

Revisiting Out-of-SSA Translation for Correctness, Code Quality, and Efficiency

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CGO'09, March 24, 2009, Seattle, WA

Outline

- 1 SSA foundations
 - Out-of-SSA translation
- 2 Correctness and code quality
 - Translation with copy insertions
 - Improving code quality
 - Qualitative experiments
- 3 Speed and memory footprint
 - Linear-time algorithm for coalescing congruence classes
 - Experimental results for speed and memory footprint
- 4 Conclusion

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Static single assignment (SSA)

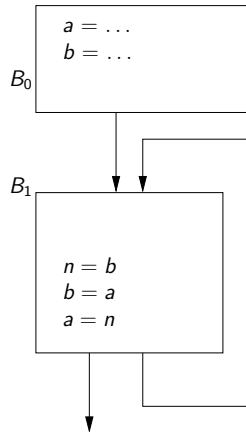
SSA with dominance property

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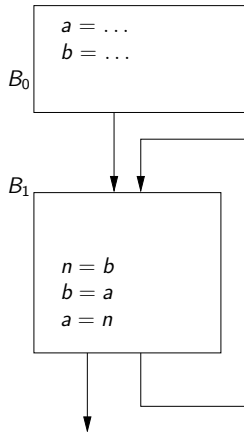
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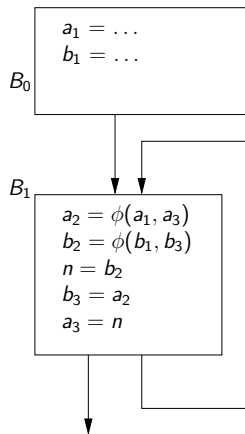
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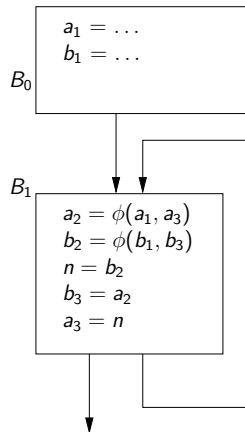
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- Code optimizations: efficient, easy-to-implement, fast;
- Two-phases register allocation;
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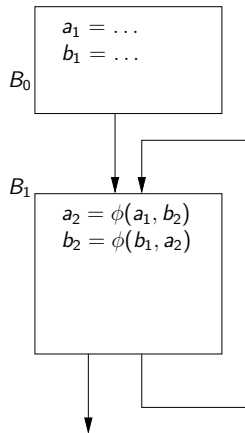
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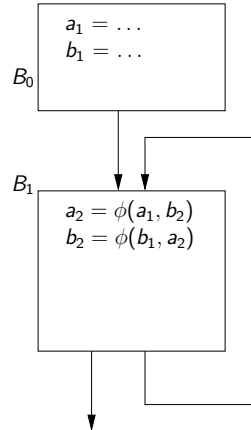
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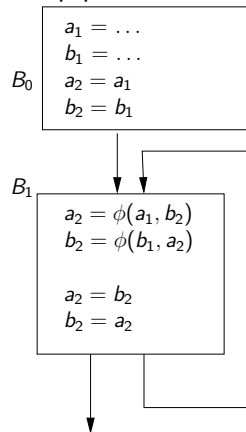
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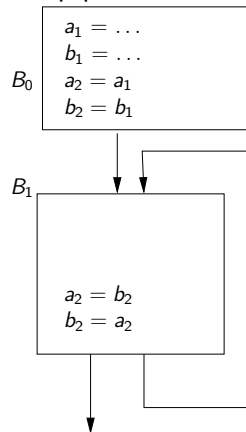
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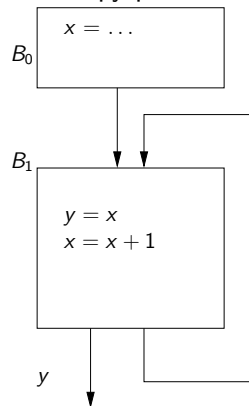
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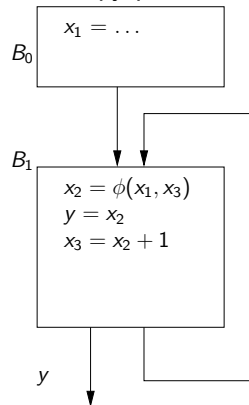
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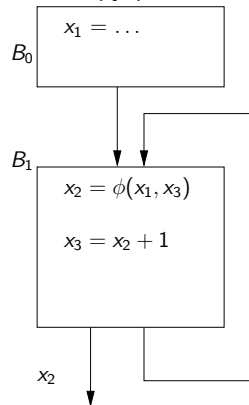
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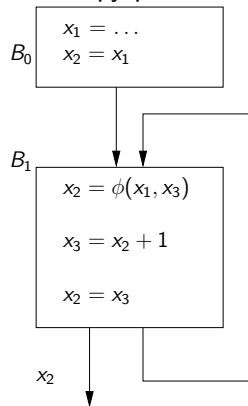
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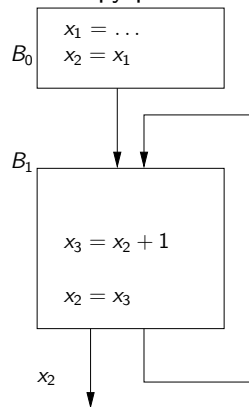
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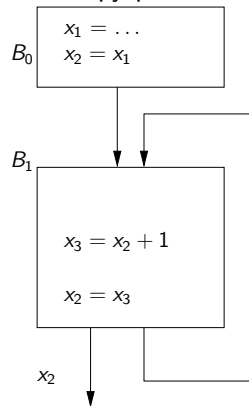
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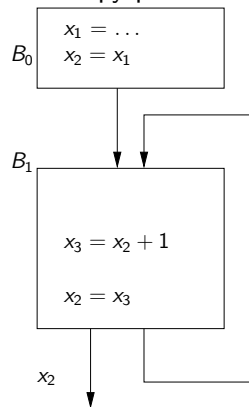
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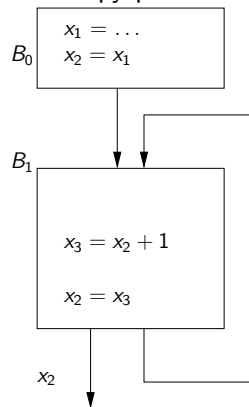


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☞ Many SSA optimizations turned off in gcc and Jikes.

Lost copy problem



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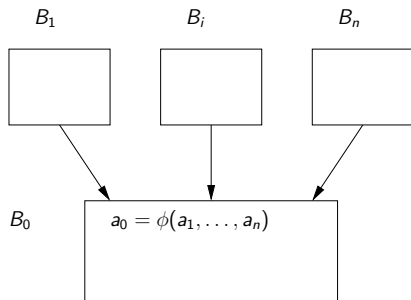
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Going to CSSA (conventional SSA)

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For any ϕ -function $a_0 = \phi(a_1, \dots, a_n)$, the variables a_0, \dots, a_n can be safely replaced by a common resource.

From SSA to CSSA



Going to CSSA (conventional SSA)

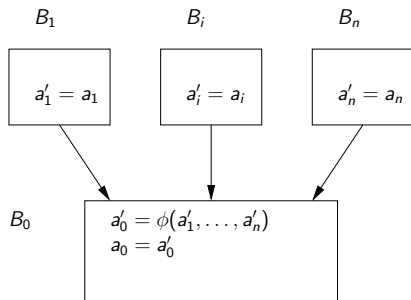
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by a common resource.

Correctness

Add copies with new local
variables around every ϕ .
 \implies CSSA

From SSA to CSSA



Code quality


Removing copies

Useless copies can be removed by standard **aggressive coalescing**. Using an accurate notion of interference (value-based) gives excellent results.

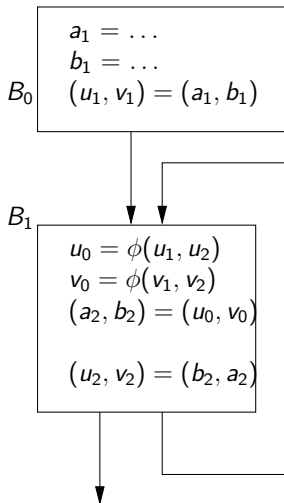
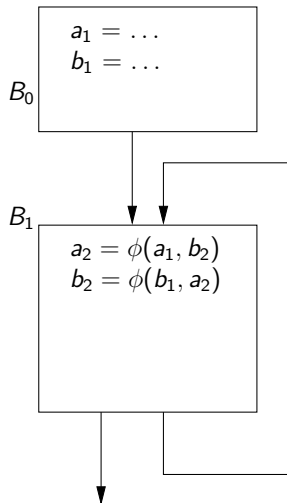
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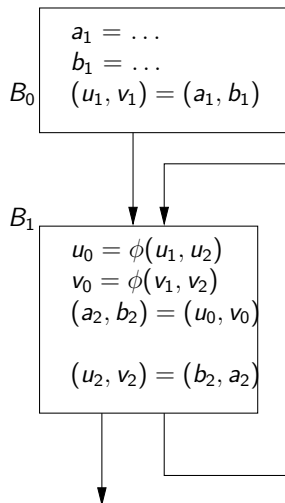
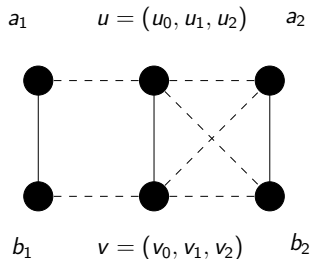
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“Liveness of ϕ ” defined by the a'_i . † Be careful with potential bugs due to conditional branches that use or define variables. 

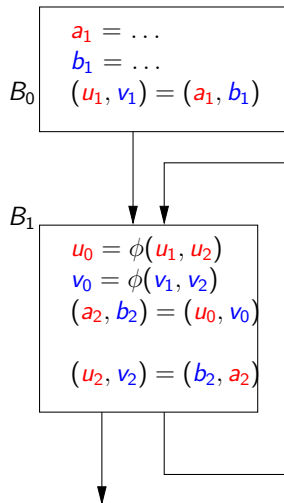
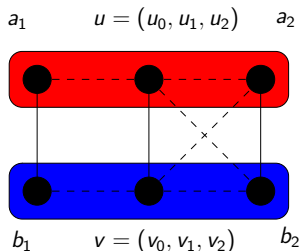
Coalesced example: the swap problem



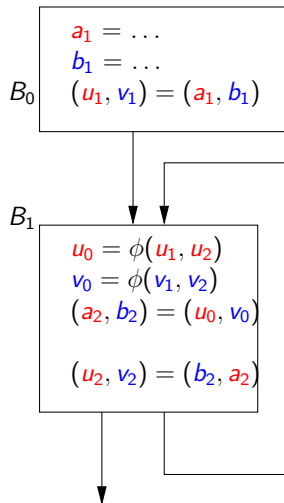
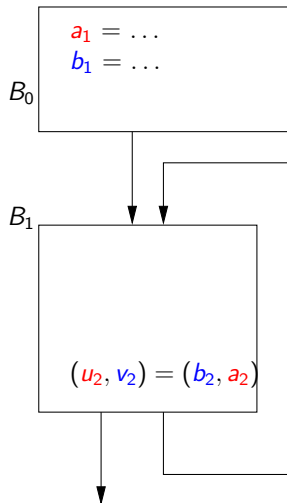
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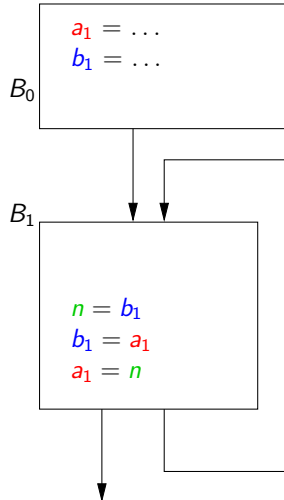
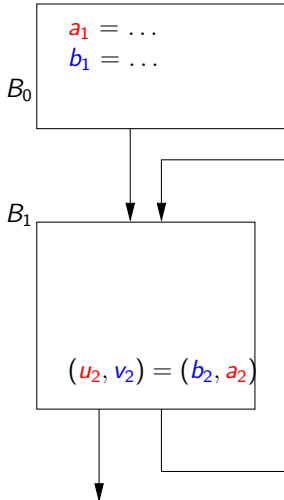
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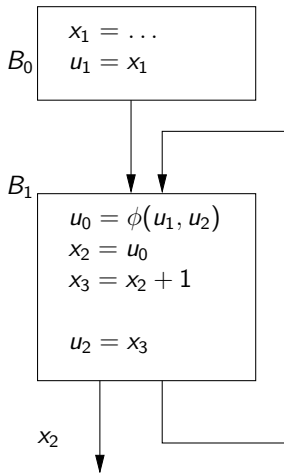
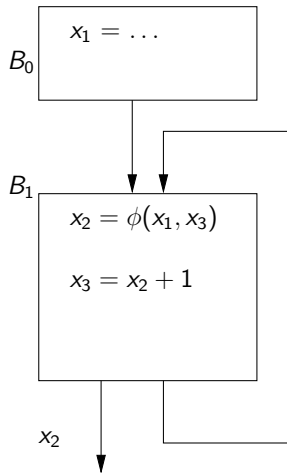
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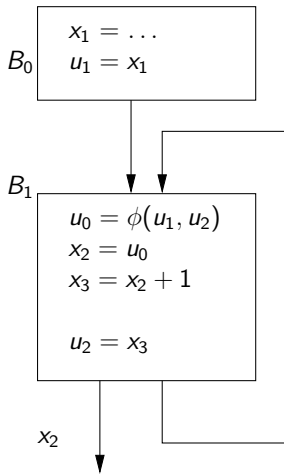
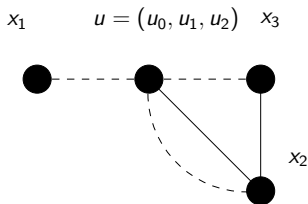
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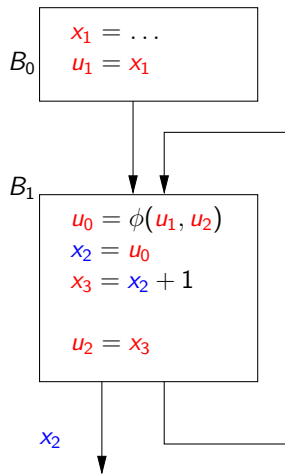
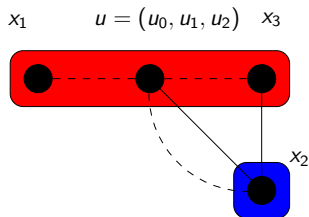
Coalesced example: the lost copy problem



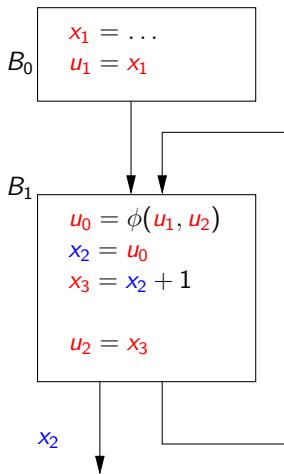
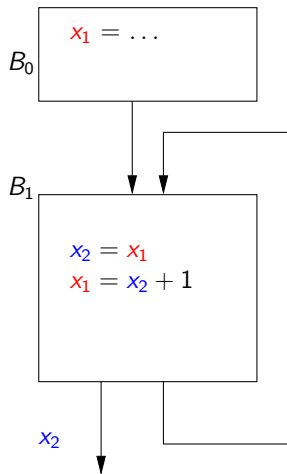
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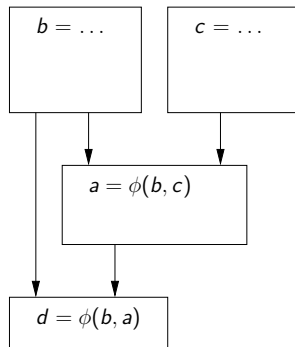
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Exploiting SSA: value-based interferences

Definition (Chaitin interference)

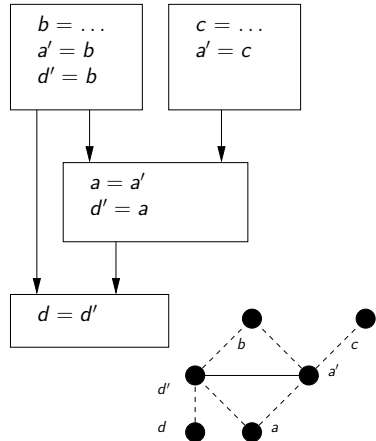
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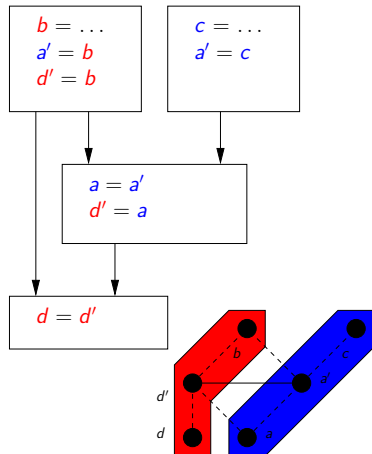
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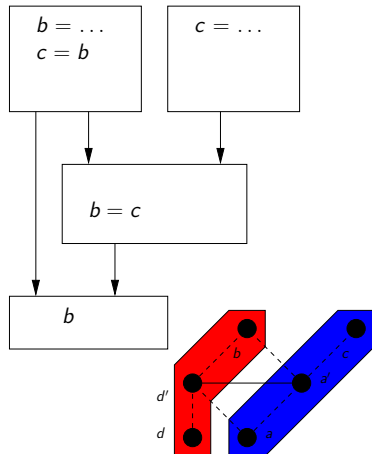


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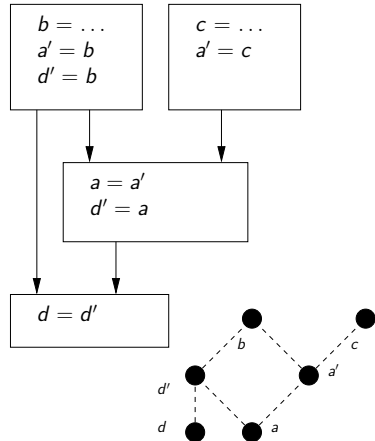
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Unique value V of a SSA variable

For a copy $b = a$, $V(b) = V(a)$
(traversal of dominance tree).

Value-based interference

a and b interfere if $V(a) \neq V(b)$ and $\text{Live-range}(a) \cap \text{Live-range}(b) \neq \emptyset$.



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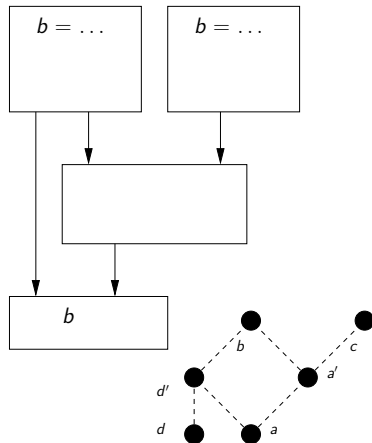
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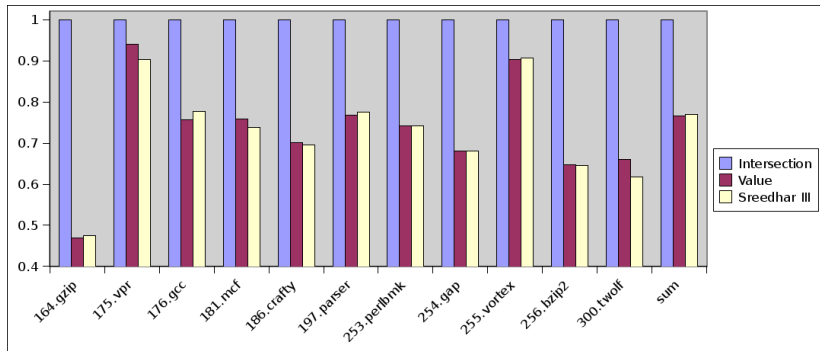
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Qualitative experiments with SPEC CINT2000



Number of remaining moves

Qualitative experiments with SPEC CINT2000

Key points of the out-of-SSA translation

- Copy insertion (to go to CSSA and to handle register renaming constraints) followed by coalescing.
- Value-based interferences ➡ coalescing is improved and independent of virtualization (i.e., as in Sreedhar III).
- Parallel copies followed by sequentialization.

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How to coalesce variables?

Two alternatives

- Use a **working interference graph** where, in case of coalescing, corresponding vertices are merged. $O(1)$ interference query.
- Manipulate **congruence classes**, i.e., sets of coalesced variables. Interferences must be tested between sets.

Chaitin, Sreedhar, Budimlić use congruence classes. Also useful to avoid interference graph. Naive algorithm: quadratic complexity.

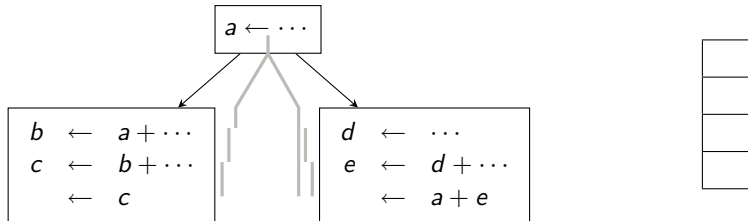
Fast interference test for a set of variables

Key properties for linear-complexity live range intersection

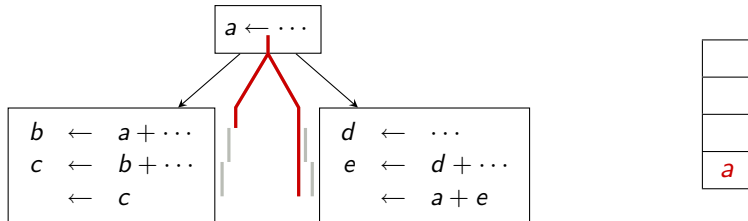
- 2 SSA variables intersect if one is live at the definition of the other.
- In this case, the first definition dominates the second one.
- **Budimlić:** If a and b intersect ($a \text{ dom } b$), then $\forall c$ with $a \text{ dom } c$ and $c \text{ dom } b$: b and c interferes.

\implies For each variable, the only test needed is with the “closest” dominating variable

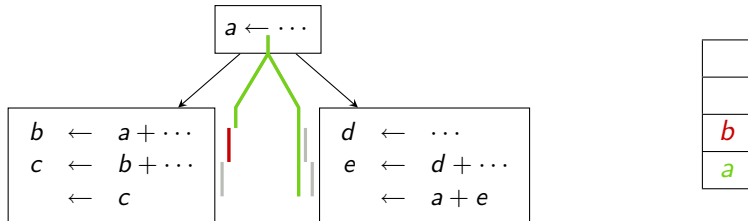
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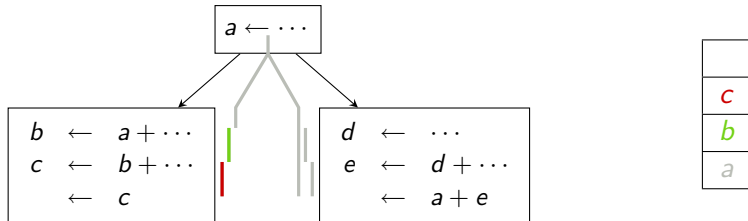
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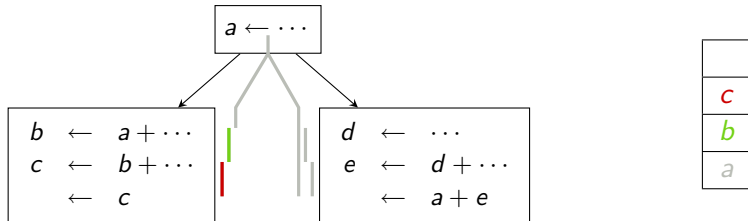
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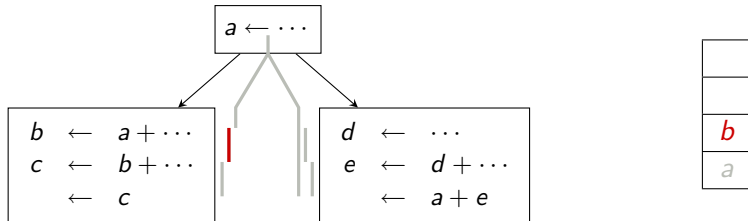
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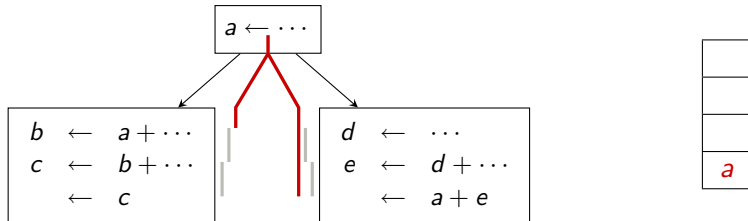
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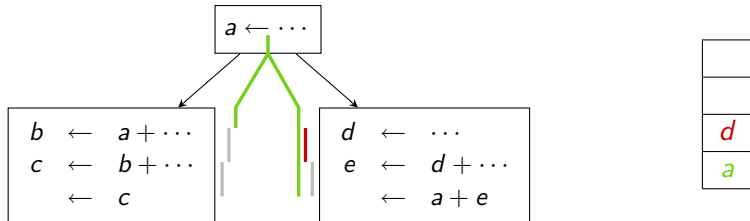
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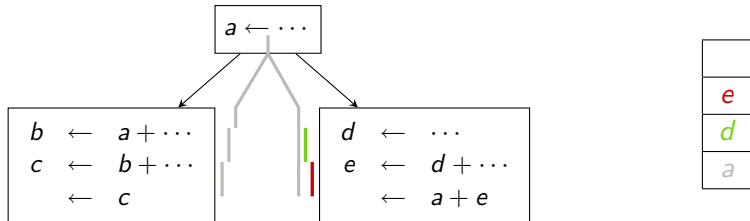
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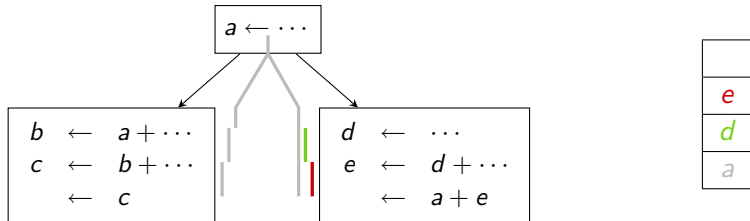
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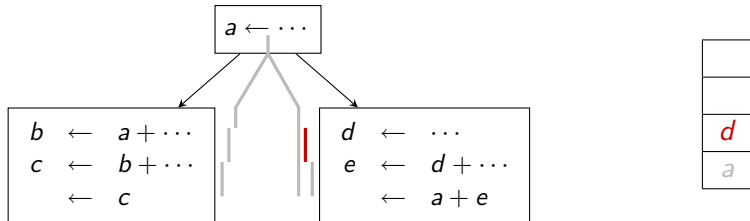
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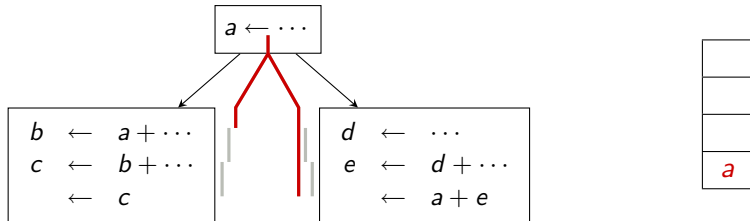
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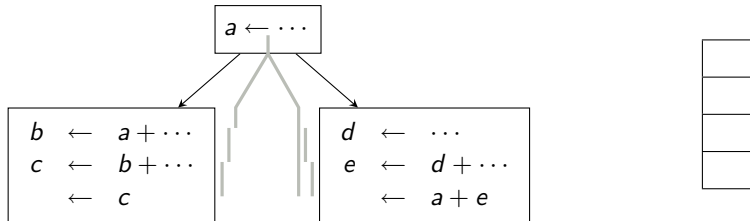
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Fast interference test for a set of variables



Fast interference test for a set of variables



Linear interference test of two congruence classes

Generalization to interference test of two sets

- Emulate a stack-based DFS traversal of dominance tree, for two sorted sets instead of one → linear number of tests. Also no need to test intersection of variables in the same set.
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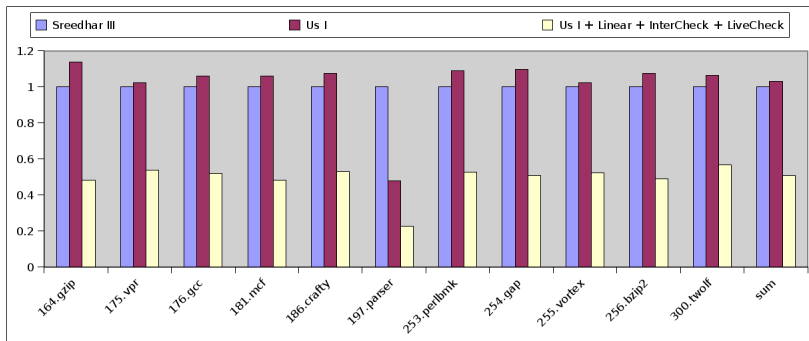
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Fewer intersection tests → possible now to use more expensive queries for intersection and liveness and avoid interference graph:

- Budimlić intersection test, still using liveness sets.
- Fast liveness checking of Boissinot et al. (CGO'08).

Speed-up for SPEC CINT2000: x2

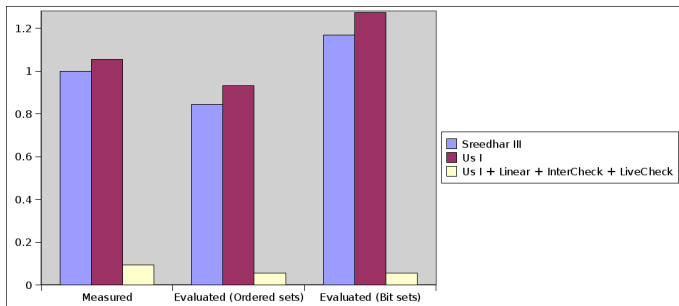


Time to go out of SSA (valgrind cycles)
 Default: Liveness sets + interference graph

Memory footprint reduction for SPEC CINT2000: $\times 10$

- Interference graph: half-size bit matrix.
- Liveness sets: enumerated sets. Does not count construction.
- Liveness check: bit sets. Construction taken into account.

Data structures grow during virtualization. “Perfect memory” evaluated, with both enumerated/bit sets for liveness sets.



Max of memory footprint

Outline

- 1 SSA foundations
 - Out-of-SSA translation
- 2 Correctness and code quality
 - Translation with copy insertions
 - Improving code quality
 - Qualitative experiments
- 3 Speed and memory footprint
 - Linear-time algorithm for coalescing congruence classes
 - Experimental results for speed and memory footprint
- 4 Conclusion

General framework

- Correctness clarified even for complex cases
- Two phases solution, based on coalescing

Results

- Value-based interference as good as Sreedhar III
- Fast algorithm: **Speed-up x2, memory reduction x10.**

Implementation

- No need to virtualize (at least for us)
- Simple implementation

General framework

- Correctness clarified even for complex cases
- Two phases solution, based on coalescing

Results

- Value-based interference as good as Sreedhar III
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Implementation

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- Simple implementation

Journal version should contain:

- Virtualization of register renaming constraints.
- All pseudo-codes, e.g., virtualization in general case.

The End

Thank you!

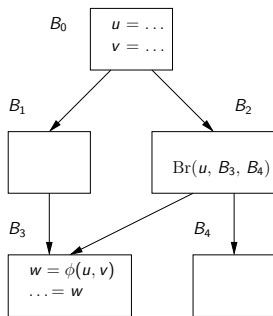
Bug tracking RVM-254 of Jikes RVM

Problems with SSA form: lack of loop unrolling breaks VM

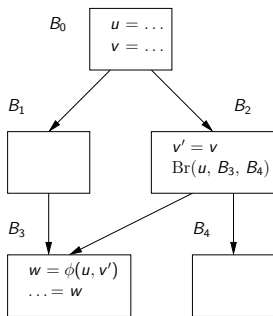
This problem is probably one of the most serious in the RVM currently. When loop unrolling is disabled and SSA enabled the created IR is corrupt. The error has in the past look like we were suffering from the "lost copy" problem, but implementing a naive solution to this didn't solve the problem. There is sound logic behind the code so we need to identify a small test case where things are broken and then reason about what's wrong in leave SSA. This has been attempted once (with the code that removes an element from the live set) but the problem no longer appears to surface here. Currently these optimizations are disabled but by RVM 3.0 they should be re-enable and this bug cured.



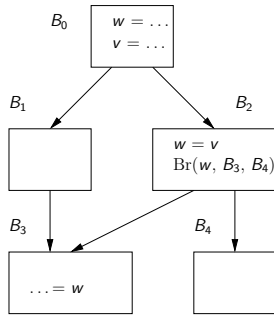
Potential bugs with conditional branches



Initial code



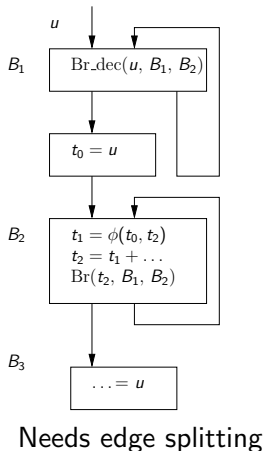
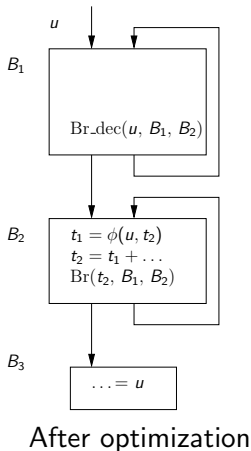
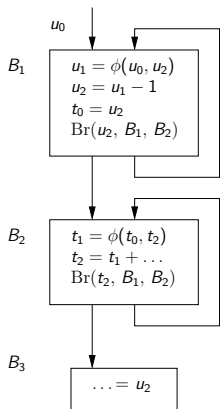
"Blind" Sreedhar III



Wrong output code

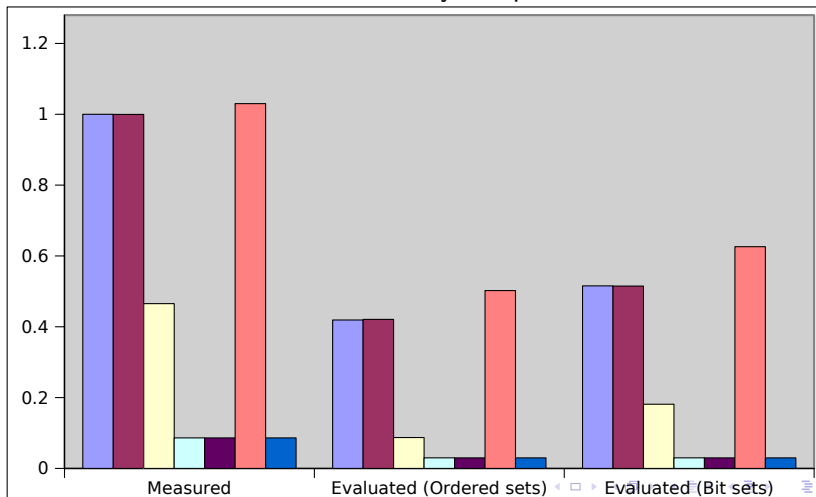


Unfeasible out-of-SSA translation example

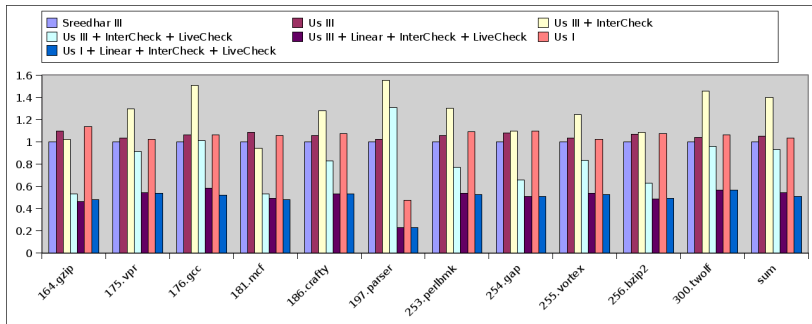


Sum of memory over benchmarks

Sum of memory footprint



Speedup



Qualitatives

