Lecture 2: Static Analysis Principles – Lexical and Syntactical Language Analysis

Passive Testing Techniques for Communication Protocols

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Outline

Goal & Motivation

Lexical Analysis using Finite State Automata / Regular Expressions

Syntactical Analysis with Context Free Grammars

STATIC ANALYSIS

```
/*Test equal distribution of random number generation algorithm*/
#include <stdio.h>
#include <stdlib.h>
#define NUM 30
#define MEM_SIZE 512*1024 //512MB
int main()
{
        long i = 0 , j;
        short acc = 0;
        if(!numbers)
        {
                printf(``Can't allocate memory\n'');
                exit(-1);
        }
        while (1)
        {
                numbers[i] = rand() % NUM ;  //random numbers from 0 - NUM
                acc = 0;
                for (j = 0; j < i; j++)
                        acc += numbers[j];
                printf(``New average: %ld\n'',  acc/++i); //should converge to NUM/2
        }
}
```

Do you see any problems with this code?

Static Analysis (cont.)

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See how hard it is? :)

Static Analysis Principles

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- The analysis (performed by a program) of code without executing the program

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Static Analysis is?..

- The analysis (performed by a program) of code without executing the program
- Not looking for lexical, syntactical, or *type* errors that a compiler finds, i.e., the code is assumed to be compilable

Static Analysis Principles (cont.)

How do we analyze source code then?

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How to structure code: A natural language comparison

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- A language can produce sentences. Sentences are structured; composed by words

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How to structure code: A natural language comparison

- A language can produce sentences. Sentences are structured; composed by words
- How to recognize allowed words in a language?

Lexical Analysis

using Deterministic Finite Automata (DFA) and Regular Expressions (RE)

LEXICAL ANALYSIS

DFA and RE equivalence

Lexical Analysis

DFA and RE equivalence

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Lexical Analysis

DFA and RE equivalence

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DFA and RE equivalence

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- There is a way to go from one to the other, describing the same language

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Let's start with regular expressions…

REGULAR EXPRESSIONS

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Example

Over the alphabet $\{0, 1, 2, 3, 4, 5, 6, 7, 8, 9\}$,
$(1|2|3|4|5|6|7|8|9)(0|1|2|3|4|5|6|7|8|9)^*$

Regular expressions (cont.)

Generating from $(1|2|3|4|5|6|7|8|9)(0|1|2|3|4|5|6|7|8|9)^*$

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- $(1|2|3|4|5|6|7|8|9) \mapsto 8$
  $8(0|1|2|3|4|5|6|7|8|9)^*$

REGULAR EXPRESSIONS (CONT.)

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Remarks on generation

- Can be non-deterministic, applying different rules will produce different results
- Our goal is to describe language with a regular expression

Exercises with REs

What language the RE describes?

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Create the RE such that…

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Create the RE such that…

- It generates valid Binary Code Decimal (BCD) strings (In case you don't know, binary strings of length 4, representing digits, example: 1001 1000 0011 = 983, note that 1100 0000 0101 is not valid)

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  - $A = \{0, 1, \text{“ ”}\}$, RE = $100(1|0)|0(1|0)(1|0)(1|0)\text{“ ”}(100(1|0)|0(1|0)(1|0)(1|0)\text{“ ”})^*$

Short RE notations

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- $\{n\}$ represents exactly n occurrences of the preceding RE
  - e.g., for $A = \{a,b\}$, RE = $aaa(a|b)(a|b) \mapsto a\{3\}.\{2\}$

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- $\{m,n\}$ represents at least m, and at most n occurrences of the preceding RE
  - e.g., for $A = \{a,b\}$, RE = $(a|aa|aaa)b \mapsto a\{1,3\}b$

SHORT RE NOTATIONS (CONT.)

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- $[a_1 a_2 ... a_n]$ represents choice between all a_i
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- $[a_1 - a_n]$ represents choice between a range. Note that it only makes sense for ranges
  - e.g., $A = \{0, 1, 2, 3, 4, 5, 6, 7, 8, 9\}$, the RE $(0|1|2|3|4|5|6|7|8|9) \mapsto [0 - 9]$ (note it is different from $0| - |9$, $-$ has a special meaning inside brackets, useful for REs like $[a - z]$ or $[a - zA - Z]$, the later combined with the previous short notation)

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- $[\hat{}r]$ negation of r
  - e.g., $A = \{0, 1, 2, 3, 4, 5, 6, 7, 8, 9\}$, the RE $(1|2|3|4|5|6|7|8|9) \mapsto [\hat{}0]$ (note it is different from $0|\hat{}$ by using the "short OR")

Short RE notations – Final Remarks

In practice (not formal)...

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- The alphabet is usually omitted and assumed from the symbols appearing in the RE
  - e.g., the RE $[0-9]$ is assumed to have the alphabet $A = \{0, 1, 2, 3, 4, 5, 6, 7, 8, 9\}$

SHORT RE NOTATIONS – FINAL REMARKS

In practice (not formal)...

- The alphabet is usually omitted and assumed from the symbols appearing in the RE
  - e.g., the RE $[0-9]$ is assumed to have the alphabet $A = \{0, 1, 2, 3, 4, 5, 6, 7, 8, 9\}$
- REs are used for **pattern matching**, which means if a part of a string can be generated by the RE (or accepted by the equivalent automaton, more on this later), the string matches the pattern described by the RE. This leads to some notations, as: ^ to denote the beginning of the string, and $ for the end of the string.
  - e.g., the RE $\hat{}a. * b\$$ means anything that starts with a, and finishes with b

Exercises with short RE notations

What language the RE describes?

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- $[0-9]\{4\} - (0[1-9]|1[0-2]) - (0[1-9]|(1|2)[0-9]|3(0|1)$?

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  - Dates in the format yyyy-mm-dd (not well specified since it accepts 2016-02-31, for example)

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EXERCISES WITH SHORT RE NOTATIONS

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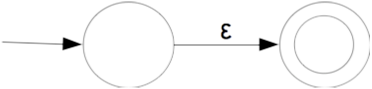
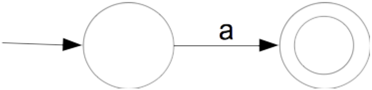


$a \in A$



CONVERTING REs TO NFA (CONT.)

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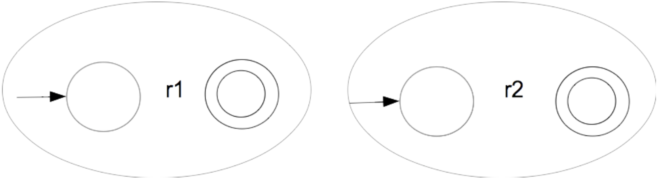

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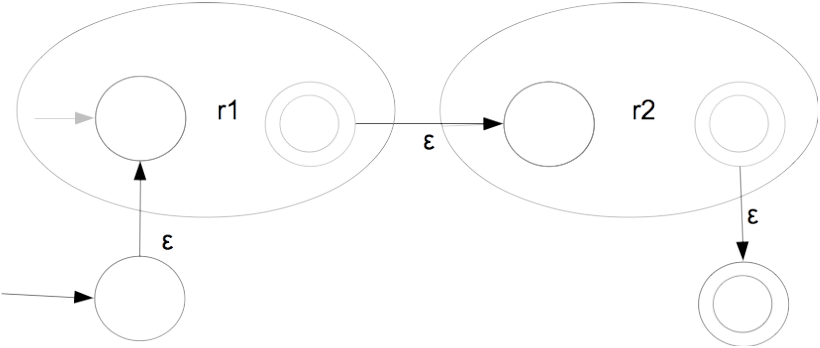

Converting REs to NFA (cont. 2)

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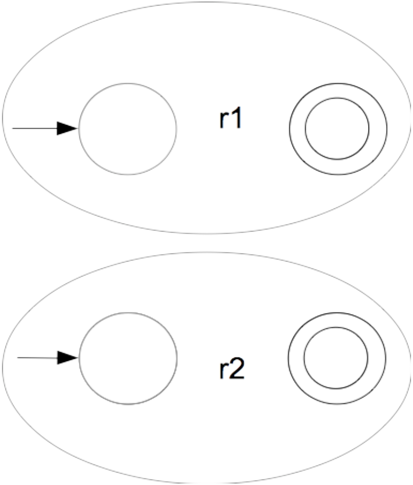

Converting REs to NFA (cont. 2)

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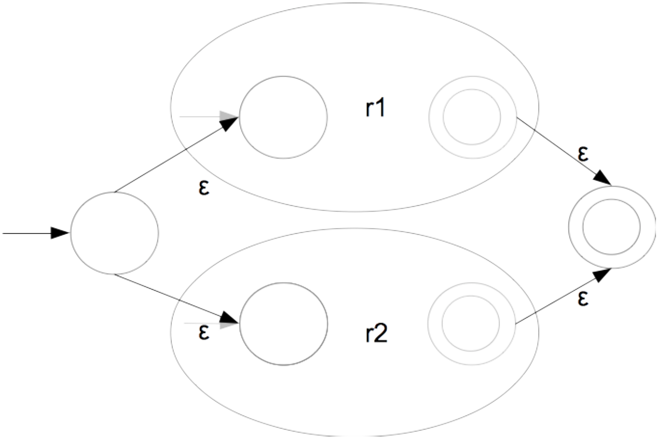
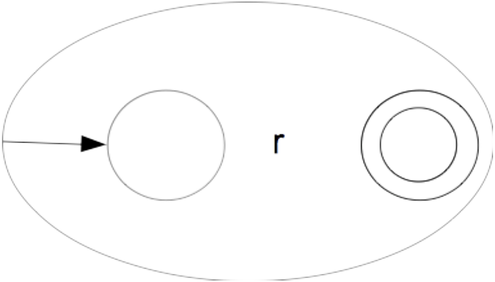


Converting REs to NFA (cont. t3)

Kleene Star, r^*



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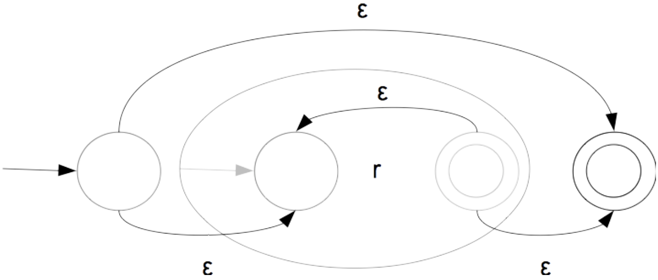

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NFA to DFA example

Consider the NFA obtained from $a^*(b|c)$

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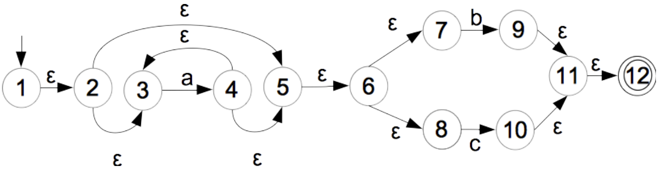

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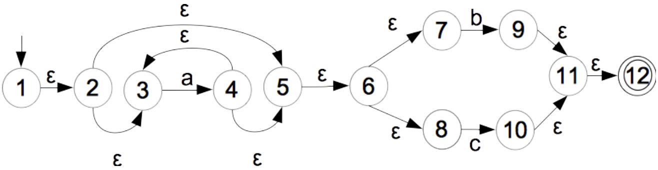

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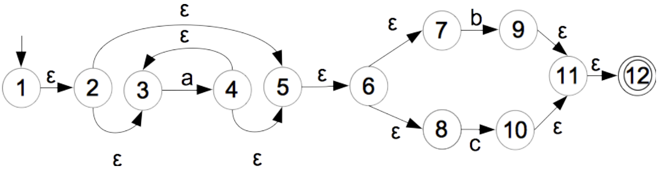

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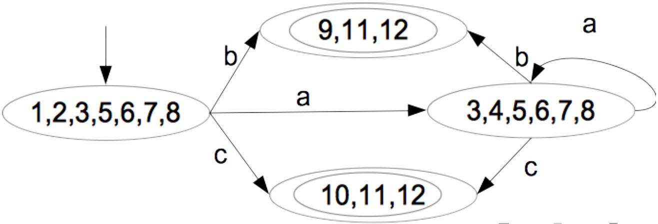

(simple) NFA to DFA exercise

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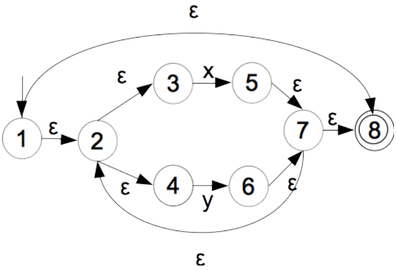

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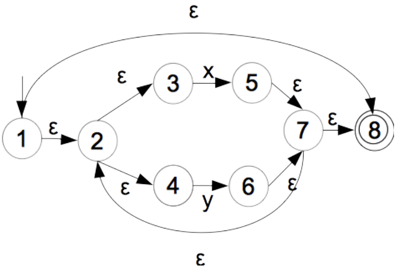

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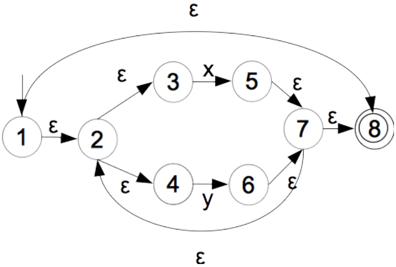

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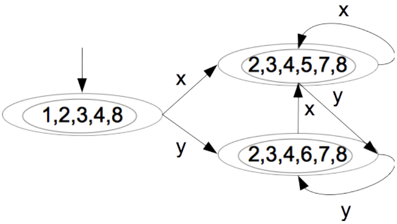

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- The important REs for the source code include keywords (if, while, for, etc.), numbers (floats, ints, etc.) identifiers (variable names, etc.), each category is specified with a RE.
- When the source code is passed to the lexer (the program performing the lexical analysis), it returns a **tokenized** string. For example:

```
if(j + 2) return 10;
```

Yields:

```
keyword(if) l_paren identifier(j) add_op num(2) r_paren keyword(return) num(10) sc
```

Back to the big picture. . .

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Solution:

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