Script generated by TTT

Title: Seidl: Programmoptimierung (16.12.2013)

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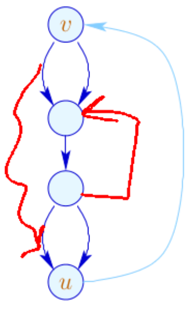
Pages: 42

We are interested in edges which during each iteration are executed exactly once:



This property can be expressed by means of the pre-dominator relation ...

Assume that $(u, \_, v)$ is the back edge.

Then edges $k = (u_1, \_, v_1)$ could be selected such that:

- v pre-dominates u_1;
- u_1 pre-dominates v_1;
- v_1 predominates u.

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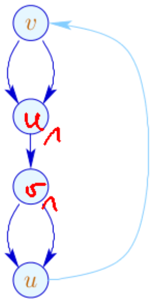

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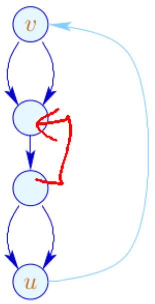

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On the level of source programs, this is trivial:

$$\texttt{do } \{ \; s_1 \ldots s_k \; \} \; \texttt{while } (e);$$

The desired assignments must be among the s_i :-)

Iteration Variable:

i is an iteration variable if the only definition of i inside the loop occurs at an edge which separates the body and is of the form:

$$i = i + h;$$

for some loop constant h .

A loop constant is simply a constant (e.g., 42), or slightly more libaral, an expression which only depends on variables which are not modified during the loop :-)

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(3) Differences for Sets

Consider the fixpoint computation:

$$x = \emptyset;$$
$$\texttt{for } (t = F\,x; t \not\subseteq x; \boxed{t = F\,x;}) \quad x = x \cup t;$$

If F is distributive, it could be replaced by:

$$x = \emptyset;$$
$$\texttt{for } (\Delta = F\,x; \Delta \neq \emptyset; \boxed{\Delta = (F\,\Delta) \setminus x;}) \quad x = x \cup \Delta;$$

The function F must only be computed for the smaller sets Δ :-)
semi-naive iteration

Instead of the sequence: $\emptyset \subseteq F(\emptyset) \subseteq F^2(\emptyset) \subseteq \ldots$

we compute: $\Delta_1 \cup \Delta_2 \cup \ldots$

where:

$$\begin{aligned}\Delta_{i+1} &= F(F^i(\emptyset))\backslash F^i(\emptyset) \\ &= F(\Delta_i)\backslash(\Delta_1 \cup \ldots \cup \Delta_i) \quad \text{with } \Delta_0 = \emptyset\end{aligned}$$

Assume that the costs of $F\ x$ is $1 + \#x$.

Then the costs may sum up to:

naive	$1 + 2 + \ldots + n + n$	$= \frac{1}{2}n(n+3)$
semi-naive		$2n$

where n is the cardinality of the result.

$\Longrightarrow$ A linear factor is saved :-)

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2.2 Peephole Optimization

Idea:

- Slide a small window over the program.
- Optimize agressively inside the window, i.e.,
  - → Eliminate redundancies!
  - → Replace expensive operations inside the window by cheaper ones!

Examples:

$y = M[x]; x = x + 1; \quad \Longrightarrow \quad y = M[x{+}{+}];$

// given that there is a specific post-increment instruction :-)

$z = y - a + a; \quad \Longrightarrow \quad z = y;$

// algebraic simplifications :-)

$x = x; \quad \Longrightarrow \quad ;$

$x = 0; \quad \Longrightarrow \quad x = x \oplus x;$

$x = 2 \cdot x; \quad \Longrightarrow \quad x = x + x;$

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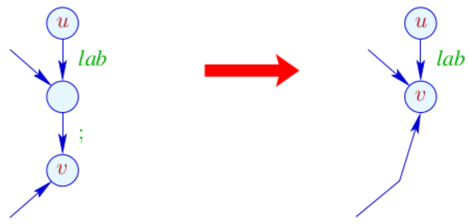
Important Subproblem: *nop*-Optimization



→ If $(v_1, ;, v)$ is an edge, v_1 has no further out-going edge.

→ Consequently, we can identify v_1 and v :-)

→ The ordering of the identifications does not matter :-))

while(1);

Implementation:

- We construct a function $\textsf{next} : \textit{Nodes} \to \textit{Nodes}$ with:

$$\textsf{next}\ u = \begin{cases} \textsf{next}\ v & \text{if} \quad (u, ;, v) \quad \text{edge} \\ u & \text{otherwise} \end{cases}$$

Warning: This definition is only recursive if there are ;-loops ???

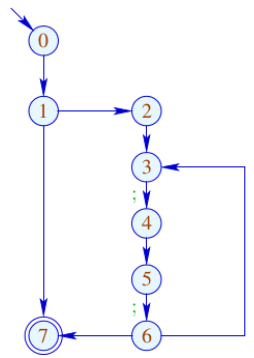
- We replace every edge:

$$(u, \textit{lab}, v) \quad \Longrightarrow \quad (u, \textit{lab}, \textsf{next}\ v)$$

... whenever $\textit{lab} \neq ;$

- All ;-edges are removed ;-)

Example:

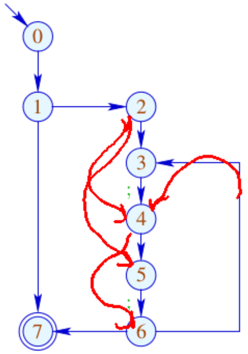


$\textsf{next}\ 1 = 1$

$\textsf{next}\ 3 = 4$

$\textsf{next}\ 5 = 6$

Example:



next 1 = 1
next 3 = 4
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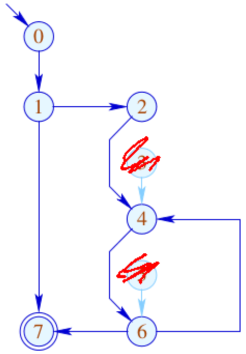


next 1 = 1
next 3 = 4
next 5 = 6

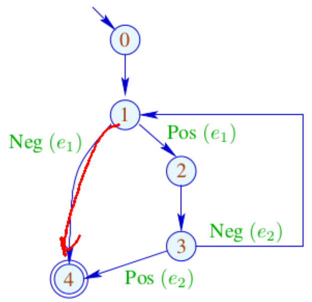
2. Subproblem: Linearization

After optimization, the CFG must again be brought into a linearly arrangement of instructions :-)

Warning:

Not every linearization is equally efficient !!!

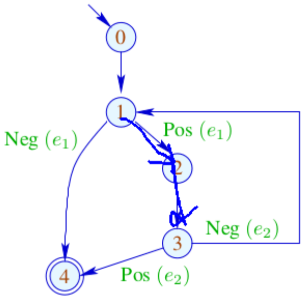
Example:



0:
1: if (e_1) goto 2;
4: halt
2: Rumpf
3: if (e_2) goto 4;
goto 1;

Bad: The loop body is jumped into :-(

Example:



0:
1: if ($!e_1$) goto 4;
2: Rumpf
3: if ($!e_2$) goto 1;
4: halt

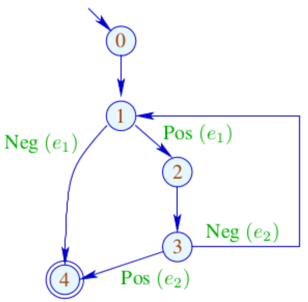
⟹ better cache behavior :-)

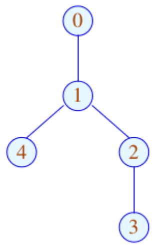
Idea:

- Assign to each node a temperature!
- always jumps to
  - (1) nodes which have already been handled;
  - (2) colder nodes.
- Temperature ≈ nesting-depth

For the computation, we use the pre-dominator tree and strongly connected components ...

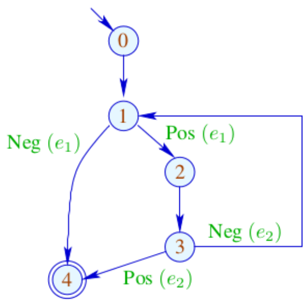
... in the Example:

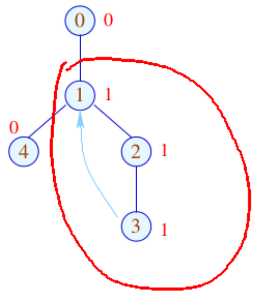




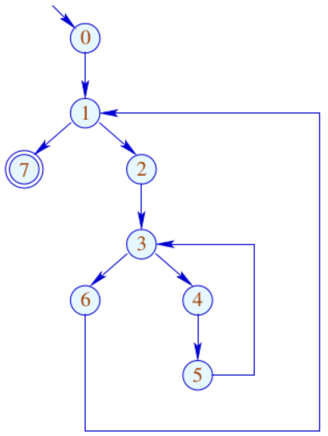
The sub-tree with back edge is hotter ...

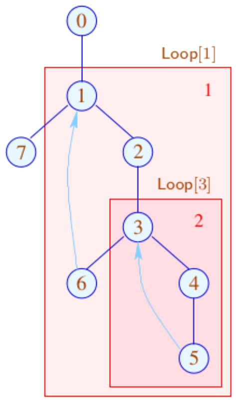
... in the Example:





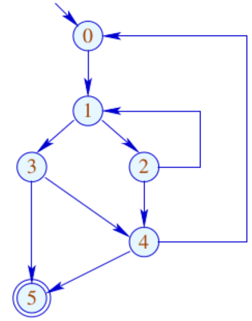
More Complicated Example:

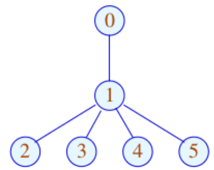




Our definition of Loop implies that (detected) loops are necessarily nested :-)

Is is also meaningful for do-while-loops with breaks ...





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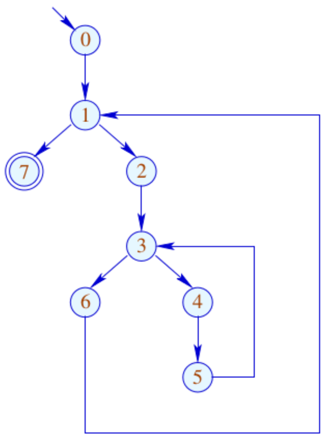

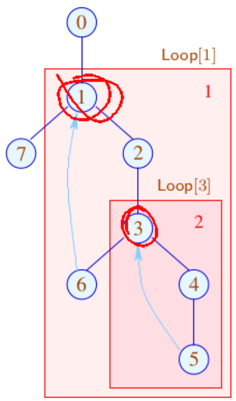

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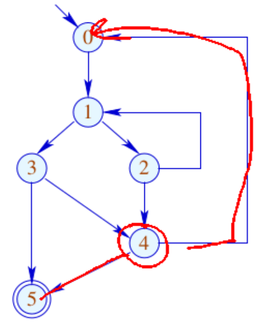

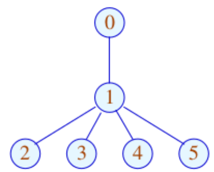

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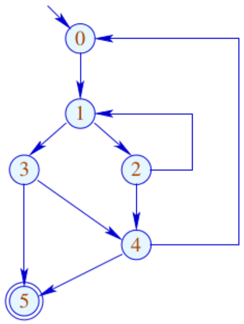

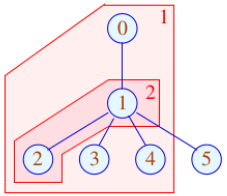

Summary: The Approach

(1) For every node, determine a temperature;

(2) Pre-order-DFS over the CFG;

→ If an edge leads to a node we already have generated code for, then we insert a jump.

→ If a node has two successors with different temperature, then we insert a jump to the colder of the two.

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2.3 Procedures

We extend our mini-programming language by procedures without parameters and procedure calls.

For that, we introduce a new statement:

$$f();$$

Every procedure f has a definition:

$$f\,()\ \{\ stmt^*\ \}$$

Additionally, we distinguish between global and local variables.

Program execution starts with the call of a procedure main () .

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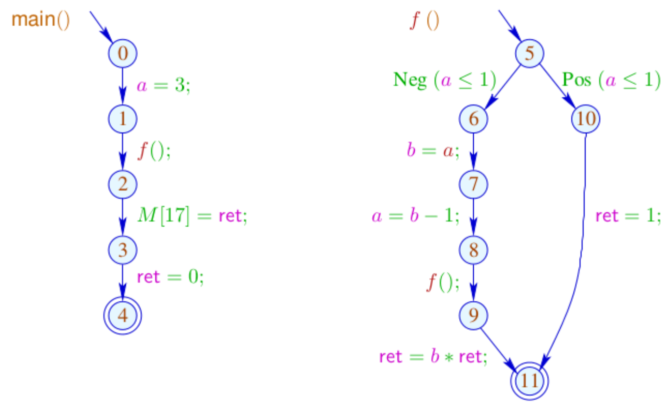
Example:

```
int a, ret;                f () {
main () {                      int b;
    a = 3;                     if (a ≤ 1) {ret = 1; goto exit; }
    f();                       b = a;
    M[17] = ret;               a = b − 1;
    ret = 0;                   f();
}                              ret = b · ret;
                           exit :
                           }
```

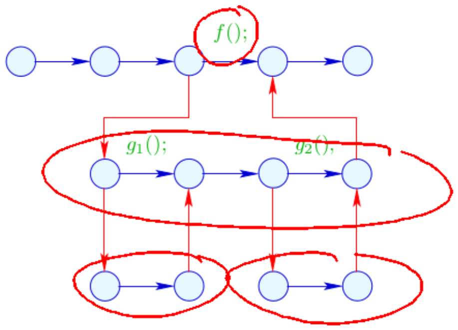
Such programs can be represented by a set of CFGs: one for each procedure ...

... in the Example:



In order to optimize such programs, we require an extended operational semantics ;-)

Program executions are no longer paths, but forests:



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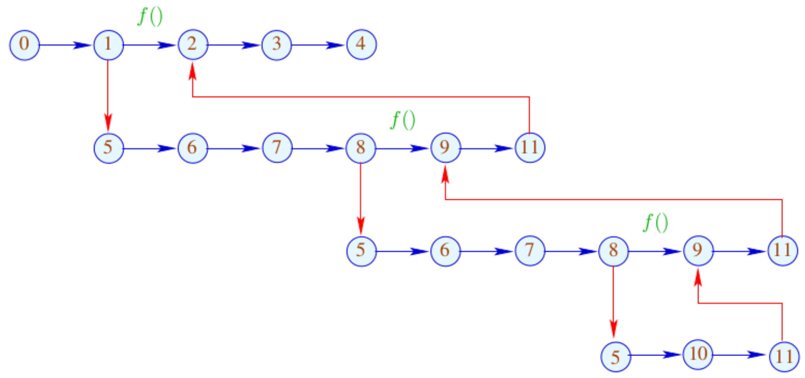

The function $[\![.]\!]$ is extended to computation forests: w :

$$[\![w]\!] : (Vars \to \mathbb{Z}) \times (\mathbb{N} \to \mathbb{Z}) \to (Vars \to \mathbb{Z}) \times (\mathbb{N} \to \mathbb{Z})$$

For a call $k = (u, f();, v)$ we must:

- determine the initial values for the locals:

$$\mathsf{enter}\ \rho = \{x \mapsto 0 \mid x \in Locals\} \oplus (\rho|_{Globals})$$

- ... combine the new values for the globals with the old values for the locals:

$$\mathsf{combine}\ (\rho_1, \rho_2) = (\rho_1|_{Locals}) \oplus (\rho_2|_{Globals})$$

- ... evaluate the computation forest inbetween:

$$\begin{array}{lll} [\![k\ \langle w \rangle]\!]\ (\rho, \mu) & = & \mathsf{let}\ (\rho_1, \mu_1) = [\![w]\!]\ (\mathsf{enter}\ \rho, \mu) \\ & & \mathsf{in}\ \ (\mathsf{combine}\ (\rho, \rho_1), \mu_1) \end{array}$$