Exercise 1.4, page 72, of Culler (see also p87 of 2.2.1 for help):

1.4 Given a histogram of available parallelism such as that shown in Figure 1.7, where \( f_i \) is the fraction of cycles on an ideal machine in which \( i \) instructions issue, derive a generalization of Amdahl’s Law to estimate the potential speedup on a \( k \)-issue superscalar machine. Apply your formula to the histogram data in Figure 1.7 to produce the speedup curve shown in that figure.

The histogram shows fractions of cycles for which exactly \( M \) instructions (\( M = 0, 1, \ldots, 5, 6 \) or more) could be issued while running the program on a theoretical infinite-issue machine. The histogram corresponds to the shortest possible running time for the program. Limits on the number of instructions issued per cycle are those inherent to the dependencies of the program.

The speedup curve shows the execution time ratios for the same program running on the same hardware, but with the restriction that at most \( N \) instructions can be issued per cycle. For \( N = 1, 2, 4, 8, \) and 16, the speedup factor is the ratio of (longest) execution time for a single-issue machine to the (shorter) time on an \( N \)-issue machine. You must estimate the heights of the histogram bars and the values of the speedup factors. Your calculated speedup factors will nearly but not quite equal the values shown on the speedup curve.

\[ \text{Figure 1.7- Assumes infinite resources and fetch bandwidth, perfect branch prediction and register renaming, but real caches and non-zero miss latencies} \]