Cours M2: Compilation avancée et optimisation de programmes

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Back-end code optimizations

Outline

Back-end code analysis

Control-flow analysis determines control flow and control structure of a program and build a program representation.

- Basic block
- Control-flow graph
- Loop-nesting forest
- Static single assignment

Data-flow analysis determines the flow of scalar variables, their live-ranges, and possibly their values.

- Constant propagation
- Redundancy elimination, dead-code elimination
- Code motion and scheduling
- Register allocation

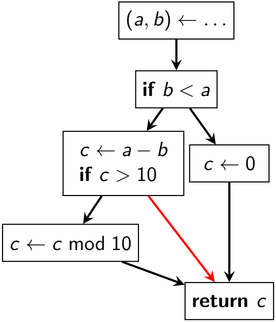
Analysis: local, intra-procedural, or inter-procedural.

Basic block and control-flow graph

Basic block sequence of consecutive statements in any execution: single entry & single exit.

Control-flow graph directed graph:

- nodes are basic blocks
- edges represent control flow (jumps or fall-through), i.e., paths that *may* be taken
- block/edge frequencies



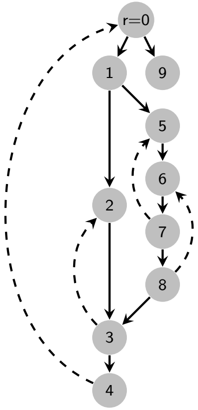
Vocabulary

- DFS, back-edge, cross-edge
- loop, entry node, join node
- reducible and irreducible graph
- critical edge (in red)

Dominance, post-dominance, control dependences

Dominance relation

- a single entry node r.
- each node reachable from r.
- a dominates b if every path from r to b contains a.



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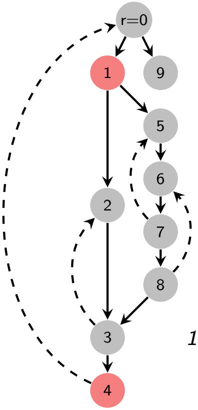

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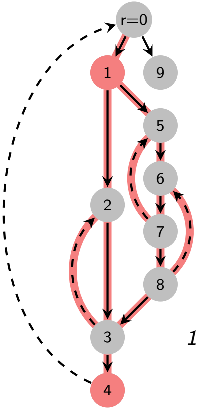

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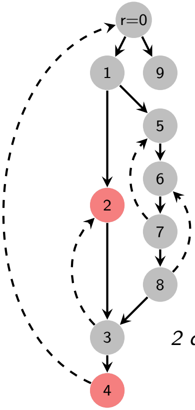

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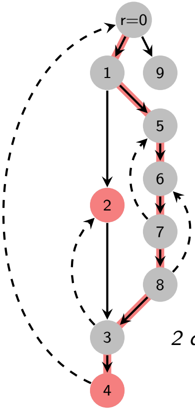

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Properties

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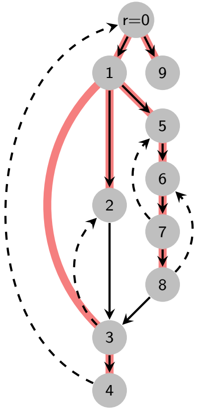
- With tree labeling, testing if a dominates b takes $O(1)$.



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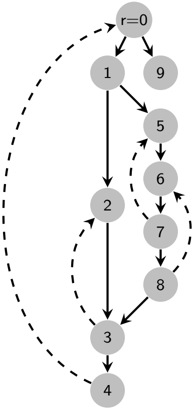

Similar for post-dominance, used for defining control dependences: b is control-dependent on a if there is a path from a to b and b does not strictly post-dominate a.

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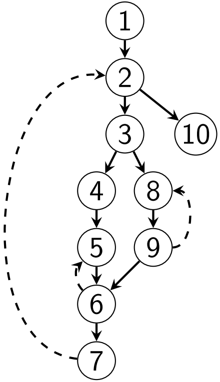
Corresponding loop-nesting forest

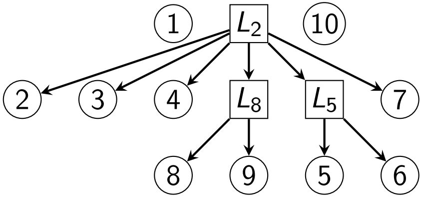
- Leaves are the nodes of the CFG.
- Internal nodes, labeled by loop-headers, correspond to loops.
- The children of a loop's node represent all inner loops it contains as well as the regular basic blocks of the loop's body.

Loop-nesting forest: example

An irreducible CFG



A possible loop-nesting forest



As the CFG is not reducible, several loop forests are possible, with loop headers 5 and/or 6.
Also, in general, the depth of a loop forest is not uniquely defined.

Tarjan's algorithm for detecting loops (reducible case)

```
procedure collapse(loopBody, loopHeader)
  for every z ∈ loopBody do
    loop-parent(z) := loopHeader; LP.union(z, loopHeader)
  endfor

procedure findloop(potentialHeader)
  loopBody = {}
  worklist = {LP.find(y) | y → potentialHeader is a back-edge} \ {potentialHeader}
  while (worklist is not empty) do
    remove an arbitrary element y from worklist; add y to loopBody
    for every predecessor z of y such that (z, y) is not a back-edge do
      if (LP.find(z) ∉ (loopBody ∪ {potentialHeader} ∪ worklist)) then
        add LP.find(z) to worklist
      endif
    endfor
  endwhile
  if (loopBody is not empty) then collapse(loopBody, potentialHeader)

procedure TarjanAlgorithm(G)
  for every vertex x of G do loop-parent(x) := NULL; LP.add(x); endfor
  for every vertex x of G in reverse-DFS-order do findloop(x); endfor
```

Ramalingam's modified Havlak's algorithm (general case)

```
procedure markIrreducibleLoops(z)
  t := loop-parent(z)
  while (t ≠ NULL) do
    u = RLH.find(t); mark u as irreducible-loop-header
    t := loop-parent(u)
    if (t ≠ NULL) then RLH.union(u, t)
  endwhile

procedure processCrossFwdEdges(x)
  for every edge (y, z) in CrossFwdEdges[x] do
    add edge (find(y), find(z)) to the graph; markIrreducibleLoops(z)
  endfor

procedure ModifiedHavlakAlgorithm(G)
  for every vertex x of G do
    loop-parent(x) := NULL; crossFwdEdges[x] := {}; LP.add(x); RLH.add(x);
  endfor
  for every forward edge and cross edge (y, x) of G do
    remove (y, x) from G and add it to crossFwdEdges[LCA(y, x)]
  endfor
  for every vertex x of G in reverse-DFS-order do
    processCrossFwdEdges(x)
    findloop(x) /* same procedure as for Tarjan's algorithm */
  endfor
```