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n-DISTRIBUTIVE NEARLATTICES

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Abstract

For a neutral element $n \in L$,[III] have introduced the concept of n-distributive lattices which is a generalization of both 0-distributive and 1-distributive lattices. For a central element n of a nearlattice S, we have discussed n-distribitive nearlattices which is a generalization of both0-distributive semilattices and n-distributive lattices. For an element n of nearlattice S, a convex subnearlattice of$S$ containing n is called an n-ideal of$S$. In this paper, we have given some properties of n-distributivenearlattices. Finally, we have included a generalization of prime Separation Theorem in terms of annihilator n-ideal.

Keywords: Central element, 0-distributive lattice,n-distributive lattice, n-annihilator, annihilator n-ideal, prime n-ideal, n-distributive nearlattice.

I. Introduction

J.C. Varlet has given the concept of 0-distributive and 1-distributive lattices. A lattice L with 0 is called 0-distributive if for all $a, b, c \in L$, $a \wedge b = 0 = a \wedge c$ imply $a \wedge (b \vee c) = 0$. Similarly, a lattice L with 1 is called 1-distributive if for all $a, b, c \in L$, $a \vee b = 1 = a \vee c$ imply $a \vee (b \wedge c) = 1$. Of course, every distributive lattice with 0 and 1 is both 0-distributive and1-distributive. A pseudo complemented lattice L can be characterized by the fact that for each $a \in L$, the set of all elements which are disjoint with element a forms a principal ideal. But a 0-distributive lattice L says that for each $a \in L$, the set of all elements which are disjoint with a is simply an ideal not necessarily a principal ideal. Hence, every pseudocomplemented lattice is 0-distributive. For detailed literature on 0-distributive lattice we refer the readers to consult [IV] and [I].

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In this paper, we generalize the concept of 0-distributive lattice and n-distributive lattice and give the notion of n-distributive nearlattice where n is a central element of this nearlattice.

A nearlattice$S$ is a meet semilattice with the property that, any two elements possessing a common upper bound, have a supremum. Nearlattice S is distributive if for all $x, y, z \in S, x \wedge (y \vee z) = (x \wedge y) \vee (x \vee z)$provided $y \vee z$ exists. For detailed literature on nearlattices, we refer the reader to consult [V] and [VIII]. An element n of a nearlattice S is called medial if $m(x, n, y) = (x \wedge y) \vee (x \wedge n) \vee (y \wedge n)$ exists in S for all $x, y \in S$.A nearlattice$S$ is called a medial nearlattice if $m(x, y, z)$ exists for all $x, y, z \in S$.

An element s of a nearlattice S is called standard if forall $t, x, y \in S$,$t \wedge [(x \wedge y) \vee (x \wedge s)] = (t \wedge x \wedge y) \vee (t \wedge x \wedge s)$. The element s is called neutral if (i) s is standard and (ii) for all $x, y, z \in S$, $s \wedge [(x \wedge y) \vee (x \wedge z)] = (s \wedge x \wedge y) \vee (s \wedge x \wedge z)$.

In a distributive nearlattice, every element is neutral and hence standard. An element n in a nearlattice Siscalled sesquimedial if for all $x, y, z \in S$, $([(x \wedge n) \vee (y \wedge n)] \wedge [(y \wedge n) \vee (z \wedge n)]) \vee (x \wedge y) \vee (y \wedge z)$ exists in S.

An element n of a nearlattice S is called a upper element if $x \vee n$ exists for all $x \in S$. Every upper element is of course a sesquimedial element. An element n is called a central element of S if it is neutral, upper and complemented in each interval containing it.

Let S be a nearlattice and $n \in S$. Any convex subnearlattice of S containing n is called an n-ideal of S. For two n-ideals I and J of a nearlattice S, [V] has given a description of $I \vee J$ while the set theoretic intersection is the infimum. Hence, the set of all n-ideals of a nearlattice S is a lattice which is denoted by $I_n(S)$. $\{n\}$and$S$ are the smallest and largest elements of $I_n(S)$.

An n-ideal generated by a finite number of elements $a_1, a_2, \cdots, a_m$ is called a finitely generated n-ideal and it is denoted by $< a_1, a_2, \cdots, a_m >_n$. The set of all finitely generated n-ideals is denoted by $F_n(S)$. Clearly, $< a_1, a_2, \cdots, a_m >_n = < a_1 >_n \vee < a_2 >_n \vee \cdots \vee < a_m >_n$. An n-ideal generated by a single element a is called a principal n-ideal denoted by $< a >_n$. The set of principal n-ideals is denoted by $P_n(S)$.

Let S be a nearlattice and $n \in S$.For any $a \in S$,

$$< a >_n = \{y \in S: a \wedge n \leq y = (y \wedge a) \vee (y \wedge n)\}$$

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$= \{y \in S: \ y = (y \wedge a) \vee (y \wedge n) \vee (a \wedge n)\}$ whenever n is standard element in S.

If n is an upper element in a nearlattice S, then $< a >_n = [a \wedge n, a \vee n]$.

We know that when n is standard and medial, the set of all principal n-ideals $P_n(S)$ is a meet semilattice and $< a >_n \cap < b >_n = < m(a, n, b) >_n$ for all $a, b \in S$. Also, when n is neutral and sesquimedial, then $P_n(S)$ is a nearlattice. By[V] if S is medial nearlattice and n is a neutral elementof S, then $P_n(S)$ is also a medial nearlattice.

For a distributive nearlattice S with an upper element n, $P_n(S)$ is a distributive nearlattice with the smallest element $\{n\}$.

A proper convex subnearlattice M of a nearlattice S is called a maximal convex subnearlattice if for any convex subnearlattice Q with $Q \supseteq M$ implies either $Q = M$ or $Q = S$. A proper convex subnearlattice M of a medial nearlattice S is called a prime convex subnearlattice if for any $t \in M, m(a, t, b) \in M$ implies either $a \in M$ or $b \in M$. For a medial element n, an n-ideal P of a nearlattice S is a prime n-ideal if $P \neq S$ and $m(x, n, y) \in P$ $(x, y \in S)$ implies either $x \in P$ or $y \in P$. Equivalently, P is prime if and only if $< a >_n \cap < b >_n \subseteq P$ implies either $< a >_n \subseteq P$ or $< b >_n \subseteq P$.

Let n be a central element of a nearlattice S. For $a \in S$, we define $\{a\}^{\perp n} = \{x \in S: m(x, n, a) = n\}$, known as an n-annihilator of $\{a\}$. Also for $A \subseteq S$, we define $A^{\perp n} = \{x \in S: m(x, n, a) = n \text{ for all } a \in A\}$. $A^{\perp n}$ is always a convex subnearlattice containing n. If S is a distributive nearlattice, then it is easy to check $\{a\}^{\perp n}$ and $A^{\perp n}$ are n-ideals. Moreover, $A^{\perp n} = \cap_{a \in A} \{ \{a\}^{\perp n}\}$. If A is an n-ideal, then $A^{\perp n}$ is called an annihilator n-ideal which is obviously the pseudocomplement of A in $I_n(S)$. Therefore, for a distributive nearlattice S with central element n, $I_n(S)$ is pseudocomplemented.

A nearlattice S with central element n, is called an n-distributive nearlattice if for all $a, b, c \in S, < a >_n \cap < b >_n = \{n\}$ and $< a >_n \cap < c >_n = \{n\}$ imply $< a >_n \cap [< b >_n \vee < c >_n] = \{n\}$. Equivalently, S is called n-distributive nearlattice if $a \wedge b \leq n \leq a \vee b$ and $a \wedge c \leq n \leq a \vee c$ imply $a \wedge (b \vee c) \leq n \leq a \vee (b \wedge c)$.

II. Main results

To obtain the main results of this paper we need to prove the following lemmas.

Lemma (2.1): Every convex subnearlattice not containing n is contained in a maximal convex subnearlattice not containing n.

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Proof: Let F be a convex subnearlattice such that $n \notin F$. Let $\mathcal{F}$ be the set of all convex subnearlattice containing F but not containing n. $\mathcal{F}$ is non-empty as $F \in \mathcal{F}$. Let C be a chain in $\mathcal{F}$ and $M = \cup (X | X \in C)$. Let $x, y \in M$. Then $x \in X$ and $y \in Y$ for some $X, Y \in C$. Since C is a chain, so either $X \subseteq Y$ or $Y \subseteq X$. Suppose $X \subseteq Y$. Then $x, y \in Y$. Hence $x \wedge y, x \vee y \in M$. Thus M is a subnearlattice of a nearlattice containing F. Also it is convex as each $X \in C$ is convex. Clearly $n \notin M$. Hence M is a maximal element of C. Therefore, by Zorn's Lemma, $\mathcal{F}$ has a maximal element, say Q with $F \subseteq Q$.

Lemma (2.2): Let S be a nearlattice with a central element n. A convex subnearlattice M not containing n is maximal if and only if for all $a \notin M$ there exists $b \in M$ such that $m(a, n, b) = n$.

Proof: Suppose M is a maximal convex subnearlattice and $n \notin M$. Also let $a \notin M$. Suppose for all $b \in M$, $m(a, n, b) \neq n$. Set $M_1 = \{y \in L: y \wedge n \leq (a \vee b) \leq (a \wedge b) \vee n \leq y \vee n\}$. Obviously, M_1 is convex subnearlattice as n is central. Moreover, $n \notin M_1$. For otherwise $n \wedge n \leq (a \vee b) \wedge n \leq (a \wedge b) \vee n \leq n \vee n$ implies $m(a, n, b) = n$ which gives a contradiction to the assumption. For $b \in M$, $b \wedge n \leq (a \vee b) \wedge n \leq (a \wedge b) \vee n \leq b \vee n$ implies $b \in M_1$ and so $M \subset M_1$. Also, $a \wedge n \leq (a \vee b) \wedge n \leq (a \wedge b) \vee n \leq a \vee n$ implies $a \in M_1$ but $a \notin M$ so $M \subset M_1$. Therefore, we have a contradiction to the maximality of M and so there exists some $b \in M$ such that $m(a, n, b) = n$. Conversely, if M is not maximal and $n \notin M$, then by **Lemma (2.1)**, M properly contained in a maximal convex subnearlattice N not containing n. Then for any element $a \in N - M$ there exists an element $b \in M$ such that $m(a, n, b) = n$. Thus, by contvexity $a, b \in N$ and $a \wedge b \leq n \leq a \vee b$ imply $n \in N$ which is a contradiction. Hence, M must be maximal.

Following two lemmas are due to [VII]

Lemma(2.3): A proper subset I of a join semilattice S is a maximal ideal if and only if $S - I$ is a minimal prime up set (filter).

Lemma (2.4): Let I be an ideal of a join semilattice S with 1. Then there exists a maximal ideal containing I.

Theorem (2.5): For a medial element n, any prime ideal P containing n of a nearlattice S is a prime n-ideal.

Proof: Since every ideal P is a convex subnearlattice, so any ideal P containing n is an n-ideal. To show the primeness, let $m(a, n, b) \in P$. Then $a \wedge b \leq m(a, n, b)$ implies $a \wedge b \in P$. Since P is prime ideal so either $a \in P$ or $b \in P$. Hence P is a prime n-ideal.

Following lemma is due to [VI]

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Lemma (2.6): Every ideal disjoint from a filter F is contained in a maximal ideal disjoint from F.

Theorem(2.7): Let S be a nearlattice with a center element n . If the intersection of all prime n-ideals of S is $\{n\}$, then S is n-distributive.

Proof: Let $<a>_n \cap <b>_n = \{n\}$and $<a>_n \cap <c>_n = \{n\}$. Let P be any prime n-ideal. If $a \in P$, then $<a>_n \subseteq P$ and so $<a>_n \cap [<b>_n \vee <c>_n] \subseteq P$. If $a \notin P$, then $<b>_n$, $<c>_n \subseteq P$ as P is prime n-ideal. Hence $<b>_n \vee <c>_n \subseteq P$. Therefore, $<a>_n \cap [<b>_n \vee <c>_n] \subseteq P$. That is, in either case, $<a>_n \cap [<b>_n \vee <c>_n] \subseteq P$ for all prime n-ideals P. Therefore, $<a>_n \cap [<b>_n \vee <c>_n] = \{n\}$ and so S is n-distributive.

Lemma (2.8): Let S be a nearlattice with a central element n. Then $p \in \{x\}^{\perp_n}$ if and only if $p \wedge x \leq n \leq p \vee x$.

Proof:$p \in \{x\}^{\perp_n}$ if and only if $m(p,n,x) = n$ if and only if $(p \wedge x) \vee (p \wedge n) \vee (x \wedge n) = (p \vee x) \wedge (p \vee n) \wedge (x \vee n) = n$, as n is central. This implies that $p \wedge x \leq n \leq p \vee x$.

Lemma (2.9): Let S be a nearlatticewith a central element n. Then $p \in \{x\}^{\perp_n}$ if and only if $p \vee n \in \{x \vee n\}^{\perp_n}$ in $[n)$ and $p \wedge n \in \{x \wedge n\}^{\perp^d}$in $(n]$.

Proof: Let $p \in \{x\}^{\perp_n}$. Then $p \wedge x \leq n \leq p \vee x$ and so $(p \vee n) \wedge (x \vee n) = (p \wedge x) \vee n = n$ and $(p \wedge n) \vee (x \wedge n) = (p \vee x) \wedge n = n$ as n is central element. Thus $p \vee n \in \{x \vee n\}^{\perp}$ in $[n)$ and $p \wedge n \in \{x \wedge n\}^{\perp^d}$ in $(n]$. Conversely, let $p \vee n \in \{x \vee n\}^{\perp}$ in $[n)$ and $p \wedge n \in \{x \wedge n\}^{\perp^d}$in $(n]$. Then since n is central element, so $(p \vee n) \wedge (x \vee n) = n$ and $(p \wedge x) \vee n = n$. This implies $p \wedge x \leq n$. Also, $(p \wedge n) \vee (x \wedge n) = n$ implies $(p \vee x) \wedge n = n$ and so $n \leq p \vee x$. Hence $p \wedge x \leq n \leq p \vee x$. Therefore, by **Lemma (2.8)**, $p \in \{x\}^{\perp_n}$.

Now, we give somecharacterizations of n-distributive nearlattices.

Theorem (2.10): For a nearlattice$S$ with a central element n, the following conditions are equivalent:

(i) S is n-distributive

(ii) For every$a \in S$, $\{a\}^{\perp_n}$ is an n-ideal

(iii) For any $A \subseteq S$, $A^{\perp_n}$ is an n-ideal

(iv) $I_n(S)$is pseudocomplemented.

(v) $I_n(S)$ is 0-distributive

(vi) Every maximal convex subnearlattice not containing n is prime.

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Proof: (i)⇒(ii). Let $x, y \in \{a\}^{\perp_n}$. Then $a \wedge x \leq n \leq a \vee x$and $a \wedge y \leq n \leq a \vee y$. Since S is distributive, so $a \wedge (x \vee y) \leq n \leq a \vee (x \wedge y)$. Then $a \wedge (x \vee y) \leq n \leq a \vee (x \vee y)$ and $a \wedge (x \wedge y) \leq n \leq a \vee (x \wedge y)$ imply $x \wedge y,\ x \vee y \in \{a\}^{\perp_n}$ [by

Lemma (2.8)].Since $m(x, n, a) = n$, so $n \in \{a\}^{\perp_n}$.

Again, let $x, y \in \{a\}^{\perp_n}$ and $x \leq t \leq y$. Then $a \wedge x \leq n \leq a \vee x$ and $a \wedge y \leq n \leq a \vee y$ so $a \wedge t \leq n \leq a \vee t$ which implies that $t \in \{a\}^{\perp_n}$. Hence $\{a\}^{\perp_n}$ is an n-ideal.

(ii)⇒(iii). Since $\{a\}^{\perp_n}$ is an n-ideal and $A^{\perp_n} = \cap_{a \in A} \{\{a\}^{\perp_n}\}$, so $A^{\perp_n}$ is an n-ideal.

(iii) ⇒(iv) is trivial as for any n-ideal $A \in I_n(S)$, $A^{\perp_n}$ is the pseudocomplment of A in $I_n(S)$.

(iv) ⇒(v) is also trivial because every pseudocomlemented lattice is 0-distributive.

(v) ⇒(vi). Suppose F is maximal convex subnearlattice not containing n. Since $F = (F] \cap [F)$and $n \in F$, so either $n \notin (F]$ or $n \notin [F)$. Hence by the maximality of$F$, either F is an ideal or a filter. Let $x \notin F$ and $y \notin F$. Then by **Lemma (2.2)**, there exist $a \in F$ and $b \in F$ such that $m(x, n, a) = n = m(y, n, b)$.This implies $x \wedge a \leq n \leq x \vee a$ and y$\wedge\, b \leq n \leq y \vee b$. Hence $x \wedge a \wedge b \leq n,\ y \wedge a \wedge b \leq n$ and $x \vee a \vee b \geq n,\ y \vee a \vee b \geq n$ and so $a \wedge b, a \vee b \in F$. Then $< x \vee n >_n \cap < a \wedge b >_n = [n, x \vee n] \cap [a \wedge b \wedge n, (a \wedge b) \vee n]$

$= [n, (x \wedge a \wedge b) \vee n] = [n, n] = \{n\}asn$ is central.

Similarly, $< y \vee n >_n \cap < a \wedge b >_n = \{n\}$. Since $I_n(S)$ 0-distributive, so $< a \wedge b >_n \cap (< x \vee n >_n \vee < y \vee n >_n) = \{n\}$.This implies $\left[n, \left(a \wedge b \wedge (x \vee y)\right) \vee n\right] = \{n\}$. Hence $a \wedge b \wedge (x \vee y) \leq n$. Dually, $< x \wedge n >_n \cap < a \vee b >_n = \{n\}$ and $< y \wedge n >_n \cap < a \vee b >_n = \{n\}$.Without loss of generality, suppose F is filter. If $x \vee y \in F$, then $a \wedge b \wedge (x \vee y) \leq n$ implies $n \in F$ which is a contradiction. Hence $x \vee y \notin F$. Therefore, F is prime filter.Similarly, if F is an ideal, then it is a prime ideal

(vi) ⇒(i). Let $a \wedge b \leq n \leq a \vee b$ and $a \wedge c \leq n \leq a \vee c$ provided $a \vee b$ and $a \vee c$ exist. We need to show that $a \wedge (b \vee c) \leq n \leq a \vee (b \wedge c)$. If not, without loss of generality, let $a \wedge (b \vee c) \notin n$. Consider $F = [a \wedge (b \vee c)]$, when $b \vee c$ exists. So $n \notin F$. Then by Lemma 1, there exists maximal convex subnearlattice$M \supseteq F$ and $n \notin M$. But a convex subnearlattice containing a filter is itself a filter. Then by (vi), M is a filter. Now, $a \in M$ and $b \vee c \in M$ imply $a \wedge b \in M$ or $a \wedge c \in M$ as M is prime. This implies $n \in M$ which is a contradiction. Hence $a \wedge (b \vee c) \leq n \leq a \vee (b \wedge c)$. Therefore, S is n-distributive.

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Corollary(2.11): In an n-distributive nearlattice every filter not containing n is contained in a prime filter.

Proof: This is trivial by **Lemma (2.1)** and **Theorem (2.10)**.

Theorem (2.12): Let S be an n-distributive nearlattice. If $A \neq \{n\}$and $A = \cap \{I \in I_n(S): I \neq \{n\}\}$, then$A^{\perp_n} = \{x \in S: \{x\}^{\perp_n} \neq \{n\}\}$.

Proof: Let $x \in A^{\perp_n}$. Then $m(x,n,a) = n$ for all $x \in A$. Since $A \neq \{n\}$so $\{x\}^{\perp_n} \neq \{n\}$. Hence $x \in$ R.H.S.So $A^{\perp_n} \subseteq$ R.H.S.Conversely, let $x \in$ R.H.S. Since S is n-distributive so $\{x\}^{\perp_n}$ is an n-ideal and so $\{x\}^{\perp_n} \neq \{n\}$. Then $A \subseteq \{x\}^{\perp_n}$ and so $A^{\perp_n} \supseteq \{x\}^{\perp_n \perp_n}$ .Therefore, $A^{\perp_n} = \{x \in S: \{x\}^{\perp_n} \neq \{n\}\}$.

Theorem (2.13): Let S be a nearlattice with a central element n. Then S is$n$-distributive if and only if for a convex subnearlattice$F$ disjoint with $\{x\}^{\perp_n}(x \in S)$, there exists a prime convex subnearlattice $P \supseteq F$ and disjoint with$\{x\}^{\perp_n}$.

Proof: Let S be n-distributive and F be a convex subnearlattice disjoint from $\{x\}^{\perp_n}$. Then by Zorn's Lemma, there exists a maximal convex subnearlattice$P$ disjoint from $\{x\}^{\perp_n}$. Since $P = (P] \cap [P)$ so either $(P] \cap \{x\}^{\perp_n} = \phi$or $[P) \cap \{x\}^{\perp_n} = \phi$. Thus by the maximality of P, it is either an ideal or a filter. Without loss of generality, let P be a filter. We claim that $x \in P$. If not $P \vee [x) \supset P$. Then by the maximality of P, $\left(P \vee [x)\right) \cap \{x\}^{\perp_n} \neq \phi$.Let $t \in \left(P \vee [x)\right) \cap \{x\}^{\perp_n}$. Then $t \geq p \wedge x$ for some $p \in P$and $t \wedge x \leq n \leq t \vee x$. Thus $p \wedge x \leq t \wedge s \leq n$. hence$m(p \vee n, n, x) = n$ which implies $p \vee n \in \{x\}^{\perp_n}$. But $p \vee n \in P$ as P is a filter. This gives a contradiction to the fact that $P \cap \{x\}^{\perp_n} = \phi$. Therefore $x \in P$.Let $z \notin P$, then$\left(P \vee [z)\right) \cap \{x\}^{\perp_n} \neq \phi$.Let $y \in \left(P \vee [z)\right) \cap \{x\}^{\perp_n}$. Then $y \wedge x \leq n \leq y \vee x$ and $y \geq p_1 \wedge z$ for some $p_1 \in P$ so $p_1 \wedge x \wedge z \leq y \wedge x \leq n$. Hence $m(z, n, (p_1 \wedge x) \vee n) = n$ where $(p_1 \wedge x) \vee n \in P$ as P is a filter. Then by **Lemma (2.2)**, P is a maximal filter not containing$n$. Therefore, by **Theorem (2.10)**, P is Prime.

Conversely, let $< x >_n \cap < y >_n = \{n\}$and $< x >_n \cap < z >_n = \{n\}$. We need to prove that $< x >_n \cap (< y >_n \vee < z >_n) = \{n\}$. That is, $x \wedge (y \vee z) \nleq n$.Then $[y \vee z) \cap \{x\}^{\perp_n} = \phi$. Otherwise $t \in [y \vee z) \cap \{x\}^{\perp_n}$ implies $t \wedge x \leq n \leq t \vee x$ and $t \geq y \vee z$.These imply $x \wedge (y \vee z) \leq t \wedge x \leq n$ is a contradiction. So there exists a prime filter P containing $[y \vee z)$ disjoint with $\{x\}^{\perp_n}$. Since $z \in \{x\}^{\perp_n}$ so $y, z \notin P$. Hence $y \vee z \notin P$ as P is aprime filter. This implies $P \not\supset [y \vee z]$ is a contradiction. Dually by taking $x \vee (y \wedge z) \ngeq n$, we would have another contradiction. Therefore,$x \wedge (y \vee z) \leq n \leq x \vee (y \wedge z)$ and so S is n-distributive.

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III. Conclusion

In this paper, we generalize the concept of 0-distributive lattice and n-distributive lattice where n is a neutral element of this lattice and give the notion of n-distributive nearlattice where n is a central element of this nearlattice. We also include several nice characterizations of n-distributive nearlattices and prove some interesting results on$n$-distributive nearlattices.

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