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A Tree of Execution of a Macroinstruction[1]

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Summary. A tree of execution of a macroinstruction is defined. It is a tree decorated by the instruction locations of a computer. Successors of each vertex are determined by the set of all possible values of the instruction counter after execution of the instruction placed in the location indicated by given vertex.

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The articles [22], [14], [25], [15], [1], [20], [3], [4], [16], [26], [11], [13], [12], [5], [6], [21], [9], [8], [10], [2], [7], [18], [23], [19], [24], and [17] provide the notation and terminology for this paper.

For simplicity, we adopt the following convention: x, y, X are sets, m, n are natural numbers, O is an ordinal number, and R, S are binary relations.

Let D be a set, let f be a partial function from D to $\mathbb{N}$, and let n be a set. One can verify that $f(n)$ is natural.

Let R be an empty binary relation and let X be a set. Observe that $R{\restriction}X$ is empty.

One can prove the following two propositions:

(1) If $\operatorname{dom} R = \{x\}$ and $\operatorname{rng} R = \{y\}$, then $R = x \dot{\longmapsto} y$.

(2) $\operatorname{field}\{\langle x, x\rangle\} = \{x\}$.

Let X be an infinite set and let a be a set. One can verify that $X \longmapsto a$ is infinite.

One can check that there exists a function which is infinite.

Let R be a finite binary relation. One can verify that $\operatorname{field} R$ is finite.

The following proposition is true

(3) If $\operatorname{field} R$ is finite, then R is finite.

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Let R be an infinite binary relation. Note that field R is infinite.

One can prove the following proposition

(4) If $\operatorname{dom} R$ is finite and $\operatorname{rng} R$ is finite, then R is finite.

Let us observe that $\subseteq_{\emptyset}$ is empty.

Let X be a non empty set. One can verify that $\subseteq_{X}$ is non empty.

Next we state two propositions:

(5) $\subseteq_{\{x\}} = \{\langle x, x\rangle\}$.

(6) $\subseteq_{X} \subseteq [\!: X, X :\!]$.

Let X be a finite set. Note that $\subseteq_{X}$ is finite.

One can prove the following proposition

(7) If $\subseteq_{X}$ is finite, then X is finite.

Let X be an infinite set. One can verify that $\subseteq_{X}$ is infinite.

The following propositions are true:

(8) If R and S are isomorphic and R is well-ordering, then S is well-ordering.

(9) If R and S are isomorphic and R is finite, then S is finite.

(10) $x \mathrel{\dot{\longmapsto}} y$ is an isomorphism between $\{\langle x, x\rangle\}$ and $\{\langle y, y\rangle\}$.

(11) $\{\langle x, x\rangle\}$ and $\{\langle y, y\rangle\}$ are isomorphic.

One can verify that $\overline{\emptyset}$ is empty.

The following propositions are true:

(12) $\overline{\subseteq_{O}} = O$.

(13) For every finite set X such that $X \subseteq O$ holds $\overline{\subseteq_{X}} = \operatorname{card} X$.

(14) If $\{x\} \subseteq O$, then $\overline{\subseteq_{\{x\}}} = 1$.

(15) If $\{x\} \subseteq O$, then the canonical isomorphism between $\subseteq_{\overline{\subseteq_{\{x\}}}}$ and $\subseteq_{\{x\}} = 0 \mathrel{\dot{\longmapsto}} x$.

Let O be an ordinal number, let X be a subset of O, and let n be a set. One can check that (the canonical isomorphism between $\subseteq_{\overline{\subseteq_{X}}}$ and $\subseteq_{X}$)(n) is ordinal.

Let X be a natural-membered set and let n be a set. Note that (the canonical isomorphism between $\subseteq_{\overline{\subseteq_{X}}}$ and $\subseteq_{X}$)(n) is natural.

Next we state three propositions:

(16) If $n \mapsto x = m \mapsto x$, then $n = m$.

(17) For every tree T and for every element t of T holds $t \restriction \operatorname{Seg} n \in T$.

(18) For all trees T_1, T_2 such that for every natural number n holds $T_1\text{-level}(n) = T_2\text{-level}(n)$ holds $T_1 = T_2$.

The functor TrivialInfiniteTree is defined by:

(Def. 1) $\text{TrivialInfiniteTree} = \{k \mapsto 0 : k \text{ ranges over natural numbers}\}$.

One can check that TrivialInfiniteTree is non empty and tree-like.

We now state the proposition

(19) $\mathbb{N} \approx \text{TrivialInfiniteTree}$.

Let us note that TrivialInfiniteTree is infinite.

The following proposition is true

(20) For every natural number n holds TrivialInfiniteTree-level$(n) = \{n \mapsto 0\}$.

For simplicity, we adopt the following convention: N denotes a set with non empty elements, S denotes a standard IC-Ins-separated definite non empty non void AMI over N, L, l_1 denote instruction-locations of S, J denotes an instruction of S, and F denotes a subset of the instruction locations of S.

Let N be a set with non empty elements, let S be a standard IC-Ins-separated definite non empty non void AMI over N, and let F be a finite partial state of S. Let us assume that F is non empty and F is programmed. The functor FirstLoc(F) yields an instruction-location of S and is defined by the condition (Def. 2).

(Def. 2) There exists a non empty subset M of $\mathbb{N}$ such that $M = \{\mathrm{locnum}(l); l$ ranges over elements of the instruction locations of S: $l \in \mathrm{dom}\, F\}$ and FirstLoc$(F) = \mathrm{il}_S(\min M)$.

One can prove the following four propositions:

(21) For every non empty programmed finite partial state F of S holds FirstLoc$(F) \in \mathrm{dom}\, F$.

(22) For all non empty programmed finite partial states F, G of S such that $F \subseteq G$ holds FirstLoc$(G) \leqslant$ FirstLoc(F).

(23) For every non empty programmed finite partial state F of S such that $l_1 \in \mathrm{dom}\, F$ holds FirstLoc$(F) \leqslant l_1$.

(24) For every lower non empty programmed finite partial state F of S holds FirstLoc$(F) = \mathrm{il}_S(0)$.

Let N be a set with non empty elements, let S be a standard IC-Ins-separated definite non empty non void AMI over N, and let F be a subset of the instruction locations of S. The functor LocNums(F) yields a subset of $\mathbb{N}$ and is defined by:

(Def. 3) LocNums$(F) = \{\mathrm{locnum}(l); l$ ranges over instruction-locations of S: $l \in F\}$.

We now state the proposition

(25) $\mathrm{locnum}(l_1) \in$ LocNums(F) iff $l_1 \in F$.

Let N be a set with non empty elements, let S be a standard IC-Ins-separated definite non empty non void AMI over N, and let F be an empty subset of the instruction locations of S. Observe that LocNums(F) is empty.

Let N be a set with non empty elements, let S be a standard IC-Ins-separated definite non empty non void AMI over N, and let F be a non empty subset of the instruction locations of S. Observe that LocNums(F) is non empty.

We now state several propositions:

(26) If $F = \{\mathrm{il}_S(n)\}$, then LocNums$(F) = \{n\}$.

(27) $F \approx \mathrm{LocNums}(F)$.

(28) $\overline{\overline{F}} \subseteq \overline{\subseteq_{\mathrm{LocNums}(F)}}$.

(29) If S is realistic and J is halting, then $\mathrm{LocNums}(\mathrm{NIC}(J, L)) = \{\mathrm{locnum}(L)\}$.

(30) If S is realistic and J is sequential, then $\mathrm{LocNums}(\mathrm{NIC}(J, L)) = \{\mathrm{locnum}(\mathrm{NextLoc}\, L)\}$.

Let N be a set with non empty elements, let S be a standard IC-Ins-separated definite non empty non void AMI over N, and let M be a subset of the instruction locations of S. The functor $\mathrm{LocSeq}(M)$ yielding a transfinite sequence of elements of the instruction locations of S is defined as follows:

(Def. 4) $\mathrm{dom}\, \mathrm{LocSeq}(M) = \overline{\overline{M}}$ and for every set m such that $m \in \overline{\overline{M}}$ holds $(\mathrm{LocSeq}(M))(m) = \mathrm{il}_S(($the canonical isomorphism between $\subseteq_{\overline{\subseteq_{\mathrm{LocNums}(M)}}}$ and $\subseteq_{\mathrm{LocNums}(M)})(m))$.

One can prove the following proposition

(31) If $F = \{\mathrm{il}_S(n)\}$, then $\mathrm{LocSeq}(F) = 0 \dot{\longmapsto} \mathrm{il}_S(n)$.

Let N be a set with non empty elements, let S be a standard IC-Ins-separated definite non empty non void AMI over N, and let M be a subset of the instruction locations of S. Note that $\mathrm{LocSeq}(M)$ is one-to-one.

Let N be a set with non empty elements, let S be a standard IC-Ins-separated definite non empty non void AMI over N, and let M be a finite partial state of S. The functor $\mathrm{ExecTree}(M)$ yields a tree decorated with elements of the instruction locations of S and is defined by the conditions (Def. 5).

(Def. 5)(i) $(\mathrm{ExecTree}(M))(\emptyset) = \mathrm{FirstLoc}(M)$, and

(ii) for every element t of $\mathrm{dom}\, \mathrm{ExecTree}(M)$ holds $\mathrm{succ}\, t = \{t \frown \langle k \rangle; k$ ranges over natural numbers: $k \in \overline{\overline{\mathrm{NIC}(\pi_{(\mathrm{ExecTree}(M))(t)} M, (\mathrm{ExecTree}(M))(t))}}\}$ and for every natural number m such that $m \in \overline{\overline{\mathrm{NIC}(\pi_{(\mathrm{ExecTree}(M))(t)} M, (\mathrm{ExecTree}(M))(t))}}$ holds $(\mathrm{ExecTree}(M))(t \frown \langle m \rangle) = (\mathrm{LocSeq}(\mathrm{NIC}(\pi_{(\mathrm{ExecTree}(M))(t)} M, (\mathrm{ExecTree}(M))(t))))(m)$.

One can prove the following proposition

(32) For every standard halting realistic IC-Ins-separated definite non empty non void AMI S over N holds $\mathrm{ExecTree}(\mathrm{Stop}\, S) = \mathrm{TrivialInfiniteTree} \longmapsto \mathrm{il}_S(0)$.

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References

[1] Grzegorz Bancerek. Cardinal numbers. *Formalized Mathematics*, 1(**2**):377–382, 1990.

[2] Grzegorz Bancerek. Introduction to trees. *Formalized Mathematics*, 1(**2**):421–427, 1990.
[3] Grzegorz Bancerek. The ordinal numbers. *Formalized Mathematics*, 1(**1**):91–96, 1990.
[4] Grzegorz Bancerek. Sequences of ordinal numbers. *Formalized Mathematics*, 1(**2**):281–290, 1990.
[5] Grzegorz Bancerek. The well ordering relations. *Formalized Mathematics*, 1(**1**):123–129, 1990.
[6] Grzegorz Bancerek. Zermelo theorem and axiom of choice. *Formalized Mathematics*, 1(**2**):265–267, 1990.
[7] Grzegorz Bancerek. König's lemma. *Formalized Mathematics*, 2(**3**):397–402, 1991.
[8] Grzegorz Bancerek and Krzysztof Hryniewiecki. Segments of natural numbers and finite sequences. *Formalized Mathematics*, 1(**1**):107–114, 1990.
[9] Czesław Byliński. A classical first order language. *Formalized Mathematics*, 1(**4**):669–676, 1990.
[10] Czesław Byliński. Finite sequences and tuples of elements of a non-empty sets. *Formalized Mathematics*, 1(**3**):529–536, 1990.
[11] Czesław Byliński. Functions and their basic properties. *Formalized Mathematics*, 1(**1**):55–65, 1990.
[12] Czesław Byliński. Functions from a set to a set. *Formalized Mathematics*, 1(**1**):153–164, 1990.
[13] Czesław Byliński. Partial functions. *Formalized Mathematics*, 1(**2**):357–367, 1990.
[14] Czesław Byliński. Some basic properties of sets. *Formalized Mathematics*, 1(**1**):47–53, 1990.
[15] Agata Darmochwał. Finite sets. *Formalized Mathematics*, 1(**1**):165–167, 1990.
[16] Agata Darmochwał and Andrzej Trybulec. Similarity of formulae. *Formalized Mathematics*, 2(**5**):635–642, 1991.
[17] Artur Korniłowicz. On the composition of macro instructions of standard computers. *Formalized Mathematics*, 9(**2**):303–316, 2001.
[18] Yatsuka Nakamura and Andrzej Trybulec. A mathematical model of CPU. *Formalized Mathematics*, 3(**2**):151–160, 1992.
[19] Yasushi Tanaka. On the decomposition of the states of SCM. *Formalized Mathematics*, 5(**1**):1–8, 1996.
[20] Andrzej Trybulec. Subsets of complex numbers. *To appear in Formalized Mathematics.*
[21] Andrzej Trybulec. Binary operations applied to functions. *Formalized Mathematics*, 1(**2**):329–334, 1990.
[22] Andrzej Trybulec. Tarski Grothendieck set theory. *Formalized Mathematics*, 1(**1**):9–11, 1990.
[23] Andrzej Trybulec and Yatsuka Nakamura. Some remarks on the simple concrete model of computer. *Formalized Mathematics*, 4(**1**):51–56, 1993.
[24] Andrzej Trybulec, Piotr Rudnicki, and Artur Korniłowicz. Standard ordering of instruction locations. *Formalized Mathematics*, 9(**2**):291–301, 2001.
[25] Zinaida Trybulec. Properties of subsets. *Formalized Mathematics*, 1(**1**):67–71, 1990.
[26] Edmund Woronowicz. Relations and their basic properties. *Formalized Mathematics*, 1(**1**):73–83, 1990.

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