFA

procedure SIMNFA(N, inp)

Simulation of NFA

procedure SIMNFA(N, inp)
    $S \leftarrow \epsilon$-CLOSURE($N.s_0$)
    $c \leftarrow$ NEXTCHAR
    while there is input left **do**
        $T' \leftarrow$ MOVE(S, c)
        $S \leftarrow \epsilon$-CLOSURE(T')
        $c \leftarrow$ NEXTCHAR
    end while
    if $S \cap N.F \neq \{\}$ **then**
        return true
    else
        return false
    end if
end procedure

Computing ϵ-closure

procedure ϵ-CLOSURE(s)

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    $stack \leftarrow$ COPY(s)
    $ep \leftarrow$ COPY(s)
    while $stack$ is not empty **do**
        $t \leftarrow stack$.POP
        $U \leftarrow \{u : u \in M.Trans[t, \epsilon]\}$
        for $u \in U$ **do**
            if $u \notin ep$ **then**
                ep.ADD(u)
                $stack$.PUSH(u)
            end if
        end for
    end while
    return ep
end procedure

NFA to DFA

procedure NFA2DFA(N)

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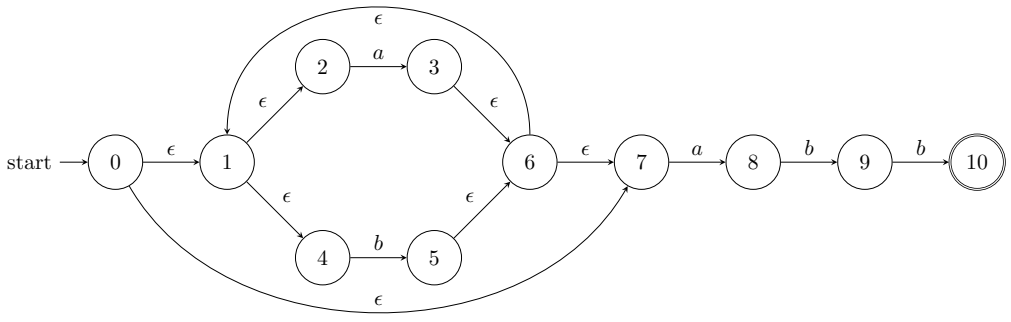
procedure NFA2DFA(N)
    $s'_0 \leftarrow \epsilon$-CLOSURE($N.s_0$)
    add s'_0 to $D.states$
    UNMARK(s'_0)
    while there is unmarked state T in $D.states$ **do**
        MARK(T)
        for all $a \in \sum$ **do**
            $T' \leftarrow$ MOVE(T, a)
            $\mathcal{U} \leftarrow \epsilon$-CLOSURE($T'$)
            if $\mathcal{U} \notin D.states$ **then**
                add $\mathcal{U}$ to $D.states$
                UNMARK($\mathcal{U}$)
            end if
        end for
    end while
    return D
end procedure

NFA to DFA

Example

NFA:



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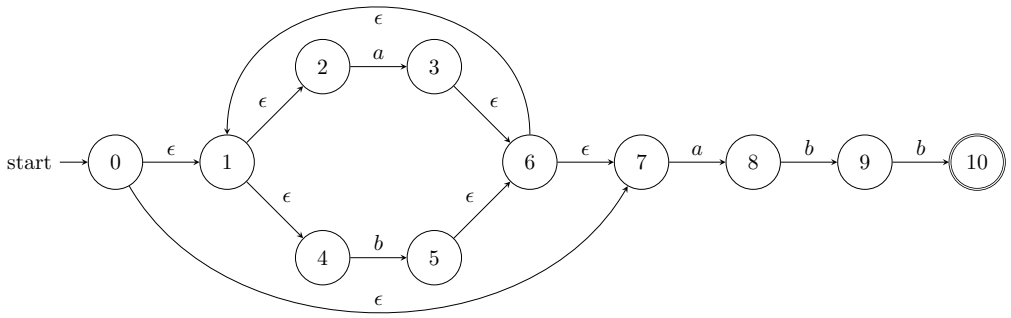
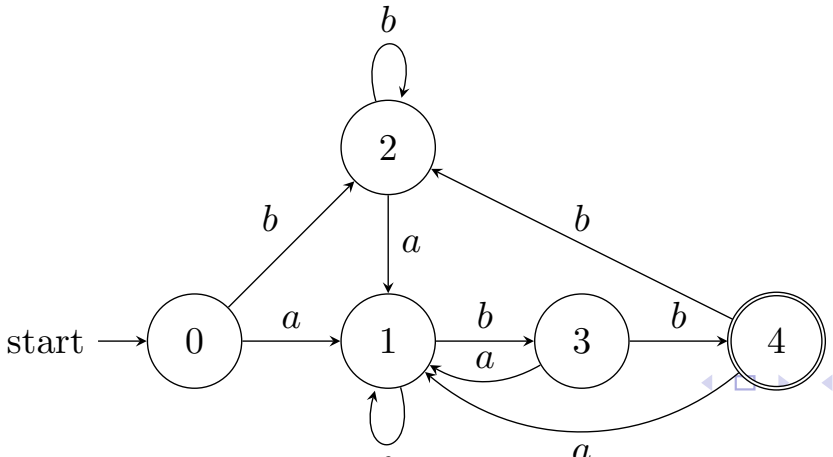
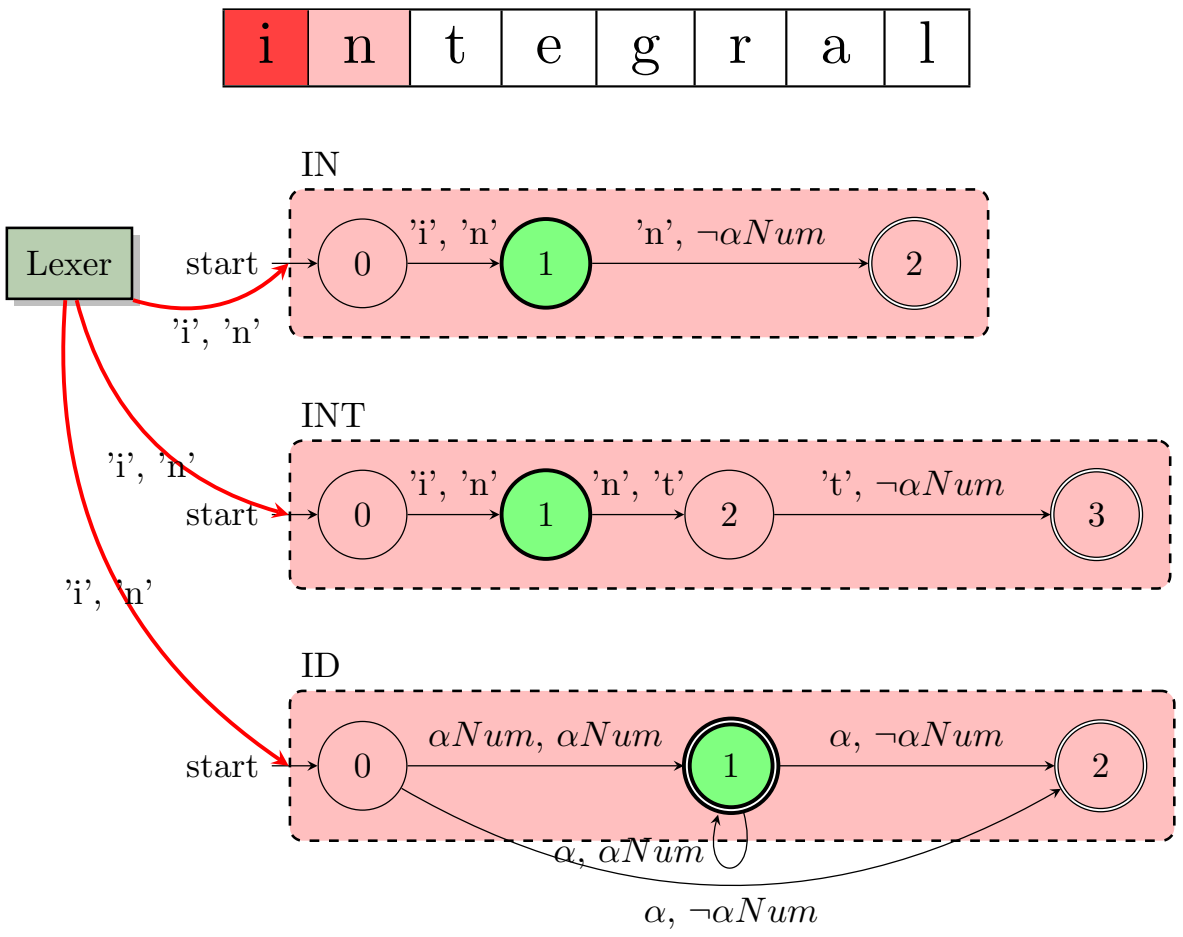


DFA:



Implementation of Lexical Analysis

Manual Implementation of Lexical Analysers – Example



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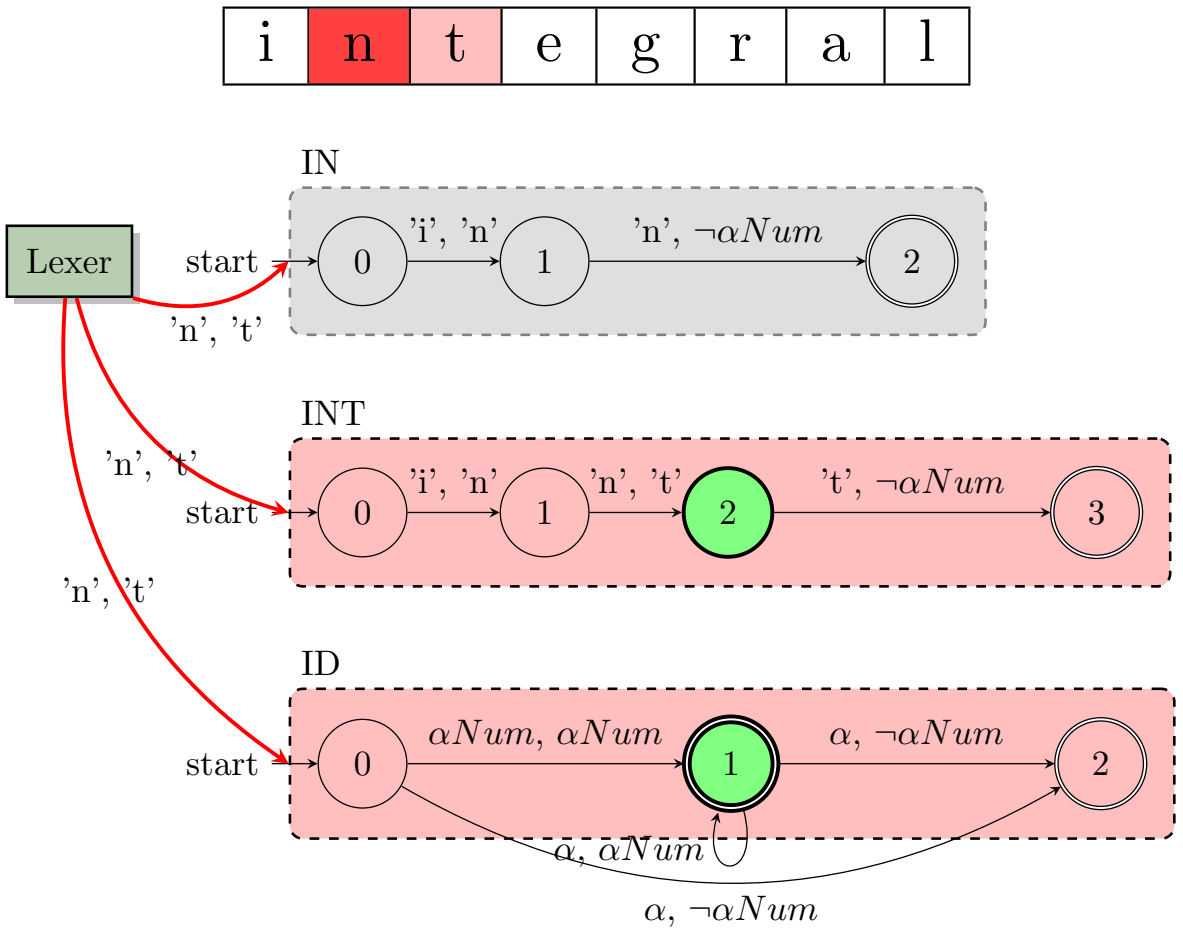

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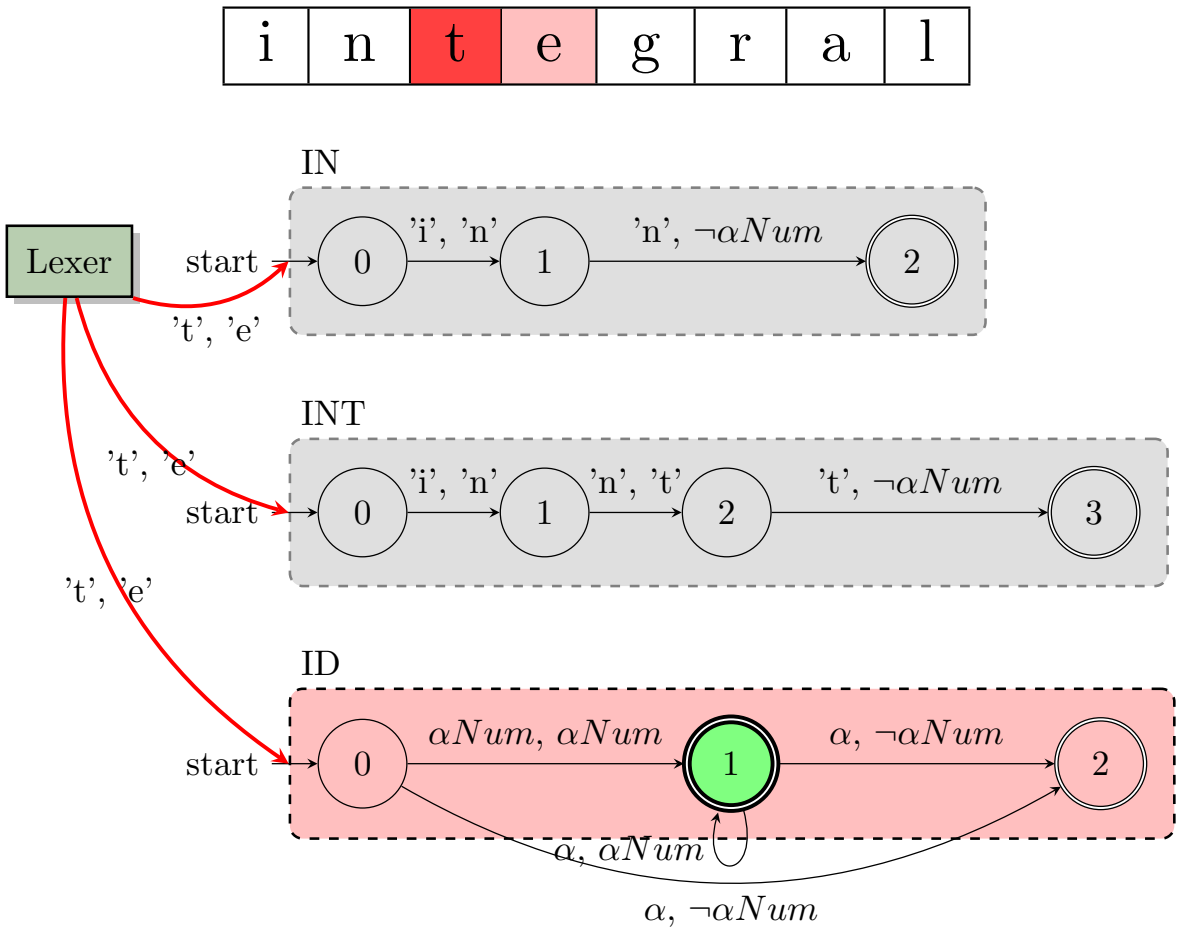

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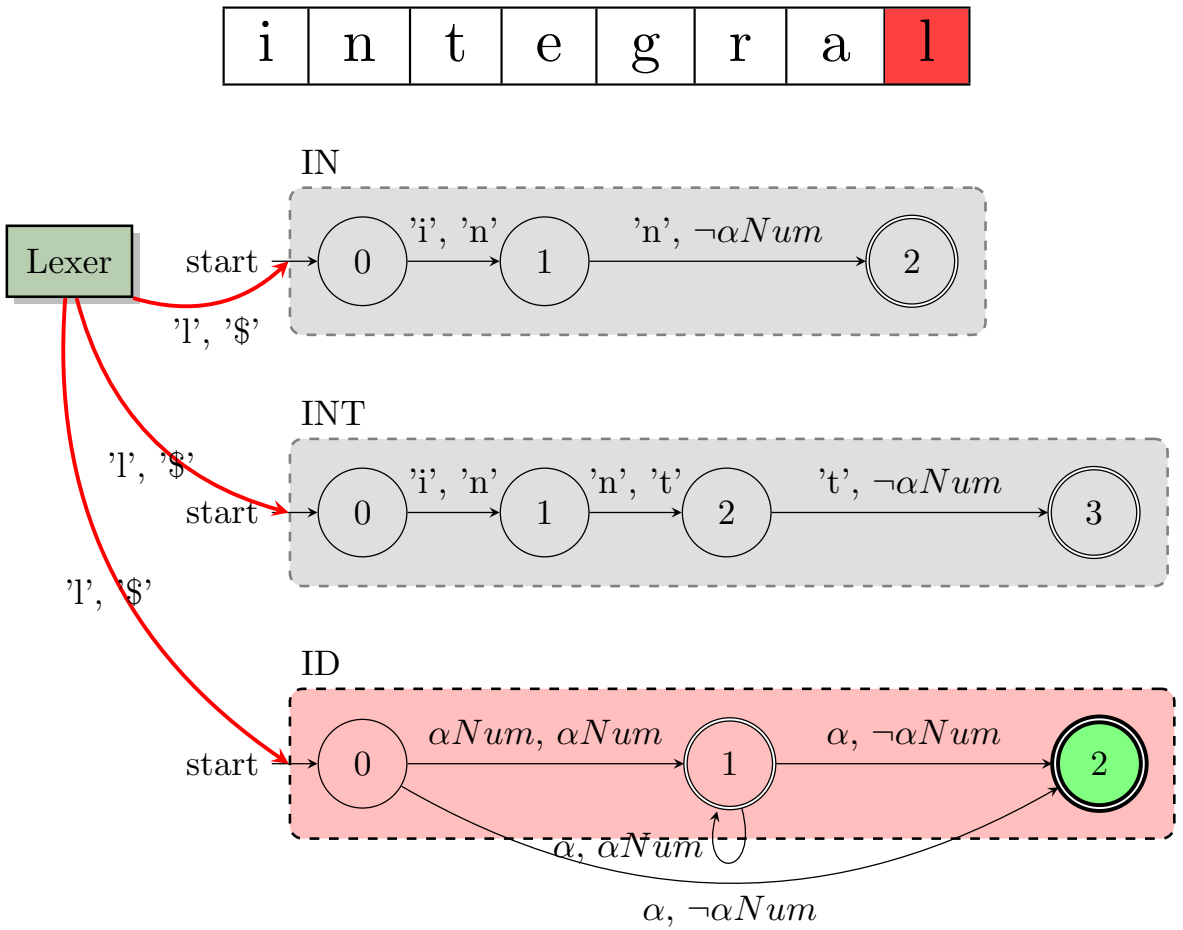


Implementation of Lexical Analysis

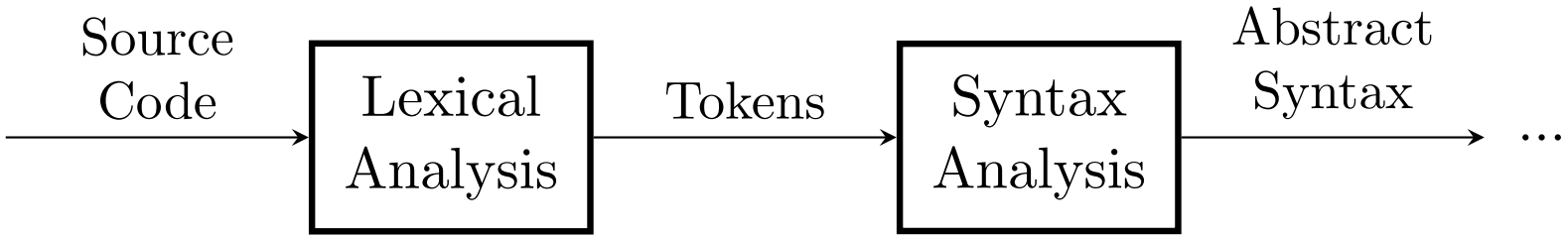
Manual Implementation of Lexical Analysers

Important Points

1. The scanners must be ordered carefully.
2. Alternative design.
   - No separate scanner for keywords
   - Maintain a table of keywords
   - On detecting an identifier, check if it's a keyword. If yes, return suitable token. Otherwise, return identifier.

Implementation of Lexical Analysis

Automatic Generation of Lexical Analysers



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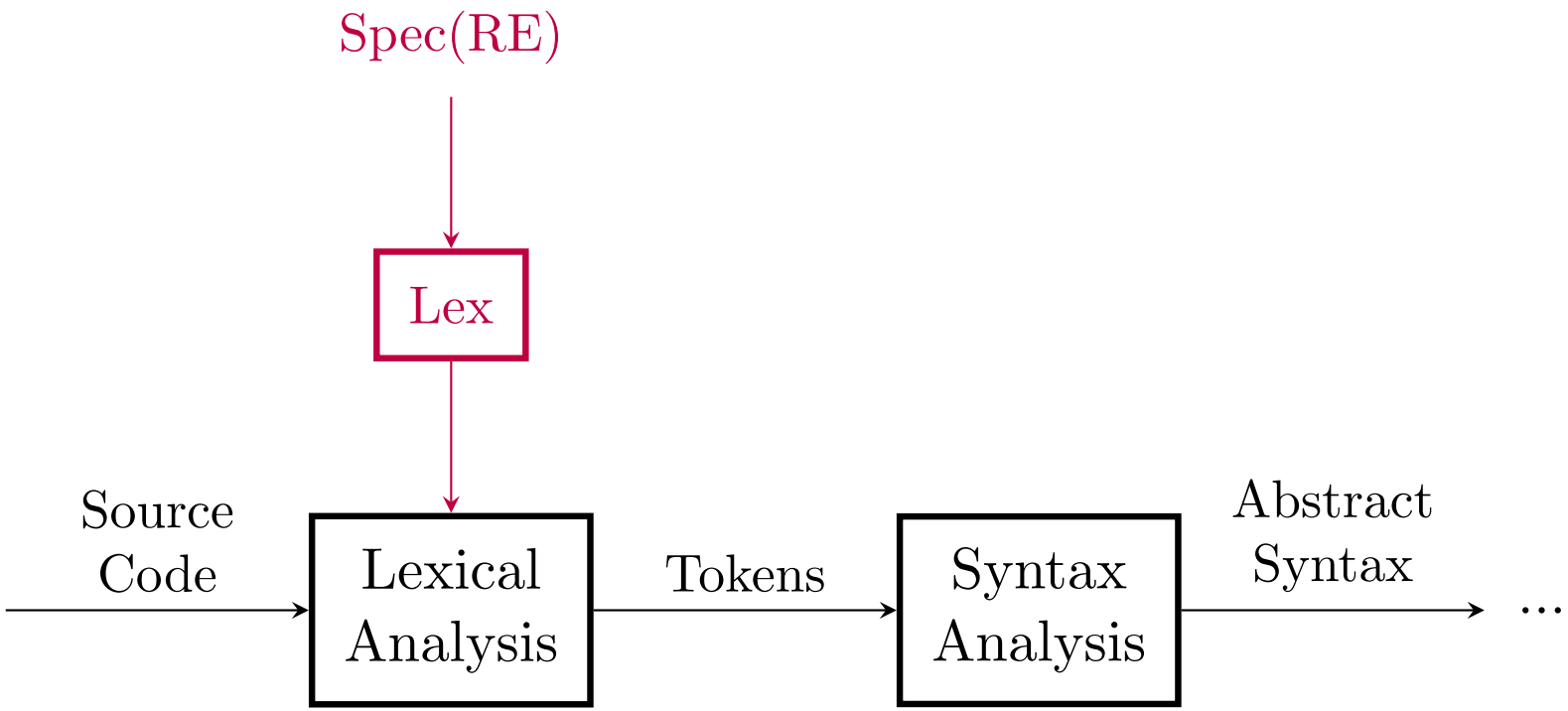

Implementation of Lexical Analysis

Automatic Generation of Lexical Analysers