

## Automated **Black-Box** Verification of **Networking** Systems

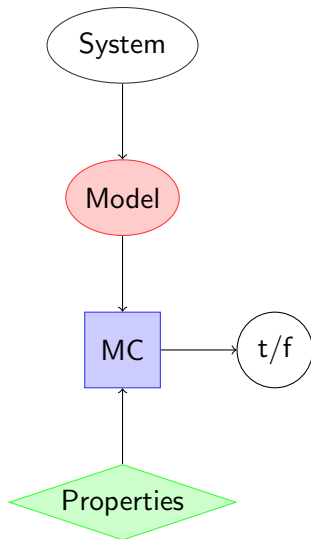
## Introduction

*Can host A send packets to host B?*

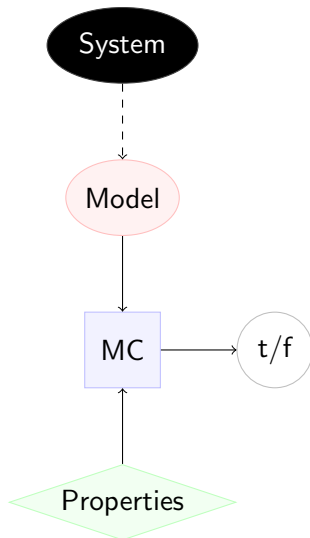
*Do all packets from A to C pass B?*

*Is there a loop involving A?*

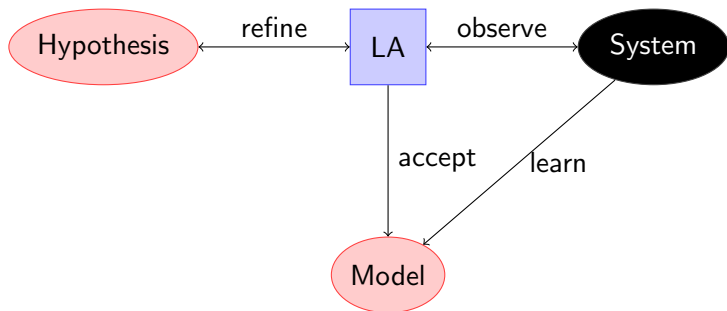
# White box vs. Black box



# White box vs. Black box

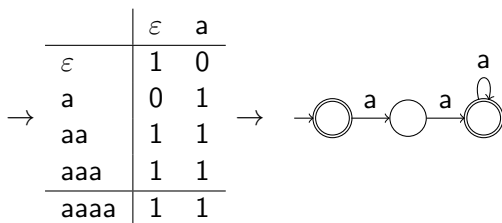
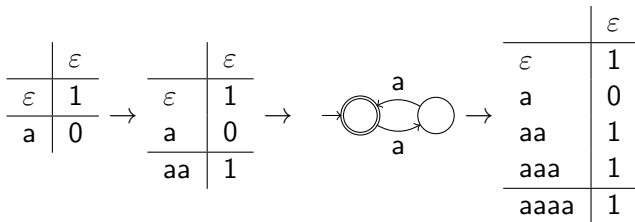


# Black box learning



# L\*: Example

- ▶ **Actions**  $A = \{a\}$
- ▶ **Behaviour**  $\mathcal{L} = \{w \in A^* \mid |w| \neq 1\} = 1 + a \cdot a \cdot a^*$



$X \rightarrow FTX$ **Deterministic Automata**

$$FX = X^A \times 2$$

$$TX = X$$

**Non-deterministic Automata**

$$FX = X^A \times \mathcal{P}(1)$$

$$TX = \mathcal{P}(X)$$

**Partial Automata**

$$FX = X^A \times (1 + 1)$$

$$TX = 1 + X$$

**Weighted Automata**

$$FX = X^A \times \mathbb{S}^1$$

$$TX = \mathbb{S}^X$$

**Writer Automata**

$$FX = X^A \times (1 \times \mathbb{M})$$

$$TX = X \times \mathbb{M}$$

**NetKAT Automata**

$$FX = X^{\text{Pk}} \times (2^{\text{Pk}})^{\text{Pk}}$$

$$TX = X^{\text{Pk}}$$

NetKAT =  
Kleene Algebra with Tests (KAT) +  
Expressions for the modification and  
filtering of packets



# NetKAT

$sw = A; pt = 1; pt \leftarrow 2 + sw = B; \text{drop}$

“Let switch  $A$  only forward packets from port 1 to port 2, and let switch  $B$  drop all packets”

$sw = A; pt = 1; sw \leftarrow B; pt \leftarrow 2$   
 $+sw = B; pt = 2; sw \leftarrow A; pt \leftarrow 1$

“There exists a bidirectional link between the port 1 of switch  $A$  and the port 2 of switch  $B$ ”

# NetKAT automata

NetKAT automata read packets:

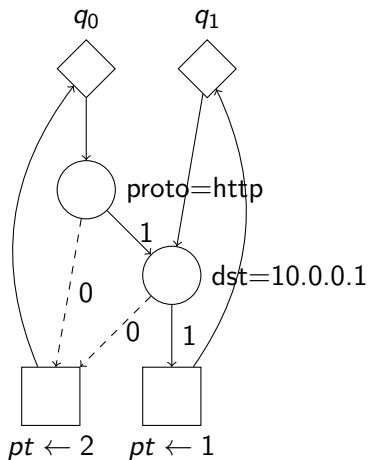
(sw=A; pt=80; dst=10.0.2.1; proto=http; ...),  
(sw=B; pt=22; dst=10.0.0.2; proto=ssh; ...),  
(sw=X; pt=25; dst=10.0.0.1; proto=smtp; ...),  
(sw=D; pt=20; dst=10.0.3.1; proto=ftp; ...),  
(sw=E; pt=443; dst=10.0.7.1; proto=https; ...),  
...

NetKAT automata accept packet traces:

$$h = p_1 :: p_2 :: \dots :: p_n :: []$$

# Symbolic NetKAT automata

$$X \rightarrow (X^{P_k})^{P_k} \times (2^{P_k})^{P_k}$$



Learnable?