

# Filters on posets and generalizations

Victor Porton

77711, Metzada 107-39, Ashdod, Israel

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## Abstract

Studied in details properties of filters on lattices, filters on posets, and certain generalizations thereof. Also done some more general lattice theory research. Posed several open problems. Detailed study of filters is required for my ongoing research which will be published as "Algebraic General Topology" series.

*Keywords:* filters, ideals, lattice of filters, pseudodifference, pseudocomplement

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**A.M.S. subject classification:** 54A20, 06A06, 06B99

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*Email address:* porton@narod.ru (Victor Porton)  
*URL:* <http://www.mathematics21.org> (Victor Porton)

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## 1. Preface

This article is intended to collect in one document the known properties of filters on posets (and some generalizations thereof, namely “filtrators” defined below).

It seems that until now were published no reference on the theory of filters. This text is to fill the gap.

This text will also serve as the reference base for my further articles. It is too hard to find theorems about filters in the literature and even to check if a particular theorem is proved somewhere in the literature. This text provides a definitive place to refer as to the collection of theorems about filters.

Detailed study of filters is required for my ongoing research which will be published as ”Algebraic General Topology” series.

This text contains well known theorems as well as some seemingly new results. Although it is hard to differentiate which of the results are new. Also here are several open problems.

In place of studying filters in this article are instead researched what the author calls “filter objects”. Filter objects are basically the lattice of filters ordered reverse to set inclusion, with principal filters equated with the poset element which generates them. (See below for formal definition of “filter objects”).

Although our primary interest are properties of filters on a set, in this work are instead researched the more general theory of “filtrators” (see below).

## 2. Notation and basic results

We denote  $\mathcal{P}S$  the set of all subsets of a set  $S$ .

$\langle f \rangle X \stackrel{\text{def}}{=} \{fx \mid x \in X\}$  for any set  $X$  and function  $f$ .

### 2.1. Intersecting and joining elements

Let  $\mathfrak{A}$  is a poset with least element 0.

**Definition 1** I will call elements  $a$  and  $b$  **intersecting** and denote  $a \not\asymp b$  when

$$\exists c \in \mathfrak{A} : (c \neq 0 \wedge c \subseteq a \wedge c \subseteq b).$$

**Definition 2**  $a \asymp b \stackrel{\text{def}}{=} \neg(a \not\asymp b)$ .

**Obvious 1** If  $\mathfrak{A}$  is a meet-semilattice with least element 0 then  $a \not\leq b \Leftrightarrow a \cap b \neq 0$ .

**Obvious 2**  $a_0 \not\leq b_0 \wedge a_1 \supseteq a_0 \wedge b_1 \supseteq b_0 \Rightarrow a_1 \not\leq b_1$ .

Let now  $\mathfrak{A}$  is a poset with greatest element 1.

**Definition 3** I will call elements  $a$  and  $b$  **joining** and denote  $a \equiv b$  when

$$\nexists c \in \mathfrak{A} : (c \neq 1 \wedge c \supseteq a \wedge c \supseteq b).$$

**Definition 4**  $a \not\equiv b \stackrel{\text{def}}{=} \neg(a \equiv b)$ .

**Obvious 3** *Intersecting is the dual of non-joining.*

**Obvious 4** If  $\mathfrak{A}$  is a join-semilattice with greatest element 1 then  $a \equiv b \Leftrightarrow a \cup b = 1$ .

**Obvious 5**  $a_0 \equiv b_0 \wedge a_1 \supseteq a_0 \wedge b_1 \supseteq b_0 \Rightarrow a_1 \equiv b_1$ .

## 2.2. Atoms of a poset

I will denote  $(\text{atoms}^{\mathfrak{A}} a)$  or just  $(\text{atoms } a)$  the set of atoms contained in element  $a$  of a poset  $\mathfrak{A}$  with least element.

**Definition 5** A poset  $\mathfrak{A}$  with least element is called **atomic** when  $\forall a \in \mathfrak{A} \setminus \{0\} : \text{atoms } a \neq \emptyset$ .

**Definition 6** **Atomistic lattice** is such lattice that  $a = \bigcup \text{atoms } a$  for every element  $a$  of this lattice.

**Proposition 1** Let  $\mathfrak{A}$  is a poset with least element. If  $a$  is an atom of  $\mathfrak{A}$  and  $B \in \mathfrak{A}$  then  $a \subseteq B \Leftrightarrow a \not\leq B$ .

**Proof**

$\Rightarrow a \subseteq B \Rightarrow a \subseteq a \wedge a \subseteq B$ , thus  $a \not\leq B$  because  $a \neq 0$ .

$\Leftarrow a \not\leq B$  implies existence of  $x \neq 0$  such that  $x \subseteq B$  and  $x \subseteq a$ . Because  $a$  is an atom, we have  $x = a$ . So  $a \subseteq B$ .

□

**Theorem 1** If  $\mathfrak{A}$  is a distributive lattice with least element then

$$\text{atoms}(a \cup b) = \text{atoms } a \cup \text{atoms } b$$

for every  $a, b \in \mathfrak{A}$ .

**Proof** For any atomic element  $c$

$$\begin{aligned}
c \in \text{atoms}(a \cup b) &\Leftrightarrow \\
c \cap (a \cup b) \neq 0 &\Leftrightarrow \\
(c \cap a) \cup (c \cap b) \neq 0 &\Leftrightarrow \\
c \cap a \neq 0 \vee c \cap b \neq 0 &\Leftrightarrow \\
c \in \text{atoms } a \vee c \in \text{atoms } b. &
\end{aligned}$$

□

**Theorem 2**  $\text{atoms} \bigcap S = \bigcap \langle \text{atoms} \rangle S$  whenever  $\bigcap S$  is defined for every  $S \in \mathcal{P}\mathfrak{A}$  where  $\mathfrak{A}$  is a poset with least element.

**Proof** For any atom  $c$

$$\begin{aligned}
c \in \text{atoms} \bigcap S &\Leftrightarrow \\
c \subseteq \bigcap S &\Leftrightarrow \\
\forall a \in S : c \subseteq a &\Leftrightarrow \\
\forall a \in S : c \in \text{atoms } a &\Leftrightarrow \\
c \in \bigcap \langle \text{atoms} \rangle S. &
\end{aligned}$$

□

**Corollary 1**  $\text{atoms}(a \cap b) = \text{atoms } a \cap \text{atoms } b$  for arbitrary meet-semilattice with least element.

**Theorem 3** A complete boolean lattice is atomic iff it is atomistic.

**Proof**

⇐ Obvious.

⇒ Let  $\mathfrak{A}$  is an atomic boolean lattice. Let  $a \in \mathfrak{A}$ . Suppose  $b = \bigcup \text{atoms } a \subset a$ .  
If  $x \in \text{atoms}(a \setminus b)$  then  $x \subseteq a \setminus b$  and so  $x \subseteq a$  and hence  $x \subseteq b$ . But we have  $x = x \cap b \subseteq (a \setminus b) \cap b = 0$  what contradicts to our supposition.

□

### 2.3. Difference and complement

**Definition 7** Let  $\mathfrak{A}$  is a distributive lattice with least element 0. The **difference** (denoted  $a \setminus b$ ) of elements  $a$  and  $b$  is such  $c \in \mathfrak{A}$  that  $b \cap c = 0$  and  $a \cup b = b \cup c$ . I will call  $b$  **subtractive** from  $a$  when  $a \setminus b$  exists.

**Theorem 4** *If  $\mathfrak{A}$  is a distributive lattice with least element 0, there exists no more than one difference of elements  $a, b \in \mathfrak{A}$ .*

**Proof** Let  $c$  and  $d$  are both differences  $a \setminus b$ . Then  $b \cap c = b \cap d = 0$  and  $a \cup b = b \cup c = b \cup d$ . So

$$c = c \cap (b \cup c) = c \cap (b \cup d) = (c \cap b) \cup (c \cap d) = 0 \cup (c \cap d) = c \cap d.$$

Analogously,  $d = d \cap c$ . Consequently  $c = c \cap d = d \cap c = d$ . □

**Definition 8** *I will call  $b$  **complementive** to  $a$  when there exists  $c \in \mathfrak{A}$  such that  $b \cap c = 0$  and  $b \cup c = a$ .*

**Proposition 2**  *$b$  is complementive to  $a$  iff  $b$  is subtractive from  $a$  and  $b \subseteq a$ .*

**Proof**

$\Leftarrow$  Obvious.

$\Rightarrow$  We deduce  $b \subseteq a$  from  $b \cup c = a$ . Thus  $a \cup b = a = b \cup c$ . □

**Proposition 3** *If  $b$  is complementive to  $a$  then  $(a \setminus b) \cup b = a$ .*

**Proof** Because  $b \subseteq a$  by the previous proposition. □

**Definition 9** *Let  $\mathfrak{A}$  is a bounded distributive lattice. The **complement** (denoted  $\bar{a}$ ) of element  $a \in \mathfrak{A}$  is such  $b \in \mathfrak{A}$  that  $a \cap b = 0$  and  $a \cup b = 1$ .*

**Proposition 4** *If  $\mathfrak{A}$  is a bounded distributive lattice then  $\bar{\bar{a}} = 1 \setminus a$ .*

**Proof**  $b = \bar{a} \Leftrightarrow b \cap a = 0 \wedge b \cup a = 1 \Leftrightarrow b \cap a = 0 \wedge 1 \cup a = a \cup b \Leftrightarrow b = 1 \setminus a$ . □

**Corollary 2** *If  $\mathfrak{A}$  is a bounded distributive lattice then exists no more than one complement of an element  $a \in \mathfrak{A}$ .*

**Definition 10** *An element of bounded distributive lattice is called **complementmented** when its complement exists.*

**Definition 11** *A distributive lattice is a **complementmented lattice** iff every its element is complementmented.*

**Proposition 5** *For a distributive lattice  $(a \setminus b) \setminus c = a \setminus (b \cup c)$  if  $a \setminus b$  and  $(a \setminus b) \setminus c$  are defined.*

**Proof**  $((a \setminus b) \setminus c) \cap c = 0$ ;  $((a \setminus b) \setminus c) \cup c = (a \setminus b) \cup c$ ;  $(a \setminus b) \cap b = 0$ ;  
 $(a \setminus b) \cup b = a \cup b$ .

We need to prove  $((a \setminus b) \setminus c) \cap (b \cup c) = 0$  and  $((a \setminus b) \setminus c) \cup (b \cup c) = a \cup (b \cup c)$ .  
 In fact,

$$\begin{aligned}
 ((a \setminus b) \setminus c) \cap (b \cup c) &= \\
 (((a \setminus b) \setminus c) \cap b) \cup (((a \setminus b) \setminus c) \cap c) &= \\
 (((a \setminus b) \setminus c) \cap b) \cup 0 &= \\
 ((a \setminus b) \setminus c) \cap b &\subseteq \\
 (a \setminus b) \cap b &= 0,
 \end{aligned}$$

so  $((a \setminus b) \setminus c) \cap (b \cup c) = 0$ ;

$$\begin{aligned}
 ((a \setminus b) \setminus c) \cup (b \cup c) &= \\
 (((a \setminus b) \setminus c) \cup c) \cup b &= \\
 (a \setminus b) \cup c \cup b &= \\
 ((a \setminus b) \cup b) \cup c &= \\
 a \cup b \cup c.
 \end{aligned}$$

□

#### 2.4. Center of a lattice

**Definition 12** The **center**  $Z(\mathfrak{A})$  of a bounded distributive lattice  $\mathfrak{A}$  is the set of its complemented elements.

**Remark 1** For definition of center of non-distributive lattices see [3].

**Remark 2** In [9] the word center and the notation  $Z(\mathfrak{A})$  is used in a different sense.

**Definition 13** A complete lattice  $\mathfrak{A}$  is **join infinite distributive** when  $x \cap \bigcup S = \bigcup \langle x \cap \rangle S$ ; complete lattice is **meet infinite distributive** when  $x \cup \bigcap S = \bigcap \langle x \cup \rangle S$  for all  $x \in \mathfrak{A}$  and  $S \in \mathcal{P}\mathfrak{A}$ .

**Definition 14** **Infinitely distributive complete lattice** is a complete lattice which is both join infinite distributive and meet infinite distributive.

**Definition 15** A sublattice  $K$  of a complete lattice  $L$  is a closed sublattice of  $L$  if  $K$  contains the meet and the join of any its nonempty subset.

**Theorem 5** Center of a infinitely distributive lattice is its closed sublattice.

**Proof** See [6].

□

**Remark 3** See [7] for a more strong result.

**Theorem 6** *The center of a bounded distributive lattice constitutes its sublattice.*

**Proof** Let  $\mathfrak{A}$  is a bounded distributive lattice and  $Z(\mathfrak{A})$  is its center. Let  $a, b \in Z(\mathfrak{A})$ . Consequently  $\bar{a}, \bar{b} \in Z(\mathfrak{A})$ . Then  $\bar{a} \cup \bar{b}$  is the complement of  $a \cap b$  because

$$\begin{aligned}(a \cap b) \cap (\bar{a} \cup \bar{b}) &= (a \cap b \cap \bar{a}) \cup (a \cap b \cap \bar{b}) = 0 \cup 0 = 0 \quad \text{and} \\ (a \cap b) \cup (\bar{a} \cup \bar{b}) &= (a \cup \bar{a} \cup \bar{b}) \cap (b \cup \bar{a} \cup \bar{b}) = 1 \cap 1 = 1.\end{aligned}$$

So  $a \cap b$  is complemented, analogously  $a \cup b$  is complemented.  $\square$

**Theorem 7** *The center of a bounded distributive lattice constitutes a boolean lattice.*

**Proof** Because it is a distributive complemented lattice.  $\square$

### 2.5. Galois connections

See [1] and [5] for more detailed treatment of Galois connections.

**Definition 16** *Let  $\mathfrak{A}$  and  $\mathfrak{B}$  are two posets. A **Galois connection** between  $\mathfrak{A}$  and  $\mathfrak{B}$  is a pair of functions  $f = (f^*; f_*)$  with  $f^* : \mathfrak{A} \rightarrow \mathfrak{B}$  and  $f_* : \mathfrak{B} \rightarrow \mathfrak{A}$  such that:*

$$\forall x \in \mathfrak{A}, y \in \mathfrak{B} : (f^*x \subseteq^{\mathfrak{B}} y \Leftrightarrow x \subseteq^{\mathfrak{A}} f_*y).$$

$f_*$  is called **upper adjoint** of  $f^*$  and  $f^*$  is called **lower adjoint** of  $f_*$ .

**Theorem 8** *A pair  $(f^*; f_*)$  of functions  $f^* : \mathfrak{A} \rightarrow \mathfrak{B}$  and  $f_* : \mathfrak{B} \rightarrow \mathfrak{A}$  is a Galois connection iff both of the following:*

1.  $f^*$  and  $f_*$  are monotone.
2.  $x \subseteq^{\mathfrak{A}} f_*f^*x$  and  $f^*f_*y \subseteq^{\mathfrak{B}} y$  for every  $x \in \mathfrak{A}$  and  $y \in \mathfrak{B}$ .

**Proof**

$$\Rightarrow 2. \quad x \subseteq^{\mathfrak{A}} f_*f^*x \text{ since } f^*x \subseteq^{\mathfrak{B}} f^*x; \quad f^*f_*y \subseteq^{\mathfrak{B}} y \text{ since } f_*y \subseteq^{\mathfrak{A}} f_*y.$$

1. Let  $a, b \in \mathfrak{A}$  and  $a \subseteq^{\mathfrak{A}} b$ . Then  $a \subseteq^{\mathfrak{A}} b \subseteq^{\mathfrak{A}} f_*f^*b$ . So by definition  $f^*a \subseteq f^*b$  that is  $f^*$  is monotone. Analogously  $f_*$  is monotone.

$$\Leftarrow f^*x \subseteq^{\mathfrak{B}} y \Rightarrow f_*f^*x \subseteq^{\mathfrak{A}} f_*y \Rightarrow x \subseteq^{\mathfrak{A}} f_*y. \text{ The other direction is analogous.}$$

$\square$

**Theorem 9**

$$1. f^* \circ f_* \circ f^* = f^*.$$

$$2. f_* \circ f^* \circ f_* = f_*.$$

**Proof**

1. Let  $x \in \mathfrak{A}$ . We have  $x \subseteq^{\mathfrak{A}} f_* f^* x$ ; consequently  $f^* x \subseteq^{\mathfrak{B}} f^* f_* f^* x$ . On the other hand,  $f^* f_* f^* x \subseteq^{\mathfrak{B}} f^* x$ . So  $f^* f_* f^* x = f^* x$ .

2. Analogously. □

**Proposition 6**  $f^* \circ f_*$  and  $f_* \circ f^*$  are idempotent.

**Proof**  $f^* \circ f_*$  is idempotent because  $f^* f_* f^* f_* y = f^* f_* y$ .  $f_* \circ f^*$  is similar. □

**Theorem 10** Each of two adjoints is uniquely determined by the other.

**Proof** Let  $p$  and  $q$  are both upper adjoints of  $f^*$ . We have for all  $x \in \mathfrak{A}$  and  $y \in \mathfrak{B}$ :

$$x \subseteq p(y) \Leftrightarrow f(x) \subseteq y \Leftrightarrow x \subseteq q(y).$$

For  $x = p(y)$  we obtain  $p(y) \subseteq q(y)$  and for  $x = q(y)$  we obtain  $q(y) \subseteq p(y)$ . So  $p(y) = q(y)$ . □

**Theorem 11** Let  $f$  is a monotone function from  $\mathfrak{A}$  to  $\mathfrak{B}$ .

1. Both:

1. If  $g(b) = \max \{x \in \mathfrak{A} \mid fx \subseteq b\}$  is defined for every  $b \in \mathfrak{B}$  then  $g$  is the upper adjoint of  $f$ .

2. If  $g$  is the upper adjoint of  $f$  then  $g(b) = \max \{x \in \mathfrak{A} \mid fx \subseteq b\}$  for every  $b \in \mathfrak{B}$ .

2. Both:

1. If  $g(b) = \min \{x \in \mathfrak{A} \mid fx \supseteq b\}$  is defined for every  $b \in \mathfrak{B}$  then  $g$  is the lower adjoint of  $f$ .

2. If  $g$  is the lower adjoint of  $f$  then  $g(b) = \min \{x \in \mathfrak{A} \mid fx \supseteq b\}$  for every  $b \in \mathfrak{B}$ .

**Proof** We will prove only the first as the second is its dual.

1. Let  $g(b) = \max \{x \in \mathfrak{A} \mid fx \subseteq b\}$  for every  $b \in \mathfrak{B}$ . Then

$$x \subseteq gy \Leftrightarrow x \subseteq \max \{x \in \mathfrak{A} \mid fx \subseteq y\} \Rightarrow fx \subseteq y$$

(because  $f$  is monotone) and

$$x \subseteq gy \Leftrightarrow x \subseteq \max \{x \in \mathfrak{A} \mid fx \subseteq y\} \Leftarrow fx \subseteq y.$$

So  $fx \subseteq y \Leftrightarrow x \subseteq gy$  that is  $f$  is the lower adjoint of  $g$ .

2. We have

$$\begin{aligned} g(b) = \max \{x \in \mathfrak{A} \mid fx \subseteq b\} &\Leftrightarrow \\ fgb \subseteq b \wedge \forall x \in \mathfrak{A} : (fx \subseteq b \Rightarrow fgb \subseteq b) &\Leftarrow \\ fgb \subseteq b & \end{aligned}$$

what is true by properties of adjoints.

□

**Theorem 12** *Let  $f$  is a function from a poset  $\mathfrak{A}$  to a poset  $\mathfrak{B}$ .*

1. *If  $f$  is an upper adjoint,  $f$  preserves all existing infima in  $\mathfrak{A}$ .*
2. *If  $\mathfrak{A}$  is a complete lattice and  $f$  preserves all infima, then  $f$  is an upper adjoint.*
3. *If  $f$  is a lower adjoint,  $f$  preserves all existing suprema in  $\mathfrak{A}$ .*
4. *If  $\mathfrak{A}$  is a complete lattice and  $f$  preserves all suprema, then  $f$  is a lower adjoint.*

**Proof** We will prove only first two items because the rest items are similar.

1. Let  $S \in \mathcal{P}\mathfrak{A}$  and  $\bigcap S$  exists.  $f \bigcap S$  is a lower bound for  $\langle f \rangle S$  because  $f$  is order-preserving. If  $a$  is a lower bound for  $\langle f \rangle S$  then  $\forall x \in S : a \subseteq fx$  that is  $\forall x \in S : x \subseteq ga$  where  $g$  is the lower adjoint of  $f$ . Thus  $\bigcap S \subseteq ga$  and hence  $f \bigcap S \subseteq a$ . So  $f \bigcap S$  is the greatest lower bound for  $\langle f \rangle S$ .
2. Let  $\mathfrak{A}$  is a complete lattice and  $f$  preserves all infima. Let  $g(a) = \bigcap \{x \in \mathfrak{A} \mid fx \supseteq a\}$ . Since  $f$  preserves infima, we have

$$f(g(a)) = \bigcap \{f(x) \mid x \in \mathfrak{A}, f(x) \supseteq a\} \supseteq a.$$

$$g(f(b)) = \bigcap \{x \in \mathfrak{A} \mid fx \supseteq fb\} \subseteq b.$$

So  $f$  is the upper adjoint of  $g$ .

□

**Corollary 3** *Let  $f$  is a function from a complete lattice  $\mathfrak{A}$  to a poset  $\mathfrak{B}$ . Then:*

1.  *$f$  is an upper adjoint iff  $f$  preserves all infima in  $\mathfrak{A}$ .*
2.  *$f$  is a lower adjoint iff  $f$  preserves all suprema in  $\mathfrak{A}$ .*

2.6. Co-Brouwerian Lattices

**Definition 17** Let  $\mathfrak{A}$  is a poset with least element. Let  $a \in \mathfrak{A}$ . **Pseudocomplement** of  $a$  is

$$\max \{c \in \mathfrak{A} \mid c \asymp a\}.$$

If  $z$  is pseudocomplement of  $a$  we will denote  $z = a^*$ .

**Definition 18** Let  $\mathfrak{A}$  is a poset with greatest element. Let  $a \in \mathfrak{A}$ . **Dual pseudocomplement** of  $a$  is

$$\min \{c \in \mathfrak{A} \mid c \equiv a\}.$$

If  $z$  is dual pseudocomplement of  $a$  we will denote  $z = a^+$ .

**Definition 19** Let  $\mathfrak{A}$  is a join-semilattice. Let  $a, b \in \mathfrak{A}$ . **Pseudodifference** of  $a$  and  $b$  is

$$\min \{z \in \mathfrak{A} \mid a \subseteq b \cup z\}.$$

If  $z$  is a pseudodifference of  $a$  and  $b$  we will denote  $z = a \setminus^* b$ .

**Remark 4** I do not require that  $a^*$  is undefined if there are no pseudocomplement of  $a$  and likewise for dual pseudocomplement and pseudodifference. In fact below I will define quasicomplement, dual quasicomplement, and quasidifference which will generalize pseudo-\* counterparts. I will denote  $a^*$  the more general case of quasicomplement than of pseudocomplement, and likewise for other notation.

**Obvious 6** Dual pseudocomplement is the dual of pseudocomplement.

**Definition 20** **Co-brouwerian lattice** is a lattice for which is defined pseudodifference of any two its elements.

**Proposition 7** Every co-brouwerian lattice  $\mathfrak{A}$  has least element.

**Proof** Let  $a$  is an arbitrary lattice element. Then  $a \setminus^* a = \min \{z \in \mathfrak{A} \mid a \subseteq a \cup z\} = \min \mathfrak{A}$ . So  $\min \mathfrak{A}$  exists.  $\square$

**Definition 21** **Co-Heyting lattice** is co-brouwerian lattice with greatest element.

**Theorem 13** For a co-brouwerian lattice  $a \cup -$  is an upper adjoint of  $- \setminus^* a$  for every  $a \in \mathfrak{A}$ .

**Proof**  $g(b) = \min \{x \in \mathfrak{A} \mid a \cup x \supseteq b\} = b \setminus^* a$  exists for every  $b \in \mathfrak{A}$  and thus is the lower adjoint of  $a \cup -$ .  $\square$

**Corollary 4**  $\forall a, x, y \in \mathfrak{A} : (x \setminus^* a \subseteq y \Leftrightarrow x \subseteq a \cup y)$  for a co-brouwerian lattice.

**Definition 22** Let  $a, b \in \mathfrak{A}$  where  $\mathfrak{A}$  is a complete lattice. Quasidifference  $a \setminus^* b$  is defined by the formula

$$a \setminus^* b = \bigcap \{z \in \mathfrak{A} \mid a \subseteq b \cup z\}.$$

**Remark 5** The more detailed theory of quasidifference (as well as quasicomplement and dual quasicomplement) will be considered below.

**Lemma 1**  $(a \setminus^* b) \cup b = a \cup b$  for elements  $a, b$  of a meet infinite distributive complete lattice.

**Proof**

$$\begin{aligned} (a \setminus^* b) \cup b &= \\ \bigcap \{z \in \mathfrak{A} \mid a \subseteq b \cup z\} \cup b &= \\ \bigcap \{z \cup b \mid z \in \mathfrak{A}, a \subseteq b \cup z\} &= \\ \bigcap \{t \in \mathfrak{A} \mid t \supseteq b, a \subseteq t\} &= \\ a \cup b. & \end{aligned}$$

□

**Theorem 14** The following are equivalent for a complete lattice  $\mathfrak{A}$ :

1.  $\mathfrak{A}$  is meet infinite distributive.
2.  $\mathfrak{A}$  is a co-brouwerian lattice.
3.  $\mathfrak{A}$  is a co-Heyting lattice.
4.  $a \cup -$  has lower adjoint for every  $a \in \mathfrak{A}$ .

**Proof**

(2)  $\Leftrightarrow$  (3) Obvious (taking in account completeness of  $\mathfrak{A}$ ).

(4)  $\Rightarrow$  (1) Let  $- \setminus^* a$  is the upper adjoint of  $a \cup -$ . Let  $S \in \mathcal{P}\mathfrak{A}$ . For every  $y \in S$  we have  $y \supseteq (a \cup y) \setminus^* a$  by properties of Galois connections; consequently  $y \supseteq (\bigcap \langle a \cup \rangle S) \setminus^* a$ ;  $\bigcap S \supseteq (\bigcap \langle a \cup \rangle S) \setminus^* a$ . So

$$a \cup \bigcap S \supseteq ((\bigcap \langle a \cup \rangle S) \setminus^* a) \cup a \supseteq \bigcap \langle a \cup \rangle S.$$

But  $a \cup \bigcap S \subseteq \bigcap \langle a \cup \rangle S$  is obvious.

(1)  $\Rightarrow$  (2) Let  $a \setminus^* b = \bigcap \{z \in \mathfrak{A} \mid a \subseteq b \cup z\}$ . To prove that  $\mathfrak{A}$  is a co-brouwerian lattice is enough to prove that  $a \subseteq b \cup (a \setminus^* b)$ . But it follows from the lemma.

(2) $\Rightarrow$ (4)  $a \setminus^* b = \min \{z \in \mathfrak{A} \mid a \subseteq b \cup z\}$ . So  $a \cup -$  is an upper adjoint of  $-\setminus^* a$ .

(1) $\Rightarrow$ (4) Because  $a \cup -$  preserves all meets.

□

**Corollary 5** *Co-brouwerian lattices are distributive.*

The following theorem is essentially borrowed from [8]:

**Theorem 15** *A lattice  $\mathfrak{A}$  with least element 0 is co-brouwerian with pseudodifference  $\setminus^*$  iff  $\setminus^*$  is a binary operation on  $\mathfrak{A}$  satisfying the following identities:*

1.  $a \setminus^* a = 0$ ;
2.  $a \cup (b \setminus^* a) = a \cup b$ ;
3.  $b \cup (b \setminus^* a) = b$ ;
4.  $(b \cup c) \setminus^* a = (b \setminus^* a) \cup (c \setminus^* a)$ .

**Proof**

$\Leftarrow$  We have

$$c \supseteq b \setminus^* a \Rightarrow c \cup a \supseteq a \cup (b \setminus^* a) = a \cup b \supseteq b;$$

$$c \cup a \supseteq b \Rightarrow c = c \cup (c \setminus^* a) \supseteq (a \setminus^* a) \cup (c \setminus^* a) = (a \cup c) \setminus^* a \supseteq b \setminus^* a.$$

So  $c \supseteq b \setminus^* a \Leftrightarrow c \cup a \supseteq b$  that is  $a \cup -$  is an upper adjoint of  $-\setminus^* a$ . By a theorem above our lattice is co-brouwerian. By an other theorem above  $\setminus^*$  is a pseudodifference.

$\Rightarrow$  1. Obvious.

2.

$$\begin{aligned} a \cup (b \setminus^* a) &= \\ a \cup \bigcap \{z \in \mathfrak{A} \mid b \subseteq a \cup z\} &= \\ \bigcap \{a \cup z \mid z \in \mathfrak{A}, b \subseteq a \cup z\} &= \\ a \cup b. & \end{aligned}$$

$$3. b \cup (b \setminus^* a) = b \cup \bigcap \{z \in \mathfrak{A} \mid b \subseteq a \cup z\} = \bigcap \{b \cup z \mid z \in \mathfrak{A}, b \subseteq a \cup z\} = b.$$

4. Obviously  $(b \cup c) \setminus^* a \supseteq b \setminus^* a$  and  $(b \cup c) \setminus^* a \supseteq c \setminus^* a$ , thus  $(b \cup c) \setminus^* a \supseteq (b \setminus^* a) \cup (c \setminus^* a)$ . We have

$$\begin{aligned}
(b \setminus^* a) \cup (c \setminus^* a) \cup a &= \\
((b \setminus^* a) \cup a) \cup ((c \setminus^* a) \cup a) &= \\
(b \cup a) \cup (c \cup a) &= \\
a \cup b \cup c &\supseteq \\
b \cup c. &
\end{aligned}$$

From this by the definition of adjoints:  $(b \setminus^* a) \cup (c \setminus^* a) \supseteq (b \cup c) \setminus^* a$ .

□

**Theorem 16**  $(\bigcup S) \setminus^* a = \bigcup \{x \setminus^* a \mid x \in S\}$  for  $a \in \mathfrak{A}$  and  $S \in \mathcal{P}\mathfrak{A}$  where  $\mathfrak{A}$  is a complete co-brouwerian lattice.

**Proof** Because lower adjoint preserves all suprema. □

**Theorem 17**  $(a \setminus^* b) \setminus^* c = a \setminus^* (b \cup c)$  for elements  $a, b, c$  of a complete co-brouwerian lattice.

**Proof**  $a \setminus^* b = \bigcap \{z \in \mathfrak{A} \mid a \subseteq b \cup z\}$ .

$$(a \setminus^* b) \setminus^* c = \{z \in \mathfrak{A} \mid a \setminus^* b \subseteq c \cup z\}.$$

$$a \setminus^* (b \cup c) = \bigcap \{z \in \mathfrak{A} \mid a \subseteq b \cup c \cup z\}.$$

Left to prove  $a \setminus^* b \subseteq c \cup z \Leftrightarrow a \subseteq b \cup c \cup z$ .

Let  $a \setminus^* b \subseteq c \cup z$ . Then  $a \cup b \subseteq b \cup c \cup z$  by the lemma and consequently  $a \subseteq b \cup c \cup z$ .

Let  $a \subseteq b \cup c \cup z$ . Then  $a \setminus^* b \subseteq (b \cup c \cup z) \setminus^* b \subseteq c \cup z$  by a theorem above. □

### 3. Straight maps and separation subsets

#### 3.1. Straight maps

**Definition 23** Let  $f$  is a monotone map from a meet-semilattice  $\mathfrak{A}$  to some poset  $\mathfrak{B}$ . I call  $f$  a **straight** map when

$$\forall a, b \in \mathfrak{A} : (fa \subseteq fb \Rightarrow fa = f(a \cap b)).$$

**Proposition 8** The following statements are equivalent for a monotone map  $f$ :

1.  $f$  is a straight map.
2.  $\forall a, b \in \mathfrak{A} : (fa \subseteq fb \Rightarrow fa \subseteq f(a \cap b))$ .
3.  $\forall a, b \in \mathfrak{A} : (fa \subseteq fb \Rightarrow fa \not\supseteq f(a \cap b))$ .

4.  $\forall a, b \in \mathfrak{A} : (fa \supset f(a \cap b) \Rightarrow fa \not\subseteq fb)$ .

**Proof**

(1) $\Leftrightarrow$ (2) $\Leftrightarrow$ (3) Due  $fa \supseteq f(a \cap b)$ .

(3) $\Leftrightarrow$ (4) Obvious. □

**Remark 6** The definition of straight map can be generalized for any poset  $\mathfrak{A}$  by the formula

$$\forall a, b \in \mathfrak{A} : (fa \subseteq fb \Rightarrow \exists c \in \mathfrak{A} : (c \subseteq a \wedge c \subseteq b \wedge fa = fc)).$$

This generalization is not yet researched however.

**Proposition 9** Let  $f$  is a monotone map from a meet-semilattice  $\mathfrak{A}$  to some poset  $\mathfrak{B}$ . If

$$\forall a, b \in \mathfrak{A} : (f(a \cap b) = fa \cap fb)$$

then  $f$  is a straight map.

**Proof** Let  $fa \subseteq fb$ . Then  $f(a \cap b) = fa \cap fb = fa$ . □

**Proposition 10** Let  $f$  is a monotone map from a meet-semilattice  $\mathfrak{A}$  to some poset  $\mathfrak{B}$ . If

$$\forall a, b \in \mathfrak{A} : (fa \subseteq fb \Rightarrow a \subseteq b)$$

then  $f$  is a straight map.

**Proof**  $fa \subseteq fb \Rightarrow a \subseteq b \Rightarrow a = a \cap b \Rightarrow fa = f(a \cap b)$ . □

**Theorem 18** If  $f$  is a straight monotone map from a meet-semilattice  $\mathfrak{A}$  then the following statements are equivalent:

1.  $f$  is an injection.
2.  $\forall a, b \in \mathfrak{A} : (fa \subseteq fb \Rightarrow a \subseteq b)$ .
3.  $\forall a, b \in \mathfrak{A} : (a \subset b \Rightarrow fa \subset fb)$ .
4.  $\forall a, b \in \mathfrak{A} : (a \subset b \Rightarrow fa \neq fb)$ .
5.  $\forall a, b \in \mathfrak{A} : (a \subset b \Rightarrow fa \not\supseteq fb)$ .
6.  $\forall a, b \in \mathfrak{A} : (fa \subseteq fb \Rightarrow a \not\supseteq b)$ .

**Proof**

- (1) $\Rightarrow$ (3) Let  $a, b \in \mathfrak{A}$ . Let  $fa = fb \Rightarrow a = b$ . Let  $a \subset b$ .  $fa \neq fb$  because  $a \neq b$ .  $fa \subseteq fb$  because  $a \subseteq b$ . So  $fa \subset fb$ .
- (2) $\Rightarrow$ (1) Let  $a, b \in \mathfrak{A}$ . Let  $fa \subseteq fb \Rightarrow a \subseteq b$ . Let  $fa = fb$ . Then  $a \subseteq b \wedge b \subseteq a$  and consequently  $a = b$ .
- (3) $\Rightarrow$ (2) Let  $\forall a, b \in \mathfrak{A} : (a \subset b \Rightarrow fa \subset fb)$ . Let  $a \not\subseteq b$ . Then  $a \supset a \cap b$ . So  $fa \supset f(a \cap b)$ . If  $fa \subseteq fb$  then  $fa \subseteq f(a \cap b)$  what is a contradiction.
- (3) $\Rightarrow$ (5) $\Rightarrow$ (4) Obvious.
- (4) $\Rightarrow$ (3) Because  $a \subset b \Rightarrow a \subseteq b \Rightarrow fa \subseteq fb$ .
- (5) $\Leftrightarrow$ (6) Obvious.

□

### 3.2. Separation subsets and full stars

**Definition 24**  $\partial_Y a = \{x \in Y \mid x \not\asymp a\}$  for an element  $a$  of a poset  $\mathfrak{A}$  with least element and  $Y \in \mathcal{P}\mathfrak{A}$ .

**Definition 25** *Full star* of  $a$  is  $\star a = \partial_{\mathfrak{A}} a$ .

**Proposition 11**  $\star$  is a straight monotone map.

**Proof** Monotonicity is obvious. Let  $\star a \not\subseteq \star(a \cap b)$ . Then exists  $x \in \star a$  such that  $x \notin \star(a \cap b)$ . So  $x \cap a \notin \star b$  but  $x \cap a \in \star a$  and consequently  $\star a \not\subseteq \star b$ . □

**Definition 26** A *separation subset* of a meet-semilattice  $\mathfrak{A}$  with least element is such its subset  $Y$  that

$$\forall a, b \in \mathfrak{A} : (\partial_Y a = \partial_Y b \Rightarrow a = b).$$

**Definition 27** I call *separable* such meet-semilattice with least element that  $\star$  is an injection.

**Obvious 7** A meet-semilattice with least element is separable iff it has separation subset.

**Definition 28** A poset  $\mathfrak{A}$  with least element has *disjunction property of Wallman* iff for any  $a, b \in \mathfrak{A}$  either  $b \subseteq a$  or there exists an element  $c \subseteq b$  such that  $c \neq 0$  and  $a \asymp c$ .

**Theorem 19** For a meet-semilattice with least element the following statements are equivalent:

1.  $\mathfrak{A}$  is separable.

2.  $\forall a, b \in \mathfrak{A} : (\star a \subseteq \star b \Rightarrow a \subseteq b)$ .
3.  $\forall a, b \in \mathfrak{A} : (a \subset b \Rightarrow \star a \subset \star b)$ .
4.  $\forall a, b \in \mathfrak{A} : (a \subset b \Rightarrow \star a \neq \star b)$ .
5.  $\forall a, b \in \mathfrak{A} : (a \subset b \Rightarrow \star a \not\subseteq \star b)$ .
6.  $\forall a, b \in \mathfrak{A} : (\star a \subseteq \star b \Rightarrow a \not\subseteq b)$ .
7.  $\mathfrak{A}$  conforms to Wallman's disjunction property.
8.  $\forall a, b \in \mathfrak{A} : (a \subset b \Rightarrow \exists c \in \mathfrak{A} \setminus \{0\} : (c \succ a \wedge c \subseteq b))$ .

**Proof**

(1) $\Leftrightarrow$ (2) $\Leftrightarrow$ (3) $\Leftrightarrow$ (4) $\Leftrightarrow$ (5) $\Leftrightarrow$ (6) By the above theorem.

(8) $\Rightarrow$ (4) Let disjunction property of Wallman holds. Let  $a \subset b$ . Then exists element  $c \subseteq b$  such that  $c \neq 0$  and  $c \cap a = 0$ . But  $c \cap b \neq 0$ . So  $\star a \neq \star b$ .

(2) $\Rightarrow$ (7) Let  $\mathfrak{A}$  is separable. Let  $a \not\subseteq b$ . Then  $\star a \not\subseteq \star b$  that is exists  $c \in \star a$  such that  $c \notin \star b$ , in other words  $c \cap a \neq 0$  and  $c \cap b = 0$ . Let  $d = c \cap a$ . Then  $d \subseteq a$  and  $d \neq 0$  and  $d \cap b = 0$ . So disjunction property of Wallman holds.

(7) $\Rightarrow$ (8) Obvious.

(8) $\Rightarrow$ (7) Let  $b \not\subseteq a$ . Then  $a \cap b \subset b$  that is  $a' \subset b$  where  $a' = a \cap b$ . Consequently  $\exists c \in \mathfrak{A} \setminus \{0\} : (c \succ a' \wedge c \subseteq b)$ . We have  $c \cap a = c \cap b \cap a = c \cap a'$ . So  $c \subseteq b$  and  $c \cap a = 0$ . Thus Wallman's disjunction property holds.

□

### 3.3. Atomically separable lattices

**Proposition 12** “atoms” is a straight monotone map (for any meet-semilattice with least element).

**Proof** Monotonicity is obvious. The rest follows from the formula

$$\text{atoms}(a \cap b) = \text{atoms } a \cap \text{atoms } b$$

(the corollary 1).

□

**Definition 29** I will call **atomically separable** such a poset with least element that “atoms” is an injection.

**Proposition 13** Any atomistic lattice with least element is atomically separable.

**Proof** We need to prove that  $\text{atoms } a = \text{atoms } b \Rightarrow a = b$ . But it is obvious because

$$a = \bigcup \text{atoms } a \quad \text{and} \quad b = \bigcup \text{atoms } b.$$

□

**Theorem 20** *If a lattice with least element is atomic and separable then it is atomistic.*

**Proof** Suppose the contrary that is  $a \supset \bigcup \text{atoms } a$ . Then, because our lattice is separable, exists  $c \in \mathfrak{A}$  such that  $c \cap a \neq 0$  and  $c \cap \bigcup \text{atoms } a = 0$ . There exist atom  $d \subseteq c$  such that  $d \subseteq c \cap a$ .  $d \cap \bigcup \text{atoms } a \subseteq c \cap \bigcup \text{atoms } a = 0$ . But  $d \in \text{atoms } a$ . Contradiction. □

**Theorem 21** *Any atomistic lattice with least element is atomically separable.*

**Proof** Let  $\mathfrak{A}$  is an atomistic lattice. Let  $a, b \in \mathfrak{A}$ ,  $a \subset b$ . Then  $\bigcup \text{atoms } a \subset \bigcup \text{atoms } b$  and consequently  $\text{atoms } a \subset \text{atoms } b$ . □

**Theorem 22** *Let  $\mathfrak{A}$  is an atomic meet-semilattice with least element. Then the following statements are equivalent:*

1.  $\mathfrak{A}$  is separable.
2.  $\mathfrak{A}$  is atomically separable.
3.  $\mathfrak{A}$  conforms to Wallman's disjunction property.
4.  $\forall a, b \in \mathfrak{A} : (a \subset b \Rightarrow \exists c \in \mathfrak{A} \setminus \{0\} : (c \asymp a \wedge c \subseteq b))$ .

**Proof**

(1)  $\Leftrightarrow$  (3)  $\Leftrightarrow$  (4) Proved above.

(2)  $\Rightarrow$  (4) Let our semilattice is atomically separable. Let  $a \subset b$ . Then  $\text{atoms } a \subset \text{atoms } b$  and so exists  $c \in \text{atoms } b$  such that  $c \notin \text{atoms } a$ .  $c \neq 0$  and  $c \subseteq b$ ;  $c \not\subseteq a$ , from which (taking in account that  $c$  is an atom)  $c \subseteq b$  and  $c \cap a = 0$ . So our semilattice conforms to the formula (4).

(4)  $\Rightarrow$  (2) Let formula (4) holds. Then for any elements  $a \subset b$  exists  $c \neq 0$  such that  $c \subseteq b$  and  $c \cap a = 0$ . Because  $\mathfrak{A}$  is atomic there exists atom  $d \subseteq c$ .  $d \in \text{atoms } b$  and  $d \notin \text{atoms } a$ . So  $\text{atoms } a \neq \text{atoms } b$  and  $\text{atoms } a \subseteq \text{atoms } b$ . Consequently  $\text{atoms } a \subset \text{atoms } b$ .

□

#### 4. Filtrators

**Definition 30** I will call a **filtrator** a pair  $(\mathfrak{A}; \mathfrak{Z})$  of a poset  $\mathfrak{A}$  and its subset  $\mathfrak{Z} \subseteq \mathfrak{A}$ . I call  $\mathfrak{A}$  the **base** of a filtrator and  $\mathfrak{Z}$  the **core** of a filtrator.

**Definition 31** I will call a **lattice filtrator** a pair  $(\mathfrak{A}; \mathfrak{Z})$  of a lattice  $\mathfrak{A}$  and its subset  $\mathfrak{Z} \subseteq \mathfrak{A}$ .

**Definition 32** I will call a **complete lattice filtrator** a pair  $(\mathfrak{A}; \mathfrak{Z})$  of a complete lattice  $\mathfrak{A}$  and its subset  $\mathfrak{Z} \subseteq \mathfrak{A}$ .

**Definition 33** I will call a **central filtrator** a filtrator  $(\mathfrak{A}; Z(\mathfrak{A}))$  where  $Z(\mathfrak{A})$  is the center of a bounded lattice  $\mathfrak{A}$ .

**Remark 7** One use of filtrators is the theory of filters where the base lattice (or the lattice of principal filters) is essentially considered as the core of the lattice of filters. See below for a more exact formulation. Our primary interest is the properties of filters on sets (that is the filtrator of filters on a set), but instead we will research more general theory of filtrators.

**Remark 8** An other important example of filtrators is **filtrator of funcoids** whose base is the set of funcoids [12] and whose core is the set of binary relations (or discrete funcoids).

**Definition 34** I will call **element** of a filtrator an element of its base.

**Definition 35**  $\text{up } a = \{c \in \mathfrak{Z} \mid c \supseteq a\}$  where  $a \in \mathfrak{A}$ .

**Definition 36**  $\text{down } a = \{c \in \mathfrak{Z} \mid c \subseteq a\}$  where  $a \in \mathfrak{A}$ .

**Remark 9** I have used “down” in an other sense in an earlier version of this text.

**Obvious 8** “up” and “down” are dual.

The main purpose of this text is knowing properties of the core of a filtrator to infer properties of the base of the filtrator, specifically properties of  $\text{up } a$  for every element  $a$ .

**Definition 37** I call a filtrator with **join-closed core** such filtrator  $(\mathfrak{A}; \mathfrak{Z})$  that  $\bigcup^{\mathfrak{Z}} S = \bigcup^{\mathfrak{A}} S$  whenever  $\bigcup^{\mathfrak{Z}} S$  exists for  $S \in \mathcal{P}\mathfrak{A}$ .

**Definition 38** I call a filtrator with **meet-closed core** such filtrator  $(\mathfrak{A}; \mathfrak{Z})$  that  $\bigcap^{\mathfrak{Z}} S = \bigcap^{\mathfrak{A}} S$  whenever  $\bigcap^{\mathfrak{Z}} S$  exists for  $S \in \mathcal{P}\mathfrak{A}$ .

**Definition 39** I call a filtrator with **finitely join-closed core** such filtrator  $(\mathfrak{A}; \mathfrak{Z})$  that  $a \cup^{\mathfrak{Z}} b = a \cup^{\mathfrak{A}} b$  whenever  $a \cup^{\mathfrak{Z}} b$  exists for  $a, b \in \mathfrak{Z}$ .

**Definition 40** I call a filtrator with **finitely meet-closed core** such filtrator  $(\mathfrak{A}; \mathfrak{Z})$  that  $a \cap^{\mathfrak{Z}} b = a \cap^{\mathfrak{A}} b$  whenever  $a \cap^{\mathfrak{Z}} b$  exists for  $a, b \in \mathfrak{Z}$ .

In practice we will deal mainly with filtrators with join-closed cores. Proving that a filtrator is with finitely meet-closed core may be a difficult problem. For example as of today it is not known whether the filtrator of functors is with finitely meet-closed core.

**Definition 41** *Filtered filtrator* is a filtrator  $(\mathfrak{A}; \mathfrak{Z})$  such that  $\forall a \in \mathfrak{A} : a = \bigcap^{\mathfrak{A}} \text{up } a$ .

**Definition 42** *Prefiltered filtrator* is a filtrator  $(\mathfrak{A}; \mathfrak{Z})$  such that “up” is injective.

**Definition 43** *Semifiltered filtrator* is a filtrator  $(\mathfrak{A}; \mathfrak{Z})$  such that

$$\forall a, b \in \mathfrak{A} : (\text{up } a \supseteq \text{up } b \Rightarrow a \subseteq b).$$

**Obvious 9** • *Every filtered filtrator is semifiltered.*

• *Every semifiltered filtrator is prefiltered.*

**Obvious 10** “up” is a straight map from  $\mathfrak{A}$  to the dual of the poset  $\mathcal{P}\mathfrak{Z}$  if  $(\mathfrak{A}; \mathfrak{Z})$  is a semifiltered filtrator.

**Theorem 23** *Each semifiltered filtrator is a filtrator with join-closed core.*

**Proof** Let  $(\mathfrak{A}; \mathfrak{Z})$  is a semifiltered filtrator. Let  $S \in \mathcal{P}\mathfrak{Z}$  and  $\bigcup^{\mathfrak{Z}} S$  is defined. We need to prove  $\bigcup^{\mathfrak{A}} S = \bigcup^{\mathfrak{Z}} S$ . That  $\bigcup^{\mathfrak{Z}} S$  is an upper bound for  $S$  is obvious. Let  $a \in \mathfrak{A}$  is an upper bound for  $S$ . Enough to prove that  $\bigcup^{\mathfrak{Z}} S \subseteq a$ . Really,

$$c \in \text{up } a \Rightarrow c \supseteq a \Rightarrow \forall x \in S : c \supseteq x \Rightarrow c \supseteq \bigcup^{\mathfrak{Z}} S \Rightarrow c \in \text{up } \bigcup^{\mathfrak{Z}} S;$$

so  $\text{up } a \subseteq \text{up } \bigcup^{\mathfrak{Z}} S$  and thus  $a \supseteq \bigcup^{\mathfrak{Z}} S$  because it is semifiltered.  $\square$

#### 4.1. Core part

**Definition 44** *The core part* of an element  $a \in \mathfrak{A}$  is  $\text{Cor } a = \bigcap^{\mathfrak{Z}} \text{up } a$ .

**Definition 45** *The dual core part* of an element  $a \in \mathfrak{A}$  is  $\text{Cor}' a = \bigcup^{\mathfrak{Z}} \text{down } a$ .

**Obvious 11**  $\text{Cor}'$  is dual of  $\text{Cor}$ .

**Theorem 24**  $\text{Cor } a \subseteq a$  whenever  $\text{Cor } a$  exists for any element  $a$  of a filtered filtrator.

**Proof**  $\text{Cor } a = \bigcap^{\mathfrak{Z}} \text{up } a \subseteq \bigcap^{\mathfrak{A}} \text{up } a = a$ .  $\square$

**Corollary 6**  $\text{Cor } a \in \text{down } a$  whenever  $\text{Cor } a$  exists for any element  $a$  of a filtered filtrator.

**Theorem 25**  $\text{Cor}' a \subseteq a$  whenever  $\text{Cor}' a$  exists for any element  $a$  of a filtrator with join-closed core.

**Proof**  $\text{Cor}' a = \bigcup^3 \text{down } a = \bigcup^{\mathfrak{A}} \text{down } a \subseteq a$ . □

**Corollary 7**  $\text{Cor}' a \in \text{down } a$  whenever  $\text{Cor}' a$  exists for any element  $a$  of a filtrator with join-closed core.

**Proposition 14**  $\text{Cor}' a \subseteq \text{Cor } a$  whenever both  $\text{Cor } a$  and  $\text{Cor}' a$  exist for any element  $a$  of a filtrator with join-closed core.

**Proof**  $\text{Cor } a = \bigcap^3 \text{up } a \supseteq \text{Cor}' a$  because  $\forall A \in \text{up } a : \text{Cor}' a \subseteq A$ . □

**Theorem 26**  $\text{Cor}' a = \text{Cor } a$  whenever both  $\text{Cor } a$  and  $\text{Cor}' a$  exist for any element  $a$  of a filtered filtrator.

**Proof** It is with join-closed core because it is semifiltered. So  $\text{Cor}' a \subseteq \text{Cor } a$ .  $\text{Cor } a \in \text{down } a$ . So  $\text{Cor } a \subseteq \bigcup^3 \text{down } a = \text{Cor}' a$ . □

**Obvious 12**  $\text{Cor}' a = \max \text{down } a$  for an element  $a$  of a filtrator with join-closed core.

#### 4.2. Filtrators with separable core

**Definition 46** Let  $\mathfrak{A}$  is a filtrator with least element.  $\mathfrak{A}$  is a **filtrator with separable core** when

$$\forall x, y \in \mathfrak{A} : (x \succ^{\mathfrak{A}} y \Rightarrow \exists X \in \text{up } x : X \succ^{\mathfrak{A}} y).$$

**Proposition 15** Let  $\mathfrak{A}$  is a filtrator with least element.  $\mathfrak{A}$  is a filtrator with separable core iff

$$\forall x, y \in \mathfrak{A} : (x \succ^{\mathfrak{A}} y \Rightarrow \exists X \in \text{up } x, Y \in \text{up } y : X \succ^{\mathfrak{A}} Y).$$

**Proof**

$\Rightarrow$  Apply the definition twice.

$\Leftarrow$  Obvious. □

**Definition 47** Let  $\mathfrak{A}$  is a filtrator with least element.  $\mathfrak{A}$  is a **filtrator with co-separable core** when

$$\forall x, y \in \mathfrak{A} : (x \equiv^{\mathfrak{A}} y \Rightarrow \exists X \in \text{down } x : X \equiv^{\mathfrak{A}} y).$$

**Obvious 13** *Co-separability is the dual of separability.*

**Proposition 16** *Let  $\mathfrak{A}$  is a filtrator with least element.  $\mathfrak{A}$  is a filtrator with co-separable core iff*

$$\forall x, y \in \mathfrak{A} : (x \equiv^{\mathfrak{A}} y \Rightarrow \exists X \in \text{down } x, Y \in \text{down } y : X \equiv^{\mathfrak{A}} Y).$$

**Proof** By duality. □

4.3. *Intersecting and joining with an element of the core*

**Definition 48** *I call **down-aligned** filtrator such a filtrator  $(\mathfrak{A}; \mathfrak{B})$  that  $\mathfrak{A}$  and  $\mathfrak{B}$  have common least element. (Let's denote it 0.)*

**Definition 49** *I call **up-aligned** filtrator such a filtrator  $(\mathfrak{A}; \mathfrak{B})$  that  $\mathfrak{A}$  and  $\mathfrak{B}$  have common greatest element. (Let's denote it 1.)*

**Theorem 27** *For a filtrator  $(\mathfrak{A}; \mathfrak{B})$  where  $\mathfrak{B}$  is a boolean lattice, for every  $B \in \mathfrak{B}$ ,  $\mathcal{A} \in \mathfrak{A}$ :*

1.  $B \succ^{\mathfrak{A}} \mathcal{A} \Leftrightarrow \overline{B} \supseteq \mathcal{A}$  if it is down-aligned, with finitely meet-closed and separable core;
2.  $B \equiv^{\mathfrak{A}} \mathcal{A} \Leftrightarrow \overline{B} \subseteq \mathcal{A}$  if it is up-aligned, with finitely join-closed and co-separable core.

**Proof** We will prove only the first as the second is dual.

$$\begin{aligned} B \succ^{\mathfrak{A}} \mathcal{A} &\Leftrightarrow \\ \exists A \in \text{up } \mathcal{A} : B \succ^{\mathfrak{A}} A &\Leftrightarrow \\ \exists A \in \text{up } \mathcal{A} : B \cap^{\mathfrak{A}} A = 0 &\Leftrightarrow \\ \exists A \in \text{up } \mathcal{A} : B \cap^{\mathfrak{B}} A = 0 &\Leftrightarrow \\ \exists A \in \text{up } \mathcal{A} : \overline{B} \supseteq A &\Leftrightarrow \\ \overline{B} \in \text{up } \mathcal{A} &\Leftrightarrow \\ \overline{B} \supseteq \mathcal{A}. & \end{aligned}$$

□

## 5. Filters

### 5.1. Filters on posets

Let  $\mathfrak{A}$  is a poset (partially ordered set) with the partial order  $\subseteq$ . I will call it **the base poset**.

**Definition 50** ***Filter base** is a nonempty subset  $F$  of  $\mathfrak{A}$  such that*

$$\forall X, Y \in F \exists Z \in F : (Z \subseteq X \wedge Z \subseteq Y).$$

**Obvious 14** A nonempty chain is a filter base.

**Definition 51** *Upper set* is a subset  $F$  of  $\mathfrak{A}$  such that

$$\forall X \in F, Y \in \mathfrak{A} : (Y \supseteq X \Rightarrow Y \in F).$$

**Definition 52** *Filter* is a subset of  $\mathfrak{A}$  which is both filter base and upper set. I will denote the set of filters  $\mathfrak{f}$ .

**Proposition 17** If  $1$  is the maximal element of  $\mathfrak{A}$  then  $1 \in F$  for any filter  $F$ .

**Proof** If  $1 \notin F$  then  $\forall K \in \mathfrak{A} : K \notin F$  and so  $F$  is empty what is impossible.  $\square$

**Proposition 18** Let  $S$  is a filter base. If  $A_0, \dots, A_n \in S$  ( $n \in \mathbb{N}$ ), then

$$\exists C \in S : (C \subseteq A_0 \wedge \dots \wedge C \subseteq A_n).$$

**Proof** Can be easily proved by induction.  $\square$

The dual of filters is called **ideals**. We do not use ideals in this work however.

### 5.2. Filters on meet-semilattice

**Theorem 28** If  $\mathfrak{A}$  is a meet-semilattice and  $F$  is a nonempty subset of  $\mathfrak{A}$  then the following conditions are equivalent:

1.  $F$  is a filter.
2.  $\forall X, Y \in F : X \cap Y \in F$  and  $F$  is an upper set.
3.  $\forall X, Y \in \mathfrak{A} : (X, Y \in F \Leftrightarrow X \cap Y \in F)$ .

**Proof**

(1) $\Rightarrow$ (2) Let  $F$  is a filter. Then  $F$  is an upper set. If  $X, Y \in F$  then  $Z \subseteq X \wedge Z \subseteq Y$  for some  $Z \in F$ . Because  $F$  is an upper set and  $Z \subseteq X \cap Y$  then  $X \cap Y \in F$ .

(2) $\Rightarrow$ (1) Let  $\forall X, Y \in F : X \cap Y \in F$  and  $F$  is an upper set. We need to prove that  $F$  is a filter base. But it is obvious taking  $Z = X \cap Y$  (we have also taken in account that  $F \neq \emptyset$ ).

(2) $\Rightarrow$ (3) Let  $\forall X, Y \in F : X \cap Y \in F$  and  $F$  is an upper set. Then

$$\forall X, Y \in \mathfrak{A} : (X, Y \in F \Rightarrow X \cap Y \in F).$$

Let  $X \cap Y \in F$ ; then  $X, Y \in F$  because  $F$  is an upper set.

(3) $\Rightarrow$ (2) Let

$$\forall X, Y \in \mathfrak{A} : (X, Y \in F \Leftrightarrow X \cap Y \in F).$$

Then  $\forall X, Y \in F : X \cap Y \in F$ . Let  $X \in F$  and  $X \subseteq Y \in \mathfrak{A}$ . Then  $X \cap Y = X \in F$ . Consequently  $X, Y \in F$ . So  $F$  is an upper set. □

**Proposition 19** *Let  $\mathfrak{A}$  is a meet-semilattice. Let  $S$  is a filter base. If  $A_0, \dots, A_n \in S$  ( $n \in \mathbb{N}$ ), then*

$$\exists C \in S : C \subseteq A_0 \cap \dots \cap A_n.$$

**Proof** Can be easily proved by induction. □

**Proposition 20** *If  $\mathfrak{A}$  is a meet-semilattice and  $S$  is a filter base,  $A \in \mathfrak{A}$ , then  $\langle A \cap \rangle S$  is also a filter base.*

**Proof**  $\langle A \cap \rangle S \neq \emptyset$  because  $S \neq \emptyset$ .

Let  $X, Y \in \langle A \cap \rangle S$ . Then  $X = A \cap X'$  and  $Y = A \cap Y'$  where  $X', Y' \in S$ . Exists  $Z' \in S$  such that  $Z' \subseteq X' \cap Y'$ . So  $X \cap Y = A \cap X' \cap Y' \supseteq A \cap Z' \in \langle A \cap \rangle S$ . □

### 5.3. Characterization of finitely meet-closed filtrators

**Theorem 29** *The following are equivalent for a filtrator  $(\mathfrak{A}; \mathfrak{F})$  whose core is a meet-semilattice such that  $\forall a \in \mathfrak{A} : \text{up } a \neq \emptyset$ :*

1. *The filtrator is finitely meet-closed.*
2.  *$\text{up } a$  is a filter on  $\mathfrak{F}$  for every  $a \in \mathfrak{A}$ .*

**Proof**

(1) $\Rightarrow$ (2) Let  $X, Y \in \text{up } a$ . Then  $X \cap^3 Y = X \cap^{\mathfrak{A}} Y \supseteq a$ . That  $\text{up } a$  is an upper set is obvious. So taking in account that  $\text{up } a \neq \emptyset$ ,  $\text{up } a$  is a filter.

(2) $\Rightarrow$ (1) It is enough to prove that  $a \subseteq A, B \Rightarrow a \subseteq A \cap^3 B$  for every  $A, B \in \mathfrak{A}$ . Really:

$$a \subseteq A, B \Rightarrow A, B \in \text{up } a \Rightarrow A \cap^3 B \in \text{up } a \Rightarrow a \subseteq A \cap^3 B.$$

□

## 6. Filter objects

I want to equate principal filters (see below) with the elements of the base poset. Such thing can be done using the principles described in the appendix Appendix B. The formal definitions follow.

6.1. Definition of filter objects

Let  $\mathfrak{A}$  is a poset.

**Definition 53** Let  $\uparrow a \stackrel{\text{def}}{=} \{x \in \mathfrak{A} \mid x \supseteq a\}$  for every  $a \in \mathfrak{A}$ . Elements of the set  $\langle \uparrow \rangle \mathfrak{A}$  are called **principal filters**.

**Obvious 15**  $\uparrow$  is an injection from  $\mathfrak{A}$  to  $\mathfrak{f}$ .

Let  $M$  is a bijection defined on  $\mathfrak{f}$  such that  $M \circ \uparrow = \text{id}_{\mathfrak{A}}$ . (See the appendix Appendix B for a proof that such a bijection exists.)

**Definition 54** Let  $\mathfrak{F} = \text{im } M$ . I call elements of  $\mathfrak{F}$  as **filter objects** (f.o. for short).

**Remark 10** Below we will show that  $\text{up } \mathcal{A} = M^{-1}\mathcal{A}$  for each  $\mathcal{A} \in \mathfrak{F}$ .

**Obvious 16**  $\uparrow = M^{-1}|_{\mathfrak{A}}$ .

**Obvious 17**  $M^{-1}$  is a bijection  $\mathfrak{F} \rightarrow \mathfrak{f}$ .

**Proposition 21**  $\mathfrak{A} \subseteq \mathfrak{F}$ .

**Proof**  $x \in \mathfrak{A} \Rightarrow M \uparrow x = x \Rightarrow x \in \text{im } M \Rightarrow x \in \mathfrak{F}$ . □

6.2. Order of filter objects

**Proposition 22**  $a \subseteq b \Leftrightarrow M^{-1}a \supseteq M^{-1}b$ .

**Proof**  $a \subseteq b \Leftrightarrow \uparrow a \supseteq \uparrow b \Leftrightarrow M^{-1}a \supseteq M^{-1}b$ . □

As a generalization of the last proposition we may define the order on  $\mathfrak{F}$ :

**Definition 55**  $\mathcal{A} \subseteq \mathcal{B} \stackrel{\text{def}}{=} M^{-1}\mathcal{A} \supseteq M^{-1}\mathcal{B}$  for all  $\mathcal{A}, \mathcal{B} \in \mathfrak{A}$ .

I will call the pair  $(\mathfrak{F}; \mathfrak{A})$  the **primary filtrator**.

**Theorem 30** For the primary filtrator  $(\mathfrak{F}; \mathfrak{A})$  we have  $\text{up } \mathcal{A} = M^{-1}\mathcal{A}$  for each  $\mathcal{A} \in \mathfrak{F}$ .

**Proof**  $x \in \text{up } \mathcal{A} \Leftrightarrow x \supseteq \mathcal{A} \Leftrightarrow M^{-1}x \subseteq M^{-1}\mathcal{A} \Leftrightarrow \uparrow x \subseteq M^{-1}\mathcal{A} \Leftrightarrow x \in M^{-1}\mathcal{A}$  for every  $x \in \mathfrak{A}$ . □

So we have:

- "up" is a bijection from  $\mathfrak{F}$  to  $\mathfrak{f}$ .
- $\mathcal{A} \subseteq \mathcal{B} \Leftrightarrow \text{up } \mathcal{A} \supseteq \text{up } \mathcal{B}$  for each  $\mathcal{A}, \mathcal{B} \in \mathfrak{F}$ .
- $\text{up } a = \uparrow a$  for every  $a \in \mathfrak{A}$ .

A filter object  $\mathcal{A}$  is represented by the value of  $\text{up } \mathcal{A}$ . We are not interested in the internal structure of filter objects (which can be inferred from the appendix Appendix B), but only in the value of  $\text{up } \mathcal{A}$ . Thus the name “filter objects” by analogy with an object in object oriented programming where an object is completely characterized by its methods, likewise a filter object  $\mathcal{A}$  is completely characterized by  $\text{up } \mathcal{A}$ .

## 7. Lattice of filter objects

7.1. *Minimal and maximal f.o.*

**Obvious 18** *The filter object  $0 = \text{up}^{-1} \mathfrak{A}$  (equal to the least element of the poset  $\mathfrak{A}$  if this least exists) is the least element of the poset of filter objects.*

**Proposition 23** *If there exists greatest element  $1$  of the poset  $\mathfrak{A}$  then it is also the greatest element of the poset of filter objects.*

**Proof** Take in account that filters are nonempty. □

**Obvious 19** 1. *If the base poset has least element, then the primary filtrator is down-aligned.*

2. *If the base poset has greatest element, then the primary filtrator is up-aligned.*

7.2. *Primary filtrator is filtered*

**Theorem 31** *Primary filtrator is filtered.*

**Proof** We need to prove that  $\mathcal{A} = \bigcap^{\mathfrak{F}} \text{up } \mathcal{A}$  for every  $\mathcal{A} \in \mathfrak{F}$ .

$\mathcal{A}$  is obviously a lower bound for  $\text{up } \mathcal{A}$ .

Let  $\mathcal{B}$  is a lower bound for  $\text{up } \mathcal{A}$  that is  $\forall K \in \text{up } \mathcal{A} : K \supseteq \mathcal{B}$ . Then  $\text{up } \mathcal{A} \subseteq \text{up } \mathcal{B}$ ;  $\mathcal{A} \supseteq \mathcal{B}$ . So  $\mathcal{A}$  is the greatest lower bound of  $\text{up } \mathcal{A}$ . □

7.3. *Formulas for meets and joins of filter objects*

**Lemma 2** *If  $f$  is an order embedding from a poset  $\mathfrak{A}$  to a complete lattice  $\mathfrak{B}$  and  $S \in \mathcal{P}\mathfrak{A}$  and exists such  $\mathcal{F} \in \mathfrak{A}$  that  $f\mathcal{F} = \bigcup^{\mathfrak{B}} \langle f \rangle S$ , then  $\bigcup^{\mathfrak{A}} S$  exists and  $f \bigcup^{\mathfrak{A}} S = \bigcup^{\mathfrak{B}} \langle f \rangle S$ .*

**Proof**  $f$  is an order isomorphism from  $\mathfrak{A}$  to  $\mathfrak{B}|_{\langle f \rangle \mathfrak{A}}$ .  $f\mathcal{F} \in \mathfrak{B}|_{\langle f \rangle \mathfrak{A}}$ .

Consequently,  $\bigcup^{\mathfrak{B}} \langle f \rangle S \in \mathfrak{B}|_{\langle f \rangle \mathfrak{A}}$  and  $\bigcup^{\mathfrak{B}|_{\langle f \rangle \mathfrak{A}}} \langle f \rangle S = \bigcup^{\mathfrak{B}} \langle f \rangle S$ .

$f \bigcup^{\mathfrak{A}} S = \bigcup^{\mathfrak{B}|_{\langle f \rangle \mathfrak{A}}} \langle f \rangle S$  because  $f$  is an order isomorphism.

Combining,  $f \bigcup^{\mathfrak{A}} S = \bigcup^{\mathfrak{B}} \langle f \rangle S$ . □

**Theorem 32** *If  $\mathfrak{A}$  is a meet-semilattice with greatest element  $1$  then  $\bigcup^{\mathfrak{F}} S$  exists and  $\text{up } \bigcup^{\mathfrak{F}} S = \bigcap^{\mathcal{P}\mathfrak{A}} \langle \text{up} \rangle S$  for every  $S \in \mathcal{P}\mathfrak{F}$ .*

**Proof** Taking in account the lemma it is enough to prove that exists  $\mathcal{F} \in \mathfrak{F}$  such that  $\text{up } \mathcal{F} = \bigcap^{\mathcal{P}\mathfrak{A}} \langle \text{up} \rangle S$ , that is that  $R = \bigcap^{\mathcal{P}\mathfrak{A}} \langle \text{up} \rangle S$  is a filter.

$R$  is nonempty because  $1 \in R$ . Let  $A, B \in R$ ; then  $\forall \mathcal{F} \in S : A, B \in \text{up } \mathcal{F}$ , consequently  $\forall \mathcal{F} \in S : A \cap^{\mathfrak{A}} B \in \text{up } \mathcal{F}$ . Consequently  $A \cap^{\mathfrak{A}} B \in \bigcap^{\mathcal{P}\mathfrak{A}} \langle \text{up} \rangle S = R$ . So  $R$  is a filter base. Let  $X \in R$  and  $X \subseteq Y \in \mathfrak{A}$ ; then  $\forall \mathcal{F} \in S : X \in \text{up } \mathcal{F}$ ;  $\forall \mathcal{F} \in S : Y \in \text{up } \mathcal{F}$ ;  $Y \in R$ . So  $R$  is an upper set.  $\square$

**Corollary 8** *If  $\mathfrak{A}$  is a meet-semilattice with greatest element 1 then  $\mathfrak{F}$  is a complete lattice.*

**Corollary 9** *If  $\mathfrak{A}$  is a meet-semilattice with greatest element 1 then for any  $\mathcal{A}, \mathcal{B} \in \mathfrak{F}$*

$$\text{up}(\mathcal{A} \cup^{\mathfrak{F}} \mathcal{B}) = \text{up } \mathcal{A} \cap \text{up } \mathcal{B}.$$

**Theorem 33** *If  $\mathfrak{A}$  is a join-semilattice then  $\mathfrak{F}$  is a join-semilattice then and for any  $\mathcal{A}, \mathcal{B} \in \mathfrak{F}$*

$$\text{up}(\mathcal{A} \cup^{\mathfrak{F}} \mathcal{B}) = \text{up } \mathcal{A} \cap \text{up } \mathcal{B}.$$

**Proof** Taking in account the lemma it is enough to prove that  $R = \text{up } \mathcal{A} \cap \text{up } \mathcal{B}$  is a filter.

$R$  is nonempty because exist  $X \in \text{up } \mathcal{A}$  and  $Y \in \text{up } \mathcal{B}$  and  $R \ni X \cup^{\mathfrak{A}} Y$ .

Let  $A, B \in R$ . Then  $A, B \in \text{up } \mathcal{A}$ ; so exists  $C \in \text{up } \mathcal{A}$  such that  $C \subseteq A \wedge C \subseteq B$ . Analogously exists  $D \in \text{up } \mathcal{B}$  such that  $D \subseteq A \wedge D \subseteq B$ . Let  $E = C \cup^{\mathfrak{A}} D$ . Then  $E \in \text{up } \mathcal{A}$  and  $E \in \text{up } \mathcal{B}$ ;  $E \in R$  and  $E \subseteq A \wedge E \subseteq B$ . So  $R$  is a filter base.

That  $R$  is an upper set is obvious.  $\square$

**Theorem 34** *If  $\mathfrak{A}$  is a distributive lattice then for  $S \in \mathcal{P}\mathfrak{F} \setminus \{\emptyset\}$*

$$\text{up} \bigcap^{\mathfrak{F}} S = \left\{ K_0 \cap^{\mathfrak{A}} \dots \cap^{\mathfrak{A}} K_n \mid K_i \in \bigcup \langle \text{up} \rangle S \text{ where } i = 0, \dots, n \text{ for } n \in \mathbb{N} \right\}.$$

**Proof** Let's denote the right part of the equality to be proven as  $R$ . First we will prove that  $R$  is a filter.  $R$  is nonempty because  $S$  is nonempty.

Let  $A, B \in R$ . Then  $A = X_0 \cap^{\mathfrak{A}} \dots \cap^{\mathfrak{A}} X_k$ ,  $B = Y_0 \cap^{\mathfrak{A}} \dots \cap^{\mathfrak{A}} Y_l$  where  $X_i, Y_j \in \bigcup \langle \text{up} \rangle S$ . So

$$A \cap^{\mathfrak{A}} B = X_0 \cap^{\mathfrak{A}} \dots \cap^{\mathfrak{A}} X_k \cap^{\mathfrak{A}} Y_0 \cap^{\mathfrak{A}} \dots \cap^{\mathfrak{A}} Y_l \in R.$$

Let  $R \ni C \supseteq A$ . Consequently (distributivity used)

$$C = C \cup^{\mathfrak{A}} A = (C \cup^{\mathfrak{A}} X_0) \cap^{\mathfrak{A}} \dots \cap^{\mathfrak{A}} (C \cup^{\mathfrak{A}} X_k).$$

$X_i \in \text{up } P$  for some  $P \in S$ ;  $C \cup^{\mathfrak{A}} X_i \in \text{up } P$ ; consequently  $C \in \text{up } P$ ;  $C \in R$ .

We have proved that  $R$  is a filter base and an upper set. So  $R$  is a filter.

Consequently the statement of our theorem is equivalent to  $\bigcap^{\mathfrak{F}} S = \text{up}^{-1} R$ .

Let  $\mathcal{A} \in S$ . Then  $\text{up } \mathcal{A} \in \langle \text{up} \rangle S$ ;  $\text{up } \mathcal{A} \subseteq \bigcup \langle \text{up} \rangle S$ ;

$$R \supseteq \{ K_0 \cap^{\mathfrak{A}} \dots \cap^{\mathfrak{A}} K_n \mid K_i \in \text{up } \mathcal{A} \text{ where } i = 0, \dots, n \text{ for } n \in \mathbb{N} \} = \text{up } \mathcal{A}.$$

Consequently  $\mathcal{A} \supseteq \text{up}^{-1} R$ .

Let now  $\mathcal{B} \in \mathfrak{F}$  and  $\forall \mathcal{A} \in S : \mathcal{A} \supseteq \mathcal{B}$ . Then  $\forall \mathcal{A} \in S : \text{up } \mathcal{B} \supseteq \text{up } \mathcal{A}$ .  $\text{up } \mathcal{B} \supseteq \bigcup \langle \text{up} \rangle S$ . From this  $\text{up } \mathcal{B} \supseteq T$  for any finite set  $T \subseteq \bigcup \langle \text{up} \rangle S$ . Consequently  $\text{up } \mathcal{B} \ni \bigcap^{\mathfrak{A}} T$ . Thus  $\text{up } \mathcal{B} \supseteq R$ ;  $\mathcal{B} \subseteq \text{up}^{-1} R$ .

Comparing we get  $\bigcap^{\mathfrak{F}} S = \text{up}^{-1} R$ .  $\square$

**Theorem 35** *If  $\mathfrak{A}$  is a distributive lattice then for any  $\mathcal{F}_0, \dots, \mathcal{F}_m$  ( $m \in \mathbb{N}$ )*

$$\text{up}(\mathcal{F}_0 \cap^{\mathfrak{F}} \dots \cap^{\mathfrak{F}} \mathcal{F}_m) = \{K_0 \cap^{\mathfrak{A}} \dots \cap^{\mathfrak{A}} K_m \mid K_i \in \text{up } \mathcal{F}_i, i = 0, \dots, m\}.$$

**Proof** Let's denote the right part of the equality to be proven as  $R$ . First we will prove that  $R$  is a filter. Obviously  $R$  is nonempty.

Let  $A, B \in R$ . Then  $A = X_0, \dots, X_m$ ,  $B = Y_0, \dots, Y_m$  where  $X_i, Y_i \in \text{up } \mathcal{F}_i$ .

$$A \cap^{\mathfrak{A}} B = (X_0 \cap^{\mathfrak{A}} Y_0) \cap^{\mathfrak{A}} \dots \cap^{\mathfrak{A}} (X_m \cap^{\mathfrak{A}} Y_m),$$

consequently  $A \cap^{\mathfrak{A}} B \in R$ .

Let  $R \ni C \supseteq A$ .

$$C = A \cup^{\mathfrak{A}} C = (X_0 \cup^{\mathfrak{A}} C) \cap^{\mathfrak{A}} \dots \cap^{\mathfrak{A}} (X_m \cup^{\mathfrak{A}} C) \in R.$$

So  $R$  is a filter. Consequently the statement of our theorem is equivalent to

$$\mathcal{F}_0 \cap^{\mathfrak{F}} \dots \cap^{\mathfrak{F}} \mathcal{F}_m = \text{up}^{-1} R.$$

Let  $P_i \in \text{up } \mathcal{F}_i$ . Then  $P_i \in R$  because  $P_i = (P_i \cup^{\mathfrak{A}} P_0) \cap^{\mathfrak{F}} \dots \cap^{\mathfrak{F}} (P_i \cup^{\mathfrak{A}} P_m)$ . So  $\text{up } \mathcal{F}_i \subseteq R$ ;  $\mathcal{F}_i \supseteq \text{up}^{-1} R$ .

Let now  $\mathcal{B} \in \mathfrak{F}$  and  $\forall i \in \{0, \dots, m\} : \mathcal{F}_i \supseteq \mathcal{B}$ . Then  $\forall i \in \{0, \dots, m\} : \text{up } \mathcal{F}_i \subseteq \text{up } \mathcal{B}$ .

$L_i \in \text{up } \mathcal{B}$  for any  $L_i \in \text{up } \mathcal{F}_i$ .  $L_0 \cap^{\mathfrak{A}} \dots \cap^{\mathfrak{A}} L_m \in \text{up } \mathcal{B}$ . So  $\text{up } \mathcal{B} \supseteq R$ ;  $\mathcal{B} \subseteq \text{up}^{-1} R$ .

So  $\mathcal{F}_0 \cap^{\mathfrak{F}} \dots \cap^{\mathfrak{F}} \mathcal{F}_m = \text{up}^{-1} R$ .  $\square$

**Definition 56** *I will call a **lattice of filter objects on a set** a set of filter objects on the lattice of all subsets of a set. (From the above it follows that it is actually a complete lattice.)*

#### 7.4. Distributivity of the lattice of filter objects

**Theorem 36** *If  $\mathfrak{A}$  is a distributive lattice with greatest element,  $S \in \mathcal{P}\mathfrak{F}$  and  $\mathcal{A} \in \mathfrak{F}$  then  $\mathcal{A} \cup^{\mathfrak{F}} \bigcap^{\mathfrak{F}} S = \bigcap^{\mathfrak{F}} \langle \mathcal{A} \cup^{\mathfrak{F}} \rangle S$ .*

**Proof** Taking in account the previous subsection, we have:

$$\begin{aligned}
& \text{up} \left( \mathcal{A} \cup^{\mathfrak{F}} \bigcap^{\mathfrak{F}} S \right) = \\
& \text{up} \mathcal{A} \cap \text{up} \bigcap^{\mathfrak{F}} S = \\
& \text{up} \mathcal{A} \cap \left\{ K_0 \cap^{\mathfrak{A}} \dots \cap^{\mathfrak{A}} K_n \mid K_i \in \bigcup \langle \text{up} \rangle S \text{ where } i = 0, \dots, n \text{ for } n \in \mathbb{N} \right\} = \\
& \left\{ K_0 \cap^{\mathfrak{A}} \dots \cap^{\mathfrak{A}} K_n \mid K_0 \cap^{\mathfrak{A}} \dots \cap^{\mathfrak{A}} K_n \in \text{up} \mathcal{A}, K_i \in \bigcup \langle \text{up} \rangle S \text{ where } i = 0, \dots, n \text{ for } n \in \mathbb{N} \right\} = \\
& \left\{ K_0 \cap^{\mathfrak{A}} \dots \cap^{\mathfrak{A}} K_n \mid K_i \in \text{up} \mathcal{A}, K_i \in \bigcup \langle \text{up} \rangle S \text{ where } i = 0, \dots, n \text{ for } n \in \mathbb{N} \right\} = \\
& \left\{ K_0 \cap^{\mathfrak{A}} \dots \cap^{\mathfrak{A}} K_n \mid K_i \in \text{up} \mathcal{A}, K_i \in \bigcup \{ \text{up} \mathcal{X} \mid \mathcal{X} \in S \} \text{ where } i = 0, \dots, n \text{ for } n \in \mathbb{N} \right\} = \\
& \left\{ K_0 \cap^{\mathfrak{A}} \dots \cap^{\mathfrak{A}} K_n \mid K_i \in \text{up} \mathcal{A} \cap \bigcup \{ \text{up} \mathcal{X} \mid \mathcal{X} \in S \} \text{ where } i = 0, \dots, n \text{ for } n \in \mathbb{N} \right\} = \\
& \left\{ K_0 \cap^{\mathfrak{A}} \dots \cap^{\mathfrak{A}} K_n \mid K_i \in \bigcup \{ \text{up} \mathcal{A} \cap \text{up} \mathcal{X} \mid \mathcal{X} \in S \} \text{ where } i = 0, \dots, n \text{ for } n \in \mathbb{N} \right\} = \\
& \left\{ K_0 \cap^{\mathfrak{A}} \dots \cap^{\mathfrak{A}} K_n \mid K_i \in \bigcup \{ \text{up}(\mathcal{A} \cup^{\mathfrak{F}} \mathcal{X}) \mid \mathcal{X} \in S \} \text{ where } i = 0, \dots, n \text{ for } n \in \mathbb{N} \right\} = \\
& \left\{ K_0 \cap^{\mathfrak{A}} \dots \cap^{\mathfrak{A}} K_n \mid K_i \in \bigcup \langle \text{up} \rangle \{ \mathcal{A} \cup^{\mathfrak{F}} \mathcal{X} \mid \mathcal{X} \in S \} \text{ where } i = 0, \dots, n \text{ for } n \in \mathbb{N} \right\} = \\
& \text{up} \bigcap^{\mathfrak{F}} \{ \mathcal{A} \cup^{\mathfrak{F}} \mathcal{X} \mid \mathcal{X} \in S \}.
\end{aligned}$$

□

**Corollary 10** *If  $\mathfrak{A}$  is a distributive lattice with greatest element, then  $\mathfrak{F}$  is also a distributive lattice.*

**Corollary 11** *If  $\mathfrak{A}$  is a distributive lattice with greatest element, then  $\mathfrak{F}$  is a co-brouwerian lattice.*

### 7.5. Separability of core for primary filtrators

**Theorem 37** *A primary filtrator with least element, whose base is a distributive lattice, is with separable core.*

**Proof** Let  $\mathcal{A} \succ^{\mathfrak{F}} \mathcal{B}$  where  $\mathcal{A}, \mathcal{B} \in \mathfrak{F}$ .

$$\text{up}(\mathcal{A} \cap^{\mathfrak{F}} \mathcal{B}) = \{ A \cap^{\mathfrak{A}} B \mid A \in \text{up} \mathcal{A}, B \in \text{up} \mathcal{B} \}.$$

So

$$\begin{aligned}
\mathcal{A} \succ^{\mathfrak{F}} \mathcal{B} & \Leftrightarrow \\
0 \in \text{up}(\mathcal{A} \cap^{\mathfrak{F}} \mathcal{B}) & \Leftrightarrow \\
\exists A \in \text{up} \mathcal{A}, B \in \text{up} \mathcal{B} : A \cap^{\mathfrak{A}} B = 0 & \Leftrightarrow \\
\exists A \in \text{up} \mathcal{A}, B \in \text{up} \mathcal{B} : A \cap^{\mathfrak{F}} B = 0 &
\end{aligned}$$

(used the theorem 23).

□

**Theorem 38** *Let  $(\mathfrak{A}; \mathfrak{F})$  is an up-aligned filtered filtrator whose core is a meet infinite distributive complete lattice. Then this filtrator is with co-separable core.*

**Proof** Our filtrator is with join-closed core.

Let  $a, b \in \mathfrak{A}$ .  $\text{Cor } a$  and  $\text{Cor } b$  exist since  $\mathfrak{F}$  is a complete lattice.

$\text{Cor } a \in \text{down } a$  and  $\text{Cor } b \in \text{down } b$  by the corollary 6 since our filtrator is filtered. So we have

$$\begin{aligned}
\exists x \in \text{down } a, y \in \text{down } b : x \cup^{\mathfrak{A}} y = 1 &\Leftrightarrow \\
\text{Cor } a \cup^{\mathfrak{A}} \text{Cor } b = 1 &\Leftrightarrow \text{ (by finite join-closedness of the core)} \\
\text{Cor } a \cup^{\mathfrak{F}} \text{Cor } b = 1 &\Leftrightarrow \\
\bigcap^{\mathfrak{A}} \text{up } a \cup^{\mathfrak{F}} \bigcap^{\mathfrak{A}} \text{up } b = 1 &\Leftrightarrow \text{ (by infinite distributivity)} \\
\bigcap^{\mathfrak{A}} \{x \cup^{\mathfrak{F}} y \mid x \in \text{up } a, y \in \text{up } b\} = 1 &\Leftrightarrow \\
\forall x \in \text{up } a, y \in \text{up } b : x \cup^{\mathfrak{F}} y = 1 &\Leftrightarrow \text{ (by finite join-closedness of the core)} \\
\forall x \in \text{up } a, y \in \text{up } b : x \cup^{\mathfrak{A}} y = 1 &\Leftrightarrow \\
a \cup^{\mathfrak{A}} b = 1. &
\end{aligned}$$

□

#### 7.6. Filters over boolean lattices

**Theorem 39** *If  $\mathfrak{A}$  is a boolean lattice then  $a \setminus^{\mathfrak{F}} B = a \cap^{\mathfrak{F}} \overline{B}$  (where the complement is taken on  $\mathfrak{A}$ ).*

**Proof**  $\mathfrak{F}$  is distributive by the theorem 10. Our filtrator is with finitely meet-closed core by the theorem 29 and with join-closed core by the theorem 23.

$$(a \cap^{\mathfrak{F}} \overline{B}) \cup^{\mathfrak{F}} B = (a \cup^{\mathfrak{F}} B) \cap^{\mathfrak{F}} (\overline{B} \cup^{\mathfrak{F}} B) = (a \cup^{\mathfrak{F}} B) \cap^{\mathfrak{F}} (\overline{B} \cup^{\mathfrak{A}} B) = (a \cup^{\mathfrak{F}} B) \cap^{\mathfrak{F}} 1 = a \cup^{\mathfrak{F}} B.$$

$$(a \cap^{\mathfrak{F}} \overline{B}) \cap^{\mathfrak{F}} B = a \cap^{\mathfrak{F}} (\overline{B} \cap^{\mathfrak{F}} B) = a \cap^{\mathfrak{F}} (\overline{B} \cap^{\mathfrak{A}} B) = a \cap^{\mathfrak{F}} 0 = 0.$$

So  $a \cap^{\mathfrak{F}} \overline{B}$  is the difference of  $a$  and  $B$ .

□

## 8. Generalized filter base

**Definition 57** *Generalized filter base is a filter base on the set  $\mathfrak{F}$ .*

**Definition 58** *If  $S$  is a generalized filter base and  $\mathcal{A} = \bigcap^{\mathfrak{F}} S$ , then we will call  $S$  a generalized base of filter object  $\mathcal{A}$ .*

**Theorem 40** *If  $\mathfrak{A}$  is a distributive lattice and  $S$  is a generalized base of filter object  $\mathcal{F}$  then for any element  $K$  of the base poset*

$$K \in \text{up } \mathcal{F} \Leftrightarrow \exists \mathcal{L} \in S : \mathcal{L} \subseteq K.$$

**Proof**

$\Leftarrow$  Because  $\mathcal{F} = \bigcap^{\mathfrak{S}} S$ .

$\Rightarrow$  Let  $K \in \text{up}\mathcal{F}$ . Then (taken in account distributivity of  $\mathfrak{A}$  and that  $S$  is nonempty) exist  $X_1, \dots, X_n \in \bigcup \langle \text{up} \rangle S$  such that  $X_1 \cap^{\mathfrak{A}} \dots \cap^{\mathfrak{A}} X_n = K$ . Consequently (by theorem 29)  $X_1 \cap^{\mathfrak{S}} \dots \cap^{\mathfrak{S}} X_n = K$ . Replacing every  $X_i$  with such  $\mathcal{X}_i \in S$  that  $X_i \in \text{up}\mathcal{X}_i$  (this is obviously possible to do), we get a finite set  $T_0 \subseteq S$  such that  $\bigcap^{\mathfrak{S}} T_0 \subseteq K$ . From this exists  $\mathcal{C} \in S$  such that  $\mathcal{C} \subseteq \bigcap^{\mathfrak{S}} T_0 \subseteq K$ .

□

**Corollary 12** *If  $\mathfrak{A}$  is a distributive lattice with least element 0 and  $S$  is a generalized base of filter object  $\mathcal{F}$  then  $0 \in S \Leftrightarrow \mathcal{F} = 0$ .*

**Proof** Substitute 0 as  $K$ .

□

**Theorem 41** *Let  $\mathfrak{A}$  is a distributive lattice with least element 0 and  $S$  is a nonempty set of filter objects on  $\mathfrak{A}$  such that  $\mathcal{F}_0 \cap^{\mathfrak{S}} \dots \cap^{\mathfrak{S}} \mathcal{F}_n \neq 0$  for every  $\mathcal{F}_0, \dots, \mathcal{F}_n \in S$ . Then  $\bigcap^{\mathfrak{S}} S \neq 0$ .*

**Proof** Consider the set

$$S' = \{ \mathcal{F}_0 \cap^{\mathfrak{S}} \dots \cap^{\mathfrak{S}} \mathcal{F}_n \mid \mathcal{F}_0, \dots, \mathcal{F}_n \in S \}.$$

Obviously  $S'$  is nonempty and finitely meet-closed. So  $S'$  is a generalized filter base. Obviously  $0 \notin S'$ . So by properties of generalized filter bases  $\bigcap^{\mathfrak{S}} S' \neq 0$ . But obviously  $\bigcap^{\mathfrak{S}} S = \bigcap^{\mathfrak{S}} S'$ . So  $\bigcap^{\mathfrak{S}} S \neq 0$ .

□

**Corollary 13** *Let  $\mathfrak{A}$  is a distributive lattice with least element 0 and let  $S \in \mathcal{P}\mathfrak{A}$  such that  $S \neq \emptyset$  and  $A_0 \cap^{\mathfrak{A}} \dots \cap^{\mathfrak{A}} A_n \neq 0$  for every  $A_0, \dots, A_n \in S$ . Then  $\bigcap^{\mathfrak{S}} S \neq 0$ .*

**Proof** Because  $\mathfrak{A}$  is finitely meet-closed (by the theorem 29).

□

## 9. Stars

### 9.1. Free stars

**Definition 59** *Let  $\mathfrak{A}$  is a poset with least element 0. **Free stars** on  $\mathfrak{A}$  are such  $S \in \mathcal{P}\mathfrak{A}$  that  $0 \notin S$  and for every  $X, Y \in \mathfrak{A}$*

$$\forall Z \in \mathfrak{A} : (Z \supseteq X \wedge Z \supseteq Y \Rightarrow Z \in S) \Leftrightarrow X \in S \vee Y \in S.$$

**Proposition 24**  *$S \in \mathcal{P}\mathfrak{A}$  where  $\mathfrak{A}$  is a poset with least element 0 is a free star iff all of the following:*

1.  $0 \notin S$ .

2.  $\forall Z \in \mathfrak{A} : (Z \supseteq X \wedge Z \supseteq Y \Rightarrow Z \in S) \Rightarrow X \in S \vee Y \in S$  for every  $X, Y \in \mathfrak{A}$ .

3.  $S$  is an upper set.

**Proof**

$\Rightarrow$  (1) and (2) are obvious. Let prove that  $S$  is an upper set. Let  $X \in S$  and  $X \subseteq Y \in \mathfrak{A}$ . Then  $X \in S \vee X \in S$  and thus  $\forall Z \in \mathfrak{A} : (Z \supseteq X \wedge Z \supseteq X \Rightarrow Z \in S)$  that is  $\forall Z \in \mathfrak{A} : (Z \supseteq X \Rightarrow Z \in S)$ , and so  $Y \in S$ .

$\Leftarrow$  We need to prove that

$$\forall Z \in \mathfrak{A} : (Z \supseteq X \wedge Z \supseteq Y \Rightarrow Z \in S) \Leftarrow X \in S \vee Y \in S.$$

Let  $X \in S \vee Y \in S$ . Then  $Z \supseteq X \wedge Z \supseteq Y \Rightarrow Z \in S$  for every  $Z \in \mathfrak{A}$  because  $S$  is an upper set.

□

**Proposition 25** Let  $\mathfrak{A}$  is a join-semilattice with least element 0.  $S \in \mathcal{P}\mathfrak{A}$  is a free star iff all of the following:

1.  $0 \notin S$ .

2.  $X \cup Y \in S \Rightarrow X \in S \vee Y \in S$  for every  $X, Y \in \mathfrak{A}$ .

3.  $S$  is an upper set.

**Proof**

$\Rightarrow$  We need to prove only  $X \cup Y \in S \Rightarrow X \in S \vee Y \in S$ . Let  $X \cup Y \in S$ . Because  $S$  is an upper set, we have  $\forall Z \in \mathfrak{A} : (Z \supseteq X \cup Y \Rightarrow Z \in S)$  and thus  $\forall Z \in \mathfrak{A} : (Z \supseteq X \wedge Z \supseteq Y \Rightarrow Z \in S)$  from which we conclude  $X \in S \vee Y \in S$ .

$\Leftarrow$  We need to prove  $\forall Z \in \mathfrak{A} : (Z \supseteq X \wedge Z \supseteq Y \Rightarrow Z \in S) \Leftarrow X \in S \vee Y \in S$ . But this trivially follows from that  $S$  is an upper set.

□

**Proposition 26** Let  $\mathfrak{A}$  is a join-semilattice with least element 0.  $S \in \mathcal{P}\mathfrak{A}$  is a free star iff  $0 \notin S$  and for every  $X, Y \in \mathfrak{A}$

$$X \cup Y \in S \Leftrightarrow X \in S \vee Y \in S.$$

**Proof**

$\Rightarrow$  We need to prove only that  $X \cup Y \in S \Leftarrow X \in S \vee Y \in S$  what follows from that  $S$  is an upper set.

$\Leftarrow$  We need to prove only that  $S$  is an upper set. Let  $X \in S$  and  $X \subseteq Y \in \mathfrak{A}$ . Then  $X \in S \Rightarrow X \in S \vee Y \in S \Leftrightarrow X \cup Y \in S \Rightarrow Y \in S$ . So  $S$  is an upper set.

□

9.2. Stars of elements of filtrators

**Definition 60** Let  $(\mathfrak{A}; \mathfrak{F})$  is a filtrator with least element. **Core star** of an element  $a$  of this filtrator is

$$\partial a = \{x \in \mathfrak{F} \mid x \not\leq^{\mathfrak{A}} a\}.$$

**Proposition 27**  $\text{up } a \subseteq \partial a$  for any element  $a \neq 0$  of a filtrator with least element.

**Proof** For any element  $X \in \mathfrak{F}$

$$X \in \text{up } a \Rightarrow X \cap^{\mathfrak{A}} a = a \neq 0 \Rightarrow X \in \partial a.$$

□

**Theorem 42** Let  $(\mathfrak{A}; \mathfrak{F})$  is a distributive lattice filtrator with least element and finitely join-closed core which is a join-semilattice. Then  $\partial a$  is a free star for each  $a \in \mathfrak{A}$ .

**Proof** For every  $A, B \in \mathfrak{F}$

$$\begin{aligned} A \cup^{\mathfrak{F}} B \in \partial a &\Leftrightarrow \\ A \cup^{\mathfrak{A}} B \in \partial a &\Leftrightarrow \\ (A \cup^{\mathfrak{A}} B) \cap^{\mathfrak{A}} a \neq 0 &\Leftrightarrow \\ (A \cap^{\mathfrak{A}} a) \cup^{\mathfrak{A}} (B \cap^{\mathfrak{A}} a) \neq 0 &\Leftrightarrow \\ A \cap^{\mathfrak{A}} a \neq 0 \vee B \cap^{\mathfrak{A}} a \neq 0 &\Leftrightarrow \\ A \in \partial a \vee B \in \partial a. & \end{aligned}$$

That  $\partial a$  doesn't contain 0 is obvious.

□

**Definition 61** I call a filtrator **star-separable** when its core is a separation subset of its base.

9.3. Stars of filters on boolean lattices

In this section we will consider the set of filter objects  $\mathfrak{F}$  on a boolean lattice  $\mathfrak{A}$ .

**Theorem 43** If  $\mathfrak{A}$  is a boolean lattice and  $\mathcal{A} \in \mathfrak{F}$  then

1.  $\partial \mathcal{A} = \{\overline{X} \mid X \in \mathfrak{A} \setminus \text{up } \mathcal{A}\};$
2.  $\text{up } \mathcal{A} = \{\overline{X} \mid X \in \mathfrak{A} \setminus \partial \mathcal{A}\}.$

**Proof** 1. For any  $K \in \mathfrak{A}$  (taking into account the theorems 29, 37, and 27)

$$\begin{aligned}
K \in \{\overline{X} \mid X \in \mathfrak{A} \setminus \text{up } \mathcal{A}\} &\Leftrightarrow \\
\overline{K} \in \mathfrak{A} \setminus \text{up } \mathcal{A} &\Leftrightarrow \\
\overline{K} \notin \text{up } \mathcal{A} &\Leftrightarrow \\
\overline{K} \not\supseteq \mathcal{A} &\Leftrightarrow \\
K \not\prec^{\mathfrak{F}} \mathcal{A} &\Leftrightarrow \\
K \in \partial \mathcal{A}. &
\end{aligned}$$

2. For any  $K \in \mathfrak{A}$  (taking into account the same theorems)

$$\begin{aligned}
K \in \{\overline{X} \mid X \in \mathfrak{A} \setminus \partial \mathcal{A}\} &\Leftrightarrow \\
\overline{K} \in \mathfrak{A} \setminus \partial \mathcal{A} &\Leftrightarrow \\
\overline{K} \notin \partial \mathcal{A} &\Leftrightarrow \\
\overline{K} \succ^{\mathfrak{F}} \mathcal{A} &\Leftrightarrow \\
K \supseteq \mathcal{A} &\Leftrightarrow \\
K \in \text{up } \mathcal{A}. &
\end{aligned}$$

□

**Corollary 14** *If  $\mathfrak{A}$  is a boolean lattice,  $X \in \text{up } \mathcal{A} \Leftrightarrow \overline{X} \notin \partial \mathcal{A}$  for every  $X \in \mathfrak{A}$ ,  $\mathcal{A} \in \mathfrak{F}$ .*

**Corollary 15** *If  $\mathfrak{A}$  is a boolean lattice,  $\partial$  is an injection.*

**Theorem 44** *If  $\mathfrak{A}$  is a boolean lattice, then for any set  $S \in \mathcal{P}\mathfrak{A}$  exists filter object  $\mathcal{A}$  such that  $\partial \mathcal{A} = S$  iff  $S$  is a free star.*

**Proof**

$\Rightarrow$  That  $0 \notin S$  is obvious. For every  $A, B \in \mathfrak{A}$

$$\begin{aligned}
A \cup^{\mathfrak{A}} B \in S &\Leftrightarrow \\
(A \cup^{\mathfrak{A}} B) \cap^{\mathfrak{F}} \mathcal{A} \neq 0 &\Leftrightarrow \\
(A \cup^{\mathfrak{F}} B) \cap^{\mathfrak{F}} \mathcal{A} \neq 0 &\Leftrightarrow \\
(A \cap^{\mathfrak{F}} \mathcal{A}) \cup^{\mathfrak{F}} (B \cap^{\mathfrak{F}} \mathcal{A}) \neq 0 &\Leftrightarrow \\
A \cap^{\mathfrak{F}} \mathcal{A} \neq 0 \vee B \cap^{\mathfrak{F}} \mathcal{A} \neq 0 &\Leftrightarrow \\
A \in S \vee B \in S. &
\end{aligned}$$

(taken into account the theorems 10 and 29).

$\Leftarrow$  Let  $0 \notin S$  and  $\forall A, B \in S : (A \cup^{\mathfrak{A}} B \in S \Leftrightarrow A \in S \vee B \in S)$ . Let  $T = \{\overline{X} \mid X \in \mathfrak{A} \setminus S\}$ . We will prove that  $T$  is a filter.

$1 \in T$  because  $0 \notin S$ ; so  $T$  is nonempty. To prove that  $T$  is a filter is enough to show that  $\forall X, Y \in \mathfrak{A} : (X, Y \in T \Leftrightarrow X \cap^{\mathfrak{A}} Y \in T)$ . In fact,

$$\begin{aligned} X, Y \in T &\Leftrightarrow \\ \overline{X}, \overline{Y} \notin S &\Leftrightarrow \\ \neg(\overline{X} \in S \vee \overline{Y} \in S) &\Leftrightarrow \\ \overline{X \cup^{\mathfrak{A}} Y} \notin S &\Leftrightarrow \\ \overline{X \cup^{\mathfrak{A}} Y} \in T &\Leftrightarrow \\ X \cap^{\mathfrak{A}} Y \in T. & \end{aligned}$$

So  $T$  is a filter. Let  $\text{up } \mathcal{A} = T$  for some filter object  $\mathcal{A}$ .

To finish the proof we will show that  $\partial \mathcal{A} = S$ . In fact, for every  $X \in \mathfrak{A}$

$$X \in \partial \mathcal{A} \Leftrightarrow \overline{X} \notin \text{up } \mathcal{A} \Leftrightarrow \overline{X} \notin T \Leftrightarrow X \in S.$$

□

**Proposition 28** *If  $\mathfrak{A}$  is a boolean lattice then  $\mathcal{A} \subseteq \mathcal{B} \Leftrightarrow \partial \mathcal{A} \subseteq \partial \mathcal{B}$  for every  $\mathcal{A}, \mathcal{B} \in \mathfrak{F}$ .*

**Proof**

$$\begin{aligned} \partial \mathcal{A} \subseteq \partial \mathcal{B} &\Leftrightarrow \\ \{\overline{X} \mid X \in \mathfrak{A} \setminus \text{up } \mathcal{A}\} \subseteq \{\overline{X} \mid X \in \mathfrak{A} \setminus \text{up } \mathcal{B}\} &\Leftrightarrow \\ \mathfrak{A} \setminus \text{up } \mathcal{A} \subseteq \mathfrak{A} \setminus \text{up } \mathcal{B} &\Leftrightarrow \\ \text{up } \mathcal{A} \supseteq \text{up } \mathcal{B} &\Leftrightarrow \\ \mathcal{A} \subseteq \mathcal{B}. & \end{aligned}$$

□

**Corollary 16**  *$\partial$  is a straight monotone map.*

**Theorem 45** *If  $\mathfrak{A}$  is a boolean lattice then  $\partial \bigcup^{\mathfrak{F}} S = \bigcup \langle \partial \rangle S$ .*

**Proof** For boolean lattices  $\partial$  is an order embedding from the poset  $\mathfrak{F}$  to the complete lattice  $\mathcal{P}\mathfrak{A}$ . So accordingly the lemma 2 it enough to prove that exists  $\mathcal{F} \in \mathfrak{F}$  such that  $\partial \mathcal{F} = \bigcup \langle \partial \rangle S$ . To prove this is enough to show that  $0 \notin \bigcup \langle \partial \rangle S$  and

$$\forall A, B \in S : (A \cup^{\mathfrak{A}} B \in \bigcup \langle \partial \rangle S \Leftrightarrow A \in \bigcup \langle \partial \rangle S \vee B \in \bigcup \langle \partial \rangle S).$$

$0 \notin \bigcup \langle \partial \rangle S$  is obvious.

Let  $A \cup^{\mathfrak{A}} B \in \bigcup \langle \partial \rangle S$ . Then exists  $Q \in \langle \partial \rangle S$  such that  $A \cup^{\mathfrak{A}} B \in Q$ . Then  $A \in Q \vee B \in Q$ , consequently  $A \in \bigcup \langle \partial \rangle S \vee B \in \bigcup \langle \partial \rangle S$ . Let now  $A \in \bigcup \langle \partial \rangle S$ . Then exists  $Q \in \langle \partial \rangle S$  such that  $A \in Q$ , consequently  $A \cup^{\mathfrak{A}} B \in Q$  and  $A \cup^{\mathfrak{A}} B \in \bigcup \langle \partial \rangle S$ . □

9.4. More about the lattice of filters

**Theorem 46** *If  $\mathfrak{A}$  is a distributive lattice with least element 0 then  $\mathfrak{F}$  is an atomic lattice.*

**Proof** Let  $\mathcal{F} \in \mathfrak{F}$ . Let choose (by Kuratowski's lemma) a maximal chain  $S$  from 0 to  $\mathcal{F}$ . Let  $S' = S \setminus \{0\}$ .  $a = \bigcap^{\mathfrak{F}} S' \neq 0$  by properties of generalized filter bases (the corollary 12 which uses the fact that  $\mathfrak{A}$  is a distributive lattice with least element). If  $a \notin S$  then the chain  $S$  can be extended adding there element  $a$  because  $0 \subset a \subseteq \mathcal{X}$  for any  $\mathcal{X} \in S'$  what contradicts to maximality of the chain. So  $a \in S$  and consequently  $a \in S'$ . Obviously  $a$  is the minimal element of  $S'$ . Consequently (taking in account maximality of the chain) there are no  $\mathcal{Y} \in \mathfrak{F}$  such that  $0 \subset \mathcal{Y} \subset a$ . So  $a$  is an atomic filter. Obviously  $a \subseteq \mathcal{F}$ .  $\square$

**Obvious 20** *If  $\mathfrak{A}$  is a boolean lattice then  $\mathfrak{F}$  is separable.*

**Theorem 47** *If  $\mathfrak{A}$  is a boolean lattice then  $\mathfrak{F}$  is an atomistic lattice.*

**Proof** Because (used the theorem 20)  $\mathfrak{F}$  is atomic (the theorem 46) and separable.  $\square$

**Corollary 17** *If  $\mathfrak{A}$  is a boolean lattice then  $\mathfrak{F}$  is an atomically separable.*

**Proof** By the theorem 13.  $\square$

**Theorem 48** *When the base poset  $\mathfrak{A}$  is a boolean lattice, then the filtrator  $(\mathfrak{F}; \mathfrak{A})$  is central.*

**Proof** We can conclude that  $\mathfrak{F}$  is atomically separable (the corollary 17) and with separable core (the theorem 37).

We need to prove that  $Z(\mathfrak{F}) = \mathfrak{A}$ .

Let  $\mathcal{X} \in Z(\mathfrak{F})$ . Then exists  $\mathcal{Y} \in Z(\mathfrak{F})$  such that  $\mathcal{X} \cap^{\mathfrak{F}} \mathcal{Y} = 0$  and  $\mathcal{X} \cup^{\mathfrak{F}} \mathcal{Y} = 1$ . Consequently there are  $X \in \text{up } \mathcal{X}$  such that  $X \cap^{\mathfrak{F}} \mathcal{Y} = 0$ ; we have also  $X \cup^{\mathfrak{F}} \mathcal{Y} = 1$ . Suppose  $X \supset \mathcal{X}$ . Then exists  $a \in \text{atoms}^{\mathfrak{F}} X$  such that  $a \notin \text{atoms}^{\mathfrak{F}} \mathcal{X}$ . We can conclude also  $a \notin \text{atoms}^{\mathfrak{F}} \mathcal{Y}$  (otherwise  $X \cap^{\mathfrak{F}} \mathcal{Y} \neq 0$ ). Thus  $a \notin \text{atoms}^{\mathfrak{F}} (\mathcal{X} \cup^{\mathfrak{F}} \mathcal{Y})$  and consequently  $\mathcal{X} \cup^{\mathfrak{F}} \mathcal{Y} \neq 1$  what is a contradiction. We have  $\mathcal{X} = X \in \mathfrak{A}$ .

Let now  $X \in \mathfrak{A}$ . Let  $Y = 1 \setminus^{\mathfrak{A}} X$ . We have  $X \cap^{\mathfrak{A}} Y = 0$  and  $X \cup^{\mathfrak{A}} Y = 1$ . Thus  $X \cap^{\mathfrak{F}} Y = \bigcap^{\mathfrak{A}} \{X \cap^{\mathfrak{A}} Y\} = 0$ ;  $X \cup^{\mathfrak{F}} Y = \bigcap^{\mathfrak{F}} (\text{up } X \cap \text{up } Y) = \bigcap^{\mathfrak{F}} \{1\} = 1$ . We have shown that  $X \in Z(\mathfrak{F})$ .  $\square$

## 10. Atomic filter objects

See [2] and [4] for more detailed treatment of ultrafilters and prime filters.

**Theorem 49** *Let  $(\mathfrak{A}; \mathfrak{J})$  is a semifiltered down-aligned filtrator with finitely meet-closed core  $\mathfrak{J}$  which is a meet-semilattice. Then  $a$  is an atom of  $\mathfrak{J}$  iff  $a \in \mathfrak{J}$  and  $a$  is an atom of  $\mathfrak{A}$ .*

**Proof**

$\Leftarrow$  Obvious.

$\Rightarrow$  We need to prove that if  $a$  is an atom of  $\mathfrak{J}$  then  $a$  is an atom of  $\mathfrak{A}$ . Suppose the contrary that  $a$  is not an atom of  $\mathfrak{A}$ . Then exists  $x \in \mathfrak{A}$  such that  $0 \neq x \subset a$ . Because “up” is a straight monotone map from  $\mathfrak{A}$  to the dual of the poset  $\mathcal{P}\mathfrak{J}$  (the theorem 10),  $\text{up} a \subset \text{up} x$ . So exists  $K \in \text{up} x$  such that  $K \notin \text{up} a$ . Also  $a \in \text{up} x$ . We have  $K \cap^{\mathfrak{J}} a = K \cap^{\mathfrak{A}} a \in \text{up} x$ ;  $K \cap^{\mathfrak{J}} a \neq 0$  and  $K \cap^{\mathfrak{J}} a \subset a$ . So  $a$  is not an atom of  $\mathfrak{J}$ .

□

**Theorem 50** *Let  $(\mathfrak{A}; \mathfrak{J})$  is a down-aligned semifiltered filtrator and  $\mathfrak{A}$  is a meet-semilattice. Then  $a \in \mathfrak{A}$  if an atom of  $\mathfrak{A}$  iff  $\text{up} a = \partial a$ .*

**Proof**

$\Rightarrow$  Let  $a$  is an atom of  $\mathfrak{A}$ .  $\text{up} a \supseteq \partial a$  because  $a \neq 0$ .  $\text{up} a \subseteq \partial a$  because for any  $K \in \mathfrak{A}$

$$K \in \text{up} a \Leftrightarrow K \supseteq a \Rightarrow K \cap^{\mathfrak{A}} a \neq 0 \Leftrightarrow K \in \partial a.$$

$\Leftarrow$  Let  $\text{up} a = \partial a$ . Then  $a \neq 0$ . Consequently for every  $x \in \mathfrak{A}$  we have

$$\begin{aligned} 0 \subset x \subset a &\Rightarrow \\ x \cap^{\mathfrak{A}} a \neq 0 &\Rightarrow \\ \forall K \in \text{up} x : K \in \partial a &\Rightarrow \\ \forall K \in \text{up} x : K \in \text{up} a &\Rightarrow \\ \text{up} x \subseteq \text{up} a &\Rightarrow \\ x \supseteq a. & \end{aligned}$$

So  $a$  is an atom of  $\mathfrak{A}$ .

□

10.1. Prime filtrator elements

**Definition 62** Let  $(\mathfrak{A}; \mathfrak{F})$  is a down-aligned filtrator with least element 0. **Prime filtrator elements** are such  $a \in \mathfrak{A}$  that  $\text{up } a$  is a free star.

**Proposition 29** Let  $(\mathfrak{A}; \mathfrak{F})$  is a down-aligned filtrator with finitely join-closed core, where  $\mathfrak{A}$  is a distributive lattice and  $\mathfrak{F}$  is a join-semilattice. Then atomic elements of this filtrator are prime.

**Proof** Let  $a$  is an atom of the lattice  $\mathfrak{A}$ . We have for every  $X, Y \in \mathfrak{F}$

$$\begin{aligned}
 X \cup^{\mathfrak{F}} Y \in \text{up } a &\Leftrightarrow \\
 X \cup^{\mathfrak{A}} Y \in \text{up } a &\Leftrightarrow \\
 X \cup^{\mathfrak{A}} Y \supseteq a &\Leftrightarrow \\
 (X \cup^{\mathfrak{A}} Y) \cap^{\mathfrak{A}} a \neq 0 &\Leftrightarrow \\
 (X \cap^{\mathfrak{A}} a) \cup^{\mathfrak{A}} (Y \cap^{\mathfrak{A}} a) \neq 0 &\Leftrightarrow \\
 X \cap^{\mathfrak{A}} a \neq 0 \vee Y \cap^{\mathfrak{A}} a \neq 0 &\Leftrightarrow \\
 X \supseteq a \vee Y \supseteq a &\Leftrightarrow \\
 X \in \text{up } a \vee Y \in \text{up } a. &
 \end{aligned}$$

□

The following theorem is essentially borrowed from [8]:

**Theorem 51** Let  $\mathfrak{A}$  is a boolean lattice. Let  $a$  is a f.o. Then the following are equivalent:

1.  $a$  is prime.
2. For every  $A \in \mathfrak{A}$  exactly one of  $\{A, \overline{A}\}$  is in  $\text{up } a$ .
3.  $a$  is an atom of  $\mathfrak{F}$ .

**Proof**

(1) $\Rightarrow$ (2) Let  $a$  is prime. Then  $A \cup^{\mathfrak{A}} \overline{A} = 1 \in \text{up } a$ . Therefore  $A \in \text{up } a \vee \overline{A} \in \text{up } a$ . But since  $A \cap^{\mathfrak{A}} \overline{A} = 0 \notin \text{up } a$  it is impossible  $A \in \text{up } a \wedge \overline{A} \in \text{up } a$ .

(2) $\Rightarrow$ (3) Obviously  $a \neq 0$ . Let f.o.  $b \subset a$ . So  $\text{up } b \supset \text{up } a$ . Let  $X \in \text{up } b \setminus \text{up } a$ . Then  $X \notin \text{up } a$  and thus  $\overline{X} \in \text{up } a$  and consequently  $\overline{X} \in \text{up } b$ . So  $0 = X \cap^{\mathfrak{A}} \overline{X} \in \text{up } b$  and thus  $b = 0$ . So  $a$  is atomic.

(3) $\Rightarrow$ (1) By the previous proposition (taking into account the corollary 10 and the theorem 23).

□

## 11. Some criteria

**Theorem 52** For a semifiltered, star-separable, down-aligned filtrator  $(\mathfrak{A}; \mathfrak{Z})$  with finitely meet closed and separable core where  $\mathfrak{Z}$  is a boolean lattice and both  $\mathfrak{Z}$  and  $\mathfrak{A}$  are atomistic lattices the following conditions are equivalent for any  $\mathcal{F} \in \mathfrak{A}$ :

1.  $\mathcal{F} \in \mathfrak{Z}$ ;
2.  $\forall S \in \mathcal{P}\mathfrak{A} : (\mathcal{F} \cap^{\mathfrak{A}} \bigcup^{\mathfrak{A}} S \neq 0 \Rightarrow \exists K \in S : \mathcal{F} \cap^{\mathfrak{A}} K \neq 0)$ ;
3.  $\forall S \in \mathcal{P}\mathfrak{Z} : (\mathcal{F} \cap^{\mathfrak{A}} \bigcup^{\mathfrak{A}} S \neq 0 \Rightarrow \exists K \in S : \mathcal{F} \cap^{\mathfrak{A}} K \neq 0)$ .

**Proof** Our filtrator is with join-closed core.

(1) $\Rightarrow$ (2) Let  $\mathcal{F} \in \mathfrak{Z}$ . Then (taking in account the proposition 27)

$$\mathcal{F} \cap^{\mathfrak{A}} \bigcup^{\mathfrak{A}} S \neq 0 \Leftrightarrow \overline{\mathcal{F}} \not\subseteq \bigcup^{\mathfrak{A}} S \Rightarrow \exists K \in S : \overline{\mathcal{F}} \not\subseteq K \Leftrightarrow \exists K \in S : \mathcal{F} \cap^{\mathfrak{A}} K \neq 0.$$

(2) $\Rightarrow$ (3) Obvious.

(3) $\Rightarrow$ (1) Let the formula (3) is true. Then for  $L \in \mathfrak{Z}$  and  $S = \text{atoms}^{\mathfrak{Z}} L$  it takes the form  $\mathcal{F} \cap^{\mathfrak{A}} \bigcup^{\mathfrak{A}} \text{atoms}^{\mathfrak{Z}} L \neq 0 \Rightarrow \exists K \in S : \mathcal{F} \cap^{\mathfrak{A}} K \neq 0$  that is  $\mathcal{F} \cap^{\mathfrak{A}} L \neq 0 \Rightarrow \exists K \in S : \mathcal{F} \cap^{\mathfrak{A}} K \neq 0$  because  $\bigcup^{\mathfrak{A}} \text{atoms}^{\mathfrak{Z}} L = \bigcup^{\mathfrak{Z}} \text{atoms}^{\mathfrak{Z}} L = L$ . That is  $\mathcal{F} \cap^{\mathfrak{A}} L \neq 0 \Rightarrow \mathcal{F} \cap^{\mathfrak{A}} K_L \neq 0$  where  $K_L \in S$ . Thus  $K_L$  is an atom of both  $\mathfrak{A}$  and  $\mathfrak{Z}$  (see the theorem 49), so having  $\mathcal{F} \cap^{\mathfrak{A}} L \neq 0 \Rightarrow \mathcal{F} \supseteq K_L$ . Let

$$F = \bigcup^{\mathfrak{A}} \{K_L \mid L \in \mathfrak{Z}, \mathcal{F} \cap^{\mathfrak{A}} L \neq 0\}.$$

Obviously  $F \subseteq \mathcal{F}$ . We have  $L \cap^{\mathfrak{Z}} \mathcal{F} \neq 0 \Rightarrow L \cap^{\mathfrak{A}} \mathcal{F} \neq 0 \Rightarrow K_L \cap^{\mathfrak{Z}} F \neq 0 \Rightarrow L \cap^{\mathfrak{Z}} F \neq 0$ , thus by star separability of our filtrator  $\mathcal{F} \subseteq F$  and so  $\mathcal{F} = F \in \mathfrak{Z}$ .

□

**Theorem 53** If  $\mathfrak{A}$  is a complete boolean lattice then for each  $\mathcal{F} \in \mathfrak{F}$

$$\mathcal{F} \in \mathfrak{A} \Leftrightarrow \forall S \in \mathcal{P}\mathfrak{A} : \left( \bigcup^{\mathfrak{A}} S \in \partial\mathcal{F} \Rightarrow S \cap \partial\mathcal{F} \neq 0 \right).$$

**Proof**

$$\begin{aligned} \forall S \in \mathcal{P}\mathfrak{A} : \left( \bigcup^{\mathfrak{A}} S \in \partial\mathcal{F} \Rightarrow S \cap \partial\mathcal{F} \neq 0 \right) &\Leftrightarrow \\ \forall S \in \mathcal{P}\mathfrak{A} : \left( \bigcup^{\mathfrak{A}} S \notin \partial\mathcal{F} \Leftarrow S \cap \partial\mathcal{F} = 0 \right) &\Leftrightarrow \\ \forall S \in \mathcal{P}\mathfrak{A} : \left( \overline{\bigcup^{\mathfrak{A}} S} \in \text{up}\mathcal{F} \Leftarrow (\neg) S \subseteq \text{up}\mathcal{F} \right) &\Leftrightarrow \\ \forall S \in \mathcal{P}\mathfrak{A} : \left( \bigcap^{\mathfrak{A}} S \in \text{up}\mathcal{F} \Leftarrow S \subseteq \text{up}\mathcal{F} \right), & \end{aligned}$$

but

$$\begin{aligned}
& \mathcal{F} \in \mathfrak{A} \Rightarrow \\
\forall S \in \mathcal{P}\mathfrak{A} : \left( \bigcap^{\mathfrak{A}} S \in \text{up } \mathcal{F} \Leftarrow S \subseteq \text{up } \mathcal{F} \right) & \Rightarrow \\
\bigcap^{\mathfrak{A}} \text{up } \mathcal{F} \in \text{up } \mathcal{F} & \Rightarrow \\
\mathcal{F} \in \mathfrak{A}. &
\end{aligned}$$

□

**Definition 63** Let  $S$  is a subset of a meet-semilattice. The **filter base generated by  $S$**  is the set

$$[S]_{\cap} \stackrel{\text{def}}{=} \{a_0 \cap \dots \cap a_n \mid a_i \in S, i = 0, 1, \dots\}.$$

**Lemma 3** The set of all finite subsets of an infinite set  $A$  has the same cardinality as  $A$ .

**Proof** Let denote the number of  $n$ -element subsets of  $A$  as  $s_n$ . Obviously  $s_n \leq \text{card } A^n = \text{card } A$ . Then the number  $S$  of all finite subsets of  $A$  is equal to  $s_0 + s_1 + \dots \leq \text{card } A + \text{card } A + \dots = \text{card } A$ . That  $S \geq \text{card } A$  is obvious. So  $S = \text{card } A$ . □

**Lemma 4** A filter base generated by an infinite set has the same cardinality as that set.

**Proof** From the previous lemma. □

**Definition 64** Let  $\mathfrak{A}$  is a complete lattice. A set  $S \in \mathcal{P}\mathfrak{A}$  is **filter-closed** when for every filter base  $T \in \mathcal{P}S$  we have  $\bigcap T \in S$ .

**Theorem 54** A subset  $S$  of a complete lattice is filter-closed iff for every nonempty chain  $T \in \mathcal{P}S$  we have  $\bigcap T \in S$ .

**Proof** (proof sketch by Joel David Hamkins)

⇒ Because every nonempty chain is a filter base.

⇐ We will assume that cardinality of a set is an ordinal defined by von Neumann cardinal assignment (what is a standard practice in ZFC). Recall that  $\alpha < \beta \Leftrightarrow \alpha \in \beta$  for ordinals  $\alpha, \beta$ .

We will take it as given that for every nonempty chain  $T \in \mathcal{P}S$  we have  $\bigcap T \in S$ .

We will prove the following statement: If  $\text{card } S = n$  then  $S$  is filter closed, for any cardinal  $n$ .

Instead we will prove it not only for cardinals but for wider class of ordinals: If  $\text{card } S = n$  then  $S$  is filter closed, for any ordinal  $n$ .

We will prove it using transfinite induction by  $n$ .

For finite  $n$  we have  $\bigcap T \in S$  because  $T \subseteq S$  has minimal element.

Let  $\text{card } T = n$  is an infinite ordinal.

Let the assumption of induction holds for every  $n \in \text{card } T$ .

We can assign  $T = \{a_\alpha \mid \alpha \in \text{card } T\}$  for some  $a_\alpha$  because  $\text{card } \text{card } T = \text{card } T$ .

Consider  $\beta \in \text{card } T$ .

Let  $P_\beta = \{a_\alpha \mid \alpha \in \beta\}$ . Let  $b_\beta = \bigcap P_\beta$ . Obviously  $b_\beta = \bigcap [P_\beta]_\cap$ . We have

$$\text{card}[P_\beta]_\cap = \text{card } P_\beta = \text{card } \beta < \text{card } T$$

(used the lemma and von Neumann cardinal assignment). By the assumption of induction  $b_\beta \in S$ .

$\forall \beta \in \text{card } T : P_\beta \subseteq T$  and thus  $b_\beta \supseteq \bigcap T$ .

Easy to see that the set  $\{P_\beta \mid \beta \in \text{card } T\}$  is a chain. Consequently  $\{b_\beta \mid \beta \in \text{card } T\}$  is a chain.

By theorem conditions  $b = \bigcap \{b_\beta \mid \beta \in \text{card } T\} \in S$  (taken in account that  $b_\beta \in S$ ).

Obviously  $b \supseteq \bigcap T$ .

$b \subseteq b_\beta$  and so  $\forall \beta \in \text{card } T \forall \alpha \in \beta : b \subseteq a_\alpha$ . Let  $\alpha \in \text{card } T$ . Then (because  $\text{card } A$  is limit ordinal, see [15]) exist  $\beta \in \text{card } T$  such that  $\alpha \in \beta \in \text{card } T$ . So  $b \subseteq a_\alpha$  for every  $\alpha \in \text{card } T$ . Thus  $b \subseteq \bigcap T$ .

Finally  $\bigcap T = b \in S$ .

□

**Theorem 55** *Let  $\mathfrak{A}$  is a boolean lattice. For any  $S \in \mathcal{P}\mathfrak{F}$  the condition  $\exists \mathcal{F} \in \mathfrak{F} : S = \star \mathcal{F}$  is equivalent to conjunction of the following items:*

1.  $S$  is a free star on  $\mathfrak{F}$ ;
2.  $S$  is filter-closed.

**Proof**

$\Rightarrow$  1. That  $0 \notin \star \mathcal{F}$  is obvious. For every  $a, b \in \mathfrak{F}$

$$\begin{aligned} a \cup^{\mathfrak{F}} b \in \star S &\Leftrightarrow \\ (a \cup^{\mathfrak{F}} b) \cap^{\mathfrak{F}} \mathcal{F} \neq 0 &\Leftrightarrow \\ (a \cap^{\mathfrak{F}} \mathcal{F}) \cup (b \cap^{\mathfrak{F}} \mathcal{F}) \neq 0 &\Leftrightarrow \\ a \cap^{\mathfrak{F}} \mathcal{F} \neq 0 \vee b \cap^{\mathfrak{F}} \mathcal{F} \neq 0 &\Leftrightarrow \\ a \in \star S \vee b \in \star S. & \end{aligned}$$

(taken into account the corollary 10). So  $\star\mathcal{F}$  is a free star on  $\mathfrak{F}$ .

2. We have  $T \subseteq S$  and need to prove that  $\bigcap^{\mathfrak{F}} T \cap \mathcal{F} \neq 0$ . Because  $\langle \mathcal{F} \cap^{\mathfrak{F}} \rangle T$  is a generalized filter base,  $0 \in \langle \mathcal{F} \cap^{\mathfrak{F}} \rangle T \Leftrightarrow \bigcap^{\mathfrak{F}} \langle \mathcal{F} \cap^{\mathfrak{F}} \rangle T = 0 \Leftrightarrow \bigcap^{\mathfrak{F}} T \cap^{\mathfrak{F}} \mathcal{F} = 0$ . So left to prove  $0 \notin \langle \mathcal{F} \cap^{\mathfrak{F}} \rangle T$  what follows from  $T \subseteq S$ .

$\Leftarrow$  Let  $S$  is a free star on  $\mathfrak{F}$ . Then for every  $A, B \in \mathfrak{A}$

$$\begin{aligned} A, B \in S \cap \mathfrak{A} &\Leftrightarrow \\ A, B \in S &\Leftrightarrow \\ A \cup^{\mathfrak{F}} B \in S &\Leftrightarrow \\ A \cup^{\mathfrak{A}} B \in S &\Leftrightarrow \\ A \cup^{\mathfrak{A}} B \in S \cap \mathfrak{A} & \end{aligned}$$

(taken into account the theorem 23). So  $S \cap \mathfrak{A}$  is a free star on  $\mathfrak{A}$ .

Thus there exists  $\mathcal{F} \in \mathfrak{F}$  such that  $\partial\mathcal{F} = S \cap \mathfrak{A}$ . We have  $\text{up } \mathcal{X} \subseteq S \Leftrightarrow \mathcal{X} \in S$  (because  $S$  is filter-closed) for every  $\mathcal{X} \in \mathfrak{F}$ ; then (taking in account properties of generalized filter bases)

$$\begin{aligned} \mathcal{X} \in S &\Leftrightarrow \\ \forall X \in \text{up } \mathcal{X} : X \cap^{\mathfrak{F}} \mathcal{F} \neq 0 &\Leftrightarrow \\ 0 \notin \langle \mathcal{F} \cap^{\mathfrak{F}} \rangle \text{up } \mathcal{X} &\Leftrightarrow \\ \bigcap^{\mathfrak{F}} \langle \mathcal{F} \cap^{\mathfrak{F}} \rangle \text{up } \mathcal{X} \neq 0 &\Leftrightarrow \\ \mathcal{F} \cap^{\mathfrak{F}} \bigcap^{\mathfrak{F}} \text{up } \mathcal{X} \neq 0 &\Leftrightarrow \\ \mathcal{F} \cap^{\mathfrak{F}} \mathcal{X} \neq 0 &\Leftrightarrow \\ \mathcal{X} \in \partial\mathcal{F}. & \end{aligned}$$

□

## 12. Quasidifference and quasicomplement

I've got quasidifference and quasicomplement (and dual quasicomplement) replacing max and min in the definition of pseudodifference and pseudocomplement (and dual pseudocomplement) with  $\bigcup$  and  $\bigcap$ . Thus quasidifference and (dual) quasicomplement are generalizations of their pseudo- counterparts.

**Remark 11 Pseudocomplements and pseudodifferences** is standard terminology. **Quasi-** counterparts are my neologisms.

**Definition 65** Let  $\mathfrak{A}$  is a poset with least element,  $a \in \mathfrak{A}$ . **Quasicomplement** of  $a$  is

$$a^* = \bigcup \{c \in \mathfrak{A} \mid c \asymp a\}.$$

**Definition 66** Let  $\mathfrak{A}$  is a poset with greatest element,  $a \in \mathfrak{A}$ . *Dual quasicomplement* of  $a$  is

$$a^+ = \bigcap \{c \in \mathfrak{A} \mid c \equiv a\}.$$

I will denote quasicomplement and dual quasicomplement for a specific poset  $\mathfrak{A}$  as  $a^{*(\mathfrak{A})}$  and  $a^{+(\mathfrak{A})}$ .

**Definition 67** Let  $a, b \in \mathfrak{A}$  where  $\mathfrak{A}$  is a distributive lattice. *Quasidifference* of  $a$  and  $b$  is

$$a \setminus^* b = \bigcap \{z \in \mathfrak{A} \mid a \subseteq b \cup z\}.$$

**Definition 68** Let  $a, b \in \mathfrak{A}$  where  $\mathfrak{A}$  is a distributive lattice with least element. *Second quasidifference* of  $a$  and  $b$  is

$$a \# b \stackrel{\text{def}}{=} \bigcup \{z \in \mathfrak{A} \mid z \subseteq a \wedge z \asymp b\}.$$

**Theorem 56**  $a \setminus^* b = \bigcap \{z \in \mathfrak{A} \mid z \subseteq a \wedge a \subseteq b \cup z\}$  where  $\mathfrak{A}$  is a distributive lattice and  $a, b \in \mathfrak{A}$ .

**Proof** Obviously  $\{z \in \mathfrak{A} \mid z \subseteq a \wedge a \subseteq b \cup z\} \subseteq \{z \in \mathfrak{A} \mid a \subseteq b \cup z\}$ . Thus  $\bigcap \{z \in \mathfrak{A} \mid z \subseteq a \wedge a \subseteq b \cup z\} \supseteq a \setminus^* b$ .

Let  $z \in \mathfrak{A}$  and  $z' = z \cap a$ .

$a \subseteq b \cup z \Rightarrow a \subseteq (b \cup z) \cap a \Leftrightarrow a \subseteq (b \cap a) \cup (z \cap a) \Leftrightarrow a \subseteq (b \cap a) \cup z' \Rightarrow a \subseteq b \cup z'$  and  $a \subseteq b \cup z \Leftarrow a \subseteq b \cup z'$ . Thus  $a \subseteq b \cup z \Leftrightarrow a \subseteq b \cup z'$ .

If  $z \in \{z \in \mathfrak{A} \mid a \subseteq b \cup z\}$  then  $a \subseteq b \cup z'$  and thus  $z' \in \{z \in \mathfrak{A} \mid z \subseteq a \wedge a \subseteq b \cup z\}$ . But  $z' \subseteq z$  thus having  $\bigcap \{z \in \mathfrak{A} \mid z \subseteq a \wedge a \subseteq b \cup z\} \subseteq \bigcap \{z \in \mathfrak{A} \mid a \subseteq b \cup z\}$ .  $\square$

**Remark 12** If we drop the requirement that  $\mathfrak{A}$  is distributive, two formulas for quasidifference (the definition and the last theorem) fork.

**Obvious 21** *Dual quasicomplement is the dual of quasicomplement.*

**Obvious 22** • *Every pseudocomplement is quasicomplement.*

- *Every dual pseudocomplement is dual quasicomplement.*
- *Every pseudodifference is quasidifference.*

Below we will stick to the more general quasies than pseudos. If needed, one can check that a quasicomplement  $a^*$  is a pseudocomplement by the equation  $a^* \asymp a$  (and analogously with other quasies).

Next we will express quasidifference through quasicomplement.

**Proposition 30**

1.  $a \setminus^* b = a \setminus^* (a \cap b)$  for any distributive lattice;

2.  $a\#b = a\#(a \cap b)$  for any distributive lattice with least element.

**Proof**

1.  $a \subseteq (a \cap b) \cup z \Leftrightarrow a \subseteq (a \cup z) \cap (b \cup z) \Leftrightarrow a \subseteq a \cup z \wedge a \subseteq b \cup z \Leftrightarrow a \subseteq b \cup z$ . Thus  $a \setminus^* (a \cap b) = \bigcap \{z \in \mathfrak{A} \mid a \subseteq (a \cap b) \cup z\} = \bigcap \{z \in \mathfrak{A} \mid a \subseteq b \cup z\} = a \setminus^* b$ .
2.  $a\#(a \cap b) = \bigcup \{z \in \mathfrak{A} \mid z \subseteq a \wedge z \cap a \cap b = 0\} = \bigcup \{z \in \mathfrak{A} \mid z \subseteq a \wedge (z \cap a) \cap a \cap b = 0\} = \bigcup \{z \cap a \mid z \in \mathfrak{A}, z \cap a \cap b = 0\} = \bigcup \{z \in \mathfrak{A} \mid z \subseteq a, z \cap b = 0\} = a\#b$ .

□

I will denote  $Da$  the lattice  $\{x \in \mathfrak{A} \mid x \subseteq a\}$ .

**Theorem 57** For  $a, b \in \mathfrak{A}$  where  $\mathfrak{A}$  is a bounded distributive lattice

1.  $a \setminus^* b = (a \cap b)^{+(Da)}$ ;
2.  $a\#b = (a \cap b)^{*(Da)}$ .

**Proof**

1.

$$\begin{aligned}
 (a \cap b)^{+(Da)} &= \\
 \bigcap \{c \in Da \mid c \cup (a \cap b) = a\} &= \\
 \bigcap \{c \in Da \mid c \cup (a \cap b) \supseteq a\} &= \\
 \bigcap \{c \in Da \mid (c \cup a) \cap (c \cup b) \supseteq a\} &= \\
 \bigcap \{c \in \mathfrak{A} \mid c \subseteq a \wedge c \cup b \supseteq a\} &= \\
 a \setminus^* b. &
 \end{aligned}$$

2.

$$\begin{aligned}
 (a \cap b)^{*(Da)} &= \\
 \bigcup \{c \in Da \mid c \cap a \cap b = 0\} &= \\
 \bigcup \{c \in \mathfrak{A} \mid c \subseteq a \wedge c \cap a \cap b = 0\} &= \\
 \bigcup \{c \in \mathfrak{A} \mid c \subseteq a \wedge c \cap b = 0\} &= \\
 a\#b. &
 \end{aligned}$$

□

**Theorem 58** Let  $(\mathfrak{F}; \mathfrak{A})$  is a primary filtrator where  $\mathfrak{A}$  is a boolean lattice. Let  $\mathcal{A} \in \mathfrak{F}$ . Then for each  $\mathcal{X} \in \mathfrak{F}$

$$\mathcal{X} \in Z(D\mathcal{A}) \Leftrightarrow \exists X \in \mathfrak{A} : \mathcal{X} = X \cap^{\mathfrak{F}} \mathcal{A}.$$

**Proof**

$\Leftarrow$  Let  $\mathcal{X} = X \cap^{\mathfrak{F}} \mathcal{A}$  where  $X \in \mathfrak{A}$ . Let also  $\mathcal{Y} = \overline{X} \cap^{\mathfrak{F}} \mathcal{A}$ . Then  $\mathcal{X} \cap^{\mathfrak{F}} \mathcal{Y} = X \cap^{\mathfrak{F}} \overline{X} \cap^{\mathfrak{F}} \mathcal{A} = (X \cap^{\mathfrak{A}} \overline{X}) \cap^{\mathfrak{F}} \mathcal{A} = 0$  (used the theorems 23 and 29) and  $\mathcal{X} \cup^{\mathfrak{F}} \mathcal{Y} = (X \cup^{\mathfrak{F}} \overline{X}) \cap^{\mathfrak{F}} \mathcal{A} = (X \cup^{\mathfrak{A}} \overline{X}) \cap^{\mathfrak{F}} \mathcal{A} = 1 \cap^{\mathfrak{F}} \mathcal{A} = \mathcal{A}$  (used the theorems 23 and 10). So  $\mathcal{X} \in Z(D\mathcal{A})$ .

$\Rightarrow$  Let  $\mathcal{X} \in Z(D\mathcal{A})$ . Then exists  $\mathcal{Y} \in Z(D\mathcal{A})$  such that  $\mathcal{X} \cap^{\mathfrak{F}} \mathcal{Y} = 0$  and  $\mathcal{X} \cup^{\mathfrak{F}} \mathcal{Y} = \mathcal{A}$ . Then (used the theorem 37) exists  $X \in \text{up } \mathcal{X}$  such that  $X \cap^{\mathfrak{F}} \mathcal{Y} = 0$ . We have

$$\mathcal{X} = \mathcal{X} \cup^{\mathfrak{F}} (X \cap^{\mathfrak{F}} \mathcal{Y}) = X \cap^{\mathfrak{F}} (\mathcal{X} \cup^{\mathfrak{F}} \mathcal{Y}) = X \cap^{\mathfrak{F}} \mathcal{A}.$$

□

**Proposition 31**  $(a \cup b) \setminus^* b \subseteq a$  for an arbitrary complete lattice.

**Proof**  $(a \cup b) \setminus^* b = \bigcap \{z \in \mathfrak{A} \mid a \cup b \subseteq b \cup z\}$ .

But  $a \subseteq z \Rightarrow a \cup b \subseteq b \cup z$ . So  $\{z \in \mathfrak{A} \mid a \cup b \subseteq b \cup z\} \supseteq \{z \in \mathfrak{A} \mid a \subseteq z\}$ .

Consequently,  $(a \cup b) \setminus^* b \subseteq \bigcap \{z \in \mathfrak{A} \mid a \subseteq z\} = a$ . □

### 13. Complements and core parts

**Lemma 5** If  $(\mathfrak{A}; \mathfrak{F})$  is a filtered, up-aligned filtrator with co-separable core which is a complete lattice, then for any  $a, c \in \mathfrak{A}$

$$c \equiv^{\mathfrak{A}} a \Leftrightarrow c \equiv^{\mathfrak{A}} \text{Cor } a.$$

**Proof**

$\Rightarrow$  If  $c \equiv^{\mathfrak{A}} a$  then by co-separability of the core exists  $K \in \text{down } a$  such that  $c \equiv^{\mathfrak{A}} K$ . To finish the proof we will show that  $K \subseteq \text{Cor } a$ . To show this is enough to show that  $\forall X \in \text{up } a : K \subseteq X$  what is obvious.

$\Leftarrow$  Because  $\text{Cor } a \subseteq a$  (by the theorem 24 using that our filtrator is filtered).

□

**Theorem 59** If  $(\mathfrak{A}; \mathfrak{F})$  is a filtered up-aligned complete lattice filtrator with co-separable core which is a complete boolean lattice, then  $a^+ = \overline{\text{Cor } a}$  for every  $a \in \mathfrak{A}$ .

**Proof** Our filtrator is with join-closed core.

$$\begin{aligned}
a^+ &= \\
\bigcap^{\mathfrak{A}} \{c \in \mathfrak{A} \mid c \cup^{\mathfrak{A}} a = 1\} &= \\
\bigcap^{\mathfrak{A}} \{c \in \mathfrak{A} \mid c \cup^{\mathfrak{A}} \text{Cor } a = 1\} &= \\
\bigcap^{\mathfrak{A}} \{c \in \mathfrak{A} \mid c \supseteq \overline{\text{Cor } a}\} &= \\
\overline{\text{Cor } a}. &
\end{aligned}$$

(used the lemma and the theorem 27). □

**Corollary 18** *If  $(\mathfrak{A}; \mathfrak{B})$  is a filtered up-aligned complete lattice filtrator with co-separable core which is a complete boolean lattice, then  $a^+ \in \mathfrak{B}$  for every  $a \in \mathfrak{A}$ .*

**Theorem 60** *If  $(\mathfrak{A}; \mathfrak{B})$  is a filtered complete lattice filtrator with down-aligned, finitely meet-closed, separable core which is a complete boolean lattice, then  $a^* = \overline{\text{Cor } a} = \overline{\text{Cor}' a}$ .*

**Proof** Our filtrator is with join-closed core.  $a^* = \bigcup^{\mathfrak{A}} \{c \in \mathfrak{A} \mid c \cap^{\mathfrak{A}} a = 0\}$ . But  $c \cap^{\mathfrak{A}} a = 0 \Rightarrow \exists C \in \text{up } c : C \cap^{\mathfrak{A}} a = 0$ . So

$$\begin{aligned}
a^* &= \\
\bigcup^{\mathfrak{A}} \{C \in \mathfrak{B} \mid C \cap^{\mathfrak{A}} a = 0\} &= \\
\bigcup^{\mathfrak{A}} \{C \in \mathfrak{B} \mid a \subseteq \overline{C}\} &= \\
\bigcup^{\mathfrak{A}} \{\overline{C} \mid C \in \mathfrak{B}, a \subseteq C\} &= \\
\bigcup^{\mathfrak{A}} \{\overline{C} \mid C \in \text{up } a\} &= \\
\bigcup^{\mathfrak{B}} \{\overline{C} \mid C \in \text{up } a\} &= \\
\overline{\bigcap^{\mathfrak{B}} \{C \mid C \in \text{up } a\}} &= \\
\overline{\bigcap^{\mathfrak{B}} \text{up } a} &= \\
\overline{\text{Cor } a}. &
\end{aligned}$$

(used the theorem 27).

$\text{Cor } a = \overline{\text{Cor}' a}$  by the theorem 26. □

**Corollary 19** *If  $(\mathfrak{A}; \mathfrak{B})$  is filtered down-aligned and up-aligned complete lattice filtrator with finitely meet-closed, separable and co-separable core which is a complete boolean lattice, then  $a^* = a^+$  for every  $a \in \mathfrak{A}$ .*

**Proof** Comparing two last theorems. □

**Theorem 61** *If  $(\mathfrak{A}; \mathfrak{Z})$  is a complete lattice filtrator with join-closed separable core which is a complete lattice, then  $a^* \in \mathfrak{Z}$  for every  $a \in \mathfrak{A}$ .*

**Proof**  $\{c \in \mathfrak{A} \mid c \cap^{\mathfrak{A}} a = 0\} \supseteq \{A \in \mathfrak{Z} \mid A \cap^{\mathfrak{A}} a = 0\}$ ; consequently  $a^* \supseteq \bigcup^{\mathfrak{A}} \{A \in \mathfrak{Z} \mid A \cap^{\mathfrak{A}} a = 0\}$ .

But if  $c \in \{c \in \mathfrak{A} \mid c \cap^{\mathfrak{A}} a = 0\}$  then exists  $A \in \mathfrak{Z}$  such that  $A \supseteq c$  and  $A \cap^{\mathfrak{A}} a = 0$  that is  $A \in \{A \in \mathfrak{Z} \mid A \cap^{\mathfrak{A}} a = 0\}$ . Consequently  $a^* \subseteq \bigcup^{\mathfrak{A}} \{A \in \mathfrak{Z} \mid A \cap^{\mathfrak{A}} a = 0\}$ .

We have  $a^* = \bigcup^{\mathfrak{A}} \{A \in \mathfrak{Z} \mid A \cap^{\mathfrak{A}} a = 0\} = \bigcup^{\mathfrak{Z}} \{A \in \mathfrak{Z} \mid A \cap^{\mathfrak{A}} a = 0\} \in \mathfrak{Z}$ .  $\square$

**Theorem 62** *If  $(\mathfrak{A}; \mathfrak{Z})$  is an up-aligned filtered complete lattice filtrator co-separable core which is a complete boolean lattice, then  $a^+$  is dual pseudocomplement of  $a$ , that is  $a^+ = \min \{c \in \mathfrak{A} \mid c \cup^{\mathfrak{A}} a = 1\}$  for every  $a \in \mathfrak{A}$ .*

**Proof** Our filtrator is with join-closed core. It's enough to prove that  $a^+ \cup^{\mathfrak{A}} a = 1$ . But  $a^+ \cup^{\mathfrak{A}} a = \overline{\text{Cor } a} \cup^{\mathfrak{A}} a \supseteq \overline{\text{Cor } a} \cup^{\mathfrak{A}} \text{Cor } a = \overline{\text{Cor } a} \cup^{\mathfrak{Z}} \text{Cor } a = 1$  (used the theorem 24 and the fact that our filtrator is filtered).  $\square$

**Definition 69** *The edge part of an element  $a \in \mathfrak{A}$  is  $\text{Edg } a = a \setminus \text{Cor } a$ , the dual edge part is  $\text{Edg}' a = a \setminus \text{Cor}' a$ .*

**Proposition 32** *For a primary filtrator over a complete boolean lattice both edge part and dual edge part are always defined.*

**Proof** Using the theorem 39.  $\square$

Knowing core part and edge part or dual core part and dual edge part of a filter object, the filter object can be restored by the formulas:

$$a = \text{Cor } a \cup^{\mathfrak{A}} \text{Edg } a \text{ and } a = \text{Cor}' a \cup^{\mathfrak{A}} \text{Edg}' a.$$

### 13.1. Core part and atomic elements

**Proposition 33** *Let  $(\mathfrak{A}; \mathfrak{Z})$  is a filtrator with join-closed core and  $\mathfrak{Z}$  is an atomistic lattice. Then for every  $a \in \mathfrak{A}$  such that  $\text{Cor}' a$  exists we have*

$$\text{Cor}' a = \bigcup^{\mathfrak{Z}} \{x \mid x \text{ is an atom of } \mathfrak{Z}, x \subseteq a\}.$$

**Proof**

$$\begin{aligned} \text{Cor}' a &= \\ &= \bigcup^{\mathfrak{Z}} \{A \in \mathfrak{Z} \mid A \subseteq a\} = \\ &= \bigcup^{\mathfrak{Z}} \left\{ \bigcup^{\mathfrak{Z}} \text{atoms}^{\mathfrak{Z}} A \mid A \in \mathfrak{Z}, A \subseteq a \right\} = \\ &= \bigcup^{\mathfrak{Z}} \bigcup \{ \text{atoms}^{\mathfrak{Z}} A \mid A \in \mathfrak{Z}, A \subseteq a \} = \\ &= \bigcup^{\mathfrak{Z}} \{x \mid x \text{ is an atom of } \mathfrak{Z}, x \subseteq a\}. \end{aligned}$$

$\square$

#### 14. Distributivity of core part over lattice operations

**Theorem 63** *If  $\mathfrak{A}$  is a distributive lattice then  $\text{Cor}(a \cap^{\mathfrak{F}} b) = \text{Cor } a \cap^{\mathfrak{A}} \text{Cor } b$  for elements  $a, b$  of the filtrator  $(\mathfrak{F}; \mathfrak{A})$ .*

**Proof**  $\text{Cor}(a \cap^{\mathfrak{F}} b) = \bigcap^{\mathfrak{A}} \text{up}(a \cap^{\mathfrak{F}} b) = \bigcap^{\mathfrak{A}} \{A \cap^{\mathfrak{A}} B \mid A \in \text{up } a, B \in \text{up } b\} = \bigcap^{\mathfrak{A}} \text{up } a \cap^{\mathfrak{A}} \bigcap^{\mathfrak{A}} \text{up } b = \text{Cor } a \cap^{\mathfrak{A}} \text{Cor } b$  (used the theorem 34).  $\square$

**Theorem 64** *Let  $(\mathfrak{A}; \mathfrak{Z})$  is a semifiltered down-aligned filtrator with finitely meet-closed core  $\mathfrak{Z}$  which is an atomistic lattice and  $\mathfrak{A}$  is a distributive lattice, then  $\text{Cor}'(a \cup^{\mathfrak{A}} b) = \text{Cor}' a \cup^{\mathfrak{Z}} \text{Cor}' b$  for every  $a, b \in \mathfrak{A}$ .*

**Proof**  $\text{Cor}'(a \cup^{\mathfrak{A}} b) = \bigcup^{\mathfrak{Z}} \{x \mid x \text{ is an atom of } \mathfrak{Z}, x \subseteq a \cup^{\mathfrak{A}} b\}$  (used proposition 33).

By the theorem 49 we have  $\text{Cor}'(a \cup^{\mathfrak{A}} b) = \bigcup^{\mathfrak{Z}} (\text{atoms}^{\mathfrak{A}}(a \cup^{\mathfrak{A}} b) \cap \mathfrak{Z}) = \bigcup^{\mathfrak{Z}} (\text{atoms}^{\mathfrak{A}} a \cup \text{atoms}^{\mathfrak{A}} b) \cap \mathfrak{Z} = \bigcup^{\mathfrak{Z}} ((\text{atoms}^{\mathfrak{A}} a \cap \mathfrak{Z}) \cup (\text{atoms}^{\mathfrak{A}} b \cap \mathfrak{Z})) = \bigcup^{\mathfrak{Z}} (\text{atoms}^{\mathfrak{A}} a \cap \mathfrak{Z}) \cup \bigcup^{\mathfrak{Z}} (\text{atoms}^{\mathfrak{A}} b \cap \mathfrak{Z})$  (used the theorem 1). Again using theorem 49, we get  $\text{Cor}'(a \cup^{\mathfrak{A}} b) = \bigcup^{\mathfrak{Z}} \{x \mid x \text{ is an atom of } \mathfrak{Z}, x \subseteq a\} \cup \bigcup^{\mathfrak{Z}} \{x \mid x \text{ is an atom of } \mathfrak{Z}, x \subseteq b\} = \text{Cor}' a \cup^{\mathfrak{Z}} \text{Cor}' b$  (again used proposition 33).  $\square$

**Theorem 65** *Let  $(\mathfrak{F}; \mathfrak{A})$  is a primary filtrator over a complete boolean lattice with co-separable core. Let  $\mathfrak{A}$  is a distributive lattice. Then  $(a \cap^{\mathfrak{F}} b)^+ = a^+ \cup^{\mathfrak{A}} b^+$  for every  $a, b \in \mathfrak{F}$ .*

**Proof**  $(\mathfrak{F}; \mathfrak{A})$  is a filtered up-aligned complete lattice filtrator with finitely join-closed (theorem 23) co-separable core (theorem 38) which is a complete boolean lattice. Thus by the theorem 59

$$(a \cap^{\mathfrak{F}} b)^+ = \overline{\text{Cor}(a \cap^{\mathfrak{F}} b)} = \overline{\text{Cor } a \cap^{\mathfrak{A}} \text{Cor } b} = \overline{\text{Cor } a} \cup^{\mathfrak{A}} \overline{\text{Cor } b} = a^+ \cup^{\mathfrak{A}} b^+.$$

$\square$

**Theorem 66** *Let  $(\mathfrak{A}; \mathfrak{Z})$  is a filtered distributive down-aligned, complete lattice filtrator with finitely meet-closed, separable core which is a complete atomistic boolean lattice. Then  $(a \cup^{\mathfrak{A}} b)^* = a^* \cap^{\mathfrak{Z}} b^*$  for every  $a, b \in \mathfrak{A}$ .*

**Proof**  $(a \cup^{\mathfrak{A}} b)^* = \overline{\text{Cor}'(a \cup^{\mathfrak{A}} b)} = \overline{\text{Cor}' a \cup^{\mathfrak{Z}} \text{Cor}' b} = \overline{\text{Cor}' a} \cap^{\mathfrak{Z}} \overline{\text{Cor}' b} = a^* \cap^{\mathfrak{Z}} b^*$  (used the theorem 60).  $\square$

**Theorem 67** *Let  $\mathfrak{A}$  is a complete boolean lattice. Then  $(a \cap^{\mathfrak{F}} b)^* = a^* \cup^{\mathfrak{A}} b^*$  for every  $a, b \in \mathfrak{A}$ .*

**Proof**  $(\mathfrak{F}; \mathfrak{A})$  is a filtered complete lattice filtrator with down-aligned, up-aligned, finitely meet-closed, separable core which is a complete boolean lattice. So

$$(a \cap^{\mathfrak{F}} b)^* = \overline{\text{Cor}(a \cap^{\mathfrak{F}} b)} = \overline{\text{Cor } a \cap^{\mathfrak{A}} \text{Cor } b} = \overline{\text{Cor } a} \cup^{\mathfrak{A}} \overline{\text{Cor } b} = a^* \cup^{\mathfrak{A}} b^*$$

(used the theorem 60).  $\square$

## 15. Number of filters on a set

**Theorem 68** *Let  $U$  is a set. The number of atomic f.o. on  $U$  is  $2^{2^{\text{card}U}}$  if  $U$  is infinite and  $\text{card}U$  if  $U$  is finite.*

**Proof** See [11]. □

**Corollary 20** *The number of filters on  $U$  is  $2^{2^{\text{card}U}}$  if  $U$  is infinite and  $2^{\text{card}U}$  if  $U$  is finite.*

**Proof** The finite case is obvious. The infinite case follows from the theorem and the fact that filters are collections of sets and there cannot be more than  $2^{2^{\text{card}U}}$  collections of sets on  $U$ . □

## 16. Isomorphic filters

Below is defined equivalence relation “being isomorphic” for filters on sets.

**Definition 70** *I call filters on sets  $a$  and  $b$  **directly isomorphic** when there are a bijection  $f : \bigcup a \rightarrow \bigcup b$  such that  $\langle f \rangle|_a$  is a bijection from  $a$  to  $b$ .*

**Definition 71** *Let  $U, W$  are sets. Let  $\mathcal{P}U, \mathcal{P}W$  are the lattices of all subsets of these sets. Let  $a$  and  $b$  are filters on the lattices  $\mathcal{P}U$  and  $\mathcal{P}W$  correspondingly. I will call filters  $a$  and  $b$  **isomorphic** when there exist sets  $A \in a$  and  $B \in b$  such that filters  $a \cap \mathcal{P}A$  and  $b \cap \mathcal{P}B$  are directly isomorphic.*

**Obvious 23** *Filters  $a$  and  $b$  are isomorphic iff there exist sets  $A \in a$  and  $B \in b$  such that there are a bijection  $f : A \rightarrow B$  such that  $\langle f \rangle|_{a \cap \mathcal{P}A}$  is a bijection from  $a \cap \mathcal{P}A$  to  $b \cap \mathcal{P}B$ .*

**Remark 13** It seems that there exist a simpler definition of isomorphic filters in terms of reloids [12], but that stumbles on some open problems about reloids.

**Proposition 34** *If two filters are directly isomorphic then they are isomorphic.*

**Proof** Take  $A = \bigcup a, B = \bigcup b$ . Then  $a \cap \mathcal{P}A = a$  and  $b \cap \mathcal{P}B = b$ . □

**Example 1** There exists a set  $U$  such that there are isomorphic filters on  $U$  which are not directly isomorphic.

**Proof** Consider two filters on  $\mathbb{N}$ :  $a = \{\mathbb{N}\}$  and  $b = \{\mathbb{N} \setminus \{0\}, \mathbb{N}\}$ . There are no bijection from  $a$  to  $b$  because  $\text{card}a \neq \text{card}b$ . So  $a$  and  $b$  are not directly isomorphic.

Now let  $A = \mathbb{N}$  and  $B = \mathbb{N} \setminus \{0\}$  and  $f : A \rightarrow B$  is defined by the formula  $fx = x + 1$ . Then  $a \cap \mathcal{P}A = \{\mathbb{N}\}$  and  $b \cap \mathcal{P}B = \{\mathbb{N} \setminus \{0\}\}$ ;  $f$  is a bijection from  $A$  to  $B$  and  $\langle f \rangle|_{a \cap \mathcal{P}A} = \langle f \rangle|_{\{\mathbb{N}\}}$  is a bijection from  $a \cap \mathcal{P}A$  to  $b \cap \mathcal{P}B$ . So  $a \cap \mathcal{P}A$  and  $b \cap \mathcal{P}B$  are directly isomorphic, that is  $a$  and  $b$  are isomorphic filters. □

**Theorem 69** “Being directly isomorphic” for filters on sets is an equivalence relation.

**Proof**

**Reflexivity** Let  $a$  is a filter on some set  $A$ . Then the identity function  $\text{Id}_A$  is a bijection from  $\bigcup a$  to  $\bigcup a$ . Evidently  $\langle \text{Id}_A \rangle|_a$  is a bijection from  $a$  to  $a$ . So  $a$  and  $a$  are directly isomorphic.

**Symmetry** Let filters  $a$  and  $b$  are directly isomorphic. Then exists a bijection  $f : \bigcup a \rightarrow \bigcup b$  such that  $\langle f \rangle|_a$  is a bijection from  $a$  to  $b$ .  $f^{-1} : \bigcup b \rightarrow \bigcup a$  is a bijection. To finish the proof it is enough to show that  $\langle f^{-1} \rangle|_b$  is a bijection from  $b$  to  $a$ . First  $\langle f^{-1} \rangle|_b$  is a function with domain  $b$ . Let  $X, Y \in b$ ; if  $X \neq Y$  then  $\langle f^{-1} \rangle X \neq \langle f^{-1} \rangle Y$  because  $f^{-1}$  is a bijection, consequently  $\langle f^{-1} \rangle|_b X \neq \langle f^{-1} \rangle|_b Y$ . So  $\langle f^{-1} \rangle|_b$  is an injection. Let  $X \in a$ ; then  $\langle f \rangle X \in b$  that is  $\langle f \rangle X = Y$  where  $Y \in b$ ;  $X = \langle f^{-1} \rangle \langle f \rangle X = \langle f^{-1} \rangle Y = \langle f^{-1} \rangle|_b Y$ ; that is  $\langle f^{-1} \rangle|_b$  is a function onto  $a$ . So  $\langle f^{-1} \rangle|_b$  is a bijection from  $b$  to  $a$ . Hence  $b$  and  $a$  are directly isomorphic.

**Transitivity** Let filters  $a$  and  $b$  are directly isomorphic and filters  $b$  and  $c$  are directly isomorphic. Then exist bijections  $f : \bigcup a \rightarrow \bigcup b$  and  $g : \bigcup b \rightarrow \bigcup c$  such that  $\langle f \rangle|_a$  is a bijection from  $a$  to  $b$  and  $\langle g \rangle|_b$  is a bijection from  $b$  to  $c$ . The function  $g \circ f$  is a bijection from  $\bigcup a$  to  $\bigcup c$ . We have  $\langle g \circ f \rangle|_a = \langle g \rangle|_b \circ \langle f \rangle|_a$  is a bijection as a composition of two bijections. So filters  $a$  and  $c$  are directly isomorphic. □

**Lemma 6** If  $a \cap \mathcal{P}A$  and  $b \cap \mathcal{P}B$  are directly isomorphic, then for every  $A' \in a \cap \mathcal{P}A$  there exists  $B' \in b \cap \mathcal{P}B$  such that  $a \cap \mathcal{P}A'$  and  $b \cap \mathcal{P}B'$  are directly isomorphic.

**Proof** Let  $a \cap \mathcal{P}A$  and  $b \cap \mathcal{P}B$  are directly isomorphic; let  $A' \in a \cap \mathcal{P}A$ . Then there are a bijection  $f : A \rightarrow B$  such that  $\langle f \rangle|_{a \cap \mathcal{P}A}$  is a bijection from  $a \cap \mathcal{P}A$  to  $b \cap \mathcal{P}B$ .  $a \cap \mathcal{P}A' \subseteq a \cap \mathcal{P}A$ , hence  $\langle f \rangle|_{a \cap \mathcal{P}A'}$  is an injection defined on the set  $a \cap \mathcal{P}A'$ . Let  $B' = \langle f \rangle A'$ . We have  $B' \subseteq B$ . Let  $Y \in b \cap \mathcal{P}B'$ ; then  $Y \in b \cap \mathcal{P}B$ ; by definition of “directly isomorphic” exists  $X \in a \cap \mathcal{P}A$  such that  $\langle f \rangle X = Y$ . We have  $X \subseteq A'$  because  $Y \subseteq B'$  and because  $f$  is a bijection. So  $X \in a \cap \mathcal{P}A'$ . Thus  $\langle f \rangle|_{a \cap \mathcal{P}A'}$  is a function onto  $b \cap \mathcal{P}B'$ . So  $\langle f \rangle|_{a \cap \mathcal{P}A'}$  is a bijection. □

**Theorem 70** “Being isomorphic” for filters on sets is an equivalence relation.

**Proof**

**Reflexivity** Let  $a$  is a filter. Let  $A = \bigcup a$ . Then  $a = a \cap \mathcal{P}A$  is directly isomorphic to itself. Consequently  $a$  is isomorphic to itself.

**Symmetry** Let filters  $a$  and  $b$  are isomorphic. Then there exist sets  $A \in a$  and  $B \in b$  such that filters  $a \cap \mathcal{P}A$  and  $b \cap \mathcal{P}B$  are directly isomorphic. By proved above  $b \cap \mathcal{P}B$  and  $a \cap \mathcal{P}A$  are directly isomorphic. But this means that  $b$  and  $a$  are isomorphic.

**Transitivity** Let filters  $a$  and  $b$  are isomorphic and filters  $b$  and  $c$  are isomorphic. Then  $a \cap \mathcal{P}A$  and  $b \cap \mathcal{P}B_1$  are directly isomorphic and  $b \cap \mathcal{P}B_2$  are  $c \cap \mathcal{P}C$  are directly isomorphic where  $A \in a$ ,  $B_1, B_2 \in b$ ,  $C \in c$ . Let  $B_0 = B_1 \cap B_2$ . We have  $B_0 \in b$ . By the lemma (taking in account also symmetry proved above) there exist sets  $A_0 \in a \cap \mathcal{P}A$  and  $C_0 \in c \cap \mathcal{P}C$  such that  $a \cap \mathcal{P}A_0$  and  $b \cap \mathcal{P}B_0$  are directly isomorphic and  $b \cap \mathcal{P}B_0$  and  $c \cap \mathcal{P}C_0$  are directly isomorphic. By transitivity of being direct isomorphic we have that  $a \cap \mathcal{P}A_0$  and  $c \cap \mathcal{P}C_0$  are directly isomorphic. Hence  $a$  and  $c$  are isomorphic.

□

**Proposition 35**

1. *Principal filters, generated by sets of the same cardinality, are isomorphic.*
2. *If a filter is isomorphic to a principal filter, then it is also a principal filter with the same cardinality of the sets which generate these principal filters.*

**Proof**

1. Let  $a$  and  $b$  are principal filters. Let they are generated by the sets  $A$  and  $B$  correspondingly where  $\text{card } A = \text{card } B$ . Enough to prove that  $a \cap \mathcal{P}A$  and  $b \cap \mathcal{P}B$  are directly isomorphic. But this follows from  $a \cap \mathcal{P}A = \{A\}$  and  $b \cap \mathcal{P}B = \{B\}$  and  $\text{card } A = \text{card } B$ , because any bijection from  $A$  to  $B$  sends  $\{A\}$  to  $\{B\}$ .
2. Let  $a$  is a principal filter generated by a set  $A$ , let  $b$  is a filter isomorphic to  $a$ . We shall prove that  $b$  is principal and is generated by a set  $B$  such that  $\text{card } B = \text{card } A$ . Let  $A \in a$  and  $B \in b$  and  $f$  is a bijection from  $A$  to  $B$  such that  $\langle f \rangle|_{a \cap \mathcal{P}A}$  is a bijection from  $a \cap \mathcal{P}A$  to  $b \cap \mathcal{P}B$ . We have  $b \cap \mathcal{P}B = \{\langle f \rangle|_{a \cap \mathcal{P}A} X \mid X \in a \cap \mathcal{P}A\}$ . So  $b \cap \mathcal{P}B$  has the smallest element  $\langle f \rangle A$ . Consequently  $b$  has the smallest element  $\langle f \rangle A$  and so  $b$  is a principal filter generated by the set  $B = \langle f \rangle A$  whose cardinality is  $\text{card } A$ .

□

**Proposition 36** *A filter isomorphic to a nontrivial ultrafilter is a nontrivial ultrafilter.*

**Proof** Let  $a$  is a nontrivial ultrafilter and let  $b$  is isomorphic to  $a$ . Then there are sets  $A \in a$  and  $B \in b$  and a bijection  $f : A \rightarrow B$  such that  $\langle f \rangle|_{a \cap \mathcal{P}A}$  is a bijection from  $a \cap \mathcal{P}A$  to  $b \cap \mathcal{P}B$ .

The filter  $b$  cannot be a trivial ultrafilter because otherwise  $a$  would be also a principal filter. So it's enough to prove that  $b$  is an ultrafilter. We will prove that for any set  $Y \in \mathcal{P} \cup b$  either  $Y$  or  $(\cup b) \setminus Y$  is an element of  $b$ .

Let  $Y \in \mathcal{P} \cup b$ . Then  $Y' = Y \cap B \in \mathcal{P}B$ ;  $Y' = \langle f \rangle X'$  for some  $X' \in \mathcal{P}A$ . Because  $a$  is an ultrafilter, either  $X' \in a$  or  $(\cup a) \setminus X' \in a$ . If  $X' \in a$  then  $X' \in a \cap \mathcal{P}A$  and so  $Y' = \langle f \rangle X' = \langle f \rangle|_{a \cap \mathcal{P}A} X' \in b \cap \mathcal{P}B$  and consequently  $Y \in b$ . If  $(\cup a) \setminus X' \in a$  then  $A \setminus X' \in a \cap \mathcal{P}A$ ; consequently  $\langle f \rangle|_{a \cap \mathcal{P}A}(A \setminus X') \in b \cap \mathcal{P}B$ ;  $\langle f \rangle|_{a \cap \mathcal{P}A}(A) \setminus \langle f \rangle|_{a \cap \mathcal{P}A}(X') \in b \cap \mathcal{P}B$ ;  $B \setminus Y' \in b$ ;  $(\cup b) \setminus Y \in b$ .  $\square$

**Theorem 71** For an infinite set  $U$  there exist  $2^{2^{\text{card } U}}$  equivalence classes of isomorphic ultrafilters.

**Proof** The number of bijections between any two given subsets of  $U$  is no more than  $(\text{card } U)^{\text{card } U} = 2^{\text{card } U}$ . The number of bijections between all pairs of subsets of  $U$  is no more than  $2^{\text{card } U} \cdot 2^{\text{card } U} = 2^{\text{card } U}$ . Therefore each isomorphism class contains at most  $2^{\text{card } U}$  ultrafilters. But there are  $2^{2^{\text{card } U}}$  ultrafilters. So there are  $2^{2^{\text{card } U}}$  classes.  $\square$

**Remark 14** One of the above mentioned equivalence classes contains trivial ultrafilters.

**Corollary 21** There exist non-isomorphic nontrivial ultrafilters on any infinite set.

## 17. Partitioning filter objects

**Definition 72** Let  $\mathfrak{A}$  is a complete lattice. **Thorning** of an element  $a \in \mathfrak{A}$  is a set  $S \in \mathcal{P}\mathfrak{A} \setminus \{0\}$  such that

$$\bigcup^{\mathfrak{A}} S = a \quad \text{and} \quad \forall x, y \in S : x \succ^{\mathfrak{A}} y.$$

**Definition 73** Let  $\mathfrak{A}$  is a complete lattice. **Weak partitioning** of an element  $a \in \mathfrak{A}$  is a set  $S \in \mathcal{P}\mathfrak{A} \setminus \{0\}$  such that

$$\bigcup^{\mathfrak{A}} S = a \quad \text{and} \quad \forall x \in S : x \succ^{\mathfrak{A}} \bigcup^{\mathfrak{A}} (S \setminus \{x\}).$$

**Definition 74** Let  $\mathfrak{A}$  is a complete lattice. **Strong partitioning** of an element  $a \in \mathfrak{A}$  is a set  $S \in \mathcal{P}\mathfrak{A} \setminus \{0\}$  such that

$$\bigcup^{\mathfrak{A}} S = a \quad \text{and} \quad \forall A, B \in \mathcal{P}S : (A \succ B \Rightarrow \bigcup^{\mathfrak{A}} A \succ^{\mathfrak{A}} \bigcup^{\mathfrak{A}} B).$$

**Obvious 24** 1. Every strong partitioning is a weak partitioning.

2. *Every weak partitioning is a thorning.*

See the section “Open problems” for supposed properties of partitionings.

## 18. Open problems

In this section I will formulate some conjectures about lattices of filter objects on a set. If a conjecture comes true, it may be generalized for more general lattices (such as, for example, lattices of filters on arbitrary lattices). I deem that the main challenge is to prove the special case about lattices of filter objects on a set, and generalizing the conjectures is expected to be a simple task.

### 18.1. Partitioning

**Conjecture 1** *Weak partitioning of an element of a lattice of filter objects on a set is the same as its strong partitioning.*

Now consider the complete lattice  $[S]$  generated by the set  $S$  where  $S$  is a strong partitioning of some element  $a$ .

**Conjecture 2**  $[S] = \{\bigcup^{\mathfrak{F}} X \mid X \in \mathcal{P}S\}$ , where  $[S]$  is the complete lattice generated by a strong partitioning  $S$  of an element of a lattice  $\mathfrak{F}$  of filter objects on a set.

**Proposition 37** *Provided that the last conjecture is true, we have that  $[S]$  is a complete atomic boolean lattice with the set of its atoms being  $S$ .*

**Remark 15** Consequently  $S$  is atomistic, completely distributive and isomorphic to a power set algebra (see [13]).

**Proof** Completeness of  $[S]$  is obvious. Let  $A \in [S]$ . Then exists  $X \in \mathcal{P}S$  such that  $A = \bigcup^{\mathfrak{F}} X$ . Let  $B = \bigcup^{\mathfrak{F}} (S \setminus X)$ . Then  $B \in [S]$  and  $A \cap B = 0$ .  $A \cup B = \bigcup^{\mathfrak{F}} S$  is the biggest element of  $S$ . So we have proved that  $[S]$  is a boolean lattice.

Now let prove that  $[S]$  is atomic with the set of atoms being  $S$ . Let  $z \in S$  and  $A \in [S]$ . If  $A \neq z$  then either  $A = 0$  or  $x \in X$  where  $A = \bigcup^{\mathfrak{F}} X$ ,  $X \in \mathcal{P}S$  and  $x \neq z$ . Because  $S$  is a partitioning,  $\bigcup^{\mathfrak{F}} (X \setminus \{z\}) \cap^{\mathfrak{F}} z = 0$  and  $\bigcup^{\mathfrak{F}} (X \setminus \{z\}) \neq 0$ . So  $A = \bigcup^{\mathfrak{F}} X = \bigcup^{\mathfrak{F}} (X \setminus \{z\}) \cup^{\mathfrak{F}} z \not\subseteq z$ .

Finally we will prove that elements of  $[S] \setminus S$  are not atoms. Let  $A \in [S] \setminus S$  and  $A \neq 0$ . Then  $A \supseteq x \cup^{\mathfrak{F}} y$  where  $x, y \in S$  and  $x \neq y$ . If  $A$  is an atom then  $A = x = y$  what is impossible.  $\square$

**Proposition 38** *The conjecture about the value of  $[S]$  is equivalent to closedness of  $\{\bigcup^{\mathfrak{F}} X \mid X \in \mathcal{P}S\}$  under arbitrary meets and joins.*

**Proof** If  $\{\bigcup^{\mathfrak{F}} X \mid X \in \mathcal{P}S\} = [S]$  then trivially  $\{\bigcup^{\mathfrak{F}} X \mid X \in \mathcal{P}S\}$  is closed under arbitrary meets and joins.

If  $\{\bigcup^{\mathfrak{F}} X \mid X \in \mathcal{P}S\}$  is closed under arbitrary meets and joins, then it is the complete lattice generated by the set  $S$  because it cannot be smaller than the set of all suprema of subsets of  $S$ .  $\square$

That  $\{\bigcup^{\mathfrak{F}} X \mid X \in \mathcal{P}S\}$  is closed under arbitrary joins is trivial. I have not succeeded to prove that it is closed under arbitrary meets, but have proved a weaker statement that it is closed under finite meets:

**Proposition 39**  $\{\bigcup^{\mathfrak{F}} X \mid X \in \mathcal{P}S\}$  is closed under finite meets.

**Proof** Let  $R = \{\bigcup^{\mathfrak{F}} X \mid X \in \mathcal{P}S\}$ . Then

$$\begin{aligned} \bigcup^{\mathfrak{A}} X \cap^{\mathfrak{A}} \bigcup^{\mathfrak{A}} Y &= \\ \bigcup^{\mathfrak{A}} ((X \cap Y) \cup (X \setminus Y)) \cap^{\mathfrak{A}} \bigcup^{\mathfrak{A}} Y &= \\ \left( \bigcup^{\mathfrak{A}} (X \cap Y) \cup^{\mathfrak{A}} \bigcup^{\mathfrak{A}} (X \setminus Y) \right) \cap^{\mathfrak{A}} \bigcup^{\mathfrak{A}} Y &= \\ \left( \bigcup^{\mathfrak{A}} (X \cap Y) \cap^{\mathfrak{A}} \bigcup^{\mathfrak{A}} Y \right) \cup^{\mathfrak{A}} \left( \bigcup^{\mathfrak{A}} (X \setminus Y) \cap^{\mathfrak{A}} \bigcup^{\mathfrak{A}} Y \right) &= \\ \left( \bigcup^{\mathfrak{A}} (X \cap Y) \cap^{\mathfrak{A}} \bigcup^{\mathfrak{A}} Y \right) \cup^{\mathfrak{A}} 0 &= \\ \bigcup^{\mathfrak{A}} (X \cap Y) \cap^{\mathfrak{A}} \bigcup^{\mathfrak{A}} Y. & \end{aligned}$$

Applying the formula  $\bigcup^{\mathfrak{A}} X \cap^{\mathfrak{A}} \bigcup^{\mathfrak{A}} Y = \bigcup^{\mathfrak{A}} (X \cap Y) \cap^{\mathfrak{A}} \bigcup^{\mathfrak{A}} Y$  twice we get

$$\begin{aligned} \bigcup^{\mathfrak{A}} X \cap^{\mathfrak{A}} \bigcup^{\mathfrak{A}} Y &= \\ \bigcup^{\mathfrak{A}} (X \cap Y) \cap^{\mathfrak{A}} \bigcup^{\mathfrak{A}} (Y \cap (X \cap Y)) &= \\ \bigcup^{\mathfrak{A}} (X \cap Y) \cap^{\mathfrak{A}} \bigcup^{\mathfrak{A}} (X \cap Y) &= \\ \bigcup^{\mathfrak{A}} (X \cap Y). & \end{aligned}$$

But for any  $A, B \in R$  exist  $X, Y \in \mathcal{P}S$  such that  $A = \bigcup^{\mathfrak{A}} X$  and  $B = \bigcup^{\mathfrak{A}} Y$ . So  $A \cap^{\mathfrak{A}} B = \bigcup^{\mathfrak{A}} X \cap^{\mathfrak{A}} \bigcup^{\mathfrak{A}} Y = \bigcup^{\mathfrak{A}} (X \cap Y) \in R$ .  $\square$

### Conjecture 3

1. Every filter object on a set can be partitioned into atomic filter objects.
2. This partitioning is unique.

#### 18.2. Quasidifference

**Problem 1** Which of the following expressions are pairwise equal for all  $a, b \in \mathfrak{F}$  for each lattice  $\mathfrak{F}$  of filters on a set? (If some are not equal, provide counter-examples.)

1.  $\bigcap^{\mathfrak{F}} \{z \in \mathfrak{F} \mid a \subseteq b \cup^{\mathfrak{F}} z\}$  (quasidifference of  $a$  and  $b$ );

2.  $\bigcup^{\mathfrak{F}} \{z \in \mathfrak{F} \mid z \subseteq a \wedge z \cap^{\mathfrak{F}} b = \emptyset\}$  (second quasidifference of  $a$  and  $b$ );
3.  $\bigcup^{\mathfrak{F}} (\text{atoms}^{\mathfrak{F}} a \setminus \text{atoms}^{\mathfrak{F}} b)$ ;
4.  $\bigcup^{\mathfrak{F}} \{a \cap^{\mathfrak{F}} (U \setminus B) \mid B \in \text{up} b\}$ .

### 18.3. Complementary filter objects

**Conjecture 4**  $Z(DA)$  is a complete lattice when  $\mathcal{A} \in \mathfrak{F}$  where  $\mathfrak{F}$  is the set of f.o. on some set  $U$ . (If true, this conjecture may be generalized.)

**Conjecture 5**  $Z(DA)$  is join-closed for any f.o.  $\mathcal{A}$ .

**Proposition 40** The last conjecture follows from the previous.

**Proof** Let  $S \in \mathcal{P}Z(DA)$ . We need to prove that  $\bigcup^{Z(DA)} S = \bigcup^{\mathfrak{F}} S$ . It is enough to prove that for any  $\mathcal{F} \in DA$

$$\forall K \in S : K \subseteq \mathcal{F} \Rightarrow \mathcal{F} \supseteq \bigcup^{Z(DA)} S.$$

Really: Let  $C \in \text{up}^{DA} \mathcal{F}$  and  $\forall K \in S : K \subseteq \mathcal{F}$ . Then  $C \supseteq \mathcal{F}$ ;  $C \supseteq \bigcup^{Z(DA)} S$ ;  $C \in \text{up} \bigcup^{Z(DA)} S$ ; consequently  $\mathcal{F} \supseteq \bigcup^{Z(DA)} S$ .  $\square$

In the light of the theorem 58, it is simple to prove that the above conjecture follows from each of two items of the following conjecture:

**Conjecture 6** Consider the filtrator  $(\mathfrak{F}; \mathcal{P}U)$  where  $U$  is some set and  $\mathfrak{F}$  is the set of filter objects on  $\mathcal{P}U$ . Let  $\mathcal{A} \in \mathfrak{F}$  and  $T \in \mathcal{P}\mathcal{P}U$ . Then:

1.  $\bigcup^{Z(DA)} \{X \cap^{\mathfrak{F}} \mathcal{A} \mid X \in T\} = \mathcal{A} \cap^{\mathfrak{F}} \bigcup T$ ;
2.  $\bigcap^{Z(DA)} \{X \cap^{\mathfrak{F}} \mathcal{A} \mid X \in T\} = \mathcal{A} \cap^{\mathfrak{F}} \bigcap T$ .

We can prove that  $a \setminus^* b = a \# b$  if we can prove that  $Da$  is a filtered filtrator with both separable and co-separable and join-closed center because of formulas expressing equality of  $a \setminus^* b$  and  $a \# b$  and the theorem providing the equality  $a^* = a^+$ .

### 18.4. Misc problems

**Conjecture 7** For a filtrator  $(\mathfrak{F}; \mathfrak{A})$  of filters on a set we have  $A \cap^{\mathfrak{F}} \bigcup^{\mathfrak{F}} S = \bigcup^{\mathfrak{F}} \langle A \cap^{\mathfrak{F}} \rangle S$  for every  $A \in \mathfrak{A}$ ,  $S \in \mathcal{P}\mathfrak{F}$ .

18.5. *Non-formal problems*

Develop the theory of atoms on posets not having least element. See [10] for the general definition of atoms.

Should we introduce the concept of star objects, analogous to filter objects, and research the lattice of star objects?

Find a common generalization of two theorems:

1. If  $\mathfrak{A}$  is a meet-semilattice with greatest element 1 then for any  $\mathcal{A}, \mathcal{B} \in \mathfrak{F}$

$$\text{up}(\mathcal{A} \cup^{\mathfrak{F}} \mathcal{B}) = \text{up} \mathcal{A} \cap \text{up} \mathcal{B}.$$

2. If  $\mathfrak{A}$  is a join-semilattice then  $\mathfrak{F}$  is a join-semilattice then and for any  $\mathcal{A}, \mathcal{B} \in \mathfrak{F}$

$$\text{up}(\mathcal{A} \cup^{\mathfrak{F}} \mathcal{B}) = \text{up} \mathcal{A} \cap \text{up} \mathcal{B}.$$

Under which conditions  $a \setminus^* b$  and  $a \# b$  are complementive to  $a$ ?

Generalize straight maps for arbitrary posets.

**19. Postface**

I have set a wiki site to collaboratively write a book which will extend and amend this article and will emerge into the exhaustive reference text about filters on posets, filters on lattices, and generalizations thereof. I call you to collaborate with me writing this book.

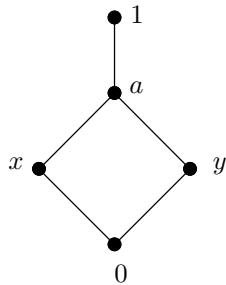
The wiki site URL is: <http://filters.wikidot.com>.

I also call you to solve open problems which I formulated in this article.

**Appendix A. Some counter-examples**

**Example 2** There exist a bounded distributive lattice which is not lattice with separable center.

**Proof** The lattice with the following Hasse diagram is bounded and distributive because it does not contain “diamond lattice” nor “pentagon lattice” as a sublattice [14].



It's center is  $\{0, 1\}$ .  $x \cap y = 0$  indeed up  $x = \{1\}$  but  $1 \cap y \neq 0$  consequently the lattice is not with separable center.  $\square$

For further examples we will use the filter object  $\Delta$  defined by the formula

$$\Delta = \bigcap^{\mathfrak{F}} \{(-\varepsilon; \varepsilon) \mid \varepsilon \in \mathbb{R}, \varepsilon > 0\}$$

and more general

$$\Delta + a = \bigcap^{\mathfrak{F}} \{(a - \varepsilon; a + \varepsilon) \mid \varepsilon \in \mathbb{R}, \varepsilon > 0\}.$$

**Example 3** There exists  $A \in \mathcal{P}U$  such that  $\bigcap^{\mathfrak{F}} A \neq \bigcap^{\mathcal{P}U} A$  for some set  $U$ .

**Proof**  $\bigcap^{\mathcal{P}\mathbb{R}} \{(-a; a) \mid a \in \mathbb{R}, a > 0\} = \{0\} \neq \Delta$ .  $\square$

**Example 4** There exists a set  $U$  and there are a f.o.  $a$  and a set  $S$  of f.o. on the lattice  $\mathcal{P}U$  such that  $a \cap^{\mathfrak{F}} \bigcup^{\mathfrak{F}} S \neq \bigcup^{\mathfrak{F}} \langle a \cap^{\mathfrak{F}} \rangle S$ .

**Proof** Let  $a = \Delta$  and  $S = \{(\varepsilon; +\infty) \mid \varepsilon > 0\}$ . Then  $a \cap^{\mathfrak{F}} \bigcup^{\mathfrak{F}} S = \Delta \cap^{\mathfrak{F}} (0; +\infty) \neq \emptyset$  while  $\bigcup^{\mathfrak{F}} \langle a \cap^{\mathfrak{F}} \rangle S = \bigcup^{\mathfrak{F}} \{\emptyset\} = \emptyset$ .  $\square$

**Example 5** There are thornings which are not weak partitionings.

**Proof**  $\{\Delta + a \mid a \in \mathbb{R}\}$  is a thorning but not weak partitioning of the real line.  $\square$

**Example 6** There exist a complete lattice for which weak partitioning and strong partitioning are not the same.

**Proof** (proof sketch by François G. Dorais) Consider the poset  $\mathfrak{A}$  of all closed (as subsets of  $\mathbb{R}$ ) subsets of  $\{1, \frac{1}{2}, \frac{1}{3}, \dots, 0\}$ . Let  $S = \{\{\frac{1}{n}\} \mid n = 1, 2, \dots\}$ . Obviously  $S \subseteq \mathfrak{A}$ .

Let  $X \in \mathcal{P}S$ . Let's prove  $\bigcup^{\mathfrak{A}} X = \text{cl} \bigcup X$ .

First  $\text{cl} \bigcup X \in \mathfrak{A}$  because  $\bigcup X \subseteq \{1, \frac{1}{2}, \frac{1}{3}, \dots, 0\}$ .

Obviously  $\forall x \in X : x \subseteq \text{cl} \bigcup X$ .

Let  $c \in \mathfrak{A}$  and  $\forall x \in X : c \supseteq x$ . Then  $c \supseteq \bigcup X$  and so  $c = \text{cl} c \supseteq \text{cl} \bigcup X$ .

So  $\bigcup^{\mathfrak{A}} X = \text{cl} \bigcup X$ . By the way this implies that  $\mathfrak{A}$  is a complete lattice.

Let  $a, b \in S$ . Let's prove  $a \cap^{\mathfrak{A}} b = \text{cl}(a \cap b)$ .

Obviously  $\text{cl}(a \cap b) \subseteq \text{cl} a = a$  so having  $\text{cl}(a \cap b) \subseteq a$  and similarly  $\text{cl}(a \cap b) \subseteq b$ .

Let  $c \in \mathfrak{A}$  and  $c \subseteq a \wedge c \subseteq b$ . Then  $c \subseteq a \cap b$  and so  $c = \text{cl} c \subseteq \text{cl}(a \cap b)$ .

So  $a \cap^{\mathfrak{A}} b = \text{cl}(a \cap b)$ .

Let  $x \in S$ . Then  $x = \{\frac{1}{n}\}$  for some  $n \in \{1, 2, \dots\}$ .

$$\bigcup^{\mathfrak{A}} (S \setminus \{x\}) = \text{cl} \bigcup (S \setminus \{x\}) = \{0\} \cup \left( S \setminus \left\{ \left\{ \frac{1}{n} \right\} \right\} \right).$$

So

$$\begin{aligned}
& \{x\} \cap^{\mathfrak{A}} \bigcup^{\mathfrak{A}} (S \setminus \{x\}) = \\
& \left\{ \frac{1}{n} \right\} \cap^{\mathfrak{A}} \left( \{0\} \cup \left( S \setminus \left\{ \left\{ \frac{1}{n} \right\} \right\} \right) \right) = \\
& \text{cl} \left( \left\{ \frac{1}{n} \right\} \cap \left( \{0\} \cup \left( S \setminus \left\{ \left\{ \frac{1}{n} \right\} \right\} \right) \right) \right) = \\
& \text{cl } \emptyset = \emptyset.
\end{aligned}$$

Thus  $S$  is a weak partitioning.

Let  $A = \left\{ \left\{ \frac{1}{2n} \right\} \mid n = 1, 2, \dots \right\}$  and  $B = \left\{ \left\{ \frac{1}{2n+1} \right\} \mid n = 1, 2, \dots \right\}$ .  
 $A \cap B = \emptyset$  but  $\bigcup^{\mathfrak{A}} A \cap^{\mathfrak{A}} \bigcup^{\mathfrak{A}} B = (\text{cl } \bigcup A) \cap^{\mathfrak{A}} (\text{cl } \bigcup B) \supseteq \{0\} \cap^{\mathfrak{A}} \{0\} = \{0\} \neq \emptyset$ .  
Thus  $S$  is not a strong partitioning.  $\square$

## Appendix B. Logic of Generalizations

In mathematics it is often encountered that a smaller set  $S$  naturally bijectively corresponds to a subset  $R$  of a larger set  $B$ . (In other words, there is specified an injection from  $S$  to  $B$ .) It is a widespread practice to equate  $S$  with  $R$ .

**Remark 16** I denote the first set  $S$  from the first letter of the word “small” and the second set  $B$  from the first letter of the word “big”, because  $S$  is intuitively considered as smaller than  $B$ . (However we do not require  $\text{card } S < \text{card } B$ .)

The set  $B$  is considered as a generalization of the set  $S$ , for example: whole numbers generalizing natural numbers, rational numbers generalizing whole numbers, real numbers generalizing rational numbers, complex numbers generalizing real numbers, etc.

But strictly speaking this equating may contradict to the axioms of ZF/ZFC because we are not insured against  $S \cap B \neq \emptyset$  incidents. Not wonderful, as it is often labeled as “without proof”.

To work around of this (and formulate things exactly what could benefit computer proof assistants) we will replace the set  $B$  with a new set  $B'$  having a bijection  $M : B \rightarrow B'$  such that  $S \subseteq B'$ . (I call this bijection  $M$  from the first letter of the word “move” which signifies the move from the old set  $B$  to a new set  $B'$ ).

### Appendix B.1. The formalistic

Let  $S$  and  $B$  are sets. Let  $E$  is an injection from  $S$  to  $B$ . Let  $R = \text{im } E$ .

Let  $t = \mathcal{P} \cup \bigcup S$ .

Let  $M(x) = \begin{cases} E^{-1}x & \text{if } x \in R; \\ (t; x) & \text{if } x \notin R. \end{cases}$

Recall that in standard ZF  $(t; x) = \{\{t\}, \{t, x\}\}$  by definition.

**Theorem 72**  $(t; x) \notin S$ .

**Proof** Suppose  $(t; x) \in S$ . Then  $\{\{t\}, \{t, x\}\} \in S$ . Consequently  $\{t\} \in \bigcup S$ ;  $t \subseteq \bigcup \bigcup S$ ;  $t \in \mathcal{P} \bigcup \bigcup S$ ;  $t \in t$  what contradicts to the axiom of foundation (aka axiom of regularity).  $\square$

**Definition 75** Let  $B' = \text{im } M$ .

**Theorem 73**  $S \subseteq B'$ .

**Proof** Let  $x \in S$ . Then  $Ex \in R$ ;  $M(Ex) = E^{-1}Ex = x$ ;  $x \in \text{im } M = B'$ .  $\square$

**Obvious 25**  $E$  is a bijection from  $S$  to  $R$ .

**Theorem 74**  $M$  is a bijection from  $B$  to  $B'$ .

**Proof** Surjectivity of  $M$  is obvious. Let's prove injectivity. Let  $a, b \in B$  and  $M(a) = M(b)$ . Consider all cases:

$a, b \in R$   $M(a) = E^{-1}a$ ;  $M(b) = E^{-1}b$ ;  $E^{-1}a = E^{-1}b$ ; thus  $a = b$  because  $E^{-1}$  is a bijection.

$a \in R, b \notin R$   $M(a) = E^{-1}a$ ;  $M(b) = (t; b)$ ;  $M(a) \in S$ ;  $M(b) \notin S$ . Thus  $M(a) \neq M(b)$ .

$a \notin R, b \in R$  Analogous,

$a, b \notin R$   $M(a) = (t; a)$ ;  $M(b) = (t; b)$ . Thus  $M(a) = M(b)$  implies  $a = b$ .

$\square$

**Theorem 75**  $M \circ E = \text{id}_S$ .

**Proof** Let  $x \in S$ . Then  $Ex \in R$ ;  $M(Ex) = E^{-1}Ex = x$ .  $\square$

**Obvious 26**  $E = M^{-1}|_S$ .

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