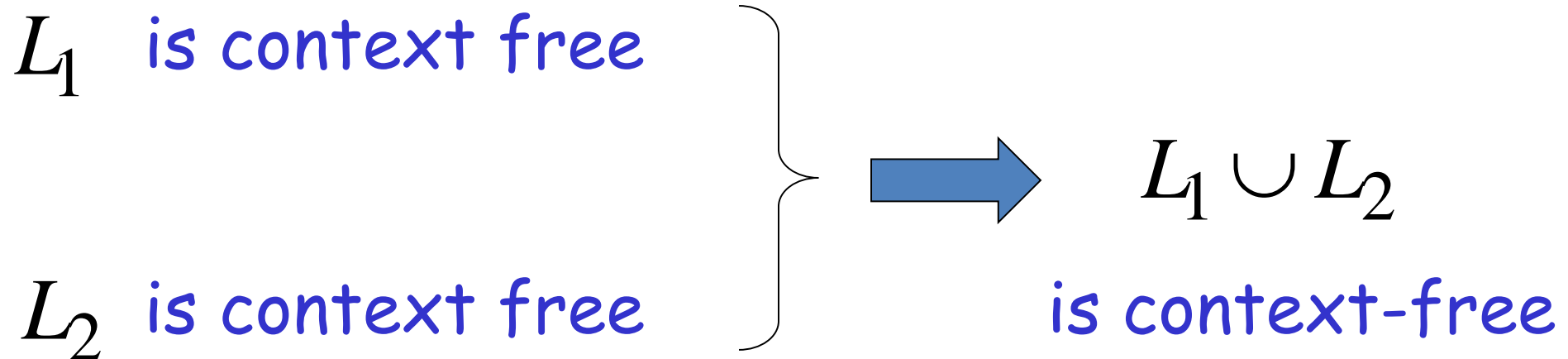


Properties of Context-Free languages

Union

Context-free languages
are closed under: **Union**



Example

Language

Grammar

$$L_1 = \{a^n b^n\}$$

$$S_1 \rightarrow aS_1b \mid \lambda$$

$$L_2 = \{ww^R\}$$

$$S_2 \rightarrow aS_2a \mid bS_2b \mid \lambda$$

Union

$$L = \{a^n b^n\} \cup \{ww^R\}$$

$$S \rightarrow S_1 \mid S_2$$

In general:

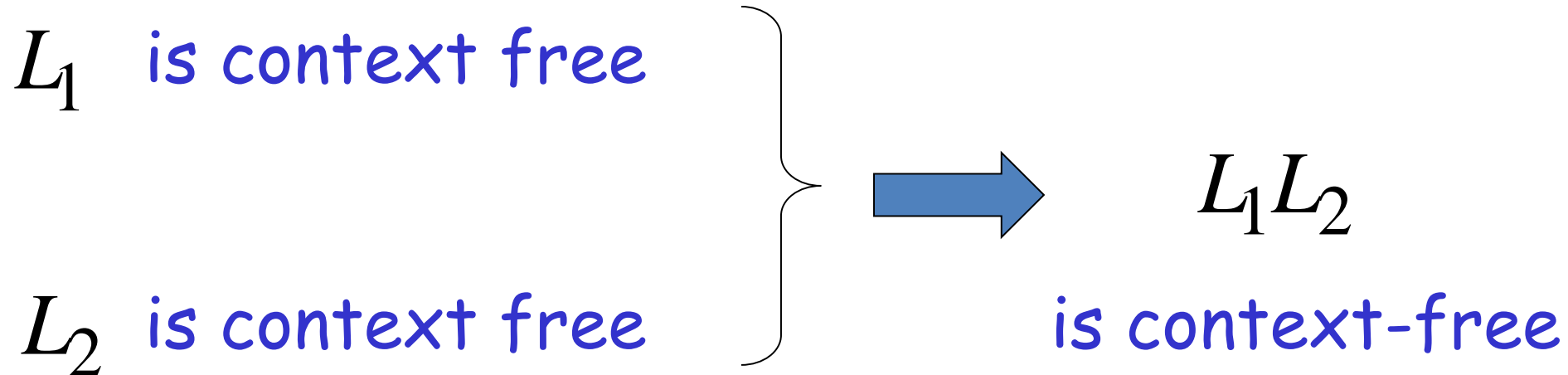
For context-free languages	L_1, L_2
with context-free grammars	G_1, G_2
and start variables	S_1, S_2

The grammar of the union	$L_1 \cup L_2$
has new start variable	S
and additional production	$S \rightarrow S_1 \mid S_2$

Concatenation

Context-free languages
are closed under:

Concatenation



Example

Language

Grammar

$$L_1 = \{a^n b^n\}$$

$$S_1 \rightarrow aS_1b \mid \lambda$$

$$L_2 = \{ww^R\}$$

$$S_2 \rightarrow aS_2a \mid bS_2b \mid \lambda$$

Concatenation

$$L = \{a^n b^n\} \{ww^R\}$$

$$S \rightarrow S_1 S_2$$

In general:


For context-free languages	L_1, L_2
with context-free grammars	G_1, G_2
and start variables	S_1, S_2

The grammar of the concatenation	$L_1 L_2$
has new start variable	S
and additional production	$S \rightarrow S_1 S_2$

Star Operation

Context-free languages
are closed under:

Star-operation

L is context free  L^* is context-free

Example

Language

Grammar

$$L = \{a^n b^n\}$$

$$S \rightarrow aSb \mid \lambda$$

Star Operation

$$L = \{a^n b^n\}^*$$

$$S_1 \rightarrow SS_1 \mid \lambda$$

In general:

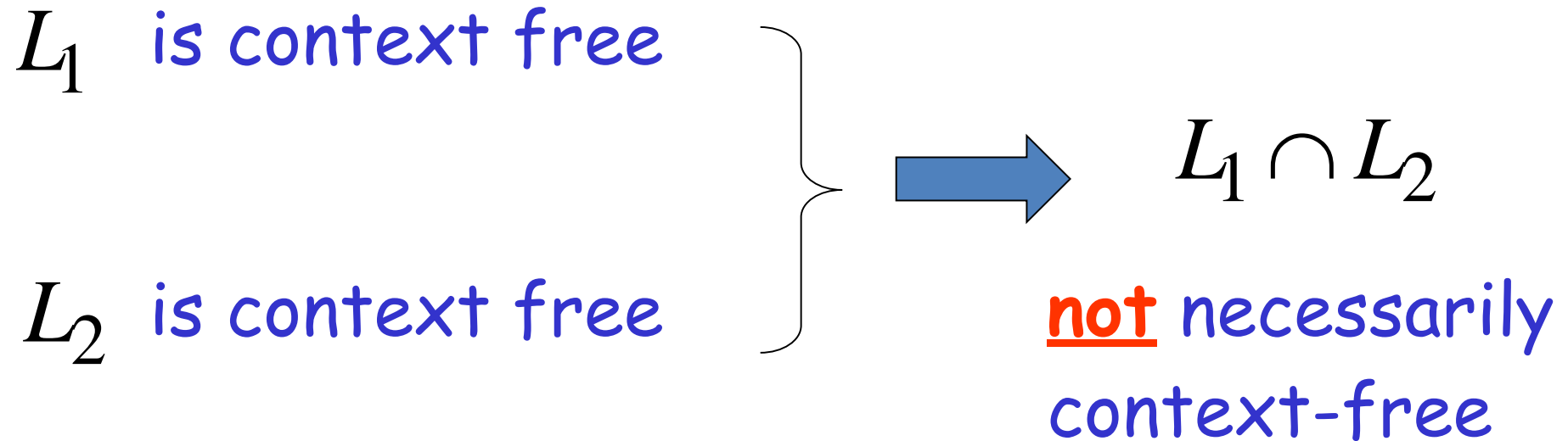
For context-free language	L
with context-free grammar	G
and start variable	S

The grammar of the star operation	L^*
has new start variable	S_1
and additional production	$S_1 \rightarrow SS_1 \mid \lambda$

Negative Properties of Context-Free Languages

Intersection

Context-free languages
are not closed under: **intersection**



Example

$$L_1 = \{a^n b^n c^m\}$$

$$L_2 = \{a^n b^m c^m\}$$

Context-free:

$$S \rightarrow AC$$

$$A \rightarrow aAb \mid \lambda$$

$$C \rightarrow cC \mid \lambda$$

Context-free:

$$S \rightarrow AB$$

$$A \rightarrow aA \mid \lambda$$

$$B \rightarrow bBc \mid \lambda$$

Intersection

$$L_1 \cap L_2 = \{a^n b^n c^n\} \quad \text{NOT context-free}$$

Example

$$L_1 = \{a^n b^n c^m\}$$

$$L_2 = \{a^n b^m c^m\}$$

Context-free:

$$S \rightarrow AC$$

$$A \rightarrow aAb \mid \lambda$$

$$C \rightarrow cC \mid \lambda$$

Context-free:

$$S \rightarrow AB$$

$$A \rightarrow aA \mid \lambda$$

$$B \rightarrow bBc \mid \lambda$$

Intersection

$$L_1 \cap L_2 = \{a^n b^n c^n\} \quad \text{NOT context-free}$$

Complement

Context-free languages
are not closed under: **complement**

L is context free $\longrightarrow \bar{L}$ not necessarily
context-free

Example

$$L_1 = \{a^n b^n c^m\}$$

$$L_2 = \{a^n b^m c^m\}$$

Context-free:

$$S \rightarrow AC$$

$$A \rightarrow aAb \mid \lambda$$

$$C \rightarrow cC \mid \lambda$$

Context-free:

$$S \rightarrow AB$$

$$A \rightarrow aA \mid \lambda$$

$$B \rightarrow bBc \mid \lambda$$

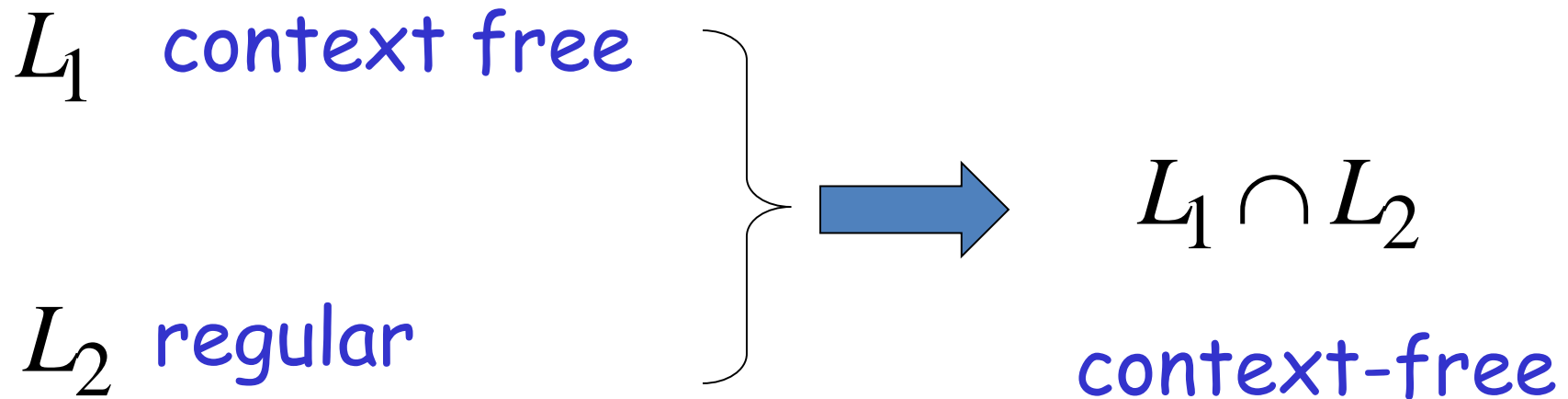
Complement

$$\overline{\overline{L_1} \cup \overline{L_2}} = L_1 \cap L_2 = \{a^n b^n c^n\}$$

NOT context-free

Intersection
of
Context-free languages
and
Regular Languages

The intersection of
a context-free language and
a regular language
is a context-free language



Machine M_1

NPDA for L_1
context-free

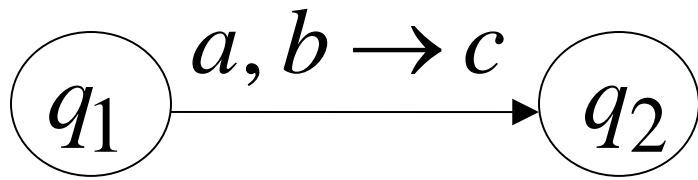
Machine M_2

DFA for L_2
regular

Construct a new NPDA machine M
that accepts $L_1 \cap L_2$

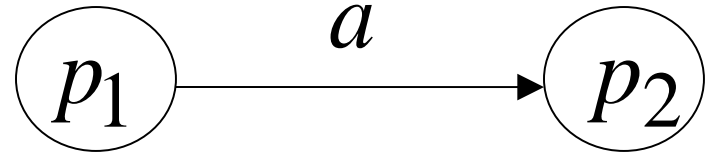
M simulates in parallel M_1 and M_2

NPDA M_1

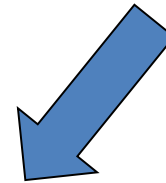
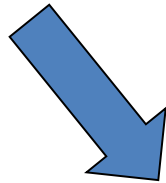


transition

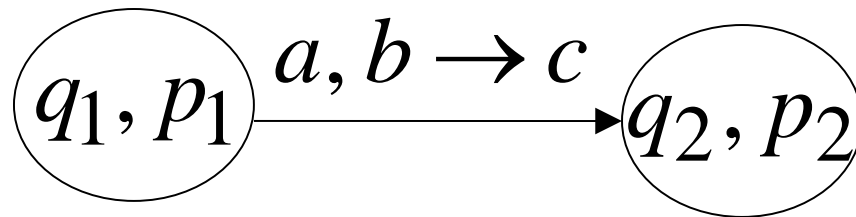
DFA M_2



transition

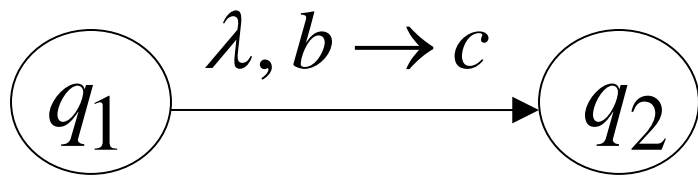


NPDA M



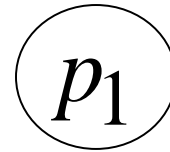
transition

NPDA M_1

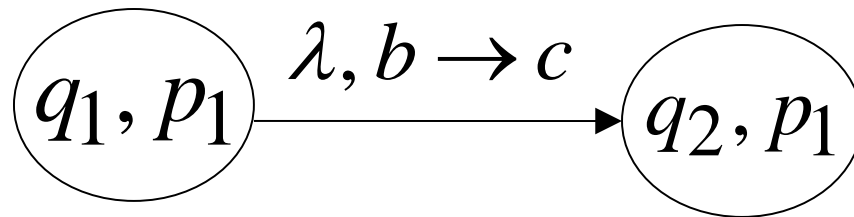


transition

DFA M_2

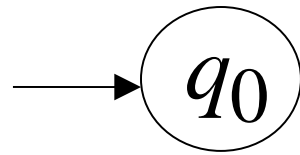


NPDA M



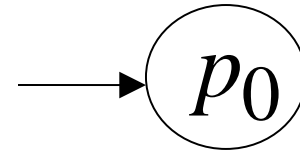
transition

NPDA M_1



initial state

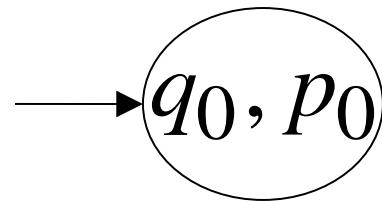
DFA M_2



initial state

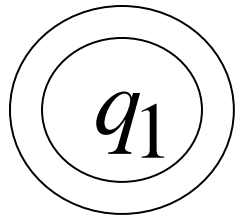


NPDA M



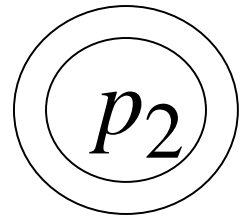
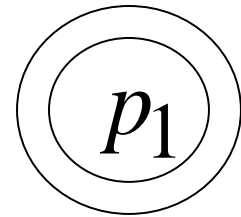
Initial state

NPDA M_1



final state

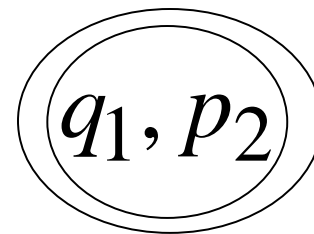
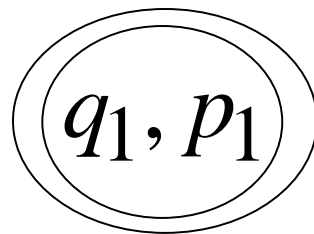
DFA M_2



final states



NPDA M



final states

Example:

context-free

$$L_1 = \{ w_1 w_2 : |w_1| = |w_2|, w_1 \in \{a, b\}^*, w_2 \in \{c, d\}^* \}$$

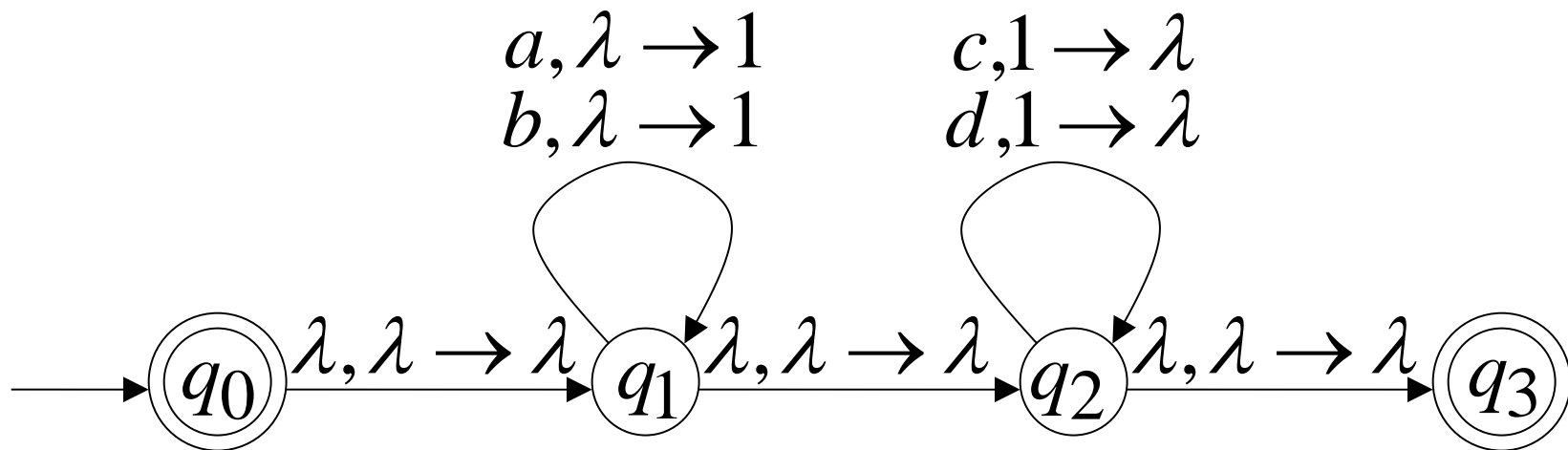
NPDA

Example:

context-free

$$L_1 = \{w_1 w_2 : |w_1| = |w_2|, w_1 \in \{a, b\}^*, w_2 \in \{c, d\}^*\}$$

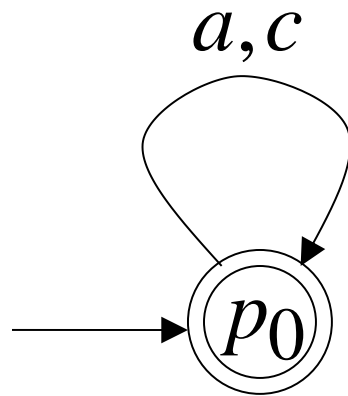
NPDA M_1



regular

$$L_2 = \{a, c\}^*$$

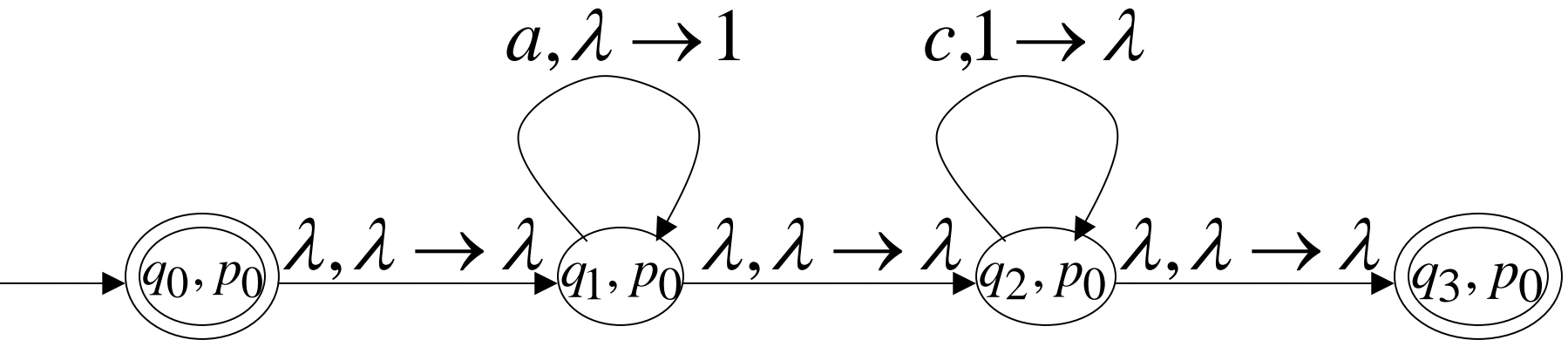
DFA M_2



context-free

Automaton for: $L_1 \cap L_2 = \{a^n c^n : n \geq 0\}$

NPDA M



In General:

M simulates in parallel M_1 and M_2

M accepts string w if and only if

M_1 accepts string w and

M_2 accepts string w

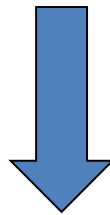
$$L(M) = L(M_1) \cap L(M_2)$$

Therefore:

M is NPDA



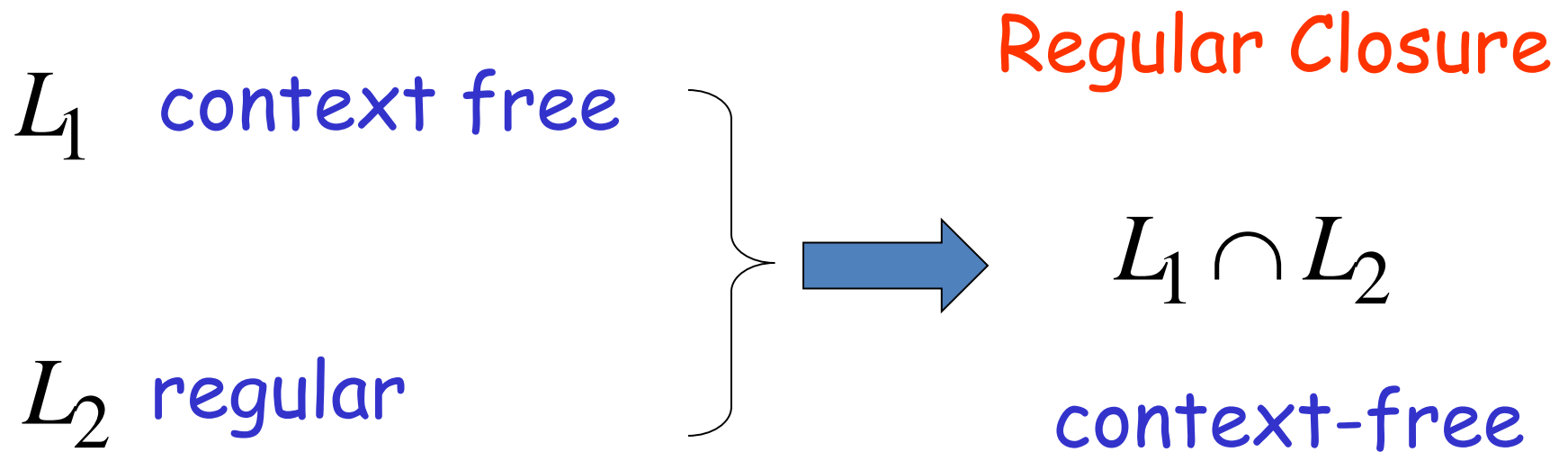
$L(M_1) \cap L(M_2)$ is context-free



$L_1 \cap L_2$ is context-free

Applications of Regular Closure

The intersection of
a context-free language and
a regular language
is a context-free language



An Application of Regular Closure

Prove that: $L = \{a^n b^n : n \neq 100, n \geq 0\}$

is context-free

We know:

$\{a^n b^n : n \geq 0\}$ is context-free

We also know:

$$L_1 = \{a^{100}b^{100}\} \quad \text{is regular}$$



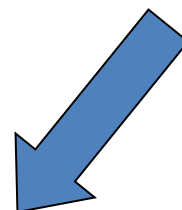
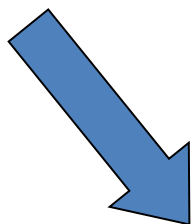
$$\overline{L_1} = \{(a+b)^*\} - \{a^{100}b^{100}\} \quad \text{is regular}$$

$$\{a^n b^n\}$$

$$\overline{L_1} = \{(a+b)^*\} - \{a^{100}b^{100}\}$$

context-free

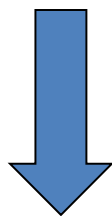
regular



(regular closure)

$$\{a^n b^n\} \cap \overline{L_1}$$

context-free



$$\{a^n b^n\} \cap \overline{L_1} = \{a^n b^n : n \neq 100, n \geq 0\} = L$$

is context-free

Another Application of Regular Closure

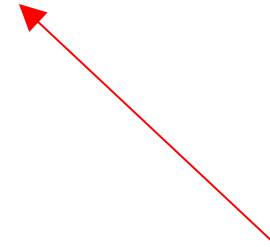
Prove that: $L = \{w : n_a = n_b = n_c\}$

is **not** context-free

If $L = \{w : n_a = n_b = n_c\}$ is context-free

(regular closure)

Then $L \cap \{a^*b^*c^*\} = \{a^n b^n c^n\}$



context-free

regular

context-free

Impossible!!!

Therefore, L is **not** context free

Quiz

Quiz

- Show that family of unambiguous context free languages is not closed under intersection.
- Show that family of context free languages are closed under reversal.