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Five-Stage Pipeline:

Trace File	prediction_method=0 (cycles)	prediction_method=1 (cycles)	% Reduction in Cycles
sample1.tr	1233112	1128480	8.4851984
sample2.tr	1159167	1140907	1.5752691
sample3.tr	1278927	1268969	0.7786215
sample4.tr	3671198	3538348	3.6187098
sample_large1.tr	108044161	103703599	4.0173962
sample_large2.tr	119348777	115530363	3.1993742

Eight-Stage Pipeline:

Trace File	prediction_method=0 (cycles)	prediction_method=1 (cycles)	% Reduction in Cycles
sample1.tr	3514261	3501066	0.3754701
sample2.tr	3131749	3119427	0.3934543
sample3.tr	3369978	3359077	0.3234739
sample4.tr	10015948	9979533	0.3635702
sample_large1.tr	318830015	315661622	0.9937562
sample_large2.tr	321386948	315481058	1.837626

On average, (considering prediction_method = 0) the number of cycles increases by a factor of 2.760 times when moving from five-stage to eight-stage. With prediction_method set to 1, this actually increases to a factor of 2.846 times since branch prediction is less effective on the eight-stage pipeline than it is on the five-stage. Considering numbers from both the eight-stage and five-stage architectures, branch prediction reduces the number of cycles by 2.163%. What's interesting here is that on the five-stage pipeline a branch predictor reduces the number of cycles by an average of 3.612% while on the eight-stage pipeline, the branch predictor only reduces the number of cycles by 0.715%. A branch predictor isn't even 1/5 as effective on the eight-stage pipeline as it is on the five-stage pipeline.

Below are values representing the factor of increase in cycles when moving from the five-stage to the eight-stage pipeline. For example, we interpret the first number as meaning, "the eight-stage pipeline takes 2.850 times as many cycles to run trace file sample1.tr when prediction_method = 0."

$$\frac{eight\ stage\ (cycles)}{five\ stage\ (cycles)}$$

sample1.tr

3514261 cycles / 1233112 cycles = 2.850 (prediction_method = 0)
3501066 cycles / 1128480 cycles = 3.102 (prediction_method = 1)

sample2.tr

3131749 cycles / 1159167 cycles = 2.702
3119427 cycles / 1140907 cycles = 2.734

sample3.tr

3369978 cycles / 1278927 cycles = 2.635
3359077 cycles / 1268969 cycles = 2.647

sample4.tr

10015948 cycles / 3671198 cycles = 2.728
9979533 cycles / 3538348 cycles = 2.820

sample_large1.tr

318830015 cycles / 108044161 cycles = 2.951
315661622 cycles / 103703599 cycles = 3.044

sample_large2.tr

321386948 cycles / 119348777 cycles = 2.693
315481058 cycles / 115530363 cycles = 2.731

From the results of the trace files, we see that the eight-stage pipeline uses approximately 2.803 times as many cycles as the five-stage pipeline. We reached this number by finding the average value when considering all the cycle increase factors from five-stage to eight-stage (including both prediction_method = 0 and prediction_method = 1).

Since we are assuming the clock frequency of the eight-stage pipeline is double that of the five-stage pipeline, the efficiency of both programs can be calculated as follows:

Let x = clock frequency on the five-stage pipeline ($\frac{cycles}{second}$)

Let y = the number of cycles needed to run a program on the five-stage pipeline *(cycles)*

We can calculate the time per program with the following equation:

time per program *(seconds)* = $\frac{y\left(\frac{cycles}{second}\right)}{x\,(cycles)}$

FIVE_STAGE.C:

clock frequency = $x\,\frac{cycles}{second}$ (by definition of x);

 # cycles = $y\ cycles$ (by definition of y);

time per program = $\frac{y}{x}$ *seconds* (by equation defined above);

EIGHT_STAGE.C:

clock frequency = $2x\,\frac{cycles}{second}$ (by definition of eight-stage pipeline clock frequency in project description);

 # cycles = $2.803y\ cycles$ (by calculated value of average factor of increase in cycles from five-stage to eight-stage above);

time per program = $\frac{2.803y}{2x}\ seconds = 1.402 * \frac{y}{x}\ seconds$ (by equation defined above);

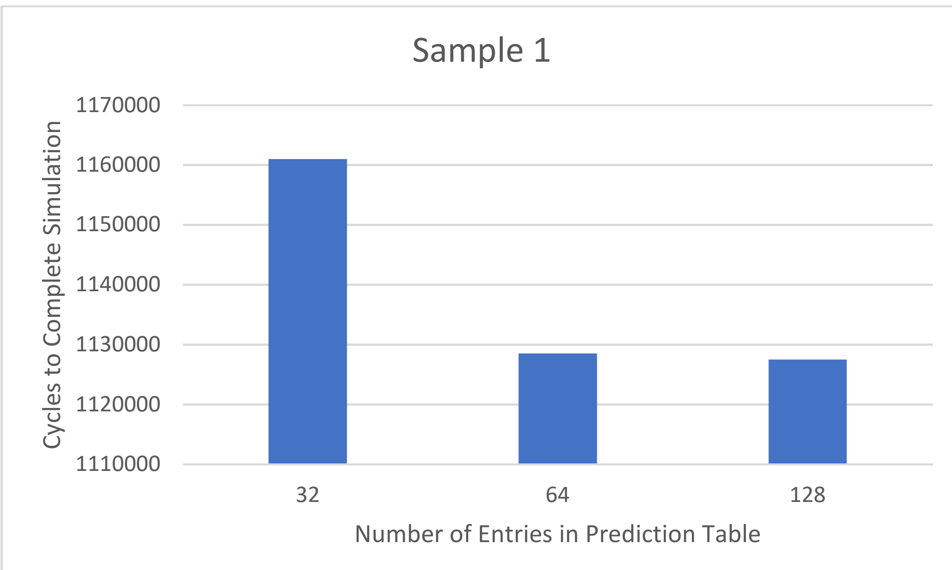
From calculations performed above, we can see that the eight-stage design runs, on average, approximately 1.402 times longer than the five-stage pipeline. This leads us to our conclusion that even with twice the clock frequency, the eight-stage design is still less efficient than the five-stage design. **Therefore, we recommend use of the five-stage architecture over the eight-stage architecture.**

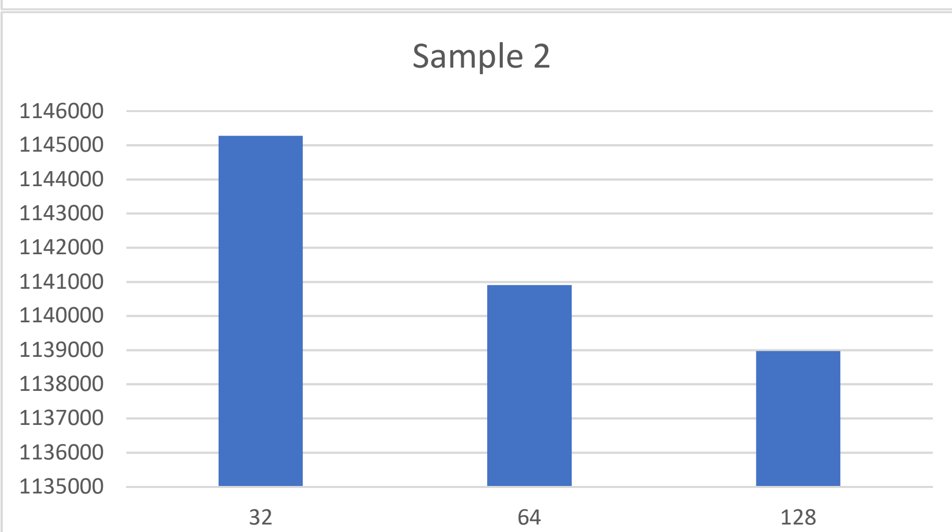
Effects of Prediction Table Size

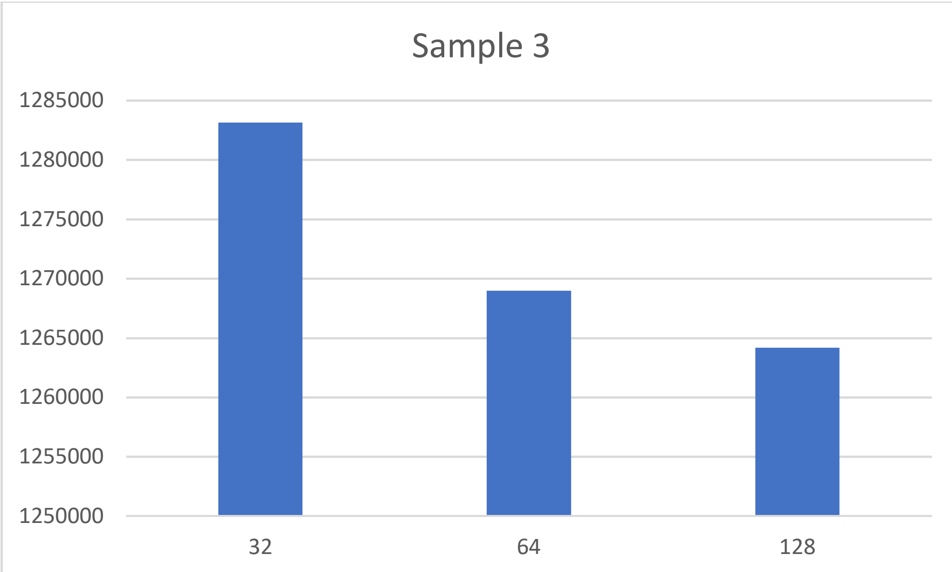
This table shows how many cycles each sample took to terminate with different sizes of the prediction table

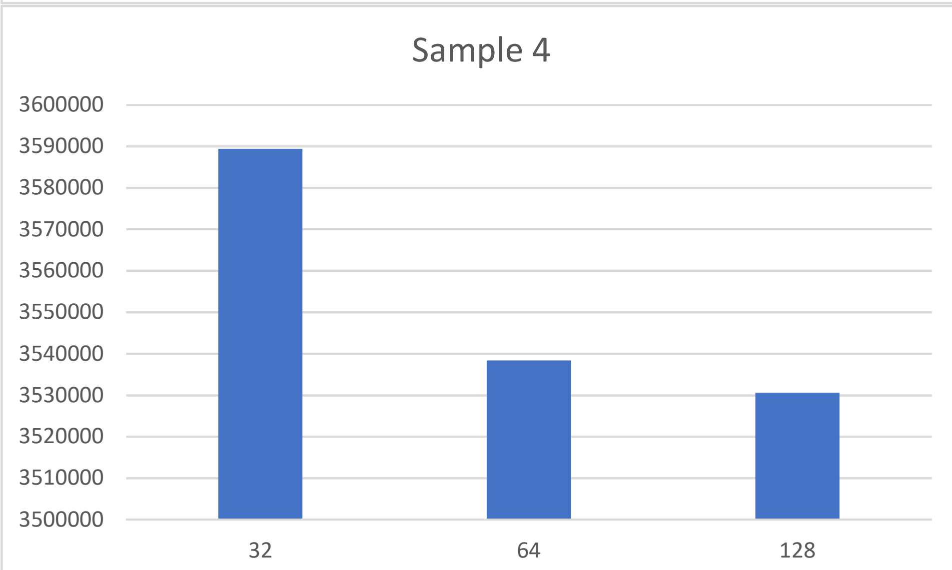
	32 Entries	64 Entries	128 Entries
Sample 1	1160991	1128480	1127473
Sample 2	1145276	1140907	1138972
Sample 3	1283147	1268969	1264178
Sample 4	3589406	3538348	3530615
Large Sample 1	105402700	103703599	103703513
Large Sample 2	116974556	115530363	115116953

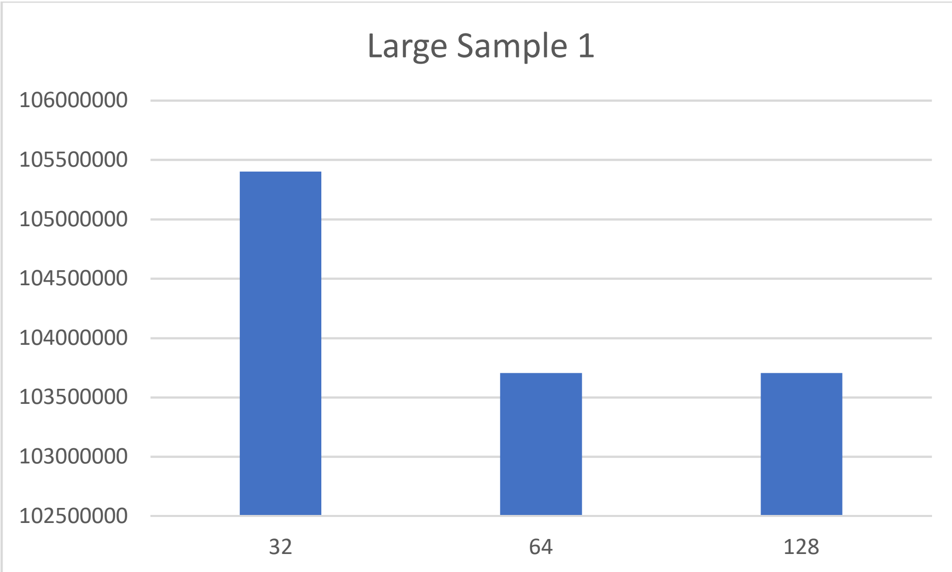
The graphs below show the effect of number of entries in the prediction table on the number of cycles to complete the simulation for each sample.

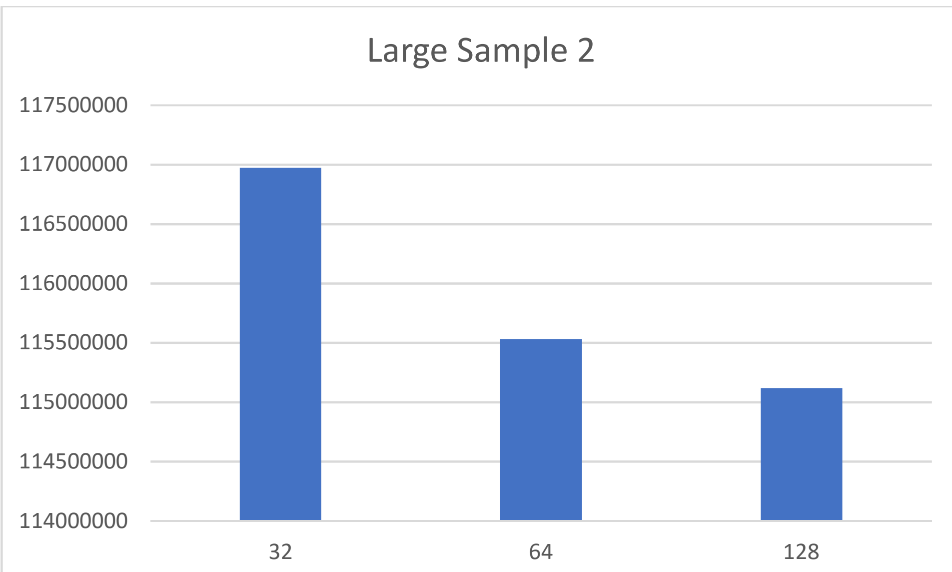





Sample 3
1285000
1280000
1275000
1270000
1265000
1260000
1255000
1250000
32
64
128


Sample 4
3600000
3590000
3580000
3570000
3560000
3550000
3540000
3530000
3520000
3510000
3500000
32
64
128





These graphs make it clear that the difference in performance between a prediction table of size 64 and 32 is greater than the difference in performance between table of size 128 and 64. The average percentage decrease of cycles to complete each sample between size 32 and size 64 prediction tables is 1.4191%, while the average percentage decrease between size 128 and size 64 is only 0.2021%. Increasing the size of the prediction table has diminishing returns: the increase from size 32 to size 64 has a significant impact on performance, but the increase from size 64 to size 128 has a much less significant impact on performance.