Construct a  $\boldsymbol{\mathsf{non\text{-}deterministic}}$   $\boldsymbol{\mathsf{TM}}$  that accepts the language:

$$L(M) = \{ww^R \mid w \in \{\mathtt{a},\mathtt{b}\}^*\}$$

... | B | a | b | b | a | B | ...

- 1: Find the middle in the input
- 2: Check if first and second half are reverse of each other

$$L(M) = \{ww^R \mid w \in \{a,b\}^*\}$$

$$\dots \mid B \mid a \mid b \mid b \mid a \mid B \mid \dots$$

$$[a \to a]R \qquad [X \to X]R \qquad [b \to b]R \qquad [Y \to Y]R$$

$$[b \to b]R \qquad [a \to a]R \qquad [a \to X]L \qquad [X \to X]L \qquad [Y \to Y]L$$

$$[B \to B]L \qquad [B \to B]R \qquad [b \to Y]R \qquad [b \to Y]L$$

$$[B \to B]R \qquad [A \to X]L \qquad [A$$

Find the middle in the input.

$$L(M) = \{ww^R \mid w \in \{a,b\}^*\}$$

$$\hline \cdots \mid B \mid a \mid b \mid b \mid a \mid B \mid \cdots$$

$$\begin{bmatrix} [a \to a]R & [X \to X]R \\ [b \to b]R & [Y \to Y]R \end{bmatrix}$$

$$[a \to a]R & [a \to X]L \\ [b \to b]R & [a \to X]L \end{bmatrix}$$

$$[B \to B]L & [a \to X]L \\ [b \to Y]R & [a \to X]L \\ [b \to Y]L & [a \to X]L \end{bmatrix}$$

$$[B \to B]R & [b \to Y]R & [b \to Y]L$$

$$[B \to B]R & [a \to X]L \\ [b \to Y]L & [b \to Y]L & [b \to Y]L$$

$$L(M) = \{ww^R \mid w \in \{a, b\}^*\}$$

$$\dots \mid B \mid a \mid b \mid b \mid a \mid B \mid \dots$$

$$[a \to a]R \qquad [Y \to Y]R \qquad [a \to X]L \qquad [$$

Check if first and second half are reverse of each other.

$$L(M) = \{ww^R \mid w \in \{a, b\}^*\}$$

$$\dots \mid B \mid a \mid b \mid Y \mid a \mid B \mid \dots$$

$$[a \to a]R \qquad [Y \to Y]R$$

$$[b \to b]R \qquad [Y \to Y]R$$

$$[a \to a]R \qquad [a \to x]L$$

$$[b \to b]R \qquad [a \to x]L$$

$$[a \to x]L \qquad [a \to x]L \qquad [x \to x]L$$

$$[a \to x]L \qquad [a \to x]L \qquad [x \to x]L$$

$$[a \to x]L \qquad [a \to x]L \qquad [x \to x]L$$

$$[a \to x]L \qquad [a \to x]L \qquad [x \to x]L$$

$$[b \to Y]L \qquad [a \to x]L \qquad [x \to x]L$$

$$[a \to x]L \qquad [a \to x]L \qquad [x \to x]L$$

$$[a \to x]L \qquad [a \to x]L \qquad [x \to x]L$$

$$[a \to x]L \qquad [x \to x]L \qquad [x \to x]L$$

$$[a \to x]L \qquad [x \to x]L \qquad [x \to x]L$$

$$[a \to x]L \qquad [x \to x]L \qquad [x \to x]L$$

$$[a \to x]L \qquad [x \to x]L \qquad [x \to x]L$$

$$[a \to x]L \qquad [x \to x]L \qquad [x \to x]L$$

$$[x \to x]L \qquad [x \to x]L \qquad [x \to x]L$$

$$[x \to x]L \qquad [x \to x]L \qquad [x \to x]L$$

$$[x \to x]L \qquad [x \to x]L \qquad [x \to x]L$$

$$[x \to x]L \qquad [x \to x]L \qquad [x \to x]L$$

$$[x \to x]L \qquad [x \to x]L \qquad [x \to x]L$$

$$L(M) = \{ww^R \mid w \in \{a, b\}^*\}$$

$$\dots \mid B \mid a \mid Y \mid Y \mid a \mid B \mid \dots$$

$$[a \to a]R \qquad [Y \to Y]R$$

$$[b \to b]R \qquad [Y \to Y]R$$

$$[a \to a]R \qquad [a \to x]L$$

$$[b \to b]R \qquad [a \to x]L$$

$$[a \to x]L \qquad [a \to x]L \qquad [x \to x]L$$

$$[b \to y]L \qquad [a \to x]L \qquad [x \to x]L$$

$$[b \to y]L \qquad [a \to x]L \qquad [x \to x]L$$

$$[b \to y]L \qquad [a \to x]L \qquad [x \to x]L$$

$$[b \to y]L \qquad [a \to x]L \qquad [x \to x]L$$

$$[a \to x]L \qquad [a \to x]L \qquad [x \to x]L$$

$$[a \to x]L \qquad [a \to x]L \qquad [x \to x]L$$

$$[a \to x]L \qquad [x \to x]L \qquad [x \to x]L$$

$$[a \to x]L \qquad [x \to x]L \qquad [x \to x]L$$

$$[a \to x]L \qquad [x \to x]L \qquad [x \to x]L$$

$$[x \to x]L \qquad [x \to x]L \qquad [x \to x]L$$

$$[x \to x]L \qquad [x \to x]L \qquad [x \to x]L$$

$$[x \to x]L \qquad [x \to x]L \qquad [x \to x]L$$

$$[x \to x]L \qquad [x \to x]L \qquad [x \to x]L$$

$$[x \to x]L \qquad [x \to x]L \qquad [x \to x]L$$

$$[x \to x]L \qquad [x \to x]L \qquad [x \to x]L$$

$$[x \to x]L \qquad [x \to x]L \qquad [x \to x]L$$

$$L(M) = \{ww^R \mid w \in \{a, b\}^*\}$$

$$\dots \mid B \mid a \mid Y \mid Y \mid a \mid B \mid \dots$$

$$[a \to a]R \qquad [X \to X]R \qquad [b \to b]R \qquad [Y \to Y]R$$

$$[b \to b]R \qquad [a \to a]R \qquad [a \to X]L \qquad [X \to X]L \qquad [Y \to Y]L$$

$$[B \to B]L \qquad [b \to Y]R \qquad [b \to Y]L \qquad [B \to B]R$$

$$[A \to X]L \qquad [A \to X]L \qquad [$$

$$L(M) = \{ww^R \mid w \in \{a, b\}^*\}$$

$$\dots \mid B \mid a \mid Y \mid Y \mid X \mid B \mid \dots$$

$$[a \to a]R \qquad [X \to X]R \qquad [b \to b]R \qquad [Y \to Y]R$$

$$[a \to a]R \qquad [Y \to Y]R \qquad [a \to X]L \qquad [X \to X]L \qquad [X \to X]L \qquad [Y \to Y]L$$

$$[B \to B]L \qquad [B \to B]R \qquad [b \to Y]R \qquad [b \to Y]L \qquad [B \to B]R \qquad [X \to X]L \qquad [X \to X]L \qquad [Y \to Y]L$$

$$L(M) = \{ww^R \mid w \in \{a,b\}^*\}$$

$$\dots \mid B \mid a \mid Y \mid Y \mid X \mid B \mid \dots$$

$$[a \to a]R \quad [X \to X]R \quad [b \to b]R \quad [Y \to Y]R$$

$$[a \to a]R \quad [Y \to Y]R \quad [a \to X]L \quad [X \to X]L \quad [Y \to Y]L$$

$$[B \to B]L \quad [B \to B]R \quad [b \to Y]R \quad [b \to Y]L$$

$$[B \to B]R \quad [A \to X]L \quad [A$$

$$L(M) = \{ww^R \mid w \in \{a, b\}^*\}$$

$$\dots \mid B \mid a \mid Y \mid Y \mid X \mid B \mid \dots$$

$$[a \to a]R \qquad [X \to X]R \qquad [b \to b]R \qquad [Y \to Y]R$$

$$[a \to a]R \qquad [Y \to Y]R \qquad [a \to X]L \qquad [X \to X]L \qquad [X \to X]L \qquad [Y \to Y]L$$

$$[B \to B]L \qquad [B \to B]R \qquad [b \to Y]R \qquad [b \to Y]L \qquad [B \to B]R \qquad [X \to X]L \qquad [X \to X]L \qquad [Y \to Y]L$$

$$L(M) = \{ww^{R} \mid w \in \{a, b\}^{*}\}$$

$$\vdots \qquad B \mid X \mid Y \mid Y \mid X \mid B \mid \cdots$$

$$[a \to a]R \qquad [X \to X]R \qquad [b \to b]R \qquad [Y \to Y]R$$

$$start \longrightarrow q_{0} \qquad [a \to a]R \qquad [a \to X]L \qquad [X \to X]L \qquad [Y \to Y]L$$

$$[B \to B]L \qquad [b \to Y]R \qquad [b \to Y]L \qquad [B \to B]R \qquad [A \to X]L \qquad [A$$

$$L(M) = \{ww^R \mid w \in \{a, b\}^*\}$$

$$\dots \mid B \mid X \mid Y \mid Y \mid X \mid B \mid \dots$$

$$[a \to a]R \quad [X \to X]R \quad [b \to b]R \quad [Y \to Y]R$$

$$[a \to a]R \quad [Y \to Y]R \quad [a \to X]L \quad [X \to X]L \quad [Y \to Y]L$$

$$[B \to B]L \quad [B \to B]R \quad [b \to Y]R \quad [b \to Y]L$$

$$[B \to B]R \quad [A \to X]L \quad [$$

$$L(M) = \{ww^R \mid w \in \{a, b\}^*\}$$

$$\dots \mid B \mid X \mid Y \mid Y \mid X \mid B \mid \dots$$

$$[a \to a]R \quad [X \to X]R \quad [b \to b]R \quad [Y \to Y]R$$

$$[a \to a]R \quad [Y \to Y]R \quad [a \to X]L \quad [X \to X]L \quad [Y \to Y]L$$

$$[B \to B]L \quad [B \to B]R \quad [b \to Y]R \quad [b \to Y]L$$

$$[B \to B]R \quad [A \to X]L \quad [$$

$$L(M) = \{ww^R \mid w \in \{a, b\}^*\}$$

$$\dots \mid B \mid X \mid Y \mid Y \mid X \mid B \mid \dots$$

$$[a \to a]R \quad [X \to X]R \quad [b \to b]R \quad [Y \to Y]R$$

$$[a \to a]R \quad [Y \to Y]R \quad [a \to X]L \quad [X \to X]L \quad [Y \to Y]L$$

$$[B \to B]L \quad [B \to B]R \quad [b \to Y]R \quad [b \to Y]L$$

$$[B \to B]R \quad [A \to X]L \quad [$$

$$L(M) = \{ww^R \mid w \in \{a, b\}^*\}$$

$$\dots \mid B \mid X \mid Y \mid Y \mid X \mid B \mid \dots$$

$$[a \to a]R \quad [X \to X]R \quad [b \to b]R \quad [Y \to Y]R$$

$$[a \to a]R \quad [Y \to Y]R \quad [a \to X]L \quad [X \to X]L \quad [Y \to Y]L$$

$$[B \to B]L \quad [B \to B]L \quad [b \to Y]R \quad [b \to Y]L$$

$$[B \to B]R \quad [A \to X]L \quad [$$

$$L(M) = \{ww^R \mid w \in \{a, b\}^*\}$$

$$\vdots \qquad B \mid X \mid Y \mid Y \mid X \mid B \mid \cdots$$

$$\begin{bmatrix} [a \to a]R & [X \to X]R \\ [b \to b]R & [Y \to Y]R \end{bmatrix}$$

$$\vdots \qquad [a \to a]R & [a \to X]L \\ [b \to b]R & [q_1] & [a \to X]L \end{bmatrix}$$

$$\vdots \qquad [B \to B]L \qquad [b \to Y]R \qquad [b \to Y]L$$

$$\vdots \qquad [B \to B]R \qquad [b \to Y]R \qquad [b \to Y]L$$

$$\vdots \qquad [B \to B]R \qquad [a \to X]L \qquad [b \to Y]L$$

$$\vdots \qquad [b \to Y]L \qquad [b \to Y]L \qquad [b \to Y]L$$

$$L(M) = \{ww^R \mid w \in \{a, b\}^*\}$$

$$\dots \mid B \mid X \mid Y \mid Y \mid X \mid B \mid \dots$$

$$[a \to a]R \quad [X \to X]R \quad [b \to b]R \quad [Y \to Y]R$$

$$[b \to b]R \quad [a \to a]R \quad [a \to X]L \quad [x \to Y]L$$

$$[B \to B]L \quad [b \to Y]R \quad [b \to Y]L \quad [b \to Y]L$$

$$[B \to B]R \quad [a \to X]L \quad [x \to X]L \quad [x \to X]L \quad [x \to X]L \quad [x \to Y]L$$

$$L(M) = \{ww^R \mid w \in \{a, b\}^*\}$$

$$\dots \mid B \mid X \mid Y \mid Y \mid X \mid B \mid \dots$$

$$[a \to a]R \quad [X \to X]R \quad [b \to b]R \quad [Y \to Y]R$$

$$[a \to a]R \quad [Y \to Y]R \quad [a \to X]L \quad [X \to X]L \quad [Y \to Y]L$$

$$[B \to B]L \quad [B \to B]R \quad [b \to Y]R \quad [b \to Y]L$$

$$[B \to B]R \quad [A \to X]L \quad [$$

$$L(M) = \{ww^{R} \mid w \in \{a, b\}^{*}\}$$

$$\vdots \qquad B \mid X \mid Y \mid Y \mid X \mid B \mid \cdots$$

$$[a \to a]R \qquad [X \to X]R \qquad [b \to b]R \qquad [Y \to Y]R$$

$$start \longrightarrow q_{0} \qquad [a \to a]R \qquad [a \to X]L \qquad [X \to X]L \qquad [Y \to Y]L$$

$$[B \to B]L \qquad [b \to Y]R \qquad [b \to Y]L \qquad [B \to B]R \qquad [A \to X]L \qquad [A$$

$$L(M) = \{ww^R \mid w \in \{a, b\}^*\}$$

$$\dots \mid B \mid X \mid Y \mid Y \mid X \mid B \mid \dots$$

$$[a \to a]R \qquad [X \to X]R \qquad [b \to b]R \qquad [Y \to Y]R$$

$$[a \to a]R \qquad [Y \to Y]R \qquad [a \to X]L \qquad [X \to X]L \qquad [Y \to Y]L$$

$$[B \to B]L \qquad [B \to B]L \qquad [B \to Y]R \qquad [b \to Y]L \qquad [B \to B]R \qquad [X \to X]L \qquad [Y \to Y]L$$