# Logical Platforms for Mobile Application in Decision Support Systems Based on Color Information Processing

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## Abstract

This work is devoted to the creation of mobile applications for a wide class of decision-making problems with large databases based on effective optical logical systems. Such systems use (a) the representation of color as a carrier of logical fuzzy information and (b) the construction of logical decisions by transforming the light emitter with appropriate color filters. Optical processing of fuzzy information is carried out using the proposed block diagram of fuzzy logic gates (logical coloroid). Input data is generated based on expert assessments. The fuzzy database is formed by defining the corresponding color as a quantum (set) of information. The article discusses (a) the main steps in the synthesis of logical inference procedures for decision-making

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systems and (b) a generalized block diagram of an optical logical coloroid as the basis for creating multi-level mobile decision-making systems with artificial intelligence components. The use of color as a carrier of logical information allows the creation of high-speed mobile devices with convenient visualization.

**Keywords:** Logical coloroid, decision support system, optical logic architecture, color fuzzy information.

## 1 Introduction

The development of optoelectronic technologies in recent years has generated interest in the development of optical computing devices capable of performing parallel computing operations at high speed. Two main directions have emerged in the development of optical computing (logical) devices, the first uses binary optoelectronic logic devices that combine the advantages of optical and semiconductor components with the ability to parallel process large amounts of data. The second direction is to design all-optical logic devices [1–6] on the physical principles of interference, polarization, and coherence, as well as the use of the properties of diffraction gratings and photonic crystals. The researchers demonstrated experimental results [7, 8] that showed an increase in the performance of all-optical devices. The wider use of such devices is hampered by currently imperfect production technologies.

At the same time, in computer science, an approach based on linguistic variables and fuzzy sets developed [9–19]. The implementation of optical devices for fuzzy sets [20–23] is based on: polarization effects [20], matrix prism systems [21], printed color filters [22] and other solutions. The papers [24, 25] present a detailed comparative analysis of the elements of integrated optics computing systems, which reflect the advantages and disadvantages of optical and semiconductor architectures.

The use of optical logic devices in artificial intelligence systems or, somewhat narrower, in decision-making systems involves processing an extremely large array of data and a multi-level decision-making process. Using a binary encoding and calculation system for the simplest data input and inference tasks requires performing many binary computational operations, which naturally reduces their performance. The works [26–28] provide an analysis of the effectiveness of various approaches to the generalized problem of creating artificial intelligence and draw a conclusion with which we can agree that data input and the decision-making process are inherently vague and unclear.

The authors have now developed the basic principles of operation and proposed the architecture of optical computing components (coloroids), which perform all the necessary logical operations: disjunction, conjunction, negation, and triggered of a new solution.

At the same time, for a more complete mathematical description of logical operations, including using a matrix description of color quanta, it is necessary to expand the implementation base of optical color conversion to all possible logical rules (axioms).

The use of the basic principles of optical physics, already used in modern television and video devices for the additive and subtractive transformation of the light emitter with color filters, as well as giving a certain color the property of a fuzzy information set, made it possible to present this transformation as natural logical operations and form a new approach to processing big databases.

The proposed architecture of optical computing and decision-making has autonomous color mathematics, but naturally, its development depends on technological solutions for creating nano-sized coloroids, which are currently at the initial stage of development.

The use of color as a source of information and the associated high-quality visualization of the results of data assessment and decision-making, as well as the matrix description of color (developed by the authors) and basic logical operations corresponding to optical operations, allow us to propose principles for constructing the structures of mobile applications with various purposes for use in mobile gadgets.

For example, in the medical field: the constant and steady growth of interest in scientific developments to create decision-making systems with elements of artificial intelligence, including for mobile applications, is explained by the desire to increase the efficiency and reliability of processing a large array of input information [29, 30].

Let's explain the main idea of combining color information processing and mobile applications in decision-making processes using the specific purpose of the mobile application in the direction mentioned above.

Consider a family doctor who cares for a group of patients and the procedure of remote monitoring of health conditions in the chain of "medical doctor–patient".

We can propose a special mobile application or device that provides, for example, 12 input data about the patient's condition in the form of information of a certain color.

The input data obviously assesses the general condition of the patient at the beginning of the day: temperature, pressure, general condition, condition of certain organs and other similar things, which of course presupposes a professional approach. Each color presentation of each of the 12 input data involves, for example, six ratings (granules of information) and, accordingly, a specific color: *Very Bad* (high temperature, pressure, etc.) – *red*; *Threatening – yellow*; *Anxious – magenta*; *More or Less Normal – green*; *Good – cyan*; *Very Good – blue*. The patient enters this color information on his mobile device and receives a score based on optical information processing. It can be in the form of a specific one of the six listed colors or a solution, or rather the absence of one, in case of a certain contradiction in assessments, which will require the generation of a new assessment by updating the input information. Next, the patient transmits the final assessment to the doctor on his mobile device, where it falls into a certain position window. Thus, the doctor sees a generalized color assessment of the condition of his patients at the beginning of the working day.

Similar tasks of qualitative expert assessment of various situations are possible for many situations in the different fields of human activity: from a preliminary assessment of the safety of working conditions to an assessment of the safety of ship navigation in narrow channels and in complicated dangerous situations at the sea and port areas [31, 32].

For the development of computing systems in mobile applications, an innovative color network architecture with a three-level hierarchy can be proposed as an element of a decision support system with a large number of input data.

Thus, the purpose of the article is to create operating principles and structures of generalized computing platforms for mobile applications with the aim of reliable and fast decision-making in a variety of tasks with a large number of input data in the social, technical, military and medical fields.

## 2 General Information About Color as a Quantum of Information

Additive light transformation describes the operations of combining (summing) corresponding combinations of three primary colors: red $\{R\}$, green $\{G\}$, and blue $\{B\}$. The absence of light radiation (and therefore color), there

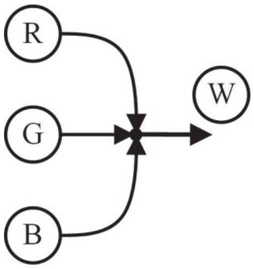

**Figure 1** Additive logical coloroid.

is black $\{Blc\}$. When three primary colors are added, the result is (Figure 1), white $\{W\}$; when red and blue light are added together, get purple $\{M\}$; when summed, red and green are $\{Yel\}$, and green and blue are cyan $\{C\}$ which is written for color as a quantum of information [33, 34] in the form:

$$\{R\} + \{G\} + \{B\} = \{W\};\ \{R\} + \{G\} = \{Yel\};$$
$$\{R\} + \{B\} = \{M\};\ \{G\} + \{B\} = \{C\}. \tag{1}$$

For primary colors, applying a light filter of a certain color blocks the light beam of a different color. For example, a red filter blocks green and blue components, allowing only red light to pass through:

$$\{R\} = \{W\} - \{G\} - \{B\}.$$

Similar formulas can be written for a blue filter

$$\{B\} = \{W\} - \{R\} - \{G\}$$

and the green filter

$$\{G\} = \{W\} - \{R\} - \{B\}.$$

When all three components of white radiation are blocked, the color black is produced (Figure 2):

$$\{W\} - \{R\} - \{G\} - \{B\} = \{Blc\}; \tag{2}$$

cyan filter

$$\{W\} - \{R\} = \{G\} + \{B\} = \{C\}; \tag{3}$$

magenta filter

$$\{W\} - \{G\} = \{R\} + \{B\} = \{M\}; \tag{4}$$

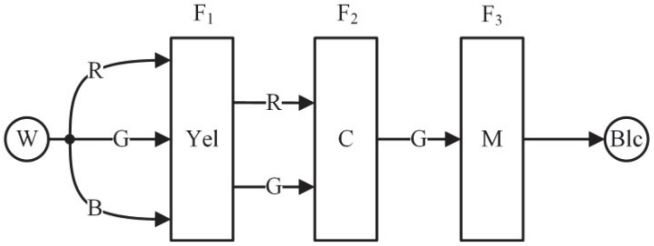

**Figure 2** Subtractive logical coloroid.

yellow filter

$$\{W\} - \{B\} = \{R\} + \{G\} = \{Yel\}. \tag{5}$$

When yellow light radiation passes through a red filter, the green color is blocked and the output is red

$$\{Yel\} - \{G\} = \{R\}. \tag{6}$$

The red color is blocked through the green filter and the output is green.

$$\{Yel\} - \{R\} = \{G\}. \tag{7}$$

Red and green colors are blocked through a blue filter and the output is black (i.e., no light radiation)

$$\{Yel\} - \{R\} - \{G\} = \{Blc\}. \tag{8}$$

The degrees of reliability of estimates and solutions ({Y} and {N}) for quanta of color information are presented in [34, 35].

When converting a quantum of color information into a fuzzy variable, it is useful to determine the weight (cores, heights) of the set based on the quantitative distribution of the weights of the primary colors in a certain sequence.

Thus, with the help of the proposed digital transformation, it is possible to use digital computing devices to process input data in the form of color quantum [33].

## 3 Logic of Color Mathematics

We can show that additive and subtractive optical color transformations have the same properties as Boolean variables using the basic axioms as an example.

- ***Associatively.***

The sum of the $\{R\}$ and $\{B\}$ colors produces magenta for both combinations, just as a red filter blocks blue, and a blue filter blocks red:

$$\{R\} \vee \{B\} = \{B\} \vee \{R\} \quad \{R\} \wedge \{B\} = \{B\} \wedge \{R\}. \tag{9}$$

- ***Commutatively.***

In any combination, the sum of the colors will give white, and subtraction will give black.

$$\begin{aligned} \{R\} \vee (\{B\} \vee \{G\}) &= (\{R\} \vee \{B\}) \vee \{G\} \\ \{R\} \wedge (\{B\} \wedge \{G\}) &= (\{R\} \wedge \{B\}) \wedge \{G\} \end{aligned} \tag{10}$$

- ***Absorption.***

For the first formula, taking a magenta color and passing it through a blue filter produces blue, for the second formula, red light passing through blue is blocked, and no color and blue produces blue color.

$$(\{R\} \vee \{B\}) \wedge \{B\} = \{B\} \quad (\{R\} \wedge \{B\}) \vee \{B\} = \{B\} \tag{11}$$

- ***Distributively.***

In the first case we get a red color for this combination, in the second - the absence of light.

$$\begin{aligned} \{R\} \vee (\{B\} \wedge \{G\}) &= (\{R\} \vee \{B\}) \wedge (\{R\} \vee \{G\}) \\ \{R\} \wedge (\{B\} \vee \{G\}) &= (\{R\} \wedge \{B\}) \vee (\{R\} \wedge \{G\}) \end{aligned} \tag{12}$$

- ***Additionalitively.***

If we define colors as opposite (i.e. $\{B\} = \neg\{R\}$), then the additionality property will be satisfied:

$$(\{R\} \vee \neg\{R\}) \wedge \{B\} = \{B\} \quad (\{R\} \wedge \neg\{R\}) \vee \{B\} = \{B\}. \tag{13}$$

- ***Idempotence.***

Summing the color does not change the color, nor does passing the color through a filter of the same color.

$$\{R\} \vee \{R\} = \{R\} \quad \{R\} \wedge \{R\} = \{R\} \tag{14}$$

The operations of addition (1) and subtraction ((2)–(8)) of color taking into account are identical to the operations of disjunction and conjunction of sets (logical statements, operations).

Naturally, the representation of primary and additional colors goes into the ternary (six-digit) logic of the concept: false/true; probably false/true; very probably false/true. The colors can be represented as follows: R (false); B (true), G (true/false), M (false/true), C (true/true/false), Yel (true/false/false) or in the form of numeric values (Table 1).

An example of the correspondence between Boolean logic and logical coloroid for red {R} (false, 0), blue {B} (true, 1) and green {G} (true/false, 1/0) colors is given in the tables for the logical operations of disjunction (2–4) and conjunction (5–7).

Analysis of the presented tables shows one, at first glance, contradictory to logic, logical operation (Table 7, first line). However, here we can give the following explanation: two identical assessments increased the truth compared to two different assessments, although one of them is closer to the truth.

**Table 1**

| Color | Boolean Logic |
|---|---|
| $\{R\}$ | 0 |
| $\{G\}$ | 1/0 |
| $\{B\}$ | 1 |
| $\{C\}$ | 1/1/0 |
| $\{M\}$ | 0/1 |
| $\{Yel\}$ | 0/0/1 |

**Table 2**

| Color1 | Color2 | Result |
|---|---|---|
| R(0) | R(0) | R $\vee$ R = R(0) |
| R(0) | B(1) | R $\vee$ B = M(0/1) |
| B(1) | R(0) | B $\vee$ R = M(0/1) |
| B(1) | B(1) | B $\vee$ B = B(1) |

**Table 3**

| Color1 | Color2 | Result |
|---|---|---|
| R(0) | R(0) | R $\vee$ R = R(0) |
| R(0) | G(1/0) | R $\vee$ G = Yel(0/0/1) |
| G(1/0) | R(0) | G $\vee$ R = Yel(0/0/1) |
| G(1/0) | G(1/0) | G $\vee$ G = G (1/0) |

**Table 4**

| Color1 | Color2 | Result |
|---|---|---|
| G(1/0) | G(1/0) | $G \vee G = G(1/0)$ |
| G(1/0) | B(1) | $G \vee B = C(1/1/0)$ |
| B(1) | G(1/0) | $B \vee G = C(1/1/0)$ |
| B(1) | B(1) | $B \vee B = B(1)$ |

**Table 5**

| Color1 | Color2 | Result |
|---|---|---|
| R(0) | R(0) | $R \wedge R = R(0)$ |
| R(0) | B(1) | $R \wedge B = 0(0)$ |
| B(1) | R(0) | $B \wedge R = 0(0)$ |
| B(1) | B(1) | $B \wedge B = B(1)$ |

**Table 6**

| Color1 | Color2 | Result |
|---|---|---|
| R(0) | R(0) | $R \wedge R = R(0)$ |
| R(0) | G(1/0) | $R \wedge G = 0(0)$ |
| G(1/0) | R(0) | $G \wedge R = 0(0)$ |
| G(1/0) | G(1/0) | $G \wedge G = G(1/0)$ |

**Table 7**

| Color1 | Color2 | Result |
|---|---|---|
| G(1/0) | G(1/0) | $G \wedge G = G(1/0)$ |
| B(1) | G(1/0) | $B \wedge G = 0(0)$ |
| G(1/0) | B(1) | $G \wedge B = 0(0)$ |
| B(1) | B(1) | $B \wedge B = B(1)$ |

## 4 Matrix Representation of Color

One can consider a more general approach to describing light emitters of different colors as sets, based on a matrix representation [34, 35] with a refinement of the expression for a certain color as a trace of the corresponding matrix.

Let us present the basic axioms ((9)–(14)) of Boolean algebra in matrix form.

- ***Associatively.***

$$diag(R,0,0) + diag(0,0,B) = diag(0,0,B) + diag(0,0,R);$$
$$diag(R,0,0) \times diag(0,0,B) = diag(0,0,B) \times diag(R,0,0).$$

- ***Commutatively.***

$$\begin{aligned}&(diag(R,0,0)+(diag(0,0,B))+diag(0,G,0)\\&\quad=diag(R,0,0)+(diag(0,0,B)+diag(0,G,0));\\&(diag(R,0,0)\times(diag(0,0,B))\times diag(0,G,0)\\&\quad=diag(R,0,0)\times(diag(0,0,B)\times diag(0,G,0))\\&\quad=diag(0,0,0).\end{aligned}$$

- ***Absorption.***

$$\begin{aligned}&(diag(R,0,0)+diag(0,0,B))\times diag(0,0,B)=diag(0,0,B);\\&(diag(R,0,0)\times diag(0,0,B))+diag(0,0,B)=diag(0,0,B).\end{aligned}$$

- ***Distributively.***

$$\begin{aligned}&diag(R,0,0)+(diag(0,0,B)\times diag(0,G,0))\\&\quad=(diag(R,0,0)+diag(0,0,B))\\&\qquad\times(diag(R,0,0)+diag(0,G,0))=diag(R,0,0);\\&diag(R,0,0)\times(diag(0,0,B)+diag(0,G,0))\\&\quad=(diag(R,0,0)\times diag(0,0,B))+(diag(R,0,0)\\&\qquad\times diag(0,G,0))=diag(0,0,0).\end{aligned}$$

- ***Additionalitively.***

$$\begin{aligned}&(diag(R,0,0)+(diag(0,0,B))\times diag(0,0,B)=diag(0,0,B);\\&(diag(R,0,0)\times(diag(0,0,B))+diag(0,0,B)=diag(0,0,B).\end{aligned}$$

- ***Idempotence.***

$$\begin{aligned}&diag(R,0,0)+diag(R,0,0)=diag(R,0,0);\\&diag(R,0,0)\times diag(R,0,0)=diag(R,0,0).\end{aligned}$$

## 5 Logic Platforms for Decision Making With 12 Input Ports

For an extended optical platform, the authors justified [31, 34] the use of a basic logical coloroid with 12 input fuzzy data (Figure 3, where F are filters of the corresponding color, S, W are a white light emitter).

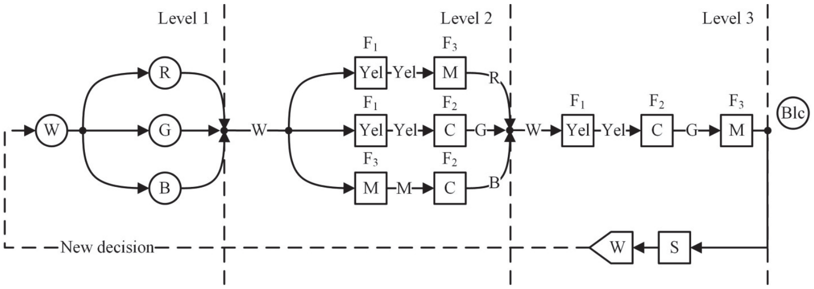

**Figure 3** Basis logical coloroid.

For example, with filter values {*R,G,B*} on the first logical level (disjunction), the decision will be positive and the decision-making process will continue at the second logical level (conjunction) with the values of filter pairs {*Yel*,*M*}, {*Yel*,*C*}, {*M*,*C*}, which for this example will also be a positive decision, but will be blocked at the third level (conjunction) by a triple of filters {*Yel*,C,*M*}, which will give the output the absence of light {*Blc*}, i.e. absence of solution.

Next, a search for a new solution is triggered using a white light emitter {*S,W*}, subject to updating the input data.

Solutions for various options for expert assessments are formed in a similar way. A logical coloroid can be an integral part of a system (network) of serial-parallel, hierarchically organized elements, then the output signal of a certain coloroid will be one of the input signals for the next coloroid, etc.

Examples of implementation of matrix logical operations for some combinations of input information:

for input set {*R*,*G*,*B*}, filters {*Yel*,*M*},{*Yel*,*C*},{*M*,*C*} and {*Yel*,*C*,*M*};
for input set {*R*,*R*,*R*}, filters {*Yel*,*M*},{*Yel*,*C*},{*M*,*C*} and {*Yel*,*C*,*M*};
for input set {*R*,*R*,*R*}, filters {*Yel*,*M*},{*Yel*,*C*},{*M*,*C*} and {*Yel*,*Yel*,*M*};
for input set {*R*,*B*,*B*}, filters {*C*,*C*},{*M*,*M*},{*Yel*,*Yel*} and {*C*,*M*,*C*}.

## 6 Logical Hierarchical Networks Based on 12-Port Platforms

The proposed structure of the optical coloroid (without the output unit of an ordinary decision [34]) (Figure 4) can be used as the basis for a coloroid's logical decision network, one of the variants of which is shown in Figure 3.

It is natural to base the construction of the network structure on the need to output one main solution (the third hierarchical level), which is provided by a 12-input platform with three main lower inputs. These inputs receive decisions or estimates of the second hierarchical level, which then consists of three platforms with a total of 9 lower inputs.

The decision logical network includes three hierarchical levels: at the first level there are 9 basic coloroids $\mathrm{Col}_1^{\mathrm{I}}, \ldots, \mathrm{Col}_9^{\mathrm{I}}$, each of which receives 12 input information quantum $\mathrm{Q}_{\mathrm{m}}^{\mathrm{I}}$ (m is coloroid number) of a certain color (108 quanta in total). At the second $\mathrm{Col}_1^{\mathrm{II}}$, $\mathrm{Col}_2^{\mathrm{II}}$, $\mathrm{Col}_3^{\mathrm{II}}$ and third $\mathrm{Col}^{\mathrm{III}}$ hierarchical levels of the network, the input information for each coloroid includes 9 quantum, $\mathrm{Q}_{\mathrm{m}}^{\mathrm{II}}$ and $\mathrm{Q}_{\mathrm{m}}^{\mathrm{III}}$, accordingly (36 quantum in total).

Examples of implementation of matrix logical operations for some combinations of input information (Tables 12, *a*–*b*):

- I hieratical network, coloroid $\mathrm{Col}_1^{\mathrm{I}}$, for input set $\{R,B,B\}$, filters $\{C,C\}$,$\{M,M\}$,$\{Yel,Yel\}$ and $\{C,M,C\}] \to \{B\}$ (Table 12, *a*);
- II hieratical network, $\mathrm{Col}_{1,2,3}^{\mathrm{II}}$, for input set $\{B,M,G\}$, filters $\{C, M\}$, $\{M,M\}$,$\{Yel, M\}$ and $\{C,M,M\}] \to \{B\}$ (Table 12, *b*);
- III hieratical network, $\mathrm{Col}^{\mathrm{III}}$, for input set $\{B,M,G\}$, filters $\{C,C\}$, $\{M,C\}$,$\{C,M\}$ and $\{C,M,C\}] \to \{B\} \to$ **Final Decision** (Table 12, *c*).

Of course, when constructing logical decision-making networks, it is necessary in further research to solve problems of optimization and increasing

**Table 12***a*

| Matrix form |
|---|
| $diag(R,0,0) + diag(0,0,B) + diag(0,0,B) = diag(R,0,B)$ |
| $diag(R,0,B) \times diag(0,G,B) \times diag(0,G,B) = diag(0,0,B)$ |
| $diag(R,0,B) \times diag(R,0,B) \times diag(R,0,B) = diag(R,0,B)$ |
| $diag(R,0,B) \times diag(R,G,0) \times diag(R,G,0) = diag(R,0,0)$ |
| $diag(0,0,B) + diag(R,0,B) + diag(R,0,0) = diag(R,0,B)$ |
| $diag(R,0,B) \times diag(0,G,B) \times diag(R,0,B) \times diag(0,G,B) = diag(0,0,B) \to \{B\}$ |

**Table 12***b*

| Matrix form |
|---|
| $diag(0,0,B) + diag(R,0,B) + diag(0,G,0) = diag(R,G,B) \to \{W\}$ |
| $diag(R,G,B) \times diag(0,G,B) \times diag(R,0,B) = diag(0,0,B)$ |
| $diag(R,G,B) \times diag(R,0,B) \times diag(R,0,B) = diag(R,0,B)$ |
| $diag(R,G,B) \times diag(R,G,0) \times diag(R,0,B) = diag(R,0,0)$ |
| $diag(0,0,B) + diag(R,0,B) + diag(R,0,0) = diag(R,0,B)$ |
| $diag(R,0,B) \times diag(0,G,B) \times diag(R,0,B) \times diag(R,0,B) = diag(0,0,B) \to \{B\}$ |

**Table 12**$c$

| Matrix form |
|---|
| $diag(0,0,B) + diag(R,0,B) + diag(0,G,0) = diag(R,G,B) \rightarrow \{W\}$ |
| $diag(R,G,B) \times diag(0,G,B) \times diag(0,G,B) = diag(0,0,B)$ |
| $diag(R,G,B) \times diag(R,0,B) \times diag(0,G,B) = diag(0,0,B)$ |
| $diag(R,G,B) \times diag(0,G,B) \times diag(R,0,B) = diag(0,0,B)$ |
| $diag(0,0,B) + diag(0,0,B) + diag(0,0,B) = diag(0,0,B)$ |
| $diag(0,0,B) \times diag(0,G,B) \times diag(R,0,B) \times diag(0,G,B) = diag(0,0,B) \rightarrow \{B\}$ |
| **Final Decision** |

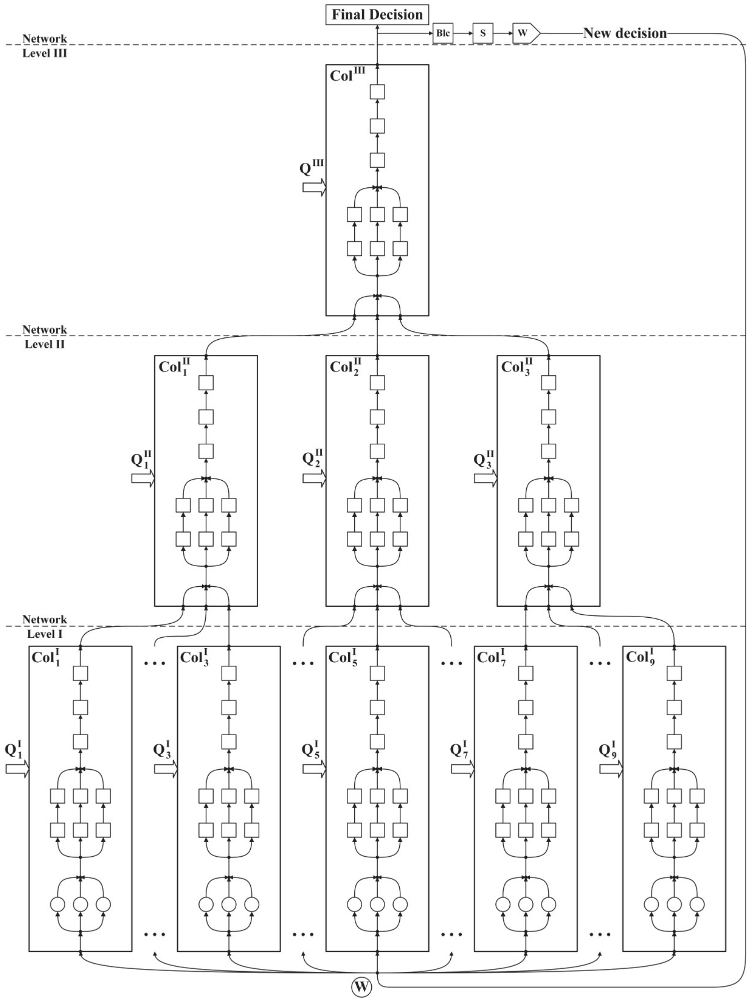

**Figure 4** Coloroid's network.

the reliability of decisions, taking into account the rules of “new decision”, “blocking decision”, “idempotency” and other logical rules for more specific decision-making problems.

## 7 Conclusion

The presented work suggests directions for the development of optical color computing to solve problems in systems with a large amount of input fuzzy information. Based on the matrix representation of optical computing, the possibility of implementing architectural solutions for optical devices in mobile digital applications is proposed.

The architecture of the logical decision network for a system with a large amount of fuzzy input information in the form of a multicoloroid parallel-serial structure is discussed in detail. Network architecture consists of 3 hierarchical levels (I, II and III) with 9, 3 and 1 coloroids platform, correspondently. During the functioning process, the network will operate with 144 information quantum. Preliminary authors’ investigations confirm the efficiency of the proposed network architecture.

With the further development of nano-architectural implementations of optical computing, it becomes possible to use a number of their advantages in mobile applications, this is, first of all, the almost unlimited possibility of implementing parallel processes and high speed of information processing, resistance to electromagnetic interference during information processing and transmission.

Formalization of fuzzy databases in the form of combinations of certain colors, application for the synthesis of computational logical procedures based on additive and subtractive transformation of light radiation without the need to use switching elements for logical operations of disjunction and conjunction will improve computational performance by more than two orders of magnitude.

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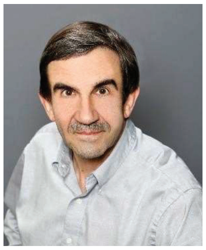

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