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## APPLICATION OF FINITE-STATE-MACHINE MODELS FOR THE TRANSFORMATION OF SYNTAX DIAGRAMS

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### Abstract.

The article deals with the questions of syntax diagrams equivalence transformations. To carry out equivalence transformations there was suggested a finite-state-machine model of a syntax diagram, which is a finite set of non-deterministic automata of Rabin-Scott with  $\epsilon$ -transitions. There are presented an algorithm of transforming a syntax diagram into a finite-state-machine model and algorithm of transforming a finite-state-machine model into a syntax diagram. It is demonstrated that if an automaton in a model is replaced with an equivalent automaton, the obtained automata set would also be a syntax diagram model. On this basis there was suggested a method of syntax diagrams equivalence transformations, which consists in the following. A finite-state-machine model is built for a certain syntax diagram. The automaton of the finite-state-machine model is transformed into an equivalent automaton by using algorithms, known in the automata theory. Then, according to the transformed finite-state-machine model a syntax diagram is built. The obtained syntax diagram would be equivalent to the initial syntax diagram. The article demonstrates the examples of using this method to exclude the excess nodes in a syntax diagram, to obtain a pseudo-deterministic syntax diagram and to reduce the number of nodes in a syntax diagram.

**Key words:** formal language, finite-state automaton, syntax diagram, equivalence transformations.

### Introduction.

Syntax diagrams (SD) is a visual method of setting a formal language, which is used for recording programming languages [1, 2], and for designing the language processing software [3 – 9]. In the process of developing programs an initial SD has to be transformed to an equivalent SD (two syntax diagrams are equivalent, if the languages, set by them, are equivalent), meeting the certain requirements. For example, to design linear complexity translators [8, 9] the deterministic syntax diagrams are used; at this, the size of translator depends on the size of syntax diagram. So, to

make a translator smaller, it's reasonable to use the «compact» syntax diagrams [10]. The equivalence SD transformation algorithms are presented in a number of works [2 – 6, 10 – 12]. Many transformation algorithms are based on evident or intuitive reasoning and their correctness is not always confirmed. This article suggests using the known algorithms of finite-state automata transformation [13 – 19], the correctness of which is rigorously proven, to carry out the SD equivalence transformation. The article defines asyntax diagram and Rabin-Scott's non-deterministic automata withε-transitions and suggests a finite-state-machine model of a syntax diagram, which is a finite set of automata; demonstrates, that if in a syntax diagram model an automaton is replaced with another automaton, equivalent to the first one, then the new set of automata would be a model of the initial SD; determines the rules of building a SD model and rules of building a syntax diagram from its finite-state-machine model, describes the algorithms of the finite-state automata equivalent transformations, gives the examples of using them for SD transformations. The examples of finite-state automata transformations are not analyzed in detail, only their results are demonstrated.

## The main part.

### 1. Syntax diagram

A syntax diagram may be denoted with the set  $D = (T, N, S, G, F)$ , where  $T$  – is a finite set of terminals;  $N$  – is a finite set of non-terminals;  $S \in N$  – initial non-terminal;  $G = (V, E)$  – a directed graph, where

$$V = V_T \cup V_N \cup V_u \cup V_{\text{entry}} \cup V_{\text{exit}}, \text{ where}$$

$$V_{\text{entry}} - \text{ a set of entry points, } |V_{\text{entry}}| = |N|;$$

$$V_T - \text{ a set of terminal nodes;}$$

$$V_N - \text{ a set of non-terminal nodes;}$$

$$V_u - \text{ a finite set of nodes;}$$

$$V_{\text{exit}} - \text{ a set of exit points, } |V_{\text{exit}}| = |N|;$$

$$E = E_1 \cup E_2 \cup E_3 \cup E_4 \cup E_5, \text{ where}$$

$$E_1 \subseteq \{(a, b) \mid a \in V_{\text{entry}}, b \in V_u\} - \text{ a set of entry curves;}$$

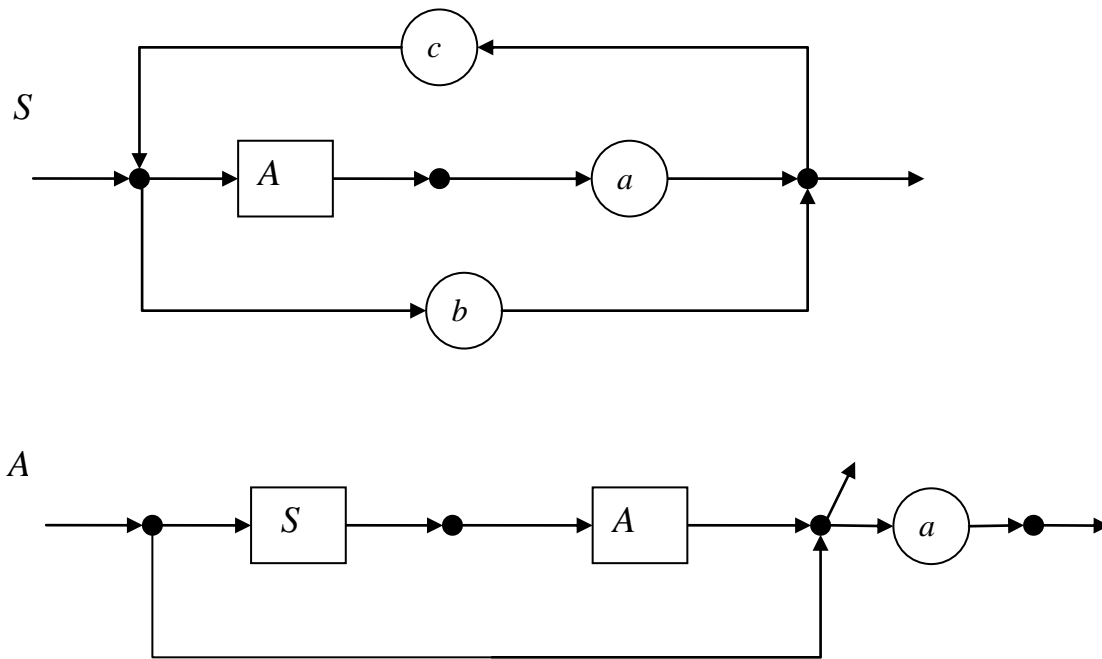
$$E_2 \subseteq \{(a, b) \mid a \in V_u, b \in V_{\text{exit}}\} - \text{ a set of exit curves;}$$

$$E_3 \subseteq \{(a, b) \mid a \in V_u, b \in V_T \cup V_N\} - \text{ a set of curves, exiting the nodes;}$$

$$E_4 \subseteq \{(a, b) \mid a \in V_T \cup V_N, b \in V_u\} - \text{ a set of curves, entering the nodes;}$$

$$E_5 \subseteq \{(a, b) \mid a \in V_u, b \in V_u\} - \text{ a set of } [\epsilon] \text{-curves, connecting the nodes;}$$

Graph  $G$  can be represented as a set of connected graphs  $G_1, G_2, \dots, G_{|N|}$ . Graph  $G_i$  corresponds to the non-terminal  $N_i \in N$  and is called the syntax diagram component. The description of graph  $G_i$  corresponds to the above mentioned description of graph  $G$ , excepting that graph  $G_i$  has only one entry point and only one exit point. In Fig. 1 there is presented a SD, consisting of two components. The capital letters  $S$  and  $A$  denote non-terminals, the small letters  $(a, b, c)$  denote terminals.



**Fig. (1).** –Syntax diagram.

A component is denoted with a certain non-terminal, has only one entry point and only one exit point and a finite set of nodes, terminal and non-terminal ones. The entry and exit points are not depicted in the component's diagram. A terminal node is depicted with a circle, in which a terminal symbol is written, a non-terminal node is depicted with a square, in which a non-terminal symbol is written. A node is depicted in the diagram with a heavy point. No curves enter the entry point and a finite set of curves exit from it (the entry curves of the component). The nodes, which are entered by entry curves, are called initial. No curves exit from the exit point and a finite set of curves enter it (the exit curves of the component). The nodes, from which the exit curves exit, are called final. The curves, connecting the nodes, are called  $\varepsilon$ -curves. Let's consider a certain path in the component  $G_i$  from node to some final node in this component. Let's go on it and add symbols, recorded in terminal and non-terminal nodes, to an initially empty string  $\alpha$  in the course of it. The string  $\alpha$  will be called a string, which connects node  $u$  with the final node of component  $G_i$ . A set of strings, connecting node with a certain final node, makes up a language  $L(u)$ . In the similar way we will

determine a string, connecting the entry point of component  $G_i$  with its exit point. A set of such strings makes up a language  $L(G_i)$ . It's obvious that the language  $L(G_i)$  is equal to the sum of all  $L(u_j)$ , where  $u_j$  – is an initial node of component  $G_i$ .

The string of language, set by a syntax diagram, can be deduced by the following rule:

1. Record a string, belonging to language  $L(G_1)$ , where component  $G_1$  corresponds to the initial non-terminal.
2. If the string contains a certain non-terminal  $N_i$ , replace it with the string of language  $L(G_i)$  and go to step 2, otherwise – finish the deduction.

From the rule of deducting a language string the following assertions result.

Assertion 1. If in a syntax diagram component  $G_i$  is replaced with component  $G_i'$ , so that  $L(G_i') = L(G_i)$ , there will be obtained a SD, equivalent to the initial SD.

Assertion 2. Let in a syntax diagram component  $G_i$  correspond to non-terminal  $N_i$ , component  $G_j$  – correspond to non-terminal  $N_j$  and  $L(G_i) = L(G_j)$ . Then exclusion of component  $G_j$  from the syntax diagram and replacement of non-terminal  $N_j$  with non-terminal  $N_i$  in a syntax diagram, will give a new SD, equivalent to the initial SD.

## 2. Finite-state automaton

A non-deterministic finite-state automaton of Rabin-Scott with [epsilon]-transitions [13] maybe denoted with the set

$A = (X, S, S_0, [\delta], Q)$ , where

$X$  – a finite non-empty set of input symbols (input alphabet);

$S$  – a finite non-empty set of states (state alphabet);

$S_0$  – a finite non-empty set of initial states,  $S_0 \subseteq S$ ;

$[\delta] : S \times \{X \cup \{\epsilon\}\} \rightarrow 2^S$  – transition function, which assigns a subset of states to a pair (state, input symbol) or to a pair (state, [epsilon]). Here  $2^S$  – is a Boolean of the set  $S$ , [epsilon] – the indicator of symbol's absence.

$Q$  – a finite set of final states,  $Q \subseteq S$ .

Automaton  $A$  can be presented with a graph, in which nodes correspond to states. Node  $s_i$  is connected with a curve, noted with symbol  $x$  ( $x \in X$ ), with nodes  $s_j$ , if  $[\delta](s_i, x) = S'$  and  $s_j \in S'$ . If  $[\delta](s_i, \epsilon) = S'$  and  $s_j \in S'$ , then nodes  $s_i$  is connected with nodes  $s_j$  with an unmarked curve. The string  $\alpha$ , obtained by writing symbols from the graph curves of automaton  $A$ , forming a path from states  $s_i$  to the final state, is allowed by state  $s_i$ . These to fall strings, allowed by state  $s_i$ , forms the language  $L(s_i)$ . The string  $\alpha$ , allowed by some initial state of automaton  $A$ , is allowed by automaton  $A$ . These to fall strings, allowed by automaton  $A$ , forms the language  $L(A)$ .

### 3. The finite-state-machine model of a syntax diagram

The finite-state-machine (FSM) model of a SD, the graph of which is  $G = \{G_1, G_2, \dots, G_n\}$ , is a set of non-deterministic automata of Rabin-Scott with  $[\epsilon]$ -transitions  $A = \{A_1, A_2, \dots, A_n\}$ , so that  $L(A_i) = L(G_i)$ .

Component  $G_i$  corresponds to automaton  $A_i = (X, S^i, S_0^i, [\delta]^i, Q^i)$ , in which

– the input alphabet  $X$  is a set of terminals and non-terminals of a syntax diagram;

– the state alphabet  $S^i$  is a set of nodes of component  $G_i$ ;

– the set of initial states  $S_0^i$  is the set of initial nodes of component  $G_i$ ;

– these to final states  $Q^i$  is the set of final nodes of component  $G_i$ ;

– the transition function is determined in the following way:

1.  $s_j \in [\delta]^i(s_i, x)$  if and only if there is a path in a syntax diagram from nodes  $s_i$  to node  $s_j$  through the only node, containing symbol  $x$ ;

2.  $s_j \in [\delta]^i(s_i, [\epsilon])$  if and only if there is a curve in a syntax diagram from nodes  $s_i$  to nodes  $s_j$ .

In order to build a finite-state machine model of a SD, for each component  $G_i \in G$  the corresponding automaton  $A_i$  must be built according to the above mentioned rules.

From the definition of a syntax diagram's FSM model the following assertion results:

Assertion 3. If in a syntax diagram's FSM model  $A = \{A_1, A_2, \dots, A_i, \dots, A_m\}$  automaton  $A_i$  is replaced with an equivalent automaton  $A_i'$  ( $L(A_i') = L(A_i)$ ), then  $A' = \{A_1, A_2, \dots, A_i', \dots, A_m\}$  also would be a FSM model of the considered syntax diagram.

By a syntax diagram's FSM model  $A = \{A_1, A_2, \dots, A_m\}$  we can unambiguously build a SD. For this purpose each automaton  $A_i \in A$  should be transformed to a component  $G_i$  of the syntax diagram. Transformation is done according to the following rules.

1. The set of nodes of component  $G_i$  is made up with the set of states of automaton  $A_i$ .

2. If in the automaton  $s_j \in [\delta]^i(s_i, [\epsilon])$ , then in component  $G_i$  a curve is drawn from node  $s_i$  to node  $s_j$ . If in the automaton  $s_j \in [\delta]^i(s_i, x)$ , where  $x$  is a terminal, then a terminal node is added to component  $G_i$ , the  $x$  symbol is written into it, a curve is drawn from nodes  $s_i$  to this node, and from it – a curve to nodes  $s_j$ . If  $x$  is a non-terminal, then the similar actions are done, except that a non-terminal node is added to component  $G_i$ .

3. The nodes, corresponding to initial states, are made initial (entry curves are drawn to them).

4. The nodes, corresponding to final states, are made final (exit curves are drawn from them).

The application of a finite-state-machine model for transforming syntax diagrams consists in the following.

According to the given SDA FSM model is built. The automaton of a FSM model is transformed to an equivalent automaton by using the known algorithms of the automata theory. Then a syntax diagram is built by the transformed FSM model. The obtained SD will be equivalent to the original SD.

Let's consider the application of this approach to carry out some syntax diagrams transformations.

#### 4. Excluding the excess nodes from a syntax diagram

In the set of nodes of a syntax diagram component two types of excess nodes can be singled out:

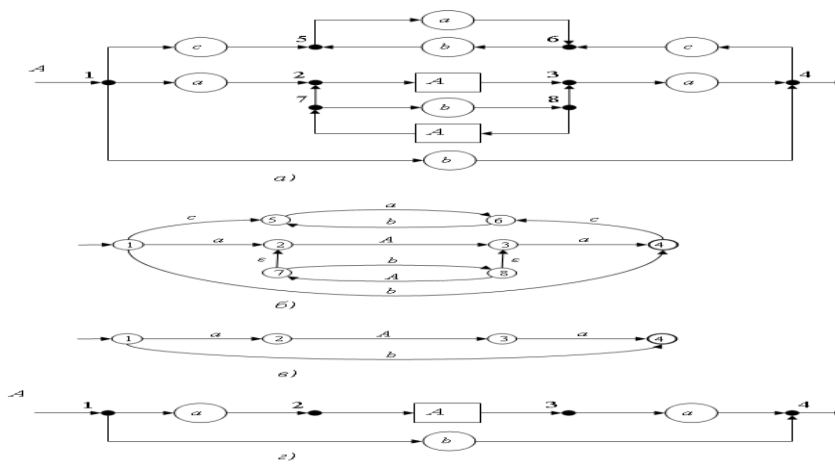
1. A node belongs to excess nodes set of the 1-st type, if there is no path from it to some other initial node of the component;
2. A node belongs to excess nodes set of the 2-nd type, if there is no path from it to some other final node of the component.

No path from the initial node to the final node goes through an excess node, so the excess node doesn't influence these to strings, drawn in the syntax diagram. A syntax diagram with excess nodes can be transformed to an equivalent syntax diagram without excess nodes. For this purpose let us build a FSM model of a syntax diagram  $A = \{A_1, A_2, \dots, A_n\}$ . In each automaton  $A_i \in A$  we exclude the excess states, using, for example, the method, described in [19]. For this purpose let us do the following actions.

1. Find the set  $E$  of reachable states according to the algorithm:
  1. Assign  $E = S_0^i$ , where  $S_0^i$  – is the set of initial states of automaton  $A_i$ .
  2. If the automaton's graph has the curve  $(s_j, s_k)$ , where  $s_j \in E$  and  $s_k \notin E$ , then add the state  $s_k$  to the set  $E$  and perform step 2, otherwise – finish the algorithm.
2. Find the set of unreachable states of automaton  $A_i$ , excluding the states of set  $E$  from the set of all states of the automaton.
3. Obtain automaton  $A_i^{-1}$  by altering the orientation of curves of automaton  $A_i$ . Consider the initial states of automaton  $A_i^{-1}$  as the final states of automaton  $A_i$ .
4. Find the set of unreachable states of automaton  $A_i^{-1}$ . This will be a set of excess states of automaton  $A_i$ .
5. Remove all the unreachable and excess states in the automaton  $A_i$  together with exit and entry curves.

Let's transform the FSM model of a syntax diagram, in which each automaton contains no excess states, into a syntax diagram without excess nodes.

Infig. 2 an example of excluding the excess nodes from a SD is given. Fig. 2 presents theoriginal syntax diagram, fig. 2б – the FSM modelof a syntax diagram, fig. 2в – automaton without excess states, fig. 2г – syntax diagram without excess nodes.



**Fig. (2). Excluding the excess nodes from a syntax diagram.**

### 5. Transforminga syntax diagram toapseudo-deterministic syntax diagram

Asyntax diagramiscalledpseudo-deterministic (PSD) [9], if:

1. it has no [epsilon]-curves;
2. each component has only one initial node;
3. ForeachnodeofaSDit'strue, that any two curves, exiting this node, go to nodes, containing various symbols.

The transformation of a SD to a PSD is the first stage in the process of transforming a SD to a deterministic SD [10].

Deterministic syntax diagrams are used for designing the efficient language processing software[8, 9].

To transform arandom SD to a PSD let's build a FSM model of a SD and transform each automaton to adeterministic one. The algorithms of transforming a non-deterministic automaton of Rabin-Scott with [epsilon]-transitions to adeterministic one are described in the works [13, 18, 19] etc.

A non-deterministic automaton of Rabin-Scott with[epsilon]-transitions can be transformed to a deterministic one in two stages:

1. eliminating the [epsilon]-transitions (transforming the automaton $A_{[\epsilon]}$ with [epsilon]-transitions to anon-deterministic automaton $A_H$ without [epsilon]-transitions);
2. transforming the automaton $A_H$ without [epsilon]-transitions to adeterministic automaton $A_D$ .

To eliminate the [epsilon]-transitions a concept of [epsilon]-closure of the state  $s_i$  ( $[\epsilon](s_i)$ ) is used. The [epsilon]-closure of the state  $s_i$  is a set of states, containing the set  $s_i$  and all sets, achievable from itonly through [epsilon]-transitions.

The automaton  $A_H$  is built in the following way.

The states of automaton  $A_H$  are  $[\epsilon]$ -closures of states of automaton  $A_{[\epsilon]}$ .

The initial states of automaton  $A_H$  are  $[\epsilon]$ -closures of the initial states of automaton  $A_{[\epsilon]}$  and  $[\epsilon]$ -closures of all states, which are achievable from initial states only through  $[\epsilon]$ -transitions.

The final states of automaton  $A_H$  are  $[\epsilon]$ -closures of states, which contain at least one final state of automaton  $A_{[\epsilon]}$ .

The transition function of automaton  $A_H$  is determined in the following way. The automaton  $A_H$  transits from  $[\epsilon](s_i)$  under the action of input symbol  $x$  to  $[\epsilon]$ -closures of states, to which automaton  $A_{[\epsilon]}$  transits from states, belonging to  $[\epsilon](s_i)$  under the action of symbol  $x$ .

The automaton  $A_D$  is built in the following way.

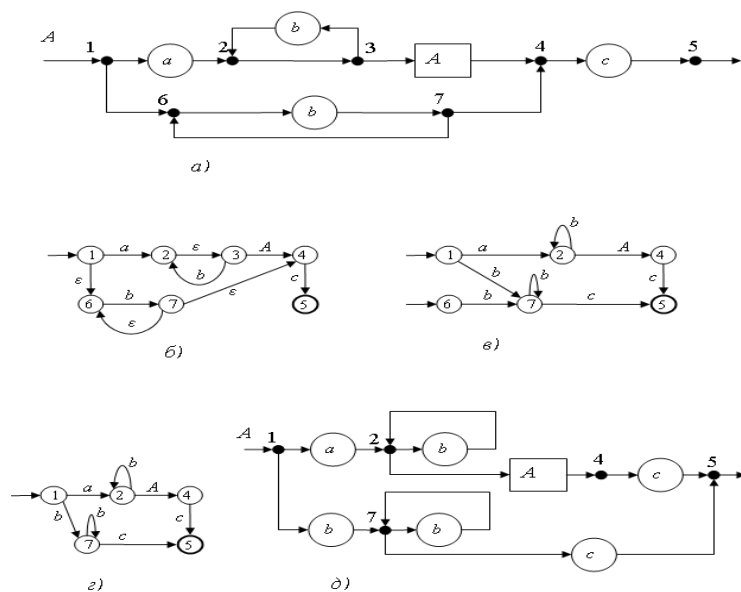
The states of automaton  $A_D$  are subsets of states of automaton  $A_H$ .

The initial state of automaton  $A_D$  is the subset of all initial states of automaton  $A_H$ .

The final states of automaton  $A_D$  are subsets, which contain at least one final state of automaton  $A_H$ .

The transition function of automaton  $A_D$  is determined in the following way. The automaton  $A_D$  transits from the subset  $S_i$  under the action of input symbol  $x$  to the subset  $S_j$ . The states belong to the subset  $S_j$ , if and only if the automaton  $A_H$  transits to the states under the action of symbol  $x$  from at least one state, belonging to the subset  $S_i$ .

In fig. 3 an example of transforming a syntax diagram to a pseudo-deterministic syntax diagram is given. Fig. 3a presents the original syntax diagram, fig. 3б – the FSM model of a syntax diagram, fig. 3в – automaton without  $[\epsilon]$ -transitions, fig. 3г – deterministic automaton and fig. 3д – a PSD.



**Fig. (3). Transforming a syntax diagram to a pseudo-deterministic syntax diagram.**



### 6. Reducing the number of nodes in components of pseudo-deterministic syntax diagrams

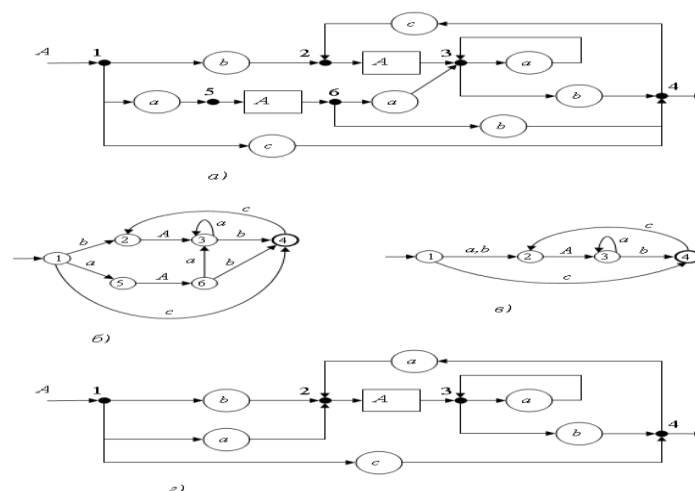
The FSM model of a PSD is a set of deterministic automata. Each automaton of a model can be transformed to a minimal automaton. The transformation algorithms are described in works [14 – 19] etc.

A minimal automaton contains no excess states and no pairs of equivalent states. Exclusion of the excess states is described above. To provide these condition we can use an algorithm, based on dividing a set of automaton's states to equivalent states classes and replacement of each class with a single state (uniting a class of equivalent states in to one state).

To divide a set of states to equivalent states classes a concept of k-equivalent states is used. Let's define  $L^k(s_i)$  as a set of words with the length of k, allowed by states<sub>i</sub>. States<sub>i</sub> and<sub>j</sub> are called k-equivalent, if  $L^k(s_i) = L^k(s_j)$ . These to fall k-equivalent to each other states forms a class of k-equivalent states. To find the partition of a set of states into equivalent states classes, the partitions into classes of 0-, 1-, ...,k-equivalent states are determined successively. The process is finished, when at acertain step the classes ofk-equivalent states coincide with classes of (k – 1)-equivalent states. At this moment he partition into classes of k-equivalent states will be presented by partition into classes of equivalent states.

Two states of the automaton are 0-equivalentin case if both of them are final or if both of them are non-final. The states<sub>i</sub> and<sub>j</sub> would bek-equivalent, if they are (k – 1)-equivalent and the states  $s_i' = [\delta](s_i, x)$  and  $s_j' = [\delta](s_j, x)$  and also (k – 1)-equivalent for allx of the automaton's alphabet.

Infig. 4 an example of reducing the number of nodes in a syntax diagram is given. Fig. 4apresents the original syntax diagram, fig. 4б – the FSM modelof a syntax diagram, fig. 4в – the minimal automaton, fig. 3r – SD with the lesser number of nodes, than in SD in figure 4a.



**Fig. (4). Reducing the number of nodes in a syntax diagram.**

**Conclusion.** The article suggests a finite-state-machine model of a syntax diagram and a method, which allows using finite-state-machine models for equivalence transformations of syntax diagrams. There are given examples of using the suggested method for carrying out some of the transformations. The application of this method is not restricted to the analyzed transformations. This work can be further developed by searching other transformations, which can be carried out by means of the suggested method.

**Inferences.** Based on the above-mentioned we can conclude that application of the suggested method allows doing the equivalent transformations of syntax diagrams correctly, using the known algorithms of the finite automata theory.

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