1. Consider the following program.

(a) Assume $x$ is a variable with unknown value. Perform Constant Propagation on all variables by iterating till a fixed-point. Is convergence guaranteed on an arbitrary graph?  **Solution:** Convergence is guaranteed on any arbitrary graph since values start as $\#$ and only increase to the upper bound.

(b) At a glance we can tell $f$ is a dead variable any point after assignments. Perform a Liveness Analysis on the variable $f$ to check this fact, assuming the Constant Propagation has not been done. Do we need to recompute liveness information after eliminating $f$ and why?  **Solution:**
Yes. The assignment to \( f \) might depend on other variables, so removing the assignment liveness information of those dependent variables might change. In this case, if we recompute liveness information after removal of \( f \) we will discover \( d \) is also a dead variable.

2. You notice Constant Propagation and Liveness Analysis are very similar and they differ only in their information transfer functions. Suppose now we wish to detect all possibility of a variable being uninitialized along any path to a point where it is used. Come up with your transfer functions and run it on several examples to verify they work.

**Solution:**
A simple approach works similar to Constant Propagation. We have values \( \{ \text{initialized} \prec \text{uninitialized} \} \). After a variable is defined, its value is set to \( \text{initialized} \), otherwise \( \text{out} \) value is the same as \( \text{in} \); the join function for branches is the least upper bound. At the beginning, all values are initialized to be \( \text{initialized} \) except the \( \text{in} \) for very first statement that’s set to be \( \text{uninitialized} \). Then iteratively fix values that do not conform to rules set forward until convergence.
3. [Extra] Come up with transfer functions to establish using Flow Analysis that two expressions are equivalent if and only if they are certain to have the same value along any path to the point in question.