Waddle

Maintaining Canonical Form After Edge Deletion

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July 17, 2018

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What Does Waddle Maintain? (1)

Dominator Tree

encodes which blocks occur on all paths to another block

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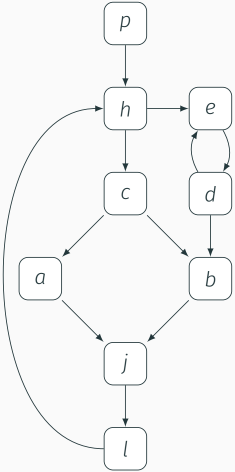

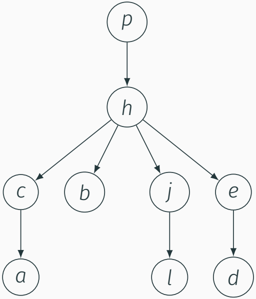

What Does Waddle Maintain? (2)

Loop Nesting Forest

encodes loop body sets · loop exit sets · loop nesting structure

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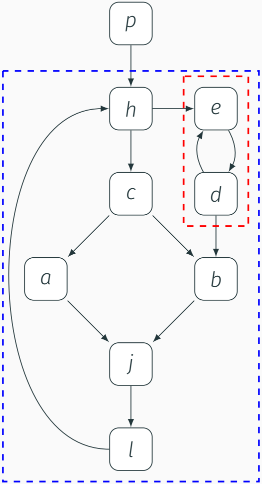

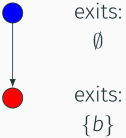

What Does Waddle Maintain? (3)

SSA + LCSSA Form

all names defined once · uses of name occur within defining loop

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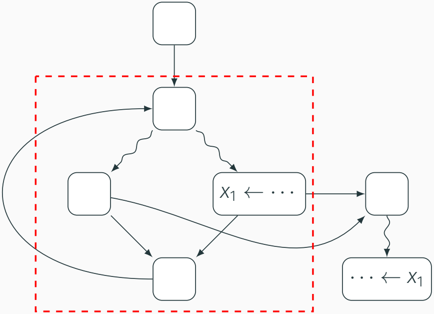

What Does Waddle Maintain? (3)

SSA + LCSSA Form

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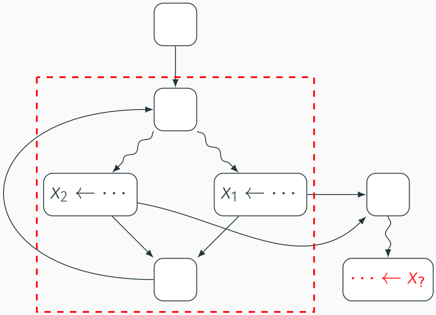


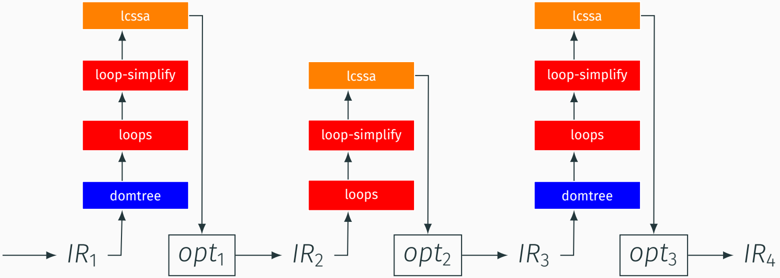
What Does Waddle Maintain? (4)

'Canonical' Properties

LLVM's Loop Simplify Form

Optimization Pipeline Strategies

Repair On-Demand (LLVM's Approach)



LLVM 6.0.0 -O2 Passes

ipsccp
globalopt
domtree
mem2reg
deadargelim
domtree
aa
loops
lazy-block-freq
instcombine
simplifycfg
basiccg
globals-aa
prune-eh
inline
functionattrs
domtree
sroa
aa
memoryssa
early-cse-memssa
speculative-
execution
domtree
aa
lazy-value-info
jump-threading
lazy-value-info
correlated-
propagation
simplifycfg
domtree
aa
loops
lazy-block-freq
instcombine
libcalls-shrinkwrap
loops
branch-prob
block-freq
lazy-block-freq
pgo-memop-opt
domtree
aa
loops
lazy-block-freq
tailcallelim
simplifycfg
reassociate
domtree
loops
loop-simplify
lcssa
aa
scalar-evolution
loop-rotate
licm
loop-unswitch
simplifycfg
domtree
aa
loops
lazy-block-freq
instcombine
loop-simplify
lcssa
scalar-evolution
indvars
loop-idiom
loop-deletion
loop-unroll
mldst-motion
aa
memdep
lazy-block-freq
gvn
aa
memdep
memcpyopt
sccp
domtree
demanded-bits
bdce
aa
loops
lazy-block-freq
instcombine
lazy-value-info
jump-threading
lazy-value-info
correlated-
propagation
domtree
aa
memdep
dse
loops
loop-simplify
lcssa
aa
scalar-evolution
licm
postdomtree
adce
simplifycfg
domtree
aa
loops
lazy-block-freq
instcombine
barrier
elim-avail-extern
basiccg
rpo-functionattrs
globalopt
globaldce
basiccg
globals-aa
float2int
domtree
loops
loop-simplify
lcssa
aa
scalar-evolution
loop-rotate
loop-accesses
lazy-block-freq
loop-distribute
branch-prob
block-freq
scalar-evolution
aa
loop-accesses
demanded-bits
lazy-block-freq
loop-vectorize
loop-simplify
scalar-evolution
aa
loop-accesses
loop-load-elim
aa
lazy-block-freq
instcombine
simplifycfg
domtree
loops
scalar-evolution
aa
demanded-bits
lazy-block-freq
slp-vectorizer
instcombine
loop-simplify
lcssa
scalar-evolution
loop-unroll
lazy-block-freq
instcombine
loop-simplify
lcssa
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licm
globaldce
constmerge
domtree
loops
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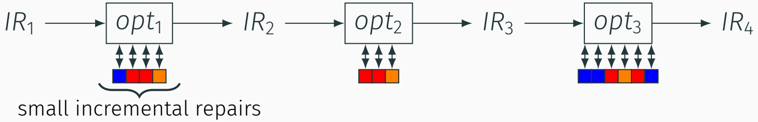
loop-simplify
lcssa
aa
scalar-evolution

Always Canonical (Waddle's Approach)



LLVM Source – LoopUnroll.cpp#L845

```
// If we have a pass and a DominatorTree we should re-simplify impacted loops
// to ensure subsequent analyses can rely on this form.  We want to simplify
// at least one layer outside of the loop that was unrolled so that any
// changes to the parent loop exposed by the unrolling are considered.
if (DT) {
  if (OuterL) {
    // OuterL includes all loops for which we can break loop-simplify, so
    // it's sufficient to simplify only it (it'll recursively simplify inner
    // loops too).

    // TODO: That potentially might be compile-time expensive.  We should try
    // to fix the loop-simplified form incrementally.
    simplifyLoop(OuterL, DT, LI, SE, AC, PreserveLCSSA);
  } else {
    // Simplify loops for which we might've broken loop-simplify form.
    for (Loop *SubLoop : LoopsToSimplify)
      simplifyLoop(SubLoop, DT, LI, SE, AC, PreserveLCSSA);
  }
}
```

Canonical Form Loop Properties

Canonical Properties

Dedicated Preheader

enables easy + efficient instruction hoisting

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Dedicated Exit Blocks

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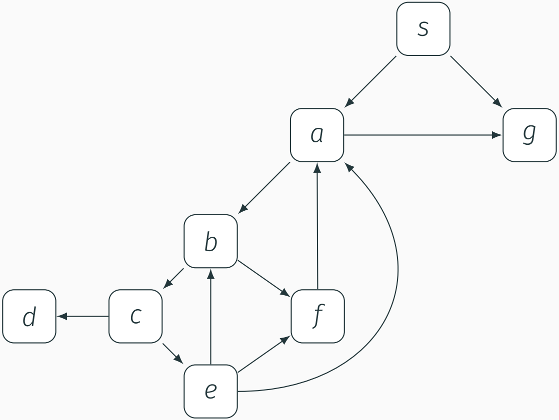
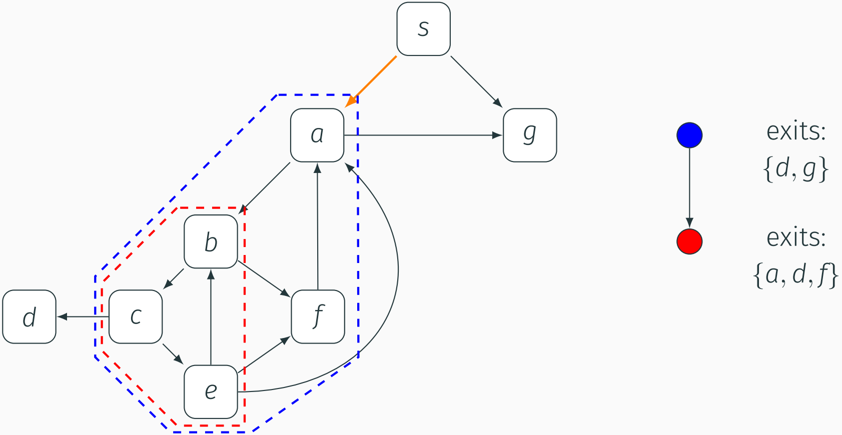
Unique Backedge + Latch

make destruction of loop unambiguous

Canonicalization

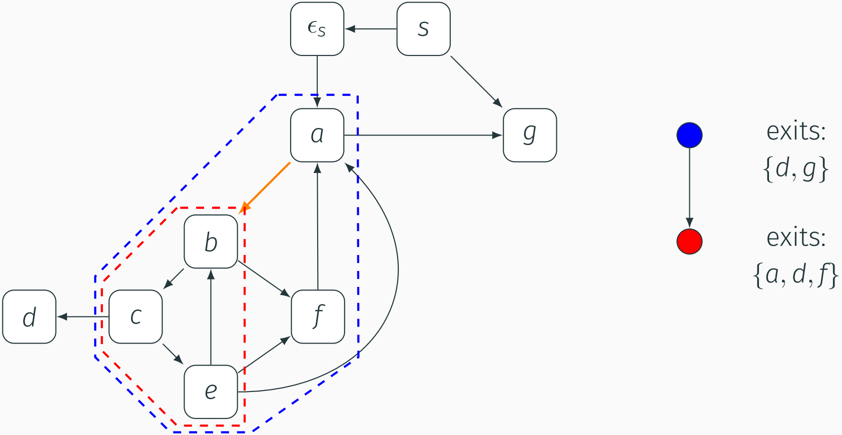


Canonicalization – Dedicate Preheaders



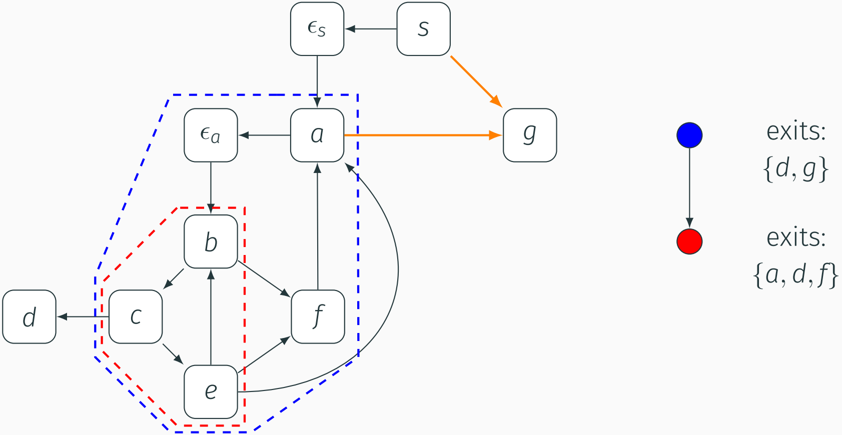
Construct loop nesting forest

Canonicalization – Dedicate Preheaders



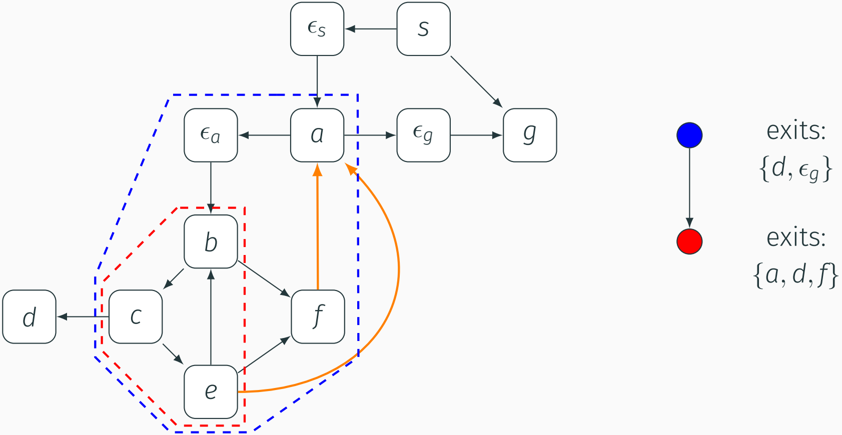
Dedicate preheader of outer (blue) loop

Canonicalization – Dedicate Exits



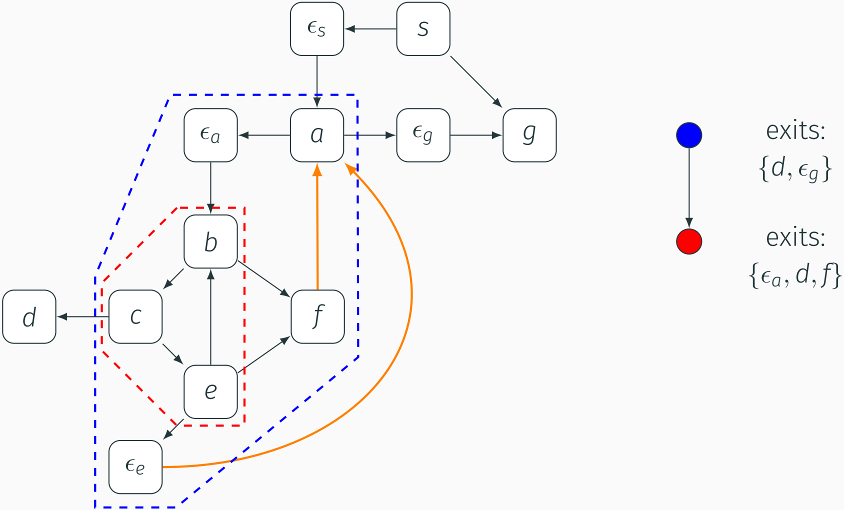
Dedicate preheader of inner (red) loop

Canonicalization – Dedicate Exits



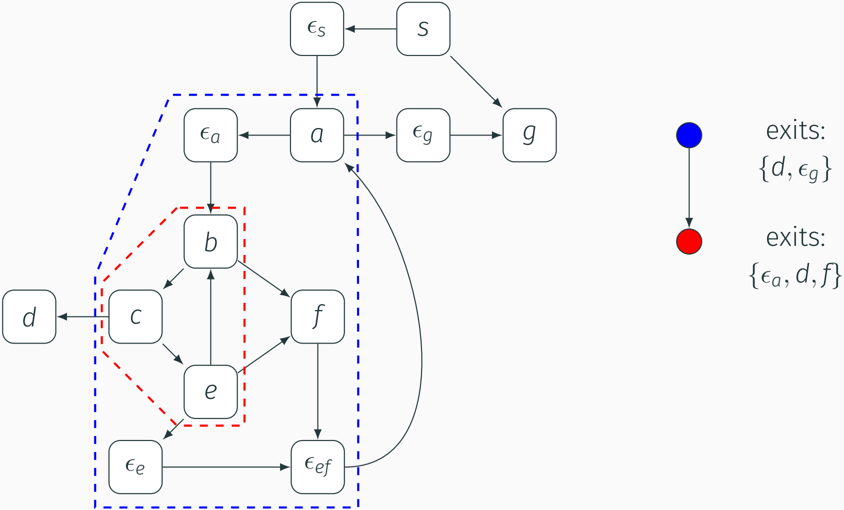
Dedicate exit (block g) of outer (blue) loop

Canonicalization – Ensure Unique Latches



Dedicate exit (block a) of inner (red) loop

Canonicalization – Ensure Unique Latches



Make latch for outer (blue) loop unique

Edge Deletion

Algorithm Outline

(1) Remove edge from graph

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(2) Remove references to unreachable blocks and edges

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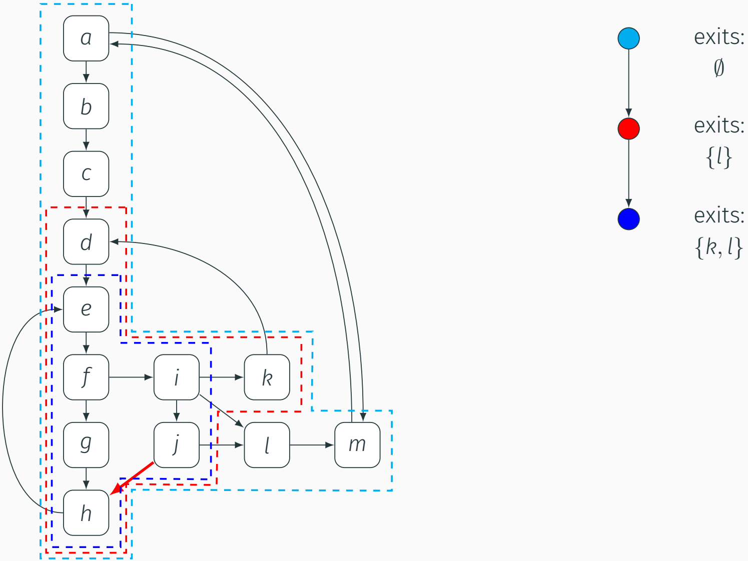
(2) Remove references to unreachable blocks and edges
(3) Eject extraneous blocks from loop where edge was removed

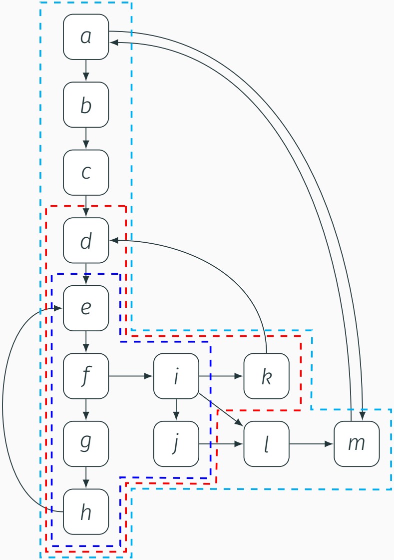
Example #1

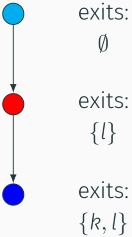
Deleting Edge (j, h) – Incremental Repair



Initial graph

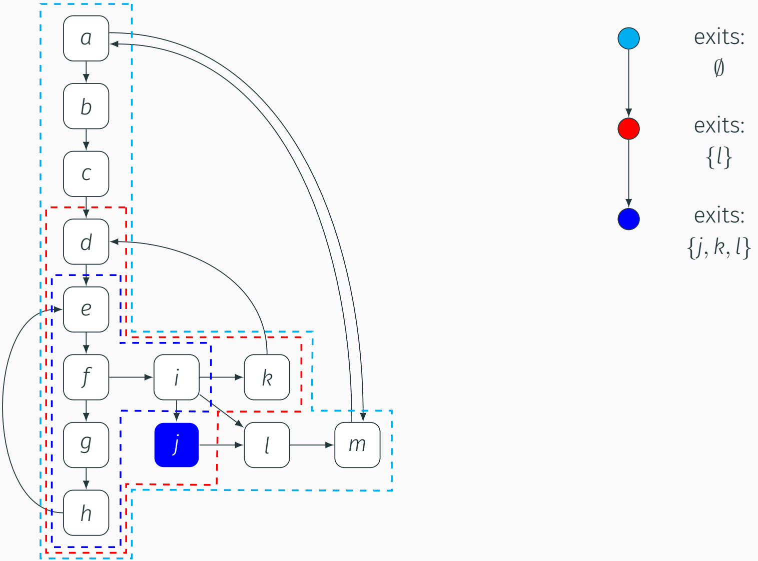
Deleting Edge (j, h) – Incremental Repair





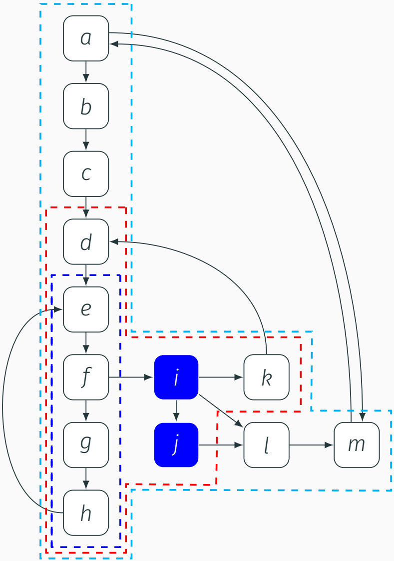
Edge deleted

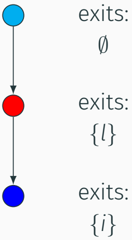
Deleting Edge (j, h) – Incremental Repair



Eject block j from inner (blue) loop

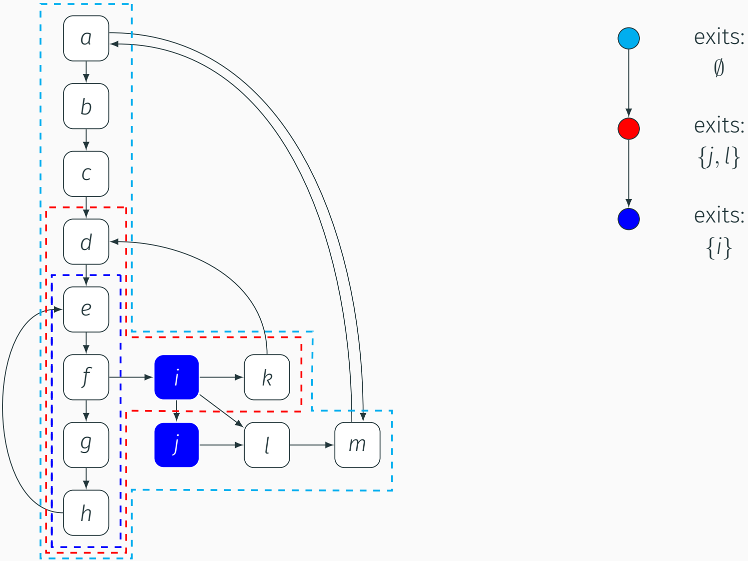
Deleting Edge (j, h) – Incremental Repair





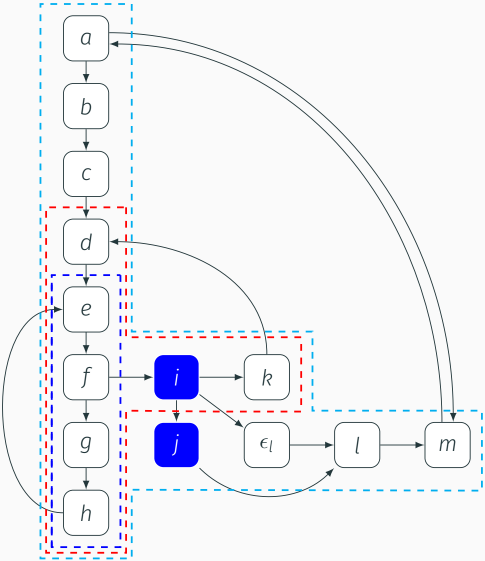
Eject block i from inner (blue) loop

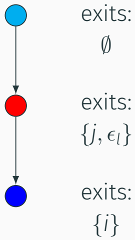
Deleting Edge (j, h) – Incremental Repair



Eject block j from middle (red) loop

Deleting Edge (j, h) – Incremental Repair

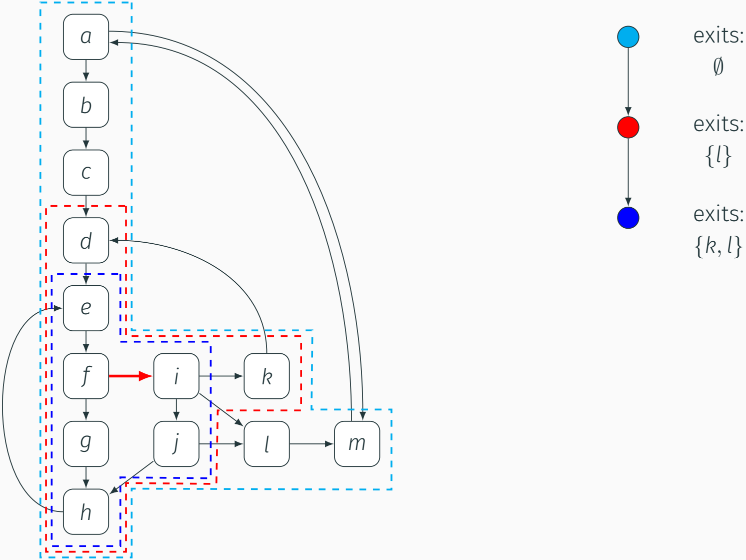




Place block ϵ_l on edge (i, l) to dedicate exit

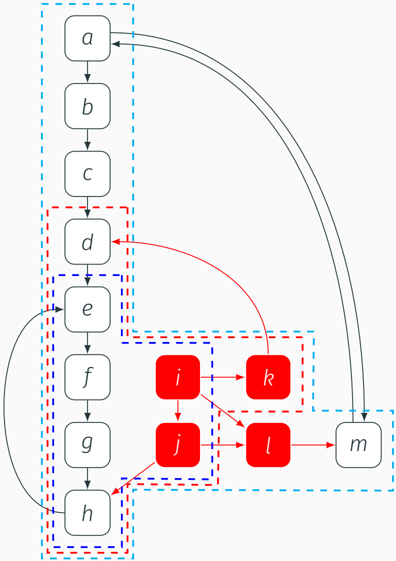
Example #2

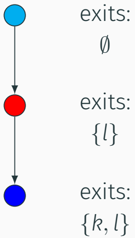
Deleting Edge (f, i) – Incremental Repair



Initial graph

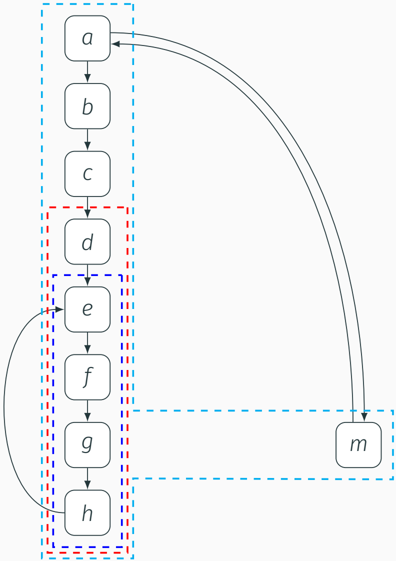
Deleting Edge (f, i) – Incremental Repair

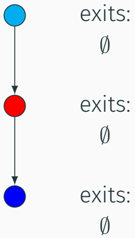




Edge deleted

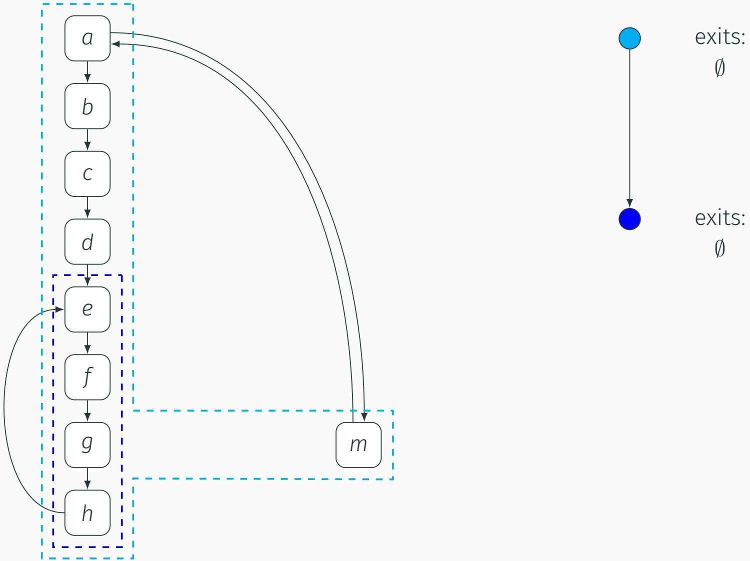
Deleting Edge (f, i) – Incremental Repair





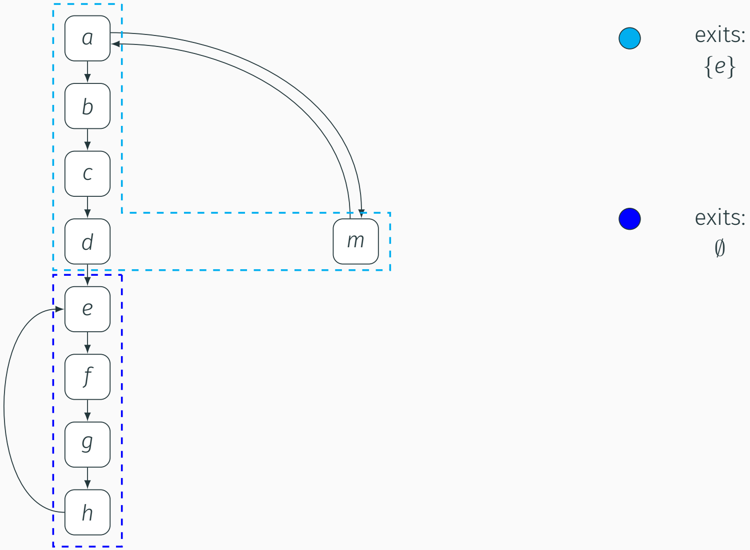
Remove unreachable blocks from graph, loop nesting forest

Deleting Edge (f, i) – Incremental Repair



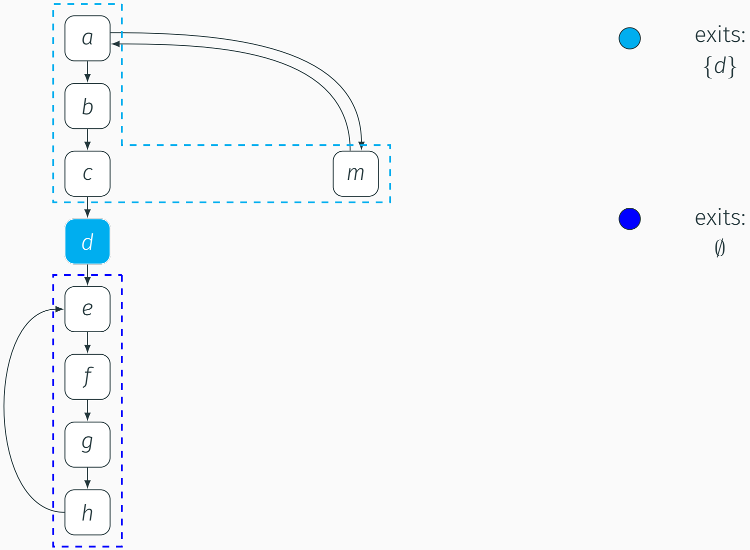
Remove destroyed middle (red) loop

Deleting Edge (f, i) – Incremental Repair



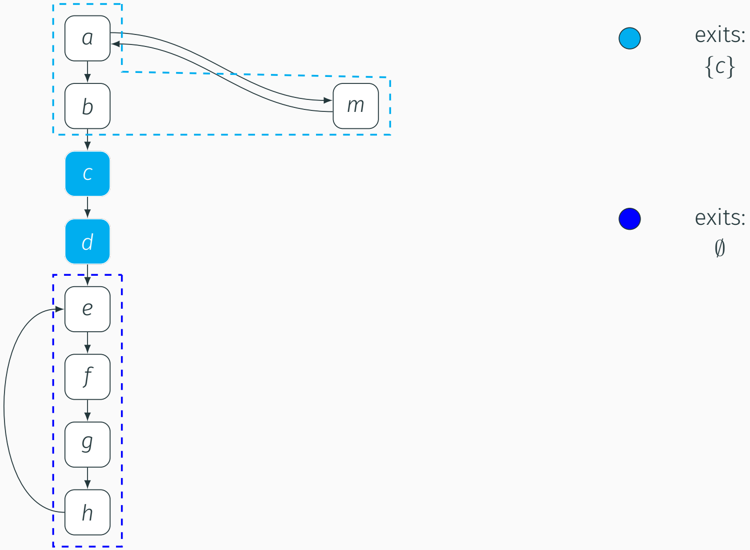
Eject block e (and its loop) from the outer (cyan) loop

Deleting Edge (f, i) – Incremental Repair



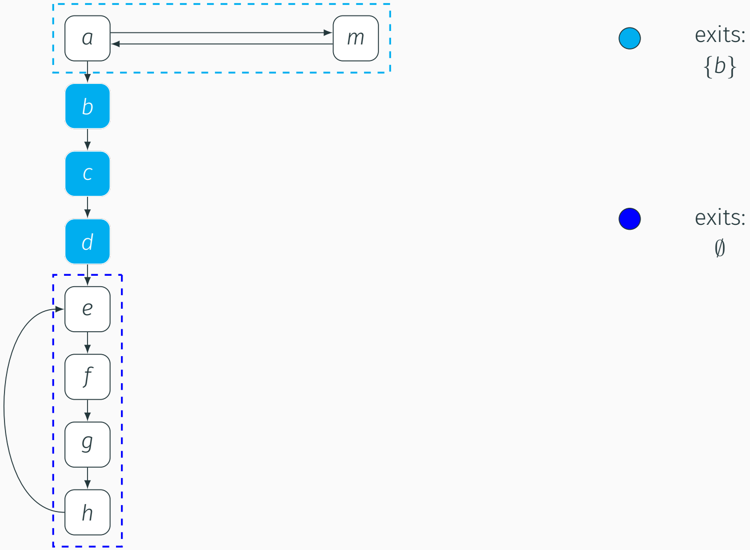
Eject block *d* from outer (cyan) loop

Deleting Edge (f, i) – Incremental Repair



Eject block c from outer (cyan) loop

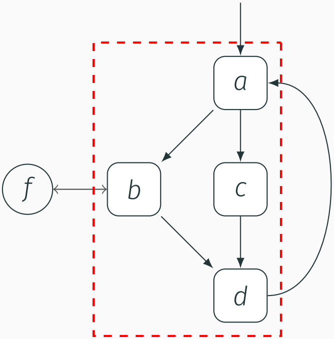
Deleting Edge (f, i) – Incremental Repair



Eject block b from outer (cyan) loop

Additional Applications

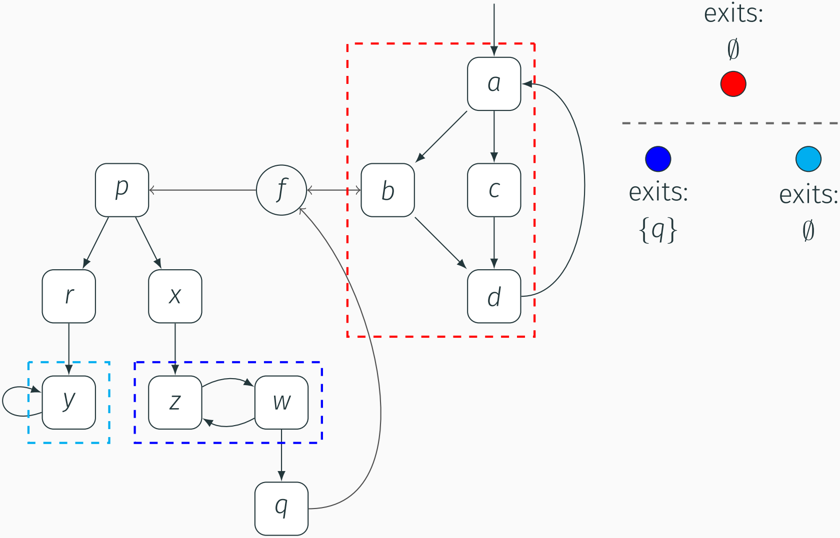
Function Inlining



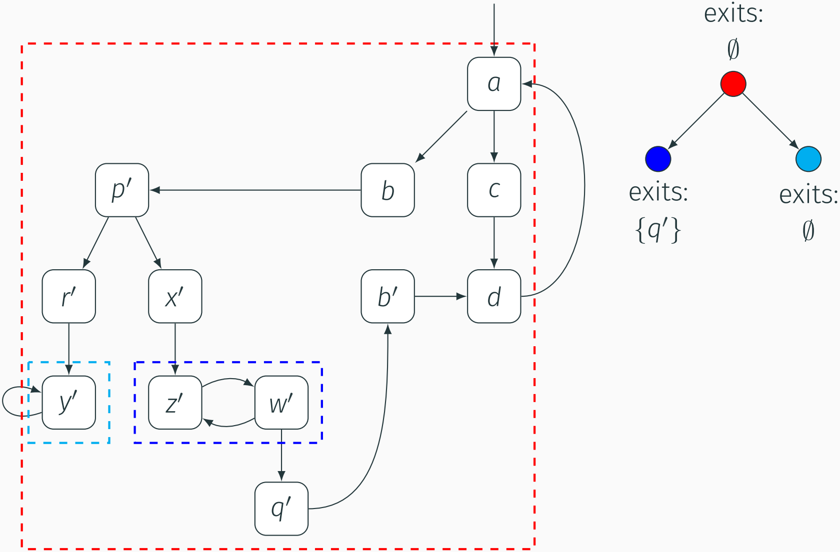
exits:

$\emptyset$

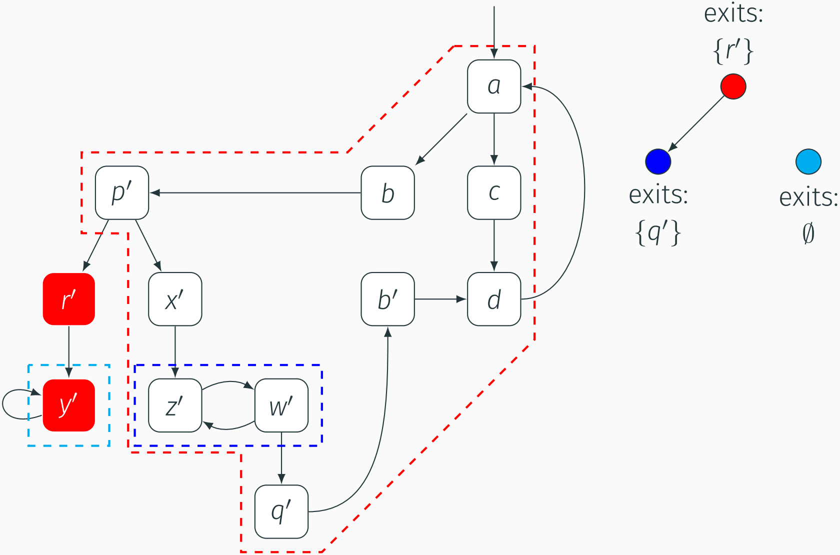
Function Inlining



Function Inlining



Function Inlining



Evaluation

Methodology

(1) Construct Waddle IR from C++ source (through LLVM)
- 6 compilation units
- ~85 interesting functions per compilation unit
- ~21 blocks, ~30 edges, $\leq$ 10 loops ($\leq$ depth of 4) per function

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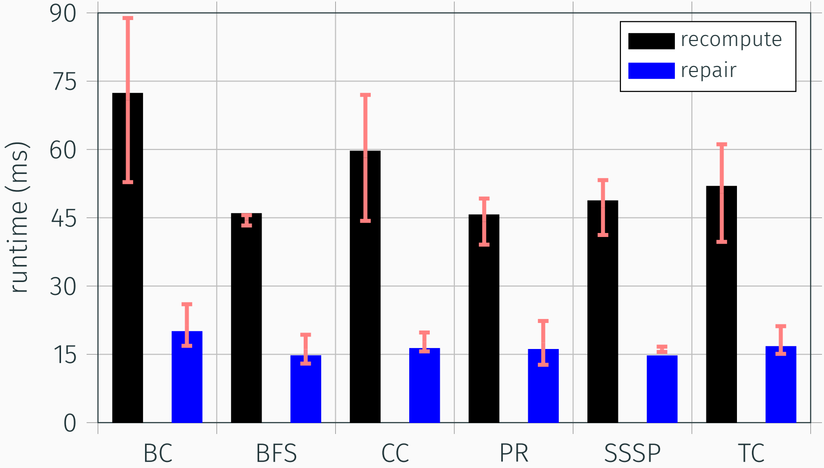
(2) Construct a stable order of edges

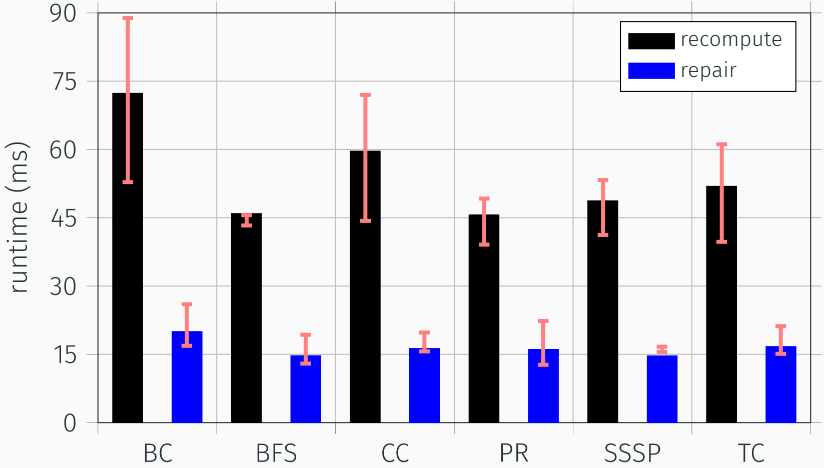
(3) For each edge that has siblings remaining:
  - Delete edge and reconstruct canonical form (baseline)
  - Delete edge using procedure described here

Results



90
75
60
45
30
15
0
runtime (ms)
recompute
repair
BC
BFS
CC
PR
SSSP
TC

Results



64.80 to 72.7% decrease in runtime

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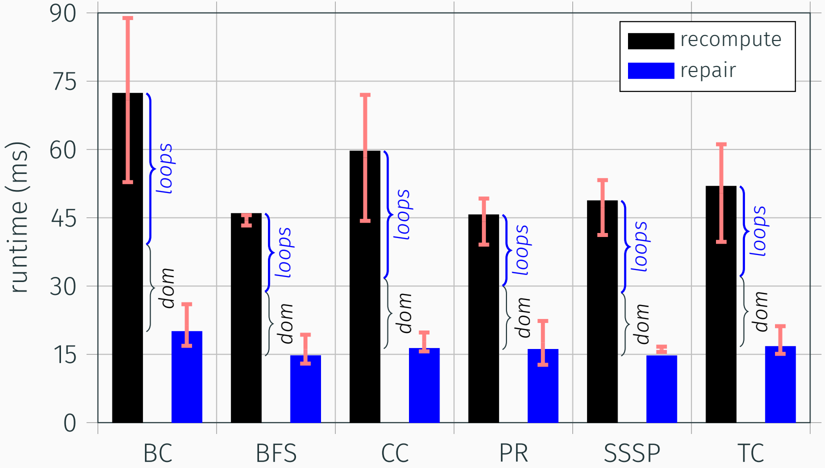

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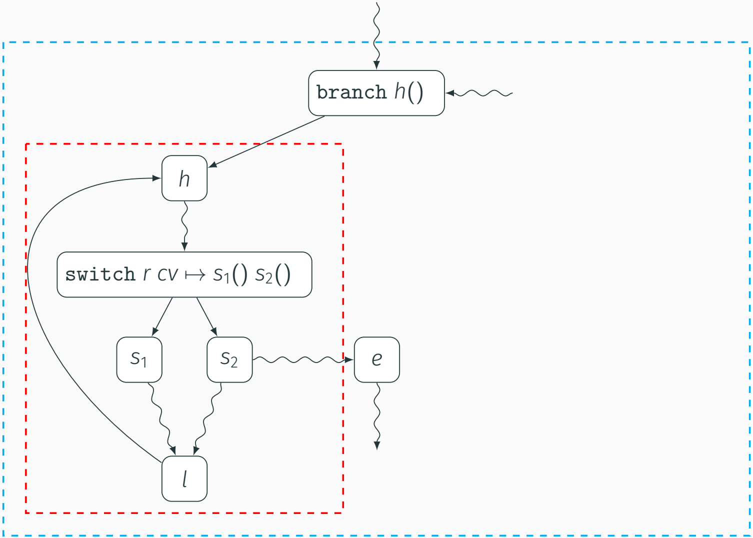
Questions?

Bonus Slides

Subgraph Duplication (Loop Unswitching)



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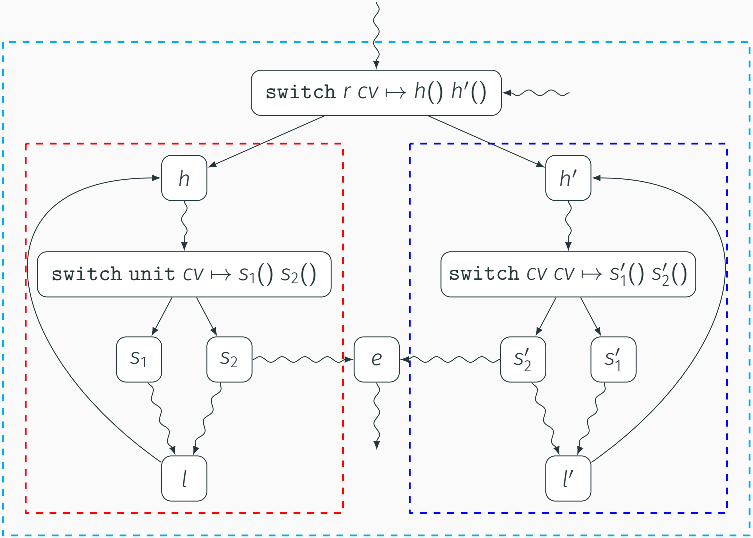

Thank You!