3. 正則表現:
(テキスト3.1,3.2)

3.1. 正則表現

- **正則表現**(または**正規表現**)とは、文字列の集合(=言語)を有限個の記号列で表現する方法の1つ
  - 例：(**01**)*　　…「01を繰り返す文字列」
    0(**0**+**1**)*　…「0の後に0か1が繰り返す文字列」
  - つまり
    (**01**)* = { **ε** ,01,0101,010101,01010101,…}
    0(**0**+**1**)*={0,00,01,000,001,010,011,0000,…}
- UNIX系の人にはおなじみ…grep, emacs, awk, perl, …
- Windows系の人にも…ファイル名のワイルドカードなど

3. Regular Expression: (Text 3.1,3.2)

3.1. Regular Expression

- Regular Expression describes a set of words (=language) by finite characters

  Ex：(**01**)*　　… words repeating ’01’

  0(**0**+**1**)*　… repeating ‘0’ or ‘1’ after 0

  I.e.

  (**01**)* = { **ε** ,01,0101,010101,01010101,…}

  0(**0**+**1**)*={0,00,01,000,001,010,011,0000,…}

- Familiar if you are UNIX-user…grep, emacs, awk, perl, …
- So-called ‘Wild-card’ in filenames on Windows

3. 正則表現:
(テキスト3.1,3.2)

3.1. 正則表現の直感的な定義と意味

- **文字や文字列はそのまま解釈**:
  - **a** → {*a*}
  - **ab** → {*ab*}
- 「**+**」は「**または**」の意味:
  - **ab**+**a** → {*ab*,*a*}
- 「()」はグループ化
- 「*」は「0回以上の繰り返し」の意味
  - (**ab**)* → { **ε** , *ab*, *abab*, *ababab*,…}

ちょっと複雑な例:

((**ab**)***c**)+(**a***)

→ { **ε** , *a*, *c*, *aa*, *aaa*, *abc*, *aaaa*, *aaaaa*, *ababc*,… }

3. Regular Expression: (Text 3.1,3.2)

3.1. Brief explanation

- A character and string is as is:
  - **a** → {*a*}
  - **ab** → {*ab*}
- '+' = OR
  - **ab**+**a** → {*ab*,*a*}
- '()' makes a group
- '*' means repetition 0 times or more
  - (**ab**)* → { **ε** , *ab*, *abab*, *ababab*,…}

An complicated example:

((**ab**)***c**)+(**a***)

→ { **ε** , *a*, *c*, *aa*, *aaa*, *abc*, *aaaa*, *aaaaa*, *ababc*,… }

3. 正則表現: (テキスト3.1,3.2)

3.1.1. 正則表現の演算

1. **和集合**(union): **二つの言語** L, M **の和集合** $L \cup M$ **は、** L **か** M **のどちらかに含まれる要素の集合**.
   - **例**: $\{AB,C\} \cup \{a,b,c\} = \{a,b,c,AB,C\}$
2. **連接**(concatenation): **二つの言語** L,M **の連接** LM **(または** $L \cdot M$**)は、それぞれの要素を一つづつとってつなげたものの集合**
   - **例**: $\{AB,C\}\{a,b,c\} = \{ABa, ABb, ABc, Ca, Cb, Cc\}$
3. **閉包**(closure): **ある言語** L **の閉包** L^* **は、** L **の要素を**0**個以上連接したものの集合**
   - **例**: $\{a,b,c\}^* = \{ \varepsilon ,a,b,c,aa,ab,ac,ba,bb,bc,ca,cb,cc,aaa,\ldots\}$

3. Regular Expression: (Text 3.1,3.2)

3.1.1. Operations over regular expressions

1. The union $L \cup M$ contains elements in L or M.
   - Ex: $\{AB, C\} \cup \{a, b, c\} = \{a, b, c, AB, C\}$
2. The concatenation of two languages L and M is denoted by LM (or $L \cdot M$) is a set of all combinations of two elements from L and M, respectively.
   - Ex: $\{AB, C\}\{a, b, c\} = \{ABa, ABb, ABc, Ca, Cb, Cc\}$
3. The closure L^* of a language L is a set of all concatenations of any number of elements in L.
   - Ex: $\{a,b,c\}^* = \{ \varepsilon, a,b,c,aa,ab,ac,ba,bb,bc,ca,cb,cc,aaa,\ldots\}$

3. 正則表現: (テキスト3.1,3.2)

3.1.1. 正則表現の演算

2.5. **言語の連接の補足**: LLはL^2, LLLはL^3と書くことがある。

- **例**: $\{a,ab\}^2 = \{a,ab\}\{a,ab\} = \{aa,aab,aba,abab\}$
- **定義**: $L^0 := \{\ \varepsilon\ \}$, $L^1 := L$, $L^k := L^{k-1}L$ $(k>1)$

3.5. **言語の閉包の補足**: 2.5 より、L^* は以下の定義と同値。

$$L^* := \bigcup_{i=0}^{\infty} L^i$$

3. Regular Expression: (Text 3.1,3.2)

3.1.1. Operations over regular expressions

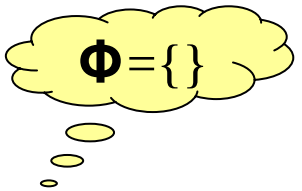
2.5. Comment on Concatenation: Sometimes, LL is denoted by L^2, and LLL *is denoted by* L^3, and so on.

- Ex: $\{a,ab\}^2 = \{a,ab\}\{a,ab\} = \{aa,aab,aba,abab\}$
- Def: $L^0 := \{ \boldsymbol{\varepsilon} \}$, $L^1 := L$, $L^k := L^{k-1}L$ $(k>1)$

3.5. Comment on Closure: By 2.5, L^* can be defined as follows.

$$L^* := \bigcup_{i=0}^{\infty} L^i$$

3. 正則表現:
(テキスト3.1,3.2)

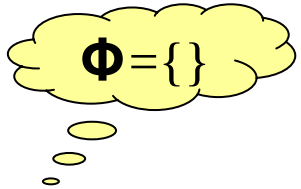


3.1.2. 正則表現の構成

正則表現 E とそれが表現する言語 $L(E)$ の定義

1. **定数 ε とΦは正則表現で、$L(\varepsilon)=\{\varepsilon\}$, $L(\Phi)=\Phi$.**
2. **記号 a に対して、a は正則表現で、$L(\mathbf{a})=\{a\}$.**
3. **E と F が正則表現のとき、**
   1. **$E+F$ は正則表現。定義される言語; $L(E+F)=L(E)\cup L(F)$**
   2. **EF(または$E\cdot F$)は正則表現。定義される言語; $L(EF)=L(E)L(F)$**
   3. **E^*は正則表現。定義される言語; $L(E^*)=(L(E))^*$**
   4. **(E)は正則表現。定義される言語; $L((E))=L(E)$**

3. Regular Expression: (Text 3.1,3.2)



3.1.2. Construction of a regular expression

Definition of a regular expression E and corresponding language $L(E)$

1. Two constants $\boldsymbol{\varepsilon}$ and $\boldsymbol{\Phi}$ are regular expressions that represent $L(\boldsymbol{\varepsilon})=\{\boldsymbol{\varepsilon}\}$, $L(\boldsymbol{\Phi})=\boldsymbol{\Phi}$.
2. For a symbol a, **a** is regular expression that represents $L(\mathbf{a}) = \{a\}$.
3. For two regular expressions E and F,
   1. $E+F$ is R.E. which represents $L(E+F) = L(E) \cup L(F)$
   2. EF(or $E \cdot F$) is R.E. which represents $L(EF) = L(E)L(F)$
   3. E^* is R.E. which represents $L(E^*) = (L(E))^*$
   4. (E) is R.E. which represents $L((E)) = L(E)$

3. 正則表現:
(テキスト3.1,3.2)

3.1.2. 正則表現の構成

例:「0と1が交互に現れる文字列」という言語

1. **発想**(1): (a)01**の繰り返し か** (b)10**の繰り返し か** (c) 1**のあとに**(a) **か** (d) 0**のあとに**(b)
   - **(01)*** + **(10)*** + **1(01)*** + **0(10)***

2. **発想**(2): 01**の繰り返しの前に**1**か ε を追加、後に**0**か ε を追加**
   - **(1+ ε)(01)*(0+ ε)**

同じ言語に違った表現があること

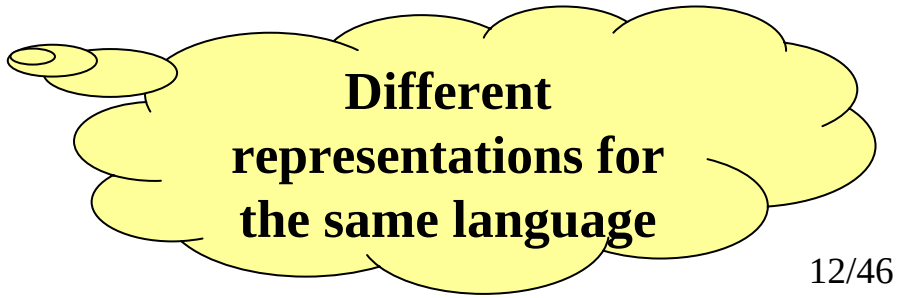
3. Regular Expression: (Text 3.1,3.2)

3.1.2. Construction of a regular expression

Ex: A language that is the set of words such that '0 and 1 appear alternately'

1. Idea (1): (a) repetition of 01, (b) repetition of 10, (c) (a) follows after 1, or (d) (b) follows after 0.
   - **(01)*** + **(10)*** + **1(01)*** + **0(10)***

2. Idea (2): add 1 or **ε** before repetition of 01, and add 0 or **ε** after it.
   - **(1+ ε)(01)*(0+ ε)**



3. 正則表現:
(テキスト3.1,3.2)

3.1.2. 正則表現の演算順序

すべて()で明記してもよいが、<u>優先順位</u>を定義すれば、()は適宜省略できる。

1. **同じ演算は左から右**: **abc = (ab)c, a+b+c=(a+b)+c**
2. ***は最優先**: **ab*=a(b)*≠(ab)***
3. **・は2番目**: **a+bc = a+(bc)≠(a+b)c**
4. **+は最後**: **a+bc*+d = (a+(b(c*)))+d**

3. Regular Expressions: (Text 3.1,3.2)

3.1.2. Priority of the operations

We can omit some ()s if we define the priority of the operations below:

1. From left to right for the same operations: **abc** = (**ab**)**c**, **a**+**b**+**c**=(**a**+**b**)+**c**
2. * has top priority: **ab***=**a**(**b**)*≠(**ab**)*
3. ・has the second: **a**+**bc** = **a**+(**bc**)≠(**a**+**b**)**c**
4. + is the last: **a**+**bc***+**d** = (**a**+(**b**(**c***)))+**d**

3. 正則表現: (テキスト3.1,3.2)

3. 2. 有限オートマトンと正則表現

- **ゴール: 正則表現で表現できる言語＝オートマトンで受理できる言語**
  1. **与えられた正則表現から、ε-NFAが構成できること**
  2. **与えられたDFAから正則表現が構成できること**
  2'. **与えられたε-NFAから正則表現が構成できること**

- **ε-NFAは(見かけ上)表現力が高い**
- **DFAは構成要素が(見かけ上)少ない**

3. Regular Expression: (Text 3.1,3.2)

3. 2. Finite automata and regular expressions

Goal: Class of languages represented by regular expressions = Class of languages accepted by automata

1. For any given regular expression, we can construct an **ε** -NFA that accepts the same language
2. For any given DFA, we can construct a regular expression that represents the same language

2'. For any given [illegible]NFA, …(this is easier)

- **ε** -NFA seems more descriptive
- DFA has simpler structure than NFA

3. 正則表現:
(テキスト3.1,3.2)

3. 2. 3. 正則表現→ ε -NFA

正則表現とそれが表現する言語の定義

1. **ε , Φ, 記号** a **は正則表現**; $L(\varepsilon)=\{\varepsilon\}$, $L(\Phi)=\Phi$, $L(\mathbf{a})=\{a\}$.
2. **正則表現** E **と** F **に対し、**
   1. $E+F$ **は正則表現**; $L(E+F)=L(E)\cup L(F)$
   2. EF(**または** $E\cdot F$)**は正則表現**; $L(EF)=L(E)L(F)$
   3. E^***は正則表現**; $L(E^*)=(L(E))^*$
   4. (E)**は正則表現**; $L((E))=L(E)$

から直接 ε -NFAを構成する。

受理状態が1つしかない

3. Regular Expression: (Text 3.1,3.2)

3. 2. 3. Regular Expression → ε -NFA

From the definition of R.E. and corresponding set

1. Two constants **ε** and **Φ** are regular expressions that represent $L(\varepsilon)=\{\varepsilon\}$, $L(\Phi)=\Phi$.
2. For a symbol a, **a** is regular expression that represents $L(\mathbf{a}) = \{a\}$.
3. For two regular expressions E and F,
   1. $E+F$ is R.E. which represents $L(E+F) = L(E) \cup L(F)$
   2. EF(or $E \cdot F$) is R.E. which represents $L(EF) = L(E)L(F)$
   3. E^* is R.E. which represents $L(E^*) = (L(E))^*$
   4. (E) is R.E. which represents $L((E)) = L(E)$

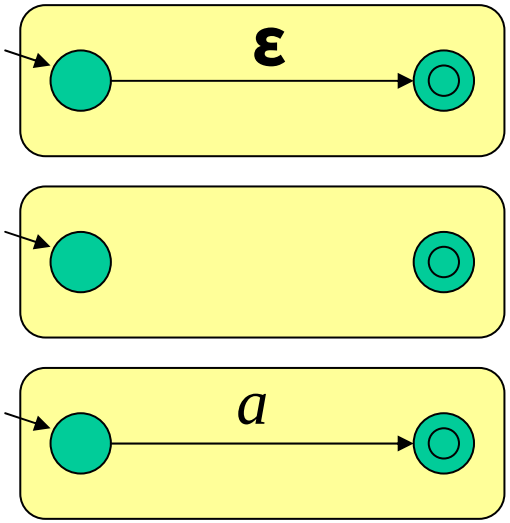
we construct an **ε** -NFA accepting the same language.

with one accepting state

3. 正則表現:
(テキスト3.1,3.2)

3. 2. 3. 正則表現→ ε -NFA

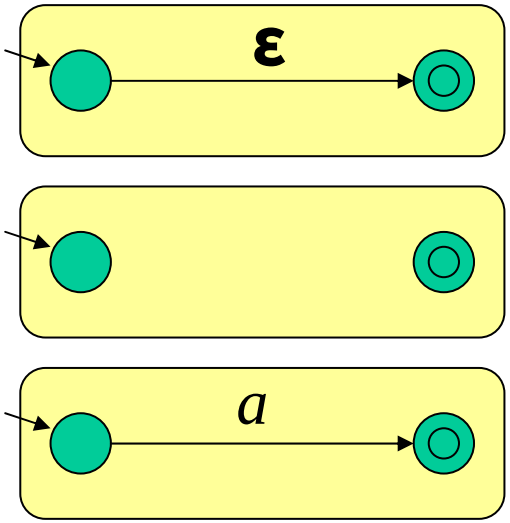
1. **ε** , **Φ**, **記号** *a* **は正則表現**; $L(\varepsilon)=\{\varepsilon\}$, $L(\Phi)=\Phi$, $L(\mathbf{a}) = \{a\}$.



3. Regular Expression
(Text 3.1,3.2)

3. 2. 3. Regular Expression → **ε** -NFA

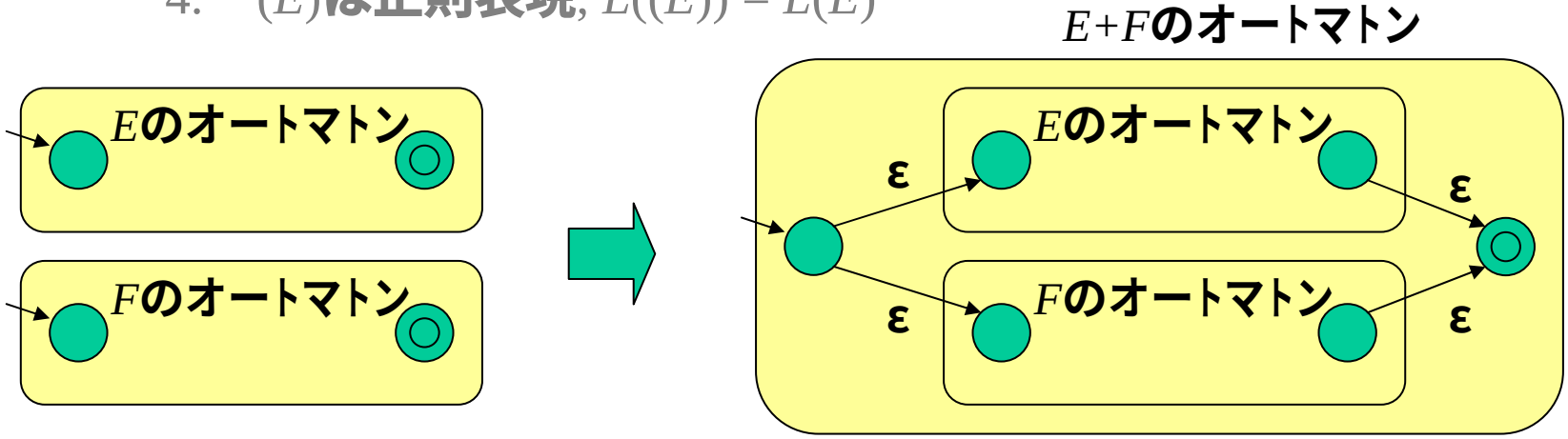
1. **ε** , **Φ**, a symbol *a* is R.E.; $L($ **ε** $)=\{$ **ε** $\}$, $L($**Φ**$)=$**Φ**, $L($**a**$) = \{a\}$.



3. 正則表現: (テキスト3.1,3.2)

3. 2. 3. 正則表現→ ε -NFA

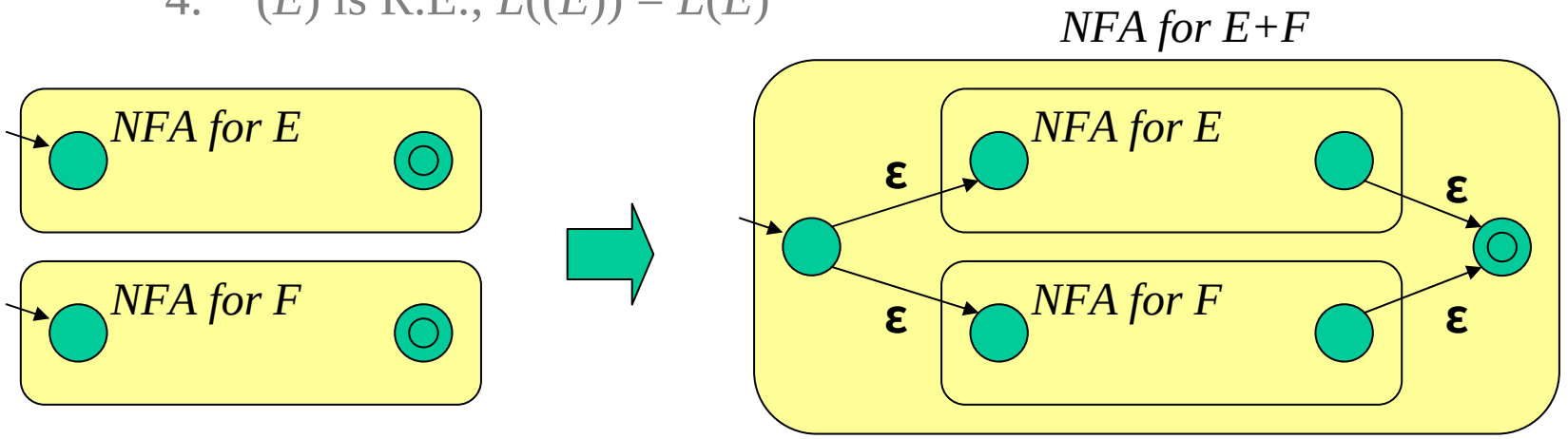
2. 正則表現 E と F に対し、
   1. $E+F$ は正則表現; $L(E+F) = L(E) \cup L(F)$
   2. EF(またはE・F)は正則表現; $L(EF) = L(E)L(F)$
   3. E^*は正則表現; $L(E^*) = (L(E))^*$
   4. (E)は正則表現; $L((E)) = L(E)$



3. Regular Expression: (Text 3.1,3.2)

3. 2. 3. Regular Expression→ ε -NFA

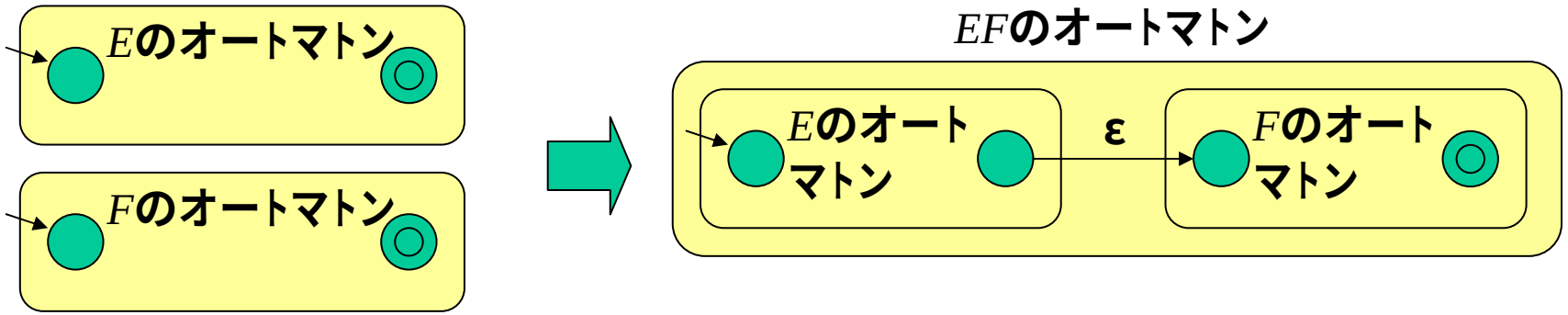
2. For R.E. *E* and *F*,
   1. *E*+*F* is R.E.; *L*(*E*+*F*) = *L*(*E*) ∪ *L*(*F*)
   2. *EF* (or *E* ·*F*) is R.E.; *L*(*EF*) = *L*(*E*)*L*(*F*)
   3. *E** is R.E.; *L*(*E**) = (*L*(*E*))*
   4. (*E*) is R.E.; *L*((*E*)) = *L*(*E*)



3. 正則表現: (テキスト3.1,3.2)

3. 2. 3. 正則表現→ ε -NFA

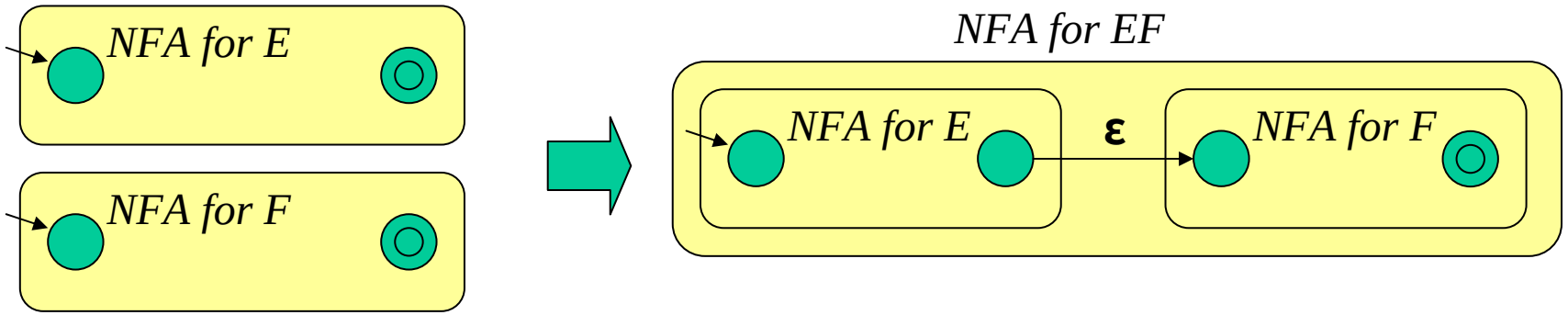
2. **正則表現** E **と** F **に対し、**
   1. $E+F$ **は正則表現**; $L(E+F) = L(E) \cup L(F)$
   2. EF(**または** $E \cdot F$)**は正則表現**; $L(EF) = L(E)L(F)$
   3. E^***は正則表現**; $L(E^*) = (L(E))^*$
   4. (E)**は正則表現**; $L((E)) = L(E)$



3. Regular Expression: (Text 3.1,3.2)

3. 2. 3. Regular Expression → ε -NFA

2. For R.E. *E* and *F* ,
   1. *E*+*F* is R.E.; *L*(*E*+*F*) = *L*(*E*) ∪ *L*(*F*)
   2. *EF* (or *E* • *F*) is R.E.; *L*(*EF*) = *L*(*E*)*L*(*F*)
   3. *E** is R.E.; *L*(*E**) = (*L*(*E*))*
   4. (*E*) is R.E.; *L*((*E*)) = *L*(*E*)



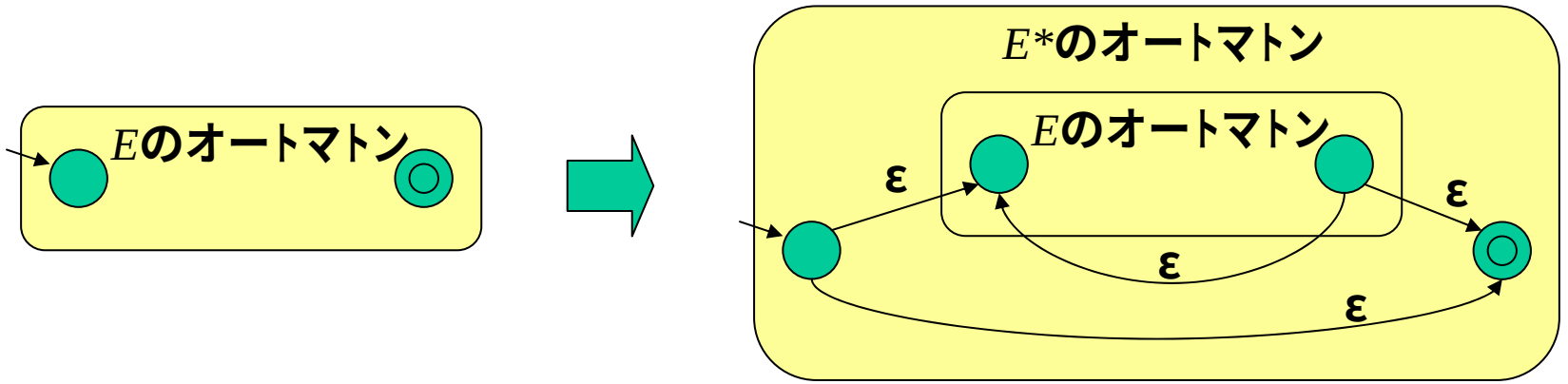
3. 正則表現: (テキスト3.1,3.2)

どの規則も受理状態が1つのオートマトンしか作らない

3. 2. 3. 正則表現→ ε -NFA

2. 正則表現 E と F に対し、
   1. $E+F$ は正則表現; $L(E+F) = L(E) \cup L(F)$
   2. EF(または$E \cdot F$)は正則表現; $L(EF) = L(E)L(F)$
   3. E^*は正則表現; $L(E^*) = (L(E))^*$
   4. (E)は正則表現; $L((E)) = L(E)$

特に何もしない



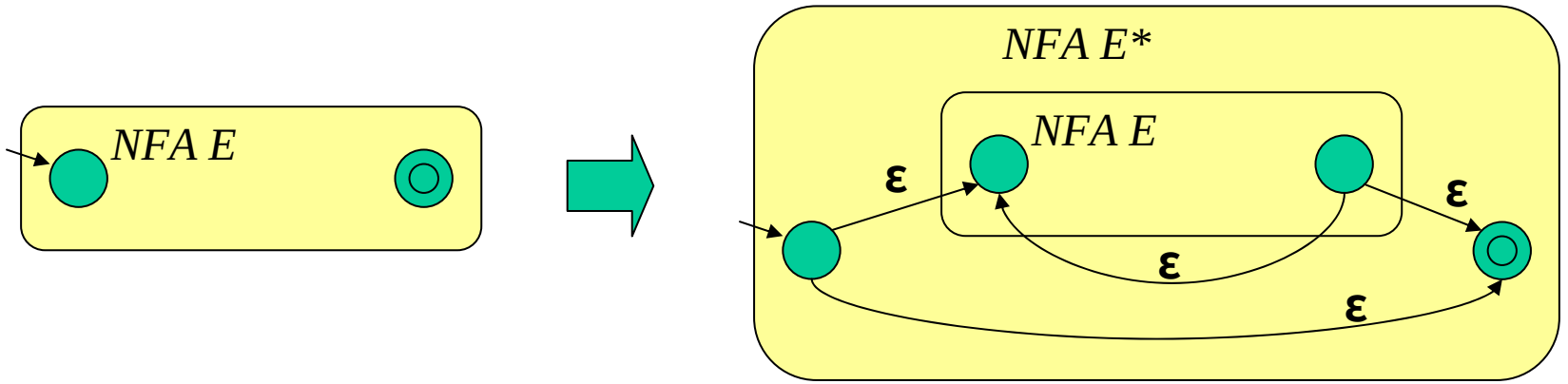
3. Regular Expression: (Text 3.1,3.2)

3. 2. 3. Regular Expression→ ε -NFA

Each automaton has exactly one accepting state

2. For R.E. *E* and *F*,
   1. *E*+*F* is R.E.; *L*(*E*+*F*) = *L*(*E*) ∪ *L*(*F*)
   2. *EF* (or *E* ·*F*) is R.E.; *L*(*EF*) = *L*(*E*)*L*(*F*)
   3. *E** is R.E.; *L*(*E**) = (*L*(*E*))*
   4. (*E*) is R.E.; *L*((*E*)) = *L*(*E*)

Nothing to do

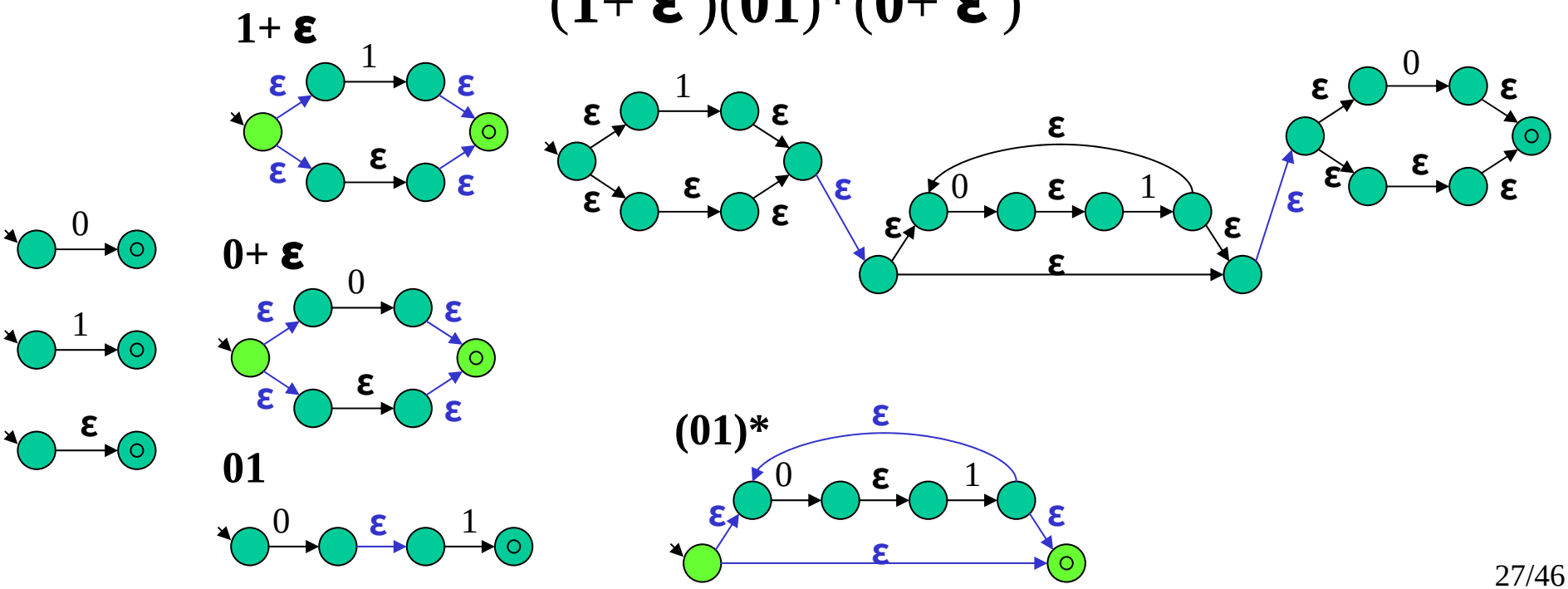


3. 正則表現:
(テキスト3.1,3.2)

3. 2. 3. 正則表現→ ε -NFA

例:「0と1が交互に出てくる文字列」の正則表現

(1+ ε)(01)*(0+ ε)

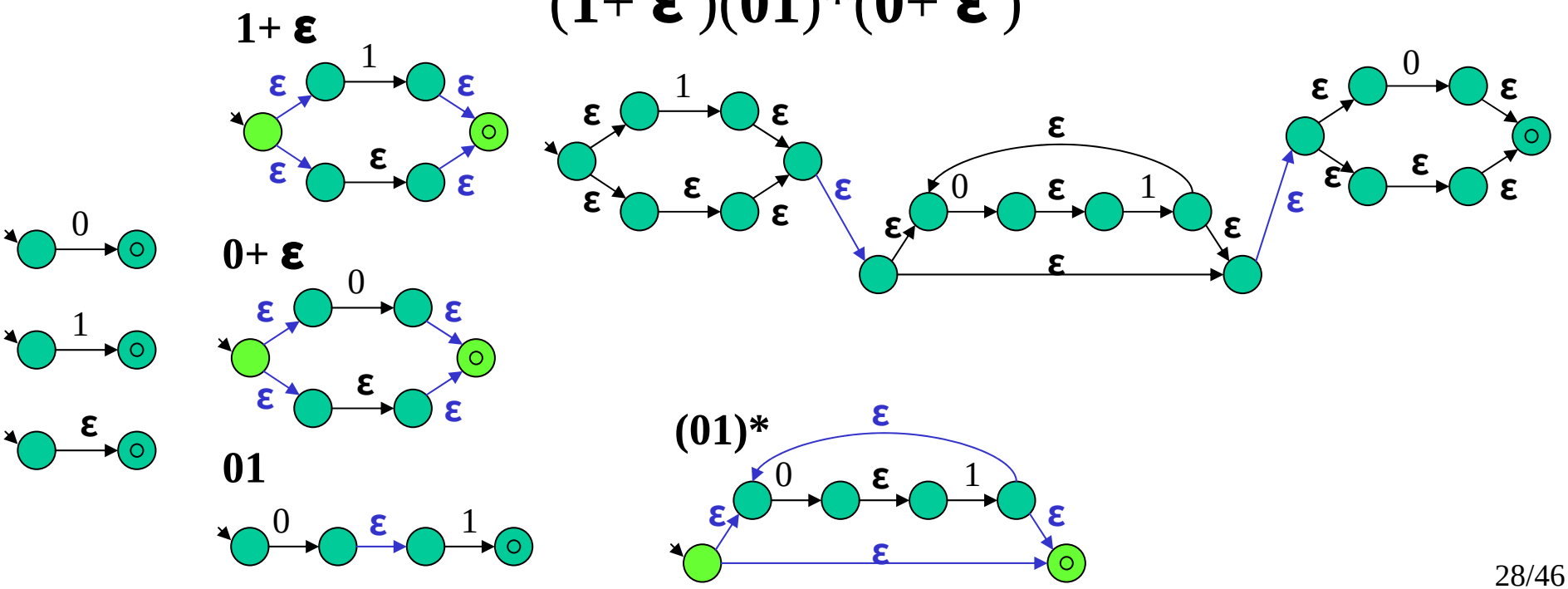


3. Regular Expression: (Text 3.1,3.2)

3. 2. 3. Regular Expression → ε -NFA

Ex：R.E. of strings s.t. 0 and 1 appear alternately;

(1+ ε)(01)*(0+ ε)



3. 正則表現:
(テキスト3.1,3.2)

3. 2. *. ε -NFA→正則表現

補題: **任意の ε -NFA** A**に対し、** $L(A)=L(A')$**で、以下の条件を満たす ε -NFA** A'**が存在する。**

1. **受理状態は1つで、受理状態からの遷移はない**
2. **任意の状態** q **に対し、初期状態から** q **への遷移と、** q **から受理状態への遷移が存在する**

3. Regular Expression: (Text 3.1,3.2)

3. 2. *. ε -NFA→ Regular Expression

Lemma: For any ε -NFA *A*, there exists an ε -NFA *A*' with $L(A)=L(A')$ such that

1. *A*' contains exactly one accepting state, and there are no transitions from the accepting state, and
2. for any state *q*, there is a path from the initial state, and there is a path to the accepting state.

3. 正則表現:
(テキスト3.1,3.2)

3. 2. *. ε -NFA→正則表現

補題: 任意の ε -NFA Aに対し、$L(A)=L(A')$で、以下の条件を満たす ε -NFA A'が存在する。

1. 受理状態は1つで、受理状態からの遷移はない
2. 任意の状態 q に対し、初期状態から q への遷移と、q から受理状態への遷移が存在する

証明:

2. 初期状態から到達できない状態と、受理状態に到達できない状態は受理する言語とは無関係なので、取り除いてよい。

3. Regular Expression:
(Text 3.1,3.2)

3. 2. *. ε -NFA→ Regular Expression

Lemma: For any ε -NFA *A*, there exists an ε -NFA *A*' with $L(A)=L(A')$ such that

1. *A*' contains exactly one accepting state, and there are no transitions from the accepting state, and
2. for any state *q*, there is a path from the initial state, and there is a path to the accepting state.

Proof:

2. The other states are redundant, or they have nothing to accept the language. Hence we can remove them.

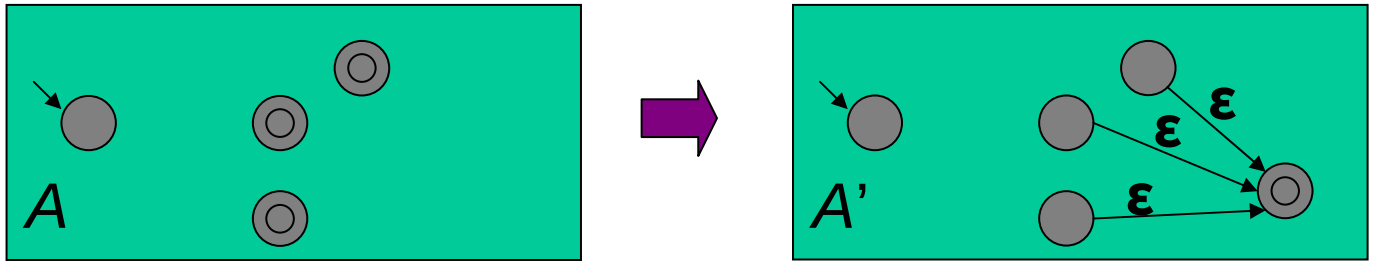
3. 正則表現: (テキスト3.1,3.2)

3. 2. *. ε-NFA→正則表現

補題: 任意の ε-NFA A に対し、$L(A)=L(A')$ で、以下の条件を満たす ε-NFA A' が存在する。

1. 受理状態は1つで、受理状態からの遷移はない
2. 任意の状態 q に対し、初期状態から q への遷移と、q から受理状態への遷移が存在する

説明: [アイデア] 複数の受理状態から、単一の受理状態へと ε-動作で遷移するように与えられたオートマトンを「改造」する。



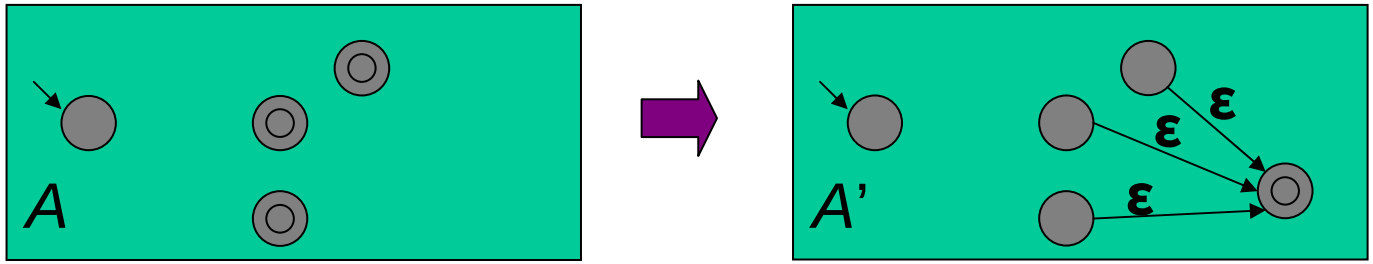
3. Regular Expression: (Text 3.1,3.2)

3. 2. *. ε -NFA→ Regular Expression

Lemma: For any ε -NFA *A*, there exists an ε -NFA *A*' with $L(A)=L(A')$ such that

1. *A*' contains exactly one accepting state, and there are no transitions from the accepting state, and
2. for any state *q*, there is a path from the initial state, and there is a path to the accepting state.

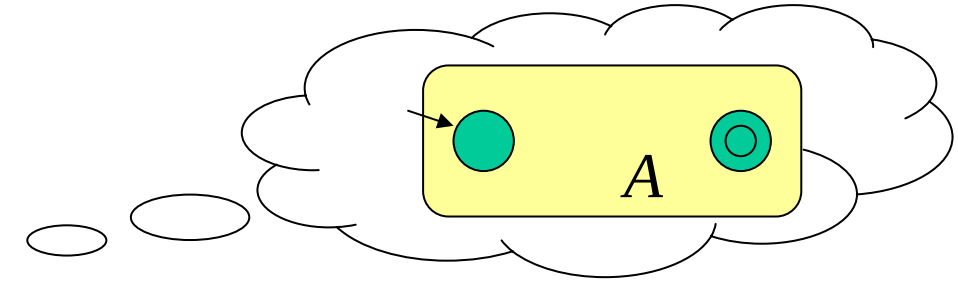
[Idea for Proof] We *modify* the automaton to translate from several accepting states to the unique accepting state by an ε -move.



3. 正則表現:
(テキスト3.1,3.2)

3. 2. *. ε-NFA→正則表現

定理: 任意の ε-NFA A に対し、$L(A)=L(E)$ となる正則表現 E が存在する。



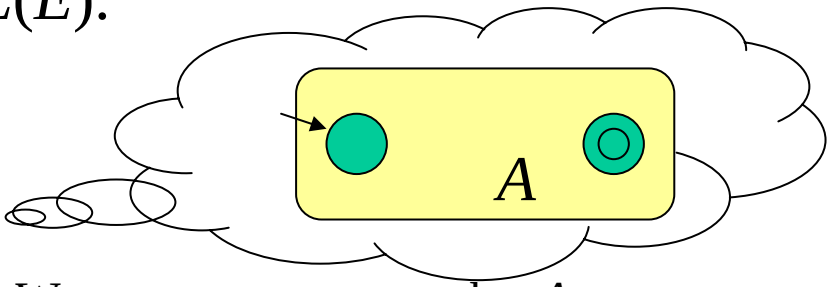
証明:

- $L(A)=\Phi$ なら、$E=\Phi$
- 以下では $L(A)\neq\Phi$ と仮定する。A は以下の補題の条件を満たすとする。
  1. 受理状態は1つで、受理状態からの遷移はない
  2. 任意の状態 q に対し、初期状態から q への遷移と、q から受理状態への遷移が存在する

3. Regular Expression: (Text 3.1,3.2)

3. 2. *. ε -NFA→ Regular Expression

Theorem: For any given ε -NFA A, there is a regular expression E such that $L(A)=L(E)$.



Proof:

- When $L(A)=\Phi$, we have $E=\Phi$.
- Thus we assume that $L(A)\neq\Phi$. We moreover suppose that A satisfies the following conditions by Lemma.

1. A contains exactly one accepting state, and there are no transitions from the accepting state, and
2. for any state q, there is a path from the initial state, and there is a path to the accepting state.

3. 正則表現:
(テキスト3.1,3.2)

3. 2. *. ε-NFA→正則表現

定理: 任意の ε-NFA A に対し、$L(A)=L(E)$ となる正則表現 E が存在する。

証明:

証明のアイデア:

- 辺のラベルに正規表現を構築していく
- 頂点を順番に削除していく

[注意] 構築途中で現れる``NFA''は正確にはNFAではない
(∵NFAでは辺のラベルはアルファベット1文字しか許されていない)

3. **正則表現**: (**テキスト**3.1,3.2)

3. 2. *. ε-NFA→ Regular Expression

Theorem: For any given ε-NFA A, there is a regular expression E such that $L(A)=L(E)$.

Proof:

Idea of the proof:

- We construct the regular expression as the label on an edge of A, and
- We remove states step by step.

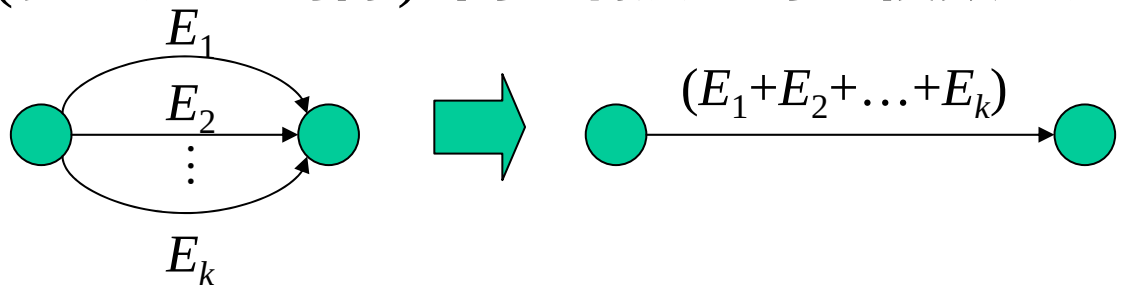
[Note] The ``NFA'' during the process is not real NFA.
(∵Only one alphabet is allowed as a label on an edge.)

3. 2. *. ε-NFA→正則表現

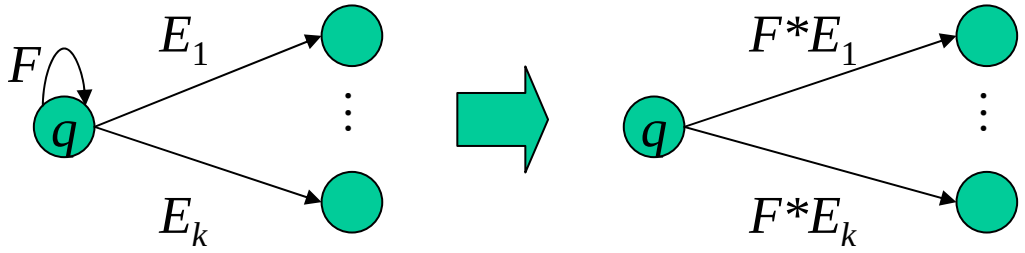
定理: **任意の** ε-NFA A **に対し、** $L(A)=L(E)$ **となる正則表現** E **が存在する。**

証明:

T1 (**多重辺の削除**): **同じ端点を持つ複数の辺の一本化**



T2: (**ループの除去**): **頂点**q**から**q**への遷移が**1**本のとき**



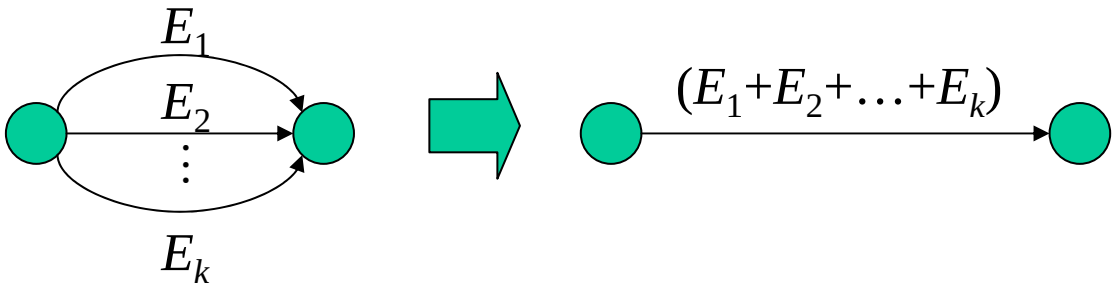
T3: (**頂点** q **の削除**):

3. 2. *. ε-NFA→Regular Expression

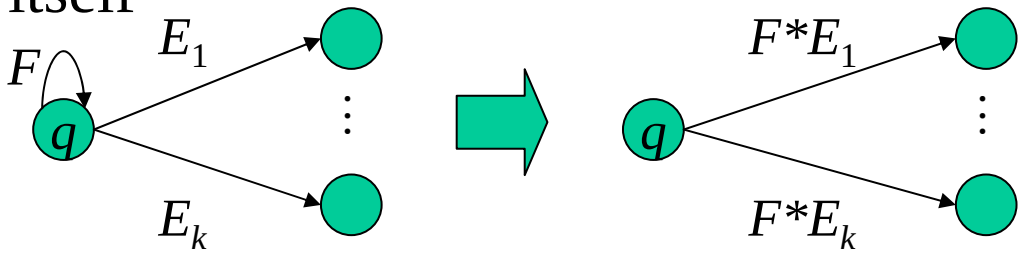
Theorem: For any given ε-NFA A, there is a regular expression E such that $L(A)=L(E)$.

Proof:

T1 (Remove multi-edges): Unify several edges with the same endpoints



T2: (Remove self-loops): When one loop from the node q to itself



T3: (Remove the node q):

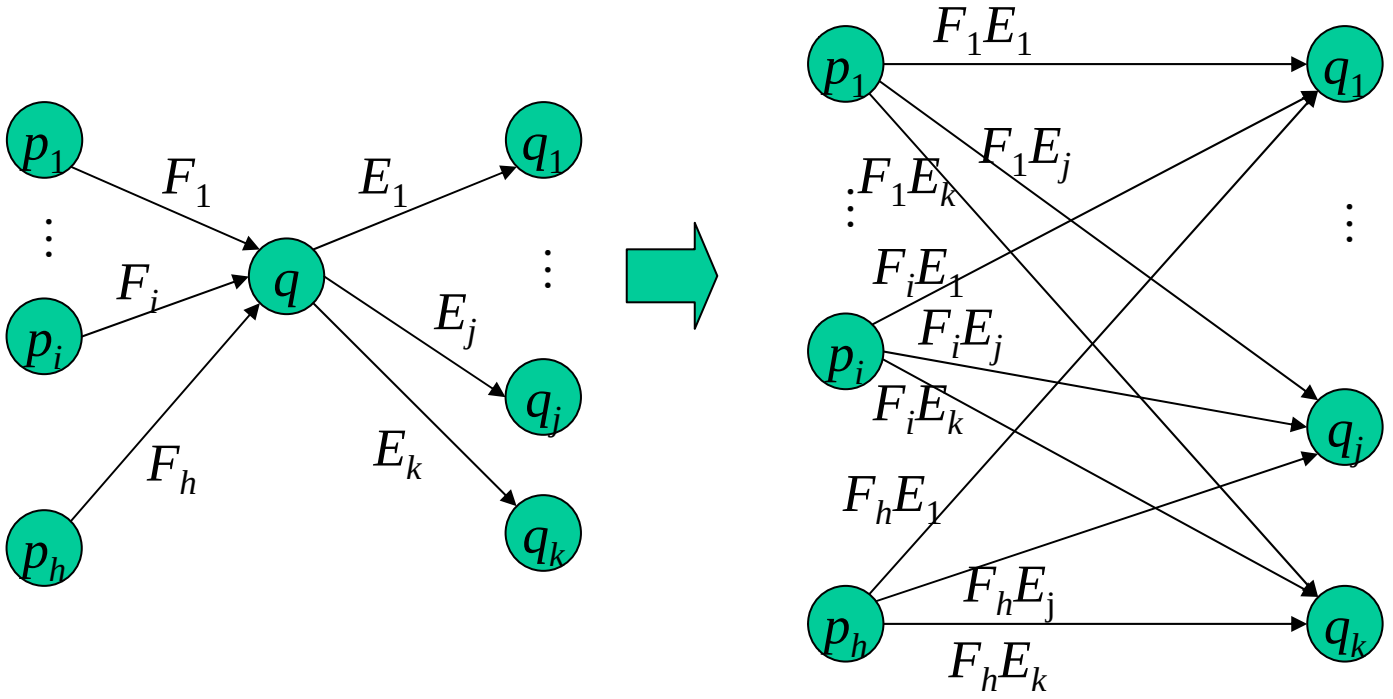
3. 2. *. ε-NFA→正則表現

定理: **任意の** ε-NFA A **に対し、** $L(A)=L(E)$ **となる正則表現** E **が存在する。**

証明:

T3: (**頂点** q **の削除**):

- q **は初期状態、受理状態でない**
- q **から** q **への遷移はない**



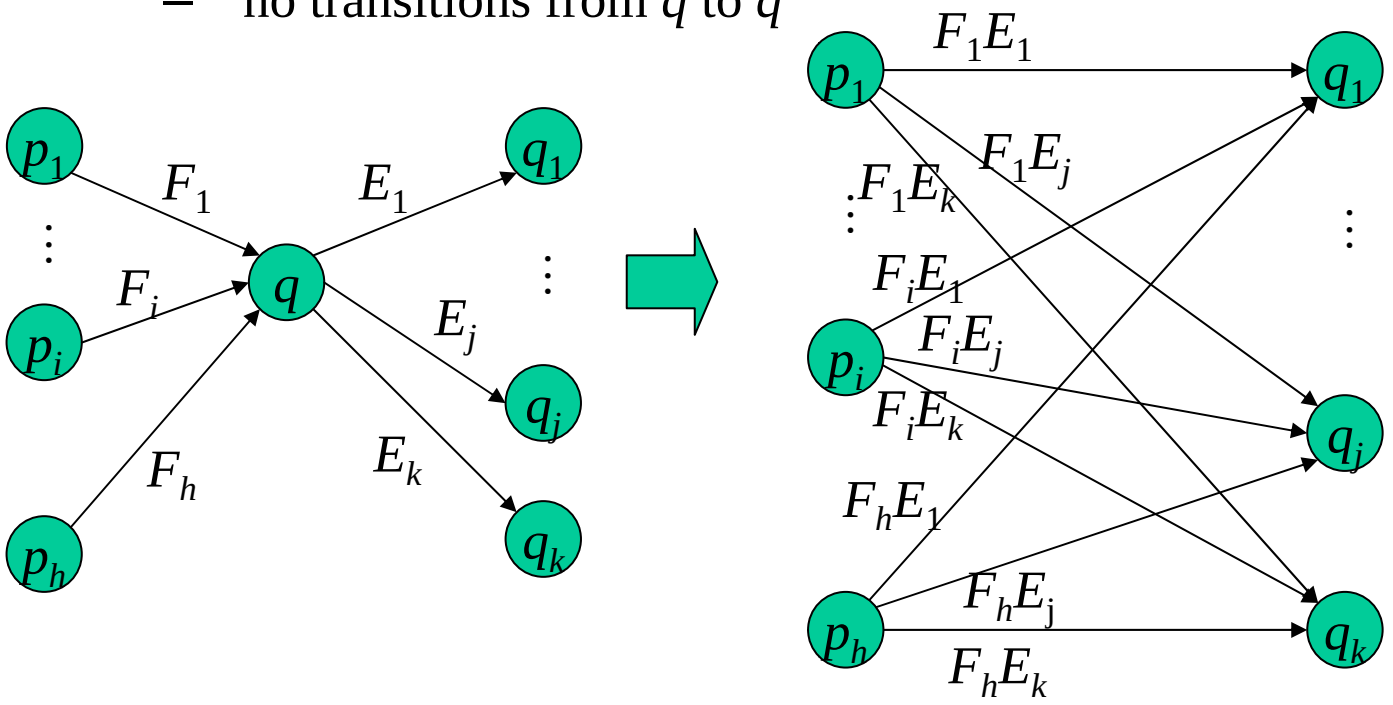
3. 2. *. ε-NFA→Regular Expression

Theorem: For any given ε-NFA A, there is a regular expression E such that $L(A)=L(E)$.

Proof:

T3: (Remove the node q):

- q is neither the initial state nor the accepting state
- no transitions from q to q



3. 正則表現:
(テキスト3.1,3.2)

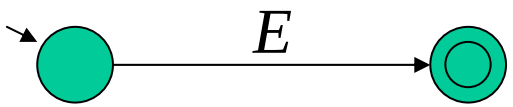
3. 2. *. ε -NFA→正則表現

定理: 任意の ε -NFA A に対し、$L(A)=L(E)$ となる正則表現 E が存在する。

証明: 与えられた ε -NFA Aに対し、

1. T1(多重辺の除去)を可能な限り適用
2. T2(ループの除去)を可能な限り適用
3. T3(頂点の削除)を適用

すると、Aの初期状態と(唯一の)受理状態以外の状態が一つ減る。これを繰り返すと、初期状態と受理状態だけのNFA A'



ができる。このときの辺のラベル E が求める正規表現となる。

3. Regular Expression: (Text 3.1,3.2)

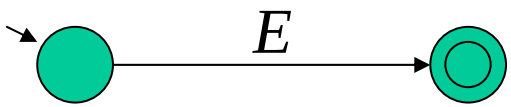
3. 2. *. ε-NFA→Regular Expression

Theorem: For any given ε-NFA *A*, there is a regular expression *E* such that $L(A)=L(E)$.

Proof: For any given ε-NFA *A*,

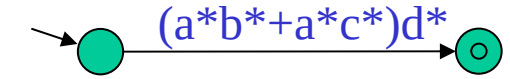
1. apply T1(Remove multi-edges) as possible as you can,
2. apply T2(Remove self-loops) as possible as you can, and
3. apply T3(Remove a node).

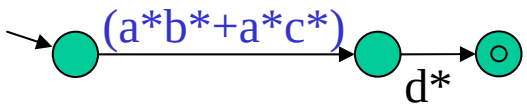
Then a state in A (except initial and accepting states) is removed. Repeating this process, we have an NFA *A'* consisting of two states:



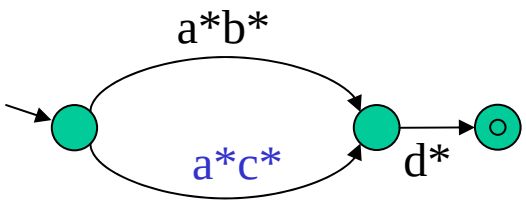
Then the label *E* of the unique edge gives us the regular expression.

3. 正則表現:
(テキスト3.1,3.2)





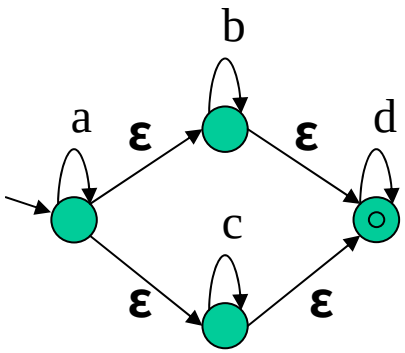
3. 2. *. ε-NFA→正則表現

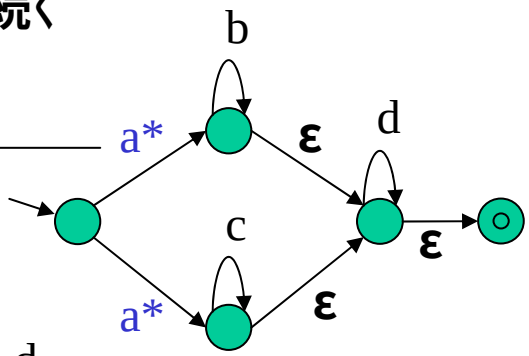


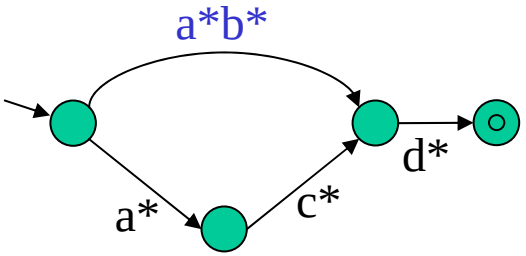
例:

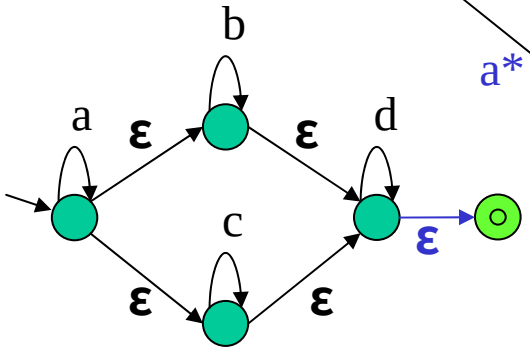
1. まずaが0個以上続き、
2. 次に[bが0個以上]または[cが0個以上]続き、
3. 最後にdが0個以上続く

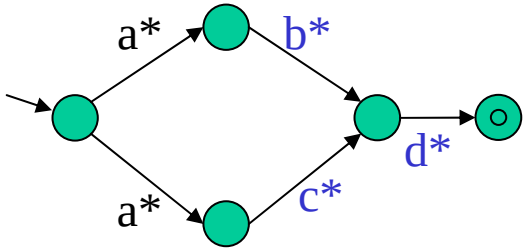
a* ε =a*



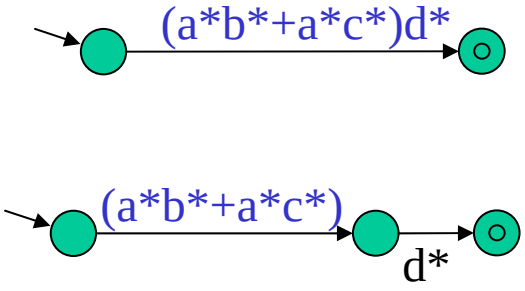








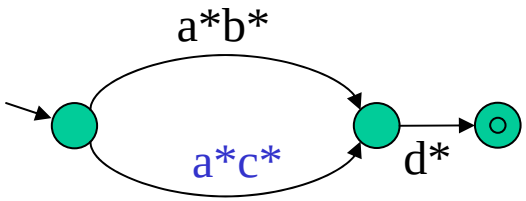
3. Regular Expression: (Text 3.1,3.2)



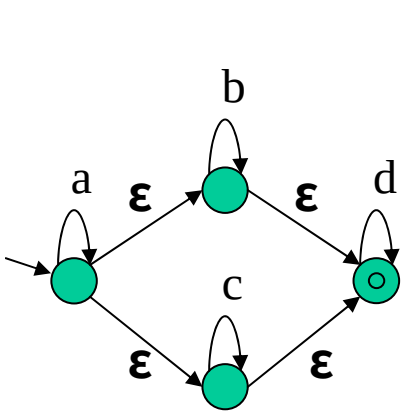
3. 2. *. **ε** -NFA→Regular Expression

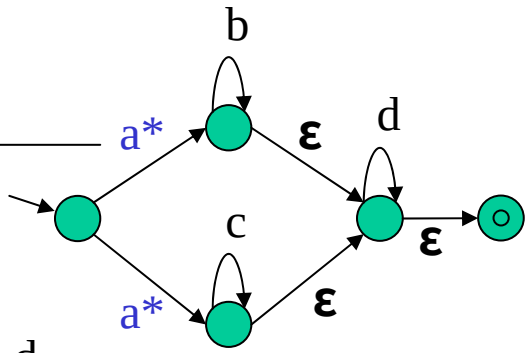
Ex.:

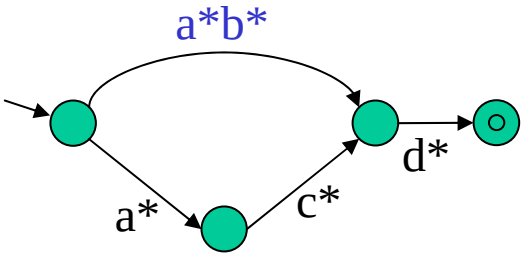
1. 0 or more ‘a’s,
2. [0 or more ‘b’s] or [0 or more ‘c’s], and
3. 0 or more ‘d’s.

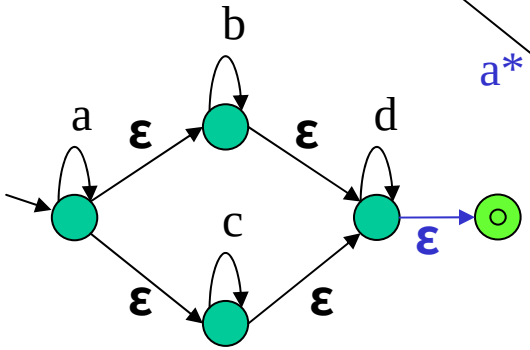


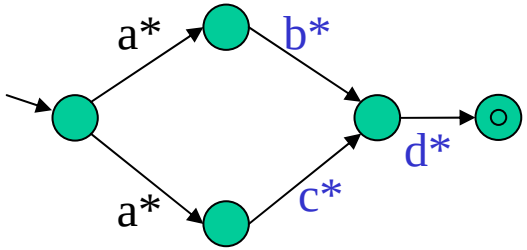
a* **ε** =a*











お知らせ

- **今日のオフィスアワーは講義**
  (5) **正則集合**(1)

Information

- Today’s Office Hour: Lecture
  (5) Regular set (1)