ShortCut: Architectural Support for Fast Object Access in Scripting Languages

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Overheads of Scripting Languages

- Scripting languages are widely used
  - Designed for productivity
  - Dynamic type system: Difficult to generate efficient code
- Many overheads include:
  - Slow interpreter
  - Dynamic type check (e.g., integer or float?)
  - Slow object access ← **Our Focus**
  - Garbage collection

Traditional Languages: Fast Object Access

- **Type declaration** tells compiler the shape of an object
  - Properties and their offsets within an object

```
struct T {
   int x;
   int y;
};
```

offset 0

```
int get_x(T o)
{
   return o.x;
}
```

```
T a;
get_x(a);
```

Compile

[Code for `get_x`]

ld R_D, &o[0]

What if there is no type declaration?

Scripting Languages: Slow Object Access

- **No type information** available ahead of execution
- A naïve approach requires an expensive dictionary lookup

```
function get_x(o)
{
  return o.x;
}

a = {}; // new obj
a.x = 0;
get_x(a);
```

Object shape unknown

Compile

[Code for `get_x`]

```
call Runtime
```

Dictionary lookup for every object access is prohibitively expensive.

Scripting Languages: Slow Object Access

- Current software solution: Dynamically generate a specialized handler for each object type and reuse it for the same type later

```
function get_x(o)
{
  return o.x;
}

a = {}; // new obj
a.x = 0;
get_x(a);
get_x(a);

b = {}; // new obj
b.y = 1; b.x = 2;
get_x(b);
get_x(b);
```

← x @ offset 0 (at `a.x = 0;`)

← x @ offset 1 (at `b.x = 2;`)

Compile

[Code for `get_x`]

```
call Dispatcher
```

[Code for `Dispatcher`]

```
if obj_type is previously seen:
   jump to a specialized handler
else:
   jump to Runtime
```

[Handler$_a$]

ld R_D, &o[**0**]
ret R_D

[Handler$_b$]

ld R_D, &o[**1**]
ret R_D

Program → Dispatcher → Handler

Scripting Languages: Slow Object Access

- This software code structure is called **Inline Cache (IC)**

- We find that IC still has major overheads:
  - **At least 14 instructions per dispatcher invocation** to choose a handler
  - **22%** of total instructions executed are in the dispatcher
  - **46%** of branch mispredictions are in the dispatcher

Contributions

- Characterization of performance bottlenecks in IC operation in a state-of-the-art JavaScript engine

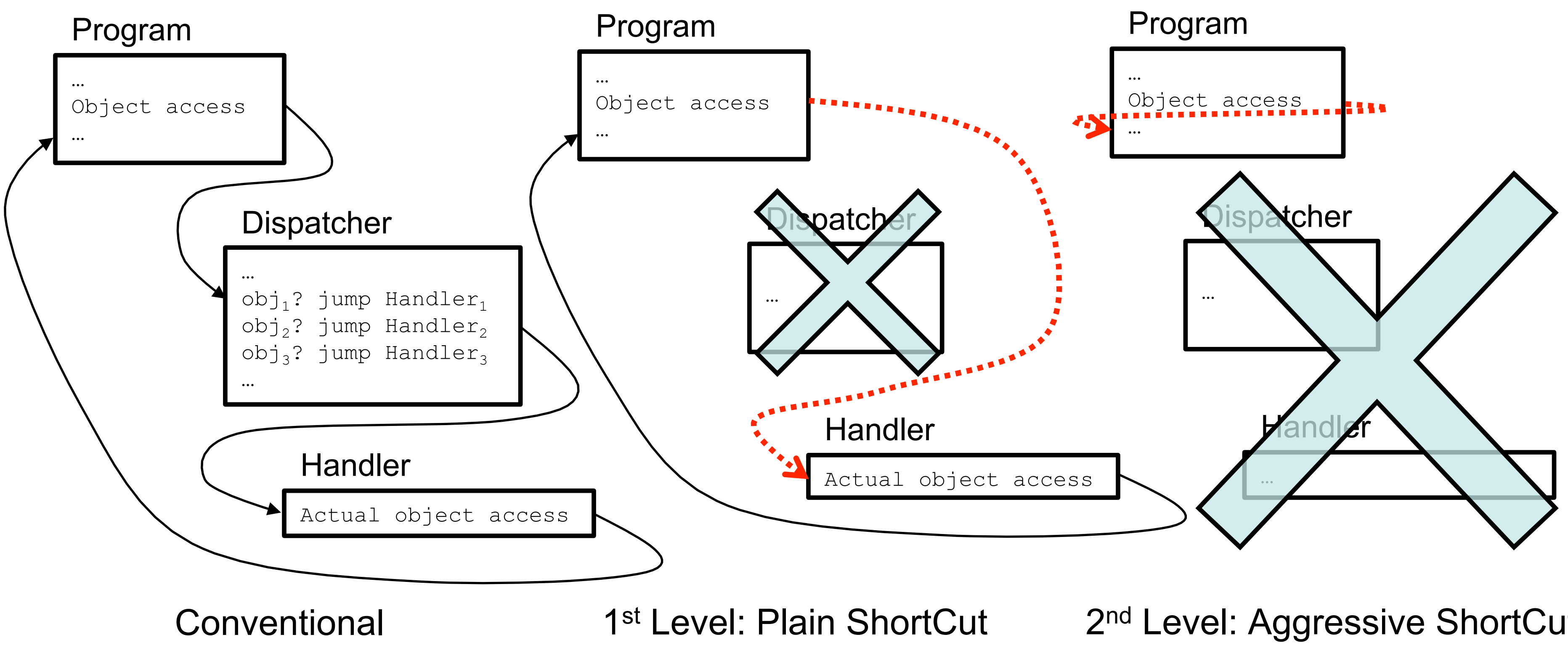
- Proposed two levels of HW/SW optimization to improve the efficiency of object access in scripting languages

- Implemented our proposal in multi-tier Google V8 compiler and reduced the average execution time:
  - by 30% running under the base tier
  - by 11% with the advanced tier enabled

Outline

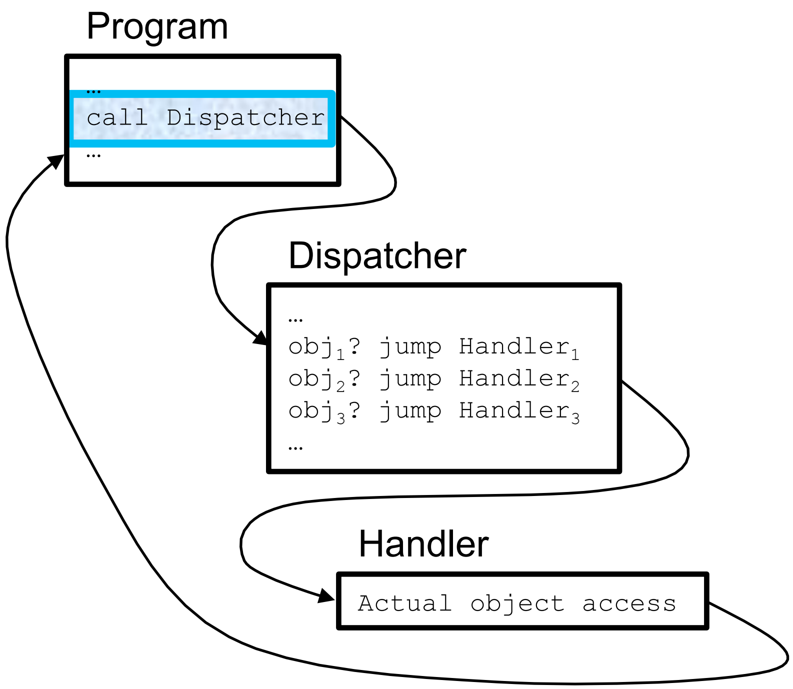
- Motivation and background
- Contribution
- Our solution: **ShortCut**
  - Key idea
  - Design
  - Compiler integration
- Evaluation
- Summary

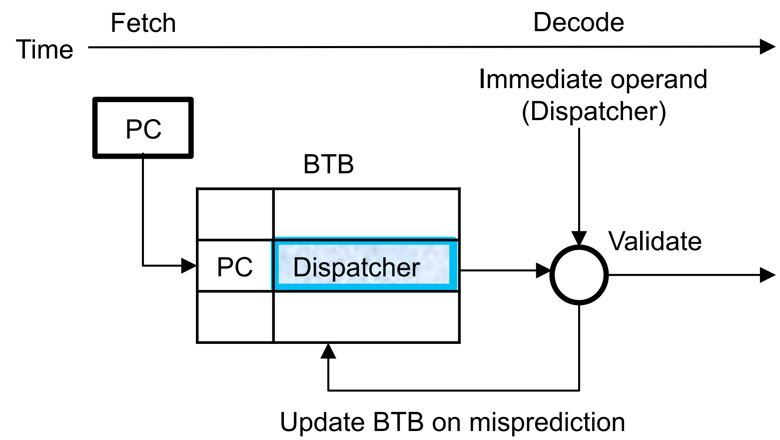
Key Idea



- **Plain ShortCut** transforms the call to the dispatcher into a call to the correct handler
- **Aggressive ShortCut** transforms the call to the dispatcher into an actual object access in place

Conventional Design

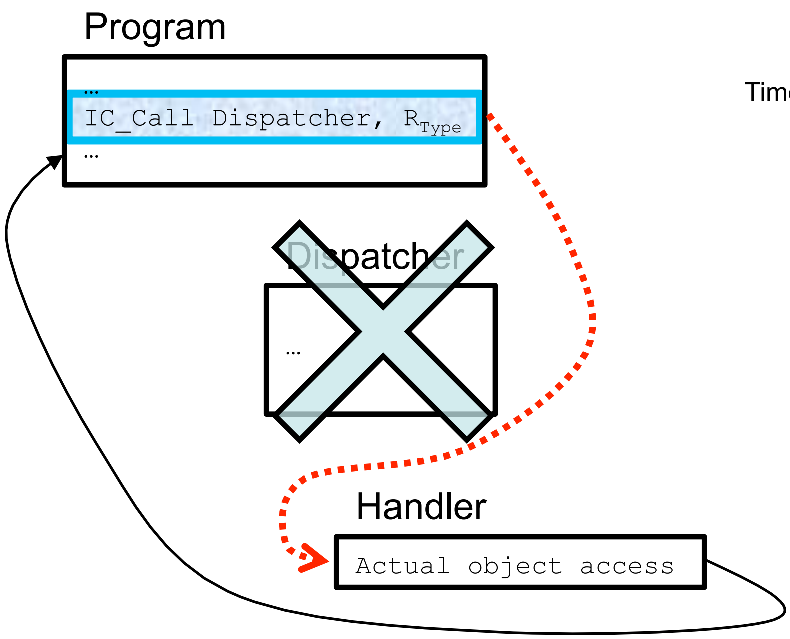


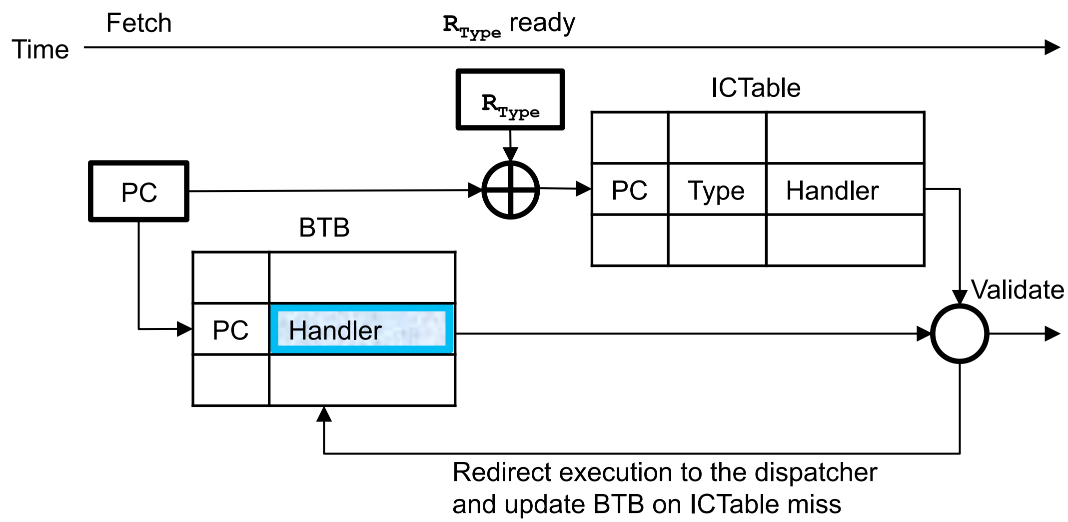


Execution of **`Call Dispatcher`**

- A program calls the dispatcher at an object access site
  - A BTB entry holds the dispatcher address
- The dispatcher chooses a handler

Plain ShortCut Design

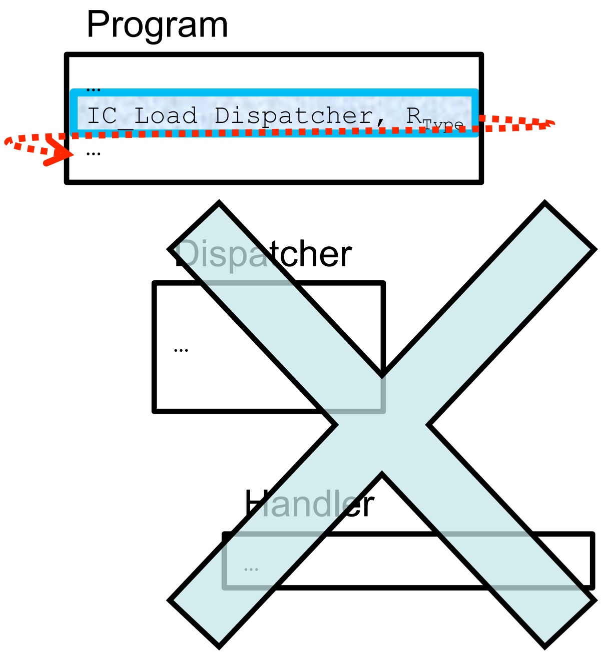


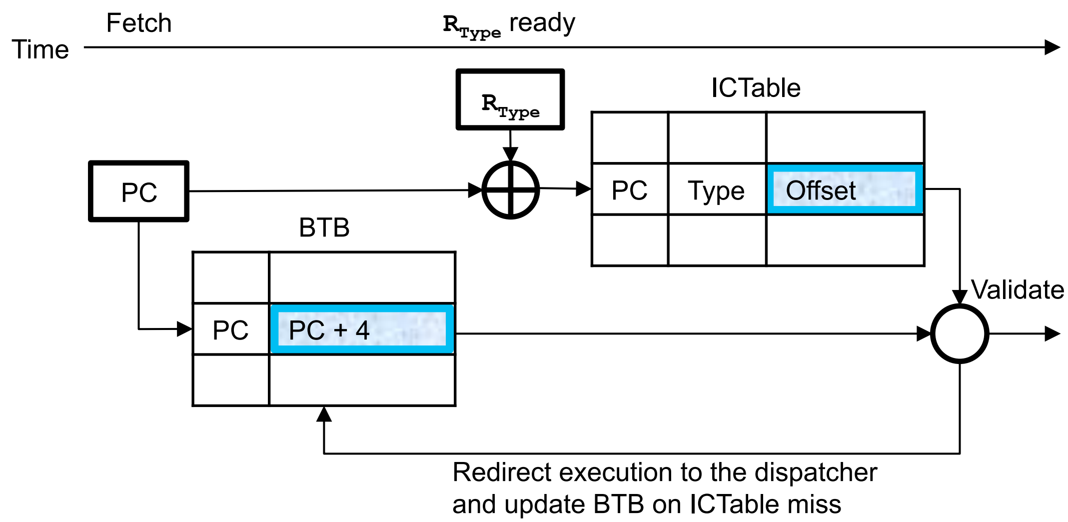


Execution of `IC_Call` R_{Type}, `Dispatcher`

- A program directly calls a handler at an object access site
  - `IC_Call` takes an additional operand: object type
  - A BTB entry holds a handler address
- A new hardware table, ***ICTable***, validates the BTB prediction
  - Falls back to the dispatcher upon ICTable miss

Aggressive ShortCut Design





Execution of **`IC_Load R_Type, Dispatcher`**

- A program performs an object access in place
  - **`IC_Load`** and **`IC_Store`** perform load and store, respectively
  - A BTB entry holds the next address
- Extend ICTable to store the offset of the property to access
- The property of the object is read or written using the offset value from ICTable.

Compiler Integration

- Replace the call to the dispatcher with the new instructions
  - **`IC_Call`** in Plain ShortCut
  - **`IC_Load`** or **`IC_Store`** in Aggressive ShortCut
- Load the incoming object type and pass as an operand to **`IC_Call/Load/Store`**
- More details are in the paper

Outline

- Motivation and background
- Contribution
- Our solution: **ShortCut**

- Evaluation
  - Experimental setup
  - Simulation Results

- Summary

Experimental Setup

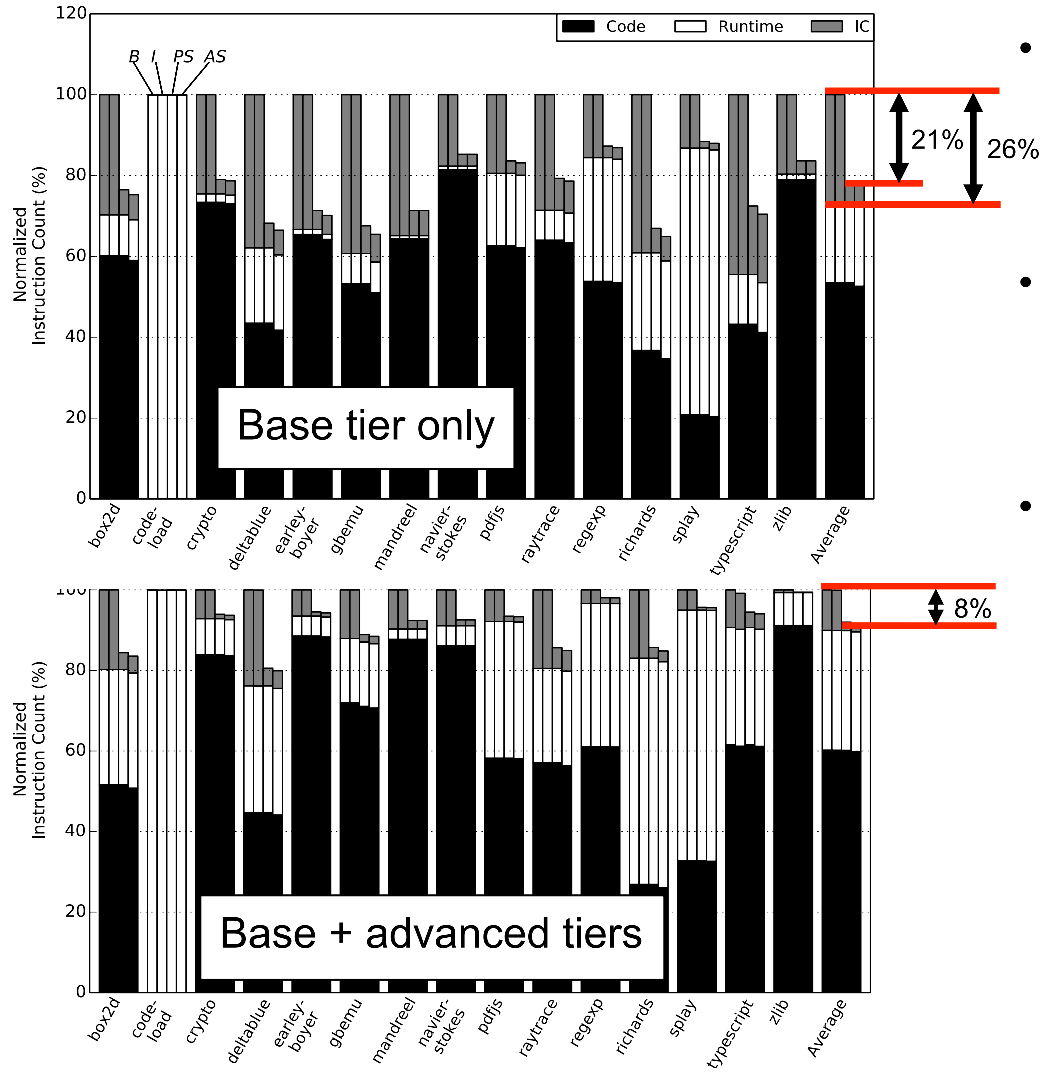
- Modified Google V8 JavaScript JIT compiler
  - Implemented in the base tier of the compiler
  - Application to the advanced tier is future work
- Extended SniperSim to model ShortCut hardware
- Benchmark Suites: Octane and SunSpider

Evaluated Configurations

Name	Description
B	Baseline: Unmodified V8
I	Ideal: Baseline with perfect BTB for the IC
PS	Plain ShortCut
AS	Aggressive ShortCut

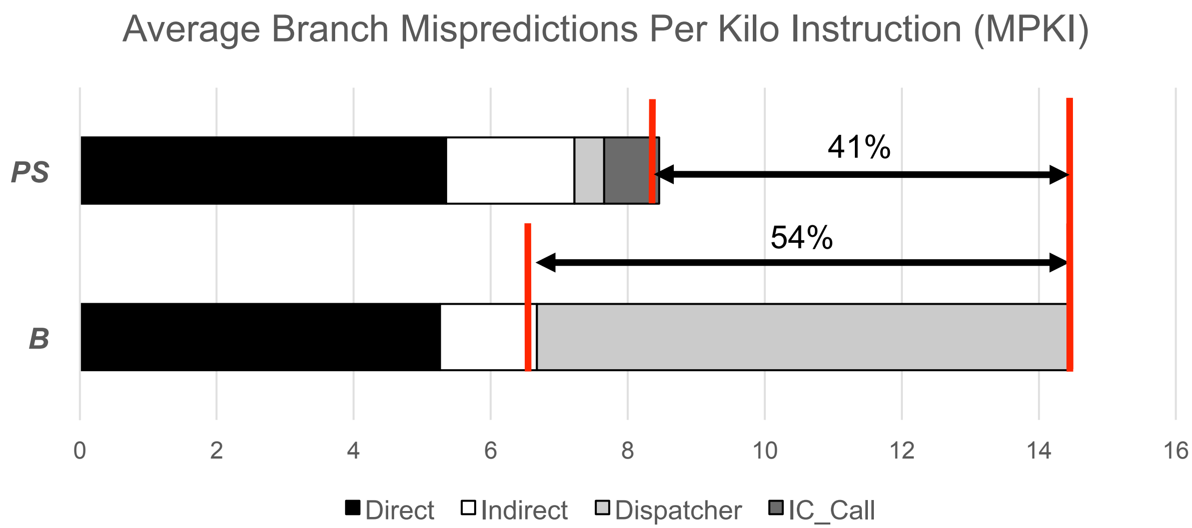
- Ideal (***I***) serves as an upper bound for BTB
- Aggressive ShortCut is currently limited to a simple form of **`IC_Load`**

Instruction Count Breakdown



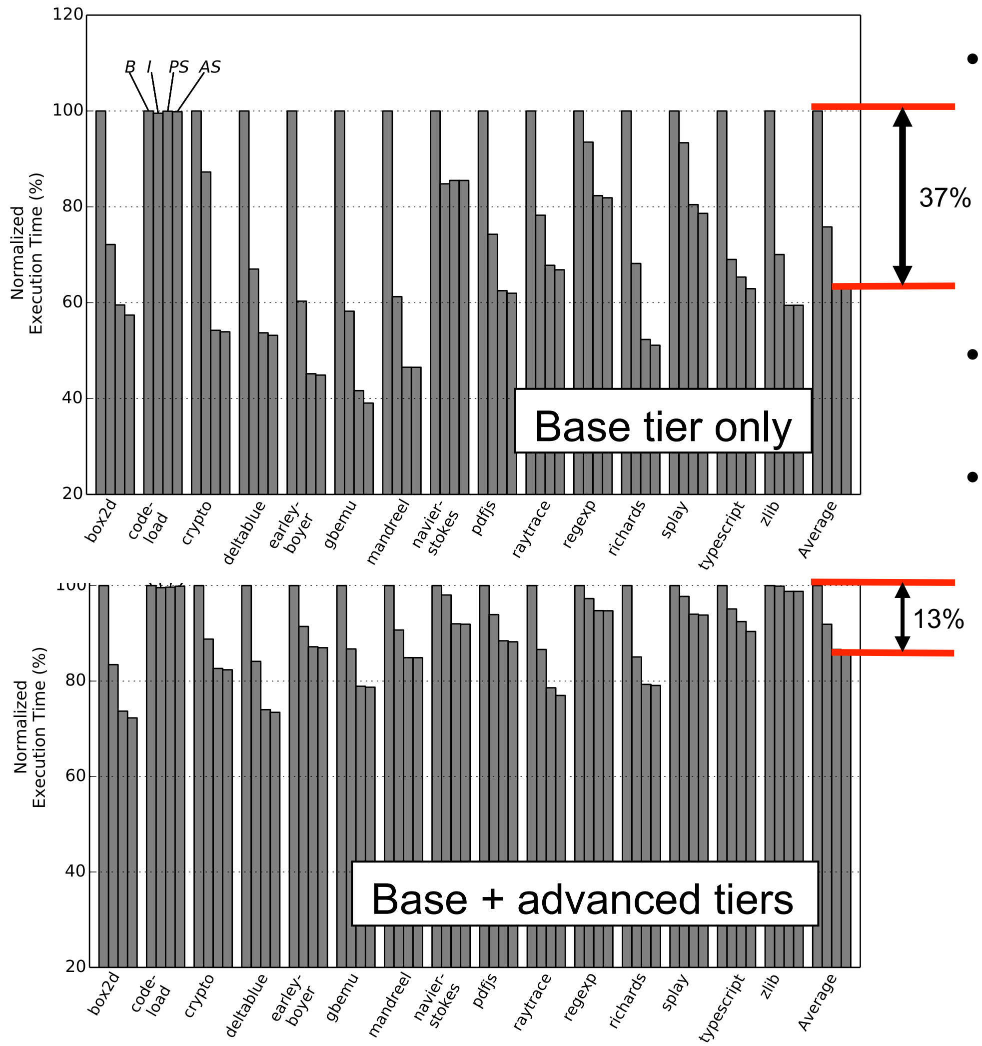
- Octane benchmark result
  - SunSpider benchmark result is in the paper
- On average 26% of total instructions executed in the dispatcher running under the base tier
- Plain ShortCut reduces the average instruction count:
  - by 21% running under the base tier
  - by 8% with the advanced tier enabled

Branch Prediction



- 54% of branch mispredictions are in the dispatcher
- ShortCut reduces branch MPKI by 41% (from 14.4 to 8.5)

Overall Performance Improvement



- Plain ShortCut reduces the average execution time
  - by 37% running under the base tier
  - by 13% with the advanced tier enabled
- ShortCut outperforms perfect BTB (***I***).
- Aggressive ShortCut delivers marginal improvement over Plain ShortCut

Conclusions

- Two main sources of slow object access in scripting languages
  - Instructions executed in the dispatcher
  - Hard-to-predict branches in the dispatcher
- Two levels of HW/SW optimization to accelerate object access
  - **Plain ShortCut**: Skips the dispatcher execution
  - **Aggressive ShortCut**: Skips even the handler execution
    - Emulates fast object access in traditional languages
- Implemented our solution in Google V8 and improved execution
  - by 30% running under the base tier
  - by 11% with the advanced tier enabled

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Multi-tier Compiler

- Even if the advanced tier is enabled, a significant fraction of the execution of programs uses code generated by the base tier:
  - It takes a while for the advanced tier to engage
  - If any assumption made by any optimization fails (e.g., unexpected object type is encountered), the base tier is re-invoked
  - There are some functions in a program that the advanced tier abstains from compiling, often based on heuristics; they include ***eval*** constructs and other complicated cases

- Execution time is short

Aggressive Shortcut

- IC_Store is not supported
- We note that of all the handler invocations
  - 75.7% are loads
    - 15.1% of them are covered by Aggressive ShortCut
  - 24.3% are stores
    - 17.2% of them can be covered by Aggressive ShortCut

Future Work

- Full implementation of Aggressive ShortCut
  - IC_Store
- Application to the advanced tier
  - using Aggressive ShortCut
- Application to interpreters

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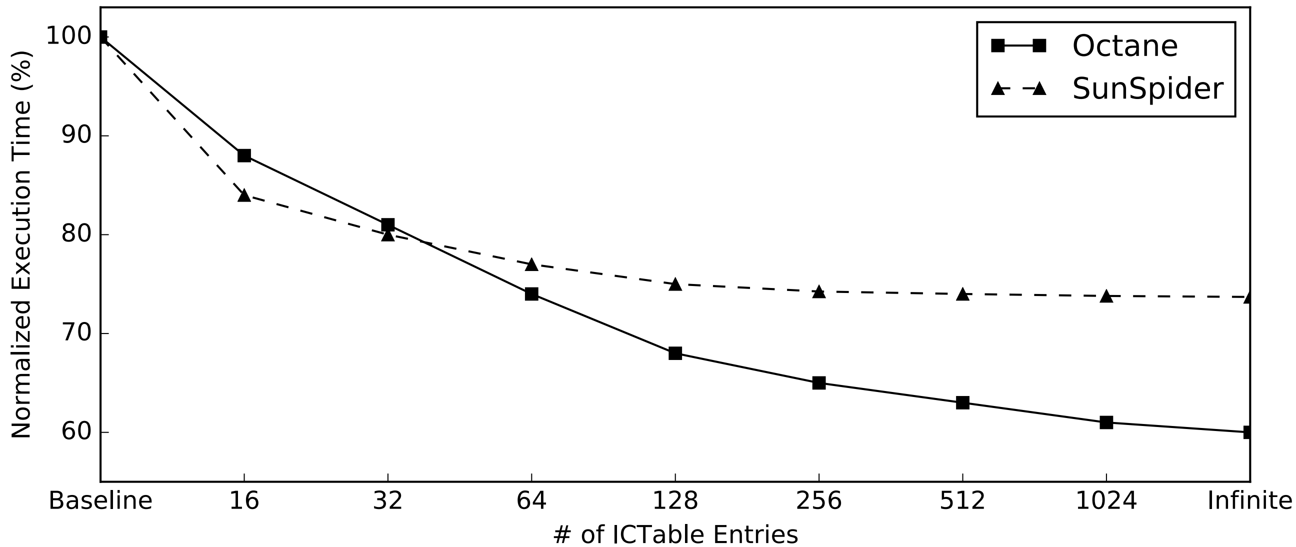
- Conventional: $\mathtt{\textbf{Call Addr}}_{\mathtt{Dispatcher}}$
- Plain ShortCut: $\mathtt{\textbf{IC\_Call Addr}}_{\mathtt{Dispatcher}}$ $\mathtt{\textbf{R}}_{\mathtt{Type}}$
  - If it hits in ICTable, call the handler
  - Otherwise, call the dispatcher
- Aggressive ShortCut: $\mathtt{\textbf{IC\_Load/Store Addr}}_{\mathtt{Dispatcher}}$ $\mathtt{\textbf{R}}_{\mathtt{type}}$
  - If it hits in ICTable, perform a load/store
  - Otherwise, call the dispatcher
- Both: $\mathtt{\textbf{IC\_Update R}}_{\mathtt{PC}}$ $\mathtt{\textbf{R}}_{\mathtt{Type}}$
  - Installs an entry in ICTable and updates BTB
- Both: **`IC_Flush`**
  - Flushes ICTable

Experimental Setup: Processor Architecture

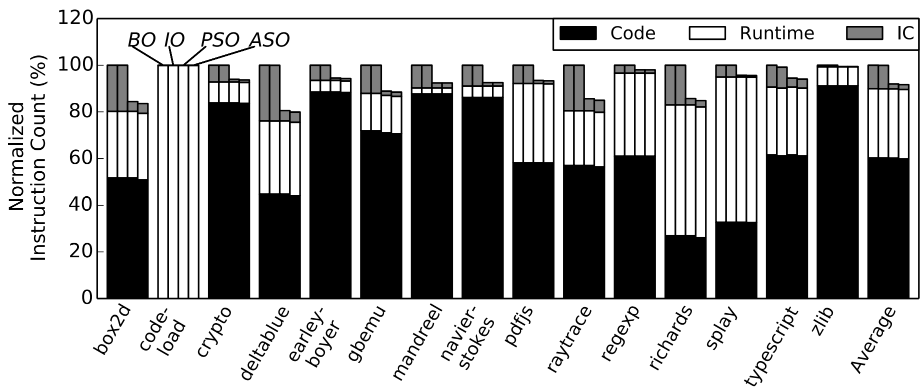
Core	4-wide out-of-order, 128-entry ROB, 2.66GHz
Branch Predictor	Hybrid predictor BTB: 4K entries, 4-way, RR replacement, 96b/entry Branch misprediction penalty: 15 cycles
ICTable	512 entries, 4-way, RR replacement, 145b/entry
Caches	L1-I: 32KB, 4-way, 4-cycle latency L1-D: 32KB, 4-way, 4-cycle latency L2: 256KB, 4-way, 12-cycle latency L3: 8MB, 16-way, 30-cycle latency Block size: 64B, LRU replacement
Memory	120-cycle minimum latency 16 DRAM banks

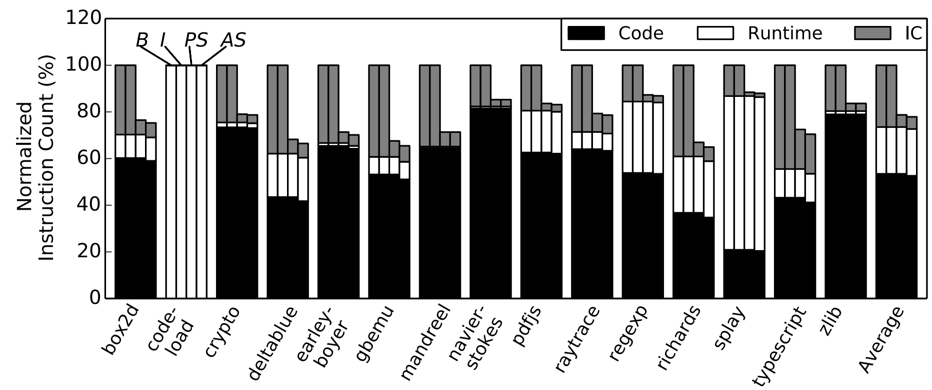
Sensitivity Study

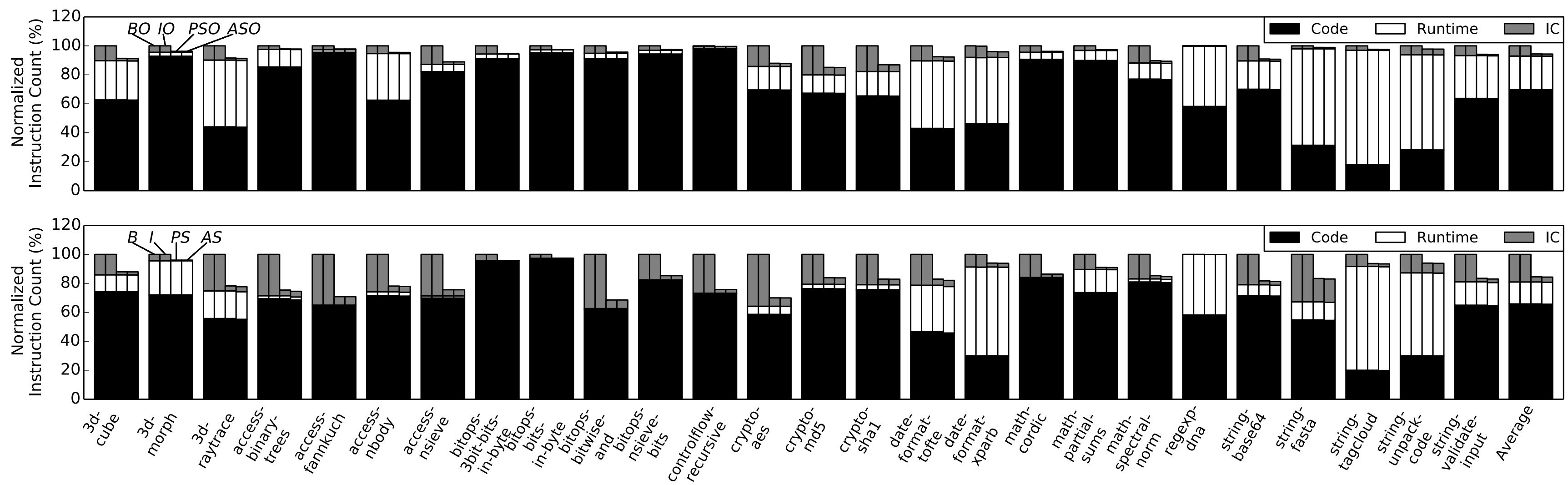


- ***PS*** outperformed ***B*** even with only 16 ICTable entries
- 512-entry ICTable is about 9 KB

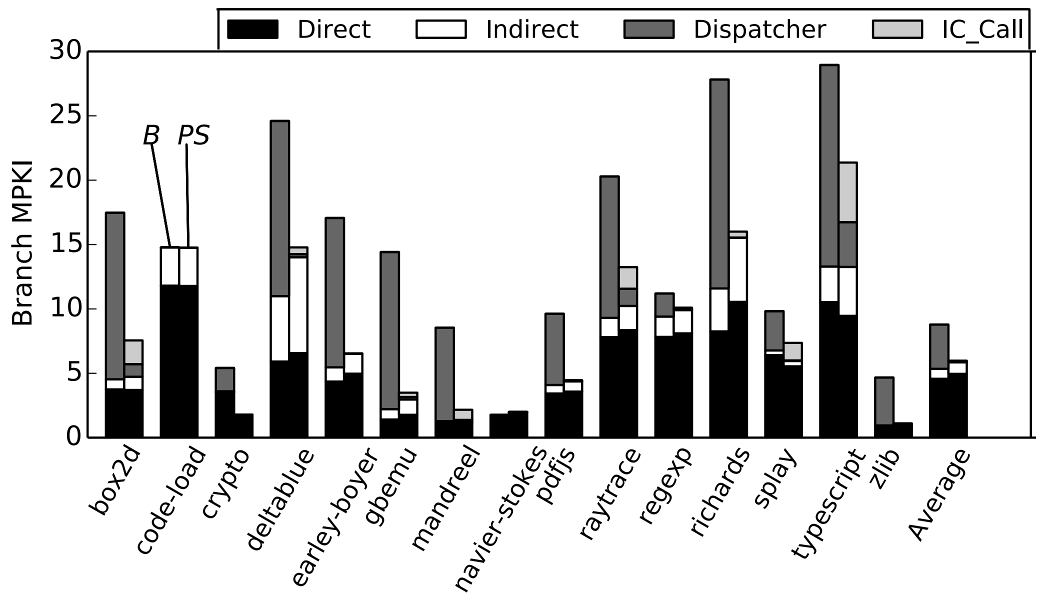
Instruction Count Breakdown







Branch MPKI Analysis



- ShortCut reduces branch MPKI from 10.8 to 6.9 running under the baseline compiler
- ShortCut avoids the hard-to-predict branch in the dispatcher

Overall Performance Improvement