Performance analysis of Graph Coloring algorithms for Register Allocation in compilers

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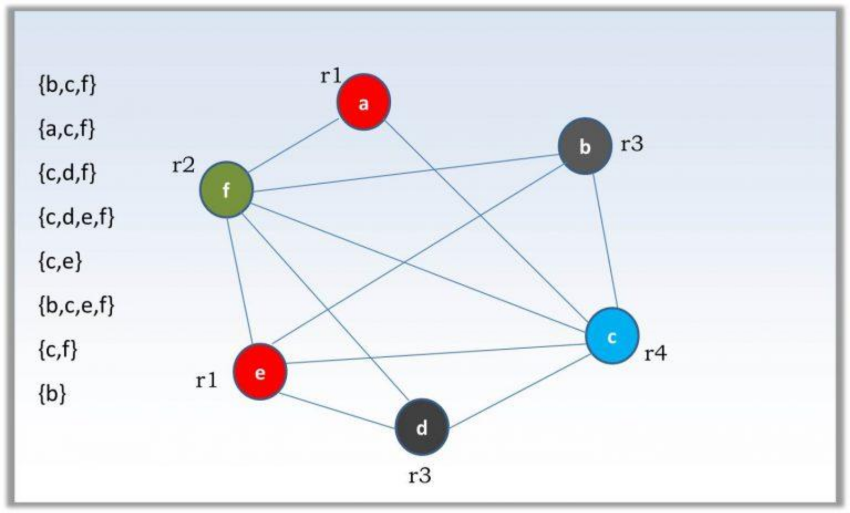
What is Register Allocation?



Process of assigning variables to registers during final phase of compiler optimisation.

Kttpro. (2020, April 24). *Register allocation via graph coloration – part II*. KTTPRO Custom Apps. https://www.kttpro.com/register-allocation-via-graph-coloration-part-ii/

Why Register Allocation?

- Registers - limited resources with faster access than cache and main memory

- Manages data transfer in and out of registers

- Efficient register allocation
  - reduces time of accessing code variables otherwise stored in main memory.

  - Optimizes the performance of compiled code .

Challenges while allocating registers

- Large number of IR variables compared to available physical general -purpose registers.

- Registers reserved for assemblers or operating systems, limiting availability for other operations.

Problem Statement

Given limited registers and minimal storage, how can we efficiently allocate the available registers to optimise their usage, increasing the speed of program execution in a compiler?

(Register Allocation Problem)

Approaches

Several approaches to solve the register allocation problem:

- ➢ Naive Register Allocation
- ➢ Linear Scan Algorithm
- ➢ Graph Coloring Algorithm

What is Graph coloring?

Technique to assign colors to the vertices (nodes) of a graph in such a way that no two adjacent vertices share the same color.

Applications of Graph Coloring

- ➢ Register Allocation
- ➢ Map Coloring
- ➢ Mobile radio frequency assignment
- ➢ Task scheduling
- ➢ Sudoku Puzzle

Graph coloring in Register Allocation

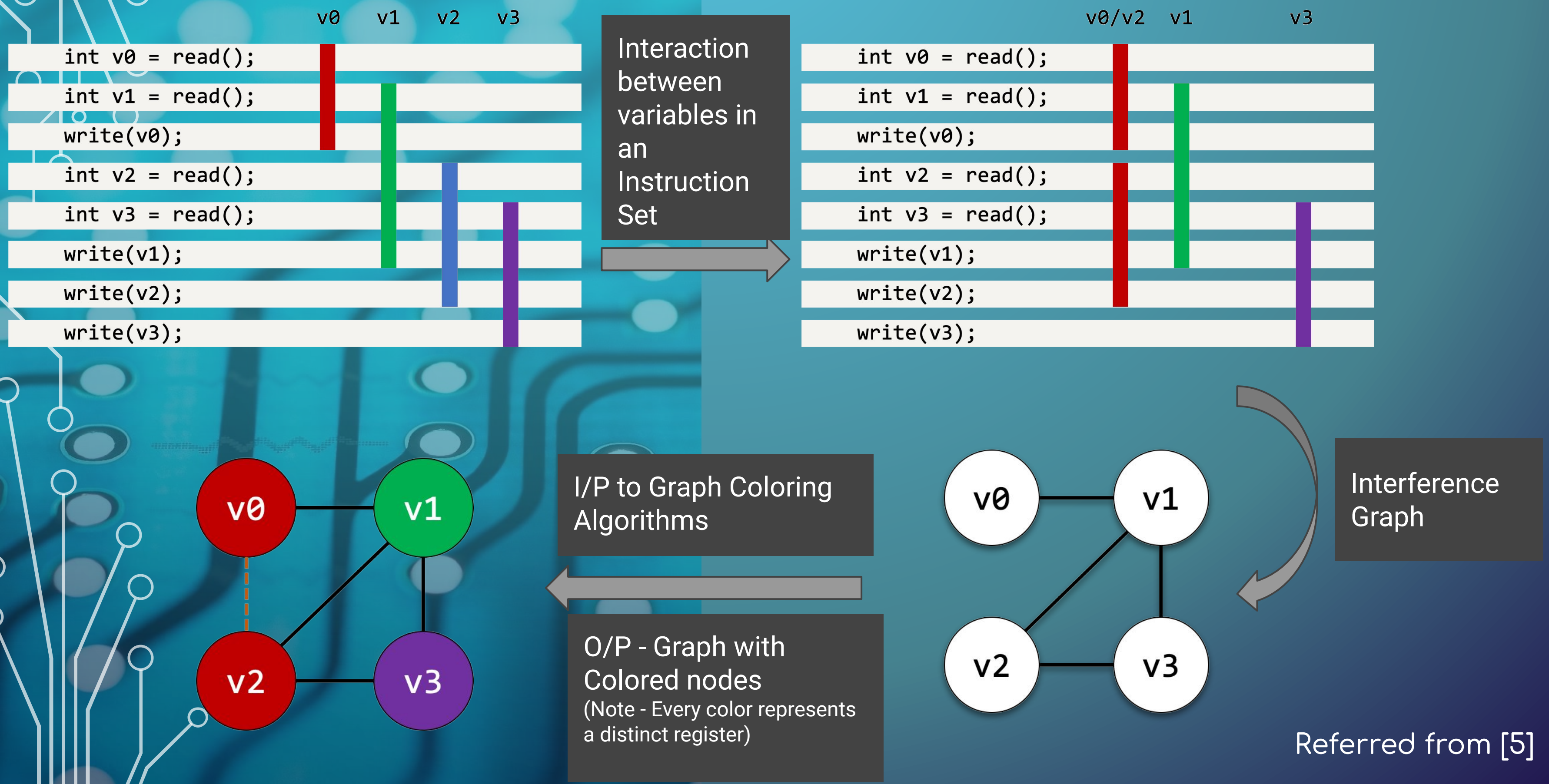
Interference Graph:
An interference graph is constructed for IR variables:

- ➢ Nodes – variables,
- ➢ Edge - if the corresponding variables interfere with each other (cannot share the same register).

Graph Coloring:
The objective is to assign colors (registers) to nodes in the interference graph.

A coloring is valid if no two adjacent nodes (connected by an edge) have the same color.

Graph coloring for Register Allocation



Referred from [5]

Graph Coloring Algorithms

Graph coloring can be performed using multiple algorithms, namely:

- ➢ Chaitin's Algorithm (specially for register allocation)
- ➢ M coloring technique using backtracking
- ➢ Welsh Powell Algorithm
- ➢ Kempe Algorithm
- ➢ Greedy Approach

Datasets

Graph	Vertices (V)	Edges (E)
mycie13	11	20
mycie17	191	2360
miles1500	128	5195
queen_14_14	196	8372

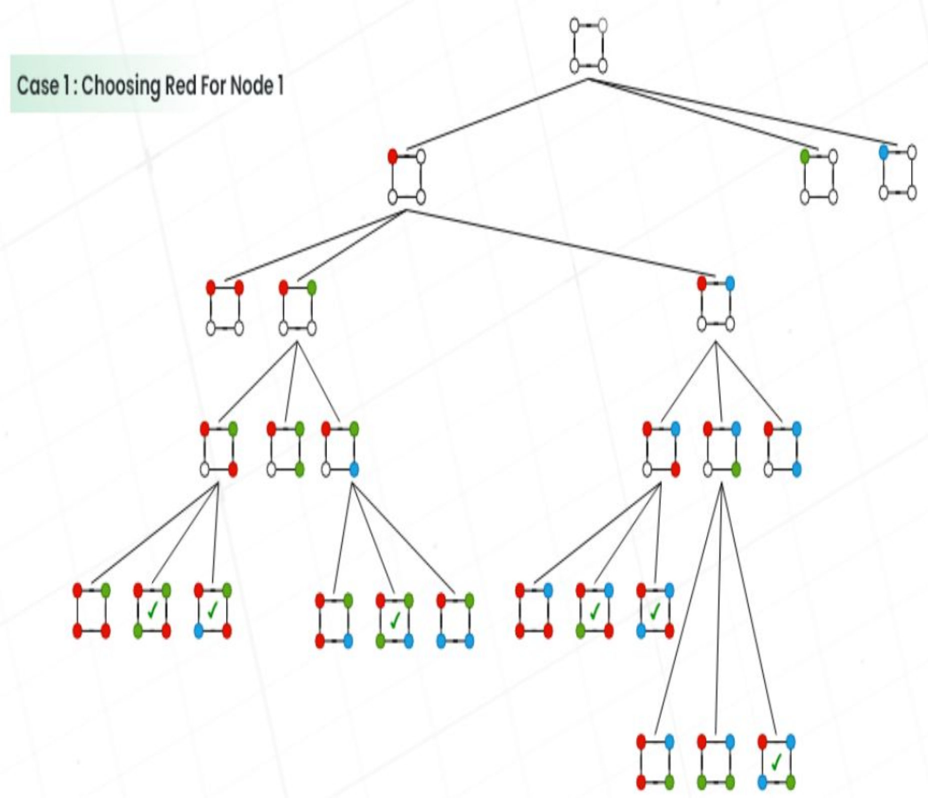
Greedy Approach

- Color the first vertex with first color.
- For all the remaining V-1 vertices
    - Color it with the lowest numbered color not used by it’s adjacent vertices
    - If all colors are used, assign a new color.
- Time complexity - $O(V^2)$

Results for Greedy Approach

Graph	Vertices (V)	Edges (E)	Chromatic Number	Running Time (s)
mycie13	11	20	4	0.002
mycie17	191	2360	8	0.008
miles1500	128	5195	76	0.016
queen_14_14	196	8372	23	0.016

Backtracking Approach



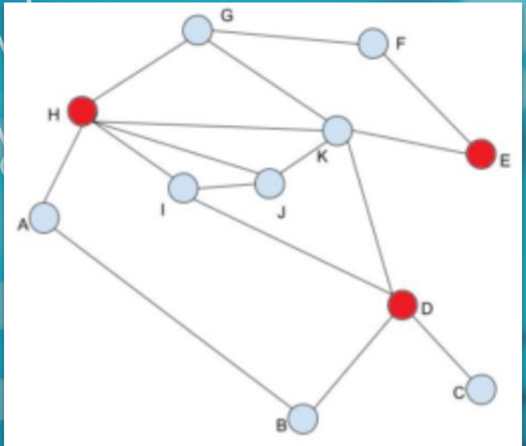
- For the selected vertex, try assigning colors one by one from a predefined set of colors while checking if the current assignment is valid (no adjacent vertices have the same color).
- If a valid color is assigned, move to the next vertex and repeat above step recursively.
- If a color cannot be assigned to the current vertex without conflicts, backtrack to the previous vertex and change its color. Repeat the above steps.
- Continue this process until all vertices are colored or until all possibilities have been explored.
- Time Complexity - k^V,
  k is the number of colors

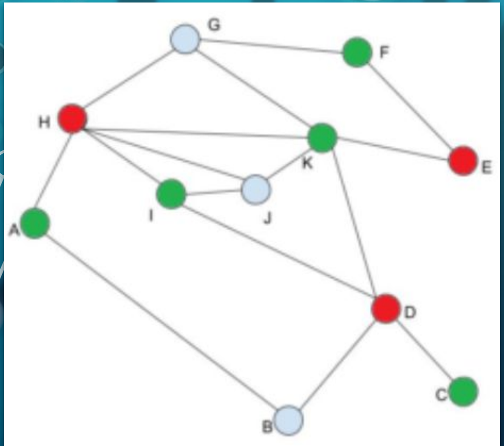
GeeksforGeeks. (2023, October 10). *M-coloring problem*. GeeksforGeeks. https://www.geeksforgeeks.org/m-coloring-problem/

Results for Backtracking

Graph	Vertices (V)	Edges (E)	Chromatic Number	Running Time (s)
mycie13	11	20	4	0.008
mycie17	191	2360	8	0.008
miles1500	128	5195	76	0.030
queen_14_14	196	8372	23	0.023

Welsh-Powell Algorithm





- Sort the vertices in descending order of their degree.
- Color first vertex with color 1.
- Color all the vertices non adjacent to the vertex with color 1 and assign them the same color (color 1).
- Repeat the above step by picking an uncolored vertex in decreasing order of their degree and assigning it a new color until all the vertices are colored.
- Time complexity - $O(V^2)$

GeeksforGeeks. (2019, October 29). *Welsh Powell graph colouring algorithm*. GeeksforGeeks. https://www.geeksforgeeks.org/welsh-powell-graph-colouring-algorithm/

Results for Welsh-Powell algorithm

Graph	Vertices (V)	Edges (E)	Chromatic Number	Running Time (s)
mycie13	11	20	4	0.003
mycie17	191	2360	8	0.008
miles1500	128	5195	73	0.012
queen_14_14	196	8372	23	0.019

Comparison of Approaches

Graph	Greedy Approach		Backtracking		Welsh-Powell	
	Chromatic Number	Running Time (s)	Chromatic Number	Running Time (s)	Chromatic Number	Running Time (s)
mycie13	4	0.002	4	0.008	4	0.003
mycie17	8	0.008	8	0.008	8	0.008
miles1500	76	0.016	76	0.030	73	0.012
queen_14_14	23	0.016	23	0.023	23	0.019

Future Work

- We would like to work on a dataset consisting of compiler instruction sets.
- Then create an interference graph from it.
- Finally consider spilling used in Chaitin's approach to reduce the number of registers.

References

1) M. Aslan and N. A. Baykan, A performance comparison of graph coloring algorithms, Int. J. Intell. Syst. Appl. Eng. 4, 1 (2016).

2) Register allocation via graph coloring - hcltech. (n.d.). https://www.hcltech.com/sites/default/files/documents/resources/whitepaper/files/register_allocation_via_graph_coloring_meena_jain_-_v2.0.pdf

3) Graph algorithms. (n.d.). https://www.cs.cornell.edu/courses/cs3110/2012sp/recitations/rec21-graphs/rec21.html

4) GeeksforGeeks. (2022, January 24). Register allocations in Code generation. GeeksforGeeks. https://www.geeksforgeeks.org/register-allocations-in-code-generation/

5) Seeing Register Allocation Working in Java. Seeing register allocation working in Java. (n.d.). https://chrisseaton.com/truffleruby/register-allocation/

Demonstration