Semantic-preserving optimization algorithm for automatic program parallelization

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Introduction to parallel loops

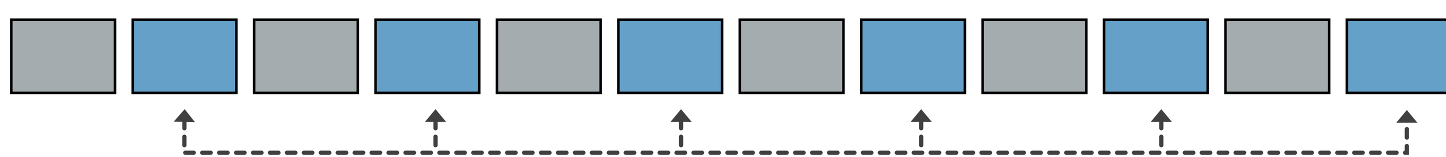
- **Loop statements** are used for implementing repeated computation, but when used extensively or carelessly, they produce performance inefficiencies.
- Modern CPUs provide critical performance improvement through **parallelism**, but software must be written specifically to utilize this available multicore hardware.

This research presents a novel algorithm for automatic program parallelization based on loop splitting. Using flow-dependency analysis inspired by Implicit Computational Complexity theory, the algorithm detects opportunities for splitting loops horizontally into smaller, parallelizable loops, then automatically applies this optimization. The transformation is **semantic-preserving**, which ensures the program behavior remains unchanged.

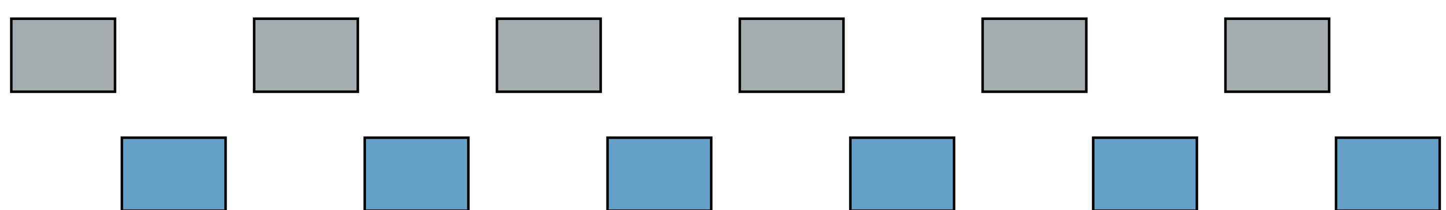
> *We hypothesize combining this algorithm with OpenMP [1], an existing state-of-the-art shared memory multiprocessing programming model, will provide noticeable performance gains for resource-intensive computational tasks.*

Our technique pictorially

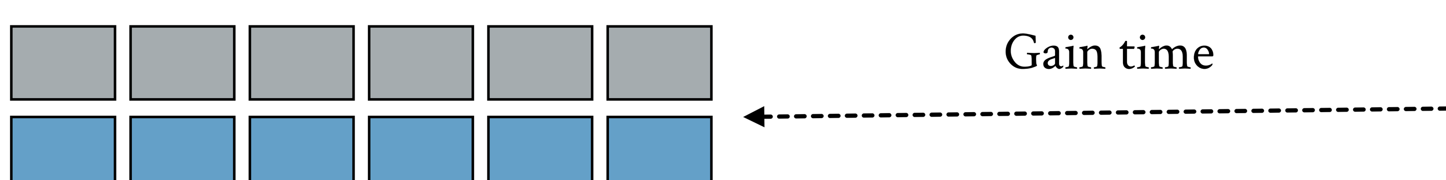
Step 1. Identify flow-independencies



Step 2. Split computation horizontally



Step 3. Parallelize



Implementation and examples

Development is currently underway for an open-source tool implementing this technique on a subset of C programming language.

Before optimization

```
void main() {
  int n = 100;
  int a[n], b[n];

  for(int i = 0; i < n; ++i){
    a[i] = i;
    b[i] = i * 2;
  }
}
```

After optimization

```
void main() {
  int n = 100;
  int a[n], b[n];

  # pragma omp parallel for
  for(int i = 0; i < n; ++i)
    a[i] = i;

  # pragma omp parallel for
  for(int i = 0; i < n; ++i)
    b[i] = i * 2;
}
```

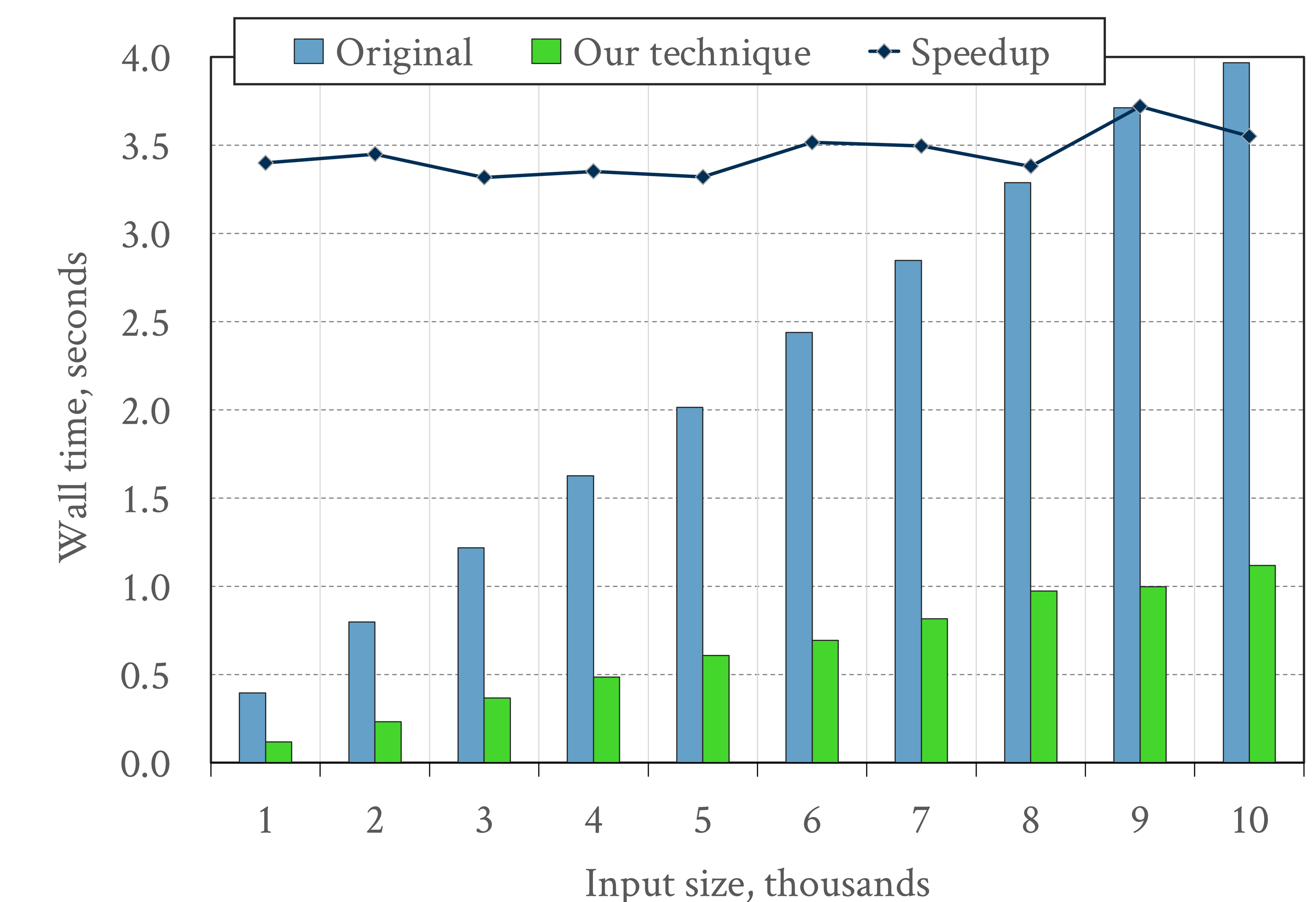
Pseudo code

```
OPTIMIZE(c_program : str) -> [str]

  Parse C program into Abstract Syntax Tree (AST)

  Recursively for each loop in AST:
      1. Find primary dependencies of loop body variables
      2. Build a directed graph of dependencies
      3. Compute strongly connected components (SCC)
      4. Separate SCCs into subgraphs
      5. Split the loops based on subgraphs
      6. Insert each split loop into AST

  Reconstruct C program from AST using C generator

  Return optimized program
```

Source code: `https://github.com/statycc/pyalp`

Preliminary benchmarks

Program wall time, as measured on example `two_arrays`, and GCC optimization level –O0, showing average speedup of factor 3.4, on executing machine: Darwin kernel v. 20.6.0, i386 processor, with 4 cores and 16 GB RAM.



Conclusion

State of the art tools for loop optimization techniques have limitations, e.g., `while` loops are not optimized [2;3], and algorithm redesign and manual effort is required to create potential for parallelism [4].

Our technique has potential to address these deficiencies: it is loop-type agnostic, identifies parallelization opportunities automatically, and has already demonstrated preliminary performance gains.

Open questions and future work

- Development of cost-benefit analysis to ensure gain
- Implementation need to be extended to support for richer C language syntax, but algorithm and prototype already exist
- Completing further benchmarking and measurements

[1] Michael Klemm and Bronis R. de Supinski, editors. OpenMP Application Programming Interface Specification Version 5.2, November 2021.

[2] Timothy G. Mattson, Beverly A. Sanders, and Berna L. Massingill. Patterns for parallel program ming. Addison-Wesley Educational, Boston, MA. 2004.

[3] Rohit Chandra, Ramesh Menon, Leo Dagum, David Kohr, Dror Maydan, and Jeff McDonald. Parallel Programming in OpenMP. Morgan Kaufmann, 2000.

[4] Jukka Suomela. Programming Parallel Computers. Aalto University, 2015. URL: https://ppc.cs.aalto.fi