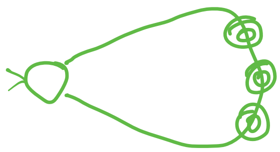
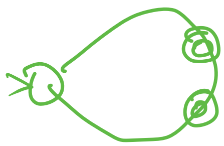
$\boxed{\text{The class RL is closed under Union, concat, } *}$ Jan 16 2025

Theorem: RL is closed under $\cup$

Proof:



$\leftarrow M_1$ FA for L_1

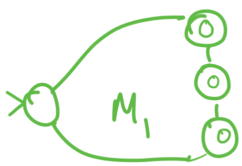


$\leftarrow M_2$ FA for L_2

∎

Theorem: RL is closed under $\circ$

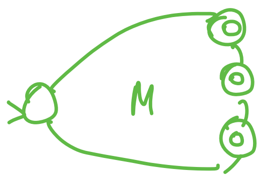
Proof: $L_1 = \{dog, cat\}$ $L_2 = \{bowl, fur\}$ $L_1 \circ L_2 = \{dogbowl, catbowl, dogfur, catfur\}$



Want: FA for $L(M_1) \circ L(M_2)$

Theorem: The class RL is closed under $*$.

Proof:



Want: FA that accept $(L(M))^*$

Aside: $(L(\emptyset))^* = \{\varepsilon\}$.

Section 1.3 Regular Expressions

Eg of r.e.'s over $\Sigma = \{0,1\}$ $\cup$ + ≡ "or" "union"

$(0 \cup 1)0^*$ $1(1 \cup 10)^*$

$(0+1)0^*$ $1(1+10)^*$ ← we will use '+' for '$\cup$'

$(0+1)^*1$

awk, grep, Perl, REGEX, Excel – all use some form.

Syntax of r.e's over Σ.

Defn: R is a r.e. over Σ if R is one of:

1. σ, $\sigma \in \Sigma$
2. ε
3. $\emptyset$

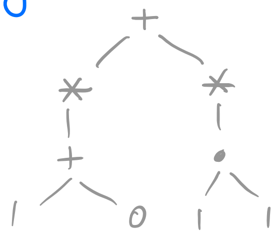
$\left.\right\}$ these are the base cases

4. $(R_1 + R_2)$ where R_1 and R_2 are r.e.s
5. $(R_1 \cdot R_2)$ " " " " " "
6. $(R_1{}^*)$ where R_1 is an r.e.

Nothing else is a r.e.

Note: This defn is recursive.

eg: $\Sigma = \{0,1\} \rightarrow \{ 1,\ (1+0),\ ((1\cdot 1)^*),\ (((1+0)^*) + ((1\cdot 1)^*)) \ \ldots \}$



Technically, for every $+, *, \circ$ $\exists$ a pair of parens.

Semantics of a r.e:

A re denotes a language $L(r)$ where

1. $L(\sigma)$ $\sigma \in \Sigma$ is $\{\sigma\}$
2. $L(\varepsilon)$ is $\{\varepsilon\}$
3. $L(\phi)$ is $\{\}$ ← ϕ
4. $L((R_1 + R_2))$ is $L(R_1) \cup L(R_2)$
5. $L((R_1 \cdot R_2))$ is $L(R_1) \cdot L(R_2)$
6. $L((R_1^*))$ is $(L(R_1))^*$

Conventions:

- replace $\bullet$ with juxtaposition
- precedence of operators will allow us to drop (,). except when we want to enforce an eval order.

1. $*$ 2. $\cdot$ 3. $+$

Hence $a + ba \begin{cases} (a+b)a \\ a+(ba) \end{cases}$?

ab^* $(ab)^*$?

$a(b^*)$

Also Σ is allowed as a r.e.

$\Sigma = \{a,b,c\}$ then $\Sigma a = \{aa, ba, ca\}$

Σ^* = all strings over Σ.

Let $\Sigma = \{a, b\}$

"ends in a"

"$\forall$ b is immediately followed by a"

"contains aab as substring"

"does not contain aab as substring"

Aside: Recursive Definitions.

Defn A string w over Σ ("$w \in \Sigma^*$") is

1. ε
2. $w'\sigma$ where $\sigma \in \Sigma$, $w' \in \Sigma^*$.

Nothing else is a string over Σ.

Defn: for $w \in \Sigma^*$ $|w|$ ("length of w") is given by:

1. $|\varepsilon| = 0$
2. $|\underline{\sigma w'}| = 1 + |w'|$

Other notational conveniences and notes

- Complement $\bar{L} = \Sigma^* \setminus L$
- $\{\varepsilon\}$ is a language; $|\{\varepsilon\}| = 1$ whereas $|\emptyset| = 0$

  Ex. Give a r.e. for $\overline{L(\varepsilon)}$

- α^+ is a notation we will use in r.e.'s to mean "at least one α (or string generated from α), concatenated together"

$$L(\alpha^+) = \begin{cases} L(\alpha^*) & \text{if } \varepsilon \in L(\alpha) \\ L(\alpha^*) & \text{otherwise} \end{cases}$$

- precedence of $^+$ is same as *

ab^+ — "a followed by at least on b"

ab^* — "a followed by 0 or more b's"

r.e.'s

Informal: "a non-zero number of a's followed by at least one b"

Formal description: $L_1 = \{w \in \{a,b\}^* \mid$ w consists of a (possibly empty) block of a's followed by a non-empty block of b's $\}$

an r.e. for L_1:

$L_2 = \{w \in \{0,1\}^* :$ all odd positions in w are $0\}$

$L_3 = \{w \in \{0,1\}^* : \#_0(w)$ is even $\}$

$L_4 = \{ w \in \{a,b,c\}^* :$ at least one of a, b, c is not in $w \}$