

[illegible]

## Part C

| #  | Stage |   |   |   | RT  |    |    |     |    |     |    |    |    | Free List          | IQ        | ROB       |           |           |           |           |
|----|-------|---|---|---|-----|----|----|-----|----|-----|----|----|----|--------------------|-----------|-----------|-----------|-----------|-----------|-----------|
|    | D     | I | W | C | x1  | x2 | x3 | x4  | x5 | x6  | x7 | x8 | x9 |                    |           | 0         | 1         | 2         | 3         | 4         |
| 0  |       |   |   |   | p0  | p1 | p2 | p3  | p4 | p5  | p6 | p7 | p8 | p9, pA, pB, pC, pD |           |           |           |           |           |           |
| 1  | 1     |   |   |   |     |    |    |     |    |     |    |    |    | p9, pA, pB, pC, pD |           |           |           |           |           |           |
| 2  | 2     | 1 |   |   | p9* |    |    |     |    |     |    |    |    | pA, pB, pC, pD     | p9/p1/p2  | p9*/x1/p0 |           |           |           |           |
| 3  | 3     |   |   |   |     |    |    | pA* |    |     |    |    |    | pB, pC, pD         | pA/p9*/p4 |           | pA*/x4/p3 |           |           |           |
| 4  | 4     | 3 |   |   |     |    |    |     |    | pB* |    |    |    | pC, pD             | pB/p6/p7  |           |           | pB*/x6/p5 |           |           |
| 5  | 5     |   |   |   | pC* |    |    |     |    |     |    |    |    | pD                 | pC/p1/p4  |           |           |           | pC*/x1/p9 |           |
| 6  |       | 2 | 3 |   |     |    |    |     |    | pD* |    |    |    |                    | pD/pB*/p8 |           |           |           |           | pD*/x6/pB |
| 7  |       | 4 | 1 |   |     |    |    |     |    |     |    |    |    |                    |           |           |           | pB/x6/p5  |           |           |
| 8  |       | 5 |   | 1 |     |    |    |     |    |     |    |    |    |                    |           | p9/x1/p0  |           |           |           |           |
| 9  |       |   |   |   |     |    |    |     |    |     |    |    |    | p0                 |           |           |           |           |           |           |
| 10 |       |   | 5 |   |     |    |    |     |    |     |    |    |    | p0                 |           |           |           |           |           |           |
| 11 |       |   | 2 |   |     |    |    |     |    | pD  |    |    |    | p0                 |           |           |           |           |           | pD/x6/pB  |
| 12 |       |   | 4 | 2 |     |    |    | pA  |    |     |    |    |    | p0                 |           |           | pA/x4/p3  |           |           |           |
| 13 |       |   |   | 3 | pC  |    |    |     |    |     |    |    |    | p0, p3             |           |           |           | *         | pC/x1/p9  |           |
| 14 |       |   |   | 4 |     |    |    |     |    |     |    |    |    | p0, p3, p5         |           |           |           |           | *         |           |
| 15 |       |   |   | 5 |     |    |    |     |    |     |    |    |    | p0, p3, p5, p9     |           |           |           |           |           | *         |
| 16 |       |   |   |   |     |    |    |     |    |     |    |    |    | p0, p3, p5, p9, pB |           |           |           |           |           |           |

## Part D

[illegible]

# Problem 2

## Part A

| i  | src[i] | Branch B0 |    |    | Branch B1 |    |    | Branch B2 |   |    |
|----|--------|-----------|----|----|-----------|----|----|-----------|---|----|
|    |        | BHT       | P  | A  | BHT       | P  | A  | BHT       | P | A  |
| 0  | 0      | WT        | T  | T  | WT        | T  | T  | WT        | T | T  |
| 1  | 0      | ST        | T  | T  | ST        | T  | T  | ST        | T | T  |
| 2  | 12     | ST        | T  | NT | ST        | T  | NT | ST        | T | T  |
| 3  | 15     | WT        | T  | NT | WT        | T  | NT | ST        | T | T  |
| 4  | 0      | WNT       | NT | T  | WNT       | NT | T  | ST        | T | T  |
| 5  | 0      | WT        | T  | T  | WT        | T  | T  | ST        | T | T  |
| 6  | 11     | ST        | T  | NT | ST        | T  | NT | ST        | T | T  |
| 7  | 17     | WT        | T  | NT | WT        | T  | NT | ST        | T | T  |
| 8  | 0      | WNT       | NT | T  | WNT       | NT | T  | ST        | T | T  |
| 9  | 0      | WT        | T  | T  | WT        | T  | T  | ST        | T | T  |
| 10 | 11     | ST        | T  | NT | ST        | T  | NT | ST        | T | T  |
| 11 | 13     | WT        | T  | NT | WT        | T  | NT | ST        | T | T  |
| 12 | 9      | WNT       | NT | T  | WNT       | NT | NT | ST        | T | T  |
| 13 | 0      | WT        | T  | T  | SNT       | NT | T  | ST        | T | T  |
| 14 | 12     | ST        | T  | NT | WNT       | NT | NT | ST        | T | T  |
| 15 | 15     | WT        | T  | NT | SNT       | NT | NT | ST        | T | T  |
| 16 | 0      | WNT       | NT | T  | SNT       | NT | T  | ST        | T | T  |
| 17 | 8      | WT        | T  | T  | WNT       | NT | NT | ST        | T | T  |
| 18 | 12     | ST        | T  | NT | SNT       | NT | NT | ST        | T | T  |
| 19 | 18     | WT        | T  | NT | SNT       | NT | NT | ST        | T | NT |

## Part B

| i  | src[i] | Branch B0 |     |    |    | Branch B1 |     |    |    | Branch B2 |     |   |    |
|----|--------|-----------|-----|----|----|-----------|-----|----|----|-----------|-----|---|----|
|    |        | BHSRT     | BHT | P  | A  | BHSRT     | BHT | P  | A  | BHSRT     | BHT | P | A  |
| 0  | 0      | 000       | WT  | T  | T  | 000       | WT  | T  | T  | 000       | WT  | T | T  |
| 1  | 0      | 001       | WT  | T  | T  | 001       | WT  | T  | T  | 001       | WT  | T | T  |
| 2  | 12     | 011       | WT  | T  | NT | 011       | WT  | T  | NT | 011       | WT  | T | T  |
| 3  | 15     | 110       | WT  | T  | NT | 110       | WT  | T  | NT | 111       | WT  | T | T  |
| 4  | 0      | 100       | WT  | T  | T  | 100       | WT  | T  | T  | 111       | ST  | T | T  |
| 5  | 0      | 001       | ST  | T  | T  | 001       | ST  | T  | T  | 111       | ST  | T | T  |
| 6  | 11     | 011       | SNT | NT | NT | 011       | SNT | NT | NT | 111       | ST  | T | T  |
| 7  | 17     | 110       | WNT | NT | NT | 110       | WNT | NT | NT | 111       | ST  | T | T  |
| 8  | 0      | 100       | ST  | T  | T  | 100       | ST  | T  | T  | 111       | ST  | T | T  |
| 9  | 0      | 001       | ST  | T  | T  | 001       | ST  | T  | T  | 111       | ST  | T | T  |
| 10 | 11     | 011       | SNT | NT | NT | 011       | SNT | NT | NT | 111       | ST  | T | T  |
| 11 | 13     | 110       | SNT | NT | NT | 110       | SNT | NT | NT | 111       | ST  | T | T  |
| 12 | 9      | 100       | ST  | T  | T  | 100       | ST  | T  | NT | 111       | ST  | T | T  |
| 13 | 0      | 001       | ST  | T  | T  | 000       | ST  | T  | T  | 111       | ST  | T | T  |
| 14 | 12     | 011       | SNT | NT | NT | 001       | ST  | T  | NT | 111       | ST  | T | T  |
| 15 | 15     | 110       | SNT | NT | NT | 010       | WT  | T  | NT | 111       | ST  | T | T  |
| 16 | 0      | 100       | ST  | T  | T  | 100       | WT  | T  | T  | 111       | ST  | T | T  |
| 17 | 8      | 001       | ST  | T  | T  | 001       | WT  | T  | NT | 111       | ST  | T | T  |
| 18 | 12     | 011       | SNT | NT | NT | 010       | WNT | NT | NT | 111       | ST  | T | T  |
| 19 | 18     | 110       | SNT | NT | NT | 100       | ST  | T  | NT | 111       | ST  | T | NT |

## Part C

| i  | src[i] | Branch B0 |     |    |    | Branch B1 |     |    |    | Branch B2 |     |   |    |
|----|--------|-----------|-----|----|----|-----------|-----|----|----|-----------|-----|---|----|
|    |        | BHSR      | BHT | P  | A  | BHSR      | BHT | P  | A  | BHSR      | BHT | P | A  |
| 0  | 0      | 0         | WT  | T  | T  | 1         | WT  | T  | T  | 1         | WT  | T | T  |
| 1  | 0      | 1         | WT  | T  | T  | 1         | ST  | T  | T  | 1         | ST  | T | T  |
| 2  | 12     | 1         | ST  | T  | NT | 0         | WT  | T  | NT | 0         | WT  | T | T  |
| 3  | 15     | 1         | WT  | T  | NT | 0         | WNT | NT | NT | 0         | ST  | T | T  |
| 4  | 0      | 1         | WNT | NT | T  | 1         | ST  | T  | T  | 1         | ST  | T | T  |
| 5  | 0      | 1         | WT  | T  | T  | 1         | ST  | T  | T  | 1         | ST  | T | T  |
| 6  | 11     | 1         | ST  | T  | NT | 0         | SNT | NT | NT | 0         | ST  | T | T  |
| 7  | 17     | 1         | WT  | T  | NT | 0         | SNT | NT | NT | 0         | ST  | T | T  |
| 8  | 0      | 1         | WNT | NT | T  | 1         | ST  | T  | T  | 1         | ST  | T | T  |
| 9  | 0      | 1         | WT  | T  | T  | 1         | ST  | T  | T  | 1         | ST  | T | T  |
| 10 | 11     | 1         | ST  | T  | NT | 0         | SNT | NT | NT | 0         | ST  | T | T  |
| 11 | 13     | 1         | WT  | T  | NT | 0         | SNT | NT | NT | 0         | ST  | T | T  |
| 12 | 9      | 1         | WNT | NT | T  | 1         | ST  | T  | NT | 0         | ST  | T | T  |
| 13 | 0      | 1         | WT  | T  | T  | 1         | WT  | T  | T  | 1         | ST  | T | T  |
| 14 | 12     | 1         | ST  | T  | NT | 0         | SNT | NT | NT | 0         | ST  | T | T  |
| 15 | 15     | 1         | WT  | T  | NT | 0         | SNT | NT | NT | 0         | ST  | T | T  |
| 16 | 0      | 1         | WNT | NT | T  | 1         | ST  | T  | T  | 1         | ST  | T | T  |
| 17 | 8      | 1         | WT  | T  | T  | 1         | ST  | T  | NT | 0         | ST  | T | T  |
| 18 | 12     | 1         | ST  | T  | NT | 0         | SNT | NT | NT | 0         | ST  | T | T  |
| 19 | 18     | 1         | WT  | T  | NT | 0         | SNT | NT | NT | 0         | ST  | T | NT |

## Part D

|              | Two-Bit FSM Accuracy | Two-Level Temporal Accuracy | Two-Level Spatial Accuracy |
|--------------|----------------------|-----------------------------|----------------------------|
| Branch B0    | 6/20 = 30%           | 18/20 = 90%                 | 6/20 = 30%                 |
| Branch B1    | 10/20 = 50%          | 13/20 = 65%                 | 17/20 = 85%                |
| Branch B2    | 19/20 = 95%          | 19/20 = 95%                 | 19/20 = 95%                |
| All Branches | 58.33%               | 83.55%                      | 70%                        |

For each predictor and each branch, discuss why the accuracy is better or worse than the other predictors on the same branch. Your answer should reflect your understanding of the temporal and spatial correlation in this example and how it impacts the various prediction accuracies.

**Branch B0's** behavior is very predictable, it follows the sequence T T NT NT. Any scheme that takes advantage of temporal locality would do well with this branching sequence, since we can clearly outline the repeating pattern. As assumed, Two-Level Adaptive Branch Predictor does significantly better than other predictors.

**Branch B1's** behavior is more complex than the rest, because it starts out with some repeating pattern and becomes less predictable later. The changes in the pattern in the latter part of B1 is somewhat predictable where the 4 sequence pattern in a way counts up in binary. This is what it mean:

|               |               |               |               |
|---------------|---------------|---------------|---------------|
| T   T   NT NT | NT T NT NT    | T NT NT NT    | NT NT NT NT   |
| 1   1   0   0 | 0   1   0   0 | 1   0   0   0 | 0   0   0   0 |

The first three entries are in the B1's sequence and the 4th is simply my speculation. But there seems to be a spatial pattern here. So, Two-Level Adaptive Branch Predictor does much better than other predictors.

**Branch B2** has the most simple behavior, where every entry in the sequence is T except the last one. This is because of its use as loop condition variable. Since it's pattern is very simple, all predictors do extremely well. Even fixed predictors, if set right, would be able to achieve this level of accuracy.