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Insert Sort on $\mathbf{SCM}_{\rm FSA}$[1]

Jing-Chao Chen
Shanghai Jiaotong University

Summary. This article describes the insert sorting algorithm using macro instructions such as if-Macro (conditional branch macro instructions), for-loop macro instructions and While-Macro instructions etc. From the viewpoint of initialization, we generalize the halting and computing problem of the While-Macro. Generally speaking, it is difficult to judge whether the While-Macro is halting or not by way of loop inspection. For this reason, we introduce a practical and simple method, called body-inspection. That is, in many cases, we can prove the halting problem of the While-Macro by only verifying the nature of the body of the While-Macro, rather than the While-Macro itself. In fact, we have used this method in justifying the halting of the insert sorting algorithm. Finally, we prove that the insert sorting algorithm given in the article is autonomic and its computing result is correct.

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The articles [25], [24], [35], [26], [8], [15], [36], [13], [14], [16], [12], [7], [10], [9], [21], [28], [11], [23], [31], [29], [30], [22], [5], [6], [3], [1], [17], [2], [32], [34], [18], [27], [4], [20], [19], and [33] provide the notation and terminology for this paper.

1. Preliminaries

Let i be a good instruction of $\mathbf{SCM}_{\rm FSA}$. Observe that ${\rm Macro}(i)$ is good.

Let a be a read-write integer location and let b be an integer location. One can check that ${\rm AddTo}(a,b)$ is good.

One can prove the following four propositions:

(1) For every function f and for all sets d, r such that $d \in {\rm dom}\, f$ holds ${\rm dom}\, f = {\rm dom}(f{+\cdot}(d \,\dot{\longmapsto}\, r))$.

(2) Let p be a programmed finite partial state of $\mathbf{SCM}_{\rm FSA}$, l be an instruction-location of $\mathbf{SCM}_{\rm FSA}$, and i_1 be an instruction of $\mathbf{SCM}_{\rm FSA}$. Suppose $l \in {\rm dom}\, p$ and there exists an instruction p_1 of $\mathbf{SCM}_{\rm FSA}$ such that $p_1 = p(l)$ and ${\rm UsedIntLoc}(p_1) = {\rm UsedIntLoc}(i_1)$. Then ${\rm UsedIntLoc}(p) = {\rm UsedIntLoc}(p{+\cdot}(l \,\dot{\longmapsto}\, i_1))$.

(3) For every integer location a and for every macro instruction I holds $(\mathbf{if}\ a > 0\ \mathbf{then}\ I;\ {\rm Goto}({\rm insloc}(0))\ \mathbf{else}\ ({\rm Stop}_{\mathbf{SCM}_{\rm FSA}}))({\rm insloc}({\rm card}\, I+4)) = {\rm goto}\ {\rm insloc}({\rm card}\, I+4)$.

(4) Let p be a programmed finite partial state of $\mathbf{SCM}_{\rm FSA}$, l be an instruction-location of $\mathbf{SCM}_{\rm FSA}$, and i_1 be an instruction of $\mathbf{SCM}_{\rm FSA}$. Suppose $l \in {\rm dom}\, p$ and there exists an instruction p_1 of $\mathbf{SCM}_{\rm FSA}$ such that $p_1 = p(l)$ and ${\rm UsedInt}^*{\rm Loc}(p_1) = {\rm UsedInt}^*{\rm Loc}(i_1)$. Then ${\rm UsedInt}^*{\rm Loc}(p) = {\rm UsedInt}^*{\rm Loc}(p{+\cdot}(l \,\dot{\longmapsto}\, i_1))$.

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For simplicity, we adopt the following convention: s is a state of $\mathbf{SCM}_{\rm FSA}$, I is a macro instruction, a is a read-write integer location, and j, k, n are natural numbers.

We now state a number of propositions:

(6)[1] For every state s of $\mathbf{SCM}_{\rm FSA}$ and for every macro instruction I such that $s(\mathrm{intloc}(0)) = 1$ and $\mathbf{IC}_s = \mathrm{insloc}(0)$ holds $s{+\cdot}I = s{+\cdot}\,\mathrm{Initialized}(I)$.

(7) Let I be a macro instruction and a, b be integer locations. If I does not destroy b, then **while** $a > 0$ **do** I does not destroy b.

(8) If $n \leq 11$, then $n = 0$ or $n = 1$ or $n = 2$ or $n = 3$ or $n = 4$ or $n = 5$ or $n = 6$ or $n = 7$ or $n = 8$ or $n = 9$ or $n = 10$ or $n = 11$.

(9) Let f, g be finite sequences of elements of $\mathbb{Z}$ and m, n be natural numbers. Suppose $1 \leq n$ and $n \leq \mathrm{len}\, f$ and $1 \leq m$ and $m \leq \mathrm{len}\, f$ and $g = f +\cdot (m, f_n) +\cdot (n, f_m)$. Then

(i) $f(m) = g(n)$,

(ii) $f(n) = g(m)$,

(iii) for every set k such that $k \neq m$ and $k \neq n$ and $k \in \mathrm{dom}\, f$ holds $f(k) = g(k)$, and

(iv) f and g are fiberwise equipotent.

(10) Let s be a state of $\mathbf{SCM}_{\rm FSA}$ and I be a macro instruction. Suppose I is halting on Initialize(s). Let a be an integer location. Then $(\mathrm{IExec}(I,s))(a) = (\mathrm{Computation}(\mathrm{Initialize}(s){+\cdot}(I{+\cdot}\,\mathrm{Start\text{-}At}(\mathrm{insloc}(0)))))(\mathrm{LifeSpan}(\mathrm{Initialize}(s){+\cdot}(I{+\cdot}\,\mathrm{Start\text{-}At}(\mathrm{insloc}(0)))))(a)$.

(11) Let s_1, s_2 be states of $\mathbf{SCM}_{\rm FSA}$ and I be an InitHalting macro instruction. Suppose Initialized$(I) \subseteq s_1$ and Initialized$(I) \subseteq s_2$ and s_1 and s_2 are equal outside the instruction locations of $\mathbf{SCM}_{\rm FSA}$. Let k be a natural number. Then $(\mathrm{Computation}(s_1))(k)$ and $(\mathrm{Computation}(s_2))(k)$ are equal outside the instruction locations of $\mathbf{SCM}_{\rm FSA}$ and $\mathrm{CurInstr}((\mathrm{Computation}(s_1))(k)) = \mathrm{CurInstr}((\mathrm{Computation}(s_2))(k))$.

(12) Let s_1, s_2 be states of $\mathbf{SCM}_{\rm FSA}$ and I be an InitHalting macro instruction. Suppose Initialized$(I) \subseteq s_1$ and Initialized$(I) \subseteq s_2$ and s_1 and s_2 are equal outside the instruction locations of $\mathbf{SCM}_{\rm FSA}$. Then $\mathrm{LifeSpan}(s_1) = \mathrm{LifeSpan}(s_2)$ and Result(s_1) and Result(s_2) are equal outside the instruction locations of $\mathbf{SCM}_{\rm FSA}$.

(13) For every macro instruction I and for every finite sequence location f holds $f \notin \mathrm{dom}\, I$.

(14) For every macro instruction I and for every integer location a holds $a \notin \mathrm{dom}\, I$.

(15) Let N be a non empty set with non empty elements, S be a halting IC-Ins-separated definite non empty non void AMI over N, and s be a state of S. If $\mathrm{LifeSpan}(s) \leq j$ and s is halting, then $(\mathrm{Computation}(s))(j) = (\mathrm{Computation}(s))(\mathrm{LifeSpan}(s))$.

2. Basic Property of **while** Macro

One can prove the following propositions:

(16) Let s be a state of $\mathbf{SCM}_{\rm FSA}$, I be a macro instruction, and a be a read-write integer location. Suppose $s(a) \leq 0$. Then **while** $a > 0$ **do** I is halting onInit s and **while** $a > 0$ **do** I is closed onInit s.

(17) Let a be an integer location, I be a macro instruction, s be a state of $\mathbf{SCM}_{\rm FSA}$, and k be a natural number. Suppose that

(i) I is closed onInit s,

(ii) I is halting onInit s,

(iii) $k < \mathrm{LifeSpan}(s{+\cdot}\,\mathrm{Initialized}(I))$,

[1] The proposition (5) has been removed.

(iv) $\mathbf{IC}_{(\mathrm{Computation}(s+\cdot\,\mathrm{Initialized}(\textbf{while}\ a>0\ \textbf{do}\ I)))(1+k)} = \mathbf{IC}_{(\mathrm{Computation}(s+\cdot\,\mathrm{Initialized}(I)))(k)} + 4$, and

(v) $(\mathrm{Computation}(s+\cdot\,\mathrm{Initialized}(\textbf{while}\ a>0\ \textbf{do}\ I)))(1+k){\restriction}D = (\mathrm{Computation}(s+\cdot\,\mathrm{Initialized}(I)))(k){\restriction}D$.

Then $\mathbf{IC}_{(\mathrm{Computation}(s+\cdot\,\mathrm{Initialized}(\textbf{while}\ a>0\ \textbf{do}\ I)))(1+k+1)} = \mathbf{IC}_{(\mathrm{Computation}(s+\cdot\,\mathrm{Initialized}(I)))(k+1)} + 4$ and $(\mathrm{Computation}(s+\cdot\,\mathrm{Initialized}(\textbf{while}\ a>0\ \textbf{do}\ I)))(1+k+1){\restriction}D = (\mathrm{Computation}(s+\cdot\,\mathrm{Initialized}(I)))(k+1){\restriction}D$, where $D = \mathrm{Int\text{-}Locations} \cup \mathrm{FinSeq\text{-}Locations}$.

(18) Let a be an integer location, I be a macro instruction, and s be a state of $\mathbf{SCM}_{\mathrm{FSA}}$. Suppose I is closed onInit s and I is halting onInit s and $\mathbf{IC}_{(\mathrm{Computation}(s+\cdot\,\mathrm{Initialized}(\textbf{while}\ a>0\ \textbf{do}\ I)))(1+\mathrm{LifeSpan}(s+\cdot\,\mathrm{Initialized}(I)))} = \mathbf{IC}_{(\mathrm{Computation}(s+\cdot\,\mathrm{Initialized}(I)))(\mathrm{LifeSpan}(s+\cdot\,\mathrm{Initialized}(I)))} + 4$. Then $\mathrm{CurInstr}((\mathrm{Computation}(s+\cdot\,\mathrm{Initialized}(\textbf{while}\ a>0\ \textbf{do}\ I)))(1+\mathrm{LifeSpan}(s+\cdot\,\mathrm{Initialized}(I)))) = \mathbf{goto}\ \mathrm{insloc}(\mathrm{card}\,I+4)$.

(19) Let s be a state of $\mathbf{SCM}_{\mathrm{FSA}}$, I be a macro instruction, and a be a read-write integer location. Suppose I is closed onInit s and I is halting onInit s and $s(a) > 0$. Then $\mathbf{IC}_{(\mathrm{Computation}(s+\cdot\,\mathrm{Initialized}(\textbf{while}\ a>0\ \textbf{do}\ I)))(\mathrm{LifeSpan}(s+\cdot\,\mathrm{Initialized}(I))+3)} = \mathrm{insloc}(0)$ and for every natural number k such that $k \leq \mathrm{LifeSpan}(s+\cdot\,\mathrm{Initialized}(I)) + 3$ holds $\mathbf{IC}_{(\mathrm{Computation}(s+\cdot\,\mathrm{Initialized}(\textbf{while}\ a>0\ \textbf{do}\ I)))(k)} \in \mathrm{dom}(\textbf{while}\ a>0\ \textbf{do}\ I)$.

(20) Let s be a state of $\mathbf{SCM}_{\mathrm{FSA}}$, I be a macro instruction, and a be a read-write integer location. Suppose I is closed onInit s and I is halting onInit s and $s(a) > 0$. Let k be a natural number. If $k \leq \mathrm{LifeSpan}(s+\cdot\,\mathrm{Initialized}(I)) + 3$, then $\mathbf{IC}_{(\mathrm{Computation}(s+\cdot\,\mathrm{Initialized}(\textbf{while}\ a>0\ \textbf{do}\ I)))(k)} \in \mathrm{dom}(\textbf{while}\ a>0\ \textbf{do}\ I)$.

(21) Let s be a state of $\mathbf{SCM}_{\mathrm{FSA}}$, I be a macro instruction, and a be a read-write integer location. Suppose I is closed onInit s and I is halting onInit s and $s(a) > 0$. Then $\mathbf{IC}_{(\mathrm{Computation}(s+\cdot\,\mathrm{Initialized}(\textbf{while}\ a>0\ \textbf{do}\ I)))(\mathrm{LifeSpan}(s+\cdot\,\mathrm{Initialized}(I))+3)} = \mathrm{insloc}(0)$ and $(\mathrm{Computation}(s+\cdot\,\mathrm{Initialized}(\textbf{while}\ a>0\ \textbf{do}\ I)))(\mathrm{LifeSpan}(s+\cdot\,\mathrm{Initialized}(I))+3){\restriction}D = (\mathrm{Computation}(s+\cdot\,\mathrm{Initialized}(I)))(\mathrm{LifeSpan}(s+\cdot\,\mathrm{Initialized}(I))){\restriction}D$, where $D = \mathrm{Int\text{-}Locations} \cup \mathrm{FinSeq\text{-}Locations}$.

(22) Let s be a state of $\mathbf{SCM}_{\mathrm{FSA}}$, I be an InitHalting macro instruction, and a be a read-write integer location. Suppose $s(a) > 0$. Then there exists a state s_2 of $\mathbf{SCM}_{\mathrm{FSA}}$ and there exists a natural number k such that

(i) $s_2 = s+\cdot\,\mathrm{Initialized}(\textbf{while}\ a>0\ \textbf{do}\ I)$,

(ii) $k = \mathrm{LifeSpan}(s+\cdot\,\mathrm{Initialized}(I)) + 3$,

(iii) $\mathbf{IC}_{(\mathrm{Computation}(s_2))(k)} = \mathrm{insloc}(0)$,

(iv) for every integer location b holds $(\mathrm{Computation}(s_2))(k)(b) = (\mathrm{IExec}(I,s))(b)$, and

(v) for every finite sequence location f holds $(\mathrm{Computation}(s_2))(k)(f) = (\mathrm{IExec}(I,s))(f)$.

Let us consider s, I, a. The functor $\mathit{StepWhile{>}0}(a,s,I)$ yielding a function from $\mathbb{N}$ into $\prod$(the object kind of $\mathbf{SCM}_{\mathrm{FSA}}$) is defined by the conditions (Def. 1).

(Def. 1)(i) $(\mathit{StepWhile{>}0}(a,s,I))(0) = s$ **qua** element of $\prod$(the object kind of $\mathbf{SCM}_{\mathrm{FSA}}$) **qua** non empty set, and

(ii) for every natural number i holds $(\mathit{StepWhile{>}0}(a,s,I))(i+1) = (\mathrm{Computation}((\mathit{StepWhile{>}0}(a,s,I))(i)+\cdot\,\mathrm{Initialized}(\textbf{while}\ a>0\ \textbf{do}\ I)))(\mathrm{LifeSpan}((\mathit{StepWhile{>}0}(a,s,I))(i)+\cdot\,\mathrm{Initialized}(I))+3)$.

Next we state several propositions:

(25)[2] $(\mathit{StepWhile{>}0}(a,s,I))(k+1) = (\mathit{StepWhile{>}0}(a,(\mathit{StepWhile{>}0}(a,s,I))(k),I))(1)$.

(26) Let I be a macro instruction, a be a read-write integer location, and s be a state of $\mathbf{SCM}_{\mathrm{FSA}}$. Then $(\mathit{StepWhile{>}0}(a,s,I))(0+1) = (\mathrm{Computation}(s+\cdot\,\mathrm{Initialized}(\textbf{while}\ a>0\ \textbf{do}\ I)))(\mathrm{LifeSpan}(s+\cdot\,\mathrm{Initialized}(I))+3)$.

[2] The propositions (23) and (24) have been removed.

(27) Let I be a macro instruction, a be a read-write integer location, s be a state of $\mathbf{SCM}_{\mathrm{FSA}}$, and k, n be natural numbers. Suppose $\mathbf{IC}_{(StepWhile{>}0(a,s,I))(k)} = \mathrm{insloc}(0)$ and $(StepWhile{>}0(a,s,I))(k) = (\mathrm{Computation}(s+\cdot\,\mathrm{Initialized}(\mathbf{while}\ a > 0\ \mathbf{do}\ I)))(n)$ and $(StepWhile{>}0(a,s,I))(k)(\mathrm{intloc}(0)) = 1$. Then $(StepWhile{>}0(a,s,I))(k) = (StepWhile{>}0(a,s,I))(k)+\cdot\,\mathrm{Initialized}(\mathbf{while}\ a > 0\ \mathbf{do}\ I)$ and $(StepWhile{>}0(a,s,I))(k+1) = (\mathrm{Computation}(s+\cdot\,\mathrm{Initialized}(\mathbf{while}\ a > 0\ \mathbf{do}\ I)))(n+(\mathrm{LifeSpan}((StepWhile{>}0(a,s,I))(k)+\cdot\,\mathrm{Initialized}(I))+3))$.

(28) Let I be a macro instruction, a be a read-write integer location, and s be a state of $\mathbf{SCM}_{\mathrm{FSA}}$. Given a function f from $\prod$(the object kind of $\mathbf{SCM}_{\mathrm{FSA}}$) into $\mathbb{N}$ such that let k be a natural number. Then

(i) if $f((StepWhile{>}0(a,s,I))(k)) \neq 0$, then $f((StepWhile{>}0(a,s,I))(k+1)) < f((StepWhile{>}0(a,s,I))(k))$ and I is closed onInit $(StepWhile{>}0(a,s,I))(k)$ and I is halting onInit $(StepWhile{>}0(a,s,I))(k)$,

(ii) $(StepWhile{>}0(a,s,I))(k+1)(\mathrm{intloc}(0)) = 1$, and

(iii) $f((StepWhile{>}0(a,s,I))(k)) = 0$ iff $(StepWhile{>}0(a,s,I))(k)(a) \leq 0$.

Then **while** $a > 0$ **do** I is halting onInit s and **while** $a > 0$ **do** I is closed onInit s.

(29) Let I be a good InitHalting macro instruction and a be a read-write integer location. Suppose that for every state s of $\mathbf{SCM}_{\mathrm{FSA}}$ such that $s(a) > 0$ holds $(\mathrm{IExec}(I,s))(a) < s(a)$. Then **while** $a > 0$ **do** I is InitHalting.

(30) Let I be a good InitHalting macro instruction and a be a read-write integer location. Suppose that for every state s of $\mathbf{SCM}_{\mathrm{FSA}}$ holds $(\mathrm{IExec}(I,s))(a) < s(a)$ or $(\mathrm{IExec}(I,s))(a) \leq 0$. Then **while** $a > 0$ **do** I is InitHalting.

Let D be a set, let f be a function from D into $\mathbb{Z}$, and let d be an element of D. Then $f(d)$ is an integer.

We now state several propositions:

(31) Let I be a good InitHalting macro instruction and a be a read-write integer location. Given a function f from $\prod$(the object kind of $\mathbf{SCM}_{\mathrm{FSA}}$) into $\mathbb{Z}$ such that let s, t be states of $\mathbf{SCM}_{\mathrm{FSA}}$. Then

(i) if $f(s) > 0$, then $f(\mathrm{IExec}(I,s)) < f(s)$,

(ii) if $s{\restriction}D = t{\restriction}D$, then $f(s) = f(t)$, and

(iii) $f(s) \leq 0$ iff $s(a) \leq 0$.

Then **while** $a > 0$ **do** I is InitHalting, where $D = \text{Int-Locations} \cup \text{FinSeq-Locations}$.

(32) Let s be a state of $\mathbf{SCM}_{\mathrm{FSA}}$, I be a macro instruction, and a be a read-write integer location. If $s(a) \leq 0$, then $\mathrm{IExec}(\mathbf{while}\ a > 0\ \mathbf{do}\ I, s){\restriction}(\text{Int-Locations} \cup \text{FinSeq-Locations}) = \mathrm{Initialize}(s){\restriction}(\text{Int-Locations} \cup \text{FinSeq-Locations})$.

(33) Let s be a state of $\mathbf{SCM}_{\mathrm{FSA}}$, I be a good InitHalting macro instruction, and a be a read-write integer location. If $s(a) > 0$ and **while** $a > 0$ **do** I is InitHalting, then $\mathrm{IExec}(\mathbf{while}\ a > 0\ \mathbf{do}\ I, s){\restriction}(\text{Int-Locations} \cup \text{FinSeq-Locations}) = \mathrm{IExec}(\mathbf{while}\ a > 0\ \mathbf{do}\ I, \mathrm{IExec}(I,s)){\restriction}(\text{Int-Locations} \cup \text{FinSeq-Locations})$.

(34) Let s be a state of $\mathbf{SCM}_{\mathrm{FSA}}$, I be a macro instruction, f be a finite sequence location, and a be a read-write integer location. If $s(a) \leq 0$, then $(\mathrm{IExec}(\mathbf{while}\ a > 0\ \mathbf{do}\ I, s))(f) = s(f)$.

(35) Let s be a state of $\mathbf{SCM}_{\mathrm{FSA}}$, I be a macro instruction, b be an integer location, and a be a read-write integer location. If $s(a) \leq 0$, then $(\mathrm{IExec}(\mathbf{while}\ a > 0\ \mathbf{do}\ I, s))(b) = (\mathrm{Initialize}(s))(b)$.

(36) Let s be a state of $\mathbf{SCM}_{\mathrm{FSA}}$, I be a good InitHalting macro instruction, f be a finite sequence location, and a be a read-write integer location. If $s(a) > 0$ and **while** $a > 0$ **do** I is InitHalting, then $(\mathrm{IExec}(\mathbf{while}\ a > 0\ \mathbf{do}\ I, s))(f) = (\mathrm{IExec}(\mathbf{while}\ a > 0\ \mathbf{do}\ I, \mathrm{IExec}(I,s)))(f)$.

(37) Let s be a state of $\mathbf{SCM}_{\mathrm{FSA}}$, I be a good InitHalting macro instruction, b be an integer location, and a be a read-write integer location. If $s(a) > 0$ and **while** $a > 0$ **do** I is InitHalting, then $(\mathrm{IExec}(\mathbf{while}\ a > 0\ \mathbf{do}\ I, s))(b) = (\mathrm{IExec}(\mathbf{while}\ a > 0\ \mathbf{do}\ I, \mathrm{IExec}(I,s)))(b)$.

3. INSERT SORT ALGORITHM

Let f be a finite sequence location. The functor insert-sort f yielding a macro instruction is defined by:

(Def. 2) insert-sort $f = i_2$; $(a_1{:=}\mathrm{len} f)$; SubFrom(a_1,a_0); Times$(a_1,(a_2{:=}\mathrm{len} f)$; SubFrom$(a_2,a_1)$; $(a_3{:=}a_2)$; AddTo(a_3,a_0); $(a_6{:=}f_{a_3})$; SubFrom(a_4,a_4); (**while** $a_2 >$ 0 **do** $((a_5{:=}f_{a_2})$; SubFrom(a_5,a_6); (**if** $a_5 > 0$ **then** Macro(SubFrom(a_2,a_2)) **else** (AddTo(a_4,a_0); SubFrom(a_2,a_0)))))); Times$(a_4,(a_2{:=}a_3)$; SubFrom(a_3,a_0); $(a_5{:=}f_{a_2})$; $(a_6{:=}f_{a_3})$; $(f_{a_2}{:=}a_6)$; $(f_{a_3}{:=}a_5)))$, where $i_2 = (a_2{:=}a_0)$; $(a_3{:=}a_0)$; $(a_4{:=}a_0)$; $(a_5{:=}a_0)$; $(a_6{:=}a_0)$, $a_2 = \mathrm{intloc}(2)$, $a_0 = \mathrm{intloc}(0)$, $a_3 = \mathrm{intloc}(3)$, $a_4 = \mathrm{intloc}(4)$, $a_5 = \mathrm{intloc}(5)$, $a_6 = \mathrm{intloc}(6)$, and $a_1 = \mathrm{intloc}(1)$.

The macro instruction Insert-Sort-Algorithm is defined by:

(Def. 3) Insert-Sort-Algorithm $=$ insert-sort fsloc(0).

The following propositions are true:

(38) For every finite sequence location f holds UsedIntLoc(insert-sort f) $= \{a_0,a_1,a_2,a_3,a_4,a_5,a_6\}$, where $a_0 = \mathrm{intloc}(0)$, $a_1 = \mathrm{intloc}(1)$, $a_2 = \mathrm{intloc}(2)$, $a_3 = \mathrm{intloc}(3)$, $a_4 = \mathrm{intloc}(4)$, $a_5 = \mathrm{intloc}(5)$, and $a_6 = \mathrm{intloc}(6)$.

(39) For every finite sequence location f holds UsedInt*Loc(insert-sort f) $= \{f\}$.

(40) For all instructions k_1, k_2, k_3, k_4 of $\mathbf{SCM}_{\rm FSA}$ holds card$(k_1; k_2; k_3; k_4) = 8$.

(41) For all instructions k_1, k_2, k_3, k_4, k_5 of $\mathbf{SCM}_{\rm FSA}$ holds card$(k_1; k_2; k_3; k_4; k_5) = 10$.

(42) For every finite sequence location f holds card insert-sort $f = 82$.

(43) For every finite sequence location f and for every natural number k such that $k < 82$ holds insloc$(k) \in$ dom insert-sort f.

One can prove the following proposition

(44) insert-sort fsloc(0) is keepInt0 1 and InitHalting.

We now state several propositions:

(45) Let s be a state of $\mathbf{SCM}_{\rm FSA}$. Then

(i) $s(f_0)$ and (IExec(insert-sort f_0,s))(f_0) are fiberwise equipotent, and

(ii) for all natural numbers i, j such that $i \geq 1$ and $j \leq \mathrm{len}\, s(f_0)$ and $i < j$ and for all integers x_1, x_2 such that $x_1 =$ (IExec(insert-sort f_0,s))$(f_0)(i)$ and $x_2 =$ (IExec(insert-sort f_0,s))$(f_0)(j)$ holds $x_1 \geq x_2$,

where $f_0 = \mathrm{fsloc}(0)$.

(46) Let i be a natural number, s be a state of $\mathbf{SCM}_{\rm FSA}$, and w be a finite sequence of elements of $\mathbb{Z}$. If Initialized(Insert-Sort-Algorithm)$+\cdot$(fsloc$(0) \longmapsto w$) $\subseteq s$, then $\mathbf{IC}_{(\mathrm{Computation}(s))(i)} \in$ dom Insert-Sort-Algorithm.

(47) Let s be a state of $\mathbf{SCM}_{\rm FSA}$ and t be a finite sequence of elements of $\mathbb{Z}$. Suppose Initialized(Insert-Sort-Algorithm)$+\cdot$(fsloc$(0) \longmapsto t$) $\subseteq s$. Then there exists a finite sequence u of elements of $\mathbb{R}$ such that

(i) t and u are fiberwise equipotent,

(ii) u is non-increasing and a finite sequence of elements of $\mathbb{Z}$, and

(iii) (Result(s))(fsloc(0)) $= u$.

(48) For every finite sequence w of elements of $\mathbb{Z}$ holds Initialized(Insert-Sort-Algorithm)$+\cdot$(fsloc$(0) \longmapsto w$) is autonomic.

(49) Initialized(Insert-Sort-Algorithm) computes Sorting-Function.

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