Unless otherwise stated, or otherwise clear from context, all languages are over $\Sigma = \{a, b\}$. Use the pumping lemma to prove that each of the following are non-regular. On the exam, Σ will be clear.

Recall the pumping lemma for regular languages:

If L is a regular language, then there is a number p (the pumping length) where if w is any string in L of length at least p, then w may be partitioned into three pieces, $w = xyz$, satisfying the following conditions:

- $|xy| \leq p$
- $|y| > 0$
- for each $i \geq 0$, $xy^iz \in L$

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1. Let L be the language $\{ww | w \in \{a, b\}^*\}$
2. Let L be the language $\{a^{n^2} | n \geq 0\}$ – that is, the set of strings whose length is a perfect square.
3. Let L be the language $\{a^i b^k | i > k\}$
4. $\{a^{10^n} | n \geq 0\}$
5. $\{a^n b^n c^n | n \geq 0\}$
6. Let L be the the set of odd-length strings in which the first, middle, and last symbols are the same.
7. **Challenge** : Let L be the set of odd-length strings where the middle symbol also appears elsewhere in the string.