CSC236 fall 2012

regular expressions

Danny Heap
heap@cs.toronto.edu
BA4270 (behind elevators)
http://www.cdf.toronto.edu/~heap/236/F12/
416-978-5899

Using Introduction to the Theory of Computation, Chapter 7

Computer Science
UNIVERSITY OF TORONTO

Outline

regular expressions

product, non-deterministic FSAs

regular languages

notes

another way to define languages

In addition to the language accepted by DFSA $L(M)$ and set description $L = \{\ldots\}$.

Definition: The regular expressions (regexps or REs) over alphabet Σ is the **smallest** set such that:

1. $\{\}$, ϵ, and a, for every $a \in \Sigma$ are REs over Σ
2. if T and S are REs over Σ, then so are:
   - $T + S$ (union) — lowest precedence operator
   - TS (concatenation) — middle precedence operator
   - T^* (star) — highest precedence

regular expression to language:

The $L(R)$, the language denoted (or described) by R is defined by structural induction:

Basis: If R is a regular expression by the basis of the definition of regular expressions, then define $L(R)$:

- $L(\emptyset) = \emptyset$ (the empty language)
- $L(\varepsilon) = \{\varepsilon\}$ (the language consisting of just the empty string)
- $L(a) = \{a\}$ (the language consisting of the one-symbol string)

Induction step: If R is a regular expression by the induction step of the definition, then define $L(R)$:

- $L(S + T) = L(S) \cup L(T)$
- $L(ST) = L(S)L(T)$
- $L(T^*) = L(T)^*$

regexp examples

- $L(0+1) = \{0, 1\}$
- $L((0+1)^*)$ All binary strings over $\{0, 1\}$
- $L((01)^*) = \{\varepsilon, 01, 0101, 010101, \ldots\}$
- $L(0^*1^*)$ 0 or more 0s followed by 0 or more 1s.
- $L(0^* + 1^*)$ 0 or more 0s or 0 or more 1s.
- $L((0+1)(0+1)^*)$ Non-empty binary strings over $\{0, 1\}$.

example

$L = \{x \in \{0,1\}^* \mid x \text{ begins and ends with a different bit}\}$

RE identities

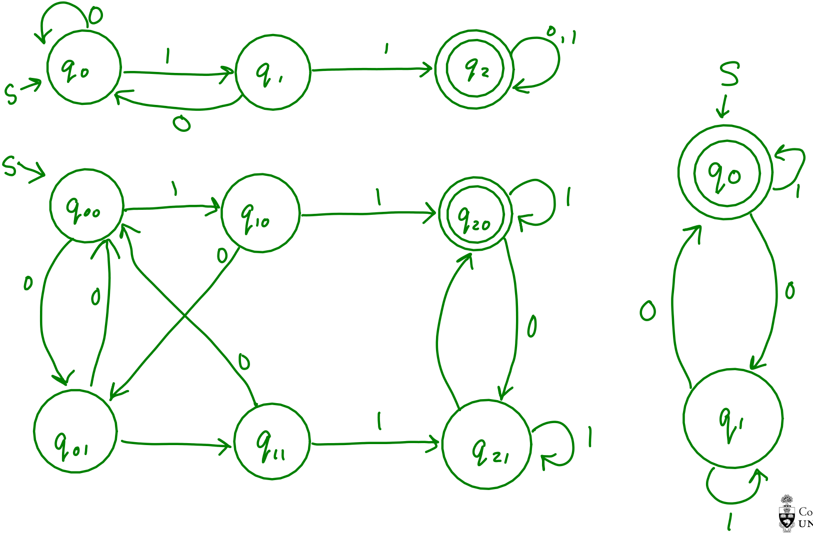
some of these follow from set properties...
others require some proof (see 7.2.5 example)

- communitativity of union: $R + S \equiv S + R$
- associativity of union: $(R + S) + T \equiv R + (S + T)$
- associativity of concatenation: $(RS)T \equiv R(ST)$
- left distributivity: $R(S + T) \equiv RS + RT$
- right distributivity: $(S + T)R \equiv SR + TR$
- identity for union: $R + \emptyset \equiv R$
- identity for concatenation: $R\varepsilon \equiv R \equiv \varepsilon R$
- annihilator for concatenation: $\emptyset R \equiv \emptyset \equiv R\emptyset$
- idempotence of Kleene star: $(R^*)^* \equiv R^*$

product construction

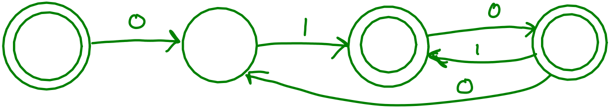
L is the language of binary strings over $\{0,1\}^*$ with two 1s in a row **and** an even number of 0s

idea: $\delta((q_i, q_j), a) = (\delta(q_i, a), \delta(q_j, a))$



non-deterministic FSA (NFSA) example

FSA that accepts $L((010 + 01)^*$



they're equivalent:

$L = L(M)$ for some DFSA $M \Leftrightarrow L = L(M')$ for some NFSA $M' \Leftrightarrow$
$L = R(R)$ for some regular expression R

notes