

# CSE471 Homework Assignment #1: Branch Prediction

Due Tuesday, April 19th before lecture

## 1 Introduction

The purpose of this assignment is to supplement your conceptual knowledge about the design of different dynamic branch prediction schemes with concrete experience in implementing them and intuition about their relative performance. As you learned in class, branch prediction is a common architectural technique for avoiding pipeline delays due to branches. A processor does branch prediction as it fetches a branch instruction. In order to continue fetching instructions that will actually be executed, the processor needs to know whether the branch will be “taken” (and consequently fetch the target instruction) or “not taken” (and fetch the fall-through code). Since a branch instruction is not actually evaluated for several cycles after it’s been fetched, the processor predicts the branch outcome. Assuming the target instruction is known, the processor then uses the prediction to fetch instructions that are hopefully needed next.

## 2 Your Task

Dynamic branch prediction is implemented as a set of hardware data structures and logic that tells the processor whether a branch is likely to be taken or not taken. In this assignment, you will write a program that simulates the behavior of three branch predictors and, using a set of benchmark programs, compare their ability to correctly predict branch outcomes.

For all three predictors you’ll use the same amount of hardware for their data structures, although for each predictor the hardware may be used to hold different types of data and may be configured differently. Your hardware budget is set at a maximum of 4 KB, which is a small, but reasonable size for current processors.

For one predictor, you will vary the size of these hardware structures and analyze the impact of changing the predictor’s size on its prediction accuracy.

Finally, you should provide a quantitative analysis in support of your conclusions about the different predictor designs. Your report should explain the data you collect, and describe your reason for concluding that a particular predictor design is best.

### 2.1 The Predictors

Four predictors will be involved in your study:

- Static branch prediction
- Local (i.e., per-branch), two-bit predictor
- Local branch history, global pattern history table, two-level adaptive predictor.
- Global branch history, global pattern history table, two-level adaptive predictor.

The static predictor will serve as your base case, against which you compare the others. It has already been implemented for you, to show you how branch predictors can be implemented in our software infrastructure.

For all the dynamic predictors, you should implement the prediction with two-bit saturating counters (which will be discussed in section). The local, two-bit predictor and the local, two-level adaptive predictor will have a branch history table (BHT) with an entry for each branch.

As a point of reference, a reasonable BHT size for a local, two-bit predictor is  $2^{14}$  entries. For the local, two-level adaptive predictor, the BHT will have to be substantially smaller, in order to budget resources for the PHT.

For predictors that use branch history information, a reasonable branch history length is 10 – 20 bits, depending on the predictor. Note that the length of the branch history determines the number of entries in the pattern history table (PHT), if present.

## 2.2 The Quantitative Analysis

Once you have implemented your predictors, you need to figure out how well they predict, using prediction accuracy as your metric. You will do this by running a set of programs on all of your branch predictor simulators. (The simulation infrastructure and benchmarks are described below in Section 3.) When your simulator is finished running a program, it will automatically report how many correct predictions each of your predictors made, as well as some other summary information about the execution. Use this metric to gain insight into the performance of the three prediction strategies. Do you gain any performance from knowing the per-branch path, as opposed to which branch instruction is executing? Do you gain from knowing the execution path through the whole program, as opposed to the execution path of an individual branch?

For each predictor create a plot that shows its *relative* accuracy for each benchmark. It may be that for some applications some predictors work better and for other applications other predictors work better. If this is the case, say so and try to hypothesize why this may be the case.

Lastly, you should analyze the performance impact of varying the size of the branch history of the local, two-bit predictor, using branch history tables that range from  $2^{14}$  entries, up to  $2^{16}$  entries. In your report, quantitatively compare the improvement in accuracy obtained by varying this hardware structure's size to the improvement in accuracy obtained by changing the design from local, two-bit prediction to local, two-level correlated prediction. Does a larger two-bit predictor ever reach the performance of a path-based prediction scheme?

Write up your results and analysis in a report, as outlined in the report handout and illustrated in the sample reports on the course web site.

## 3 Simulation Infrastructure

The simulation infrastructure is built using a *binary instrumentation* tool called Pin (<http://pintool.org>). The first discussion section will cover what binary instrumentation is and how Pin works. For this assignment, you don't need to understand how to use Pin in detail.

Pin runs a specified program, subject to a set of rules and modifications described in a “pintool”. A pintool is able to identify certain events during a program's execution, and call arbitrary code (*i.e.*, code you write) when those events occur.

For this assignment you'll use a pintool called `bp`. You are going to write a set of plugins for `bp` that implement various branch prediction strategies. `bp` is designed to call the code you wrote in these plugins when it encounters a branch during execution, thus simulating a particular branch prediction technique.

To make `bp` aware of your plugins, it takes a “-predictor” argument, that takes a *comma-separated* list of `.so` files. These shared object files should implement different predictors. For example, if you have two predictors implemented, called `two-bit.so` and `global.so`, and you want to run them both on an execution of some program, you would use the following command line:

```
pin -t bp -predictor two-bit.so,global.so -- <program> <args>
```

A version of Pin that we can all share is installed at `/cse/courses/cse471/11wi/PIN`.

**Implementing A Predictor Plugin** You will write plugins as new classes that derive from the `Predictor` base class described in `Predictor.h`. An example to get you going is declared and defined in `StaticPredictor.h/.cpp`. You should use these files as a template for all your prediction schemes.

Your predictor plugins must define three methods:

1. The predictor's constructor
2. The `predictBranch` method
3. The `updatePredictor` method

**Initializing Your Predictor** Your predictor's constructor should set up your predictor's data structures. The simulator infrastructure uses the "Factory" design pattern. In order for your predictor to be correctly loaded, you need to include the factory function `extern "C" Predictor * Create()` in the same source file as your predictor's definition. This function must not be a member of your predictor's class. This function should return a new instance of your Predictor's class.

**Predicting Branches and Updating Your Predictor** The `predictBranch()` method runs before a branch executes, and receives the branch instruction's address as its argument. You will write it so that it returns the decision of the predictor (either `Taken` or `NotTaken`).

`updatePredictor()` is called after a branch executes. It takes a branch instruction's address, and the outcome of that branch as its arguments. This method should update the data structures associated with your predictor based on the outcome of the branch. `updatePredictor()` does not return a value.

**Building Your Plugins** Please implement one predictor per `.h/.cpp` pair only (*i.e.*, putting two predictors in one file won't work). You can build your plugins using `g++`. Be sure to specify the `-fPIC` and `-shared` options, because your plugins need to be built as shared libraries. We've included a `Makefile`, and you can also add your plugins' source filenames to the list that includes `StaticPredictor.cpp`, and it will get built when you type `make`.

### 3.1 Benchmarks

Some of the SPEC benchmarks are installed at `/cse/courses/cse471/11wi/SPEC2006`, also available via a link in the Homework section of the course web pages. You will use these programs to evaluate your predictors' prediction accuracy. For your convenience we've included a script at `/cse/courses/cse471/11wi/SPEC2006/Cpu2006_test.sh`. This script will automatically run all the benchmarks with their smallest input. It takes two arguments:

1. A comma separated list of predictor plugins
2. A directory that you can write to, for storing the results

This script may take several minutes to run all the benchmarks – these programs perform large computations, and simulation adds massive overheads. When the script terminates, your output directory will contain a list of directories that each contain files called `<benchmarkname>.out` and `<benchmarkname>.err`. Your branch predictors' results are written by the script to the `<benchmarkname>.err` files.

Your quantitative evaluation must include these SPEC benchmarks, but is not restricted to these programs. A cool aspect of using Pin is that Pin-based simulators can simulate *any* x86 binary. Feel free to experiment.

We recommend that while you are developing your branch predictors, you write test cases for yourself to make testing more controlled. The benchmarking infrastructure has a long turn-around time, and if you are debugging, it is more productive to use small test programs that evaluate particular branch prediction circumstances.