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The Jónsson Theorem about the Representation of Modular Lattices

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Summary. Formalization of [16, pp. 192–199], chapter IV. Partition Lattices, theorem 8.

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The articles [22], [14], [26], [27], [28], [11], [12], [4], [24], [1], [2], [3], [23], [21], [13], [18], [9], [25], [20], [8], [5], [10], [6], [29], [17], [19], [15], and [7] provide the notation and terminology for this paper.

1. PRELIMINARIES

Let A be a non empty set and let P, R be binary relations on A. Let us observe that $P \subseteq R$ if and only if:

(Def. 1) For all elements a, b of A such that $\langle a, b\rangle \in P$ holds $\langle a, b\rangle \in R$.

Let L be a relational structure. We say that L is finitely typed if and only if the condition (Def. 2) is satisfied.

(Def. 2) There exists a non empty set A such that

(i) for every set e such that $e \in$ the carrier of L holds e is an equivalence relation of A, and

(ii) there exists a natural number o such that for all equivalence relations e_1, e_2 of A and for all sets x, y such that $e_1 \in$ the carrier of L and $e_2 \in$ the carrier of L and $\langle x, y\rangle \in e_1 \sqcup e_2$ there exists a non empty finite sequence F of elements of A such that $\operatorname{len} F = o$ and x and y are joint by F, e_1 and e_2.

Let L be a lower-bounded lattice and let n be a natural number. We say that L has a representation of type $\leq n$ if and only if the condition (Def. 3) is satisfied.

(Def. 3) There exists a non trivial set A and there exists a homomorphism f from L to $\operatorname{EqRelPoset}(A)$ such that

(i) f is one-to-one,

(ii) $\operatorname{Im} f$ is finitely typed,

(iii) there exists an equivalence relation e of A such that $e \in$ the carrier of $\operatorname{Im} f$ and $e \neq \operatorname{id}_A$, and

(iv) the type of $\operatorname{Im} f \leq n$.

Let us note that there exists a lattice which is lower-bounded, distributive, and finite.

Let A be a non trivial set. Observe that there exists a non empty sublattice of $\mathrm{EqRelPoset}(A)$ which is non trivial, finitely typed, and full.

Next we state several propositions:

(1) For every non empty set A and for every lower-bounded lattice L and for every distance function d of A, L holds $\mathrm{succ}\,\emptyset \subseteq \mathrm{DistEsti}(d)$.

(2) Every trivial semilattice is modular.

(3) Let A be a non empty set and L be a non empty sublattice of $\mathrm{EqRelPoset}(A)$. Then L is trivial or there exists an equivalence relation e of A such that $e \in$ the carrier of L and $e \neq \mathrm{id}_A$.

(4) Let L_1, L_2 be lower-bounded lattices and f be a map from L_1 into L_2. Suppose f is infs-preserving and sups-preserving. Then f is meet-preserving and join-preserving.

(5) For all lower-bounded lattices L_1, L_2 such that L_1 and L_2 are isomorphic and L_1 is modular holds L_2 is modular.

(6) Let S be a lower-bounded non empty poset, T be a non empty poset, and f be a monotone map from S into T. Then $\mathrm{Im}\, f$ is lower-bounded.

(7) Let L be a lower-bounded lattice, x, y be elements of L, A be a non empty set, and f be a homomorphism from L to $\mathrm{EqRelPoset}(A)$. If f is one-to-one, then if $f^{\circ}(x) \leq f^{\circ}(y)$, then $x \leq y$.

2. The Jónsson Theorem

We now state two propositions:

(8) Let A be a non trivial set, L be a finitely typed full non empty sublattice of $\mathrm{EqRelPoset}(A)$, and e be an equivalence relation of A. Suppose $e \in$ the carrier of L and $e \neq \mathrm{id}_A$. If the type of $L \leq 2$, then L is modular.

(9) For every lower-bounded lattice L such that L has a representation of type ≤ 2 holds L is modular.

Let A be a set. The functor new_set2A is defined by:

(Def. 4) $\mathrm{new\_set2}A = A \cup \{\{A\}, \{\{A\}\}\}$.

Let A be a set. One can verify that new_set2A is non empty.

Let A be a non empty set, let L be a lower-bounded lattice, let d be a bifunction from A into L, and let q be an element of $[:A, A, \text{the carrier of } L, \text{the carrier of } L:]$. The functor new_bi_fun2(d,q) yielding a bifunction from new_set2A into L is defined by the conditions (Def. 5).

(Def. 5)(i) For all elements u, v of A holds $(\mathrm{new\_bi\_fun2}(d,q))(u, v) = d(u, v)$,

(ii) $(\mathrm{new\_bi\_fun2}(d,q))(\{A\}, \{A\}) = \bot_L$,

(iii) $(\mathrm{new\_bi\_fun2}(d,q))(\{\{A\}\}, \{\{A\}\}) = \bot_L$,

(iv) $(\mathrm{new\_bi\_fun2}(d,q))(\{A\}, \{\{A\}\}) = (d(q_1, q_2) \sqcup q_3) \sqcap q_4$,

(v) $(\mathrm{new\_bi\_fun2}(d,q))(\{\{A\}\}, \{A\}) = (d(q_1, q_2) \sqcup q_3) \sqcap q_4$, and

(vi) for every element u of A holds $(\mathrm{new\_bi\_fun2}(d,q))(u, \{A\}) = d(u, q_1) \sqcup q_3$ and $(\mathrm{new\_bi\_fun2}(d,q))(\{A\}, u) = d(u, q_1) \sqcup q_3$ and $(\mathrm{new\_bi\_fun2}(d,q))(u, \{\{A\}\}) = d(u, q_2) \sqcup q_3$ and $(\mathrm{new\_bi\_fun2}(d,q))(\{\{A\}\}, u) = d(u, q_2) \sqcup q_3$.

The following propositions are true:

(10) Let A be a non empty set, L be a lower-bounded lattice, and d be a bifunction from A into L. Suppose d is zeroed. Let q be an element of $[:A, A, \text{the carrier of } L, \text{the carrier of } L:]$. Then new_bi_fun2$(d,q)$ is zeroed.

(11) Let A be a non empty set, L be a lower-bounded lattice, and d be a bifunction from A into L. Suppose d is symmetric. Let q be an element of $[:A, A,$ the carrier of $L,$ the carrier of $L:]$. Then new_bi_fun2(d,q) is symmetric.

(12) Let A be a non empty set and L be a lower-bounded lattice. Suppose L is modular. Let d be a bifunction from A into L. Suppose d is symmetric and satisfies triangle inequality. Let q be an element of $[:A, A,$ the carrier of $L,$ the carrier of $L:]$. If $d(q_{\mathbf{1}}, q_{\mathbf{2}}) \leq q_{\mathbf{3}} \sqcup q_{\mathbf{4}}$, then new_bi_fun2$(d,q)$ satisfies triangle inequality.

(13) For every set A holds $A \subseteq$ new_set2A.

(14) Let A be a non empty set, L be a lower-bounded lattice, d be a bifunction from A into L, and q be an element of $[:A, A,$ the carrier of $L,$ the carrier of $L:]$. Then $d \subseteq$ new_bi_fun2(d,q).

Let A be a non empty set and let O be an ordinal number. The functor ConsecutiveSet2(A,O) is defined by the condition (Def. 6).

(Def. 6) There exists a transfinite sequence L_0 such that

(i) ConsecutiveSet2$(A,O) = \mathrm{last}\, L_0$,

(ii) $\mathrm{dom}\, L_0 = \mathrm{succ}\, O$,

(iii) $L_0(\emptyset) = A$,

(iv) for every ordinal number C such that $\mathrm{succ}\, C \in \mathrm{succ}\, O$ holds $L_0(\mathrm{succ}\, C) =$ new_set2$\, L_0(C)$, and

(v) for every ordinal number C such that $C \in \mathrm{succ}\, O$ and $C \neq \emptyset$ and C is a limit ordinal number holds $L_0(C) = \bigcup \mathrm{rng}(L_0 \restriction C)$.

One can prove the following three propositions:

(15) For every non empty set A holds ConsecutiveSet2$(A,\emptyset) = A$.

(16) For every non empty set A and for every ordinal number O holds ConsecutiveSet2$(A, \mathrm{succ}\, O) =$ new_set2 ConsecutiveSet2(A,O).

(17) Let A be a non empty set, O be an ordinal number, and T be a transfinite sequence. Suppose $O \neq \emptyset$ and O is a limit ordinal number and $\mathrm{dom}\, T = O$ and for every ordinal number O_1 such that $O_1 \in O$ holds $T(O_1) =$ ConsecutiveSet2(A,O_1). Then ConsecutiveSet2$(A,O) = \bigcup \mathrm{rng}\, T$.

Let A be a non empty set and let O be an ordinal number. One can verify that ConsecutiveSet2(A,O) is non empty.

We now state the proposition

(18) For every non empty set A and for every ordinal number O holds $A \subseteq$ ConsecutiveSet2(A,O).

Let A be a non empty set, let L be a lower-bounded lattice, let d be a bifunction from A into L, let q be a sequence of quadruples of d, and let O be an ordinal number. Let us assume that $O \in \mathrm{dom}\, q$. The functor Quadr2(q,O) yields an element of $[:$ConsecutiveSet2(A,O), ConsecutiveSet2(A,O), the carrier of $L,$ the carrier of $L:]$ and is defined as follows:

(Def. 7) Quadr2$(q,O) = q(O)$.

Let A be a non empty set, let L be a lower-bounded lattice, let d be a bifunction from A into L, let q be a sequence of quadruples of d, and let O be an ordinal number. The functor ConsecutiveDelta2(q,O) is defined by the condition (Def. 8).

(Def. 8) There exists a transfinite sequence L_0 such that

(i) $\mathrm{ConsecutiveDelta2}(q,O) = \mathrm{last}\,L_0$,

(ii) $\mathrm{dom}\,L_0 = \mathrm{succ}\,O$,

(iii) $L_0(\emptyset) = d$,

(iv) for every ordinal number C such that $\mathrm{succ}\,C \in \mathrm{succ}\,O$ holds $L_0(\mathrm{succ}\,C) = \mathrm{new\_bi\_fun2}(\mathrm{BiFun}(L_0(C), \mathrm{ConsecutiveSet2}(A,C), L), \mathrm{Quadr2}(q,C))$, and

(v) for every ordinal number C such that $C \in \mathrm{succ}\,O$ and $C \neq \emptyset$ and C is a limit ordinal number holds $L_0(C) = \bigcup \mathrm{rng}(L_0 \restriction C)$.

We now state several propositions:

(19) Let A be a non empty set, L be a lower-bounded lattice, d be a bifunction from A into L, and q be a sequence of quadruples of d. Then $\mathrm{ConsecutiveDelta2}(q,\emptyset) = d$.

(20) Let A be a non empty set, L be a lower-bounded lattice, d be a bifunction from A into L, q be a sequence of quadruples of d, and O be an ordinal number. Then $\mathrm{ConsecutiveDelta2}(q, \mathrm{succ}\,O) = \mathrm{new\_bi\_fun2}(\mathrm{BiFun}(\mathrm{ConsecutiveDelta2}(q,O), \mathrm{ConsecutiveSet2}(A,O), L), \mathrm{Quadr2}(q,C$

(21) Let A be a non empty set, L be a lower-bounded lattice, d be a bifunction from A into L, q be a sequence of quadruples of d, T be a transfinite sequence, and O be an ordinal number. Suppose $O \neq \emptyset$ and O is a limit ordinal number and $\mathrm{dom}\,T = O$ and for every ordinal number O_1 such that $O_1 \in O$ holds $T(O_1) = \mathrm{ConsecutiveDelta2}(q,O_1)$. Then $\mathrm{ConsecutiveDelta2}(q,O) = \bigcup \mathrm{rng}\,T$.

(22) For every non empty set A and for all ordinal numbers O, O_1, O_2 such that $O_1 \subseteq O_2$ holds $\mathrm{ConsecutiveSet2}(A,O_1) \subseteq \mathrm{ConsecutiveSet2}(A,O_2)$.

(23) Let A be a non empty set, L be a lower-bounded lattice, d be a bifunction from A into L, q be a sequence of quadruples of d, and O be an ordinal number. Then $\mathrm{ConsecutiveDelta2}(q,O)$ is a bifunction from $\mathrm{ConsecutiveSet2}(A,O)$ into L.

Let A be a non empty set, let L be a lower-bounded lattice, let d be a bifunction from A into L, let q be a sequence of quadruples of d, and let O be an ordinal number. Then $\mathrm{ConsecutiveDelta2}(q,O)$ is a bifunction from $\mathrm{ConsecutiveSet2}(A,O)$ into L.

One can prove the following propositions:

(24) Let A be a non empty set, L be a lower-bounded lattice, d be a bifunction from A into L, q be a sequence of quadruples of d, and O be an ordinal number. Then $d \subseteq \mathrm{ConsecutiveDelta2}(q,O)$.

(25) Let A be a non empty set, L be a lower-bounded lattice, d be a bifunction from A into L, O_1, O_2 be ordinal numbers, and q be a sequence of quadruples of d. If $O_1 \subseteq O_2$, then $\mathrm{ConsecutiveDelta2}(q,O_1) \subseteq \mathrm{ConsecutiveDelta2}(q,O_2)$.

(26) Let A be a non empty set, L be a lower-bounded lattice, and d be a bifunction from A into L. Suppose d is zeroed. Let q be a sequence of quadruples of d and O be an ordinal number. Then $\mathrm{ConsecutiveDelta2}(q,O)$ is zeroed.

(27) Let A be a non empty set, L be a lower-bounded lattice, and d be a bifunction from A into L. Suppose d is symmetric. Let q be a sequence of quadruples of d and O be an ordinal number. Then $\mathrm{ConsecutiveDelta2}(q,O)$ is symmetric.

(28) Let A be a non empty set and L be a lower-bounded lattice. Suppose L is modular. Let d be a bifunction from A into L. Suppose d is symmetric and satisfies triangle inequality. Let O be an ordinal number and q be a sequence of quadruples of d. If $O \subseteq \mathrm{DistEsti}(d)$, then $\mathrm{ConsecutiveDelta2}(q,O)$ satisfies triangle inequality.

(29) Let A be a non empty set, L be a lower-bounded modular lattice, d be a distance function of A, L, O be an ordinal number, and q be a sequence of quadruples of d. If $O \subseteq \mathrm{DistEsti}(d)$, then $\mathrm{ConsecutiveDelta2}(q, O)$ is a distance function of $\mathrm{ConsecutiveSet2}(A, O)$, L.

Let A be a non empty set, let L be a lower-bounded lattice, and let d be a bifunction from A into L. The functor $\mathrm{NextSet2}\, d$ is defined as follows:

(Def. 9) $\mathrm{NextSet2}\, d = \mathrm{ConsecutiveSet2}(A, \mathrm{DistEsti}(d))$.

Let A be a non empty set, let L be a lower-bounded lattice, and let d be a bifunction from A into L. Note that $\mathrm{NextSet2}\, d$ is non empty.

Let A be a non empty set, let L be a lower-bounded lattice, let d be a bifunction from A into L, and let q be a sequence of quadruples of d. The functor $\mathrm{NextDelta2}\, q$ is defined as follows:

(Def. 10) $\mathrm{NextDelta2}\, q = \mathrm{ConsecutiveDelta2}(q, \mathrm{DistEsti}(d))$.

Let A be a non empty set, let L be a lower-bounded modular lattice, let d be a distance function of A, L, and let q be a sequence of quadruples of d. Then $\mathrm{NextDelta2}\, q$ is a distance function of $\mathrm{NextSet2}\, d$, L.

Let A be a non empty set, let L be a lower-bounded lattice, let d be a distance function of A, L, let A_1 be a non empty set, and let d_1 be a distance function of A_1, L. We say that A_1, d_1 is extension2 of A, d if and only if:

(Def. 11) There exists a sequence q of quadruples of d such that $A_1 = \mathrm{NextSet2}\, d$ and $d_1 = \mathrm{NextDelta2}\, q$.

We now state the proposition

(30) Let A be a non empty set, L be a lower-bounded lattice, d be a distance function of A, L, A_1 be a non empty set, and d_1 be a distance function of A_1, L. Suppose A_1, d_1 is extension2 of A, d. Let x, y be elements of A and a, b be elements of L. Suppose $d(x, y) \leq a \sqcup b$. Then there exist elements z_1, z_2 of A_1 such that $d_1(x, z_1) = a$ and $d_1(z_1, z_2) = (d(x, y) \sqcup a) \sqcap b$ and $d_1(z_2, y) = a$.

Let A be a non empty set, let L be a lower-bounded modular lattice, and let d be a distance function of A, L. A function is called an ExtensionSeq2 of A, d if it satisfies the conditions (Def. 12).

(Def. 12)(i) $\mathrm{dom\,it} = \mathbb{N}$,

(ii) $\mathrm{it}(0) = \langle A, d \rangle$, and

(iii) for every natural number n there exists a non empty set A' and there exists a distance function d' of A', L and there exists a non empty set A_1 and there exists a distance function d_1 of A_1, L such that A_1, d_1 is extension2 of A', d' and $\mathrm{it}(n) = \langle A', d' \rangle$ and $\mathrm{it}(n+1) = \langle A_1, d_1 \rangle$.

Next we state several propositions:

(31) Let A be a non empty set, L be a lower-bounded modular lattice, d be a distance function of A, L, S be an ExtensionSeq2 of A, d, and k, l be natural numbers. If $k \leq l$, then $S(k)_{\mathbf{1}} \subseteq S(l)_{\mathbf{1}}$.

(32) Let A be a non empty set, L be a lower-bounded modular lattice, d be a distance function of A, L, S be an ExtensionSeq2 of A, d, and k, l be natural numbers. If $k \leq l$, then $S(k)_{\mathbf{2}} \subseteq S(l)_{\mathbf{2}}$.

(33) Let L be a lower-bounded modular lattice, S be an ExtensionSeq2 of the carrier of L, $\delta_0(L)$, and F_1 be a non empty set. Suppose $F_1 = \bigcup \{S(i)_{\mathbf{1}} : i$ ranges over natural numbers$\}$. Then $\bigcup \{S(i)_{\mathbf{2}} : i$ ranges over natural numbers$\}$ is a distance function of F_1, L.

(34) Let L be a lower-bounded modular lattice, S be an ExtensionSeq2 of the carrier of L, $\delta_0(L)$, F_1 be a non empty set, F_2 be a distance function of F_1, L, x, y be elements of F_1, and a, b be elements of L. Suppose $F_1 = \bigcup \{S(i)_{\mathbf{1}} : i$ ranges over natural numbers$\}$ and $F_2 = \bigcup \{S(i)_{\mathbf{2}} : i$ ranges over natural numbers$\}$ and $F_2(x, y) \leq a \sqcup b$. Then there exist elements z_1, z_2 of F_1 such that $F_2(x, z_1) = a$ and $F_2(z_1, z_2) = (F_2(x, y) \sqcup a) \sqcap b$ and $F_2(z_2, y) = a$.

(35) Let L be a lower-bounded modular lattice, S be an ExtensionSeq2 of the carrier of L, $\delta_0(L)$, F_1 be a non empty set, F_2 be a distance function of F_1, L, f be a homomorphism from L to EqRelPoset(F_1), e_1, e_2 be equivalence relations of F_1, and x, y be sets. Suppose that

(i) $f = \alpha(F_2)$,

(ii) $F_1 = \bigcup\{S(i)_{\mathbf{1}} : i$ ranges over natural numbers$\}$,

(iii) $F_2 = \bigcup\{S(i)_{\mathbf{2}} : i$ ranges over natural numbers$\}$,

(iv) $e_1 \in$ the carrier of Im f,

(v) $e_2 \in$ the carrier of Im f, and

(vi) $\langle x, y\rangle \in e_1 \sqcup e_2$.

Then there exists a non empty finite sequence F of elements of F_1 such that len$F = 2+2$ and x and y are joint by F, e_1 and e_2.

(36) For every lower-bounded modular lattice L holds L has a representation of type ≤ 2.

(37) For every lower-bounded lattice L holds L has a representation of type ≤ 2 iff L is modular.

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