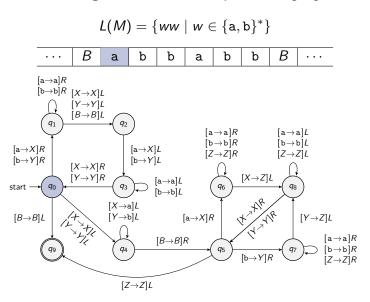
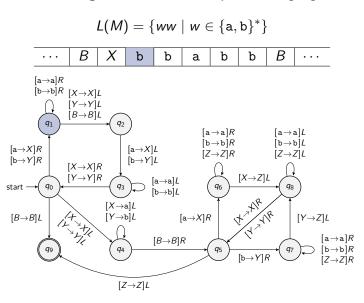
$$L(M) = \{ww \mid w \in \{a, b\}^*\}$$

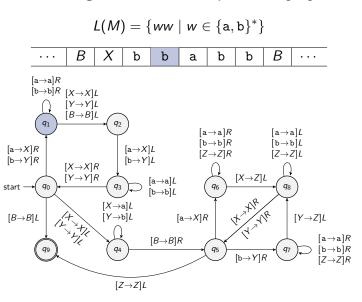
$$\cdots \mid B \mid a \mid b \mid b \mid a \mid b \mid b \mid B \mid \cdots$$

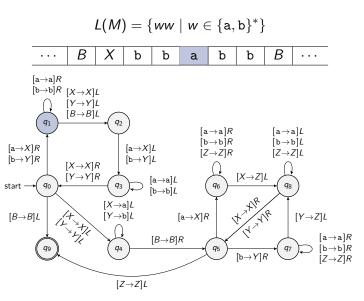
- 1: Find the middle of the input
- 2: Replace all X's (or Y's) with a's (or b's) in the first half
- 3: **while** there are input symbols in the first half **do**
- 4: Replace a (or b) with X (or Y) in the first half
- 5: Find and Replace X (or Y) with Z in the second half

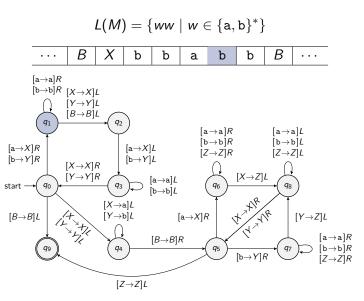


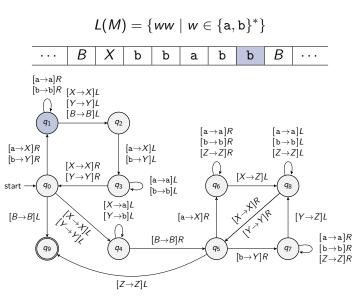
Find the middle of the input.











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

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

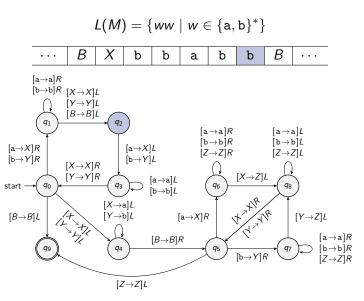
$$\begin{bmatrix} [a \to a]R \\ [b \to b]R \\ [x \to X]L \end{bmatrix}$$

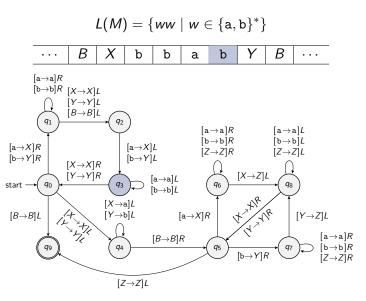
$$\begin{bmatrix} [B \to B]L \\ [b \to Y]R \end{bmatrix}$$

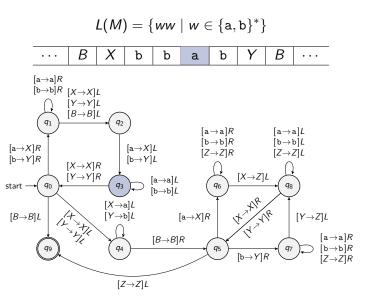
$$[a \to X]L \quad [a \to a]R \quad [a \to a]L \\ [b \to b]R \quad [x \to X]L \quad [b \to b]R \quad [x \to b]L \end{bmatrix}$$

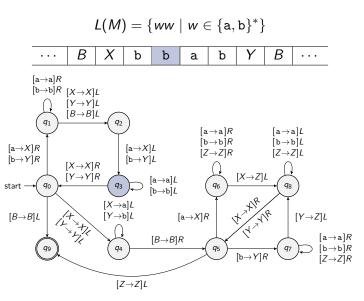
$$[a \to X]R \quad [a \to a]L \quad [b \to b]R \quad [x \to Z]L \quad [x \to Z]L \end{bmatrix}$$

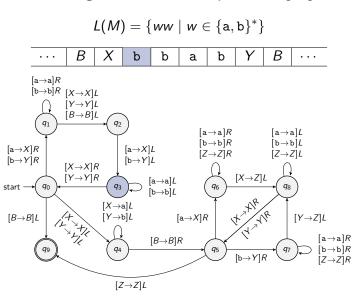
$$[a \to A]L \quad [a \to A]L \quad [x \to Z]L \quad [x \to Z$$











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

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

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

$$\begin{bmatrix} [a \to A]R \\ [b \to b]R \\ [B \to B]L \end{bmatrix}$$

$$\begin{bmatrix} [a \to A]R \\ [b \to b]R \\ [B \to B]L \end{bmatrix}$$

$$\begin{bmatrix} [a \to A]R \\ [b \to b]R \\ [b \to b]R \end{bmatrix}$$

$$\begin{bmatrix} [a \to A]R \\ [b \to b]R \\ [b \to b]R \end{bmatrix}$$

$$\begin{bmatrix} [a \to A]L \\ [b \to b]R \\ [A \to A]L \end{bmatrix}$$

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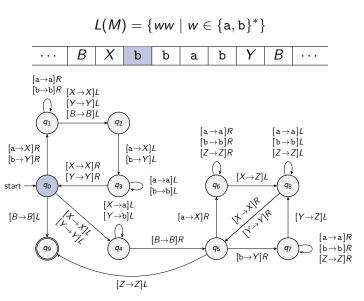
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$$\begin{bmatrix} [A \to A]R \\ [A \to A]R \end{bmatrix}$$

$$\begin{bmatrix} [A \to A]R \\$$



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

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

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

$$\begin{bmatrix} [Y \to Y]L \\ [B \to B]L \end{bmatrix}$$

$$[a \to X]R$$

$$[a \to a]R$$

$$[a \to a]R$$

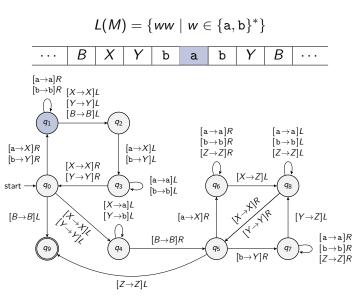
$$[a \to a]R$$

$$[b \to b]R$$

$$[x \to X]R$$

$$[x \to A]L$$

$$[x \to$$



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

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

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

$$\begin{bmatrix} [B \to B]L \\ [b \to Y]R \end{bmatrix}$$

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

$$[a \to A]L \quad [a \to A]L \quad [b \to b]R \quad [a \to A]L \quad [b \to b]L \end{bmatrix}$$

$$[a \to A]L \quad [a \to A$$

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

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

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

$$\begin{bmatrix} [a \to A]R \\ [A \to A]L \\ [A \to A]R \\ [$$

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

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

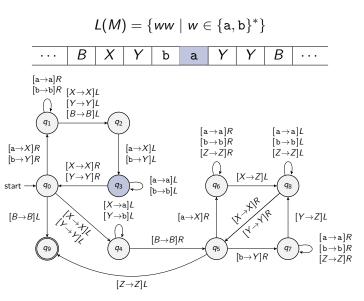
$$[a \to a]R \\ [b \to b]R \\ [X \to X]L \\ [Y \to Y]L \\ [B \to B]L$$

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

$$[a \to A]R \\ [b \to b]R \\ [b \to b]L$$

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

$$[x \to A]L \\ [x \to A]L \\ [x$$



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

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

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

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

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

$$\begin{bmatrix} [a \to A]R \\ [A \to A]L \\ [A \to A]R \\ [$$

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

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

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

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

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

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

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

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

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

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

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

$$[a \to x]R \\ [b \to Y]R$$

$$[a \to a]R \\ [b \to b]R \\ [b \to b]R$$

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

$$[a \to a]R \\ [b \to b]L \\ [z \to Z]L$$

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

$$[z \to Z]L$$

$$[z \to Z]L$$

$$[x \to a]R$$

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

$$[x \to a]L$$

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

$$[x \to a]L$$

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

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

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

$$[a \to x]R \\ [b \to Y]R$$

$$[a \to a]R \\ [b \to b]R \\ [b \to b]R$$

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

$$[a \to a]R \\ [b \to b]L \\ [Z \to Z]L$$

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

$$[z \to z]L$$

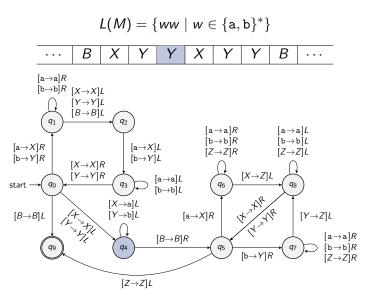
$$[z \to z]L$$

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

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

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

$$[x \to$$



Replace all X's (or Y's) with a's (or b's) in the first half.

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

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

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

$$\begin{bmatrix} [a \to A]R \\ [Y \to Y]L \\ [B \to B]L \end{bmatrix}$$

$$\begin{bmatrix} [a \to A]R \\ [b \to b]R \\ [B \to B]L \end{bmatrix}$$

$$\begin{bmatrix} [a \to A]R \\ [b \to b]R \\ [A \to A]L \\ [A \to A]L \\ [A \to A]L \end{bmatrix}$$

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

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

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

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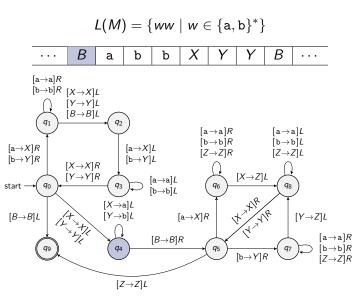
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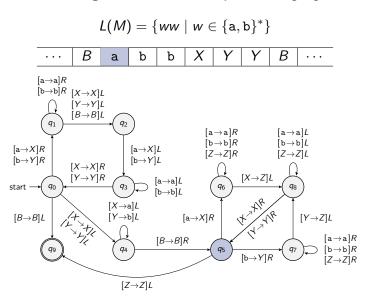
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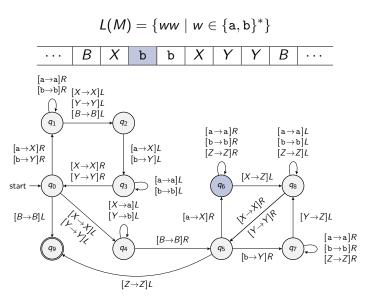
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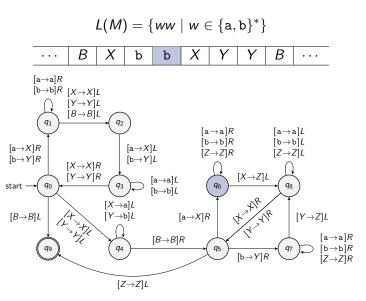


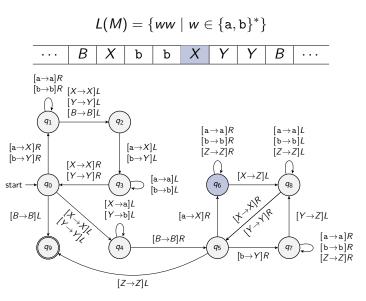


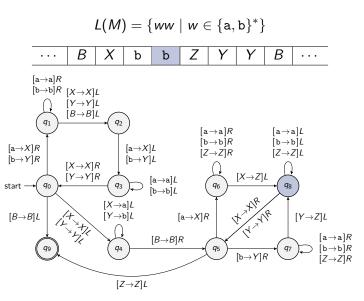
Replace a (or b) with X (or Y) in the first half.



Find and Replace X (or Y) with Z in the second half.







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

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

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

$$\begin{bmatrix} [a \to A]R \\ [A \to A]L \\ [A \to A]R \\ [$$

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

$$\dots \mid B \mid X \mid b \mid b \mid Z \mid Y \mid Y \mid B \mid \dots$$

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

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$$\begin{bmatrix} [a \to A]L \\ [b \to b]R \\ [Z \to Z]L \end{bmatrix}$$

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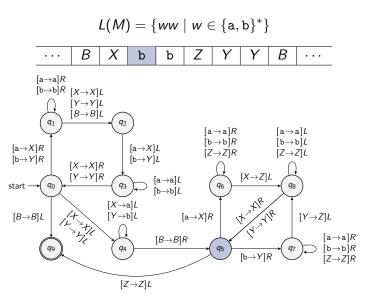
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Repeat until no input symbols in the first half.

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

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

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

$$\begin{bmatrix} [a \to a]R \\ [b \to b]R \\ [B \to B]L \end{bmatrix}$$

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

$$\begin{bmatrix} [a \to a]R \\ [b \to b]R \\ [Z \to Z]L \end{bmatrix}$$

$$\begin{bmatrix} [a \to a]R \\ [b \to b]L \\ [Z \to Z]L \end{bmatrix}$$

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

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

$$\dots \mid B \mid X \mid Y \mid b \mid Z \mid Y \mid Y \mid B \mid \dots$$

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

$$\begin{bmatrix} [a \to A]R \\ [Y \to Y]L \\ [B \to B]L \end{bmatrix}$$

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

$$\dots \mid B \mid X \mid Y \mid b \mid Z \mid Y \mid Y \mid B \mid \dots$$

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

$$[a \to x]R \\ [b \to y]R$$

$$[a \to a]R \\ [b \to b]R \\ [b \to b]R$$

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

$$[a \to a]R \\ [b \to b]L \\ [Z \to Z]L$$

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

$$\dots \mid B \mid X \mid Y \mid b \mid Z \mid Z \mid Y \mid B \mid \dots$$

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

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

$$[a \to a]R \\ [b \to b]R \\ [b \to b]R$$

$$[a \to a]L \\ [b \to b]R \\ [z \to Z]L$$

$$[a \to a]R \\ [b \to b]L \\ [z \to Z]L$$

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

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

$$\dots \mid B \mid X \mid Y \mid b \mid Z \mid Z \mid Y \mid B \mid \dots$$

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

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

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$$\dots \mid B \mid X \mid Y \mid b \mid Z \mid Z \mid Y \mid B \mid \dots$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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