CSE 431: Theory of Computation (Spring 2008) **Instructor: James R. Lee**
Problem Set #5 **Due: Thursday, May 15**

Reading assignment: Sipser, Sections 7.1–7.3.

Instructions: Same as homework #1.

This problem set has **four** regular problems worth 10 points each, and one extra credit problem. Please be as careful as possible in your arguments and your answers.

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1. Define

$$MODEXP = \left\{ \langle a, b, c, p \rangle : a, b, c, p \text{ are binary integers such that } a^b \equiv c \,(\mathrm{mod}\, p) \right\}.$$

   Show that $MODEXP \in \mathsf{P}$.

2. Show that P is closed under the $*$ operation. (Hint: Use dynamic programming!)

3. Show that NP is closed under union and concatenation.

4. Show that if $\mathsf{P} = \mathsf{NP}$, then a polynomial-time algorithm exists, that, given a 3SAT instance ϕ, actually produces a satisfying assignment for ϕ if it is satisfiable.

5. **(Extra credit, not so easy)** Let $f : \mathbb{N} \to \mathbb{N}$ be any function with $f(n) = o(n \log n)$. Show that $\mathsf{TIME}(f(n))$ contains only regular languages.

   (Hint: The key concept that aids showing the above is that of a *crossing sequence*. When a TM is run on an input, the crossing sequence at a given cell is the sequence of states that the machine enters at that cell as the computation progresses. Now, expand on the following two high-level ideas concerning crossing sequences. First, show that for a particular TM, if all crossing sequences on all inputs are of a fixed length ℓ or less, one can simulate the TM by an NFA. Second, show that a TM with unbounded crossing sequence length cannot run in $o(n \log n)$ time. For this, use a counting/pigeonhole argument to deduce repetition of crossing sequences at multiple places and then get a contradiction by "splicing" a minimal length input to a smaller string on which the TM has identical behavior.)