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Bases of Continuous Lattices[1]

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Summary. The article is a Mizar formalization of [13, 168–169]. We show definition and fundamental theorems from theory of basis of continuous lattices.

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The articles [19], [21], [16], [22], [8], [9], [10], [12], [2], [3], [1], [17], [20], [18], [4], [5], [14], [23], [6], [11], [7], and [15] provide the notation and terminology for this paper.

1. Preliminaries

The following proposition is true

(1) For every non empty poset L and for every element x of L holds $\mathrm{compactbelow}(x) = {\downarrow}x \cap$ the carrier of $\mathrm{CompactSublatt}(L)$.

Let L be a non empty reflexive transitive relational structure and let X be a subset of $\langle \mathrm{Ids}(L), \subseteq \rangle$. Then $\bigcup X$ is a subset of L.

Next we state a number of propositions:

(2) For every non empty relational structure L and for all subsets X, Y of L such that $X \subseteq Y$ holds $\mathrm{finsups}(X) \subseteq \mathrm{finsups}(Y)$.

(3) Let L be a non empty transitive relational structure, S be a sups-inheriting non empty full relational substructure of L, X be a subset of L, and Y be a subset of S. If $X = Y$, then $\mathrm{finsups}(X) \subseteq \mathrm{finsups}(Y)$.

(4) Let L be a complete transitive antisymmetric non empty relational structure, S be a sups-inheriting non empty full relational substructure of L, X be a subset of L, and Y be a subset of S. If $X = Y$, then $\mathrm{finsups}(X) = \mathrm{finsups}(Y)$.

(5) Let L be a complete sup-semilattice and S be a join-inheriting non empty full relational substructure of L. Suppose $\bot_L \in$ the carrier of S. Let X be a subset of L and Y be a subset of S. If $X = Y$, then $\mathrm{finsups}(Y) \subseteq \mathrm{finsups}(X)$.

(6) For every lower-bounded sup-semilattice L and for every subset X of $\langle \mathrm{Ids}(L), \subseteq \rangle$ holds $\sup X = {\downarrow}\mathrm{finsups}(\bigcup X)$.

(7) For every reflexive transitive relational structure L and for every subset X of L holds ${\downarrow}{\downarrow}X = {\downarrow}X$.

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(8) For every reflexive transitive relational structure L and for every subset X of L holds $\uparrow\uparrow X = \uparrow X$.

(9) For every non empty reflexive transitive relational structure L and for every element x of L holds $\downarrow\downarrow x = \downarrow x$.

(10) For every non empty reflexive transitive relational structure L and for every element x of L holds $\uparrow\uparrow x = \uparrow x$.

(11) Let L be a non empty relational structure, S be a non empty relational substructure of L, X be a subset of L, and Y be a subset of S. If $X = Y$, then $\downarrow Y \subseteq \downarrow X$.

(12) Let L be a non empty relational structure, S be a non empty relational substructure of L, X be a subset of L, and Y be a subset of S. If $X = Y$, then $\uparrow Y \subseteq \uparrow X$.

(13) Let L be a non empty relational structure, S be a non empty relational substructure of L, x be an element of L, and y be an element of S. If $x = y$, then $\downarrow y \subseteq \downarrow x$.

(14) Let L be a non empty relational structure, S be a non empty relational substructure of L, x be an element of L, and y be an element of S. If $x = y$, then $\uparrow y \subseteq \uparrow x$.

2. Relational Subsets

Let L be a non empty relational structure and let S be a subset of L. We say that S is meet-closed if and only if:

(Def. 1) $\mathrm{sub}(S)$ is meet-inheriting.

Let L be a non empty relational structure and let S be a subset of L. We say that S is join-closed if and only if:

(Def. 2) $\mathrm{sub}(S)$ is join-inheriting.

Let L be a non empty relational structure and let S be a subset of L. We say that S is infs-closed if and only if:

(Def. 3) $\mathrm{sub}(S)$ is infs-inheriting.

Let L be a non empty relational structure and let S be a subset of L. We say that S is sups-closed if and only if:

(Def. 4) $\mathrm{sub}(S)$ is sups-inheriting.

Let L be a non empty relational structure. One can verify that every subset of L which is infs-closed is also meet-closed and every subset of L which is sups-closed is also join-closed.

Let L be a non empty relational structure. Observe that there exists a subset of L which is infs-closed, sups-closed, and non empty.

We now state a number of propositions:

(15) Let L be a non empty relational structure and S be a subset of L. Then S is meet-closed if and only if for all elements x, y of L such that $x \in S$ and $y \in S$ and inf $\{x,y\}$ exists in L holds $\inf\{x,y\} \in S$.

(16) Let L be a non empty relational structure and S be a subset of L. Then S is join-closed if and only if for all elements x, y of L such that $x \in S$ and $y \in S$ and sup $\{x,y\}$ exists in L holds $\sup\{x,y\} \in S$.

(17) Let L be an antisymmetric relational structure with g.l.b.'s and S be a subset of L. Then S is meet-closed if and only if for all elements x, y of L such that $x \in S$ and $y \in S$ holds $\inf\{x,y\} \in S$.

(18) Let L be an antisymmetric relational structure with l.u.b.'s and S be a subset of L. Then S is join-closed if and only if for all elements x, y of L such that $x \in S$ and $y \in S$ holds $\sup\{x,y\} \in S$.

(19) Let L be a non empty relational structure and S be a subset of L. Then S is infs-closed if and only if for every subset X of S such that inf X exists in L holds $\bigsqcap_L X \in S$.

(20) Let L be a non empty relational structure and S be a subset of L. Then S is sups-closed if and only if for every subset X of S such that sup X exists in L holds $\bigsqcup_L X \in S$.

(21) Let L be a non empty transitive relational structure, S be an infs-closed non empty subset of L, and X be a subset of S. If inf X exists in L, then inf X exists in $\mathrm{sub}(S)$ and $\bigsqcap_{\mathrm{sub}(S)} X = \bigsqcap_L X$.

(22) Let L be a non empty transitive relational structure, S be a sups-closed non empty subset of L, and X be a subset of S. If sup X exists in L, then sup X exists in $\mathrm{sub}(S)$ and $\bigsqcup_{\mathrm{sub}(S)} X = \bigsqcup_L X$.

(23) Let L be a non empty transitive relational structure, S be a meet-closed non empty subset of L, and x, y be elements of S. Suppose inf $\{x,y\}$ exists in L. Then inf $\{x,y\}$ exists in $\mathrm{sub}(S)$ and $\bigsqcap_{\mathrm{sub}(S)}\{x,y\} = \bigsqcap_L\{x,y\}$.

(24) Let L be a non empty transitive relational structure, S be a join-closed non empty subset of L, and x, y be elements of S. Suppose sup $\{x,y\}$ exists in L. Then sup $\{x,y\}$ exists in $\mathrm{sub}(S)$ and $\bigsqcup_{\mathrm{sub}(S)}\{x,y\} = \bigsqcup_L\{x,y\}$.

(25) Let L be an antisymmetric transitive relational structure with g.l.b.'s and S be a non empty meet-closed subset of L. Then $\mathrm{sub}(S)$ has g.l.b.'s.

(26) Let L be an antisymmetric transitive relational structure with l.u.b.'s and S be a non empty join-closed subset of L. Then $\mathrm{sub}(S)$ has l.u.b.'s.

Let L be an antisymmetric transitive relational structure with g.l.b.'s and let S be a non empty meet-closed subset of L. One can verify that $\mathrm{sub}(S)$ has g.l.b.'s.

Let L be an antisymmetric transitive relational structure with l.u.b.'s and let S be a non empty join-closed subset of L. Observe that $\mathrm{sub}(S)$ has l.u.b.'s.

One can prove the following four propositions:

(27) Let L be a complete transitive antisymmetric non empty relational structure, S be an infs-closed non empty subset of L, and X be a subset of S. Then $\bigsqcap_{\mathrm{sub}(S)} X = \bigsqcap_L X$.

(28) Let L be a complete transitive antisymmetric non empty relational structure, S be a sups-closed non empty subset of L, and X be a subset of S. Then $\bigsqcup_{\mathrm{sub}(S)} X = \bigsqcup_L X$.

(29) For every semilattice L holds every meet-closed subset of L is filtered.

(30) For every sup-semilattice L holds every join-closed subset of L is directed.

Let L be a semilattice. One can check that every subset of L which is meet-closed is also filtered.

Let L be a sup-semilattice. Note that every subset of L which is join-closed is also directed.

We now state several propositions:

(31) Let L be a semilattice and S be an upper non empty subset of L. Then S is a filter of L if and only if S is meet-closed.

(32) Let L be a sup-semilattice and S be a lower non empty subset of L. Then S is an ideal of L if and only if S is join-closed.

(33) For every non empty relational structure L and for all join-closed subsets S_1, S_2 of L holds $S_1 \cap S_2$ is join-closed.

(34) For every non empty relational structure L and for all meet-closed subsets S_1, S_2 of L holds $S_1 \cap S_2$ is meet-closed.

(35) For every sup-semilattice L and for every element x of L holds $\downarrow x$ is join-closed.

(36) For every semilattice L and for every element x of L holds $\downarrow x$ is meet-closed.

(37) For every sup-semilattice L and for every element x of L holds $\uparrow x$ is join-closed.

(38) For every semilattice L and for every element x of L holds $\uparrow x$ is meet-closed.

Let L be a sup-semilattice and let x be an element of L. One can verify that $\downarrow x$ is join-closed and $\uparrow x$ is join-closed.

Let L be a semilattice and let x be an element of L. Observe that $\downarrow x$ is meet-closed and $\uparrow x$ is meet-closed.

We now state three propositions:

(39) For every sup-semilattice L and for every element x of L holds $\twoheaddownarrow x$ is join-closed.

(40) For every semilattice L and for every element x of L holds $\twoheaddownarrow x$ is meet-closed.

(41) For every sup-semilattice L and for every element x of L holds $\twoheaduparrow x$ is join-closed.

Let L be a sup-semilattice and let x be an element of L. Observe that $\twoheaddownarrow x$ is join-closed and $\twoheaduparrow x$ is join-closed.

Let L be a semilattice and let x be an element of L. One can check that $\twoheaddownarrow x$ is meet-closed.

3. About Bases of Continuous Lattices

Let T be a topological structure. The functor weight T yielding a cardinal number is defined as follows:

(Def. 5) $\mathrm{weight}\,T = \bigcap\{\overline{\overline{B}} : B \text{ ranges over bases of } T\}$.

Let T be a topological structure. We say that T is second-countable if and only if:

(Def. 6) $\mathrm{weight}\,T \subseteq \omega$.

Let L be a continuous sup-semilattice. A subset of L is called a CLbasis of L if:

(Def. 7) It is join-closed and for every element x of L holds $x = \sup(\twoheaddownarrow x \cap \mathrm{it})$.

Let L be a non empty relational structure and let S be a subset of L. We say that S has bottom if and only if:

(Def. 8) $\bot_L \in S$.

Let L be a non empty relational structure and let S be a subset of L. We say that S has top if and only if:

(Def. 9) $\top_L \in S$.

Let L be a non empty relational structure. One can verify that every subset of L which has bottom is also non empty.

Let L be a non empty relational structure. Observe that every subset of L which has top is also non empty.

Let L be a non empty relational structure. One can verify that there exists a subset of L which has bottom and there exists a subset of L which has top.

Let L be a continuous sup-semilattice. Observe that there exists a CLbasis of L which has bottom and there exists a CLbasis of L which has top.

Next we state the proposition

(42) Let L be a lower-bounded antisymmetric non empty relational structure and S be a subset of L with bottom. Then $\mathrm{sub}(S)$ is lower-bounded.

Let L be a lower-bounded antisymmetric non empty relational structure and let S be a subset of L with bottom. Observe that $\mathrm{sub}(S)$ is lower-bounded.

Let L be a continuous sup-semilattice. Note that every CLbasis of L is join-closed.

One can verify that there exists a continuous lattice which is bounded and non trivial.

Let L be a lower-bounded non trivial continuous sup-semilattice. Note that every CLbasis of L is non empty.

One can prove the following propositions:

(43) For every sup-semilattice L holds the carrier of $\mathrm{CompactSublatt}(L)$ is a join-closed subset of L.

(44) For every algebraic lower-bounded lattice L holds the carrier of $\mathrm{CompactSublatt}(L)$ is a CLbasis of L with bottom.

(45) Let L be a continuous lower-bounded sup-semilattice. If the carrier of $\mathrm{CompactSublatt}(L)$ is a CLbasis of L, then L is algebraic.

(46) Let L be a continuous lower-bounded lattice and B be a join-closed subset of L. Then B is a CLbasis of L if and only if for all elements x, y of L such that $y \not\leq x$ there exists an element b of L such that $b \in B$ and $b \not\leq x$ and $b \ll y$.

(47) Let L be a continuous lower-bounded lattice and B be a join-closed subset of L. Suppose $\perp_L \in B$. Then B is a CLbasis of L if and only if for all elements x, y of L such that $x \ll y$ there exists an element b of L such that $b \in B$ and $x \leq b$ and $b \ll y$.

(48) Let L be a continuous lower-bounded lattice and B be a join-closed subset of L. Suppose $\perp_L \in B$. Then B is a CLbasis of L if and only if the following conditions are satisfied:

(i) the carrier of $\mathrm{CompactSublatt}(L) \subseteq B$, and

(ii) for all elements x, y of L such that $y \not\leq x$ there exists an element b of L such that $b \in B$ and $b \not\leq x$ and $b \leq y$.

(49) Let L be a continuous lower-bounded lattice and B be a join-closed subset of L. Suppose $\perp_L \in B$. Then B is a CLbasis of L if and only if for all elements x, y of L such that $y \not\leq x$ there exists an element b of L such that $b \in B$ and $b \not\leq x$ and $b \leq y$.

(50) Let L be a lower-bounded sup-semilattice and S be a non empty full relational substructure of L. Suppose $\perp_L \in$ the carrier of S and the carrier of S is a join-closed subset of L. Let x be an element of L. Then $\downarrow x \cap$ the carrier of S is an ideal of S.

Let L be a non empty reflexive transitive relational structure and let S be a non empty full relational substructure of L. The functor $\mathrm{supMap}\, S$ yielding a map from $\langle \mathrm{Ids}(S), \subseteq \rangle$ into L is defined by:

(Def. 10) For every ideal I of S holds $(\mathrm{supMap}\, S)(I) = \bigsqcup_L I$.

Let L be a non empty reflexive transitive relational structure and let S be a non empty full relational substructure of L. The functor $\mathrm{idsMap}\, S$ yields a map from $\langle \mathrm{Ids}(S), \subseteq \rangle$ into $\langle \mathrm{Ids}(L), \subseteq \rangle$ and is defined as follows:

(Def. 11) For every ideal I of S there exists a subset J of L such that $I = J$ and $(\mathrm{idsMap}\, S)(I) = \downarrow J$.

Let L be a reflexive relational structure and let B be a subset of L. Note that $\mathrm{sub}(B)$ is reflexive.

Let L be a transitive relational structure and let B be a subset of L. Note that $\mathrm{sub}(B)$ is transitive.

Let L be an antisymmetric relational structure and let B be a subset of L. Observe that $\mathrm{sub}(B)$ is antisymmetric.

Let L be a lower-bounded continuous sup-semilattice and let B be a CLbasis of L with bottom. The functor $\mathrm{baseMap}\, B$ yields a map from L into $\langle \mathrm{Ids}(\mathrm{sub}(B)), \subseteq \rangle$ and is defined as follows:

(Def. 12) For every element x of L holds $(\mathrm{baseMap}\, B)(x) = \downarrow x \cap B$.

One can prove the following propositions:

(51) Let L be a non empty reflexive transitive relational structure and S be a non empty full relational substructure of L. Then $\mathrm{dom}\,\mathrm{supMap}\,S = \mathrm{Ids}(S)$ and $\mathrm{rng}\,\mathrm{supMap}\,S$ is a subset of L.

(52) Let L be a non empty reflexive transitive relational structure, S be a non empty full relational substructure of L, and x be a set. Then $x \in \mathrm{dom}\,\mathrm{supMap}\,S$ if and only if x is an ideal of S.

(53) Let L be a non empty reflexive transitive relational structure and S be a non empty full relational substructure of L. Then $\mathrm{dom}\,\mathrm{idsMap}\,S = \mathrm{Ids}(S)$ and $\mathrm{rng}\,\mathrm{idsMap}\,S$ is a subset of $\mathrm{Ids}(L)$.

(54) Let L be a non empty reflexive transitive relational structure, S be a non empty full relational substructure of L, and x be a set. Then $x \in \mathrm{dom}\,\mathrm{idsMap}\,S$ if and only if x is an ideal of S.

(55) Let L be a non empty reflexive transitive relational structure, S be a non empty full relational substructure of L, and x be a set. If $x \in \mathrm{rng}\,\mathrm{idsMap}\,S$, then x is an ideal of L.

(56) Let L be a lower-bounded continuous sup-semilattice and B be a CLbasis of L with bottom. Then $\mathrm{dom}\,\mathrm{baseMap}\,B =$ the carrier of L and $\mathrm{rng}\,\mathrm{baseMap}\,B$ is a subset of $\mathrm{Ids}(\mathrm{sub}(B))$.

(57) Let L be a lower-bounded continuous sup-semilattice, B be a CLbasis of L with bottom, and x be a set. If $x \in \mathrm{rng}\,\mathrm{baseMap}\,B$, then x is an ideal of $\mathrm{sub}(B)$.

(58) For every up-complete non empty poset L and for every non empty full relational substructure S of L holds $\mathrm{supMap}\,S$ is monotone.

(59) Let L be a non empty reflexive transitive relational structure and S be a non empty full relational substructure of L. Then $\mathrm{idsMap}\,S$ is monotone.

(60) For every lower-bounded continuous sup-semilattice L and for every CLbasis B of L with bottom holds $\mathrm{baseMap}\,B$ is monotone.

Let L be an up-complete non empty poset and let S be a non empty full relational substructure of L. One can verify that $\mathrm{supMap}\,S$ is monotone.

Let L be a non empty reflexive transitive relational structure and let S be a non empty full relational substructure of L. Note that $\mathrm{idsMap}\,S$ is monotone.

Let L be a lower-bounded continuous sup-semilattice and let B be a CLbasis of L with bottom. One can check that $\mathrm{baseMap}\,B$ is monotone.

Next we state several propositions:

(61) Let L be a lower-bounded continuous sup-semilattice and B be a CLbasis of L with bottom. Then $\mathrm{idsMap}\,\mathrm{sub}(B)$ is sups-preserving.

(62) For every up-complete non empty poset L and for every non empty full relational substructure S of L holds $\mathrm{supMap}\,S = \mathrm{SupMap}(L) \cdot \mathrm{idsMap}\,S$.

(63) For every lower-bounded continuous sup-semilattice L and for every CLbasis B of L with bottom holds $\langle \mathrm{supMap}\,\mathrm{sub}(B), \mathrm{baseMap}\,B \rangle$ is Galois.

(64) Let L be a lower-bounded continuous sup-semilattice and B be a CLbasis of L with bottom. Then $\mathrm{supMap}\,\mathrm{sub}(B)$ is upper adjoint and $\mathrm{baseMap}\,B$ is lower adjoint.

(65) Let L be a lower-bounded continuous sup-semilattice and B be a CLbasis of L with bottom. Then $\mathrm{rng}\,\mathrm{supMap}\,\mathrm{sub}(B) =$ the carrier of L.

(66) Let L be a lower-bounded continuous sup-semilattice and B be a CLbasis of L with bottom. Then $\mathrm{supMap}\,\mathrm{sub}(B)$ is infs-preserving and sups-preserving.

(67) Let L be a lower-bounded continuous sup-semilattice and B be a CLbasis of L with bottom. Then $\mathrm{baseMap}\,B$ is sups-preserving.

Let L be a lower-bounded continuous sup-semilattice and let B be a CLbasis of L with bottom. Note that $\mathrm{supMap}\,\mathrm{sub}(B)$ is infs-preserving and sups-preserving and $\mathrm{baseMap}\,B$ is sups-preserving.

The following propositions are true:

(69)[1] Let L be a lower-bounded continuous sup-semilattice and B be a CLbasis of L with bottom. Then the carrier of $\mathrm{CompactSublatt}(\langle \mathrm{Ids}(\mathrm{sub}(B)), \subseteq \rangle) = \{\downarrow b : b$ ranges over elements of $\mathrm{sub}(B)\}$.

(70) Let L be a lower-bounded continuous sup-semilattice and B be a CLbasis of L with bottom. Then $\mathrm{CompactSublatt}(\langle \mathrm{Ids}(\mathrm{sub}(B)), \subseteq \rangle)$ and $\mathrm{sub}(B)$ are isomorphic.

(71) Let L be a continuous lower-bounded lattice and B be a CLbasis of L with bottom. Suppose that for every CLbasis B_1 of L with bottom holds $B \subseteq B_1$. Let J be an element of $\langle \mathrm{Ids}(\mathrm{sub}(B)), \subseteq \rangle$. Then $J = \twoheaddownarrow \bigsqcup_L J \cap B$.

(72) Let L be a continuous lower-bounded lattice. Then L is algebraic if and only if the following conditions are satisfied:

(i) the carrier of $\mathrm{CompactSublatt}(L)$ is a CLbasis of L with bottom, and

(ii) for every CLbasis B of L with bottom holds the carrier of $\mathrm{CompactSublatt}(L) \subseteq B$.

(73) Let L be a continuous lower-bounded lattice. Then L is algebraic if and only if there exists a CLbasis B of L with bottom such that for every CLbasis B_1 of L with bottom holds $B \subseteq B_1$.

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