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Complexity Theory
Exercise 5: Space Complexity
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Exercise 5.1. Let $\mathbf{A}_{\text{LBA}}$ be the word problem of deterministic linear bounded automata. Show that $\mathbf{A}_{\text{LBA}}$ is PSPACE-complete.

$$\mathbf{A}_{\text{LBA}} = \{\langle \mathcal{M}, w\rangle \mid w \in \mathbf{L}(\mathcal{M}) \text{ and } \mathcal{M} \text{ is a deterministic linear bounded automata}\}$$

Exercise 5.2. Consider the Japanese game *go-moku* that is played by two players X and O on a 19x19 board. Players alternately place markers on the board, and the first one to have five of its markers in a row, column, or diagonal wins.

Consider the generalised version of go-moku on an $n \times n$ board. Say that a *position* of go-moku is a placement of markers on such a board as it could occur during the game, together with a marker which player moves next. Define

$$\mathbf{GM} = \{\langle B\rangle \mid B \text{ is a position of go-moku where X has a winning strategy}\}.$$

Show that **GM** is in PSPACE.

Exercise 5.3. Show that the universality problem of nondeterministic finite automata

$$\mathbf{ALL}_{\text{NFA}} = \{\langle \mathcal{A}\rangle \mid \mathcal{A} \text{ an NFA accepting every valid input}\}$$

is in PSPACE.

Hint:
Prove that, if $\mathbf{L}(\mathcal{A}) \neq \Sigma^*$ and $\mathcal{A}$ has n states, then there exists a word $w \in \Sigma^*$ of length at most 2^n such that $w \notin \mathbf{L}(\mathcal{A})$. Then, use this fact to give a non-deterministic algorithm whose space consumption is polynomially bounded. Finally, apply Savitch's Theorem.

$*$ **Exercise 5.4.** Let

$$\mathbf{EQ}_{\text{REX}} = \{\, (R, S) \mid R \text{ and } S \text{ are equivalent regular expressions} \,\}.$$

Show that $\mathbf{EQ}_{\text{REX}}$ is in PSPACE.

Hint:
Adapt the hint of Exercise 5.3 accordingly.