Review

Regular Languages

- FA, RG, RE
- recognize

Context Free Languages

- PDA, CFG
- recognize

DFA:

Turing Machine:
Turing Machine (TM)

- invented by Alan M. Turing (1936)
- computational model to study algorithms

Definition of TM

- Storage
  - tape
- actions
  - write symbol
  - read symbol
  - move left (L) or right (R)
- computation
  - initial configuration
    * start state
    * tape head on leftmost tape square
    * input string followed by blanks
  - processing computation
    * move tape head left or right
    * read from and write to tape
  - computation halts
    * final state

Formal Definition of TM

A TM $M$ is defined by $M=(Q, \Sigma, \Gamma, \delta, q_0, B, F)$ where

- $Q$ is finite set of states
- $\Sigma$ is input alphabet
- $\Gamma$ is tape alphabet
- $B \in \Gamma$ is blank
- $q_0$ is start state
- $F$ is set of final states
- $\delta$ is transition function

$\delta(q,a) = (p,b,R)$ means “if in state $q$ with the tape head pointing to an 'a', then move into state $p$, write a 'b' on the tape and move to the right”.
TM as Language recognizer

Definition: Configuration is denoted by $\vdash$.

If $\delta(q,a) = (p,b,R)$ then a move is denoted

$$abaqabba \vdash ababpbba$$

Definition: Let $M$ be a TM, $M=(Q,\Sigma,\Gamma,\delta,q_0,B,F)$. $L(M) = \{ w \in \Sigma^* | q_0w \vdash x_1q_fx_2 \text{ for some } q_f \in F , x_1,x_2 \in \Gamma^* \}$

TM as language acceptor

$M$ is a TM, $w$ is in $\Sigma^*$,

- if $w \in L(M)$ then $M$ halts in final state
- if $w \not\in L(M)$ then either
  - $M$ halts in non-final state
  - $M$ doesn’t halt

Example

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

Replace every second 'a' by a 'b' if string is even length.

- Algorithm
Example:

$L = \{a^n b^n c^n | n \geq 1\}$

Is the following TM Correct?

```
2;2,R
a;a,R
1;1,R
2;2,R
3;3,R
b;b,R
c;3,L
a;a,L
b;b,L
2;2,L
3;3,L
```

TM as a transducer

TM can implement a function: $f(w) = w'$

```
start with: w
↑
end with: w'
↑
```
Definition: A function with domain D is Turing-computable or computable if there exists TM $M=(Q, \Sigma, \Gamma, \delta, q_0, B, F)$ such that

$$q_0, w \vdash^* q_f, f(w)$$

$q_f \in F$, for all $w \in D$.

Example:

$f(x) = 2x$

x is a unary number

start with: 111
↑
end with: 111111
↑

Is the following TM correct?

![Diagram of TM]

1;1,R
1;1,L
1;x,R
B;y,L
x;x,R
y;y,R
y;y,R
x;1,L
x;1;L
y;1,L
B;B,L
B;B,R
B;B, R
1;1,R
1;1,L
1;x,R
B;y,L
x;x,R
y;y,R
y;y,R
1;1,R
1;1,L
1;x,R
B;y,L
x;x,R
y;y,R
y;y,R
x;1,L
x;1;L
y;1,L
B;B,L
B;B,R
B;B, R
1;1,R
1;1,L
1;x,R
B;y,L
x;x,R
y;y,R
y;y,R
x;1,L
x;1;L
y;1,L
B;B,L
B;B,R
B;B, R
Example:

$L = \{ww \mid w \in \Sigma^+\}, \Sigma = \{a, b\}$