PlayStation

# Profile Guided Function Layout in LLVM and LLD

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LLVM Developers' Meeting, October 2018

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# Function Layout

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```
void APInt::tcExtract(WordType *dst, unsigned dstCount, const WordType *src,
                      unsigned srcBits, unsigned srcLSB) {
  unsigned n = dstParts * APINT_BITS_PER_WORD - shift;
  if (n < srcBits) {
  } else if (n > srcBits) {
    if (srcBits % APINT_BITS_PER_WORD)
  }
  while (dstParts < dstCount)
    dst[dstParts++] = 0;
}
```

```
void APInt::tcShiftRight(WordType *Dst, unsigned Words, unsigned Count) {
  if (!Count)
    return;
  if (BitShift == 0) {
  } else {
    for (unsigned i = 0; i != WordsToMove; ++i) {
      if (i + 1 != WordsToMove)
    }
  }
}
```

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# Why Function Layout?

- Instruction cache
- Instruction Translation Lookaside Buffer (ITLB)

# Design and Implementation

# Profiling

- Standard llvm PGO workflow

# Extract

- Need to inform the linker about the profile in a way it can understand
- New LLVM pass CGProfile (Call Graph Profile)
  - Only works with the new Pass Manager
- Extract the weighted call-graph into module metadata
- Runs late in the pipeline

# Example

```
declare void @b()
define void @a() !prof !1 {
  call void @b()
  ret void
}

@foo = common global i32 ()* null, align 8
declare i32 @func1()
…
define void @freq(i1 %cond) !prof !1 {
  %tmp = load i32 ()*, i32 ()** @foo, align 8
  call i32 %tmp(), !prof !3
  br i1 %cond, label %A, label %B, !prof !2
A:
  call void @a();
  ret void
B:
  call void @b();
  ret void
}
!1 = !{!"function_entry_count", i64 32}
!2 = !{!"branch_weights", i32 5, i32 10}
!3 = !{!"VP", i32 0, i64 1600,
       i64 7651369219802541373, i64 1030, ...}
```

```
!llvm.module.flags = !{!0}

!0 = !{i32 5, !"CG Profile", !1}
!1 = !{!2, !3, !4, !5, !6, !7, !8}
!2 = !{void ()* @a, void ()* @b, i64 32}
!3 = !{void (i1)* @freq, i32 ()* @func4, i64 1030}
!4 = !{void (i1)* @freq, i32 ()* @func2, i64 410}
!5 = !{void (i1)* @freq, i32 ()* @func3, i64 150}
!6 = !{void (i1)* @freq, i32 ()* @func1, i64 10}
!7 = !{void (i1)* @freq, void ()* @a, i64 11}
!8 = !{void (i1)* @freq, void ()* @b, i64 21}
```

# Extract

- How to inform the linker about the profile in a way it understands?
  - MC writes the metadata into the object file
  - New ELF section type SHT_LLVM_CALL_GRAPH_PROFILE
  - List of weighted edges between symbols
  - Normal symbol resolution and merging resolve to the section containing the code

# Example – ELF Representation

## Module Metadata

```
!llvm.module.flags = !{!0}

!0 = !{i32 5, !"CG Profile", !1}
!1 = !{!2, !3, !4, !5, !6, !7, !8}
!2 = !{void ()* @a, void ()* @b, i64 32}
!3 = !{void (i1)* @freq, i32 ()* @func4, i64 1030}
!4 = !{void (i1)* @freq, i32 ()* @func2, i64 410}
!5 = !{void (i1)* @freq, i32 ()* @func3, i64 150}
!6 = !{void (i1)* @freq, i32 ()* @func1, i64 10}
!7 = !{void (i1)* @freq, void ()* @a, i64 11}
!8 = !{void (i1)* @freq, void ()* @b, i64 21}
```

## ELF Assembly

```
.cg_profile a, b, 32
.cg_profile freq, func4, 1030
.cg_profile freq, func2, 410
.cg_profile freq, func3, 150
.cg_profile freq, func1, 10
.cg_profile freq, a, 11
.cg_profile freq, b, 21
```

# Layout Algorithm



## Optimizing Function Placement for Large-Scale Data-Center Applications

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**Abstract**

Modern data-center applications often comprise a large amount of code, with substantial working sets, making them good candidates for code-layout optimizations. Although

While the large size and performance criticality of such applications make them good candidates for profile-guided code-layout optimizations, these characteristics also impose scalability challenges to optimize these applications.

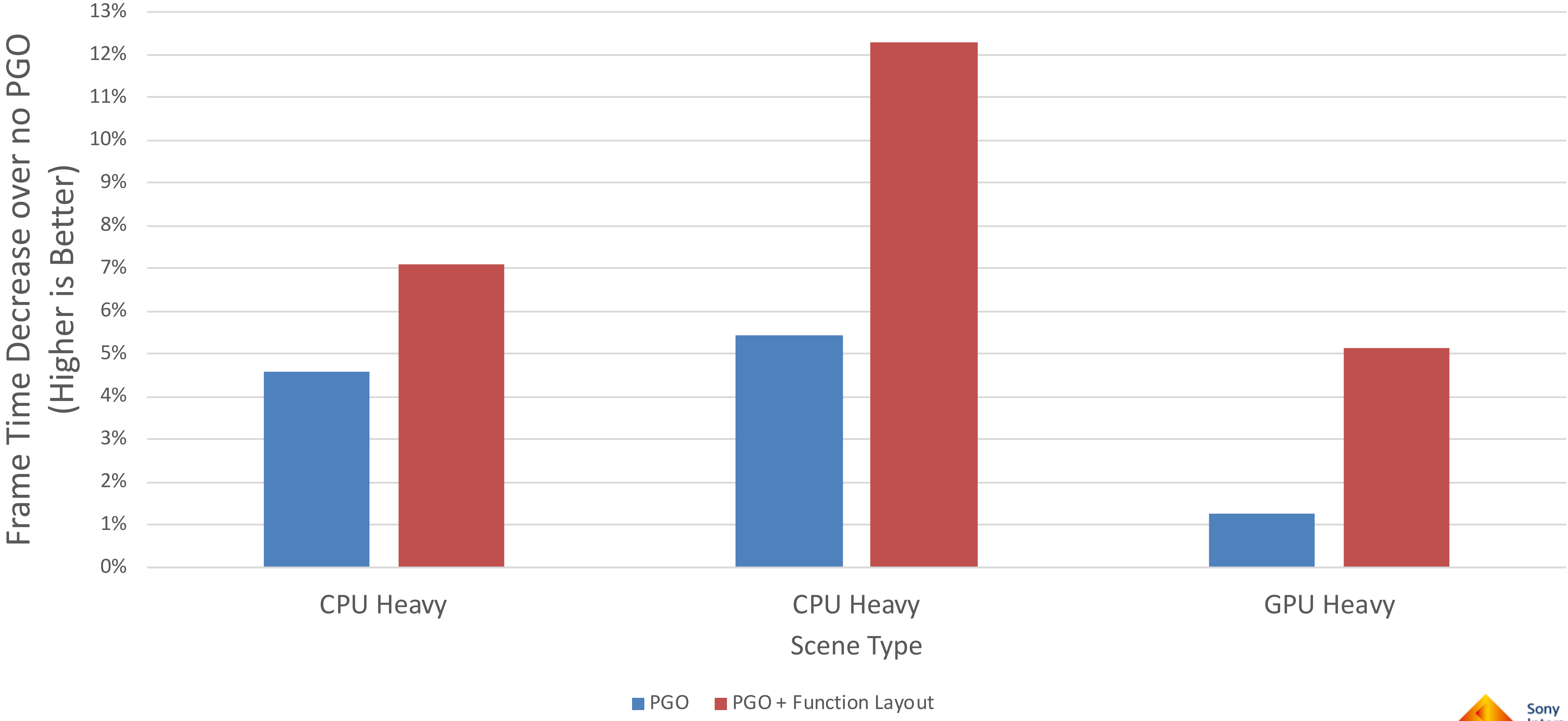
# Call Chain Clustering (aka $C^3$)

- Find a good ordering for functions
  - Minimize the average distance between hot calls and their targets
  - While obeying constraints:
    - Don’t create huge clusters
    - Don’t reduce the density (hotness / size) of the cluster too much
- Single pass over clusters starting at the highest density
  - Merge “good” hot callees
- Sort clusters by density
- Fast:
  - 40ms for a graph of 35,000 functions and 115,000 edges

# How To Use

- Profile
  - $ clang –c –fprofile-generate -fexperimental-new-pass-manager …
  - $ ld …
  - $ prog
  - $ llvm-profdata merge default.profraw –o default.profdata
- Optimize and Extract
  - $ clang –c –fprofile-use=default.profdata -fexperimental-new-pass-manager …
- Layout
  - $ lld …

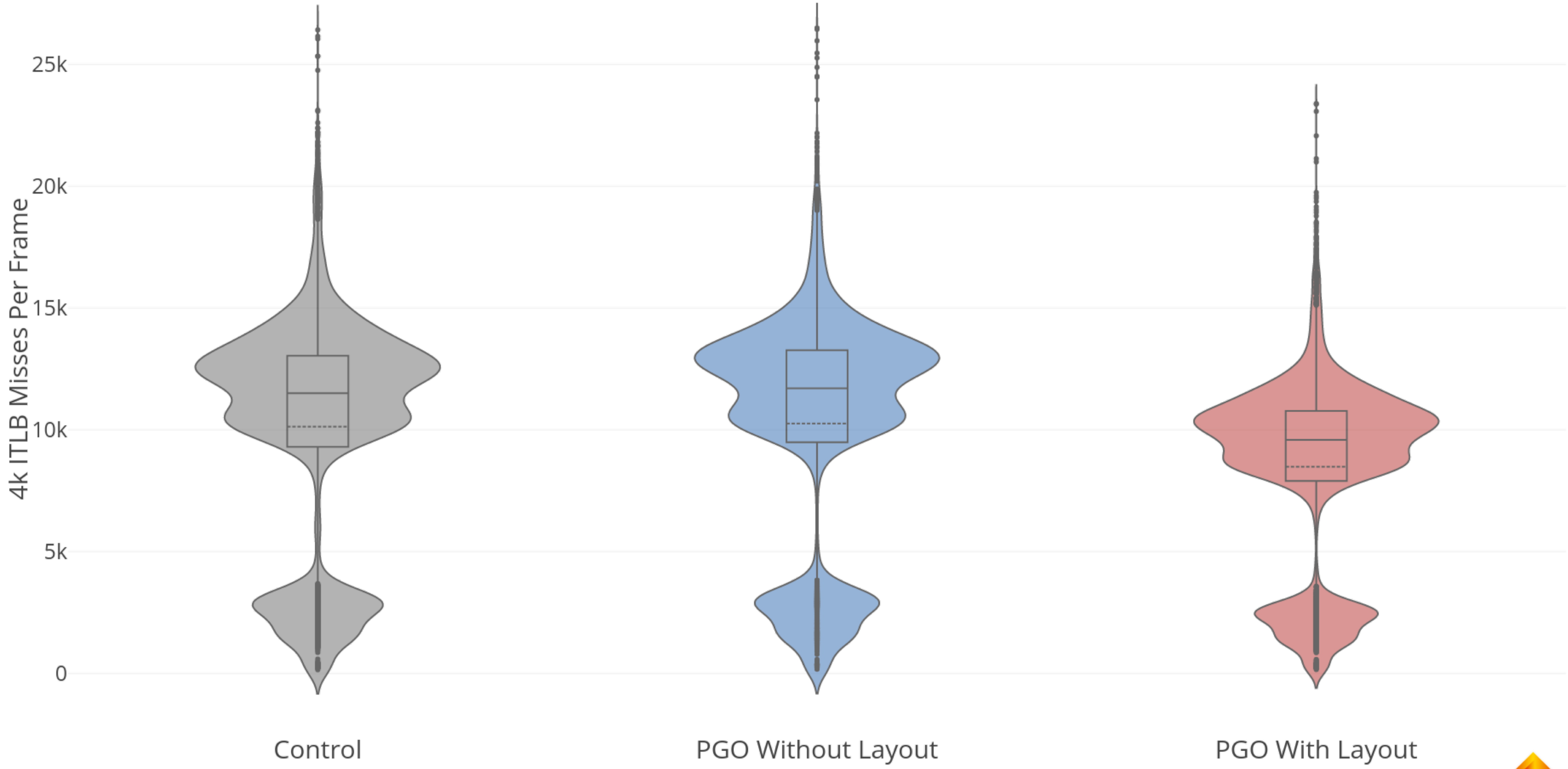
# Results – PlayStation®4 Game A



# Why the improvement?

- Why
  - Reduction in ITLB miss rate

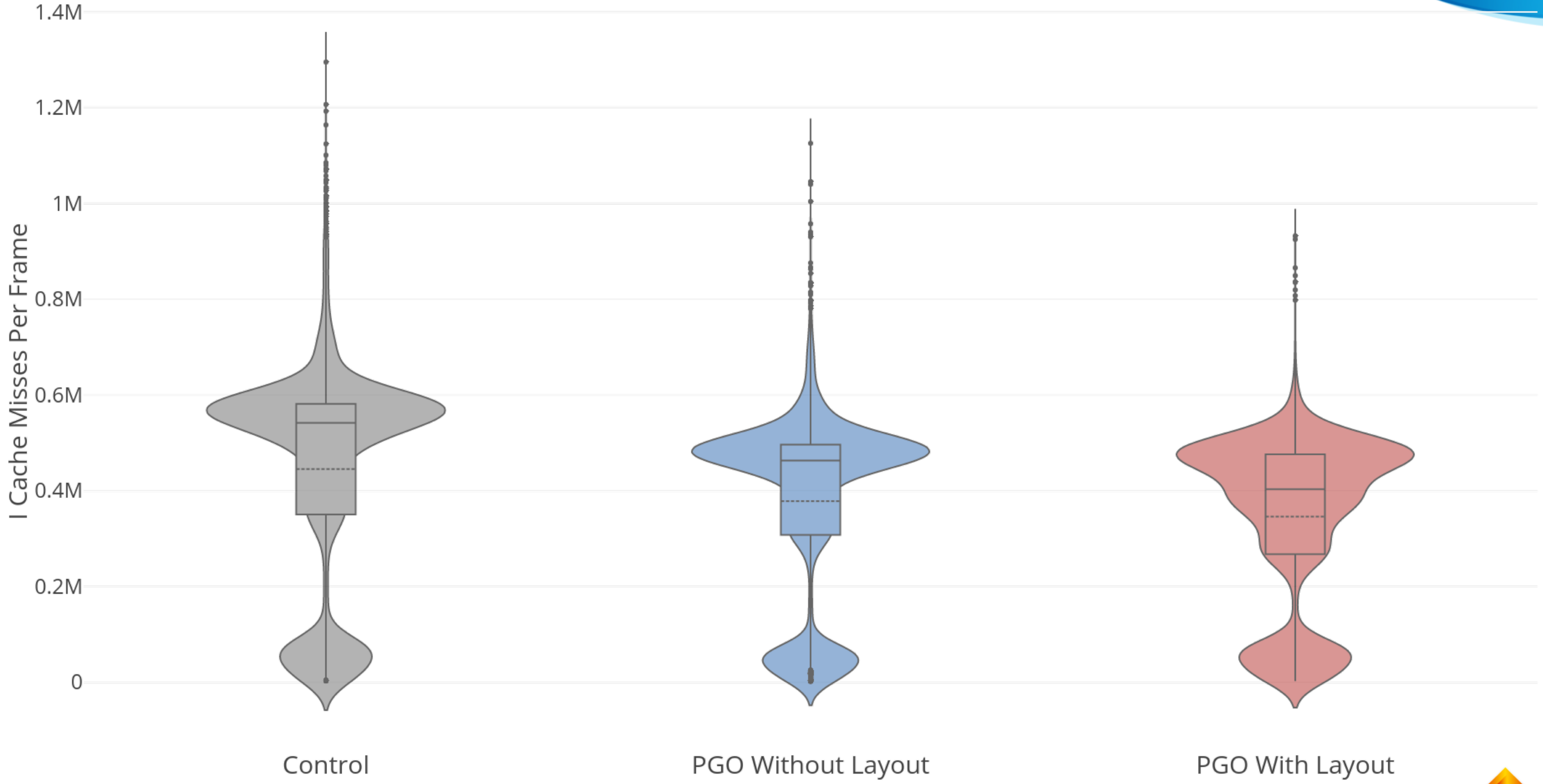
# Results – PlayStation®4 Game ITLB



# Why the improvement?

- Why
  - Reduction in ITLB miss rate
  - Reduction in instruction cache miss rate

# Results – PlayStation®4 Game I$



# Future Work

- Improved clustering heuristic
  - Max cluster size
  - Cluster quality degradation
- Function Slicing
  - Separate out cold blocks
  - Separate out hot blocks with different callees

# Questions?

PlayStation

# End Slide



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