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Code size reduction using Similar Function Merging

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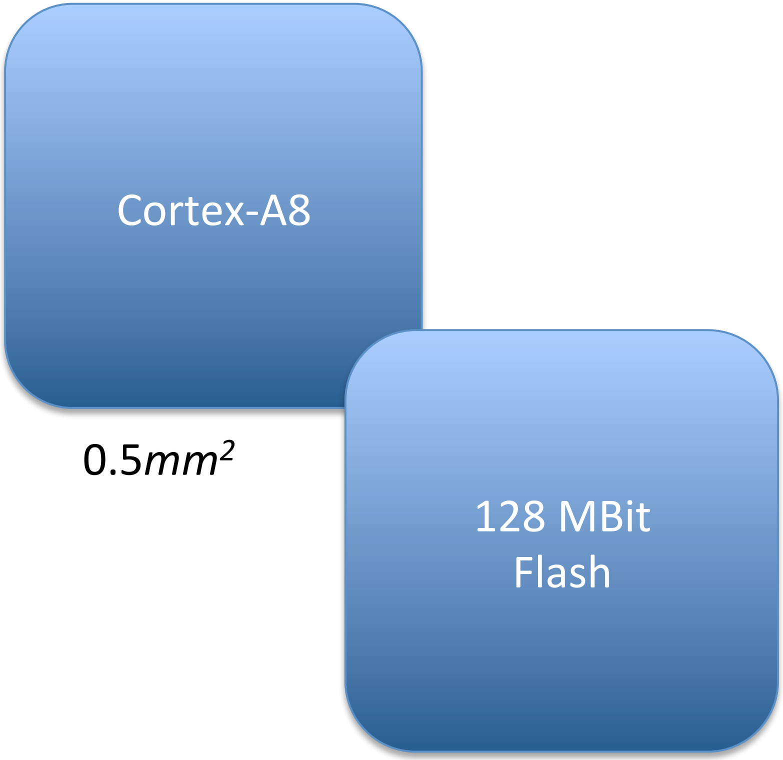
Outline

1. Why optimize for code size?
2. The Problem of Duplicate Code
3. Existing LLVM MergeFunctions Pass
4. Similar Function Merging
5. Results

Why optimize for code size?

- Traditionally three goals of compiler optimization:
  - **Performance**
  - **Power**
  - **Code size**
- External factors determine relative importance; there are complex interactions.
- Code size is key in many embedded scenarios



0.5*mm*^{2}

0.523*mm*^{2}

1 MB ≈ 1/16th of Cortex-A8 die size

Code Size Reduction Approaches

Three main types:

- Hardware-based, e.g. ARM Thumb ISA.
- Software-based:
  - By re-tuning standard optimizations, e.g. inlining thresholds, loop unroll factor, etc.
  - By actively reducing code size of existing user code, e.g. elimination of redundancy.

We're looking at the last category.

The Problem of Duplicate Code

- Software contains duplicate code due to:
  1. ① Laziness, a.k.a. copy & paste
  2. ② Manual templating
  3. ③ C++ templates
  4. ④ Compiler optimizations
- It may be possible for the user to fix ① & ② but ③ and ④ are much harder to control
- All types of duplication occur across the board in SPEC benchmarks, embedded systems code, …

Example from 400.perlbench

```c
OP *Perl_scalarkids(pTHX_ OP *o) {
  OP *kid;
  if (o && o->op_flags & OPf_KIDS) {
    for (kid = cLISTOPo->op_first; kid; kid = kid->op_sibling)
      scalar(kid);
  }
  return o;
}
```

```c
OP *Perl_listkids(pTHX_ OP *o) {
  OP *kid;
  if (o && o->op_flags & OPf_KIDS) {
    for (kid = cLISTOPo->op_first; kid; kid = kid->op_sibling)
      list(kid);
  }
  return o;
}
```

Only a 1-instruction difference between the two functions in LLVM IR!

Example from 400.perlbench

- Merge the two functions:
  - Combine code from both in a new ‘merged function’
  - Insert if-statement where there are differences
  - Replace original functions with calls to merged function
- In our case, on x86:

Original Function 1 *64 bytes* + **Original Function 2** *64 bytes* = *128 bytes*

Merged Function *80 bytes* + **Thunk 1** *16 bytes* **Thunk 2** *16 bytes* = *112 bytes*

Total savings: **12.5%**

Existing MergeFunctions Pass

- Pass originally written by Nick Lewycky
- Disabled by default
- Merges ‘identical’ functions
- Introduces two key concepts we rely on:
  - Notion of structural similarity of functions to make analysis tractable
  - Pointer-pointer-integer equivalence: *pointers* and *integers of the same size* are treated as equivalent…. except where the difference matters.
- What if functions aren’t quite identical? We should still be able to merge them!

Structural Similarity

- Comparing all functions would be $O(n^2)$
  … and we could theoretically merge everything!

- Introduce a number of practical constraints:

Functions must have

- Equivalent control flow graph and signature
- Same number of instructions in corresponding basic blocks
  but: allow differences in what these instructions are
- A minimum amount of similarity

Similar Function Merging

The algorithm involves four main steps:

① Build hash table of functions

② Compare functions pairwise

③ Merge identical functions

④ Merge similar functions

Similar Function Merging

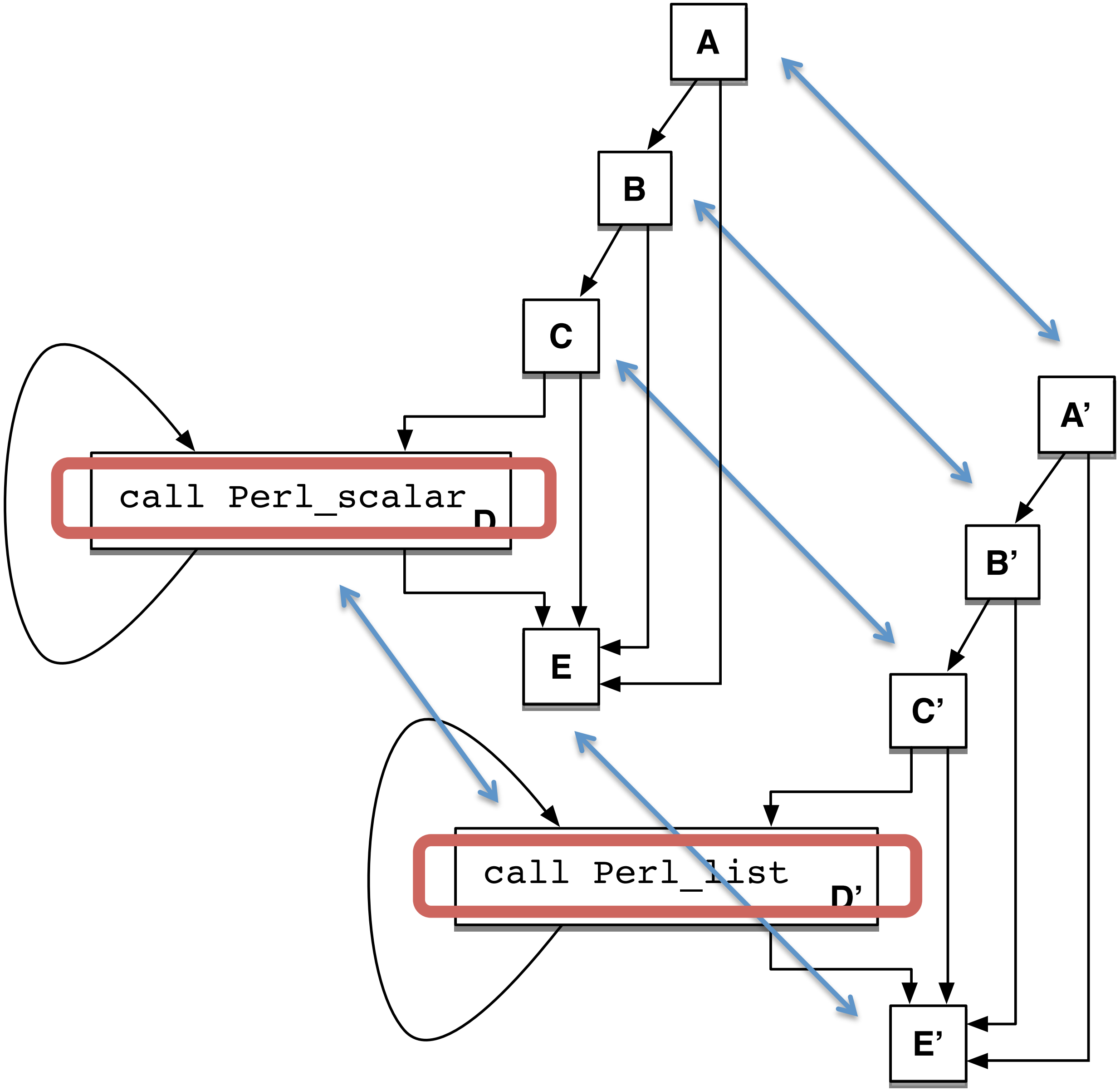
- **Step 1:** Insert functions into a hash table
  - Based on signature, number of basic blocks, …
  - This avoids comparing functions that have no chance of being merged anyway

- **Step 2:** Compare all functions in each bucket

  Still $O(n^2)$ worst case, but better in practice

  - Follow control flow and compare block-by-block, instruction-by-instruction
  - Mark differing instructions
  - Give up if control flow or basic block length differs

Example from 400.perlbench



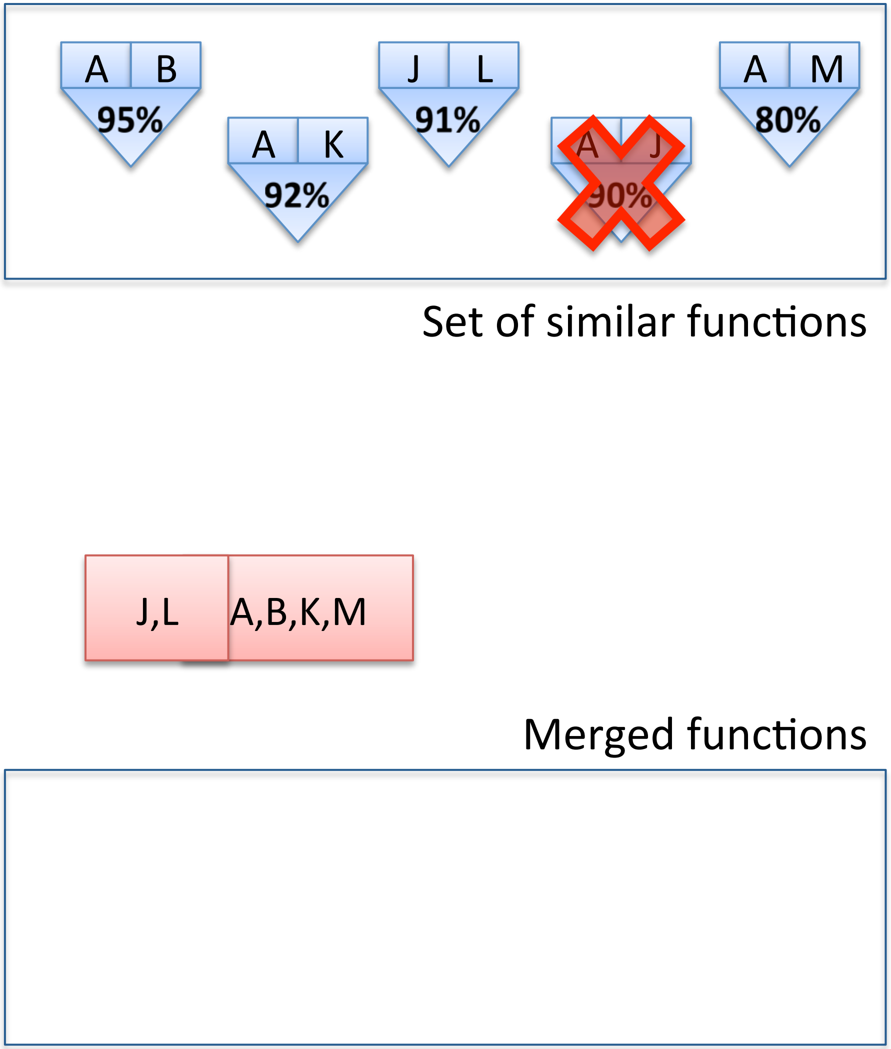
Similar Function Merging

- **Step 3:** Merge identical functions
  - Update call sites after merging
  - Other functions may become more similar as a result
  - Re-compare functions that have changed

Iterate this process until a fixed point is reached

Similar Function Merging

- **Step 4:** Merge similar functions
  - Order pairs of functions by similarity
  - Pick *most similar* pair `(A,B)`
  - Find all `(A,B’)` for which there is not a `(B’,C)` with greater similarity
  - Merge A with B and the B’s
  - Remove all pairs involving A, B, and the B’s
  - Repeat this until there are no more functions to merge



Similar Function Merging

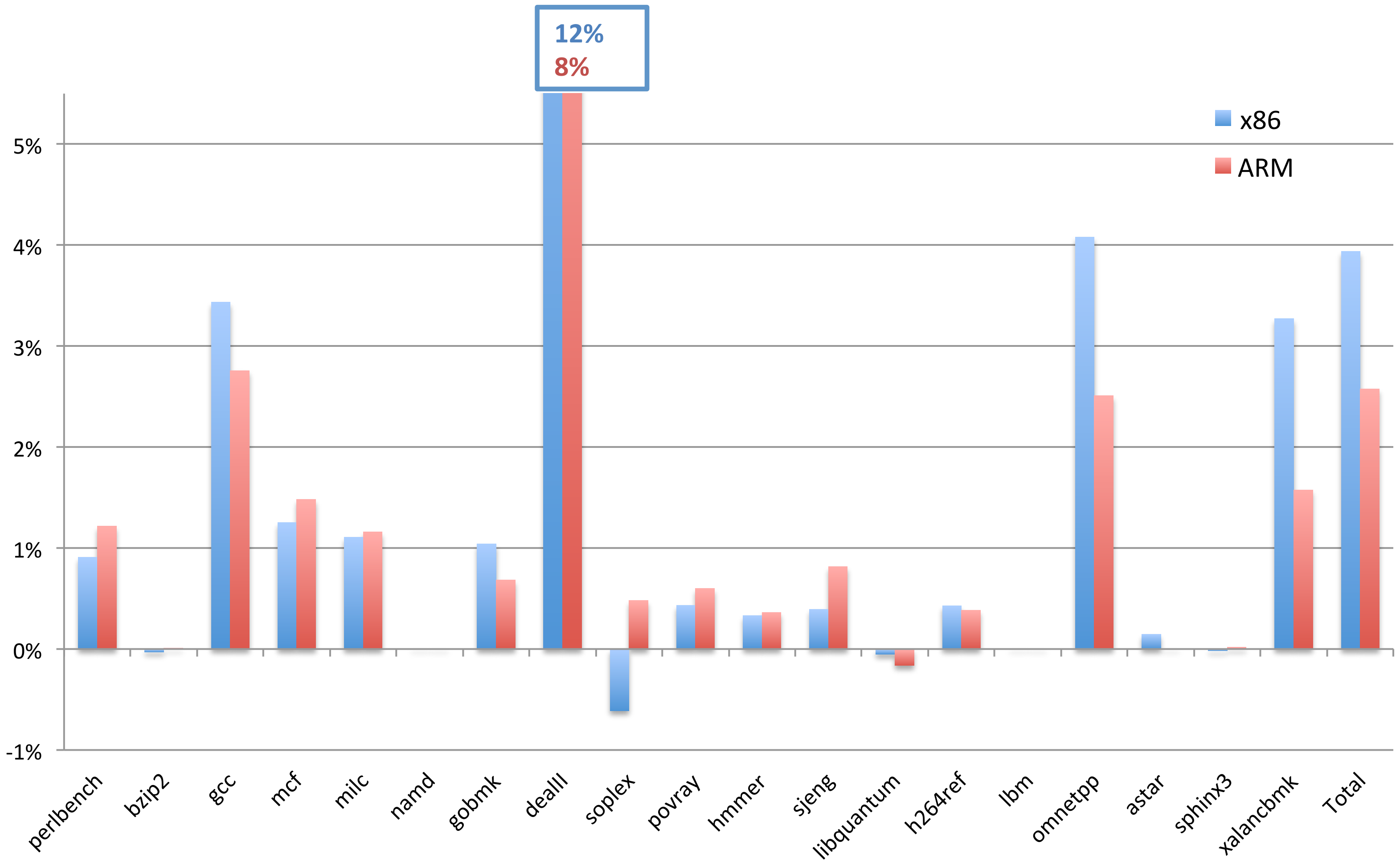
- Run as a late optimization
- Tricky bits I haven't mentioned:
  - Must maintain SSA form throughout
  - Have to compare, update, and insert PHINodes: you can't put a conditional around two differing PHINodes
  - Thresholds are ISA-specific, need tuning for each arch

- How well does it work?

Results

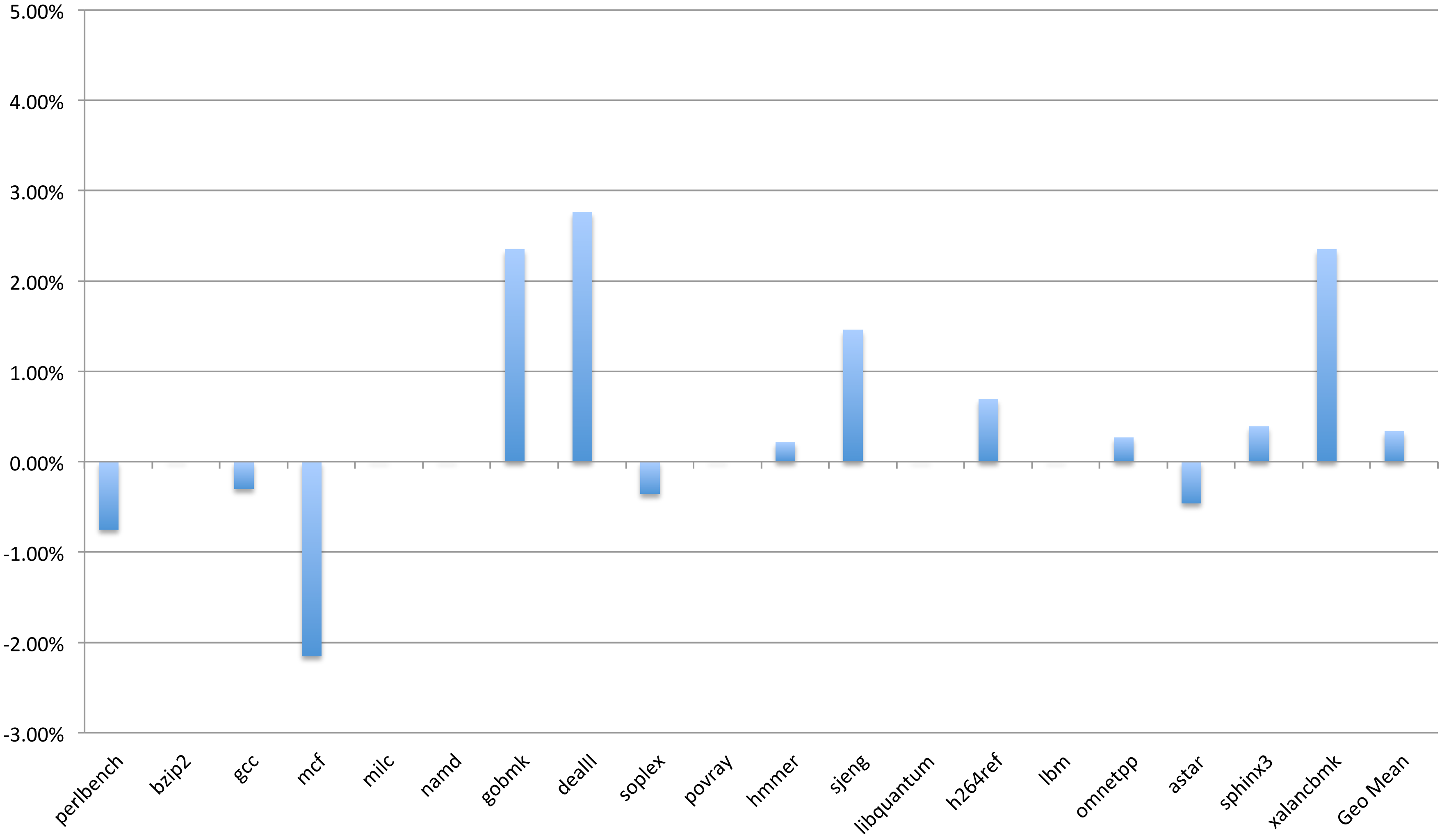
- We run the pass on
  - SPEC CPU2006 (Integer & FP benchmarks)
    - x86
    - Qualcomm Krait ™ (ARMv7-A Thumb)
  - A significant application at QuIC on Hexagon DSP ™
- At -Os optimization level
- Using LLVM/Clang 3.3

SPEC2006 – Code Size Reduction



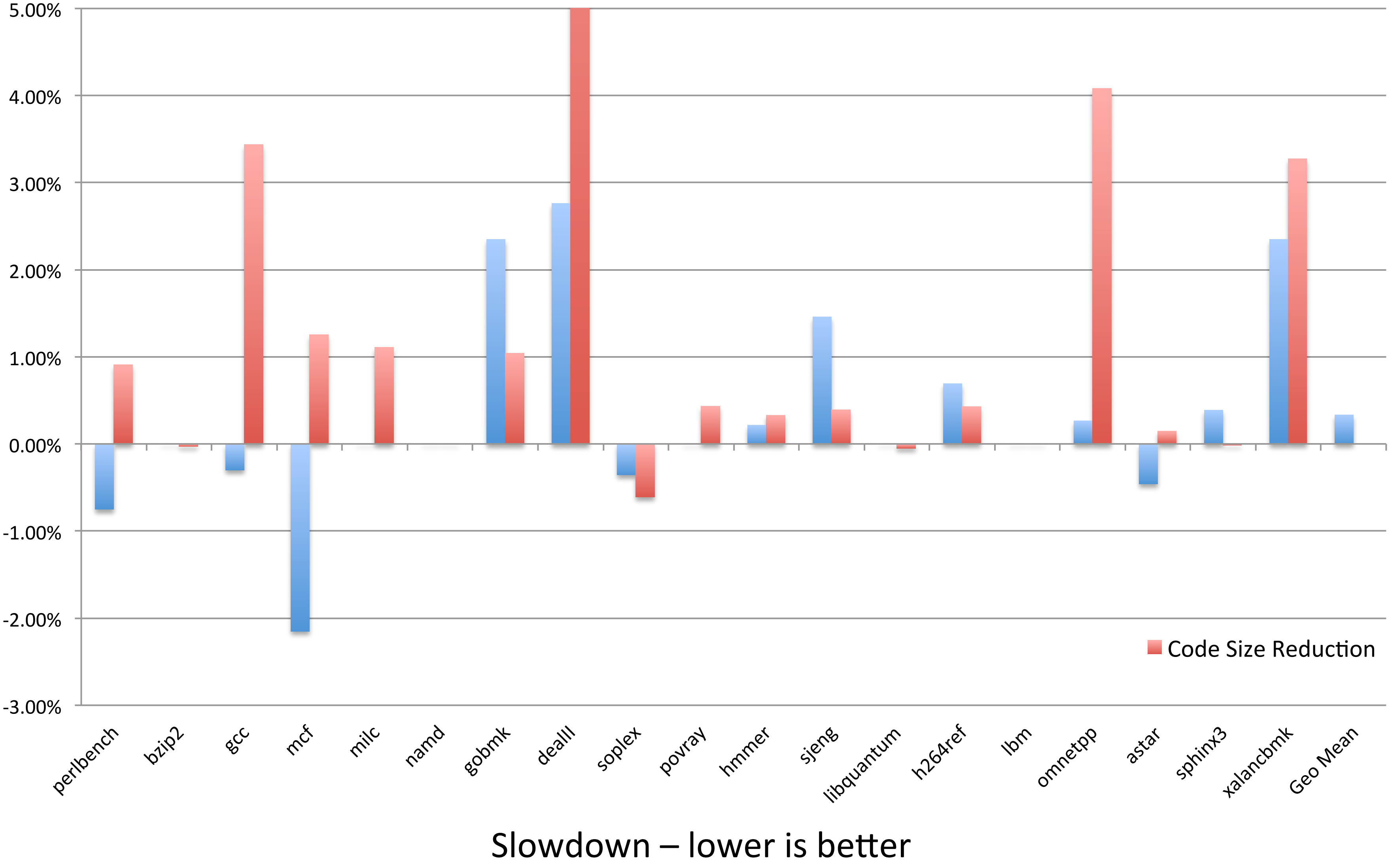
Higher is better

SPEC 2006 – x86 Performance



Slowdown – lower is better

SPEC 2006 – x86 Performance



Conclusions

- Function merging is a promising technique for code size reduction
- Can reduce total code size for SPEC benchmarks by over 4% on x86

- We need a stronger focus on code size optimizations – as LLVM adoption in the embedded world increases this is becoming more critical

Thank you

and see you in Edinburgh!