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A Study on Accepting Power of Space-bounded One-pebble Two-dimensional Turing Machines

Atsuyuki Inoue (910011)

School of School of Information Science,
Japan Advanced Institute of Science and Technology

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The theory of computational complexity is one of the main fields in computer science. One of the central subjects of the theory of computational complexity is clarifying a difference of the accepting powers of determinism, nondeterminism and alternation of various computing models. For the class of the language accepted by the space-bounded deterministic, nondeterministic and one-dimensional Turing machines, the following facts are known:

(i) In $o(\log \log n)$ space-bounded deterministic, nondeterministic and alternating Turing machines have the same accepting power as finite automata.

(ii) Alternating Turing machines are stronger in accepting power than deterministic and nondeterministic Turing machines for spaces between $\log \log n$ and $o(\log n)$.

It is unknown whether accepting power of nondeterministic Turing machines is stronger than deterministic Turing machines for spaces more than $\log \log n$ and whether accepting power of alternating Turing machines is stronger than nondeterministic Turing machines for spaces more than $\log n$.

Also in one-pebble one-dimentional Turing machines which is allowed to use of one-pebble on the input tape of one-dimensional Turing machine, it is known that $\log \log n$ space-bounded deterministic and nondeterministic machines have the same accepting power as finite automata. However, it is unknown whether accepting power of one-pebble nondeterministic Turing machines is stronger than one-pebble deterministic Turing machines for spaces more than $\log \log n$, and whether accepting power of alternating one-pebble Turing machines is stronger than nondeterministic one-pebble Turing machines for spaces more than $\log \log n$.

On the other hand, for two-dimentional Turing machines with two-dimentional input tapes, it is shown that even when it limits to a square tape, in $o(\log n)$ space-bounded, alternating machines are stronger than nondeterministic machines, and nondeterministic machines are stronger than deterministic machines for spaces less than $o(\log n)$.

This paper introduces a one-pebble two-dimensional Turing machine(p2-tm) which is allowed to use of one pebble on the input tape of a two-dimensional Turing machine, and investigates a relationship among the accepting powers of space-bounded deterministic, nondeterministic and alternating p2-tms.

P2-tm can be used as a computing model which measures the complexity of two-dimensional patterns. Chapter 2 of this paper gives definitions and notations related to this paper.Chapter 3 of this paper investigates a difference between the accepting powers of space-bounded deterministin and nondeterministic p2-tms. Let $L(n) : N \to N$ (where N denotes the set of natural numbers) be a function with one variable n. A p2-tm M whose input tapes are restricted to square tapes is called $L(n)$ space-bounded if it uses at most $L(n)$ cells of the storage tape for any input tape with n rows and n columns ($n \geq 1$). Chapter 3 shows that, even when limited to a square tape, for any function $L(n) = o(\log n)$, $L(n)$ space-bounded nondeterministic p2-tms are stronger in accepting power than $L(n)$ space-bounded deterministic p2-tms. In fact, Chapter 3 shows that there is a set of square tapes accepted by a nondeterministic one-pebble two-dimensional finite automaton, but not accepted by any $o(\log n)$ space-bounded deterministic p2-tm. Chapter 4 investigates a difference between the accepting powers of nondeterministic and alternating p2-tms. Let $L(m, n) : N^2 \to N$

be a function with two variables m and n, and let M be a p2-tm. M is called $L(m, n)$ space-bounded if M uses at most $L(m, n)$ cells of the storage tape for any input tape with m rows and n columns ($m, n \geq 1$). Chapter 4 shows that for any function $L(m, n) = f(m) + g(n)$ (where $f(m) = o(\log m)$ and $g(n) = o(\log n)$), $L(m, n)$ space-bounded alternating p2-tms are stronger in accepting power than $L(m, n)$ space-bounded nondeterministic p2-tms. In fact, Chapter 4 shows that there is a set of two-dimensional tapes accepted by an alternating one-pebble two-dimensional finite automaton, but not accepted by any $L(m, n) = f(m) + g(n)$ space-bounded nondeterministic p2-tm (where $f(m) = o(\log m)$ and $g(n) = o(\log n)$). Finally, Chapter 5 gives conclusion and future problems.