Optimal and Heuristic Global Code Motion for Minimal Spilling

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This talk

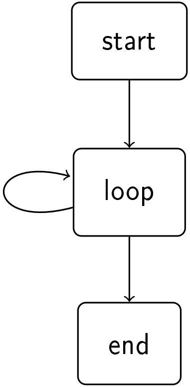
Solve global code motion and register allocation as an integrated problem.

Given: Scheduling for minimal spilling is good.

Hypothesis: Global code motion for minimal spilling might be good.

Global code motion

```
start:
   j0 := 0
   a := read()
loop:
   j1 := φ(j0, j2)
   b := a + 1
   j2 := j1 + b
   c := f(a)
   compare j2 < c
   d := j2 × 2
   blt loop
end:
   return d
```



Global code motion

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start:
   j0 := 0
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loop:
   j1 := φ(j0, j2)
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   j1 := φ(j0, j2)
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   c := f(a)
   compare j2 < c
   d := j2 × 2         partially dead
   blt loop
end:
   return d
```

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live range of b

```
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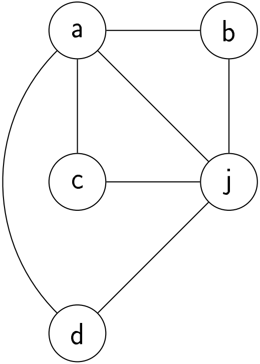
Register allocation: conflict graphs

original program



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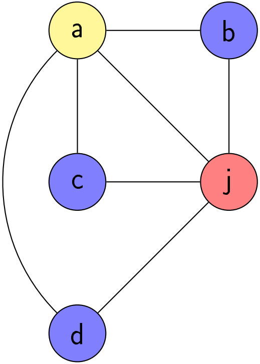

allocation to 3 registers possible

Register allocation: conflict graphs

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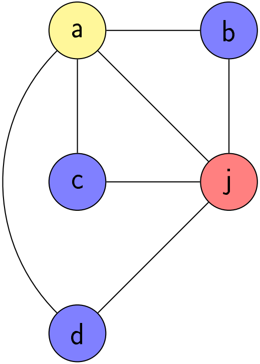
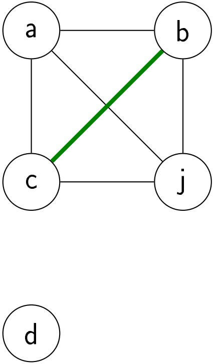


allocation to 3 registers possible

after global code motion



not 3-colorable!

Compute code motions and overlaps

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start:
i0:  j0 := 0
i1:  a := read()
loop:
i2:  j1 := φ(j0, j2)
i3:  b := a + 1
i4:  j2 := j1 + b
i5:  c := f(a)
i6:  compare j2 < c
i7:  d := j2 × 2
i8:  blt loop
end:
i9:  return d
```

All avoidable overlaps

Pair	Overlapping placement
a, d	i7 in loop
b, c	i3 in start
b, d	i3 in start, i7 in loop
b, j0	i3 in start
b, j2	i3 in start
c, d	i7 in loop, i7 before i6
d, j2	i7 in loop

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i7 in loop: overlap!

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i7 not in loop: no overlap

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i3 in start, i7 in loop: overlap!

Compute code motions and overlaps

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i3 not in start: no overlap

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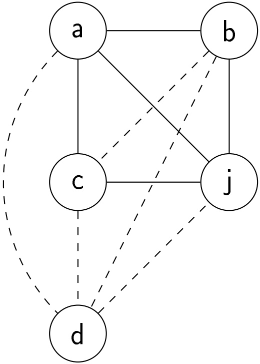
i7 not in loop: no overlap

Register allocation

Conflict graph with special edges for avoidable overlaps. Allocate to different registers if possible.



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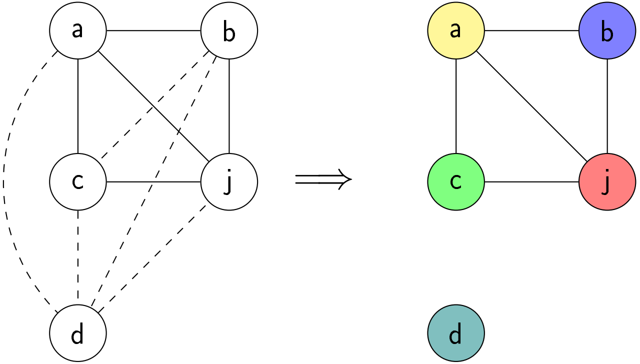

5 registers: easy allocation

Register allocation

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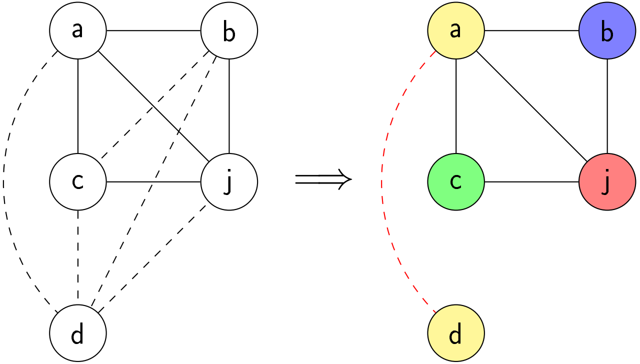

4 registers: place instruction i7 in block end to avoid overlaps

Register allocation

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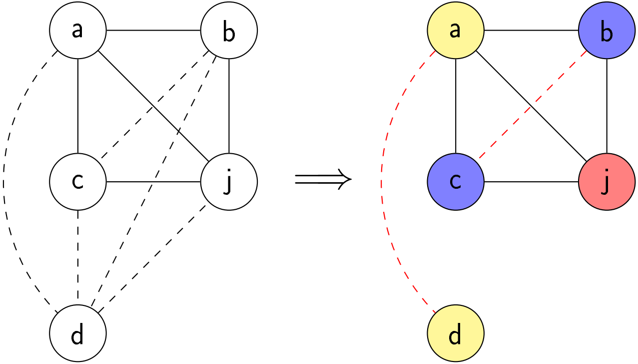

3 registers: place i3 in `loop` and i7 in `end`

There is just one problem...

Real-world programs have conflicting avoidable overlaps:

Pair	Overlapping placement
v1, v9	instruction 23 in block 0
v9, v10	instruction 23 in block 1
	⋮

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v1, v9	instruction 23 in block 0
v9, v10	instruction 23 in block 1
	must be in block 0 or 1!
	⋮

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Real-world programs have conflicting avoidable overlaps:

Pair	Overlapping placement	Overlapping schedule
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	⋮	cyclic dependence!

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	⋮	

→ Must select a subset of reuses.

Reuse candidate selection

Which subset to choose?

To minimize spilling, choose valid subset with largest total savings in spill costs.

Intuition: Hypergraph Maximum Independent Set

Hypergraph $\langle V, H \rangle$ with:

- Vertices V: reuse candidate pairs
- Hyperedges H: minimal conflicting sets

Select maximum subset of V that does not contain any $h \in H$.

Greedy heuristics

Idea: Avoid overlaps with larger spill costs.

Greedy heuristic selection

- Sort candidates by descending spill costs
- For each candidate:
  - If no conflict:
    - Add candidate to selected set
    - Commit to code motions for candidate

If greedy approach causes too many overlaps: use given schedule.

Optimal candidate selection

Can we do better than the greedy heuristics?

Integer linear programming formulation

Variables:

$select_c$	Select candidate c with savings w_c
$place_{i,b}$	Place instruction i in block b
$\ldots$	Variables for relative ordering of instructions

Objective function:

$$\text{maximize} \sum_c w_c select_c$$

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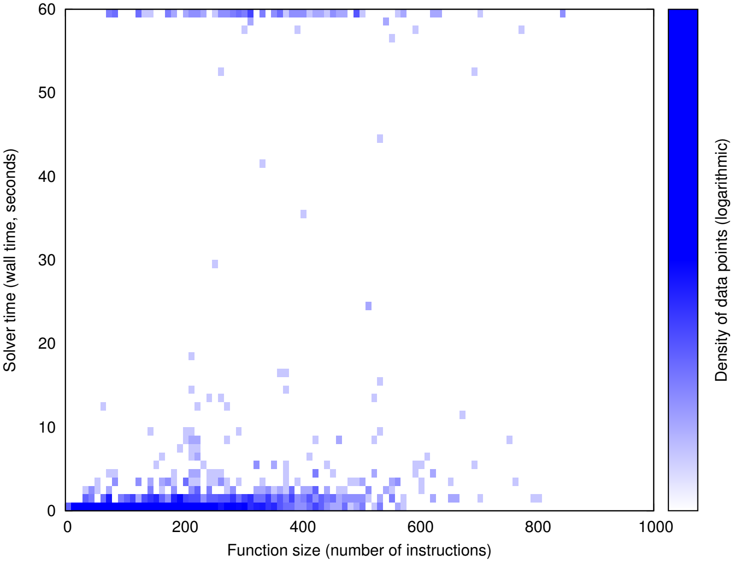
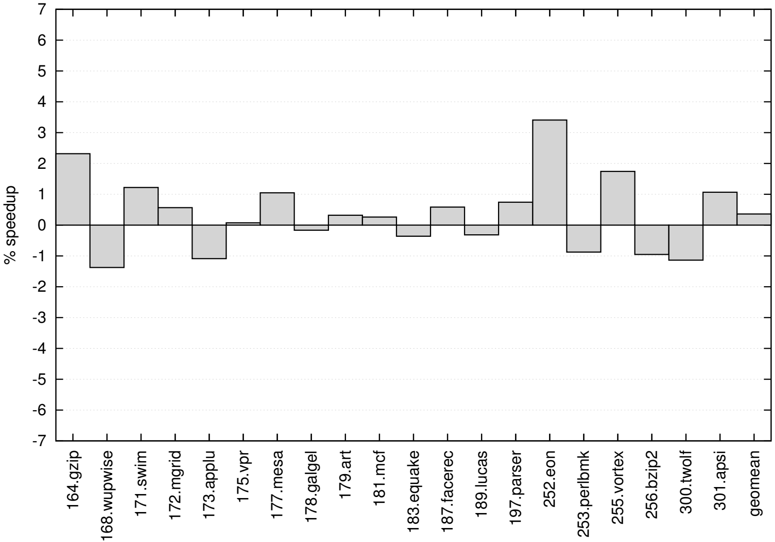
$$\text{maximize} \sum_c w_c select_c + \sum_i \sum_b place_{i,b}$$

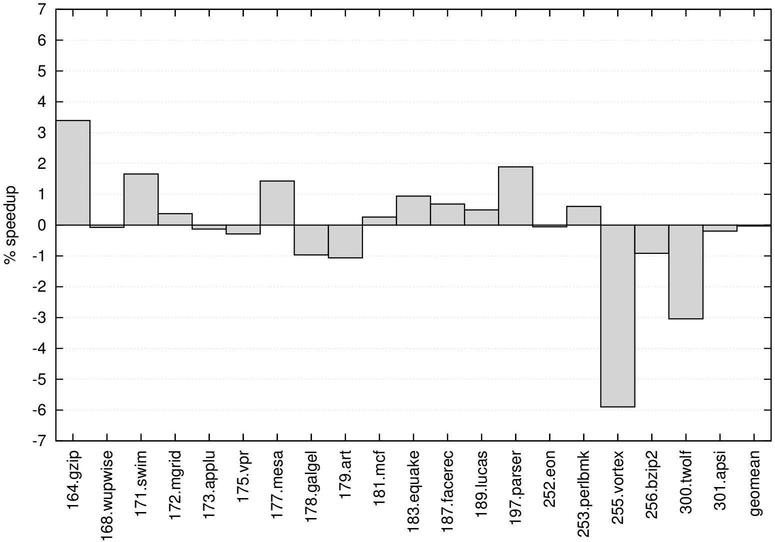
CPLEX solver time



Results: Greedy heuristics



Results: Optimal (ILP)



Future work

Some research directions

- More freedom for code motion:

$$\text{maximize} \sum_c w_c \mathit{select}_c + \beta \sum_i \sum_b \beta_b \mathit{place}_{i,b}$$

- Impact of solver time limit
- Other heuristics

Summary

- Integrate code motion and register allocation by letting the allocator choose necessary code motions.
- Speedups up to 4 % ☺
- . . . but no improvement on average ☹

Conclusion: Code motion for minimal spilling seems too restrictive.

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Thank you!

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