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

1 MB \approx 1/16^{th} \text{ 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 Laziness, a.k.a. copy & paste
  ② Manual templating
  ③ C++ templates
  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 = cLIST0Po->op_first; kid; kid = kid->op_sibling)
            scalar(kid);
    }
    return o;
}

OP *Perl_listkids(pTHX_ OP *o) {
    OP *kid;
    if (o && o->op_flags & OPf_KIDS) {
        for (kid = cLIST0Po->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:

\[
\text{Original Function 1} \quad 64 \text{ bytes} \quad + \quad \text{Original Function 2} \quad 64 \text{ bytes} \quad = \quad 128 \text{ bytes} \\
\text{Merged Function} \quad 80 \text{ bytes} \quad + \quad \text{Thunk 1} \quad 16 \text{ bytes} \quad + \quad \text{Thunk 2} \quad 16 \text{ bytes} \quad = \quad 112 \text{ bytes}
\]

Total savings: 12.5%
Existing Merge Functions 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

call Perl_list

call Perl_scalar
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

-1% 0% 1% 2% 3% 4% 5%

x86
ARM

per-bench  bzip2  gcc  mcf  milc  namd  gobmk  deall  soplex  povray  hmmr  sieng  libquantum  h264ref  ibm  omnetpp  astar  sphinx3  xalanbmk  Total
SPEC 2006 – x86 Performance

Slowdown – lower is better
SPEC 2006 – x86 Performance

Slowdown – lower is better

- Code Size Reduction

SPEC 2006 Performance Slowdown - x86
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!