THE ROAD NOT TAKEN

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Estimating Path Execution Frequency Statically

The Big Idea

- Developers often have a expectations about common and uncommon cases in programs
- The structure of code they write can sometimes reveal these expectations

Example


```
public V function(K k , V v)
{
   if ( v == null )
     throw new Exception();

   if ( c == x )
      r();

   i = k.h();

   t[i] = new E(k, v);
   c++;

   return v;
}
```

Example


```
public V function(K k , V v)
{
    if ( v == null )
      throw new Exception();

    if ( c == x )
      restructure();

    i = k.h();

    t[i] = new E(k, v);
    c++;

    return v;
}
```

Exception

Invocation that changes a lot of the object state

Some computation

Path 1


```
public V function(K k , V v)
{
    if ( v == null )
      throw new Exception();

    if ( c == x )
      restructure();

    i = k.h();

    t[i] = new E(k, v);
    c++;

    return v;
}
```

Path 2


```
public V function(K k , V v)
{
    if ( v == null )
      throw new Exception();

    if ( c == x )
      restructure();

    i = k.h();

    t[i] = new E(k, v);
    c++;

    return v;
}
```

Path 3


```
public V function(K k , V v)
{
    if ( v == null )
      throw new Exception();

    if ( c == x )
      restructure();

    i = k.h();

    t[i] = new E(k, v);
    c++;

    return v;
}
```

HashTable: put


```
public V put(K key , V value)
{
    if ( value == null )
      throw new Exception();

    if ( count >= threshold )
      rehash();

    index = key.hashCode() % length;

    table[index] = new Entry(key, value);
    count++;

    return value;
}
```

*simplified from java.util.HashTable jdk6.0

Intuition

Stack State +
Heap State

How a path modifies *program state* may correlate with its runtime execution frequency

- Paths that change a lot of *state* are rare
  - Exceptions, initialization code, recovery code, etc.
- Common paths tend to change a small amount of *state*

More Intuition

- Number of branches
- Number of method invocations
- Path length
- Percentage of statements in a method executed
- …

Hypothesis

We can *accurately* predict the runtime frequency of program paths by analyzing their static surface features

Goals:

- Know what programs are likely to do without having to run them (Produce a *static profile*)
- Understand the factors that are predictive of execution frequency

Our Path

- Intuition
- Candidates for *static profiles*
- Our approach
  - a descriptive model of path frequency
- Some Experimental Results

Applications for Static Profiles

- Indicative (dynamic) profiles are often hard to get

Profile information can improve many analyses

- Profile guided optimization
- Complexity/Runtime estimation
- Anomaly detection
- Significance of difference between program versions
- Prioritizing output from other static analyses

Approach

- **Model** path with a set of features that may correlate with runtime path frequency
- **Learn** from programs for which we have indicative workloads
- **Predict** which paths are most or least likely in other programs

Experimental Components

- Path Frequency Counter
  - Input: Program, Input
  - Output: List of paths + frequency count for each
- Descriptive Path Model
- Classifier

Our Definition of Path

- Statically enumerating full program paths doesn't **scale**
- Choosing only intra-method paths doesn't give us enough **information**
- Compromise: Acyclic Intra-Class Paths
  - Follow execution from public method entry point until return from class
  - Don’t follow back edges

Experimental Components

- Path Frequency Counter
  - Input: Program, Input
  - Output: List of paths + frequency count for each
- Descriptive Path Model
  - Input: Path
  - Output: Feature Vector describing the path
- Classifier

Count	Coverage	Feature
•		pointer comparisons
•		`new`
•		`this`
•		all variables
•		assignments
•		dereferences
•	•	fields
•	•	fields written
•	•	statements in invoked method
•		`goto` stmts
•		`if` stmts
•		local invocations
•	•	local variables
•		non-local invocations
•	•	parameters
•		`return` stmts
•		statements
•		`throw` stmts

Experimental Components

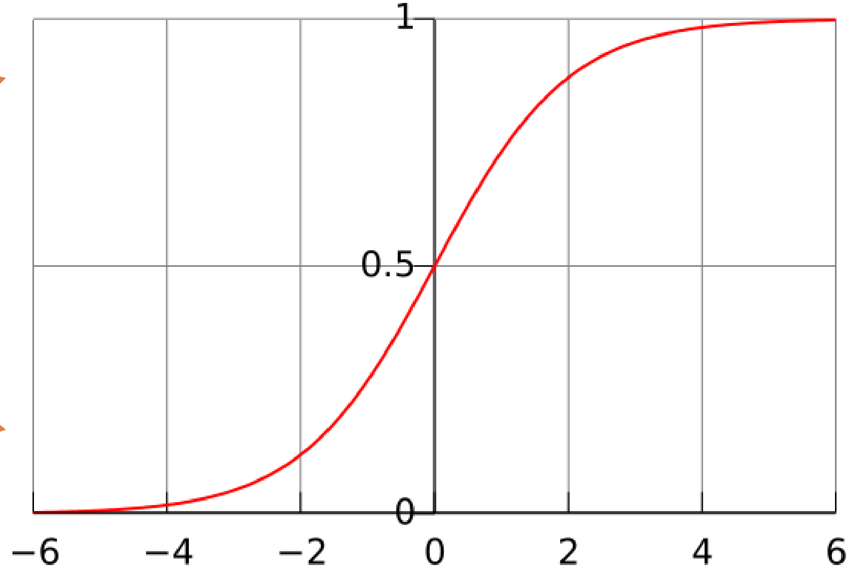
- Path Frequency Counter
  - Input: Program, Input
  - Output: List of paths + frequency count for each
- Descriptive Path Model
  - Input: Path
  - Output: Feature Vector describing the path
- Classifier
  - Input: Feature Vector
  - Output: Frequency Estimate

Classifier: Logistic Regression

- Learn a logistic function to estimate the runtime frequency of a path

Likely to be taken

Not likely to be taken



$$f(z) = \frac{1}{1+e^{-z}}$$

Input path $\{x_1, x_2 \ldots x_n\}$

$$z = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \cdots + \beta_k x_k,$$

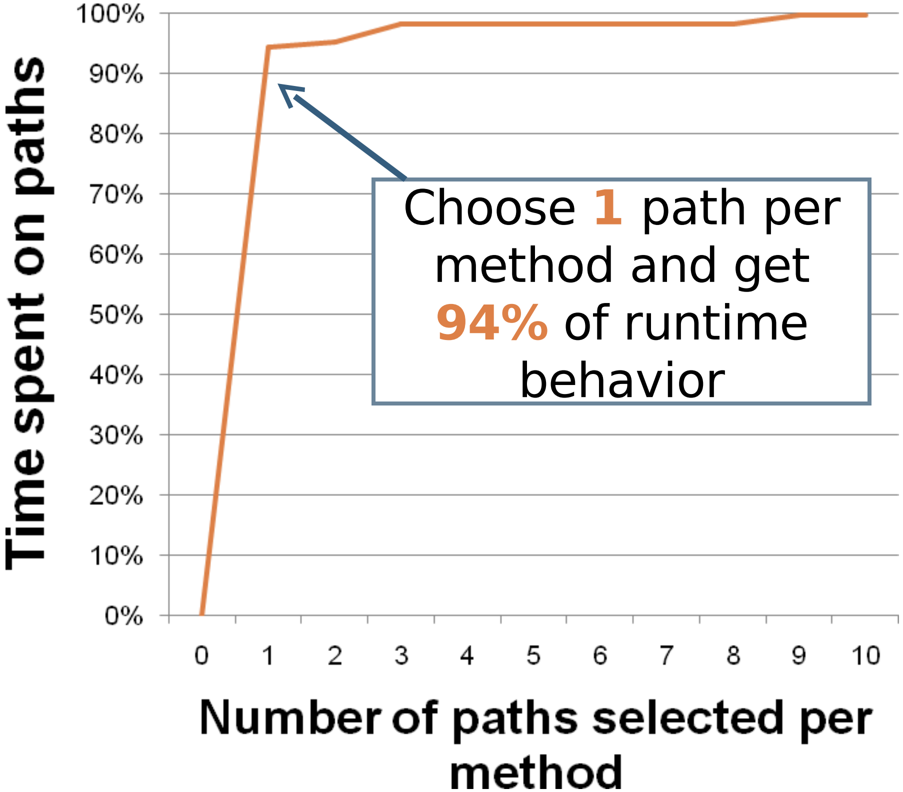
Model Evaluation

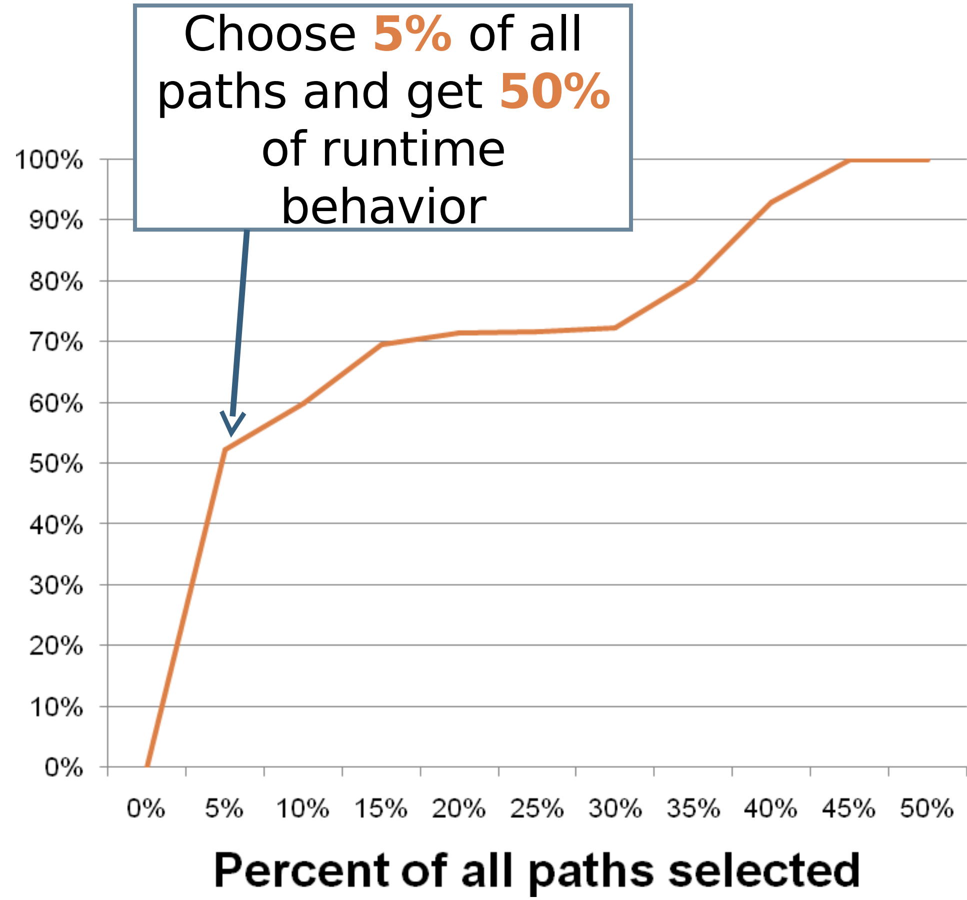
- Use the model to rank all static paths in the program
- Measure how much of total program runtime is spent:
  - On the top X paths for each method
  - On the top X% of all paths
- Also, compare to static branch predictors
- Cross validation on Spec JVM98 Benchmarks
  - When evaluating on one, train on the others

Spec JVM 98 Benchmarks

Name	Description	LOC	Methods	Paths	Paths/ Method	Runtime
check	check VM features	1627	107	1269	11.9	4.2s
compress	compression	778	44	491	11.2	2.91s
db	data management	779	34	807	23.7	2.8s
jack	parser generator	7329	304	8692	28.6	16.9s
javac	compiler	56645	1183	13136	11.1	21.4s
jess	expert system shell	8885	44	147	3.3	3.12s
mtrt	ray tracer	3295	174	1573	9.04	6.17s
Total or **Average**		**79338**	**1620**	**26131**	**12.6**	**59s**

Evaluation: Top Paths

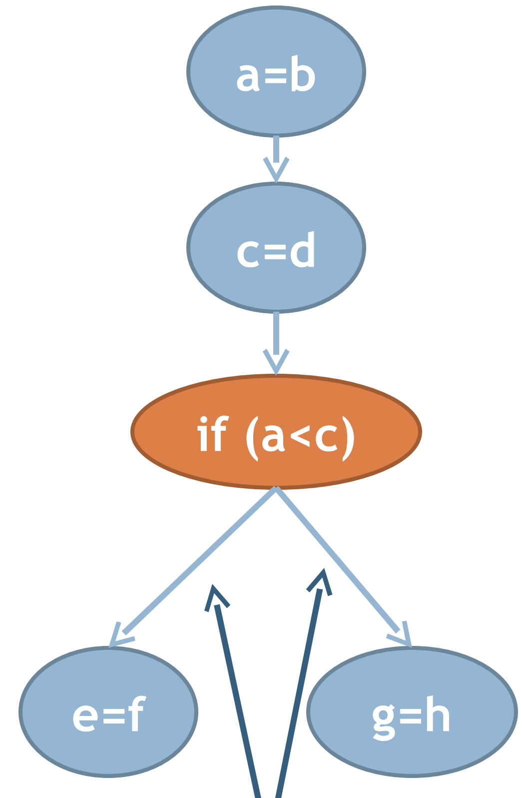




Static Branch Prediction

At each branching node…

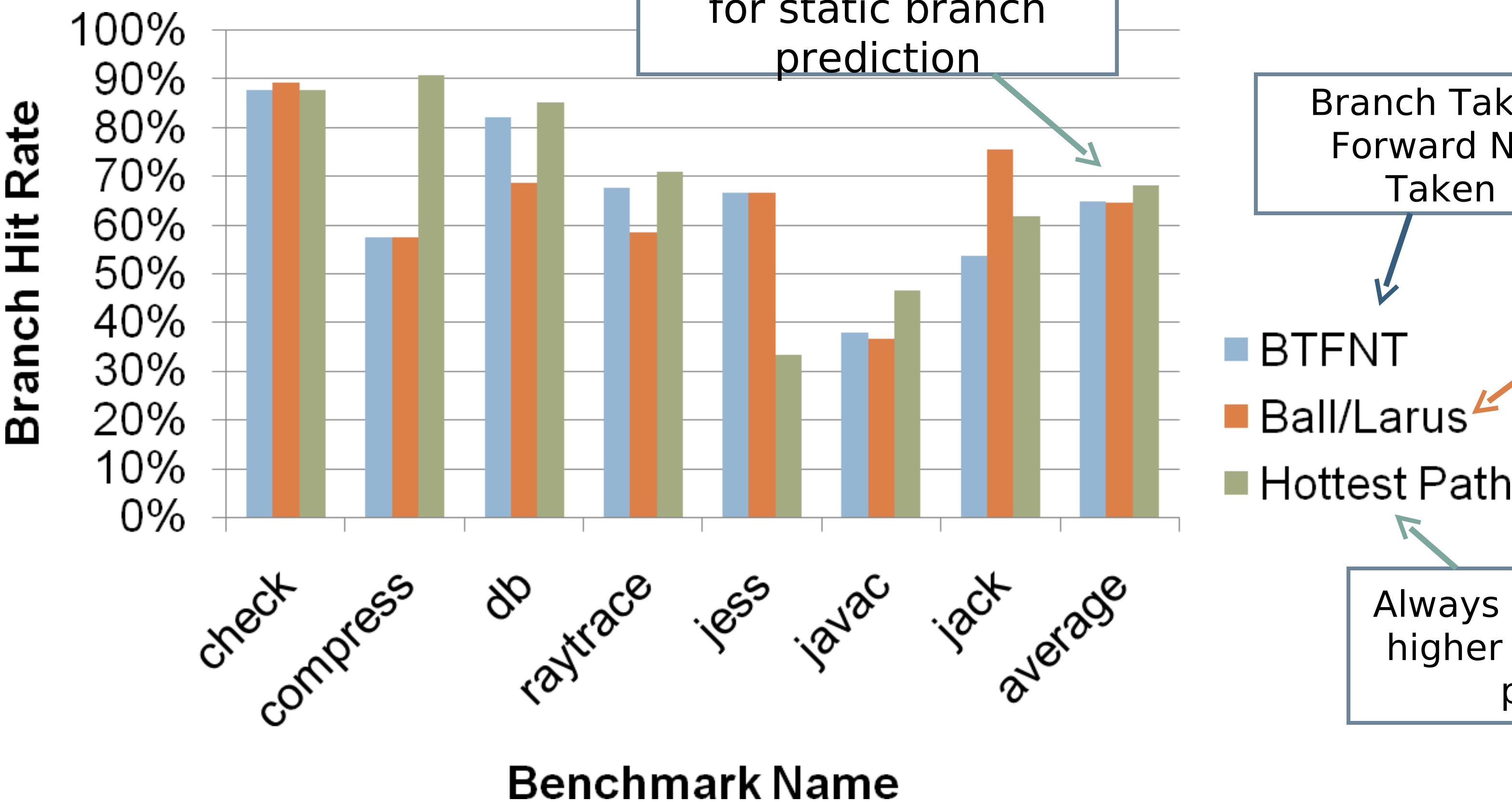
- Partition the path set entering the node into two sets corresponding to the paths that conform to each side of the branch.
- Record the prediction for that branch to be the side with the highest frequency path available.



Given where we've been, which branch represents the highest frequency path?

Evaluation: Static Branch Predictor

We are even a reasonable choice for static branch prediction

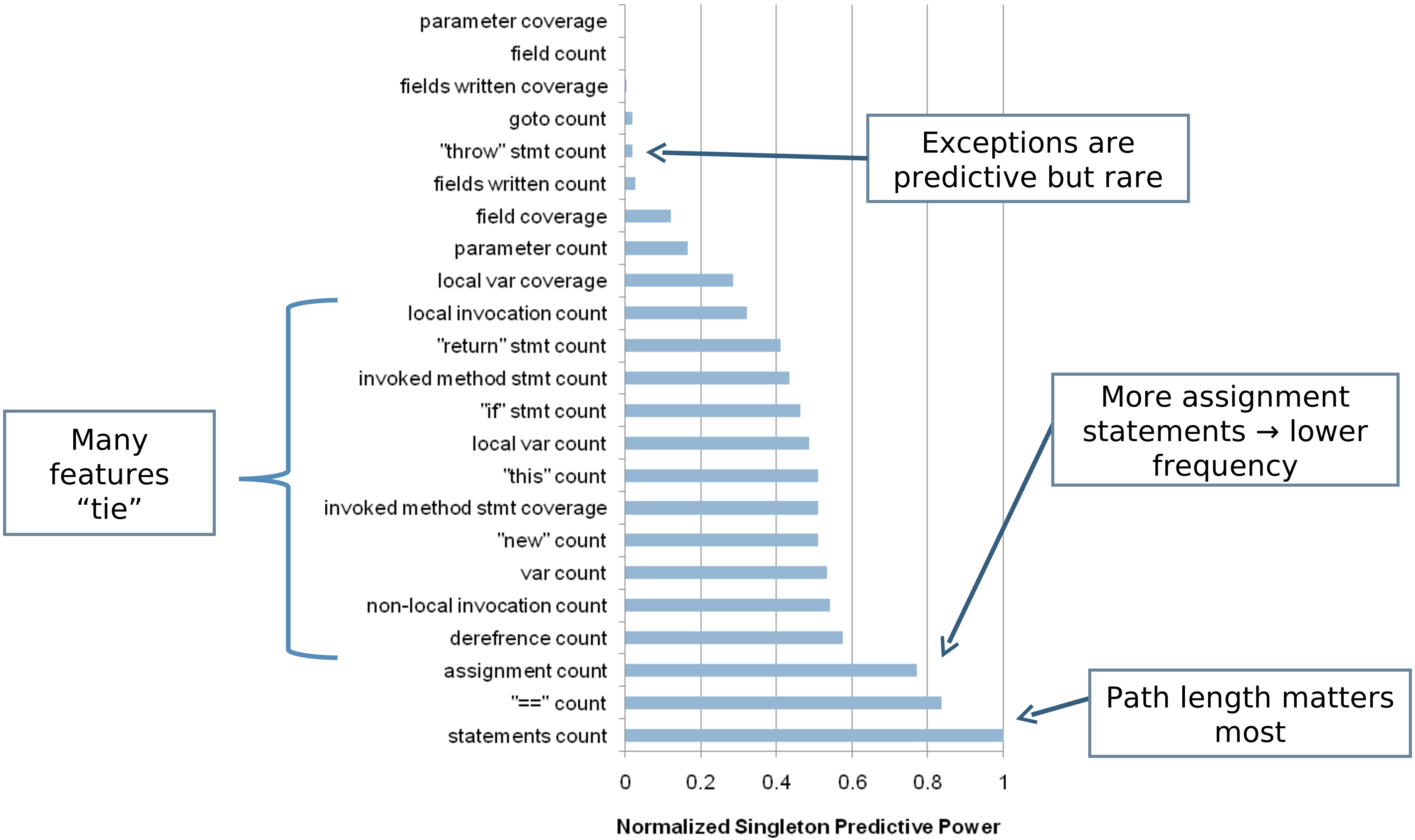


Branch Taken; Forward Not Taken

A set of heuristics

Always choose the higher frequency path

Model Analysis: Feature Power



Conclusion

- A formal model that statically predicts relative dynamic path execution frequencies
- A generic tool (built using that model) that takes only the program source code (or bytecode) as input and produces
  - for each method, an ordered list of paths through that method
- The promise of helping other program analyses and transformations

Questions? Comments?

Evaluation by Benchmark