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Research Article

Applications of Binary Intuitionistic Fine Topological Spaces for Digital Plane

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Abstract. In order to model computer images, digital spaces such as Z^2 are utilized and the link between the classical topological spaces such as $T_1, T_{1/2}, T_0$ spaces etc., and the digital spaces are studied by many authors to solve important connectivity problems, studying graphics, pattern recognition etc. In graph theoretical approach to solve connectivity contradictions 4 and 8 adjacencies serves as the basic. It is well known that key approaches to solve such problems are graph theoretic approach and topological approach. Traditional 4 and 8 adjacencies in a topology are considered in this article which aims to structure 4 and 8 adjacencies in a topology called binary intuitionistic fine topology (BI_fT). Initially 4 and 8 adjacencies-BI_fT are constructed and operators such as 4 and 8-BI_fT interiors and closures are defined and their properties are discussed. Eventually, 4 and 8 connected-BI_f-connected and non-connected points are defined and explained using example.

Keywords. 4 and 8-BI_fT adjacencies, Digital plane, BI_fTS, BI_f-connected points

Mathematics Subject Classification (2020). 54A05, 54A99

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1. Introduction

Concepts of classical topology such as interior, closure, limits, boundary, neighborhood, connectedness, compactness, continuity, generalized spaces, similarity etc., are of much important in digital topology. Digital topology and its extension was studied by Rosenfeld [4] whose contribution was immense in this field. Euclidean n-space is a special case to represent digital n-space, on the other hand computer screen deals with this space. The complete representatives of these spaces are $(4,8)$, $(8,4)$ and $(6,6)$ adjacencies (Kopperman [15]). Rosenfeld [5] proposed digital connectivity such as 4-connectivity and 8-connectivity in 2-D as well as 6-connectivity and 26-connectivity in 3-D spaces.

The notions of intuitionistic sets and intuitionistic topology were introduced by Çoker [7, 8] and the idea of fine topology was given by Powar and Rajak [14]. As an extension, intuitionistic fine topology was introduced by Vidyarani and Venish [18], and Jothi and Thangavelu [13] initiated binary topology. On further extension of the former binary intuitionistic spaces were introduced by Vidyarani and Venish [18]. Intuitionistic fuzzy digital connectivity and lattice points in the Euclidean plane is discussed by Meeakshi *et al.* [12], and intuitionistic sets consists of two important characteristics member and non-member by Çoker [7]. In image processing intuitionistic fuzzy is used to analyze the brighter and non-brighter part of the images due to the above said character of the intuitionistic set having the belongingess and non-belongingness property. More than results in fuzzy set theory, intuitionistic fuzzy set theory gives better ones (Meeakshi *et al.* [12]). Further in image processing using neutrosohic topological techniques, each image pixel is associated with four numerical values namely the membership, non-membership, indeterminacy and the hesitation measure (Salama *et al.* [16]).

To transfer the concepts of classical topology to digital topology, Kozae *et al.* [11] initiated the notion of $(4,8)$-supra topologies, in analogous to this $(4,8)$-binary intuitionistic fine topology is introduced in this article. As a special case of binary intuitionistic fine topology represented as $((X,Y),B_{I_f},\widehat{B}_{I_f})$, $(Z^2,B_{I_f},\widehat{B}_{I_f})$ is considered. In Section 1, preliminaries are proposed. In Section 2, $(4,8)$-binary intuitionistic fine topology is defined and are illustrated using examples, $(4,8)$-binary intuitionistic fine interior and closure is defined. In Section 3, properties of $(4,8)$-binary intuitionistic fine interior and closure are studied. Eventually $(4,8)$-binary intuitionistic fine connective and non-connective points are defined and explained using examples.

2. Preliminaries

Definition 2.1 ([3])**.** Two grid points, $p,q \in Z^2$ are called 4-adjacent or proper 4-neighbors, iff $p \neq q$ and $p \in N_4(q)$, where $N_4(p) = \{(x,y),(x+1,y),(x-1,y),(x,y+1),(x,y-1)\} = U_4(x,y)$, $p = (x,y)$.

Definition 2.2 ([3])**.** Two grid points, $p,q \in Z^2$ are called 8-adjacent or proper 8-neighbors, iff $p \neq q$ and $p \in N_8(q)$, where $N_8(p) = N_4(p) \cup \{(x+1,y+1),(x+1,y-1),(x-1,y+1),(x-1,y-1)\} = U_8(x,y)$, $p = (x,y)$.

Definition 2.3 ([11])**.** A digital space is (W,ψ) where V is a non-empty set and ψ is a binary, symmetric relation on V such that for any two objects u and v of W $\exists$ $(u^0,\dots,u^n)$ of elements in V such that $u = u^0 = v = u^n$ and $(u^j,v^{j+1}) \in \psi$, $k = 0,1,\dots,n-1$. The ψ is called an adjacency relation, and that $(u,v) \in \psi \to u$ and v are connected. Then, space is connected under the given relation that W is ψ-connected.

Definition 2.4 ([11])**.** A two dimensional digital picture is as usual a tuple (Z^2,B) where $B \subseteq Z^2$. Te elements of Z^2 are called points of the digital picture, and the elements of B are called the black points of the picture and the points in $Z^2 - B$ are called the white points of the picture.

Definition 2.5 ([7])**.** Suppose T be non-empty set, an *intuitionistic set* (IS), C is an element of form $C = \langle T, C_1, C_2 \rangle$, where C_1 and C_2 are subsets of T satisfying $C_1 \cap C_2 = \phi$. The C_1 is set of members of C, while C_2 is set of non-members of C.

Definition 2.6 ([8])**.** An intuitionistic topology on a non-empty set T is a family τ of ISs in T which satisfies:

(i) $\underset{\sim}{T}, \underset{\sim}{\phi} \in \tau$.

(ii) $C_1 \cap C_2 \in \tau$ for any $C_1, C_2 \in \tau$.

(iii) $\cup C_i \in \tau$ for arbitrary family $\{C_i : i \in H\} \subseteq \tau$.

(T, τ) is *intuitionistic topological space* (ITS) and IS in τ namely an *intuitionistic open set* (IOS), it's complement is *intuitionistic closed set* (ICS).

Definition 2.7 ([18])**.** An intuitionistic fine space on a non-empty set T is a family τ of IS's in T which satisfy below:
We define

$$\begin{aligned}\tau(C_\alpha) &= \widehat{\tau}_\alpha \quad \text{(say)} \\ &= \{G_\alpha(\neq \underset{\sim}{T}) : G_\alpha \cap C_\alpha \neq \underset{\sim}{\phi}\},\end{aligned}$$

for $C_\alpha \in \tau$ and $C_\alpha \neq \phi$, T for some $\alpha \in H$, H an index set}. We define $\widehat{\tau_f} = \{\underset{\sim}{\phi}, \underset{\sim}{T}\} \cup \{\widehat{\tau}_\alpha\}$. $\widehat{\tau}_f$ of subsets of T is namely the intuitionistic fine subsets of T and $(T, \tau, \widehat{\tau}_f)$ is the intuitionistic fine space T generated by τ. Elements of $\widehat{\tau}_f$ are intuitionistic fine open set $(I_f OS)$ in $(T, \tau, \widehat{\tau}_f)$ and complement of $(I_f OS)$ is intuitionistic fine closed set $(I_f CS)$.

Definition 2.8 ([18])**.** Suppose (T, S, B_I) be an BITS, we define $B_I((C^1, C^2)_\alpha) = \widehat{B}_{I_\alpha} = \{(K^1, K^2)_\alpha(\neq (\underset{\sim}{T}, \underset{\sim}{S})) : (K^1, K^2)_\alpha \cap (C^1, C^2)_\alpha \neq (\underset{\sim}{\phi}, \underset{\sim}{\phi})$, for $(C^1, C^2)_\alpha \in B_I$ and $(C^1, C^2)_\alpha \neq (\underset{\sim}{\phi}, \underset{\sim}{\phi})$, $(\underset{\sim}{T}, \underset{\sim}{S})$ for some $\alpha \in I$, an indexed set}. We define $\widehat{B}_{I_f} = \{(\underset{\sim}{\phi}, \underset{\sim}{\phi}), (\underset{\sim}{T}, \underset{\sim}{S})\} \cup_\alpha \{\widehat{B}_{I_{f\alpha}}\}$, binary intuitionistic fine subsets of (T, S) and $((T, S), B_I, \widehat{B}_{I_f})$ is known as an binary intuitionistic fine space $(BI_f S)$ generated by B_I on (T, S).

Note. For the definitions of binary topology and its operations reference [13].

Notation. If D is a B_{I_f} set then it is denoted as (C^1, C^2) or $C = (\langle T, C^1_1, C^1_2\rangle, \langle S, C^2_1, C^2_2\rangle)$. Also, if p is a binary fine intuitionistic point $(BI_f P)$ in (T, S) then it is an ordered pair which can be represented as (p^1, p^2) where p^1, p^2 each have member and non-member.

3. Binary Intuitionistic Fine Topology for Digital Planes

The definitions $(4,8)$-binary intuitionistic fine topologies by their point bases $N_4(p)$ and $N_8(p)$ and with each point x associated with member and non-member values are introduced in this section.

Definition 3.1. Two grid points, $p^1, p^2 \in (Z^2, B_I, \widehat{B}_{I_f})$ are called 4-adjacent or proper 4-neighbors, iff $p^1 \neq p^2$ and $p \in N_4(p^2)$, where $N_4(p^1) = \{(x, y), (x+1, y), (x-1, y), (x, y+1), (x, y-1)\} = U_4(x, y)$, $p = (x, y)$.

Definition 3.2. Two grid points, $p^1, p^2 \in (Z^2, B_I, \widehat{B}_{I_f})$ are called 8-adjacent or proper 8-neighbors, iff $p^1 \neq p^2$ and $p^1 \in N_8(p^2)$, where $N_8(p^2) = N_8(p^1) \cup \{(x+1, y+1), (x+1, y-1), (x-1, y+1), (x-1, y-1)\} = U_8(p^1, p^2)$, $p = (x, y)$.

Proposition 3.3. *The class* $O_4 = \cup\{U_4(p)/p \in Z^2\}$ *is a* 4-$B_{I_f}T$ *on* Z^2.

Proof. Suppose $(Z^2, B_I, \widehat{B}_{I_f})$ be a $B_{I_f}T$ and $p = (p^1, p^2) \in (Z^2, B_I, \widehat{B}_{I_f})$. Consider the class $O_4 = \cup\{U_4(p)/p \in Z^2\}$ then Z^2, $\phi \in O_4$ and since $(Z^2, B_I, \widehat{B}_{I_f})$ is considered the arbitrary union of $B_{I_f}OS$ in Z^2 is $B_{I_f}OS$ in Z^2 (i.e.) if $p, q \in (Z^2, B_I, \widehat{B}_{I_f})$, $U_4(p), U_4(q) \in O_4$ then $U_4(p) \cup U_4(q) \in O_4$. From the above we prove that O_4 is a 4-$B_{I_f}T$ on Z^2. □

Definition 3.4. (Z^2, O_4) is a 4-$B_{I_f}TS$, then the members of O_4 are called 4-$B_{I_f}OS$.

Example 3.5. Let $p = ((9,4),(5,2))$, $q = ((10,5),(5,2))$ and $r = ((11,6),(5,2))$. Now we find

$$U_4(p) = U_4(p)((9,4),(5,2))$$
$$= \{((9,4),(5,2)),((9,4),(4,1)),((8,3),(5,2)),((10,5),(5,2)),((9,4),(6,3))\},$$
$$U_4(q) = U_4(q)((10,5),(5,2))$$
$$= \{((10,5),(5,2)),((10,5),(4,1)),((9,4),(5,2)),((11,6),(5,2)),((10,5),(6,3))\},$$
$$U_4(r) = U_4(r)((11,6),(5,2))$$
$$= \{((11,6),(5,2)),((11,6),(4,1)),((10,5),(5,2)),((12,7),(5,2)),((11,6),(6,3))\},$$

hence

$$B = \{((9,4),(5,2)),((9,4),(4,1)),((8,3),(5,2)),((10,5),(5,2)),((9,4),(6,3)),((10,5),(5,2)), ((10,5),(4,1)),((11,6),(5,2)),((10,5),(6,3)),((11,6),(4,1)),((12,7),(5,2)),((11,6),(6,3))\}.$$

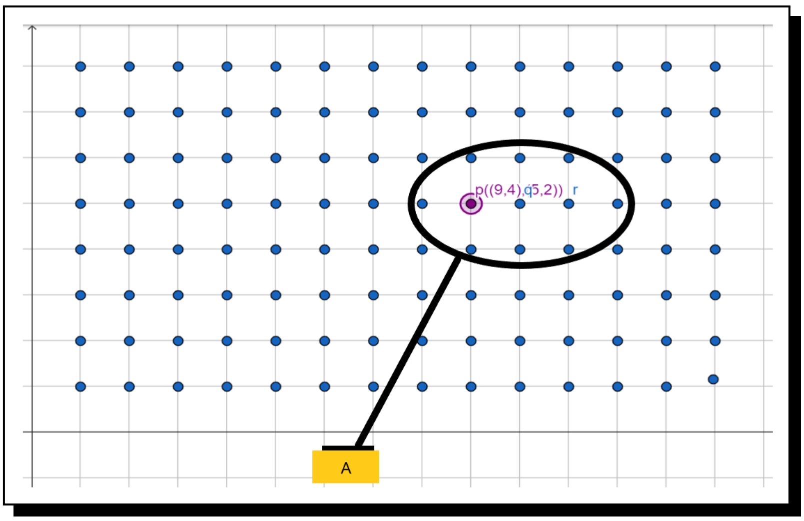

Figure 1. 4-$B_{I_f}OS$

Example 3.6. The following is an example for a non-4-$B_{I_f}OS$.

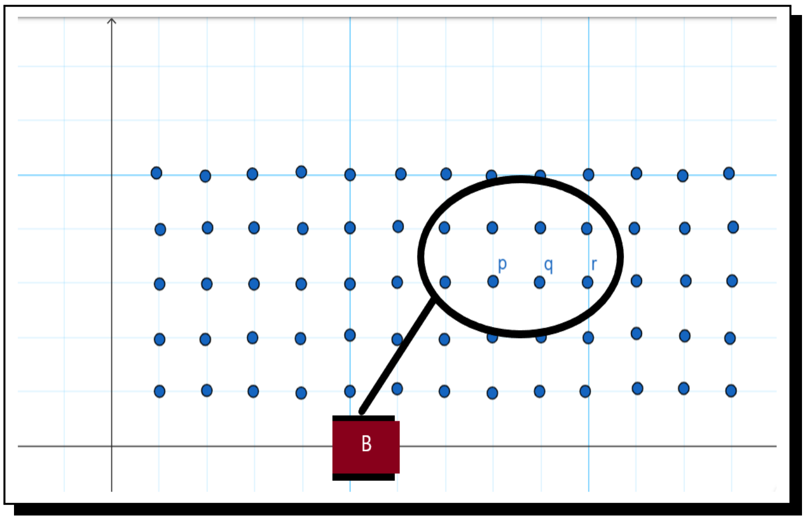

Figure 2. Non-4-$B_{I_f}OS$, since $C \neq U_4(p) \cup U_4(q) \cup U_4(r)$

Proposition 3.7. *The class $O_8 = (U_8(p)/p \in Z^2)$ is a 8-$B_{I_f}T$ on Z^2.*

Proof. Suppose $(Z^2, B_I, \widehat{B}_{I_f})$ is a $B_{I_f}T$ and $p = (p^1, p^2) \in (Z^2, B_I, \widehat{B}_{I_f})$. Consider the class $O_8 = \cup\{U_4(p)/p \in Z^2\}$ then $Z^2, \phi \in O_8$ and since $(Z^2, B_I, \widehat{B}_{I_f})$ is considered the arbitrary union of $B_{I_f}OS$ in Z^2 is $B_{I_f}OS$ in Z^2. (i.e) If $p, q \in (Z^2, B_I, \widehat{B}_{I_f})$, $U_8(p), U_8(q) \in O_8$ then $U_8(p) \cup U_8(q) \in O_4$. From the above we prove that O_8 is a 8-$B_{I_f}T$ on Z^2.

Example 3.8. Let $p = ((8,5),(3,2)), q = ((9,6),(3,2))$ and $r = ((10,7),(5,2))$. Now we find

$$\begin{aligned} U_8(p) &= U_8((8,5),(3,2)) \\ &= \{((8,5),(3,2)),((8,5),(2,1)),((7,4),(3,2)),((9,6),(3,2)),((8,5),(4,3)), \\ &\quad ((9,6),(4,3)),((9,6),(2,1)),((7,4),(4,3)),((7,4),(2,1))\}, \\ U_8(q) &= U_8((9,6),(3,2)) \\ &= \{((9,6),(3,2)),((9,6),(2,1)),((8,5),(3,2)),((10,7),(3,2)),((9,6),(4,3)), \\ &\quad ((10,7),(4,3)),((10,7),(2,1)),((8,5),(4,3)),((8,5),(2,1))\}, \\ U_8(r) &= U_8((10,7),(3,2)) \\ &= \{((10,7),(3,2)),((10,7),(2,1)),((9,6),(3,2)),((11,8),(3,2)),((10,7),(4,3)), \\ &\quad ((11,8),(4,3)),((11,8),(2,1)),((9,6),(2,1)),((9,6),(4,3))\}, \end{aligned}$$

hence

$$\begin{aligned} B = \{&((8,5),(3,2)),((8,5),(2,1)),((7,4),(3,2)),((9,6),(3,2)),((8,5),(4,3)), \\ &((9,6),(4,3)),((9,6),(2,1)),((7,4),(4,3)),((7,4),(2,1)),((10,7),(3,2)), \\ &((10,7),(4,3)),((10,7),(2,1)),((11,8),(3,2)),((11,8),(4,3)),((11,8),(2,1))\}. \end{aligned}$$

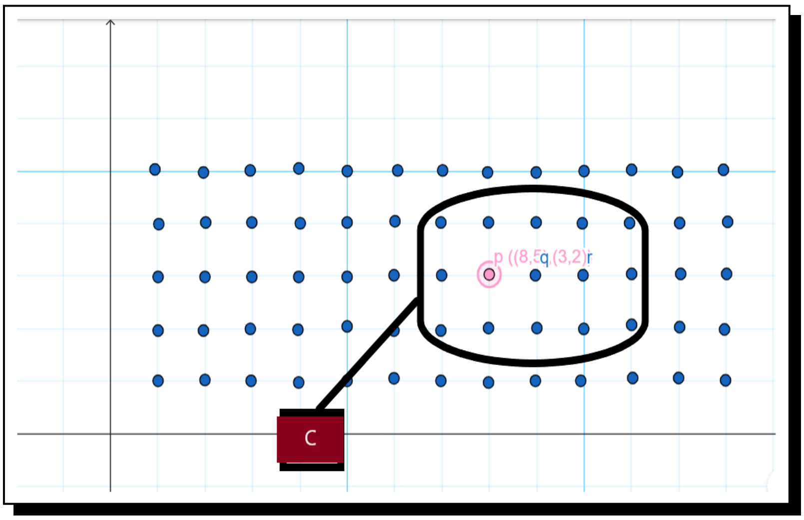

Figure 3. 8-$B_{I_f}OS$

Example 3.9. The following is an example for a non-8-$B_{I_f}OS$.

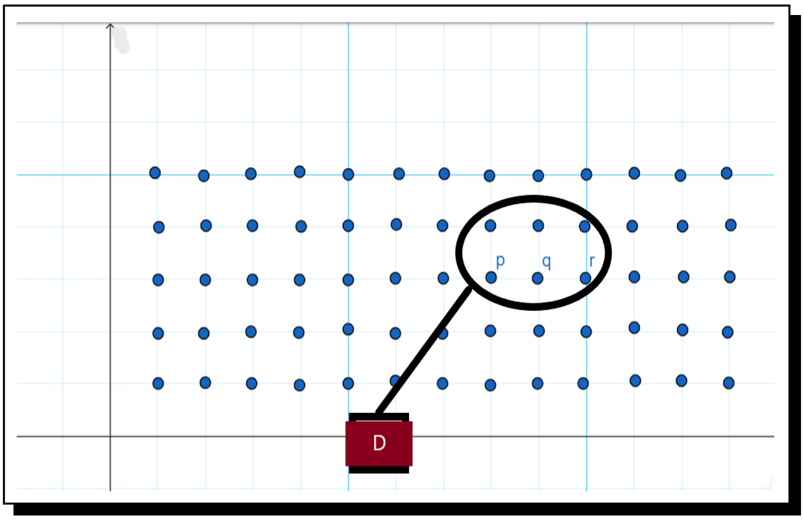

Figure 4. Non-8-$B_{I_f}OS$, since $D \neq U_8(p) \cup U_8(q) \cup U_8(r)$

Definition 3.10. Suppose $(Z^2, B_I, \widehat{B}_{I_f})$ is a $B_{I_f}T$, $B \subset Z^2$ then 4 and 8-BI_fT interiors and closures is defined as:

$$4 \text{ and } 8\text{-}BI_fT\,\text{int}(B) = \{p \in z^2 \; \exists\, q \in Z^2 \text{ with } p \in U(q) \subseteq B\} \;\; \text{(or)}$$

$$4 \text{ and } 8\text{-}BI_fT\,\text{int}(B) = \cup\{U_{4\,\text{or}\,8}(q) : U_{4\,\text{or}\,8}(q) \subset B\}.$$

Definition 3.11. Suppose $(Z^2, B_I, \widehat{B}_{I_f})$ is a $B_{I_f}T$, $B \subset Z^2$ then 4 and 8-BI_fT interiors and closures is defined as:

$$4 \text{ and } 8\text{-}BI_fT\,\text{cl}(B) = \{p \in z^2 \; \exists\, q \in Z^2 \text{ with } p \in U(q) \text{ follows } U(q) \cap B \neq (\phi, \phi)\} \;\; \text{(or)}$$

$$4 \text{ and } 8\text{-}BI_fT\,\text{cl}(B) = \cup\{U_{4\,\text{or}\,8}(q) : U_{4\,\text{or}\,8}(q) \cap B \neq (\phi, \phi)\}.$$

4. Properties of 4 and 8-BI_fT Interiors and Closures

Proposition 4.1. (i) $\text{int}(B) \subset B$,

(ii) *if* $A \subseteq B$ *then* $\text{int}(A) \subseteq \text{int}(B)$,

(iii) $\text{int}(Z^2 - B) = Z^2 - \text{cl}(B)$,

(iv) $\text{int}(A) \cup \text{int}(B) \subseteq \text{int}(A \cup B)$,

(v) $\text{int}(A) \cap \text{int}(B) \subseteq \text{int}(A \cap B)$,

(vi) $\text{int}(\text{int}B) = \text{int}B$.

Proposition 4.2. (i) $B \subset \text{cl}(B)$,

(ii) *if* $A \subseteq B$ *then* $\text{cl}(A) \subseteq \text{cl}(B)$,

(iii) $\text{cl}(Z^2 - B) = Z^2 - \text{int}(B)$,

(iv) $\text{cl}(A) \cup \text{int}(B) = \text{cl}(A \cup B)$,

(v) $\text{cl}(A) \cap \text{cl}(B) \supset \text{cl}(A \cap B)$,

(vi) $\text{cl}(\text{cl}B) = \text{cl}B$.

The following are examples of 4 and 8-BI_fT interiors and closures.

Example 4.3.

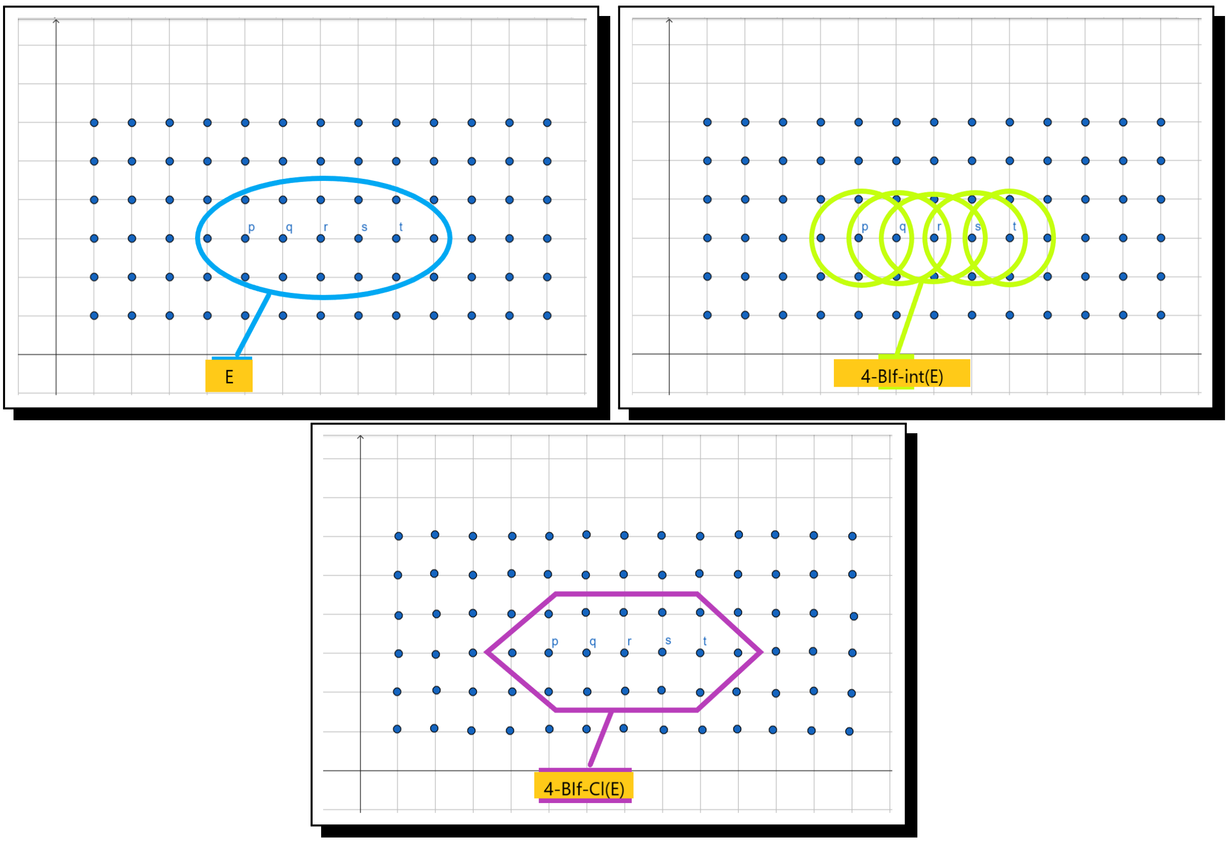

Figure 5. 4-BI_fT interiors and closures

Example 4.4.

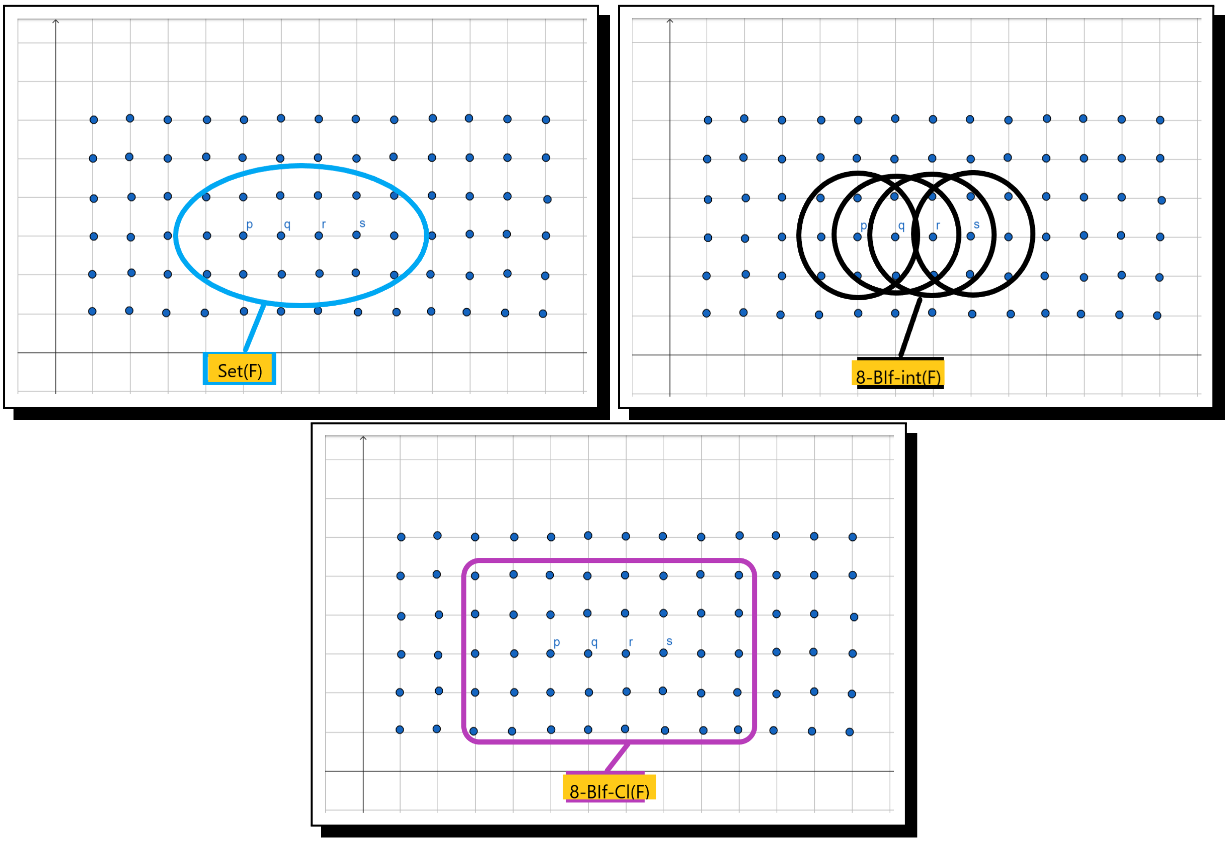

Figure 6. 8-BI_fT interiors and closures

Definition 4.5. Suppose $(Z^2, B_I, \widehat{B}_{I_f})$ is a $B_{I_f}T$, $B \subset Z^2$ then center 4 and 8-BI_fT interiors is defined as: 4 and 8-$BI_fT\,\mathrm{int}(B^0) = \{x \in B : U(x) \subseteq B\}$.

The following are the examples of center 4 and 8-BI_fT interiors and closure:

Example 4.6.

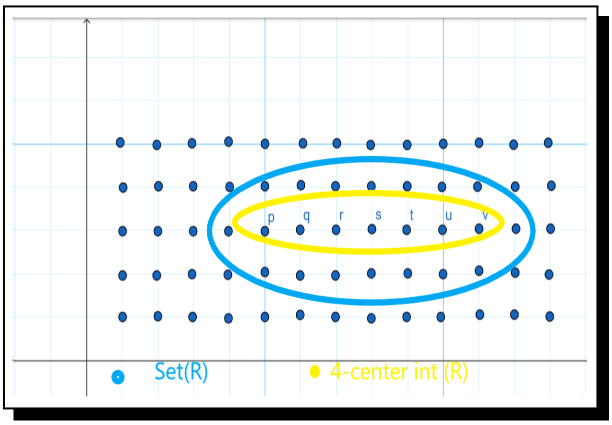

Figure 7. center 4-BI_fT interiors and closures

Example 4.7.

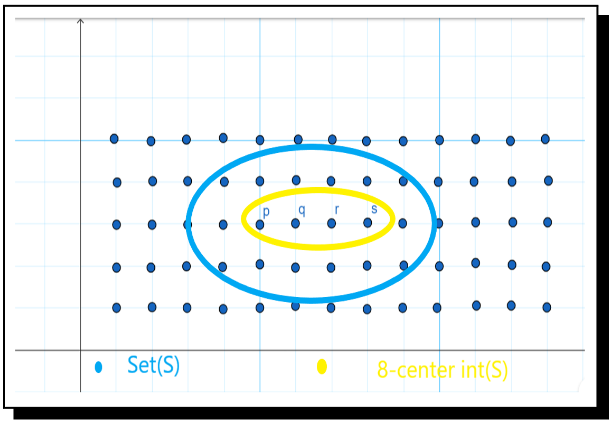

Figure 8. center 8-BI_fT interiors and closures

Proposition 4.8. *Any subset B from $(Z^2, B_I, \widehat{B}_{I_f})$ is a preopen and its closure is open (4 and 8-BI_fT int(4 and 8-BI_fT cl$(B)) = 4$ and 8-BI_fT cl(B)).*

Proof. Since $B \subset 4$ and 8-BI_fT cl$(B) = 4$ and 8-BI_fT cl$(B)^0$.
Therefore, $B \subset 4$ and 8-BI_fT cl$(B)^0$. So B is pre-open.
Therefore, 4 and 8-BI_fT cl$(B) = 4$ and 8-BI_fT cl$(B)^0$ is open. □

Proposition 4.9. *Closure operator is not unitary (4 and 8-BI_fT cl(B)(4 and 8-BI_fT cl$(B)) \neq 4$ and 8-BI_fT cl(B)).*

The following is an example to S.T (4-BI_fT cl(B)(4-BI_fT cl$(B)) \neq$ 4-BI_fT cl(B)).

Example 4.10.

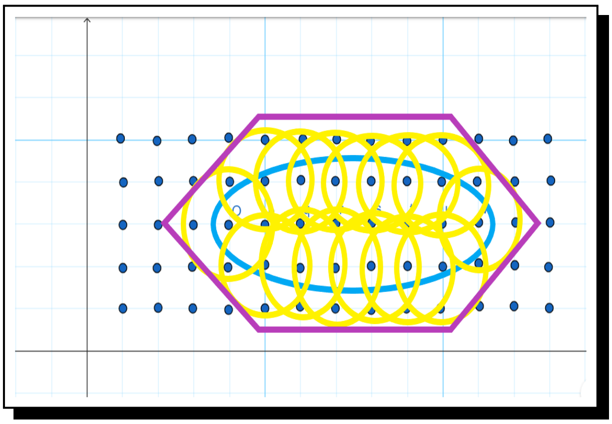

Figure 9. 4-BI_fT cl(B)(4-BI_fT cl$(B)) \neq$ 4-BI_fT cl(B)

Definition 4.11. (i) $(Z^2, B_I, \widehat{B}_{I_f})$ is connected if $x = C \cup D$, where C and D are disjoint $B_{I_f}OS$.

(ii) If $(Z^2, B_I, \widehat{B}_{I_f})$ is the space and $C \subset Z^2$, C is connected if $(C, \widehat{B}_{I_{fC}})$ is connected.

(iii) Two points p, q will be connected if $\widehat{B}_{I_f}(p, q)$ is connected.

The following is example for connected points.

Example 4.12.

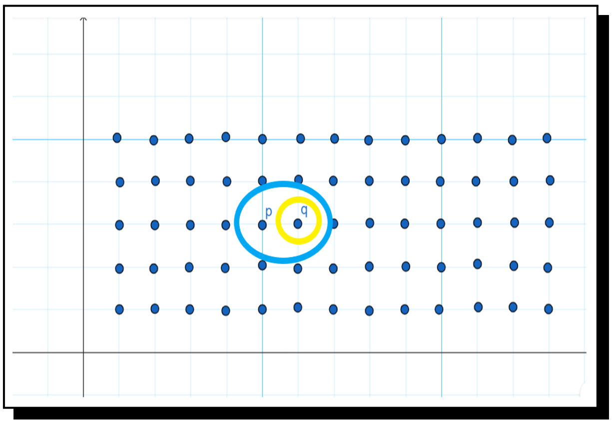

Figure 10. Connected points

Since $(Z^2, B_I, \widehat{B}_{I_f})$ contains $\{q\}$ only, p,q are connected points.

The following is an example of non-connected points:

Example 4.13.

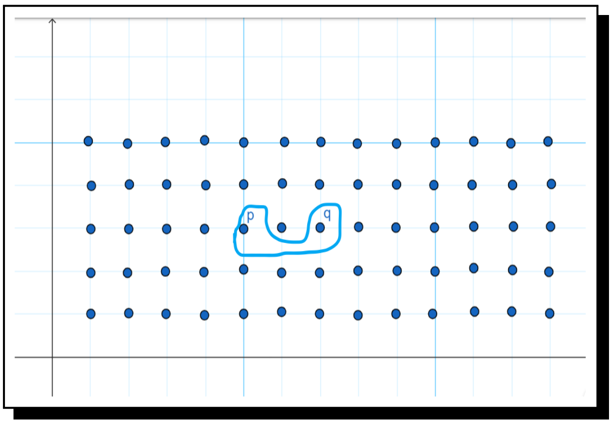

Figure 11. Non-connected points

5. Conclusion

Binary intuitionistic fine topology as a digital plane with 4 and 8 point adjacencies are define and few basic operators such as closure and interior are defined and some of their properties are discussed in the article. As an initiative of applications, connected points are defined and explained. Future work may be done on digital convexity and extensions of this work in fuzzy and neutrosophic environment may also be done.

Competing Interests

The authors declare that they have no competing interests.

Authors' Contributions

All the authors contributed significantly in writing this article. The authors read and approved the final manuscript.

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