FAST COMPUTING ARE NEEDED EVERYWHERE

FUZZY COLOR COMPUTING BASED ON OPTICAL LOGIC ARCHITECTURE

Victor Timchenko[1], Vladik Kreinovich[2],
Yuri Kondratenko[3,4],

[1] professor, Admiral Makarov National University of Shipbuilding, Ukraine
[2] professor, University of Texas at El Paso, USA
[3] professor, Petro Mohyla Black Sea National University, Ukraine
[4] Institute of Artificial Intelligence Problems of MES and NAS of Ukraine

2024

Our research group

- Horbov V. – postgraduent student NUK, Ukraine;
- Lebedev D. – postgraduent student NUK, Ukraine;
- Kosheleva O. – professor, University of Texas at El Paso (UTEP), USA;
- Alexis A. - postgraduent student, UTEP, USA;
- Phuong N. - professor, University of Hanoi, Vietnam;
- Kozlov O. – professor. Black Sea National University, Ukraine

Active discussion of the proposed approach at International IT conferences 2022-2024

- IT&I_2022 Ukraine;
- IntelITSIS’2023, Ukraine;
- ICCSEEA, 2023, Poland; ICCSEEA, 2024 - Ukraine;
- INFUS 2023, 2024 Istanbul, Türkiye;
- IDAACS’23, Germany;
- INFLAT’23, Spain;
- 20th World Congress of the International Fuzzy Systems Association’2023, Seoul, The Republic of Korea;
- AICI 2023, 2024, Hanoi, Vietnam;
- ACST 2024, Ukraine.

Published articles 2022-2024/ Basic Concepts of Color Mathematics

- V. L. Timchenko, Y. P. Kondratenko, and V. Kreinovich***, Efficient optical approach to fuzzy data processing based on colors and light filter***, International Journal of Problems of Control and Informatics, 2022, Vol. 67, No. 4, pp. 89–105
- V. L. Timchenko, Y. P. Kondratenko, and V. Kreinovich, ***Why color optical computing?,*** Book Chapter: Studies in Computational Intelligence, *Springer*, 1097, 227–233, 2023. SCOPUS.
- V. L. Timchenko, Y. P. Kondratenko, and V. Kreinovich, ***Interval-valued and set-valued extensions of discrete fuzzy logics, Belnap logic, and color optical computing***, Book Chapter: Lecture Notes in Computer Science, *Springer*, Spain, 297-303, 2023. SCOPUS.
- V. Timchenko, Y. Kondratenko, O. Kosheleva, V. Kreinovich, N. H. Phuong, ***Towards a Psychologically Natural Relation Between Colors and Fuzzy Degrees,*** Book Chapter: Studies in Computational Intelligence, Springer, 2024, *in printed*, *Scopus*
- V. L. Timchenko, V. Kreinovich, Y. P. Kondratenko, ***Color Optical Computing: Visualization, Numbers, Alphabet,*** Proccesing of ASCI 2024
- V. Timchenko, Y. Kondratenko, O. Kosheleva, V. Kreinovich, ***Why Magenta Is Not a Real Color, and How It Is Related toFuzzy Control and Quantum Computing*** *,in printed*,
- V. Timchenko, Y. Kondratenko, V. Kreinovich, O. Kosheleva, ***Natural Color Interpretation of Interval-Valued Fuzzy Degrees,*** Proceedings of the 20th World Congress of the International Fuzzy Systems Association IFSA'2023,, *Daegu, South Korea, August 20-24, 2023*

Published articles 2022-2024/ *Optical Logical Architecture*

- V. L. Timchenko, Y. P. Kondratenko, and V. Kreinovich, ***The Architecture of Optical Logical Coloroid with Fuzzy Computing***, CEUR Workshop Proceedings, 2023, 3373, 638-648. SCOPUS.
- V. L. Timchenko, Y. P. Kondratenko, O. Kozlov and V. Kreinovich, ***Fuzzy Color Computing Based on Optical Logical Architecture***, Book Chapter: Lecture Notes in Networks and Systems, ***Springer***, (2023) 758 LNNS, pp. 491–498.. SCOPUS.
- V. L. Timchenko, Y. P. Kondratenko, V. Kreinovich, ***Logical Decision Networks Based on the Optical Logical Architecture***, IDAACS'23, Dortmund, 2, 1194-1199, SCOPUS.
- V. Timchenko, V. Kreinovich, Y. Kondratenko, V. Horbov, ***Hybrid Fuzzy-Color Computing Based on Optical Logical Architecture,*** Book Chapter: Lecture Notes in Networks and Systems, ***Springer***, (2024) *in printed* ***Scopus***
- V. Timchenko, V. Kreinovich, Y. Kondratenko, ***Decision Framework for Optical Color Computing Architecture,*** Book Chapter: Lecture Notes on Data Engineering and Communications Technologies Series, ***Springer***, *in printed* (2024). ***Scopus***

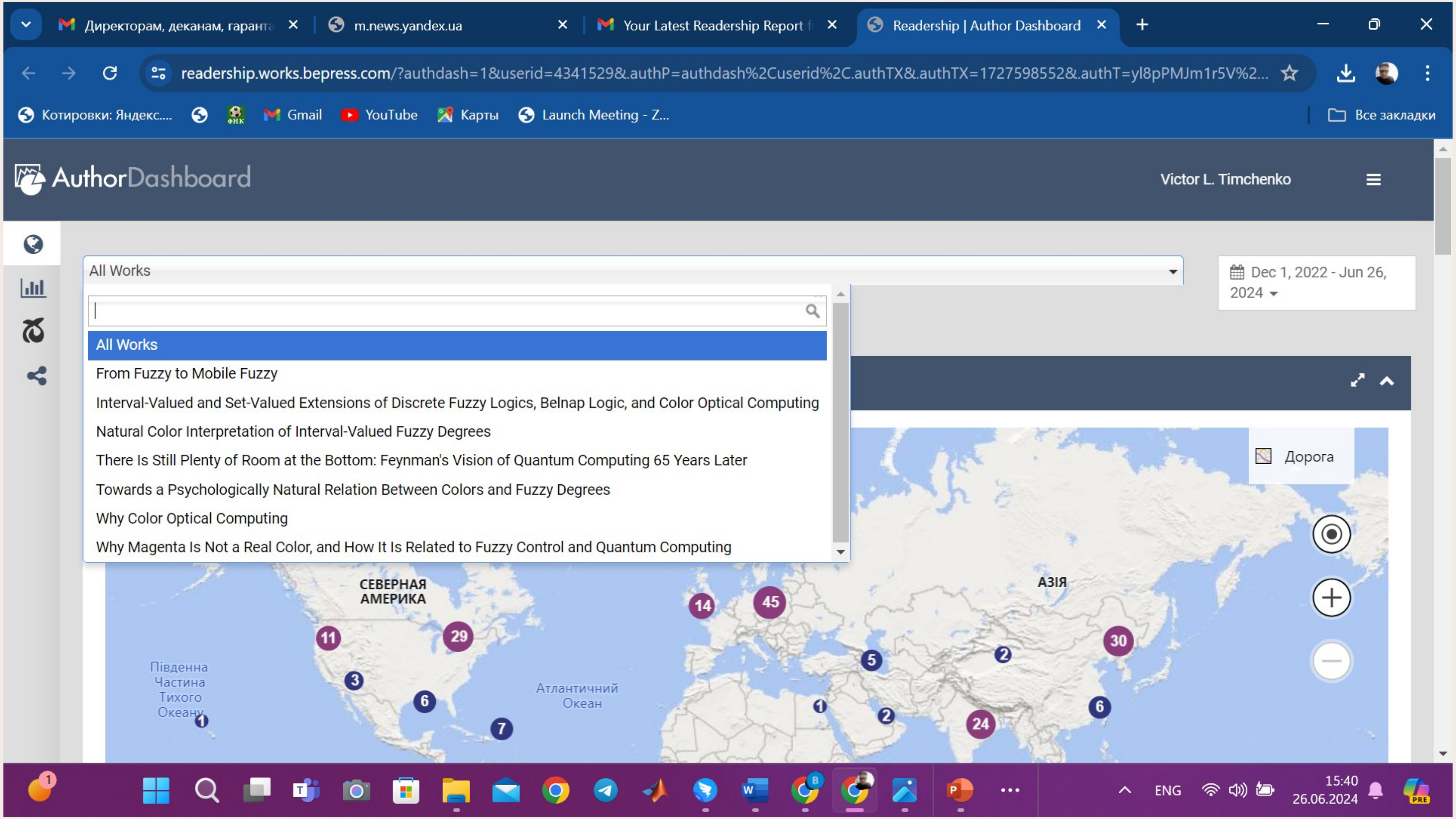
Published articles 2022-2024 | *Implementation*

- V. L. Timchenko, Y. P. Kondratenko, and V. Kreinovich, ***Decision support system for the safety of ship navigation based on optical color logic gates***, CEUR Workshop Proceedings, 2022, 3347, pp. 42-52. SCOPUS.
- V. L. Timchenko, Y. P. Kondratenko, and V. Kreinovich, ***Implementation of optical logic gates based on color filters***, Book Chapter: Lecture Notes on Data Engineering and Communications Technologies Series, ***Springer***, 181, 126-136, 2023. SCOPUS.
- V. Timchenko, V. Kreinovich, Y. Kondratenko, V. Horbov, ***Effectiveness Evaluations Of Optical Color Fuzzy Computing,*** Book Chapter: Research Tendencies and Prospect Domains for AI Development and Implementation, River Publishers, Gistrup, Denmark, 2024, *in printed*, ***Scopus***
- V. L. Timchenko, V. Kreinovich, Y. P. Kondratenko, ***Logical Platforms for Mobile Application in Decision Support Systems Based on Color Information Processing***, Journal of Mobile Multimedia, 2024: Vol. 20 Iss. 3, pp. 679-698, Scopus

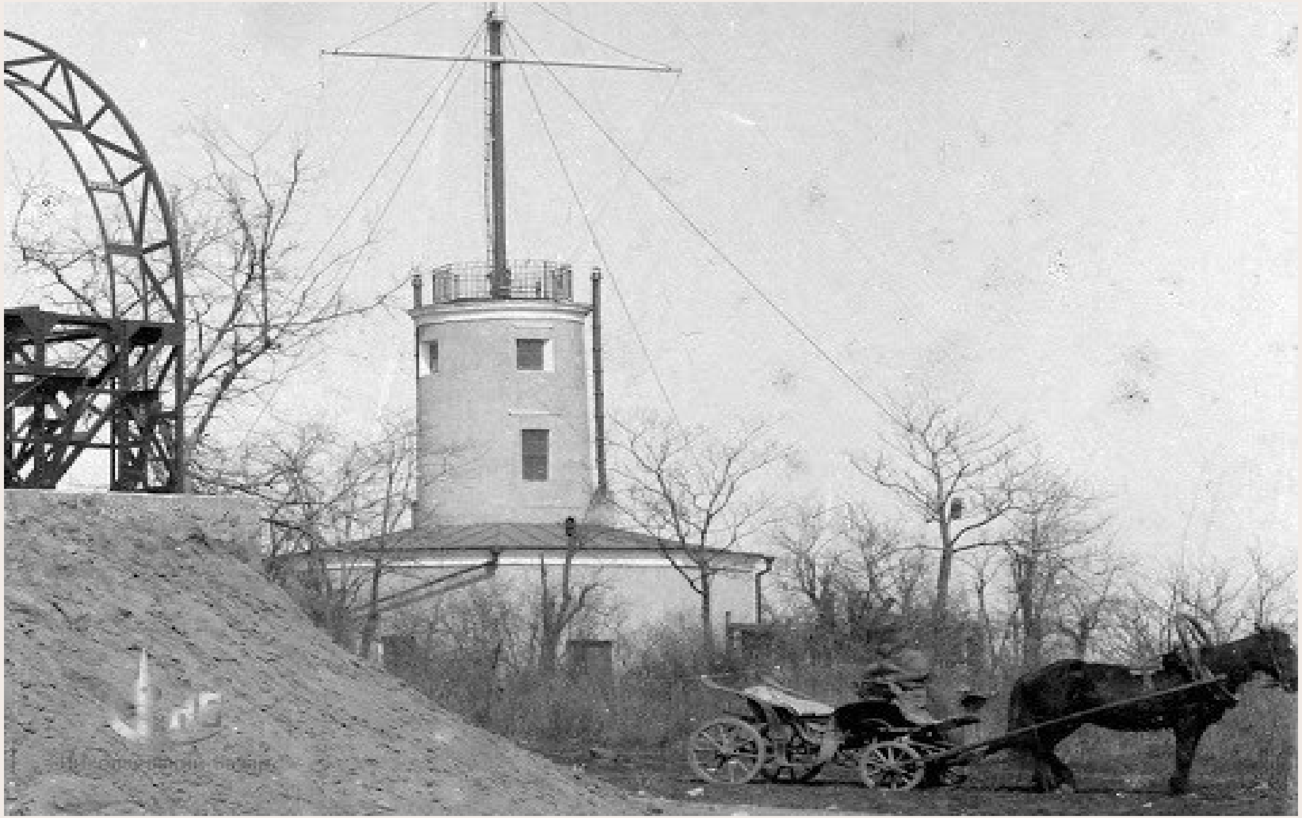
Published articles 2022-2024 / Applications

- A. Alexis, V. Kreinovich, V. Timchenko, Y. Kondratenko, ***There is Still Plenty at the Bottom: Feynman's Vision of Quantum Computing 65 Years Later,*** Book Chapter: Research Tendencies and Prospect Domains for AI Development and Implementation, River Publishers, Gistrup, Denmark, 2024, *in printed*, ***Scopus,***
- O. Kosheleva, V. Kreinovich, V. Timchenko, Y. Kondratenko, ***From Fuzzy to Mobile Fuzzy***, Journal of Mobile Multimedia, 2024: Vol. 20 Iss. 3, pp. 651-664, Scopus

Your Latest Readership Report from ScholarWorks@UTEP



Introduction



An interesting fact is that the optical telegraph, as a means of transmitting information, arose much earlier than wired telegraphy. For example, the optical telegraph Ochakiv - Mykolaiv (Ukraine) was built in 1826 (the buildings are now preserved)

The development of optoelectronic technologies over the past 30-40 years has generated interest in the development of computing devices capable of performing binary operations and providing an alternative to all-electric semiconductor devices.

Two main directions of optical computing:

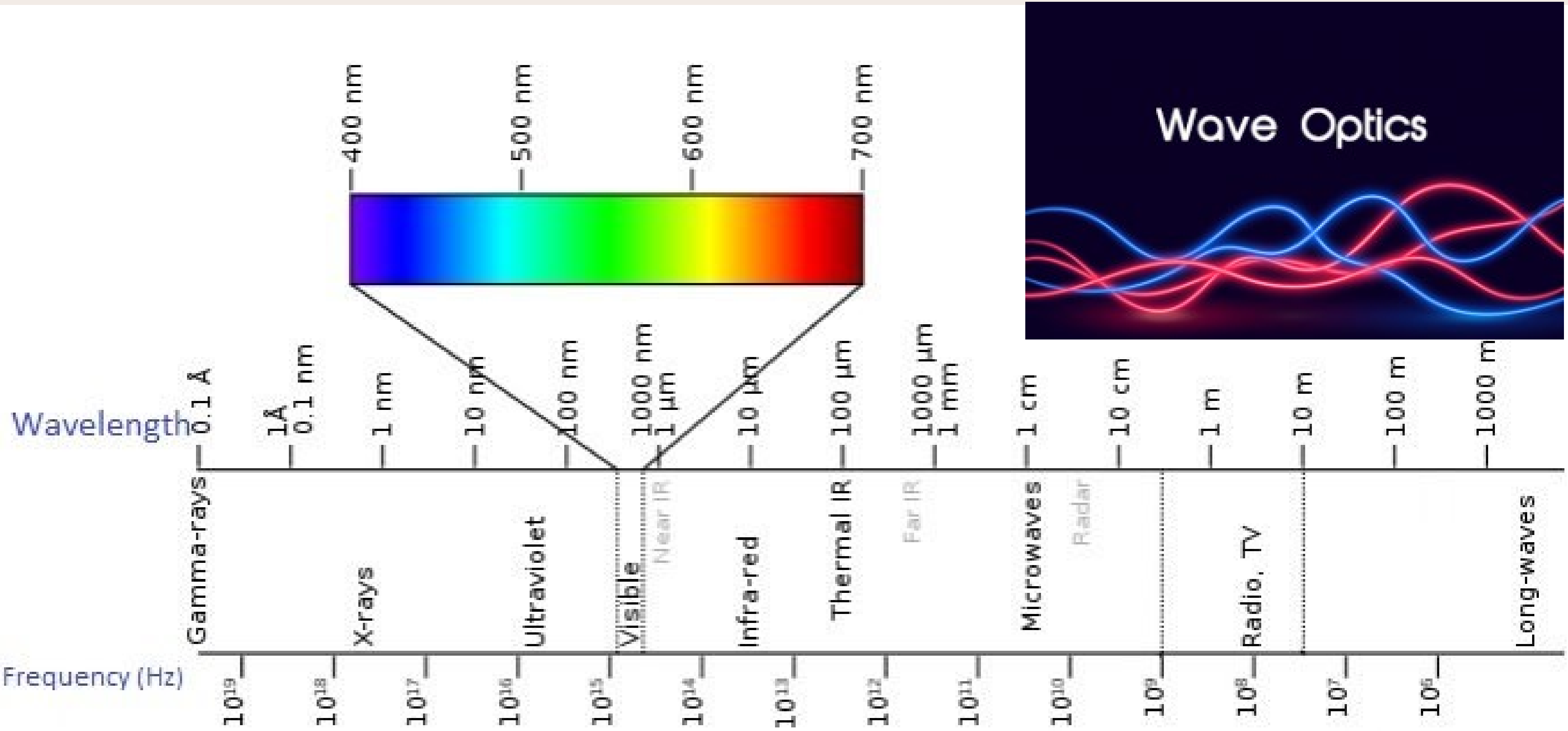
- optical-electronic devices, which to combine the advantages of optical and semiconductor components, using semiconductor switches for binary coding and calculations;
- the construction of all-optical devices on the properties of interference, polarization, diffraction and coherence of a light beam.

The researchers demonstrated experimental results that showed an increase in the performance of all-optical devices from 250 Mbit/s (2010) to 1 Tbit/s today.

Obviously, the wider use of such devices is hampered by currently imperfect production technologies.

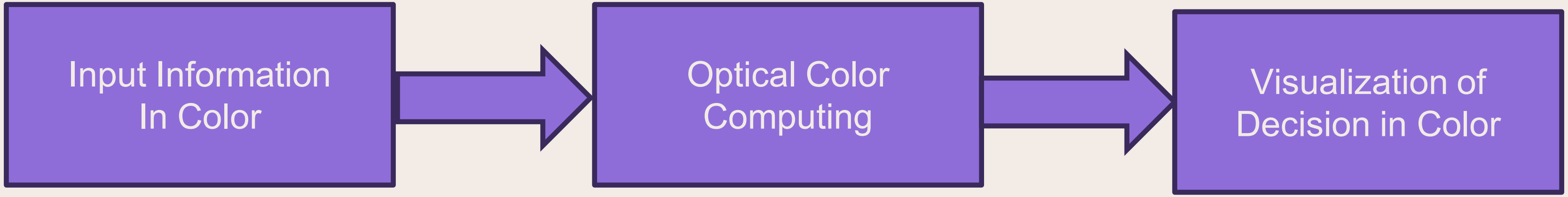
- Work in this direction shows the energy efficiency **(1)** of optical architecture, the structural possibility of parallel computing **(2)**, high speed of information processing **(3)**, and the robustness of computer networks to disturbances **(4)**, etc.

- An analysis of research in the field of technological implementation of optical computing architecture shows the significant complexity of **(1)** designing existing optical components based on physical processes such as diffraction and interference. The need for some devices to measure **(2)** light waves to determine their parameters and use complex lasers and moving structural elements **(3)**, as well as several other implementation difficulties.



ELECTROMAGNETIC SPECTRUM

1. Why is information visualization based on visible color light radiation?



Block diagram of inference of decision for optical color computing

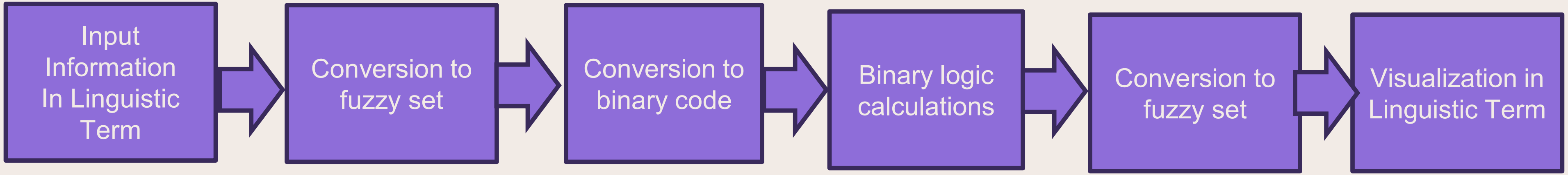
The decision support system includes the formation of an input database in the form of fuzzy (qualitative) information. An artificial intelligence system (similar to the human mind) naturally involves input in the same way as human senses. First of all, this is vision, which perceives color, but also evaluates, for example, the danger of a situation. It is also convenient to represent input information in the form of fuzzy sets with 7 ± 2 degrees of information gradation.

For example, if we simulate the thoughts of a pedestrian when crossing the road. First, he estimates the distance to the approaching car: “*very far*” , “*far*” , “*far enough*”, “*close enough*”, “*close*” , “*very close*”. Second, he estimates the speed of the car: “*very slow*”, “*slow*”, “*slow enough*”, “*fast enough*”, “*fast*”, and “*very fast*”. And finally, being an experienced pedestrian, he evaluates his own mistakes during previous crossings, and decides to speed up the transition further: “very quickly”, “*quickly*”, and “*quickly enough*”. Using the same principle, N. Minorsky approximately 100 years ago assessed the actions of the “experienced sailor-helmsman” and created a PID controller for steering the ship.

Similarly, one can evaluate a man’s sensory information by assessing the temperature of the environment and objects: “*very cold*”, “*cold*”, “*cold enough*”, “*hot enough*”, “*hot*”, and “*very hot*”; perception of pain: “*very painful*”, “*painful*”, “*painful enough*”, “*not painful enough*”, “*not painful*”, “*normal*”. You can also evaluate the volume of sounds, and to a lesser extent by gradation: environmental humidity “very humid”, “humid”, “dry”, “very dry”; vibration and a number of other similar sensations.

It is very important that expert assessments can be assessed in a similar way.

If we use classical linguistic terms (L. Zadeh), they need to be converted into a numerical fuzzy set, and then into binary codes. Further logical operations are performed by the software in binary code, the resulting decision must be converted back into a fuzzy set and then into a linguistic term for the decision maker.
Next (slide 30), we will show how much binary computation this requires compared to optical color computation on easily implemented optical devices.

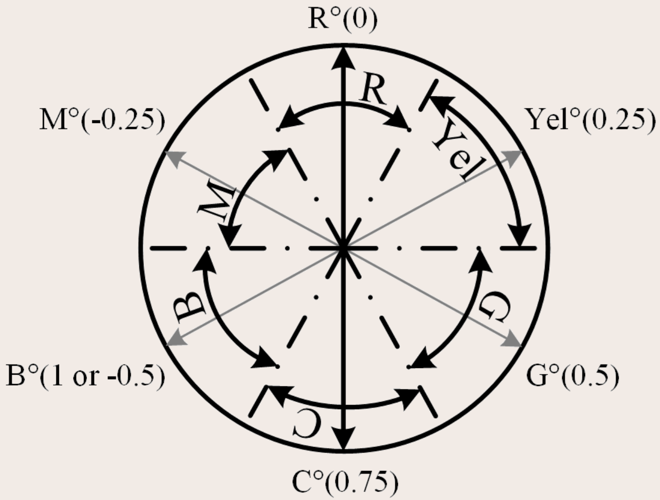


Block diagram of inference of decision for classical fuzzy computing

Naturally, color is a quantum of fuzzy information. Sequences of truth operand ***Y*** and false operand ***N*** let us represents logical decisions by converted color into color quanta:

ASSESSMENTS OF COLOR

Color	Combination	
	Assessments	Degrees of verity
R	{N}	"no"
G	{YN}	"probably yes"
B	{Y}	"yes"
Yel	{R} + {G}={R,G}= {NNY}	"very probably no"
C	{G} + {B}={G,B}= {YYN}	"very probably yes"
M	{R} + {B} ={R,B}= {NY}	"probably no"
W	{R}+ {G}+ {B}== {YYNN}	"positive decision"
Blc	{W} – {R} – {G} – {B} = {0}	"no decision"



Main Ideas of the Proposed Approach

- Optical transformations of color summation RGB and subtraction CMYel are logical operations of disjunction and conjunction. (Technologically, these optical conversions are widely used and developed in TV)

- Summing up a certain color combination R+G+B=W is the decision;

- A new decision is a light beam generated by a white light source.

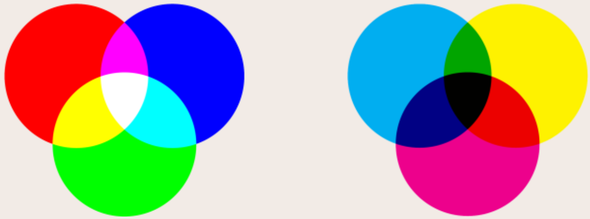
- Color is a quantum of fuzzy information;

- Input information is naturally converted into color quanta and introduced using color filters.

2. Basic Concepts of Color Mathematics

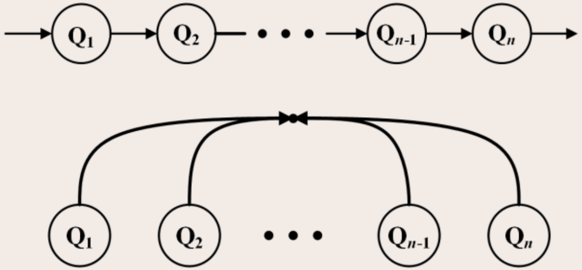
Colorimetric Transformations

Exploration of additive RGB and subtractive YelCM systems for logical color operations.



Logical Operations

Application of basic logical operations, such as disjunction and conjunction, in the context of color mathematics.



Matrix Representations

Representation of color transformations and logical operations using matrices.

$$diag(R,G,B) = \begin{bmatrix} R & 0 & 0 \\ 0 & G & 0 \\ 0 & 0 & B \end{bmatrix}$$

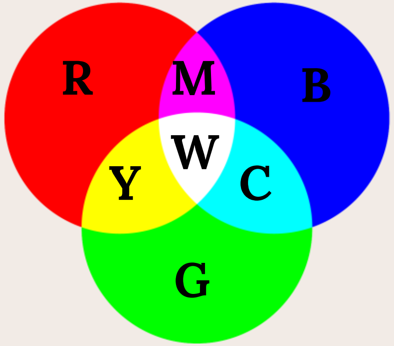
Basic Concepts of Color Mathematics

Colorimetric Transformations

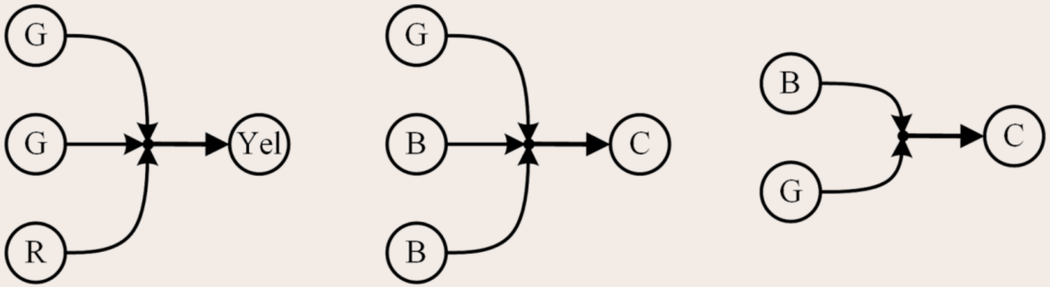
These are the well-known additive RGB system - *the logical operation **OR** (disjunction), which allows for color summation operations.*

$$\{R\} + \{G\} = \{Yel\}, \qquad \{R\} + \{B\} = \{M\}$$

$$\{G\} + \{B\} = \{C\}, \qquad \{R\} + \{G\} + \{B\} = \{W\}$$



ADDITIVE



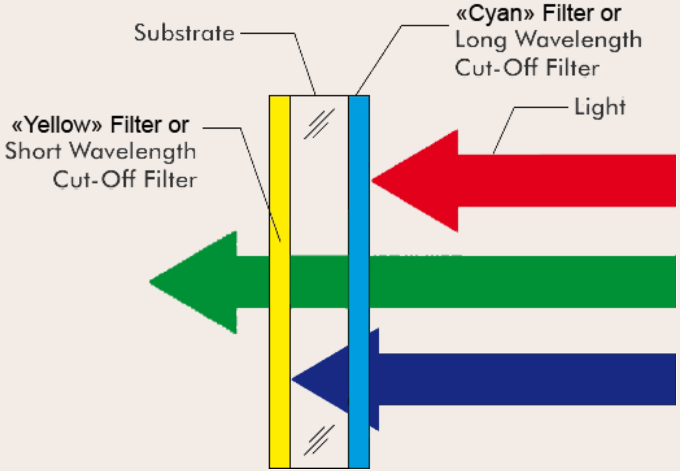
Basic Concepts of Color Mathematics

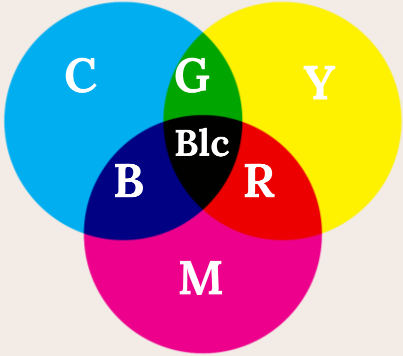
Colorimetric Transformations

The subtractive YelCM system uses color filters - the logical operation **AND** (conjunction), *which allows for color subtraction operations.*

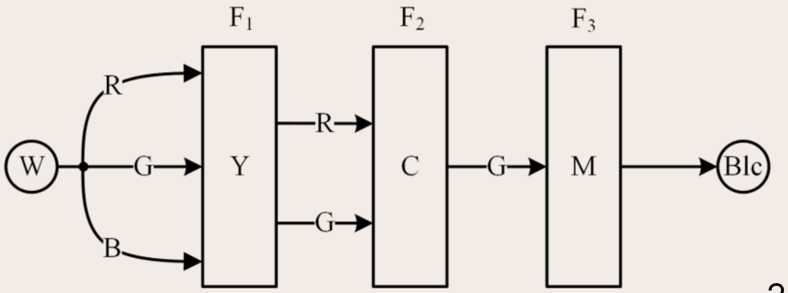
$$\{B\} = \{W\} - \{R\} - \{G\}, \qquad \{R\} = \{W\} - \{G\} - \{B\},$$

$$\{G\} = \{W\} - \{R\} - \{B\}, \qquad \{W\} - \{R\} - \{G\} - \{B\} = \{Blc\}$$





SUBTRACTIVE



Basic Concepts of Color Mathematics

Logical Operations

For additive operations:

$\{Yel\}=\{R\}+\{G\}=\{R,G\}=\{N\}+\{YN\}=\{NNY\}$,
$\{M\}=\{R\}+\{B\}=\{R,B\}=\{N\}+\{Y\}=\{NY\}$,
$\{C\}=\{G\}+\{B\}=\{G,B\}=\{YN\}+\{Y\}=\{YYN\}$,
$\{W\}=\{R\}+\{G\}+\{B\}=\{N\}+\{YN\}+\{Y\}=\{YYNN\}$

Subtractive transformation:

$\{YYNN\}-\{YN\}-\{Y\}=\{N\}$, $\{YYNN\}-\{YN\}-\{N\}=\{Y\}$,
$\{YYNN\}-\{Y\}-\{N\}=\{YN\}$,
$\{YYNN\}-\{Y\}-\{N\}-\{YN\}=\{0\}$

Using basic logical operations

Disjunction:

$\{R\}\cup\{G\}=\{Yel\}$, $\{R\}\cup\{B\}=\{M\}$,
$\{G\}\cup\{B\}=\{C\}$, $\{R\}\cup\{G\}\cup\{B\}=\{W\}$;

Conjunction:

$\{W\}\cap\{R\}=\{R\}$, $\{W\}\cap\{B\}=\{B\}$,
$\{W\}\cap\{G\}=\{G\}$, $\{W\}\cap\{Yel\}\cap\{C\}\cap\{M\}=\{Blc\}$

Basic Concepts of Color Mathematics

Matrix Representations

Representation of color transformations and logical operations using matrices enabling visual understanding and computational implementation

$$diag(R,G,B) = \begin{bmatrix} R & 0 & 0 \\ 0 & G & 0 \\ 0 & 0 & B \end{bmatrix}$$

disjunction:

$diag(R,0,0)+diag(0,G,0)=diag(R,G, 0);$

$diag(R,0,0)+diag(0,G,0)+diag(0,G,B)=diag(R,G, B).$

conjunction:

$diag(R,G,B)\times diag(R,0,0)=diag(R,0,0),$

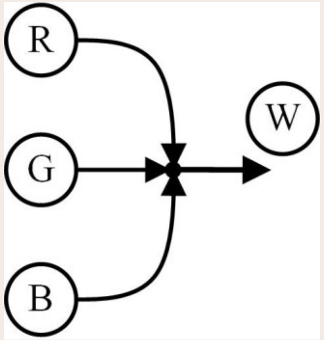
$diag(R,G,B)\times diag(R,G,0)\times diag(0,G,B)\times diag(R,0,B)=diag(0,0,0)$

***indepotence property*:**

$diag(R,G,0)+diag(R,G,0)=diag(R,G,0)$

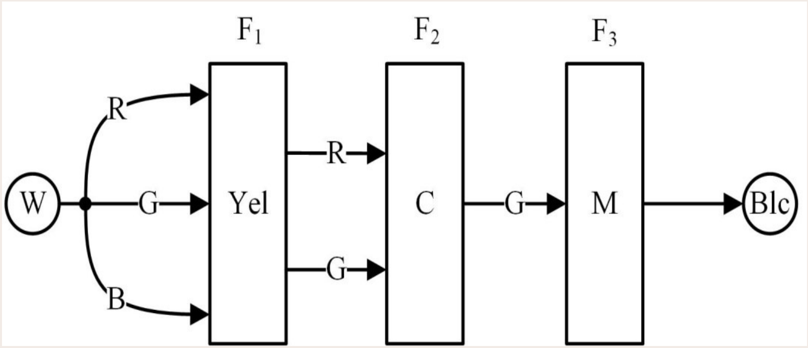
$diag(0,0,B)+diag(0,0,B)+diag(0,0,B)+diag(0,0,B)=diag(0,0,B)$

3. Optical Structural Components For Inference Operations



Additive form (disjunction OR)

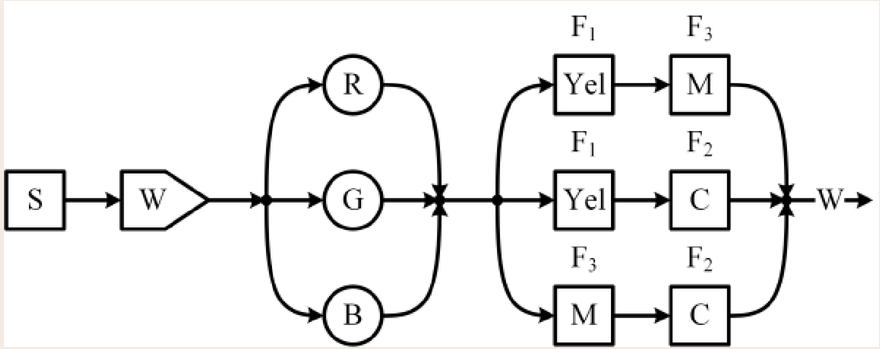
$diag(R,0,0) + diag(0,0,B)$
$+diag(0,G,0) = diag(R,G,B)$



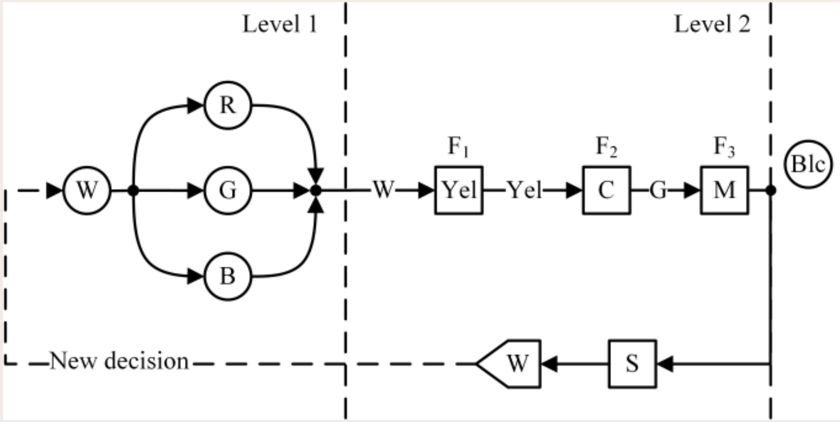
Subtractive form (conjunction AND)

$diag(R,G,B) \times diag(R,G,0) \times diag(0,G,B)$
$\times diag(R,0,B) = diag(0,0,0)$

9 input



OR – AND + New decision



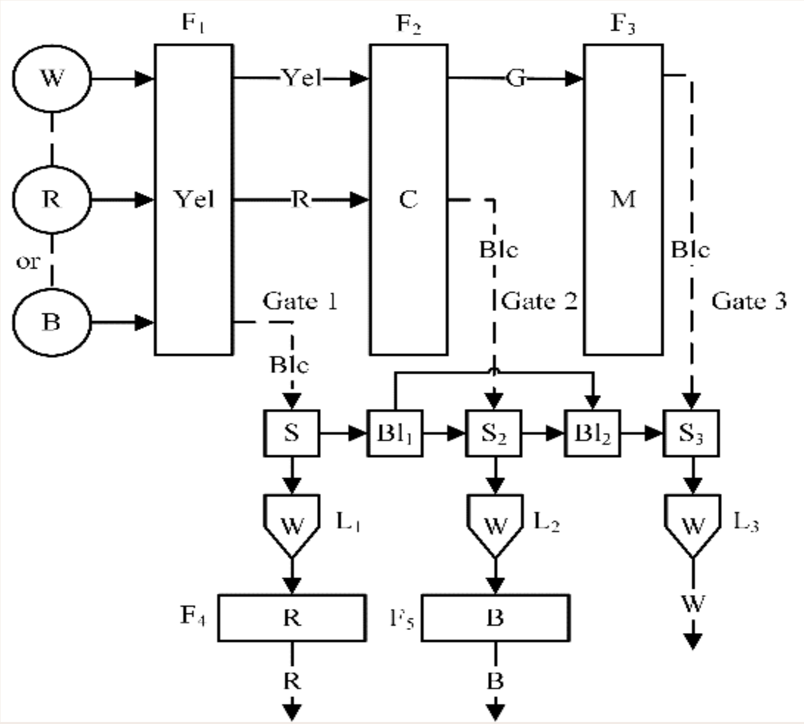
Logical Operation *NOT* (*negation*)

$$\{W\} = \neg\{Blc\}$$

$$\{Blc\} = \neg\{W\}$$

$$\{R\} = \neg\{B\}$$

$$\neg\{R\} = \{B\}$$



I hieratical network

coloroid Col_1^I, for input set $\{R\} \vee \{G\} \vee \{B\} = \{W\}$;

filters $\{Yel,C\}$→ W∧B∧R=G,
filters {M, C}→W∧G∧R=B,
filters {M,Yel}→ W∧G∧B=R,
disjunction→{R}∨{G}∨{B}={W};
filters {Yel,M,C}:→W∧B∧G∧R={Blc};

coloroid Col_2^I, for input set $\{R,B,B\}$:$\{R\} \vee \{B\} \vee \{B\} = \{M\}$

filters {Yel,C}→ M∧B∧R=Blc,
filters {M,C}→M∧G∧R=B,
filters {Yel,M}→ M∧B∧G=R,
disjunction {Blc}∨{B}∨{R}={M};
filters {Yel,M,Yel}→M∧B∧G∧B={R};

coloroid Col_3^I, for input set

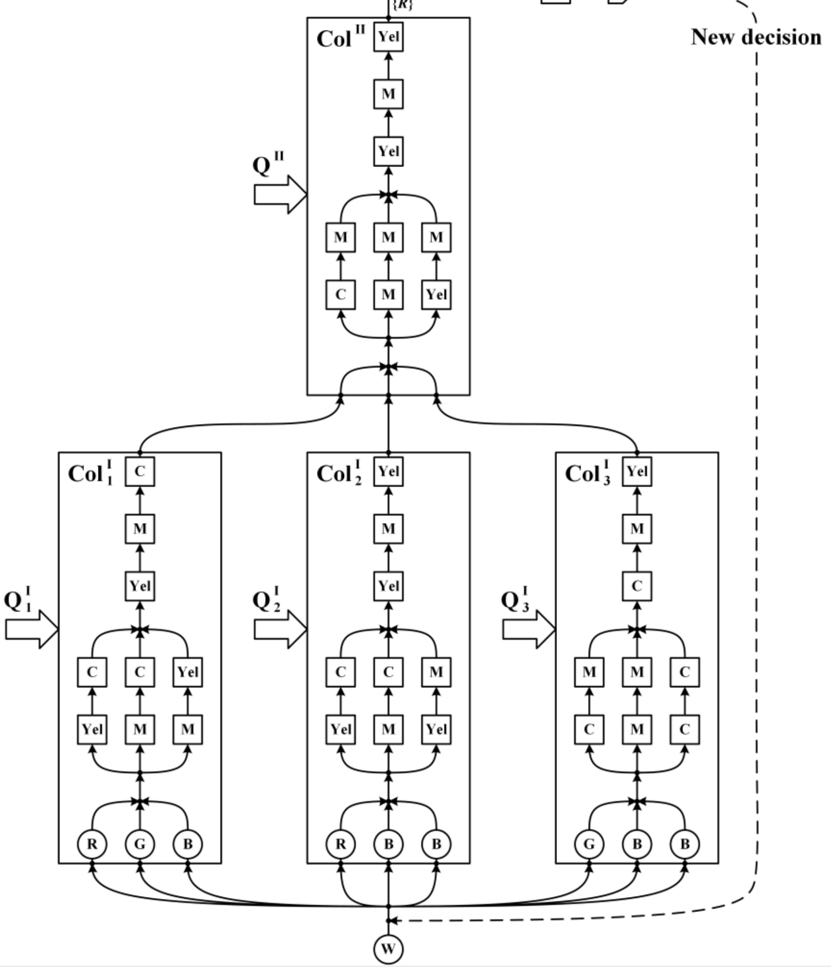
filters {C,M}→C∧R∧G=B,
filters {M,M}→C∧G∧G=B,
filters {C,C}→C∧R∧R=B,
disjunction→{B}∨{B}∨{B}={B};
filters {C,M,Yel}→B∧R∧G∧B={Blc};

II hieratical network,

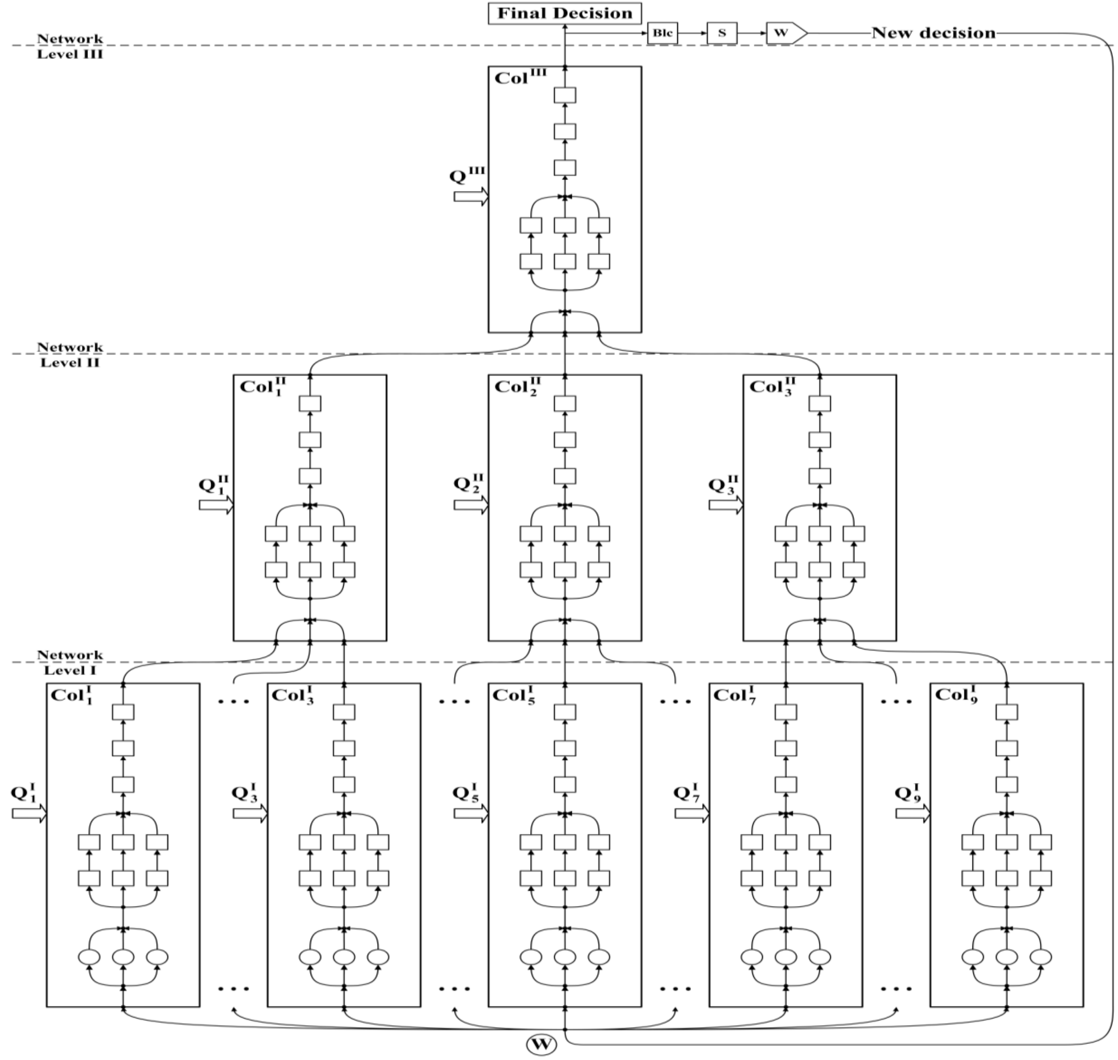
Col^{II} for input set $\{Blc,R,Blc\}$:→ $\{Blc\} \vee \{R\} \vee \{Blc\} = \{R\}$;

filters →{C,M}R∧R∧G=Blc,
filters →{M,M}R∧G∧G=R,
filters →{Yel,M}R∧B∧G=R,
disjunction→{Blc}∨{R}∨{R}={R};
filters {Yel,M,Yel} →R∧B∧G∧B={R}, **Final Decision.**

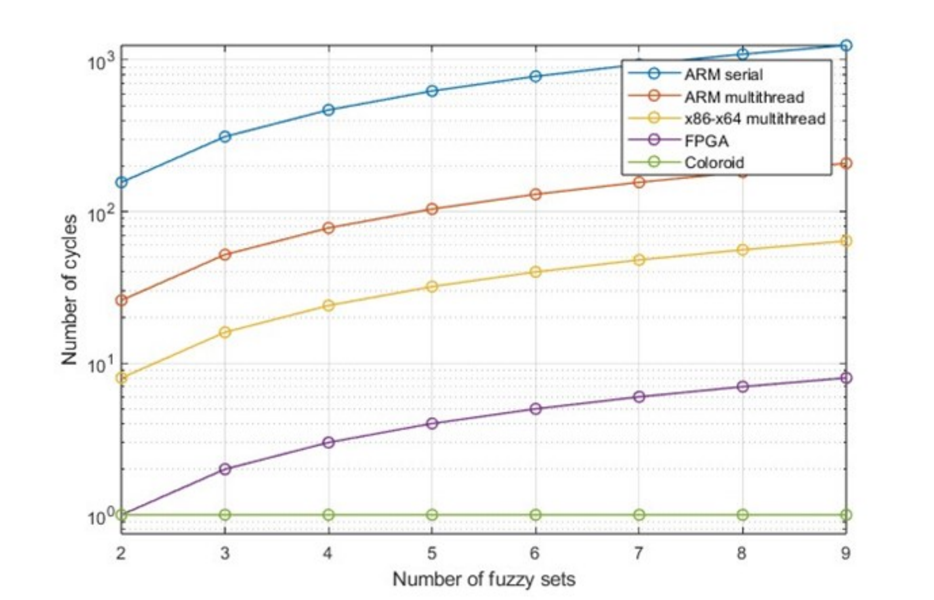
45 input quanta

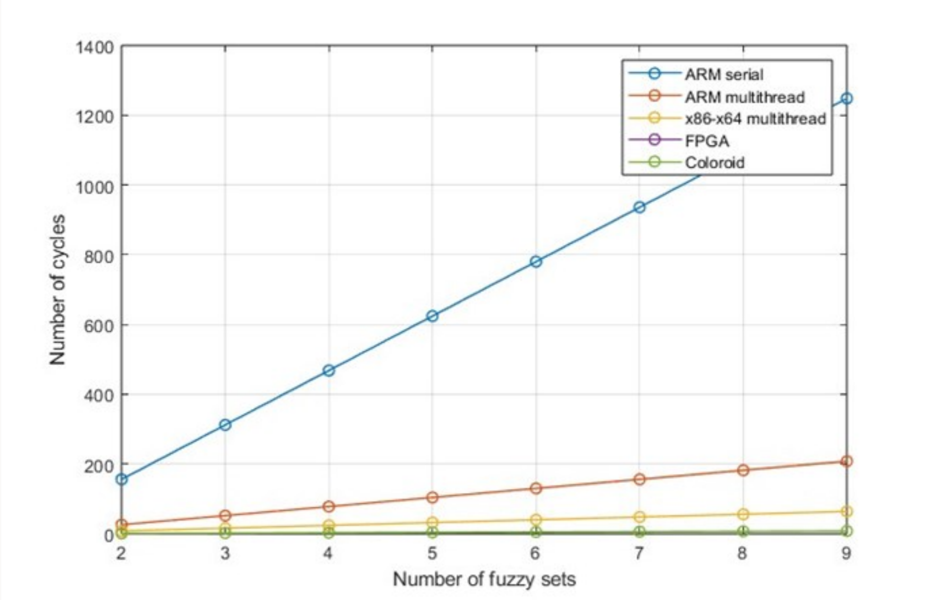


144 input quanta

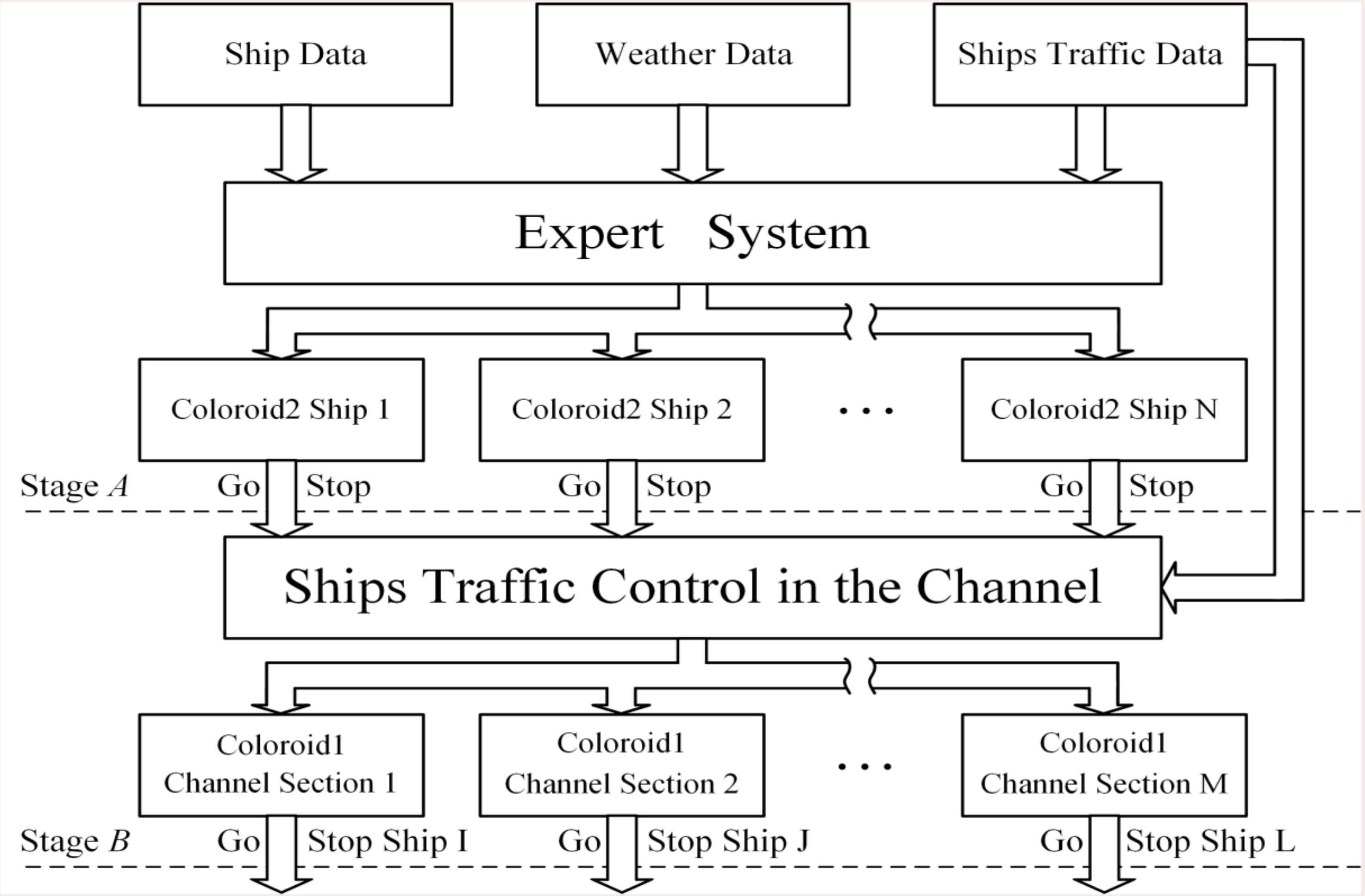


Effectiveness evaluations of optical color fuzzy computing





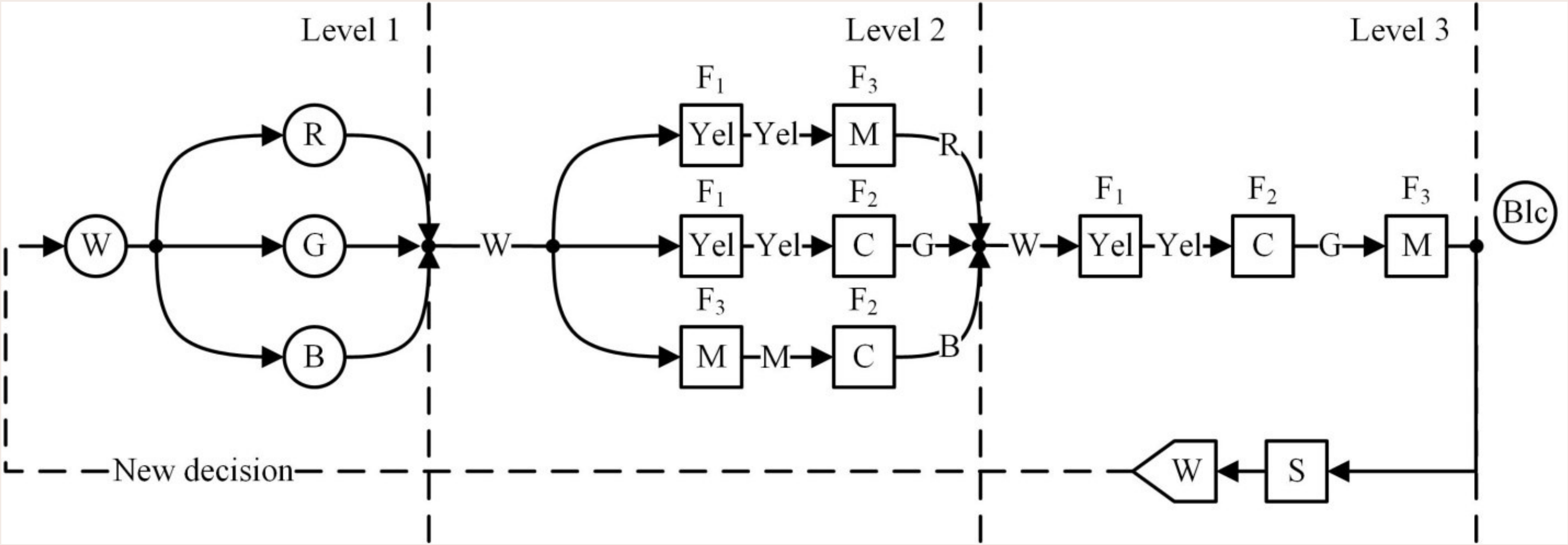
Example. DECISION SUPPORT SYSTEM FOR THE SAFETY OF SHIP NAVIGATION

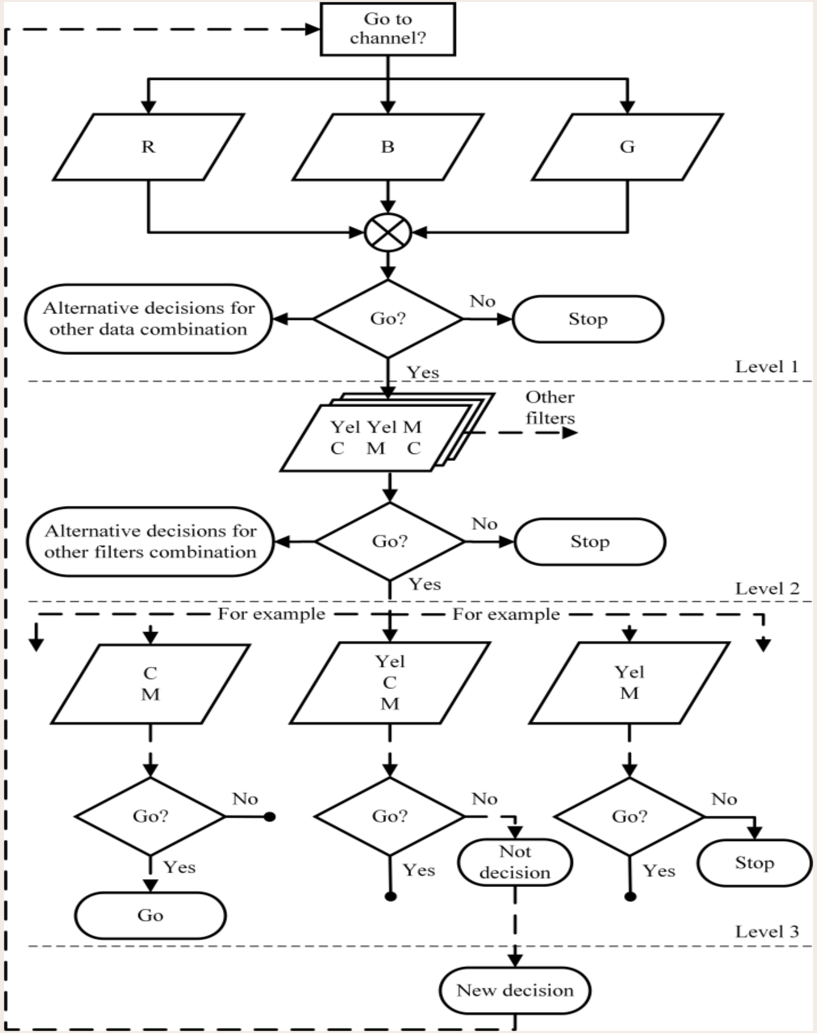


Traffic safety assessment factors for each vessels with danger levels

Main Factor	Level of danger	Additional Factor	Level of danger
1. Wind speed		7. Age of the vessel, years	
No wind (0-1 *m* /c)	**B**	0-3	**B**
Light wind (1-6 *m* /c)	**C**	3-10	**C**
moderate wind (4-11 *m* /c)	**G**	10-15	**G**
Strong wind (11-17 *m* /c)	**M**	15-20	**M**
Storm (>17 *m* /c)	**R**	>20	**Yel**
2. Time of day		8. Classification of the vessel by destination	
Daylight	**B**	Passenger	**G**
Dark time of day	**Yel**	Bulk	**C**
3. Visibility, м		Tanker	**G**
<100	**R**	General	**C**
100-500	**Yel**	Helpful	**B**
500-1000	**M**	9. Ship condition	
1000-2000	**G**	Excellent	**B**
2000-3700	**C**	Good	**C**
>3700	**B**	Satisfactory	**G**
4. Type of cargo		Partially satisfactory	**M**
No cargo, no ballast	**Yel**	10. Season	
No cargo, with ballast	**C**	Summer	**C**
Bulk	**C**	Autumn	**M**
General	**G**		**Yel**
Oil/fuel	**M**	Spring	**M**
5. Actual draft		11. Time of continuous work of the crew, mon.	
<8	**C**	<1	**Yel**
8-10	**G**	1…6	**C**
10-10.30	**M**	>6	**M**
>10.30	**Yel**	12. The number of vessels in the channel moving in the opposite direction with a draft of more than 8 *m*	
6. Maximum length of the vessel, *m*			
<170	**C**	0	**C**
170-200	**G**	1-3	**M**
>200	**M**	>3	**Yel**

12 input quanta, Basic Coloroid





Block diagram of logical inference

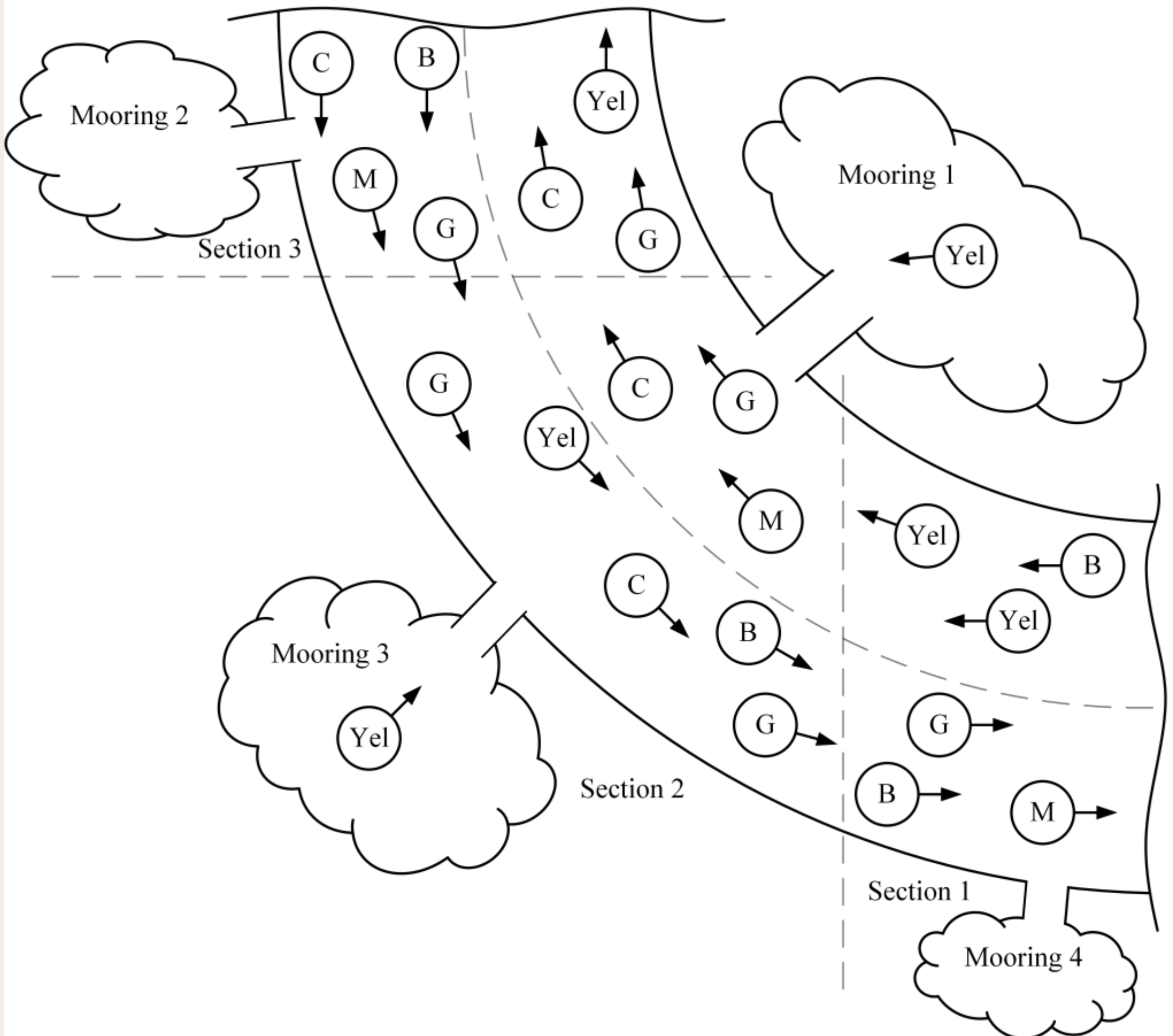
This decision was taken from the Level 1 decisions for ratings: **Storm**, **Daylight**, **Visibility** 1000-2000 m; further decision Level 2 for ratings: **Winter**, **Age of the vessel 15-20** years, the **Number of vessels** in the **opposite direction** $m > 3$, **Bulk or General**, **Partially satisfactory**; **Time** of team, decision Level 3 for ratings: **Actual draft ≤ 10.30**, **Cargo**, **with ballast** or Bulk, **Maximum length of the vessel ≤200 *m***. It should be noted that in the case of factor 6 score as **C**, **G** (the length of the ship is less than 200 *m*) the input score will be **G**, "***Go to channel***".

The obtained estimates can be used as a basis for correcting the basic speed of the ship in the channel to a safe for the given situation. Each color can be assigned a corresponding numerical value from the interval [0,1]. For example, **R**(0); **Yel** (0.25); **G** (0.5); **C** (0.75); **B** (1); **M** (-0.25); **R**(0), ***Thus, the recommended speed of the ship will take into account the correction factor. Another possible solution for the operator may be to order the vessel to be escorted by a tug.***

Traffic safety factors for sections of canal

Factor	Level of danger	Factor	Level of danger
1. Number of ships at the same time		2. Overall ships danger rating	
2-3	**B**	**C**, **B**	**B**
4-5	**G**	**W, M**, **G**	**G**
6-7	**R**	**Yel**	**R**
3. Navigational complexity of the canal section			
	Less difficult		**B**
	Difficult		**G**
	Very difficult		**R**

Scheme of vessel traffic in the shipping channel



Events Of Last Months →New Ideas

1. Why Magenta Is Not a Real Color, and How It Is Related to Fuzzy Control and Quantum Computing?

→Move to Quantum Computing

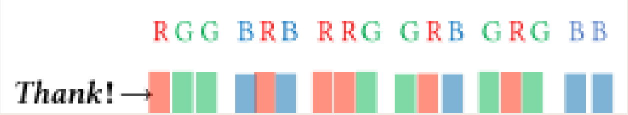
In this paper, the analogy between colors and fuzzy degrees is already known – and it has led to the ideas of using colors in fuzzy computations. The fact that there is a similar analogy between color and quantum computing makes us conjecture that this can also be useful in computations. **In particular, since most quantum algorithms now only use states with real-valued coefficients – that correspond to the two of three basic colors – we conjecture that using imaginary coefficients may lead to further speed-up of quantum computing.**

2. Color Optical Computing: Visualization, Numbers, Alphabet

→ *Transfer, storage, encryption of information*

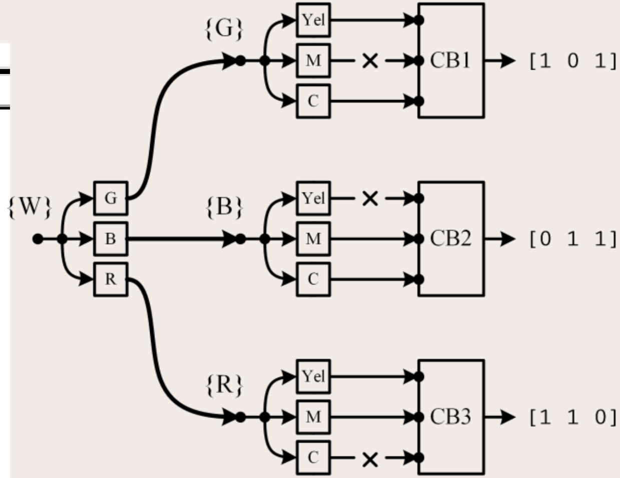
Converting numbers to colors

Color	Set	Number
Black	[0, 0, 0]	0
Red	[0, 0, 1]	1
Green	[0, 1, 0]	2
Yel	[0, 1, 1]	3
Blue	[1, 0, 0]	4
Magenta	[1, 0, 1]	5
Cayn	[1, 1, 0]	6
White	[1, 1, 1]	7



Converting alphabet to colors

Letter	Color Set
A	RRG
B	BBB
C	BBG
D	GRR
E	RRB
F	BRR
G	RBB
H	BRB
I	BBR
J	GGR
K	GRG
L	BRG



SUMMARY AND CONCLUSION

1) The main logical operations of disjunction and conjunction for processing a large amount of input fuzzy information are carried out ***by components without switching devices***.
2) The construction of computer coloroid networks is ***easily structurally parallelized.***
3) The use of light emitter in the femtosecond range ensures ***minimal energy consumption at a speed of information processing*** determined by the speed of light.
4) The optical computing architecture is ***easily integrated*** with optical information transmission.

Dissemination of results – DSS, AI, Big Date

Use and dissemination of the results of this research in various areas that require the application of intelligent DSS: ***military, medicine and production of medical products; technical and infrastructure; sociological; ecological; emergency prevention,*** etc. One of the important areas of application of the fuzzy logic systems developed in the project based on color optical devices are marine infrastructure facilities (ports, oil and gas terminals, shipping channels, etc.) with intensive traffic of transport and auxiliary vessels. The resulting problems with the safety of ships and the environment require the development and improvement of hierarchically organized man-machine decision support systems for the implementation of ***safe traffic in the conditions of non-standard scenarios and the impact of intense random external disturbances on the ship.*** Another infrastructural object of application of the decision-making system can be an aircraft traffic control system at **large airport to improve flight safety**, which should include the creation of a database and their ranking according to the degree of impact on flight safety, inference systems based on coloroid logical networks, visualization of the control process traffic with color information about dangerous traffic areas and aircraft conditions. Moreover, the developed color optical devices can be successfully used to improve the efficiency of intelligent automation systems for complex objects and processes in ***various industries in order to increase productivity and quality indicators of technological complexes***. These devices will improve accuracy, speed, reliability, expand functionality and simplify the hardware and software implementation of fuzzy control and decision systems that are used for ***automation industrial and mobile robots, unmanned aerial vehicles, floating vehicles and structures, heat and power plants, chemical reactors, processes of diagnostics and forecasting, etc***

FURTHER DEVELOPMENT

- The main problem in the further development of optical color computing is the lack of experimental samples.
- The experimental sample is an optical model of light guides, LEDs and filters on the liquid crystal of the base coloroid.
- Next, it is necessary to develop nanoscale structural elements of computational elements and ensure their manufacturability etc.
- Transition to the ultraviolet optical range is possible for the implementation of quantum computing.

THANK YOU!