

# CIRCUITOS DIGITAIS

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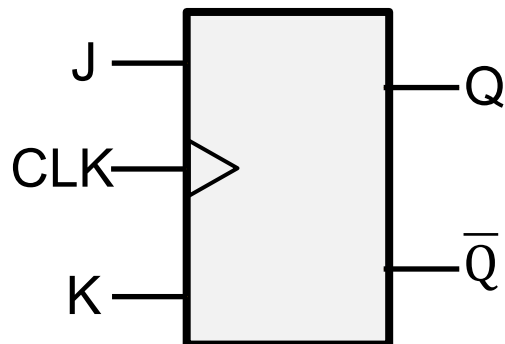
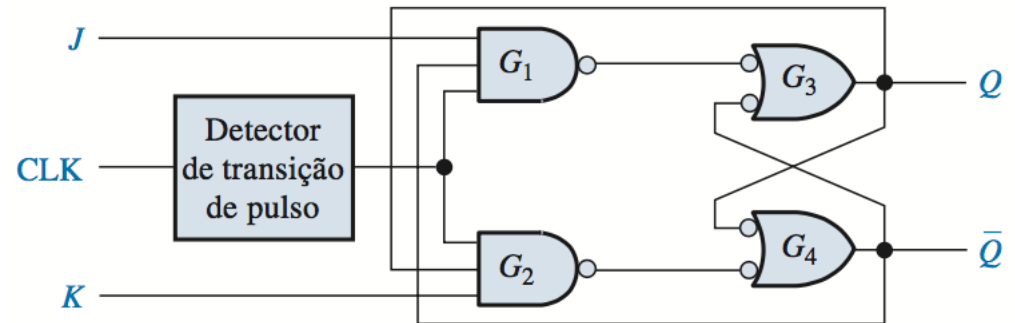
## **CIRCUITOS SEQUENCIAIS**

Prof. Marcelo Grandi Mandelli

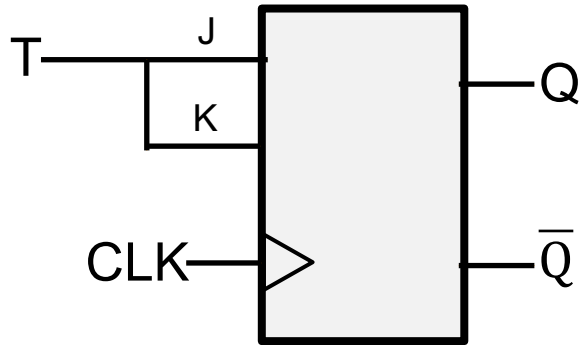
`mgmandelli@unb.br`

# Flip-Flop JK disparado por borda de subida

CLK	J	K	$Q_{t+1}$
$\neq \uparrow$	X	X	$Q_t$
$\uparrow$	0	0	$Q_t$
$\uparrow$	0	1	0
$\uparrow$	1	0	1
$\uparrow$	1	1	$\overline{Q_t}$

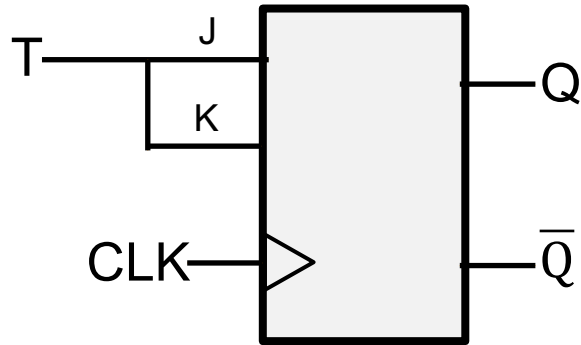


# Flip-Flop T disparado por borda de subida



CLK	J	K	$Q_{t+1}$
$\neq \uparrow$	X	X	$Q_t$
$\uparrow$	0	0	$Q_t$
$\uparrow$	0	1	0
$\uparrow$	1	0	1
$\uparrow$	1	1	$\bar{Q}_t$

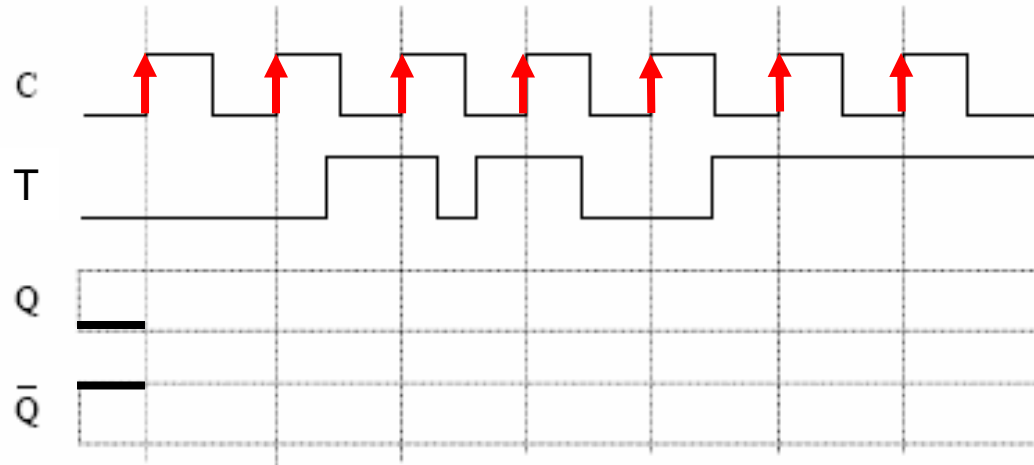
# Flip-Flop T disparado por borda de subida



CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\bar{Q}_t$

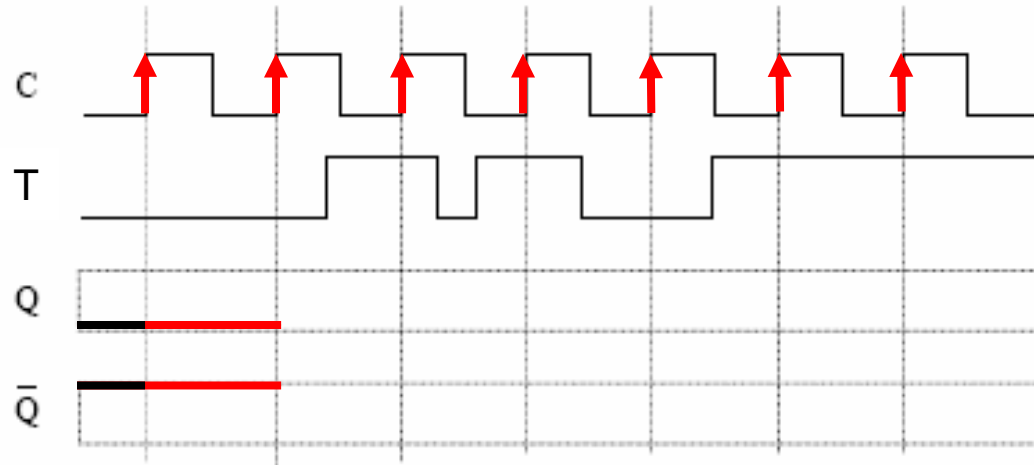
# Flip-Flop T disparado por borda de subida

CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$



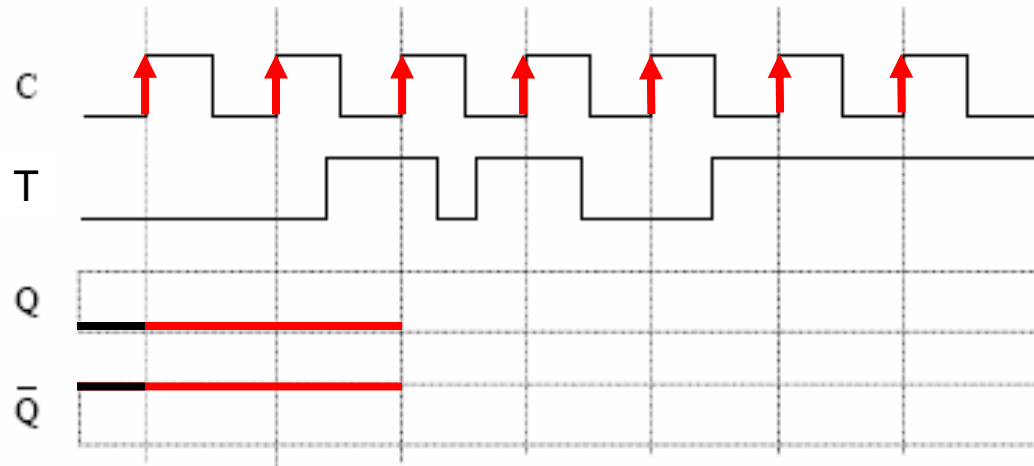
# Flip-Flop T disparado por borda de subida

CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$



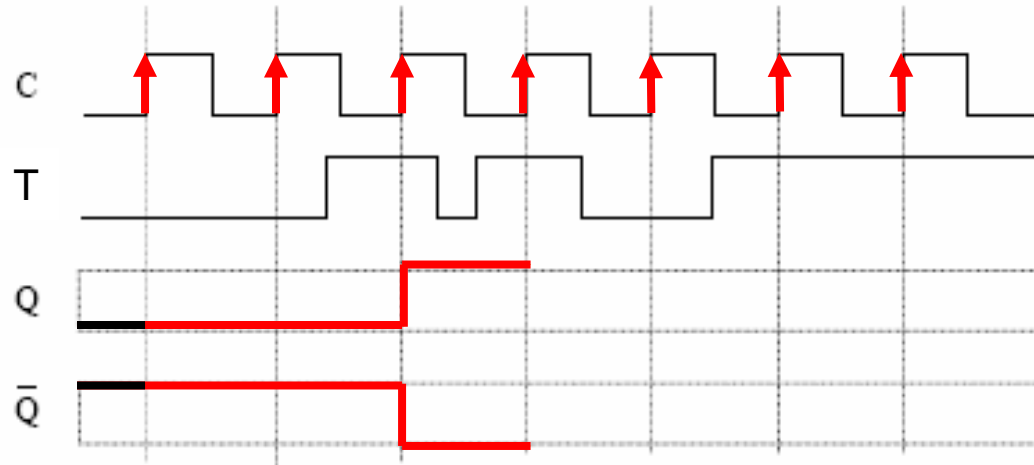
# Flip-Flop T disparado por borda de subida

CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$



# Flip-Flop T disparado por borda de subida

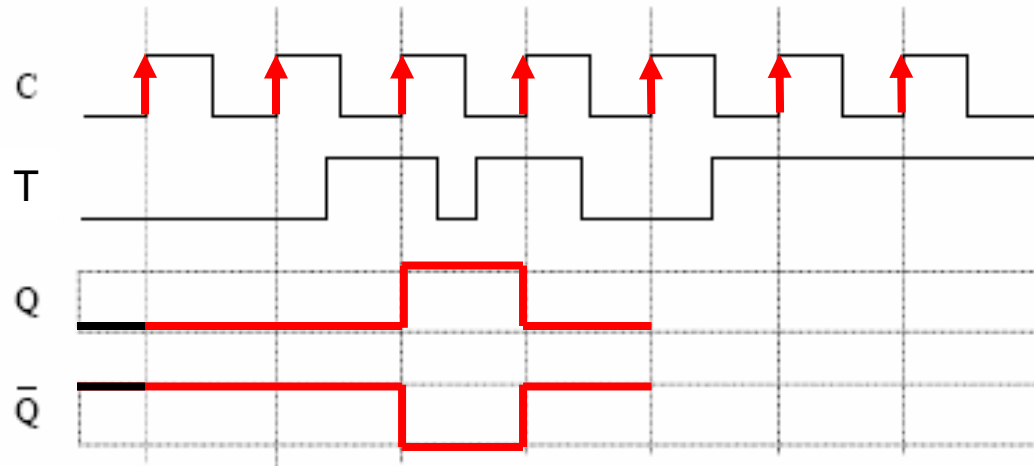
CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$





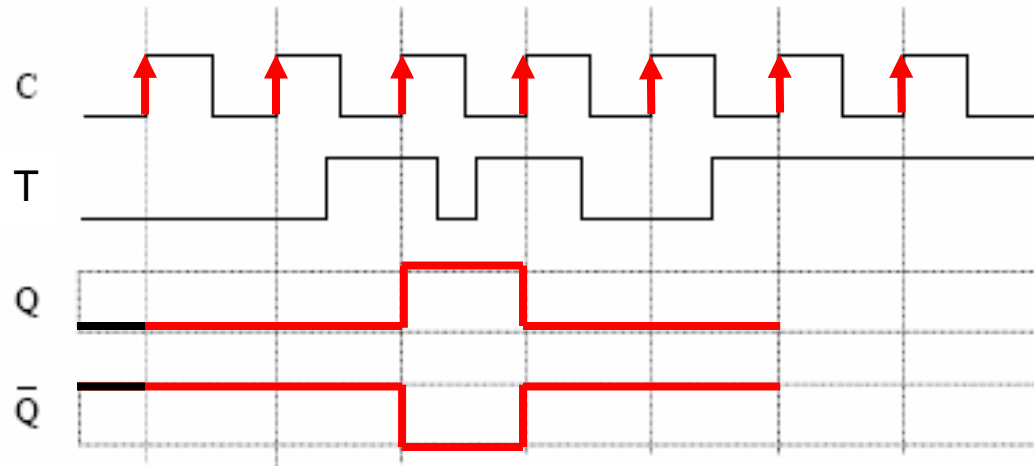
# Flip-Flop T disparado por borda de subida

CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$



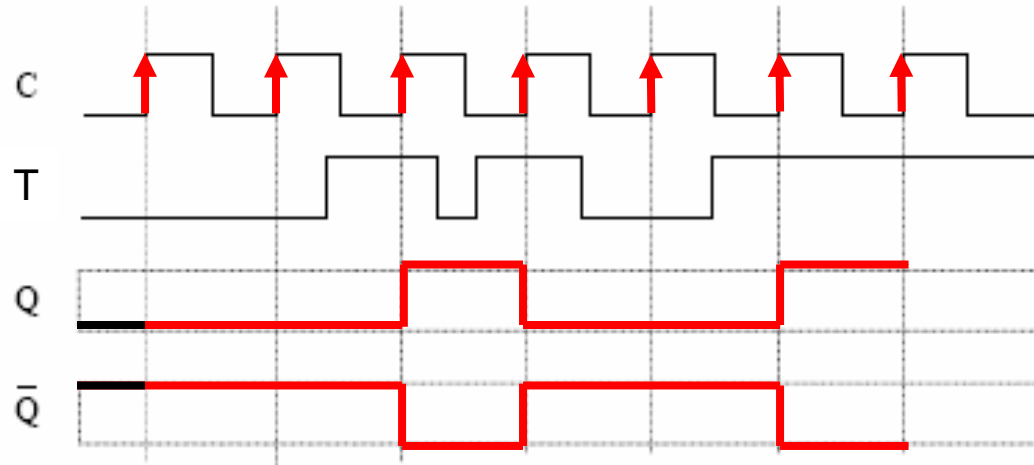
# Flip-Flop T disparado por borda de subida

CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$



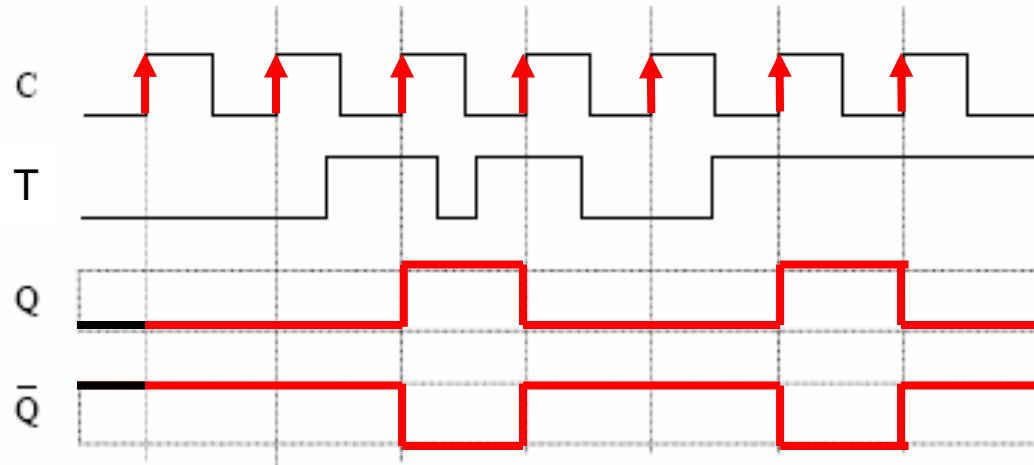
# Flip-Flop T disparado por borda de subida

CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$



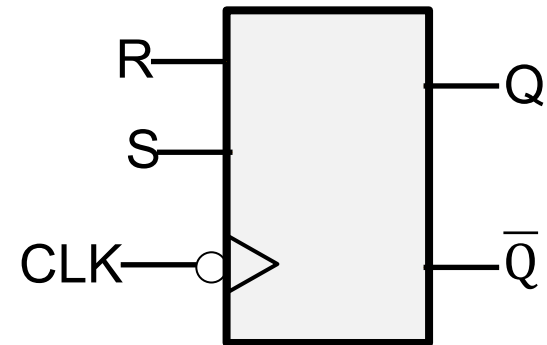
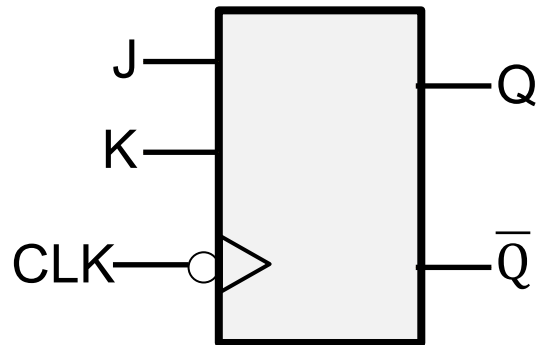
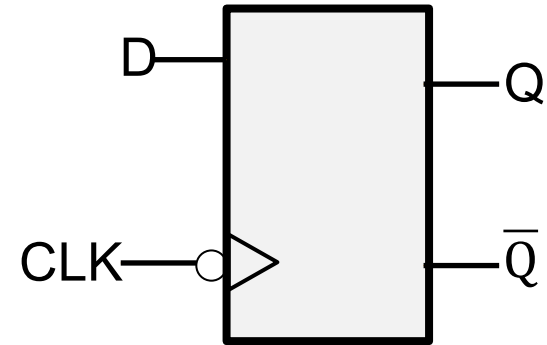
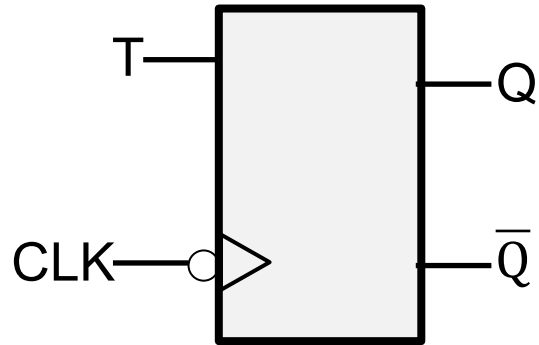
# Flip-Flop T disparado por borda de subida

CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$

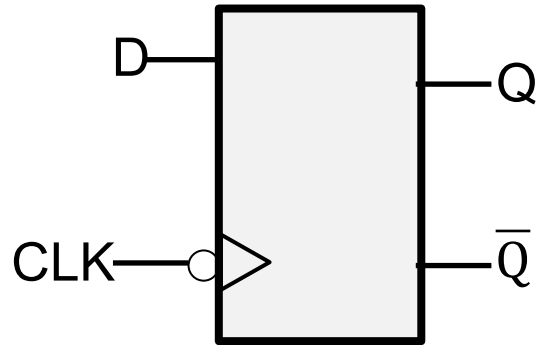


# Flip-Flops disparados por borda de descida

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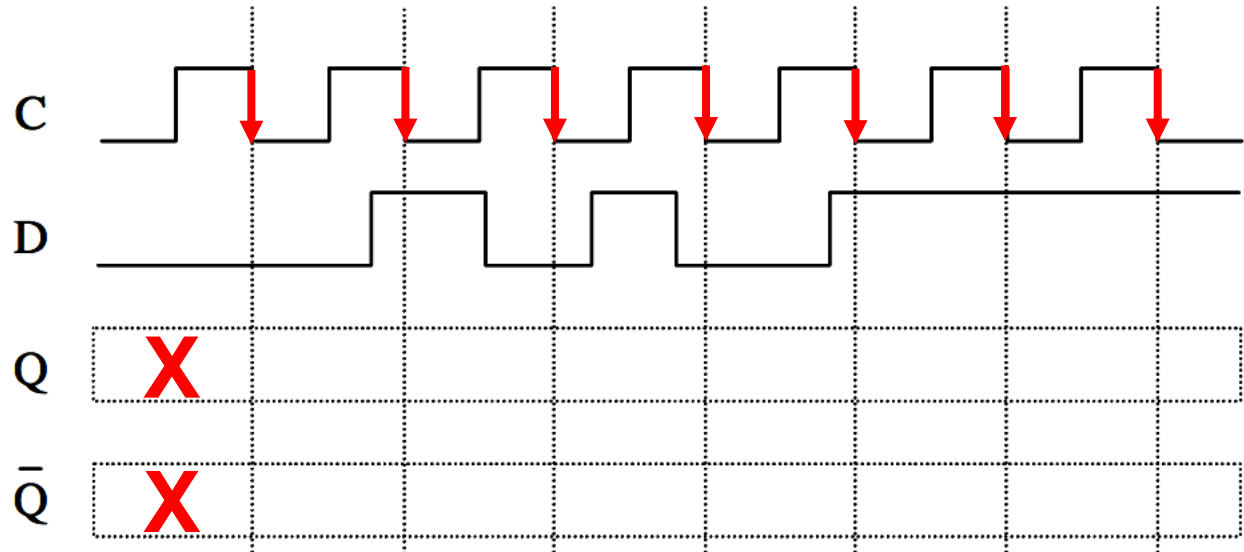
# Flip-Flop D disparado por borda de descida



CLK	D	$Q_{t+1}$
$\neq \downarrow$	X	$Q_t$
$\downarrow$	0	0
$\downarrow$	1	1

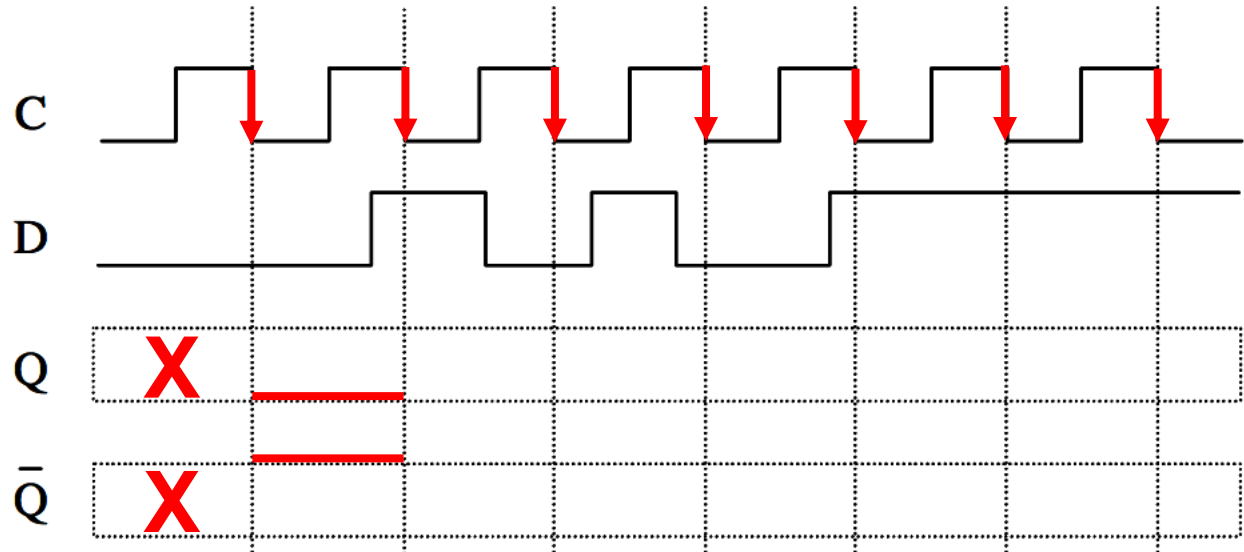
# Flip-Flop D disparado por borda de descida

CLK	D	$Q_{t+1}$
$\neq \downarrow$	X	$Q_t$
$\downarrow$	0	0
$\downarrow$	1	1



# Flip-Flop D disparado por borda de descida

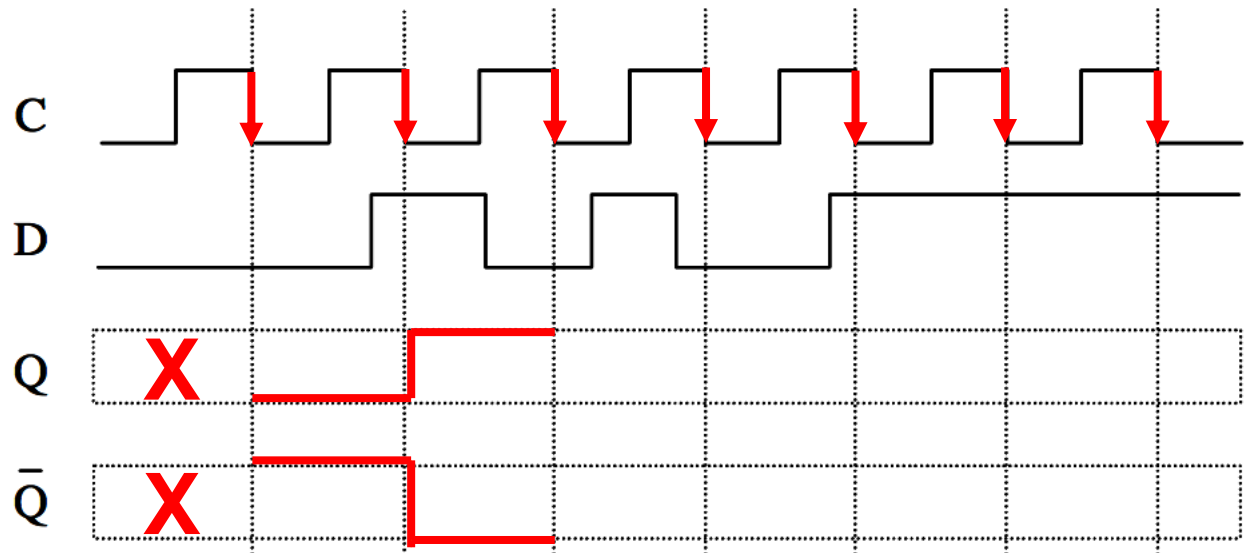
CLK	D	$Q_{t+1}$
$\neq \downarrow$	X	$Q_t$
$\downarrow$	0	0
$\downarrow$	1	1





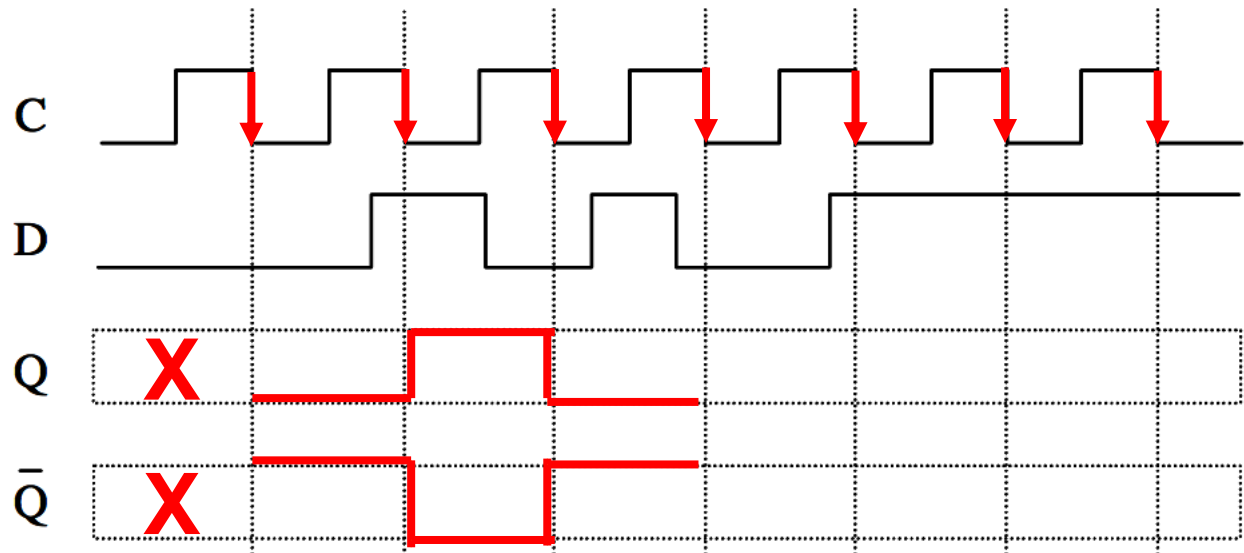
# Flip-Flop D disparado por borda de descida

CLK	D	$Q_{t+1}$
$\neq \downarrow$	X	$Q_t$
$\downarrow$	0	0
$\downarrow$	1	1



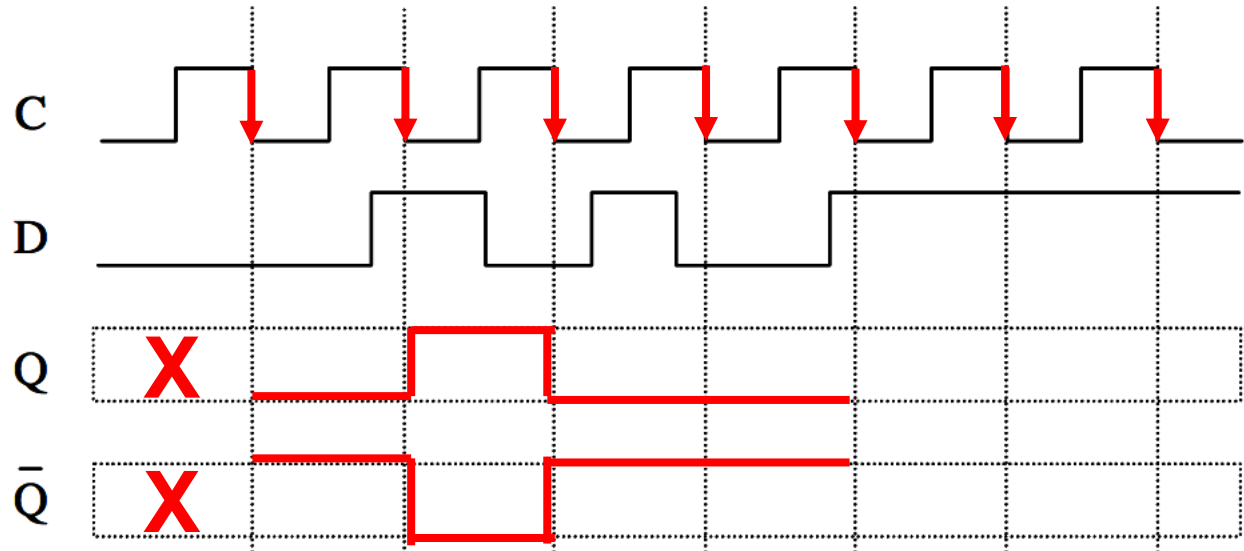
# Flip-Flop D disparado por borda de descida

CLK	D	$Q_{t+1}$
$\neq \downarrow$	X	$Q_t$
$\downarrow$	0	0
$\downarrow$	1	1



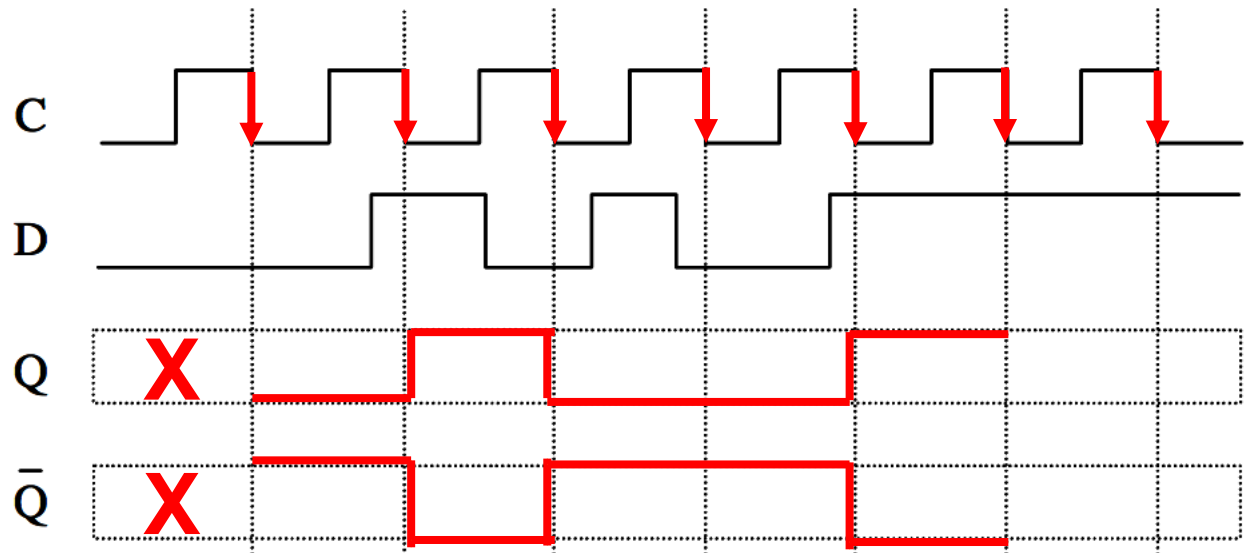
# Flip-Flop D disparado por borda de descida

CLK	D	$Q_{t+1}$
$\neq \downarrow$	X	$Q_t$
$\downarrow$	0	0
$\downarrow$	1	1



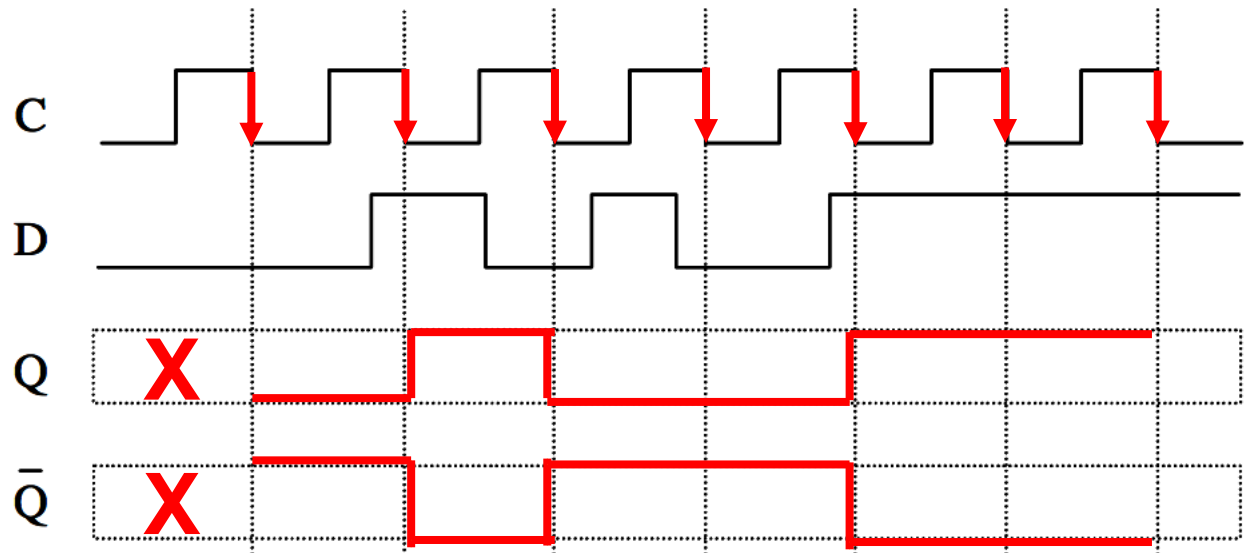
# Flip-Flop D disparado por borda de descida

CLK	D	$Q_{t+1}$
$\neq \downarrow$	X	$Q_t$
$\downarrow$	0	0
$\downarrow$	1	1



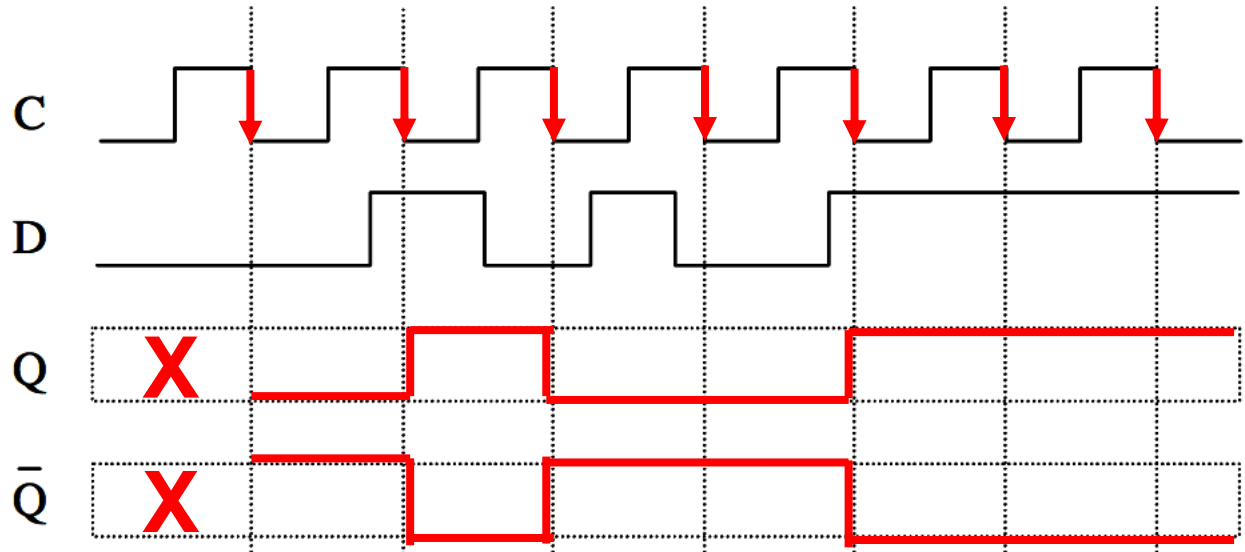
# Flip-Flop D disparado por borda de descida

CLK	D	$Q_{t+1}$
$\neq \downarrow$	X	$Q_t$
$\downarrow$	0	0
$\downarrow$	1	1

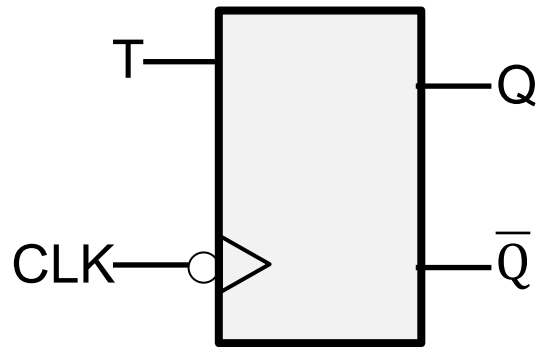


## Flip-Flop D disparado por borda de descida

CLK	D	$Q_{t+1}$
$\neq \downarrow$	X	$Q_t$
$\downarrow$	0	0
$\downarrow$	1	1



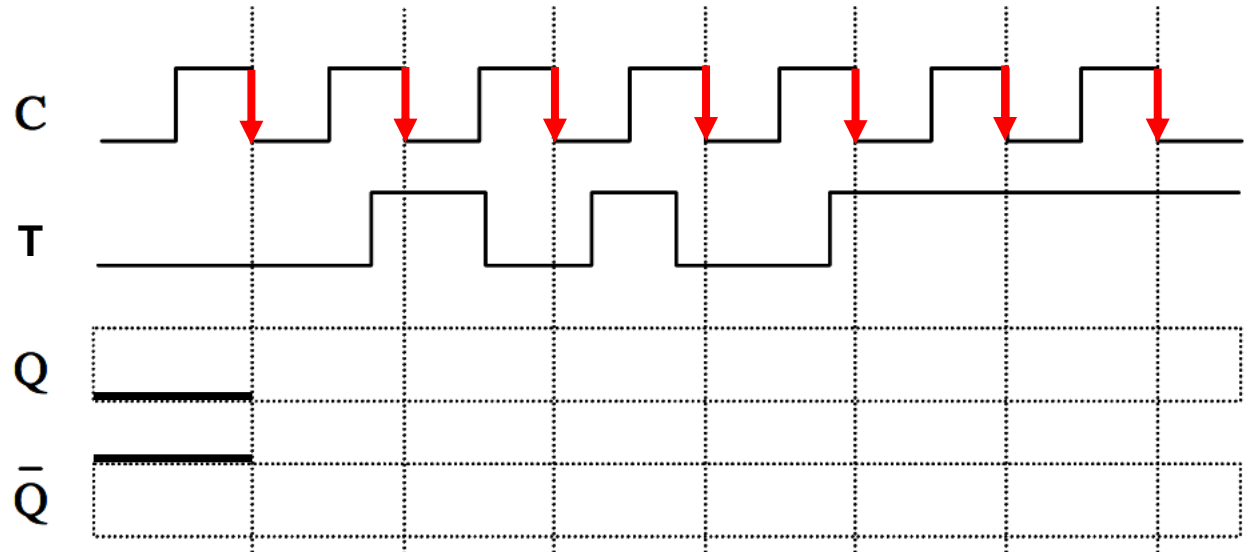
# Flip-Flop T disparado por borda de descida



CLK	T	$Q_{t+1}$
$\neq \downarrow$	X	$Q_t$
$\downarrow$	0	$Q_t$
$\downarrow$	1	$\overline{Q_t}$

# Flip-Flop T disparado por borda de descida

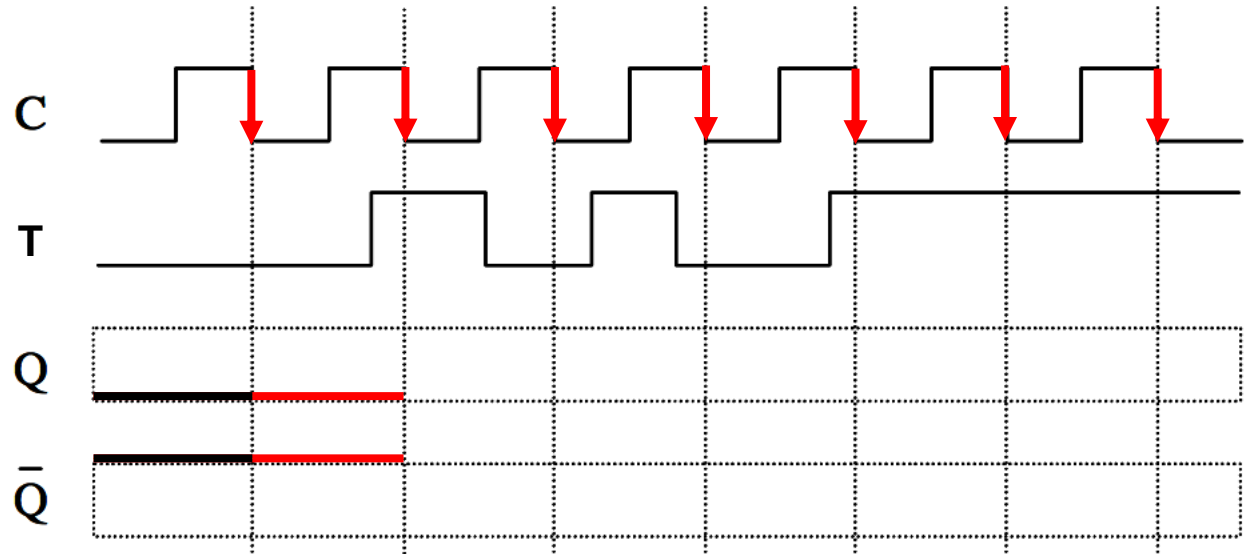
CLK	T	$Q_{t+1}$
$\neq \downarrow$	X	$Q_t$
$\downarrow$	0	$Q_t$
$\downarrow$	1	$\overline{Q_t}$





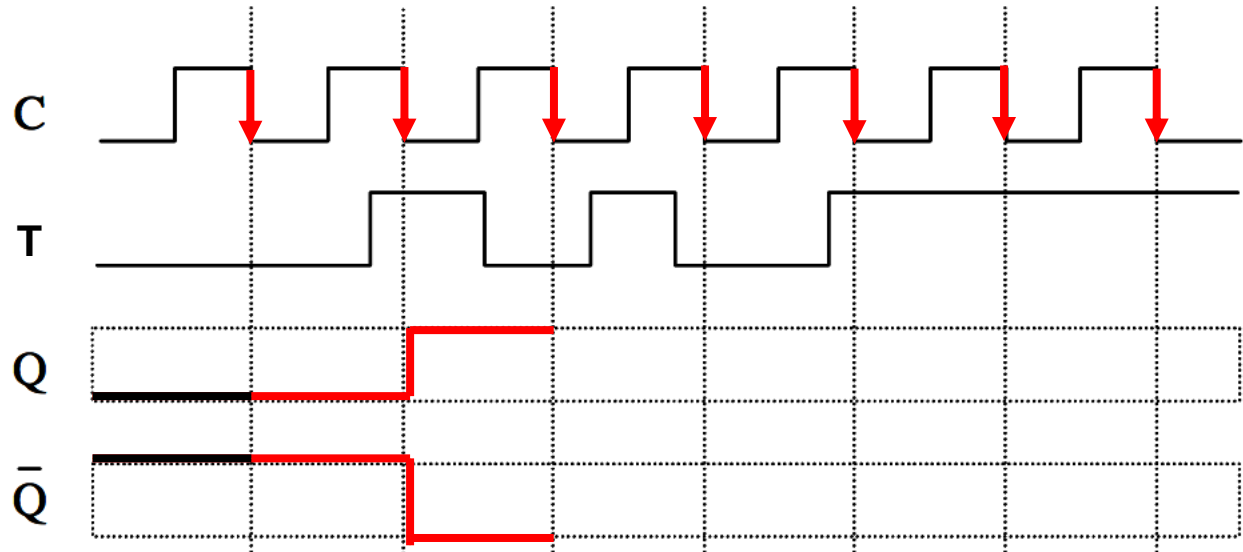
# Flip-Flop T disparado por borda de descida

CLK	T	$Q_{t+1}$
$\neq \downarrow$	X	$Q_t$
$\downarrow$	0	$Q_t$
$\downarrow$	1	$\overline{Q_t}$



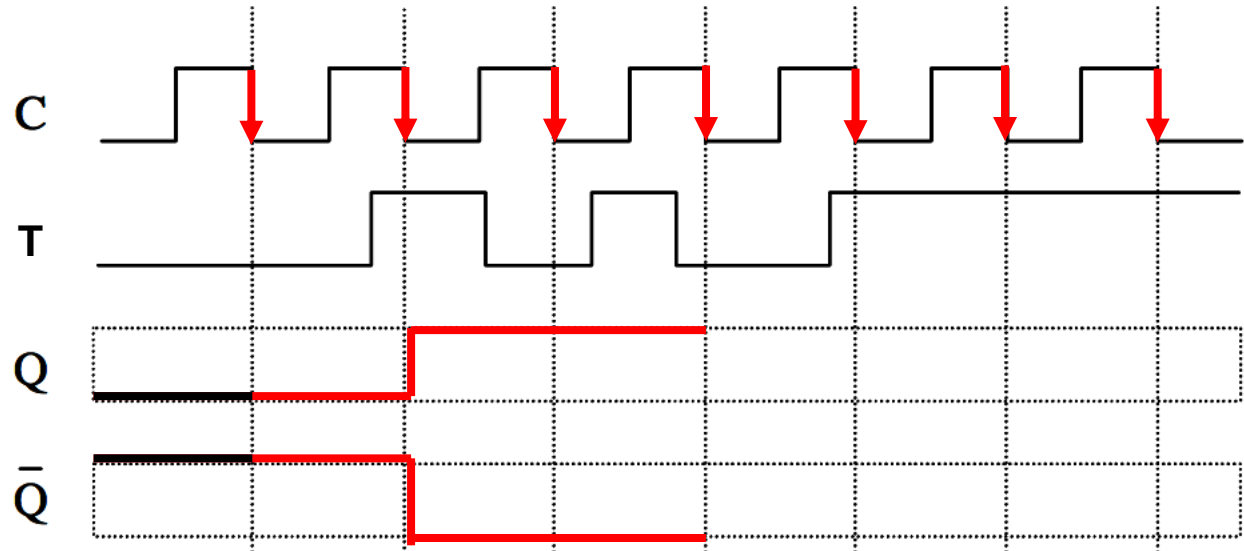
# Flip-Flop T disparado por borda de descida

CLK	T	$Q_{t+1}$
$\neq \downarrow$	X	$Q_t$
$\downarrow$	0	$Q_t$
$\downarrow$	1	$\overline{Q_t}$



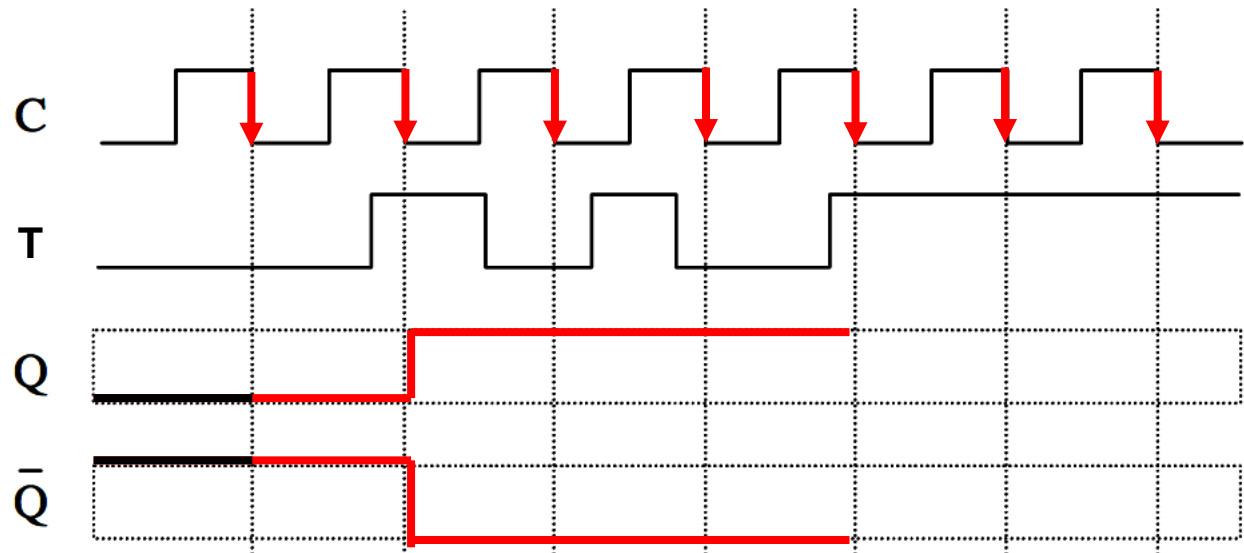
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CLK	T	$Q_{t+1}$
$\neq \downarrow$	X	$Q_t$
$\downarrow$	0	$Q_t$
$\downarrow$	1	$\overline{Q_t}$



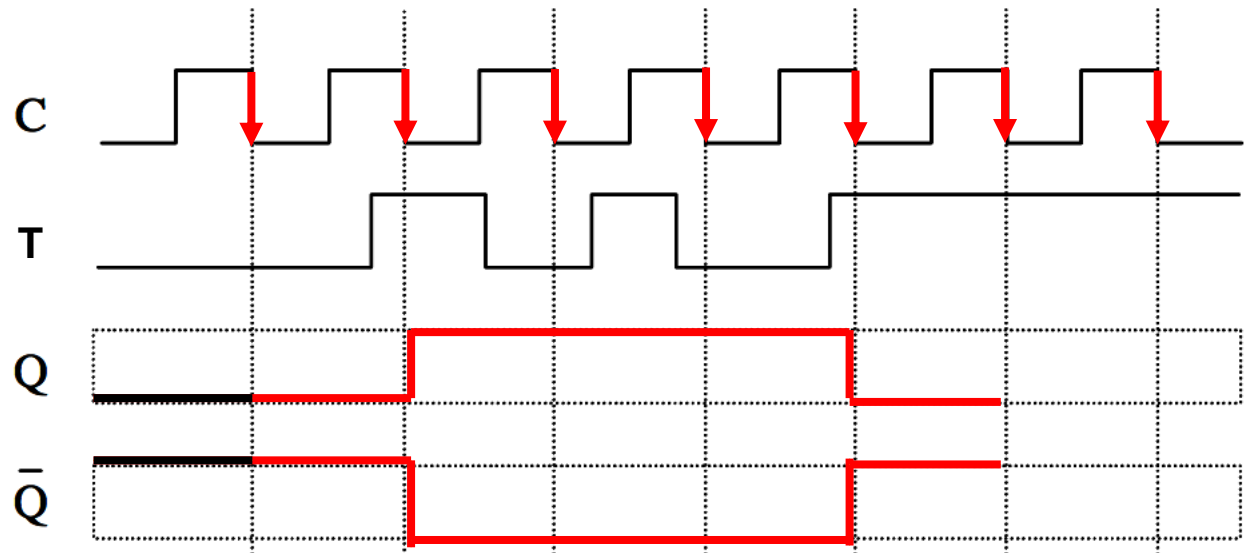
# Flip-Flop T disparado por borda de descida

CLK	T	$Q_{t+1}$
$\neq \downarrow$	X	$Q_t$
$\downarrow$	0	$Q_t$
$\downarrow$	1	$\overline{Q_t}$



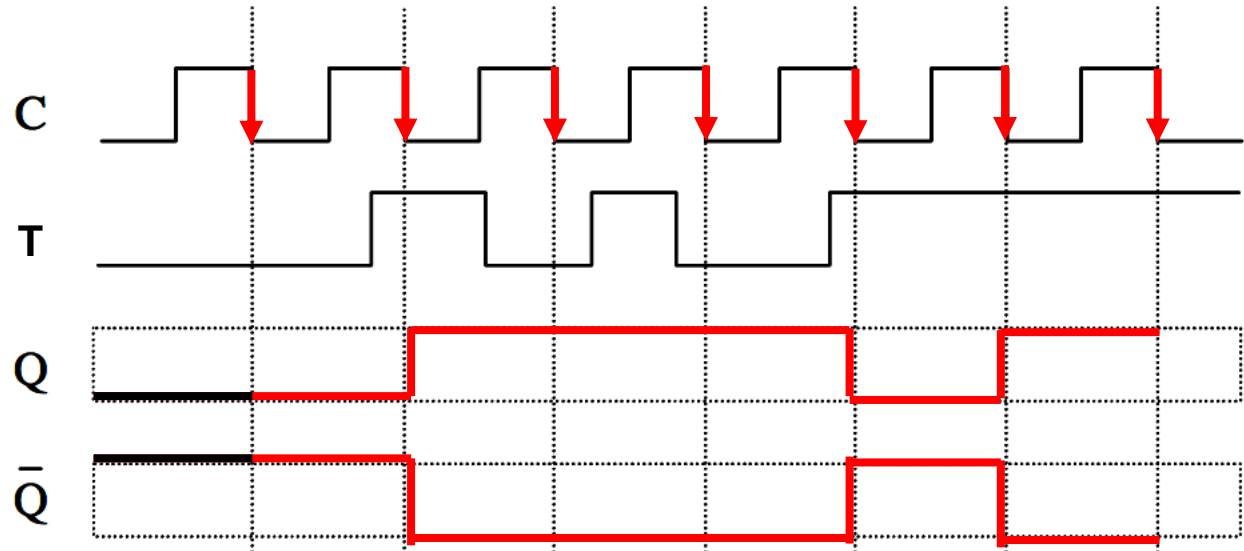
# Flip-Flop T disparado por borda de descida

CLK	T	$Q_{t+1}$
$\neq \downarrow$	X	$Q_t$
$\downarrow$	0	$Q_t$
$\downarrow$	1	$\overline{Q_t}$



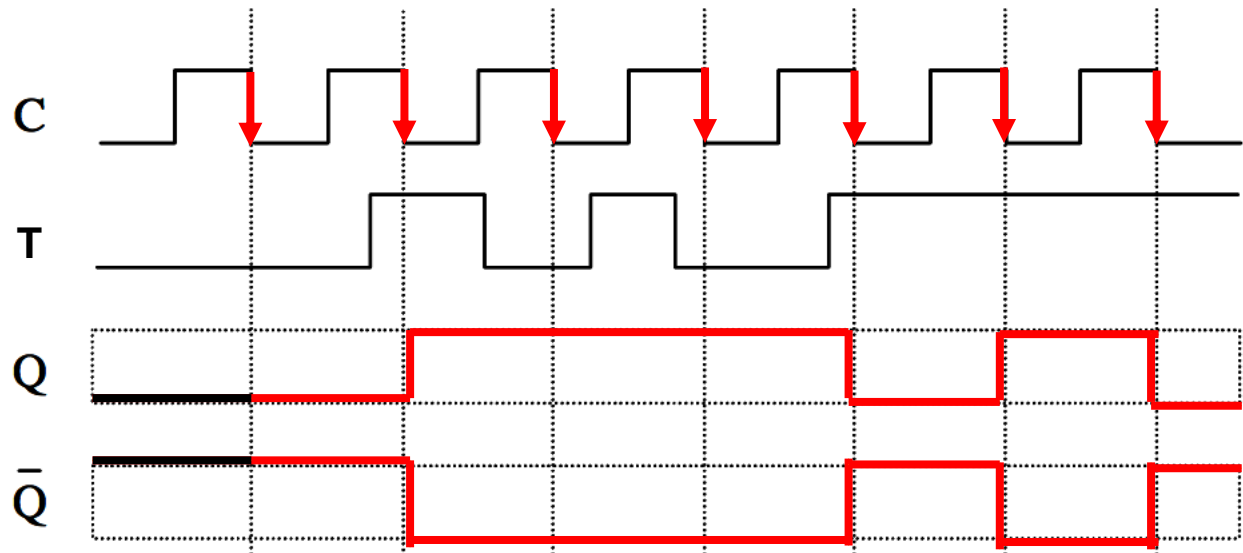
# Flip-Flop T disparado por borda de descida

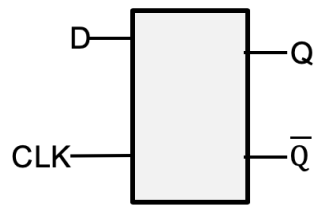
CLK	T	$Q_{t+1}$
$\neq \downarrow$	X	$Q_t$
$\downarrow$	0	$Q_t$
$\downarrow$	1	$\overline{Q_t}$



# Flip-Flop T disparado por borda de descida

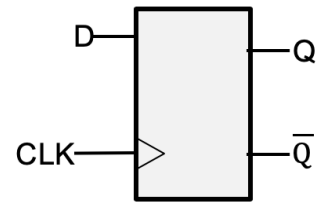
CLK	T	$Q_{t+1}$
$\neq \downarrow$	X	$Q_t$
$\downarrow$	0	$Q_t$
$\downarrow$	1	$\overline{Q_t}$



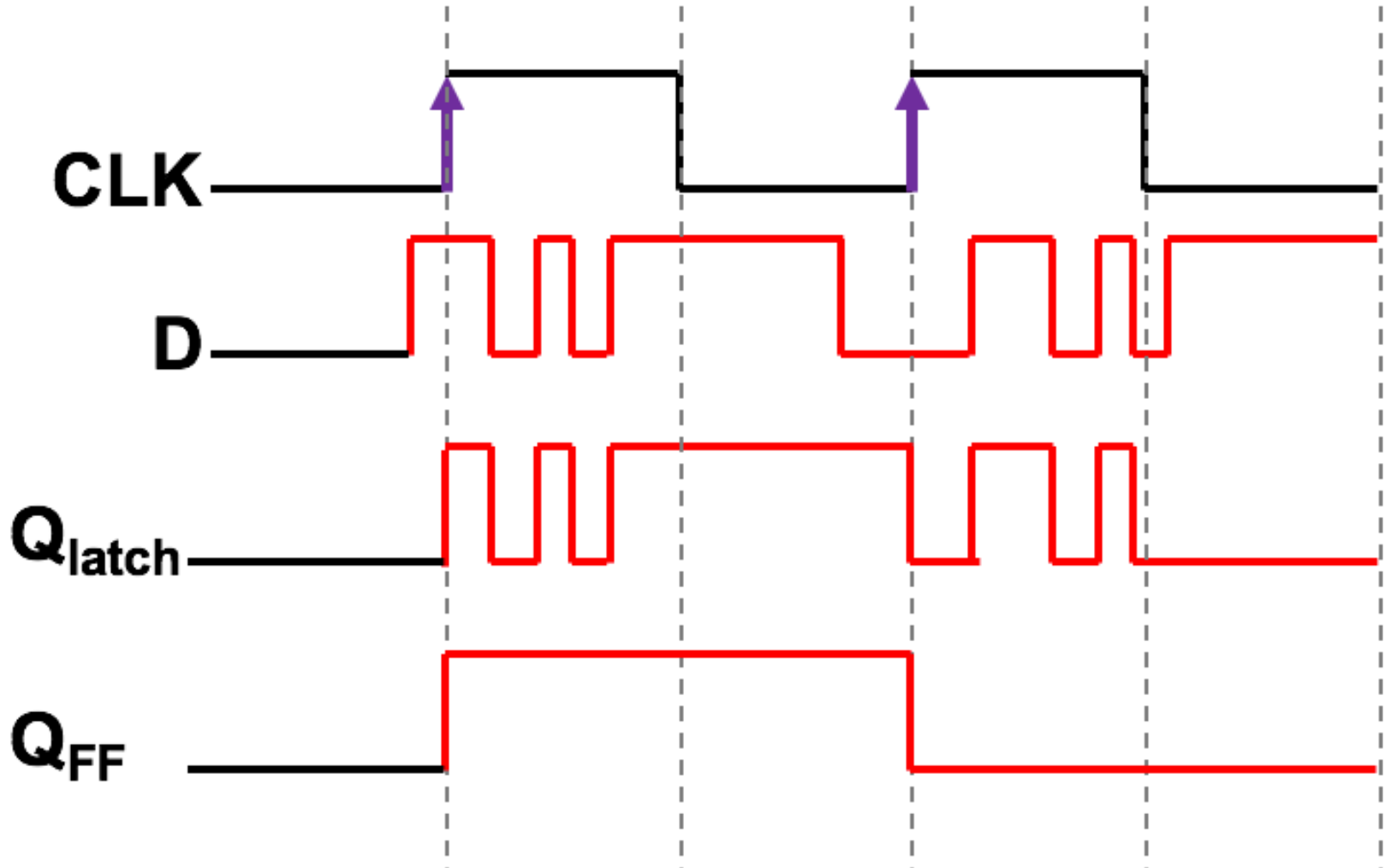


**Latch D**

**vs**

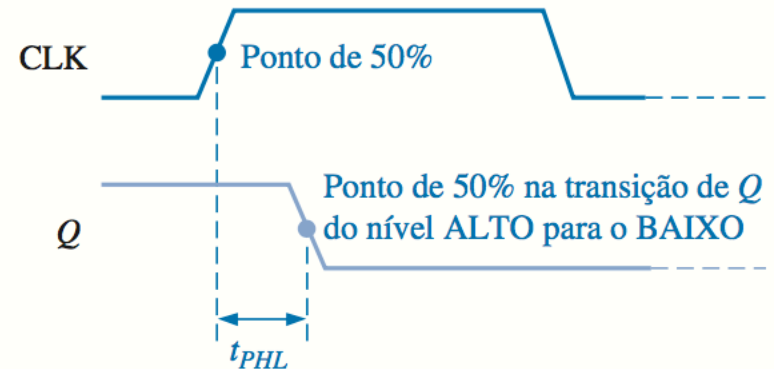
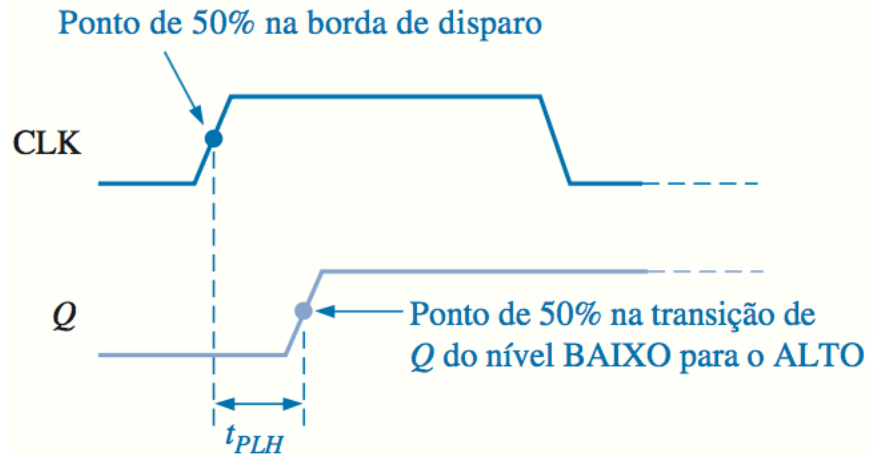


**Flip-flop D**



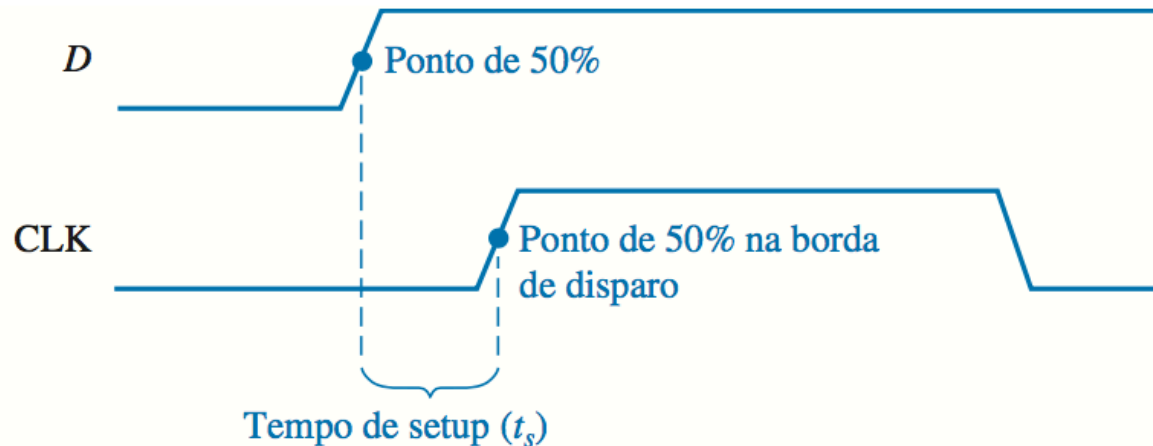


# Tempo de Atraso de Propagação



# Tempo de Setup (Preparação)

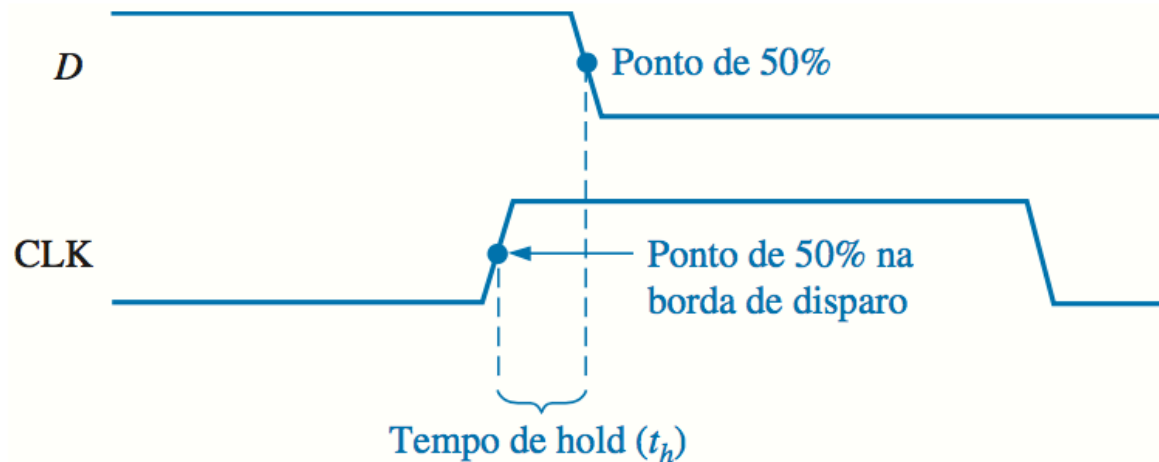
- **tempo de setup ( $t_s$ )** → tempo mínimo antes da borda do clock que a entrada deve estar estável



- A entrada deve manter o mesmo nível lógico antes da borda de disparo do clock por um tempo igual ou maior que  $t_s$

# Tempo de Hold (Manutenção)

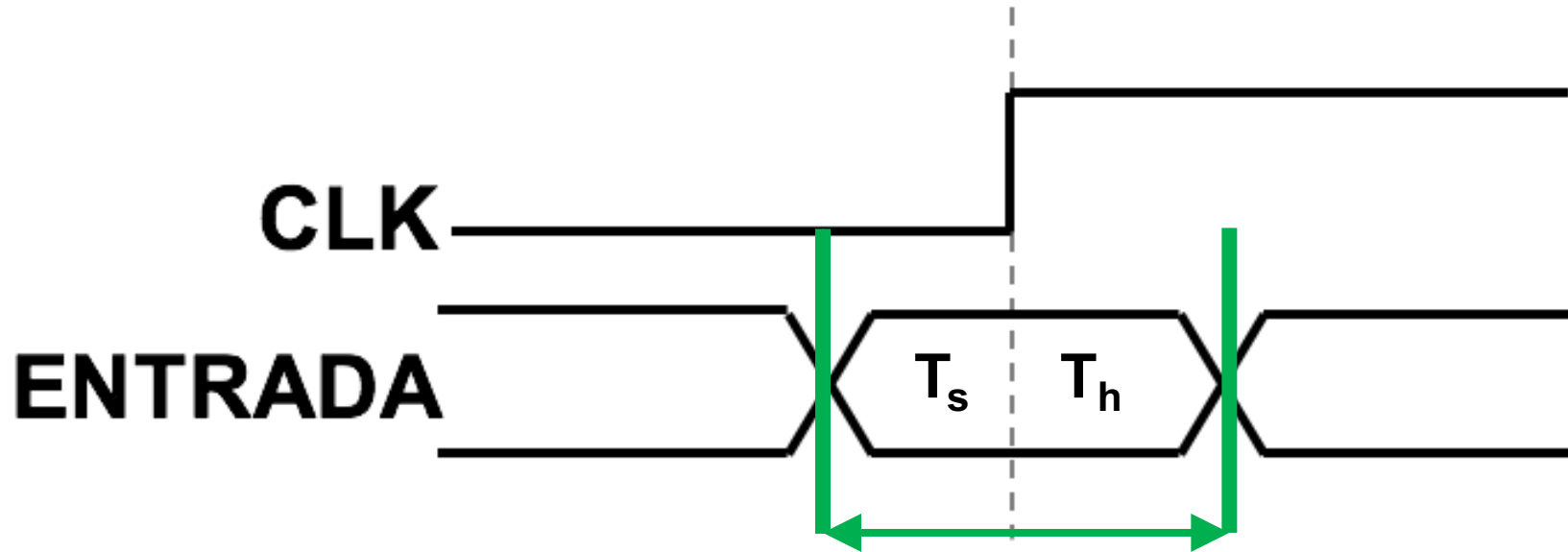
- **tempo de hold ( $t_h$ )** → tempo mínimo depois da borda do clock que a entrada deve estar estável



- A entrada deve manter o mesmo nível lógico depois da borda de disparo do clock por um tempo igual ou maior que  $t_h$

# Janela de tempo

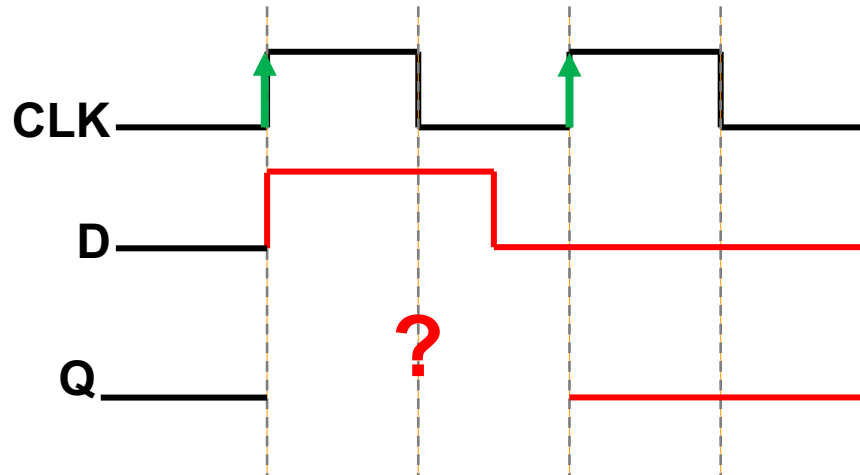
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**A entrada deve permanecer estável dentro da janela**

# Meta-estabilidade

- ❑ violação nos tempos de setup e hold → **flip-flop pode entrar em um estado onde a sua saída é imprevisível** → **meta-estabilidade**



- ❑ **Após o estado de meta-estabilidade, o flip-flop atinge o valor '1' ou '0'**

# Janela de tempo

Metastability Window 74xx74 Flip Flops					
Device	$t_{(\text{set-up})}$ nS	$t_{(\text{hold})}$ nS	$t_{(\text{total})}$ nS		
<b>74C74</b>	100.0	0.0	100.0		
<b>74HC74</b>	20.0	0.0	20.0		
<b>74HCT74</b>	20.0	0.0	20.0		
<b>7474</b>	20.0	5.0	25.0		
<b>74ALS74</b>	15.0	10.0	25.0		
<b>74LS74</b>	20.0	0.0	20.0		
<b>74S74</b>	3.0	2.0	5.0		
<b>74LS74</b>	4.5	0.0	4.5		
<b>74AC74</b>	4.0	0.5	4.5		
<b>74ACT74</b>	3.0	1.0	4.0		
<b>74ACTQ74</b>	3.0	1.5	4.5		

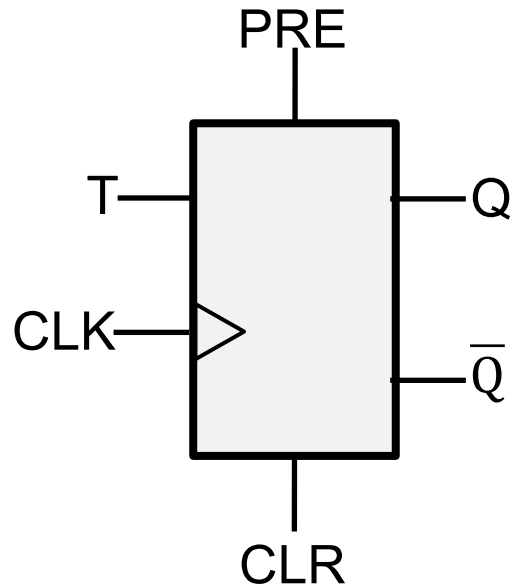
# Entradas de Preset e Clear

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- A maioria dos flip-flops também tem entradas **assíncronas**
- Essas entradas afetam o estado do flip-flop **independente do clock**
- *Elas são normalmente denominadas **preset** (**PRE**) e **clear** (**CLR**)*

# Entradas de Preset e Clear

- ❑ **PRESET** = 1 irá **setar** o flip-flop  $\rightarrow Q_{t+1} = 1$
- ❑ **CLEAR** = 1 irá **resetar** o flip-flop  $\rightarrow Q_{t+1} = 0$



PRE	CLR	$Q_{t+1}$
0	0	FUNCIONAMENTO NORMAL
0	1	0
1	0	1
1	1	NÃO PERMITIDO

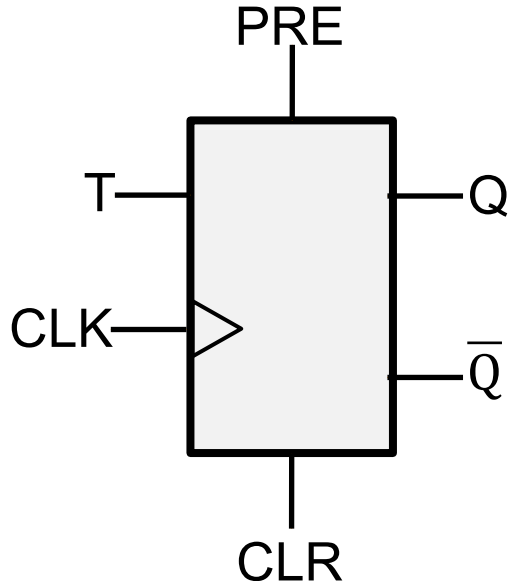


# Flip-flop T com Preset e Clear

PRE	CLR	$Q_{t+1}$
0	0	FUNCIONAMENTO NORMAL
0	1	0
1	0	1
1	1	NÃO PERMITIDO



CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$

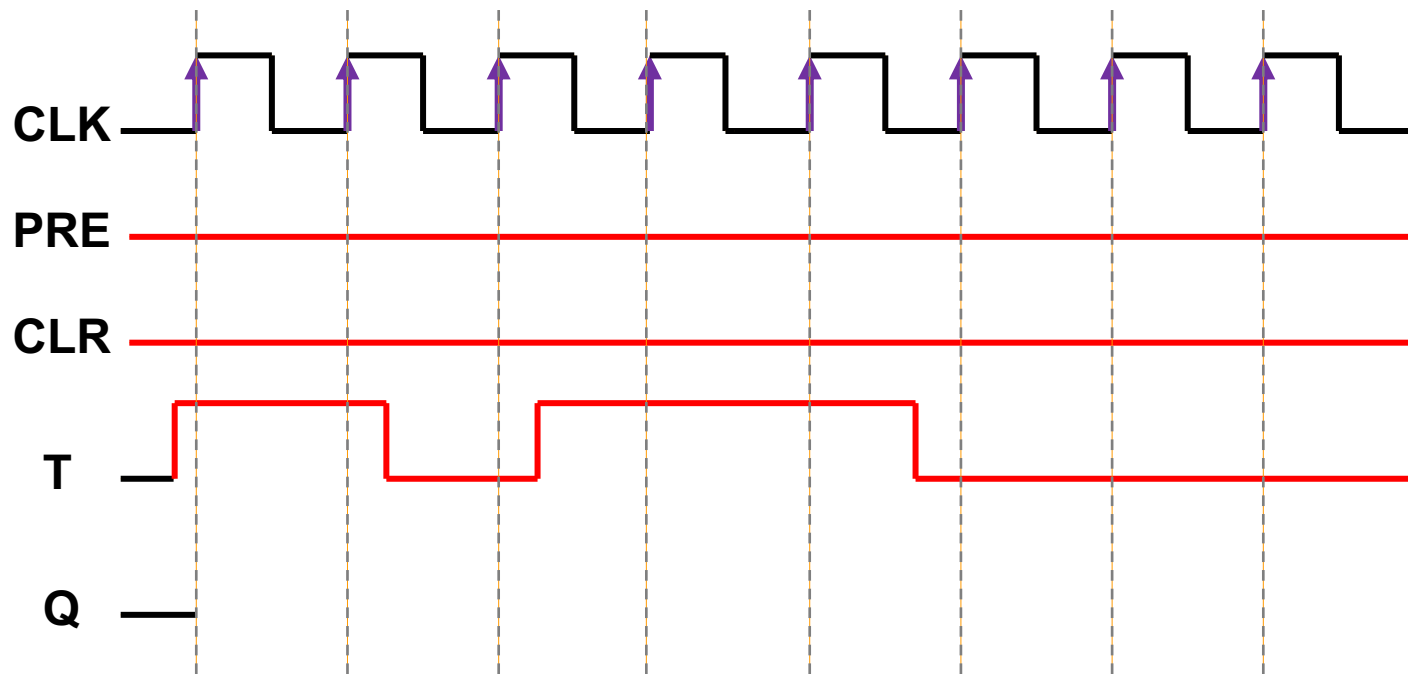


# Flip-flop T com Preset e Clear

PRE	CLR	$Q_{t+1}$
0	0	FUNCIONAMENTO NORMAL
0	1	0
1	0	1
1	1	NÃO PERMITIDO



CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$

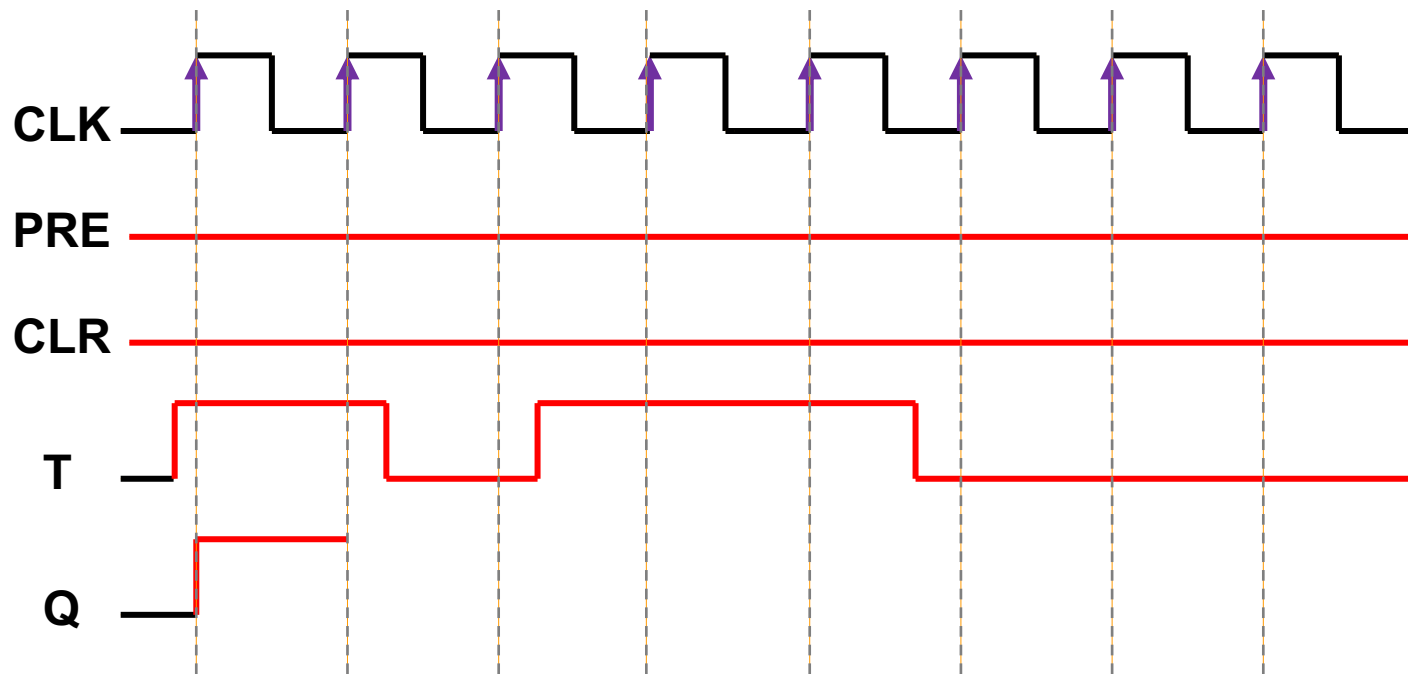


# Flip-flop T com Preset e Clear

PRE	CLR	$Q_{t+1}$
0	0	FUNCIONAMENTO NORMAL
0	1	0
1	0	1
1	1	NÃO PERMITIDO



CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$

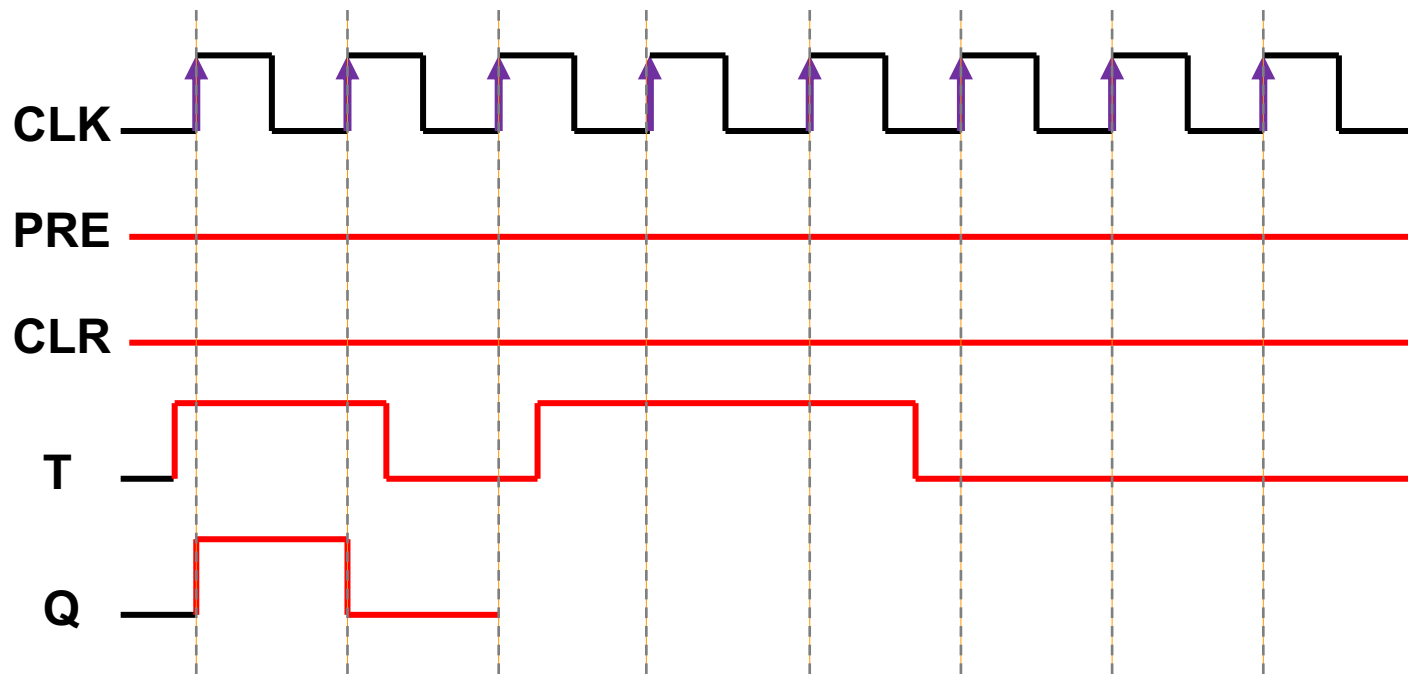


# Flip-flop T com Preset e Clear

PRE	CLR	$Q_{t+1}$
0	0	FUNCIONAMENTO NORMAL
0	1	0
1	0	1
1	1	NÃO PERMITIDO



CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$

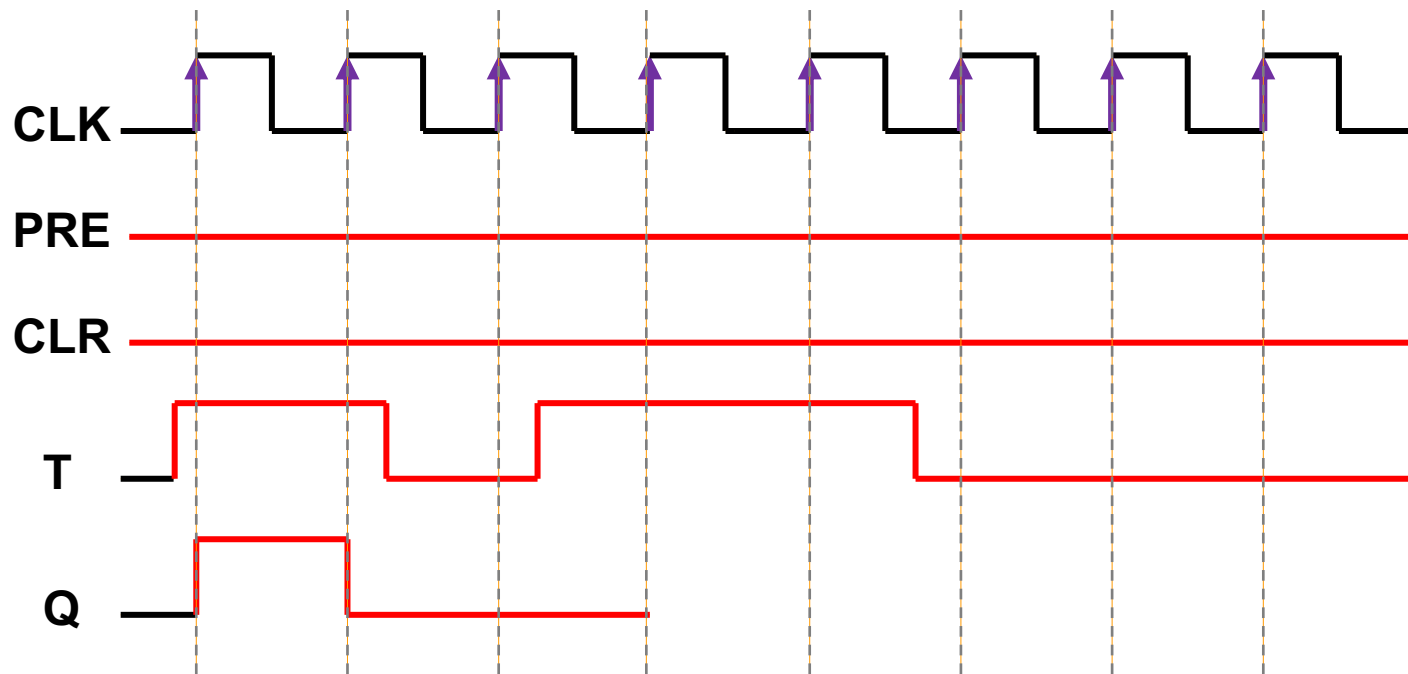


# Flip-flop T com Preset e Clear

PRE	CLR	$Q_{t+1}$
0	0	FUNCIONAMENTO NORMAL
0	1	0
1	0	1
1	1	NÃO PERMITIDO



CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$

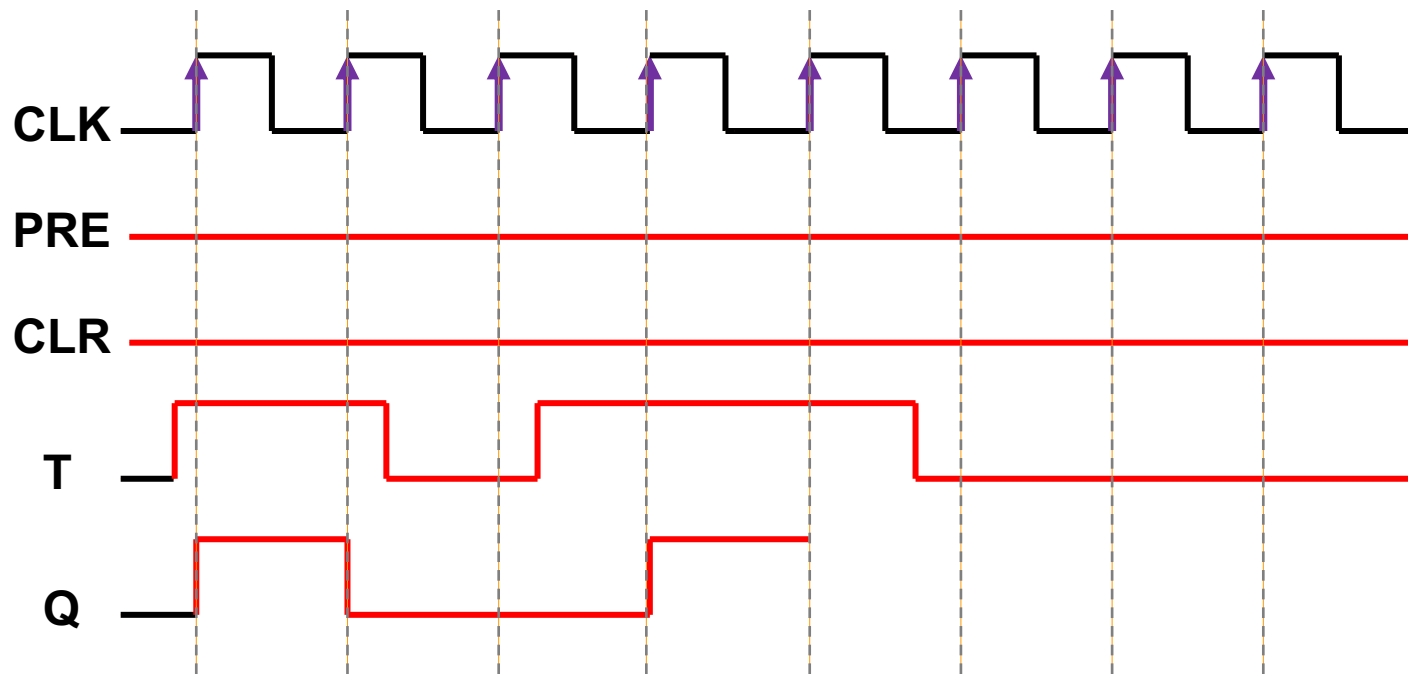


# Flip-flop T com Preset e Clear

PRE	CLR	$Q_{t+1}$
0	0	FUNCIONAMENTO NORMAL
0	1	0
1	0	1
1	1	NÃO PERMITIDO



CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$

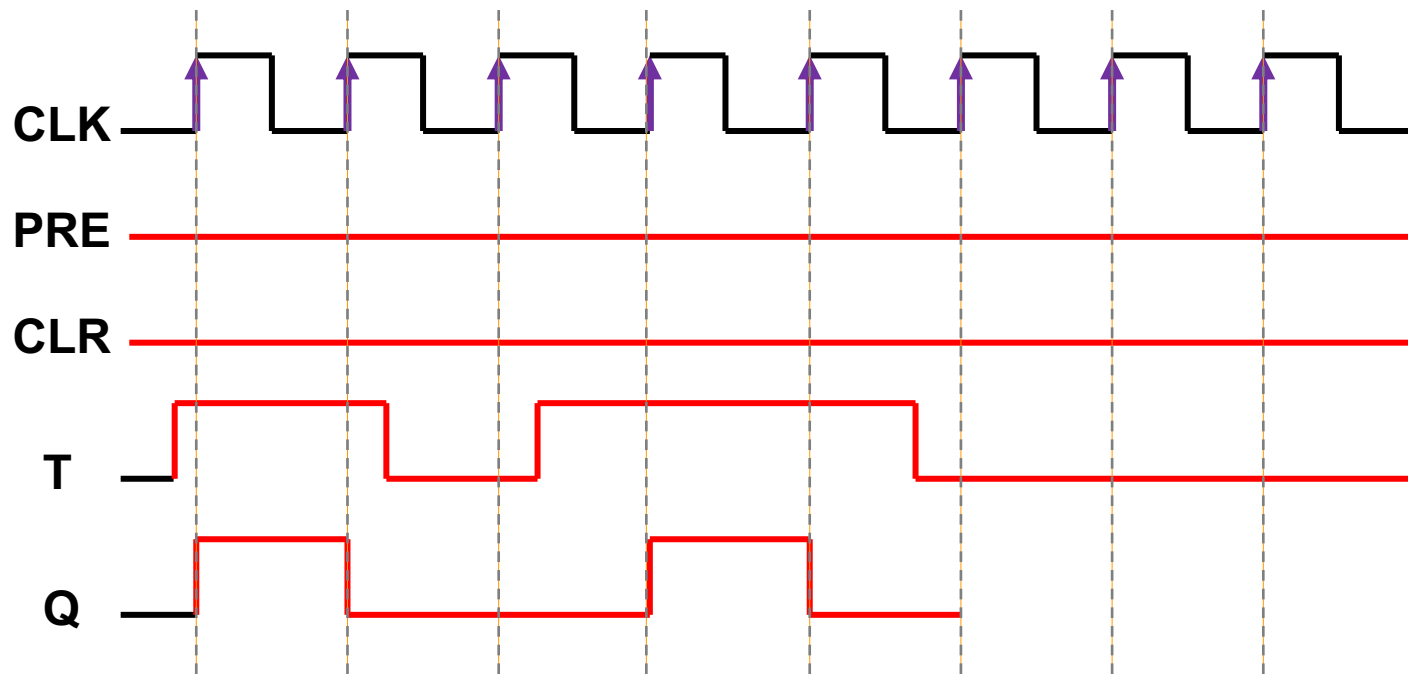


# Flip-flop T com Preset e Clear

PRE	CLR	$Q_{t+1}$
0	0	FUNCIONAMENTO NORMAL
0	1	0
1	0	1
1	1	NÃO PERMITIDO



CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$

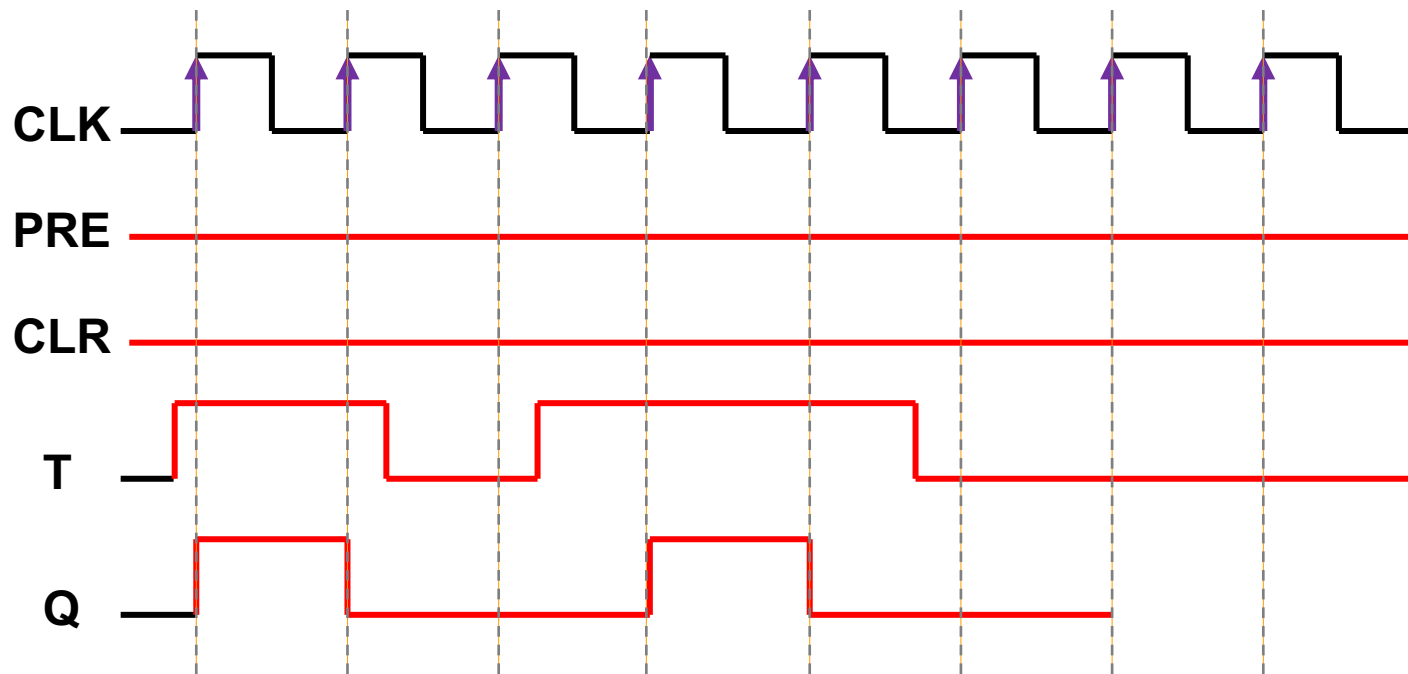


# Flip-flop T com Preset e Clear

PRE	CLR	$Q_{t+1}$
0	0	FUNCIONAMENTO NORMAL
0	1	0
1	0	1
1	1	NÃO PERMITIDO



CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$



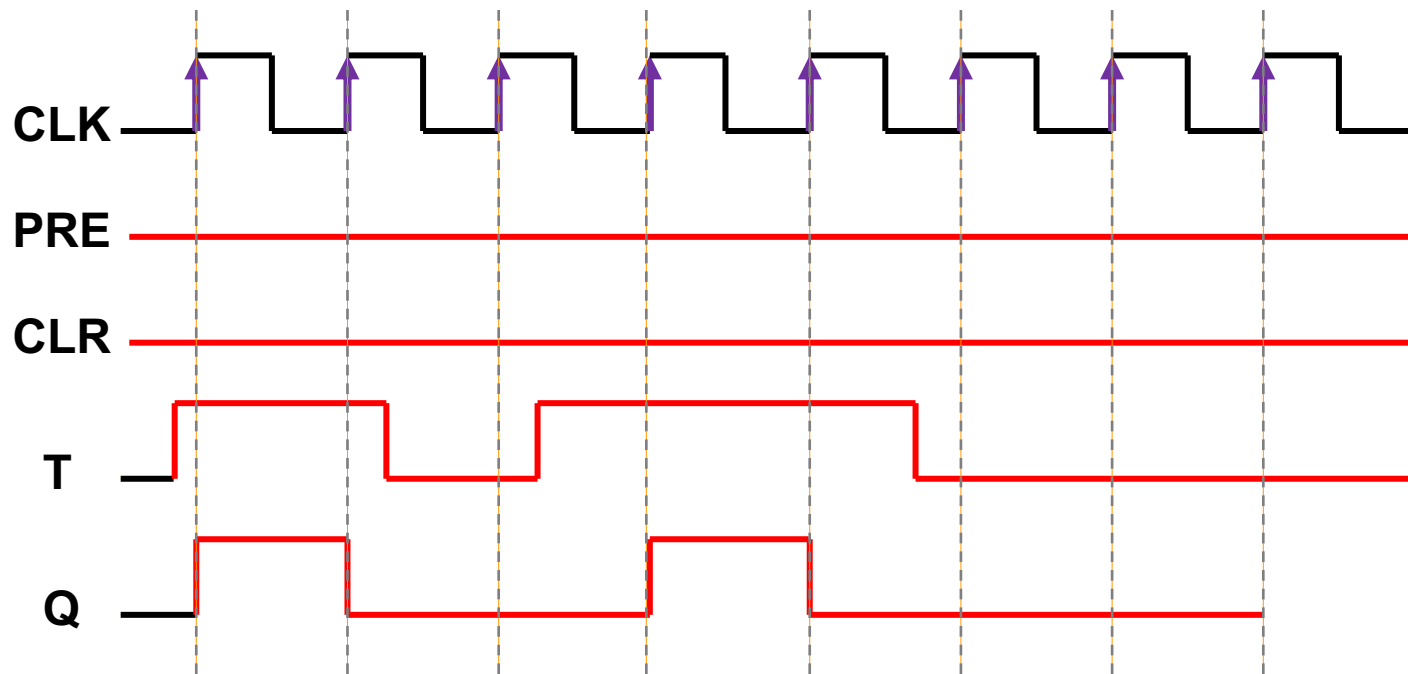


# Flip-flop T com Preset e Clear

PRE	CLR	$Q_{t+1}$
0	0	FUNCIONAMENTO NORMAL
0	1	0
1	0	1
1	1	NÃO PERMITIDO



CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$

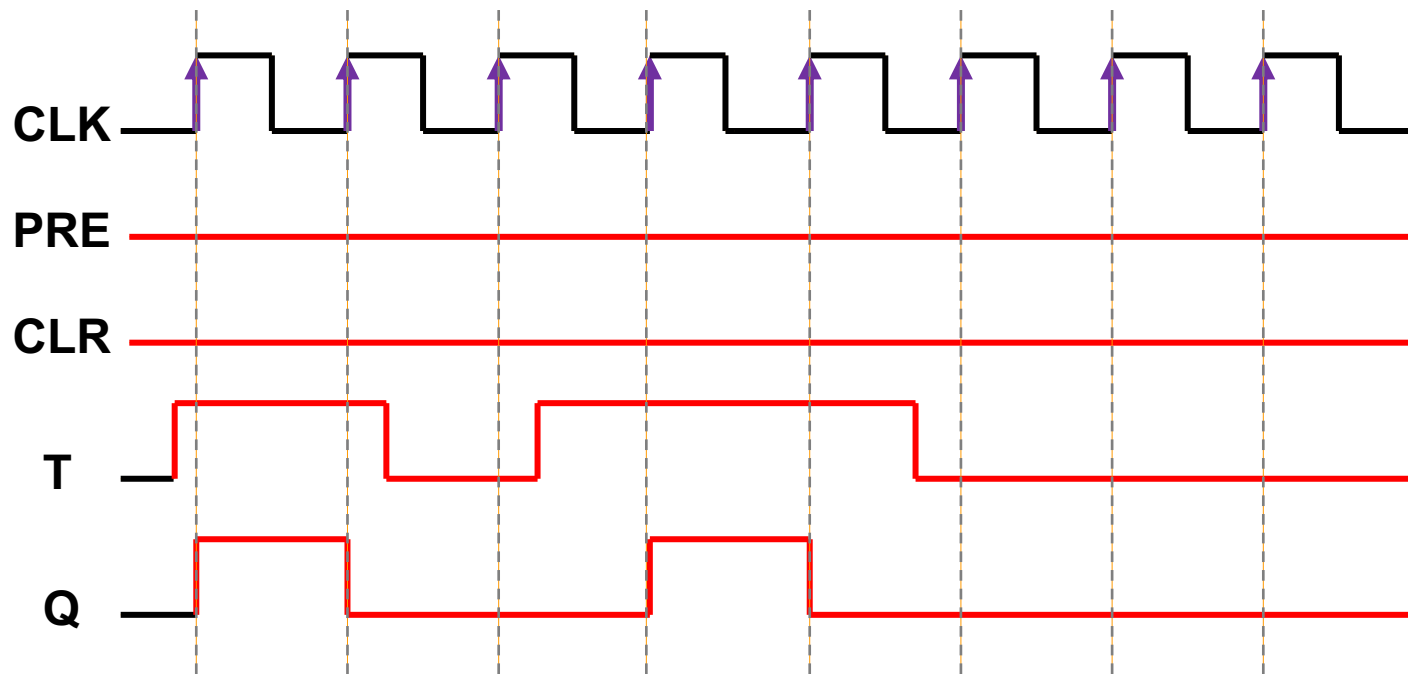


# Flip-flop T com Preset e Clear

PRE	CLR	$Q_{t+1}$
0	0	FUNCIONAMENTO NORMAL
0	1	0
1	0	1
1	1	NÃO PERMITIDO

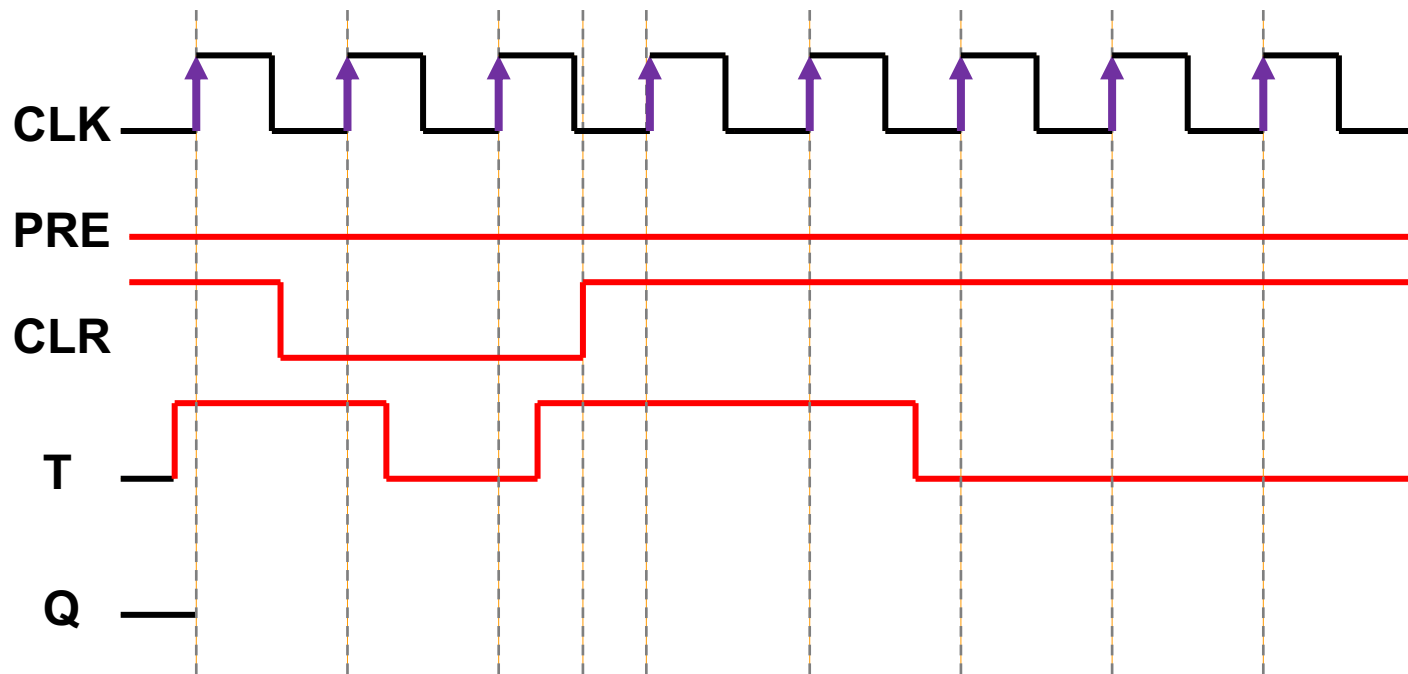


CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$



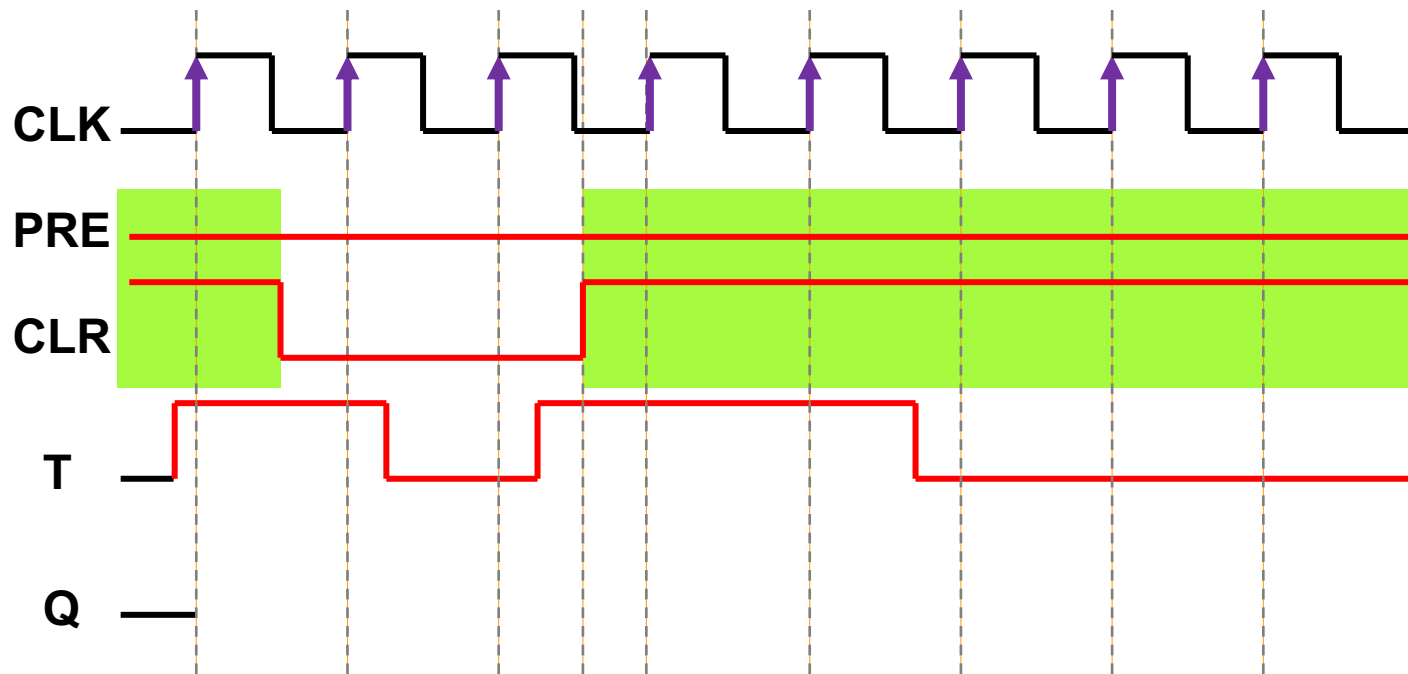
# Flip-flop T com Preset e Clear

PRE	CLR	$Q_{t+1}$
0	0	FUNCIONAMENTO NORMAL
0	1	0
1	0	1
1	1	NÃO PERMITIDO



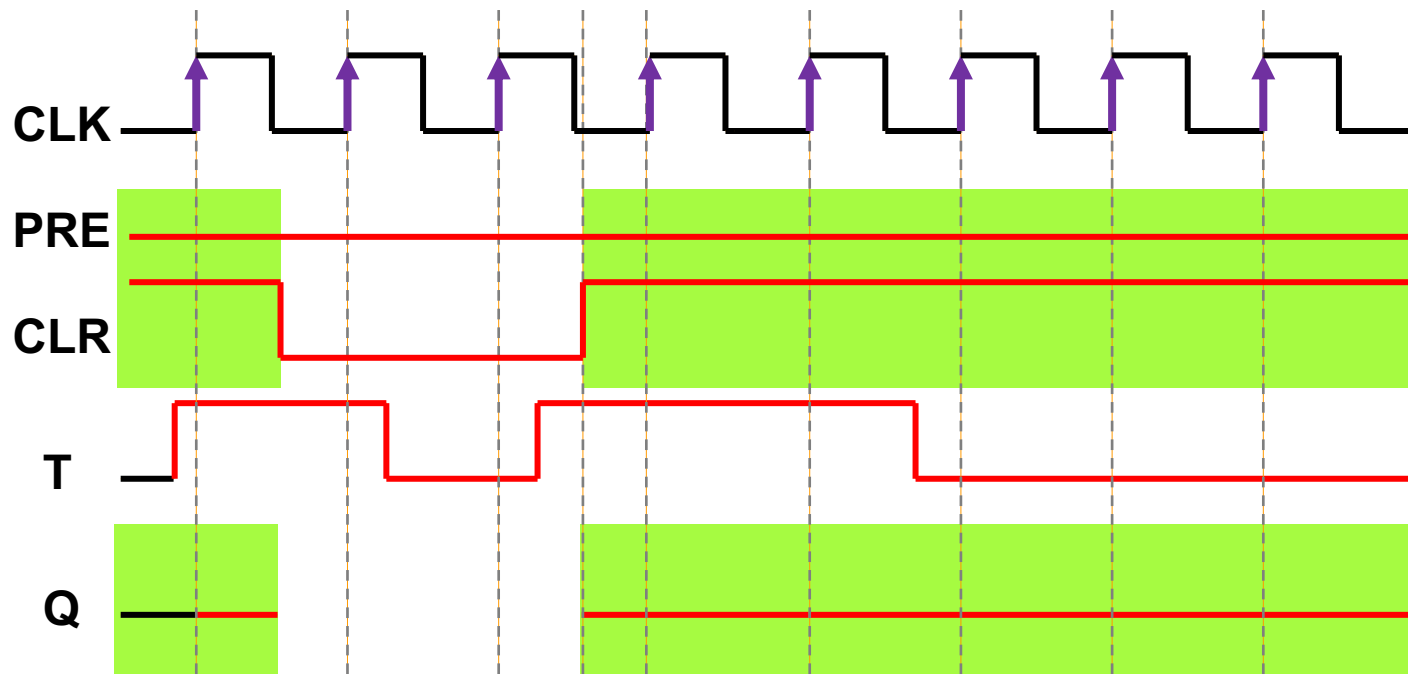
# Flip-flop T com Preset e Clear

PRE	CLR	$Q_{t+1}$
0	0	FUNCIONAMENTO NORMAL
0	1	0
1	0	1
1	1	NÃO PERMITIDO



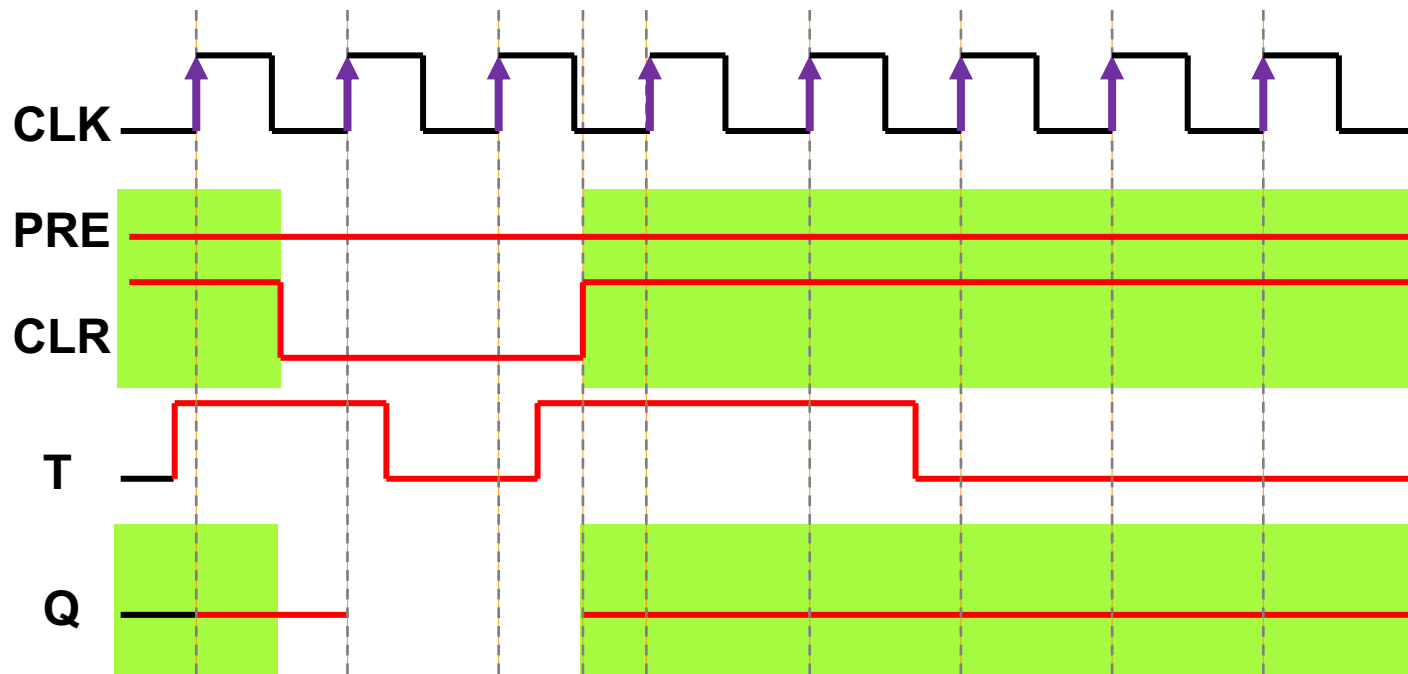
# Flip-flop T com Preset e Clear

PRE	CLR	$Q_{t+1}$
0	0	FUNCIONAMENTO NORMAL
0	1	0
1	0	1
1	1	NÃO PERMITIDO



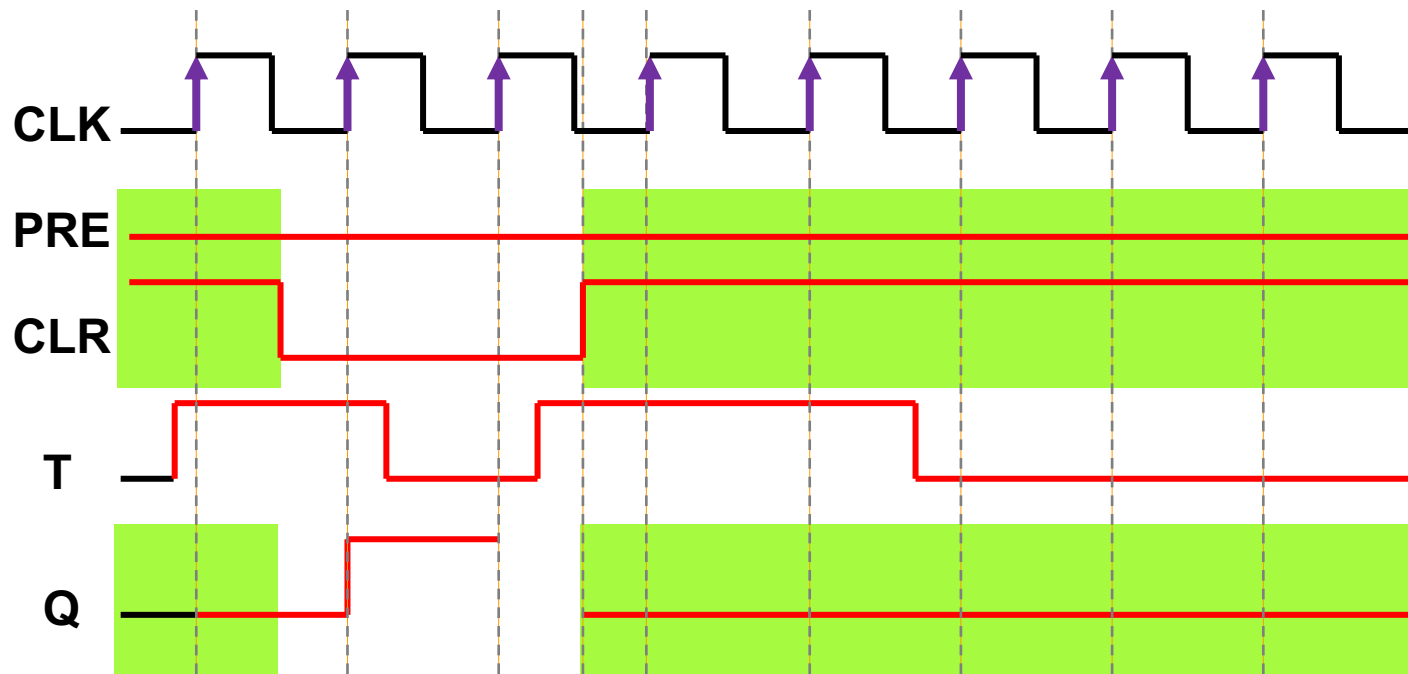
# Flip-flop T com Preset e Clear

PRE	CLR	$Q_{t+1}$
0	0	FUNCIONAMENTO NORMAL
0	1	0
1	0	1
1	1	NÃO PERMITIDO



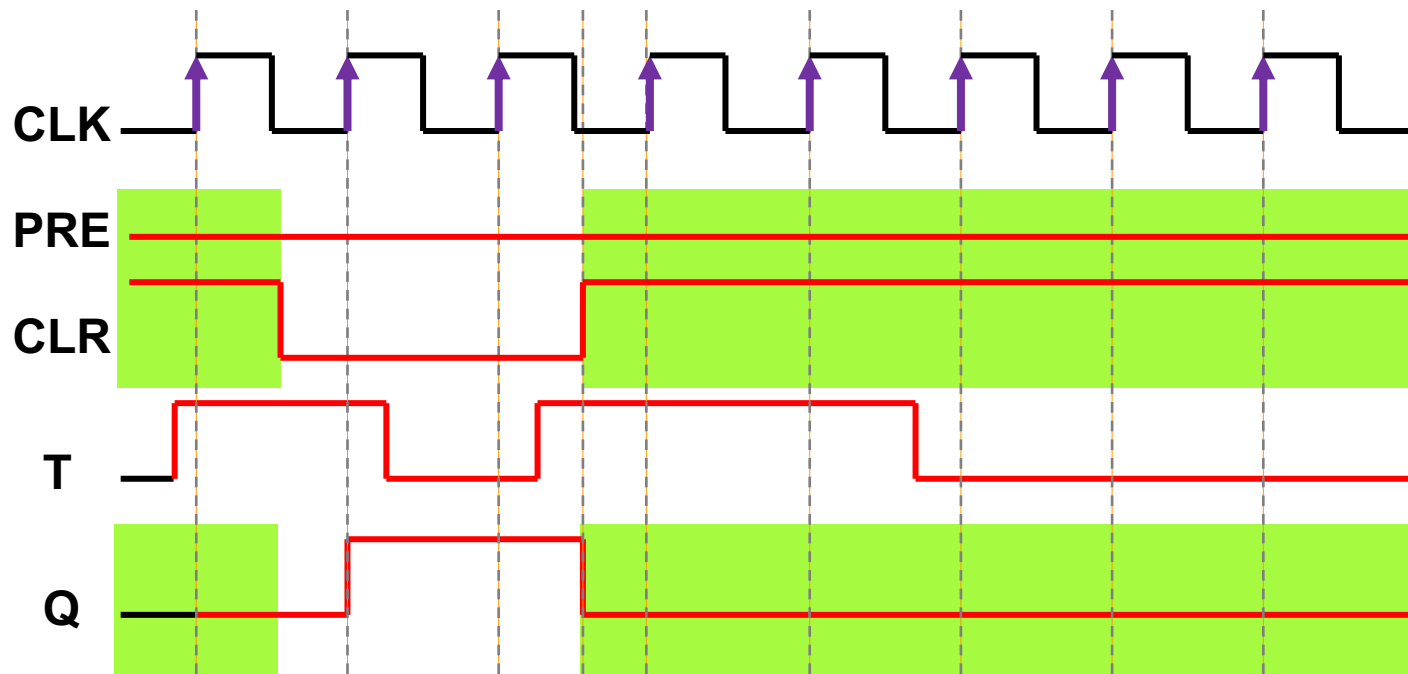
# Flip-flop T com Preset e Clear

PRE	CLR	$Q_{t+1}$
0	0	FUNCIONAMENTO NORMAL
0	1	0
1	0	1
1	1	NÃO PERMITIDO



# Flip-flop T com Preset e Clear

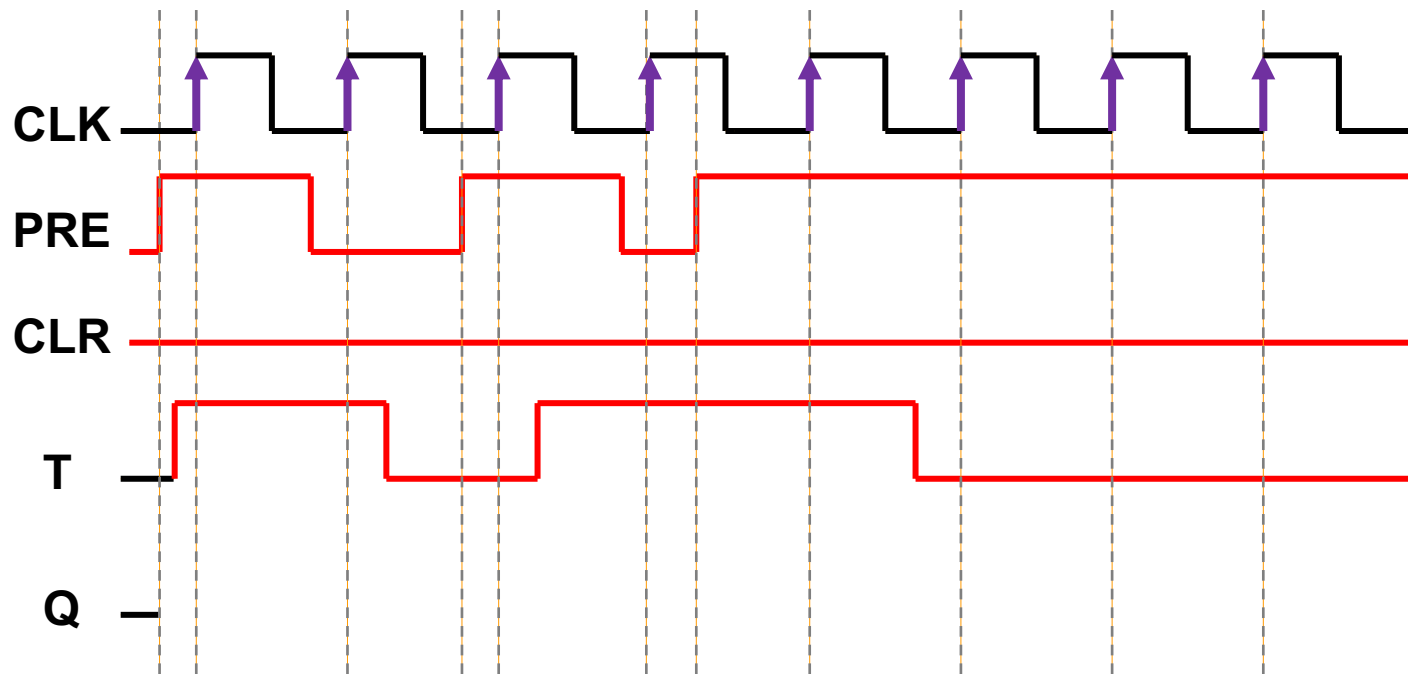
PRE	CLR	$Q_{t+1}$
0	0	FUNCIONAMENTO NORMAL
0	1	0
1	0	1
1	1	NÃO PERMITIDO





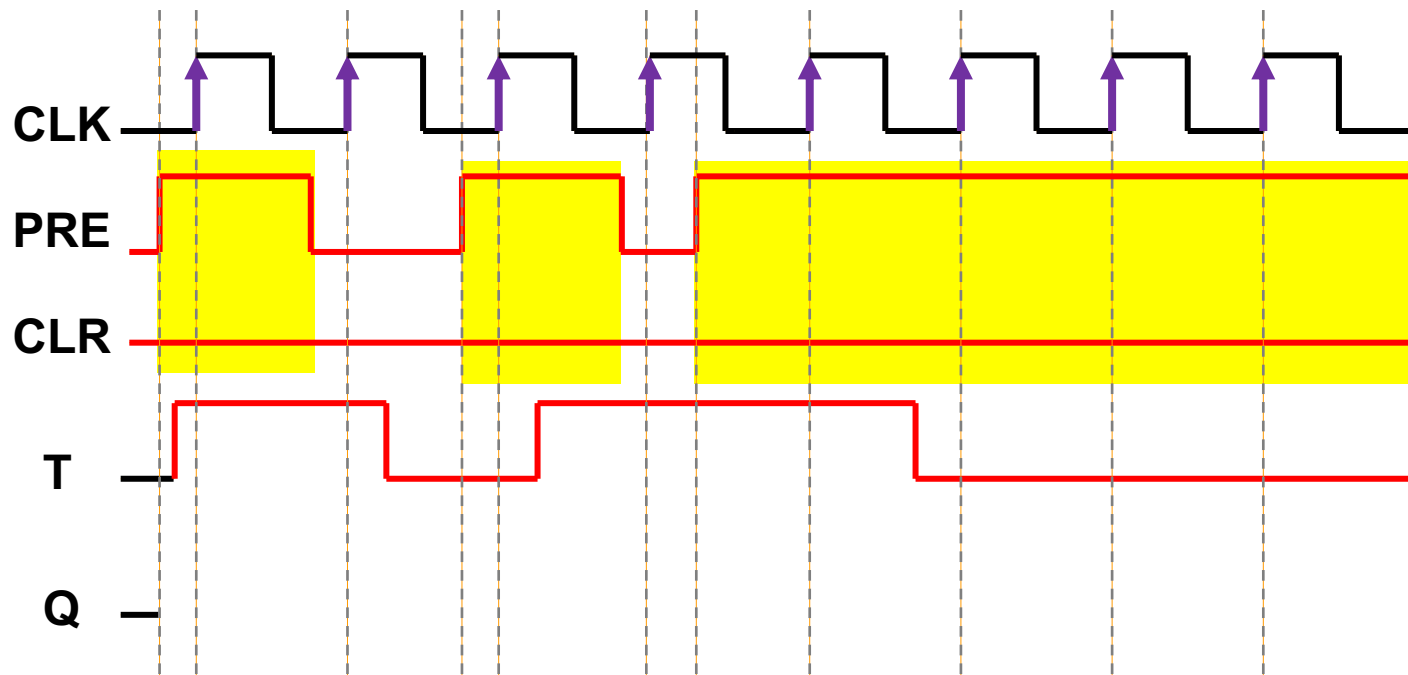
# Flip-flop T com Preset e Clear

PRE	CLR	$Q_{t+1}$
0	0	FUNCIONAMENTO NORMAL
0	1	0
1	0	1
1	1	NÃO PERMITIDO



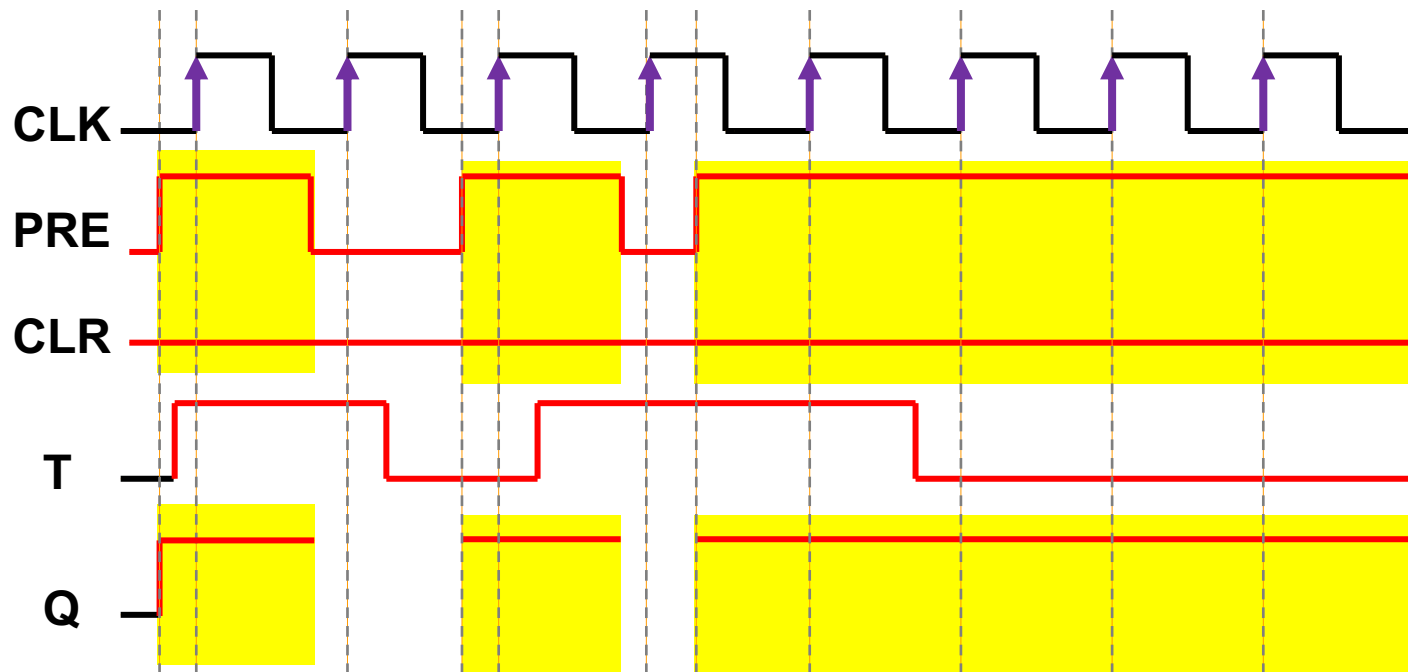
# Flip-flop T com Preset e Clear

PRE	CLR	$Q_{t+1}$
0	0	FUNCIONAMENTO NORMAL
0	1	0
1	0	1
1	1	NÃO PERMITIDO



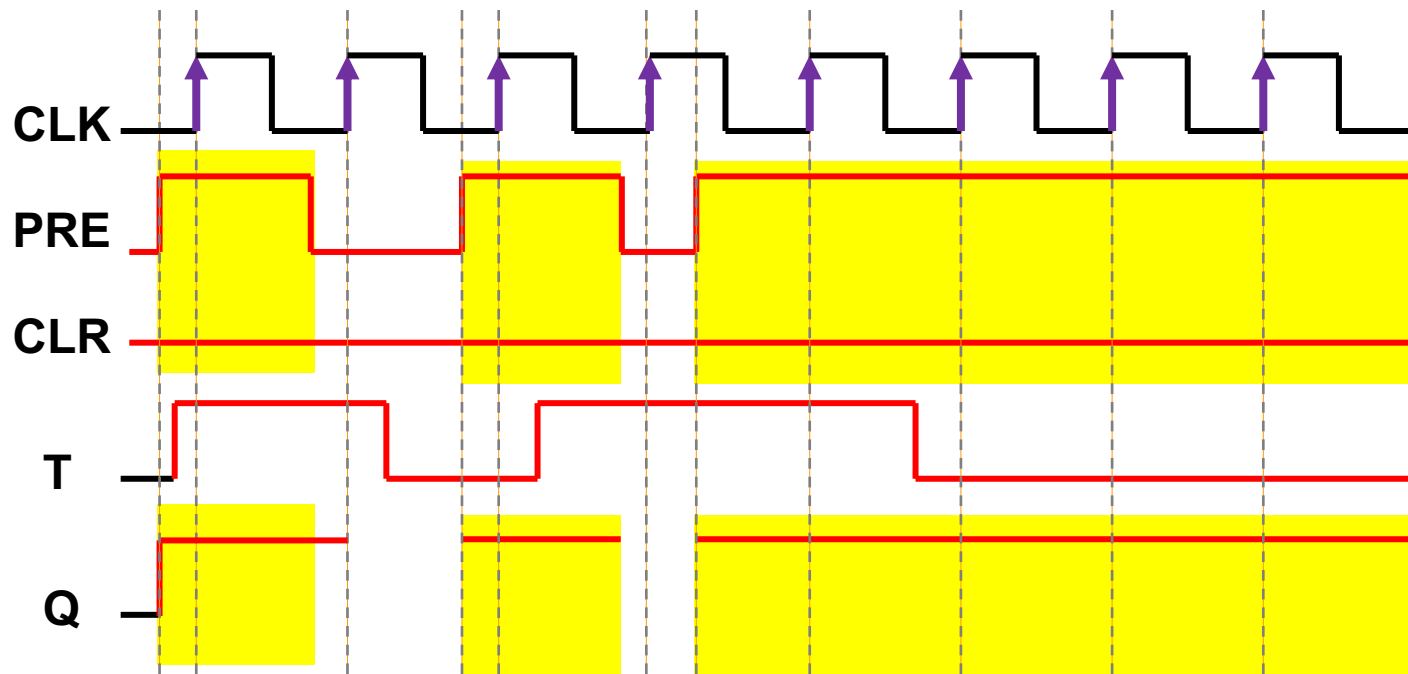
# Flip-flop T com Preset e Clear

PRE	CLR	$Q_{t+1}$
0	0	FUNCIONAMENTO NORMAL
0	1	0
1	0	1
1	1	NÃO PERMITIDO



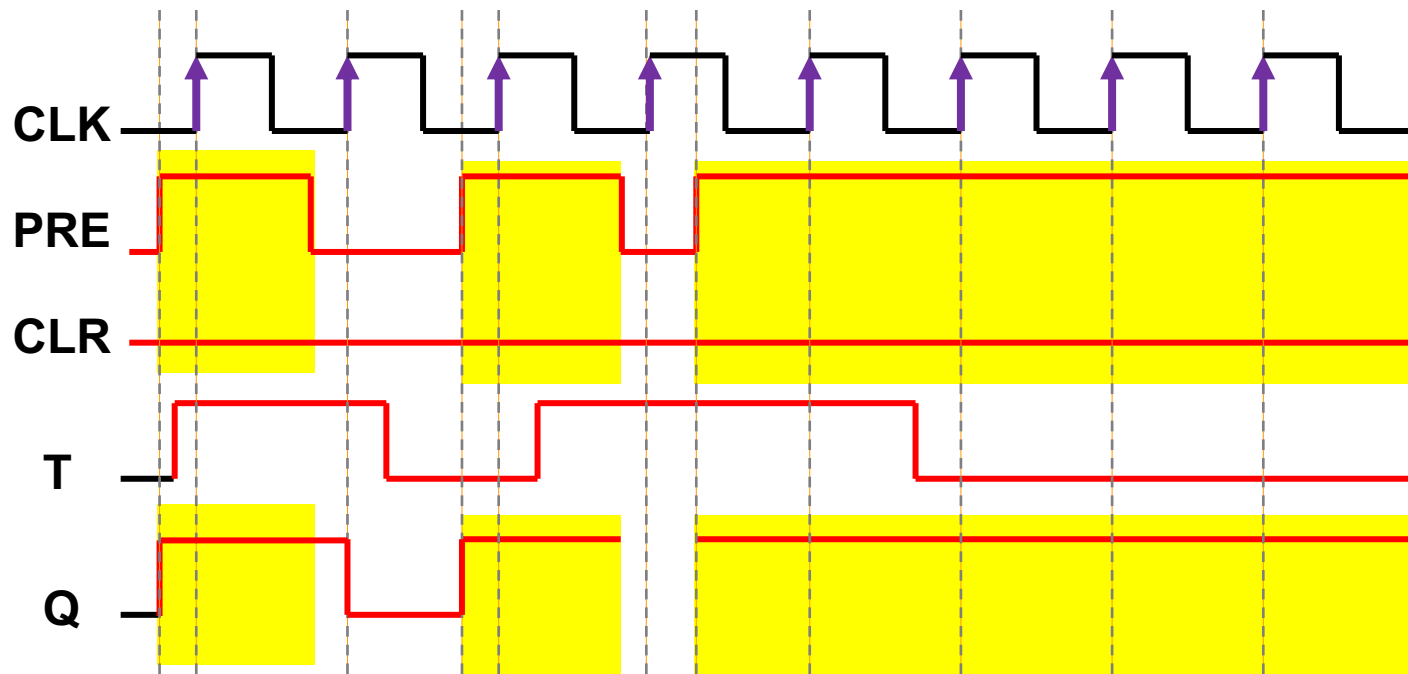
# Flip-flop T com Preset e Clear

PRE	CLR	$Q_{t+1}$
0	0	FUNCIONAMENTO NORMAL
0	1	0
1	0	1
1	1	NÃO PERMITIDO



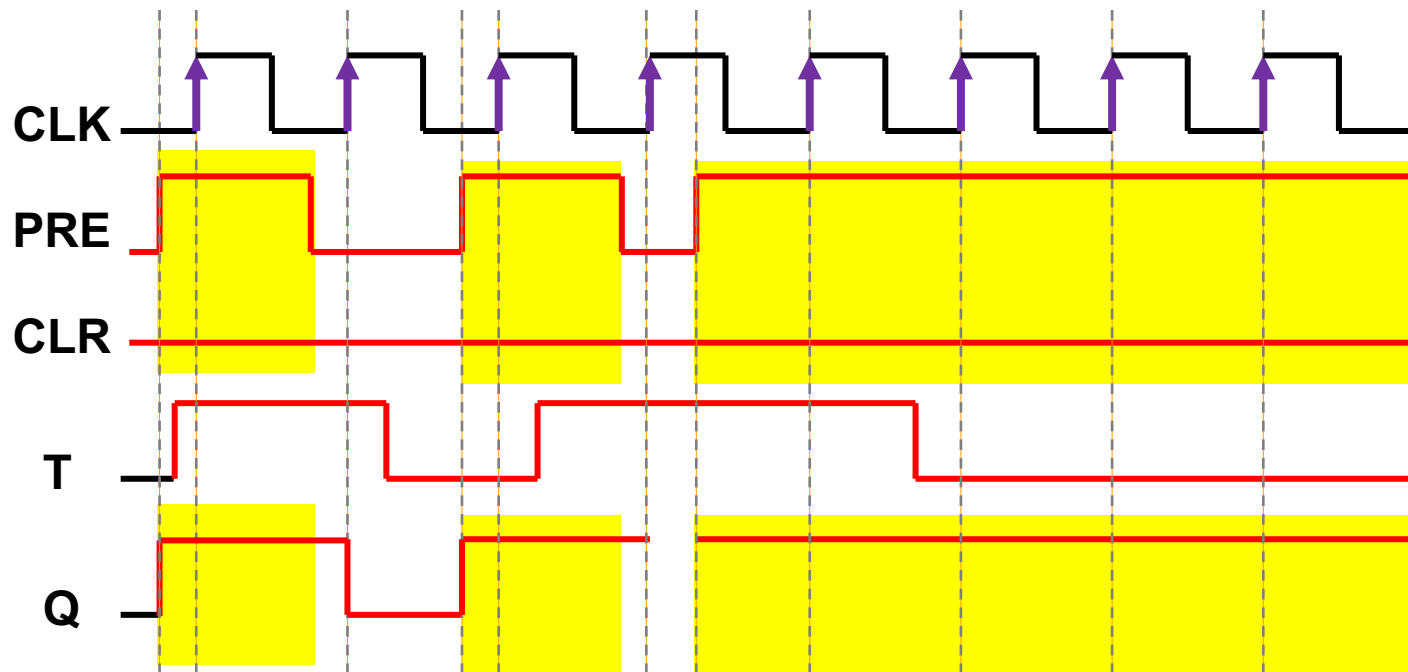
# Flip-flop T com Preset e Clear

PRE	CLR	$Q_{t+1}$
0	0	FUNCIONAMENTO NORMAL
0	1	0
1	0	1
1	1	NÃO PERMITIDO



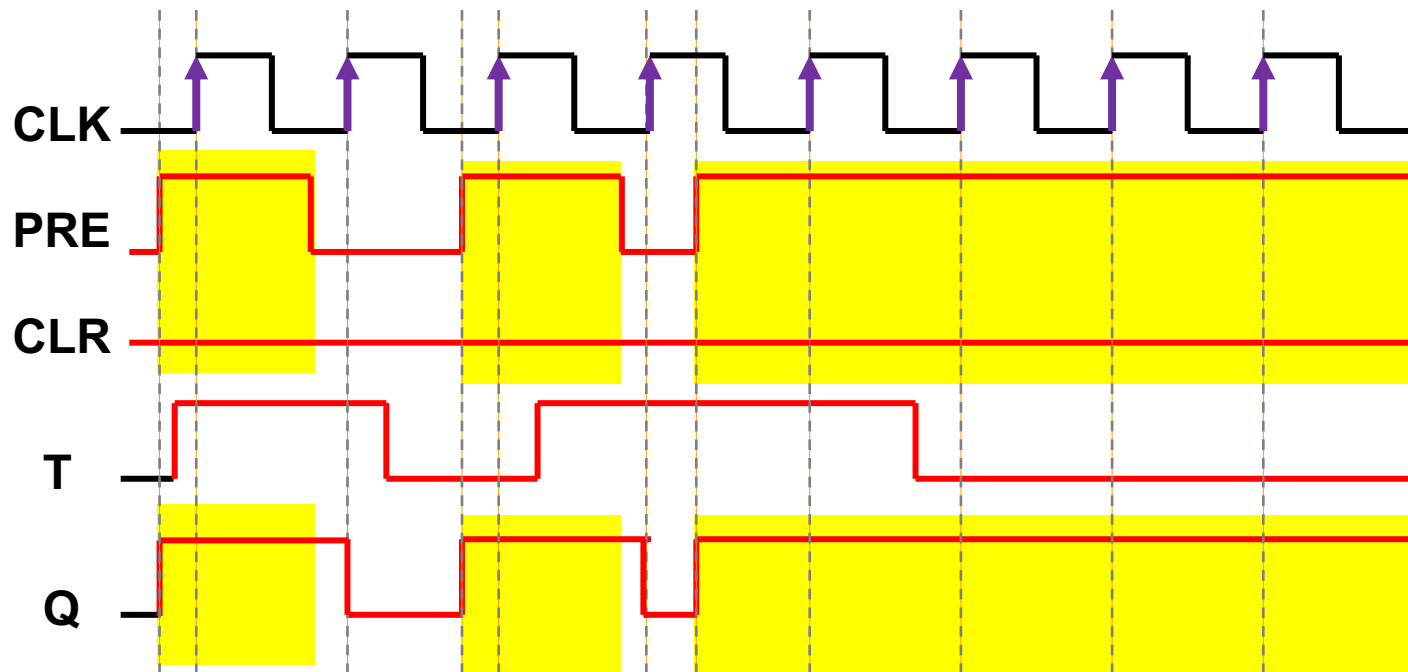
# Flip-flop T com Preset e Clear

PRE	CLR	$Q_{t+1}$
0	0	FUNCIONAMENTO NORMAL
0	1	0
1	0	1
1	1	NÃO PERMITIDO

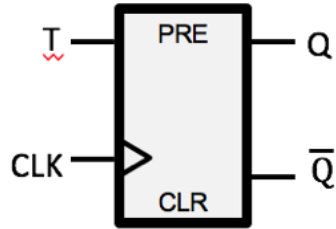


# Flip-flop T com Preset e Clear

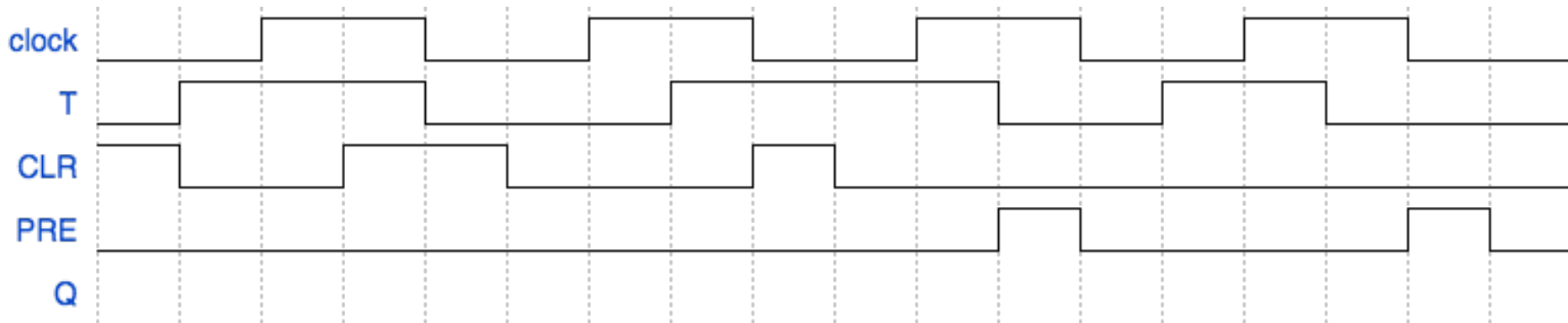
PRE	CLR	$Q_{t+1}$
0	0	FUNCIONAMENTO NORMAL
0	1	0
1	0	1
1	1	NÃO PERMITIDO



# Exemplo - Flip-flop T com Preset e Clear

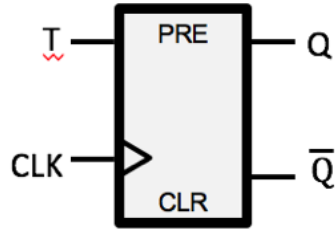


CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$

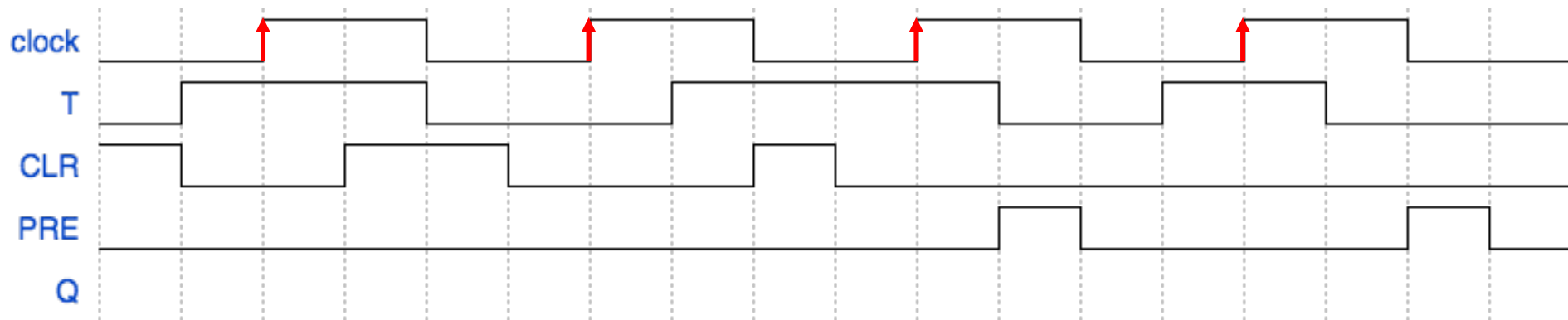




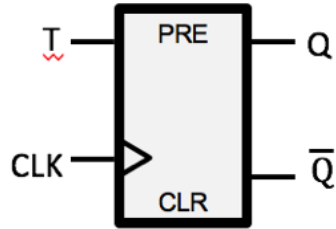
# Exemplo - Flip-flop T com Preset e Clear



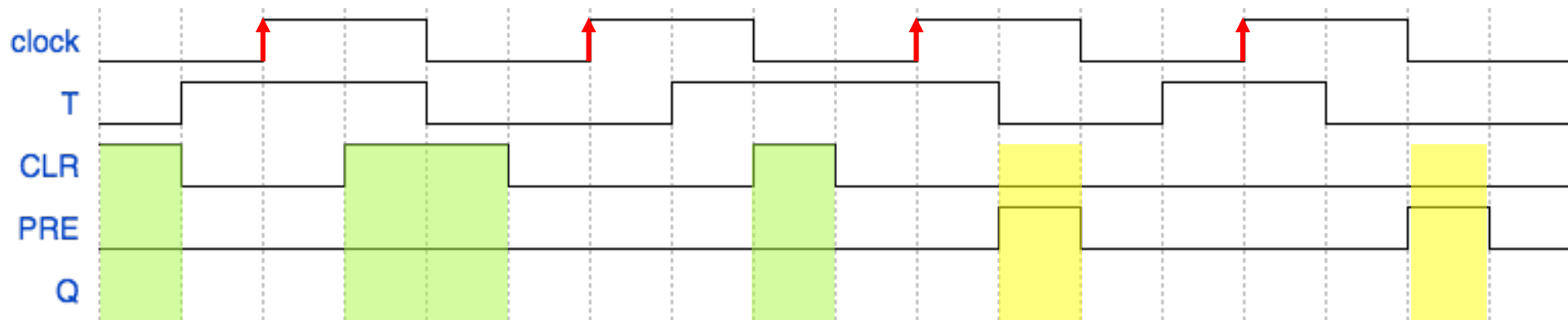
CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$



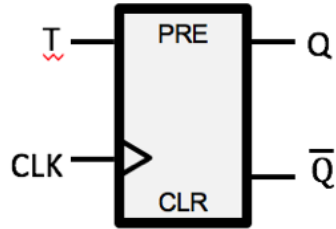
# Exemplo - Flip-flop T com Preset e Clear



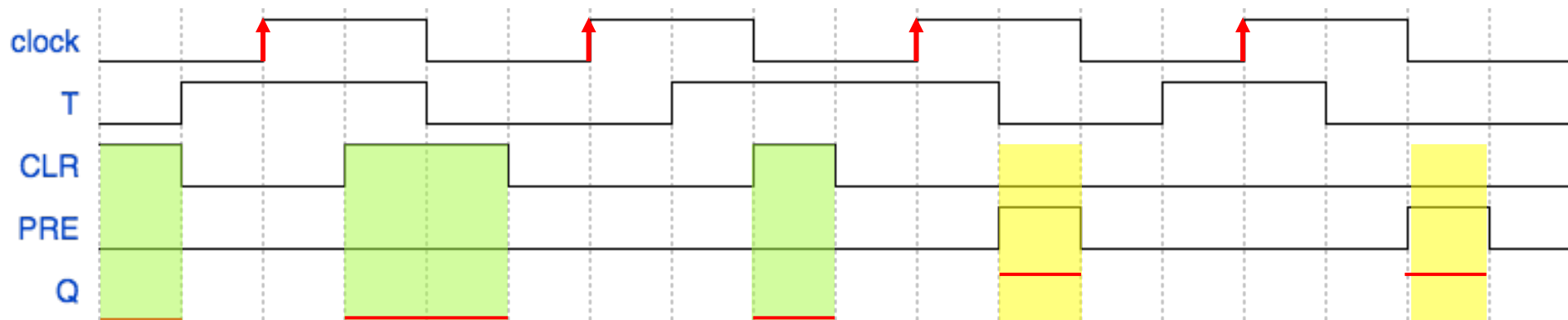
CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$



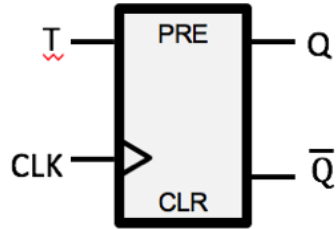
# Exemplo - Flip-flop T com Preset e Clear



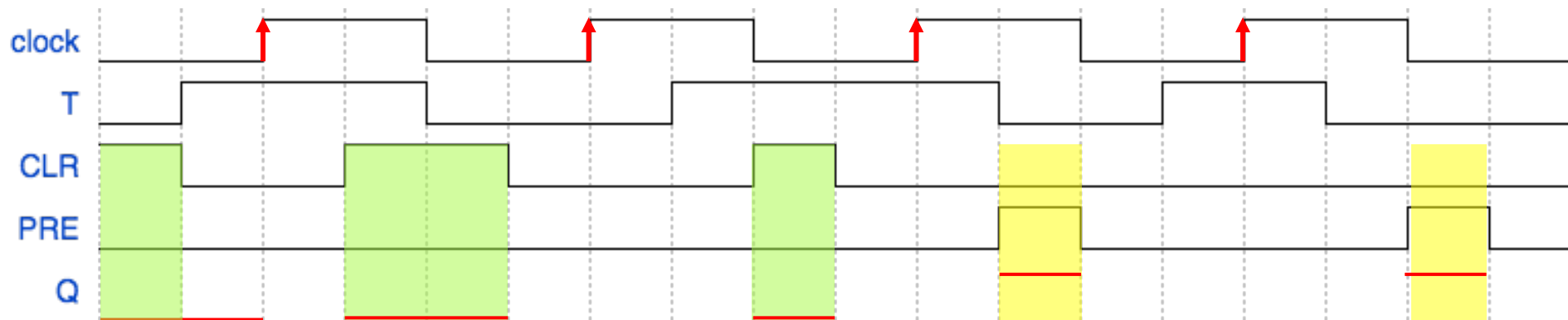
CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$



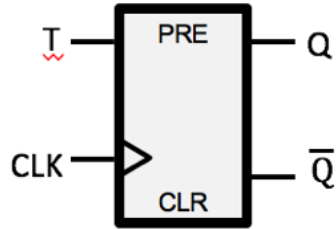
# Exemplo - Flip-flop T com Preset e Clear



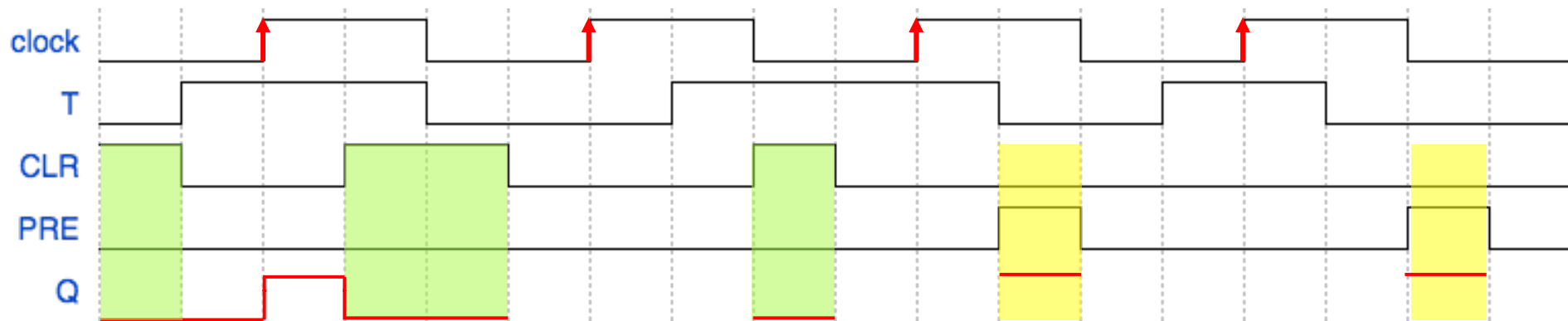
CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$



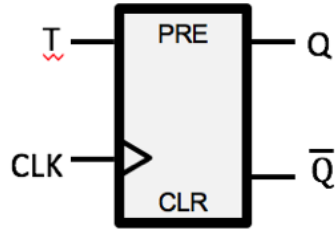
# Exemplo - Flip-flop T com Preset e Clear



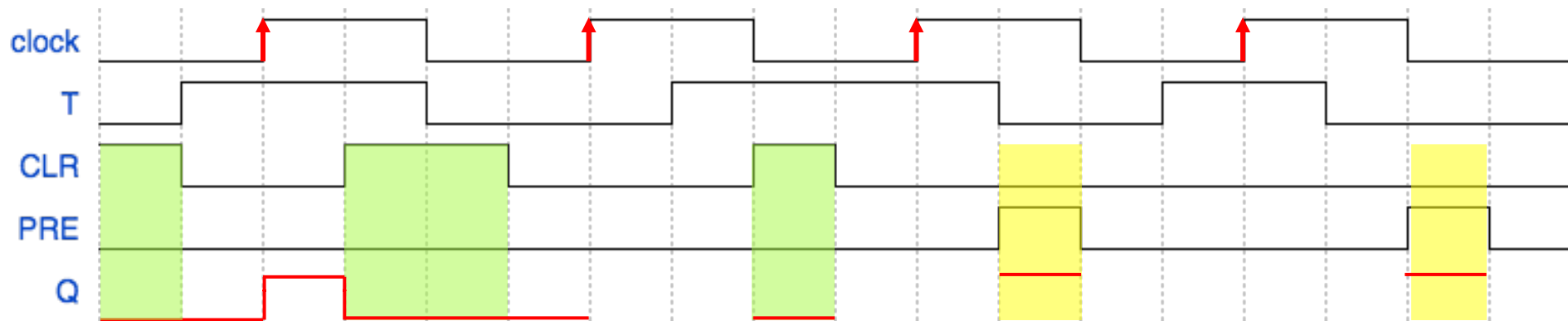
CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$



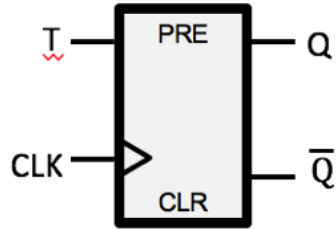
# Exemplo - Flip-flop T com Preset e Clear



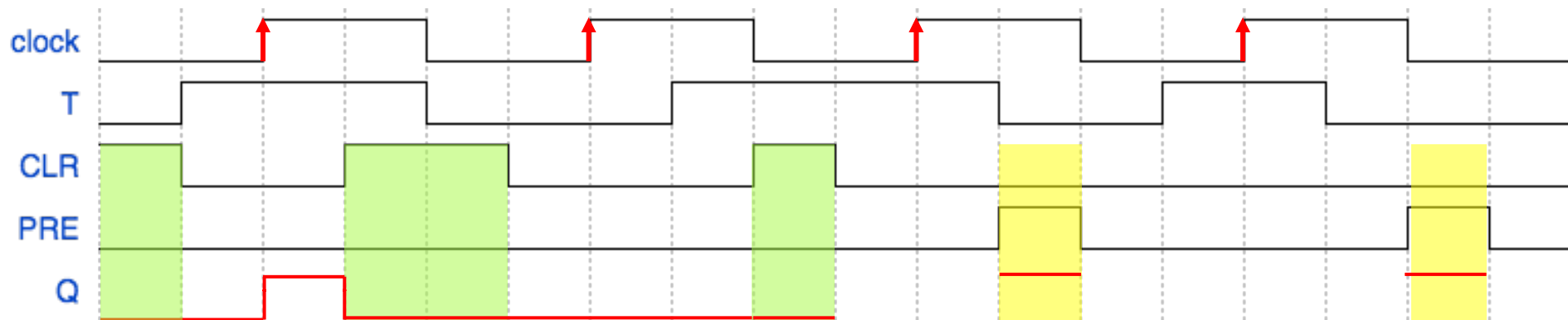
CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$



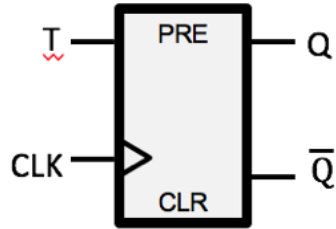
# Exemplo - Flip-flop T com Preset e Clear



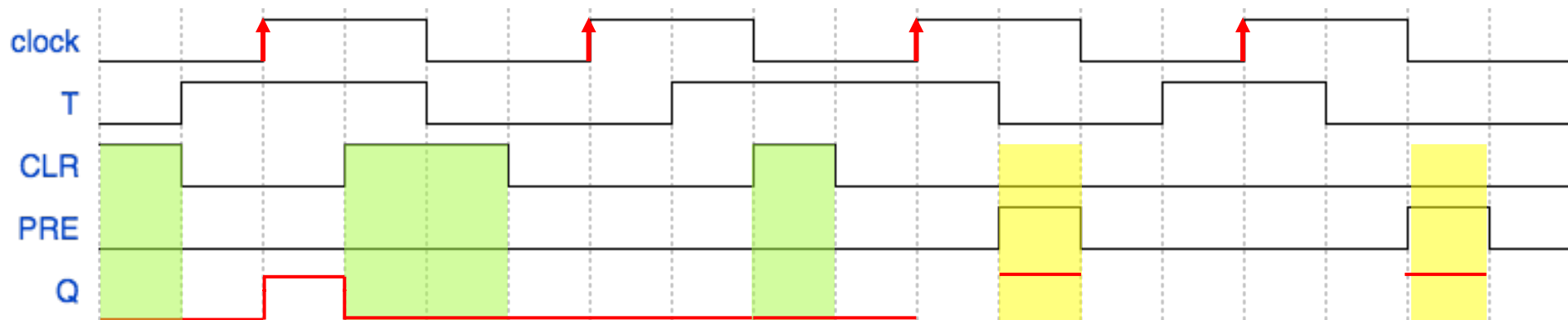
CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$



# Exemplo - Flip-flop T com Preset e Clear

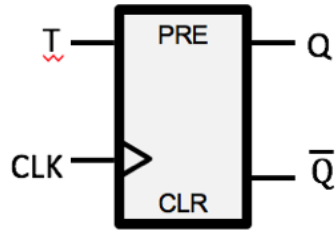


CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$

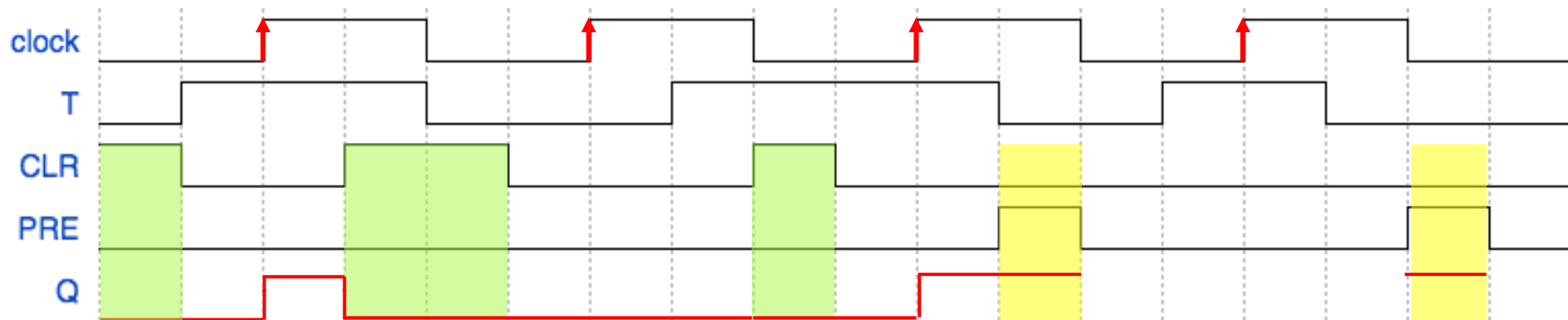




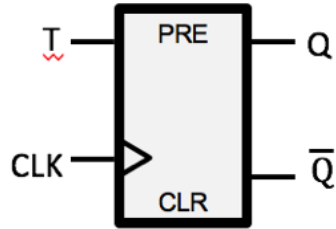
# Exemplo - Flip-flop T com Preset e Clear



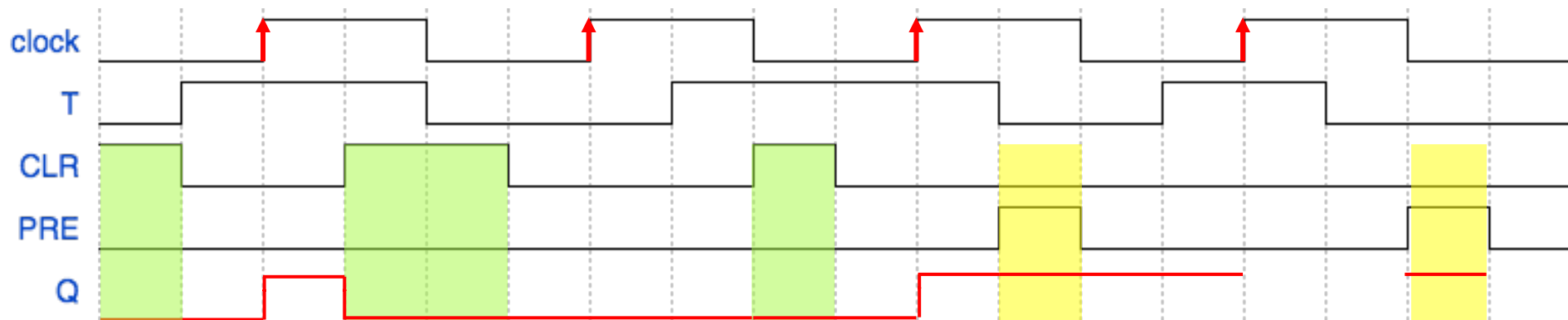
CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$



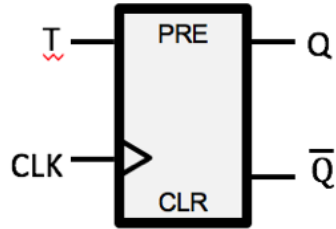
# Exemplo - Flip-flop T com Preset e Clear



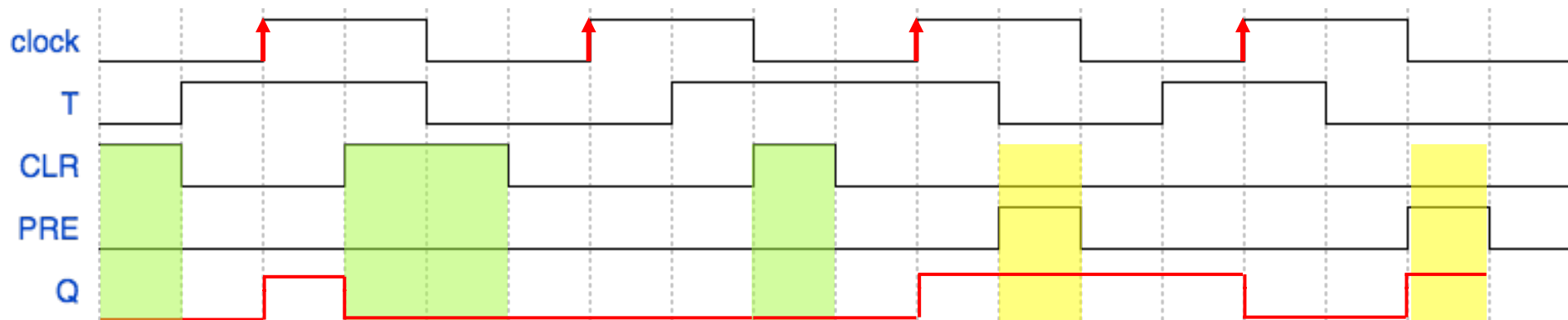
CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$



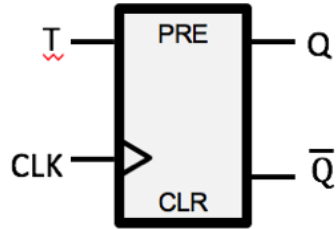
# Exemplo - Flip-flop T com Preset e Clear



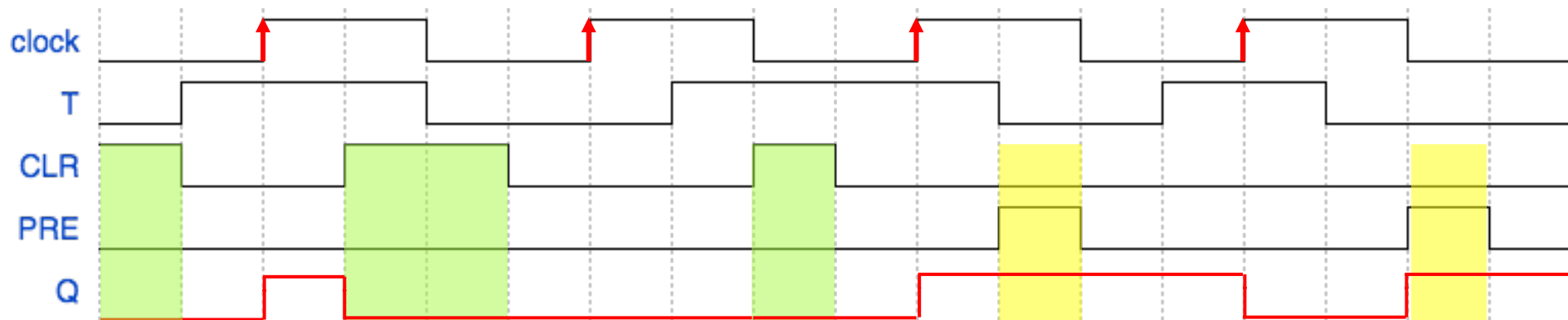
CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$



# Exemplo - Flip-flop T com Preset e Clear



CLK	T	$Q_{t+1}$
$\neq \uparrow$	X	$Q_t$
$\uparrow$	0	$Q_t$
$\uparrow$	1	$\overline{Q_t}$



# Tempo de Atraso de Propagação

