Phoenix: Language-Driven Auto-Vectorisation

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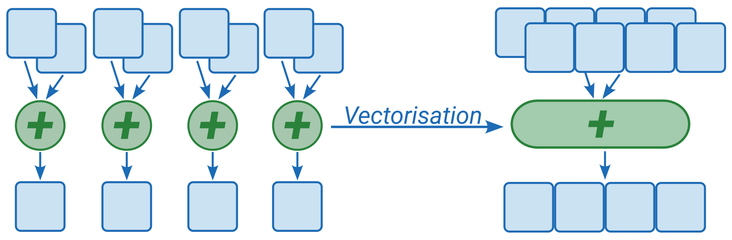
1. Research Context

Modern CPUs are equipped with SIMD units, allowing a single CPU core to evaluate the same instruction on multiple data values in parallel. Even commodity hardware is able to achieve significant performance improvements by leveraging data-parallelism.



Branching control flow obscures data-parallelism in scalar code

The problem: manual vectorisation is very complex, and existing tools fail to provide guarantees for efficiently exploiting SIMD units.

2. Existing Approaches

Manual vectorisation: guaranteed performance at extreme complexity

Automatic (auto-)vectorisation: no developer burden, but also no performance guarantees

Language extensions: low developer burden, but minor guarantees to performance and correctness (data race conditions)

3. Phoenix

Phoenix is a data-parallel programming language, designed to allow safe, efficient vectorisation while still closely resembling scalar code by employing restricted vector loops.
All restricted vector loops are subject to these three restrictions:

Iteration independence: to eliminate loop-carried dependencies, vector loops are not allowed to modify non-loop-local variables.

Loop completion: to be able to pre-compute the loop-trip-count, vector loops cannot early exit (i.e., no break or return).

Index-free loop operation: reading masked-out elements introduces undefined behavior. Phoenix prohibits arbitrary indexing in vector loops.

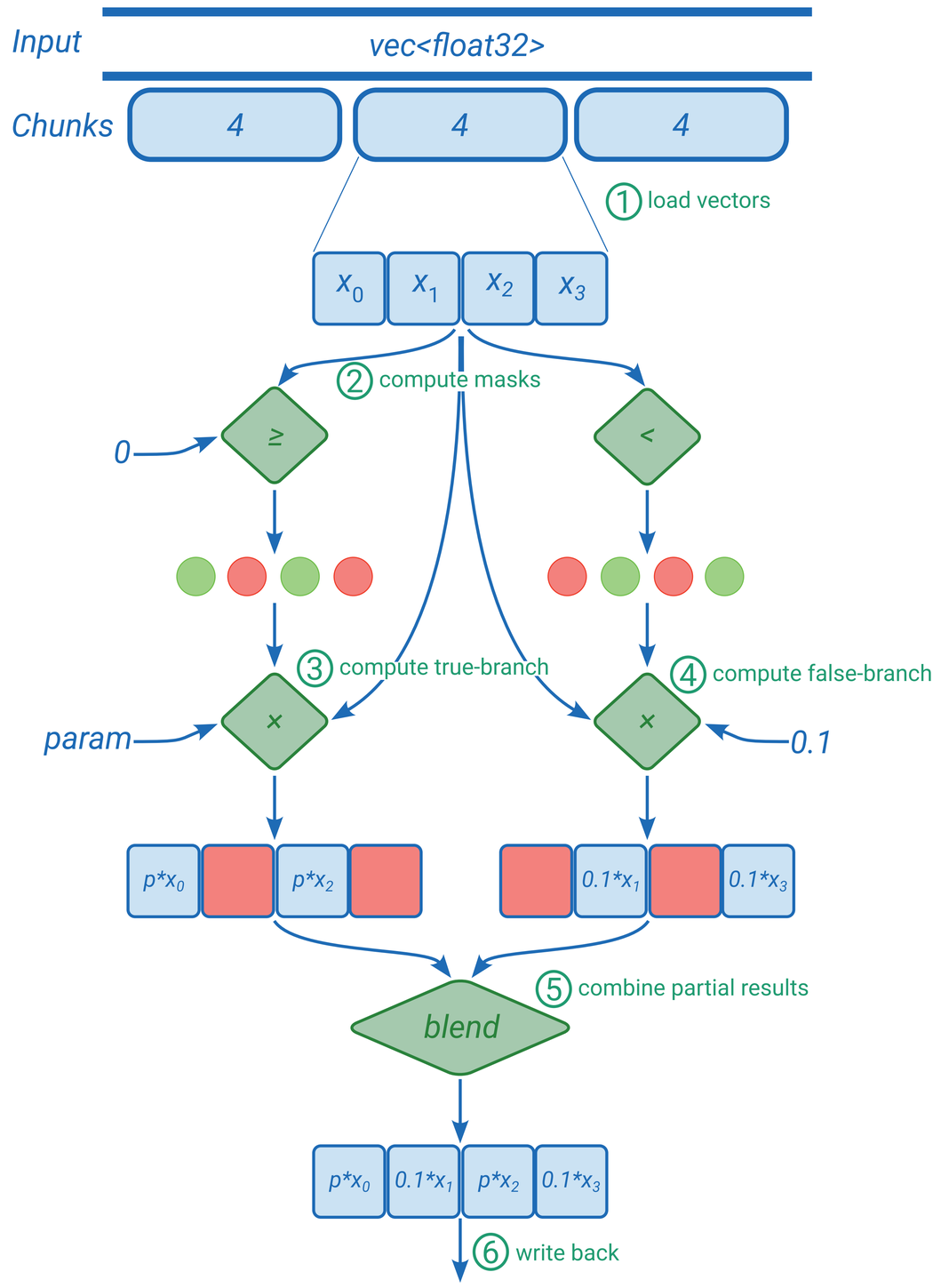
These three restrictions guarantee safe and correct vectorisability

Example: leaky scaled ReLU.

```
void leaky_relu(vec<float32> &xs, float32 param) {
  foreach x in xs {
    if (x ⩾ 0.0f) continue with param * x;
    else continue with 0.1f * x;
  }
}
```

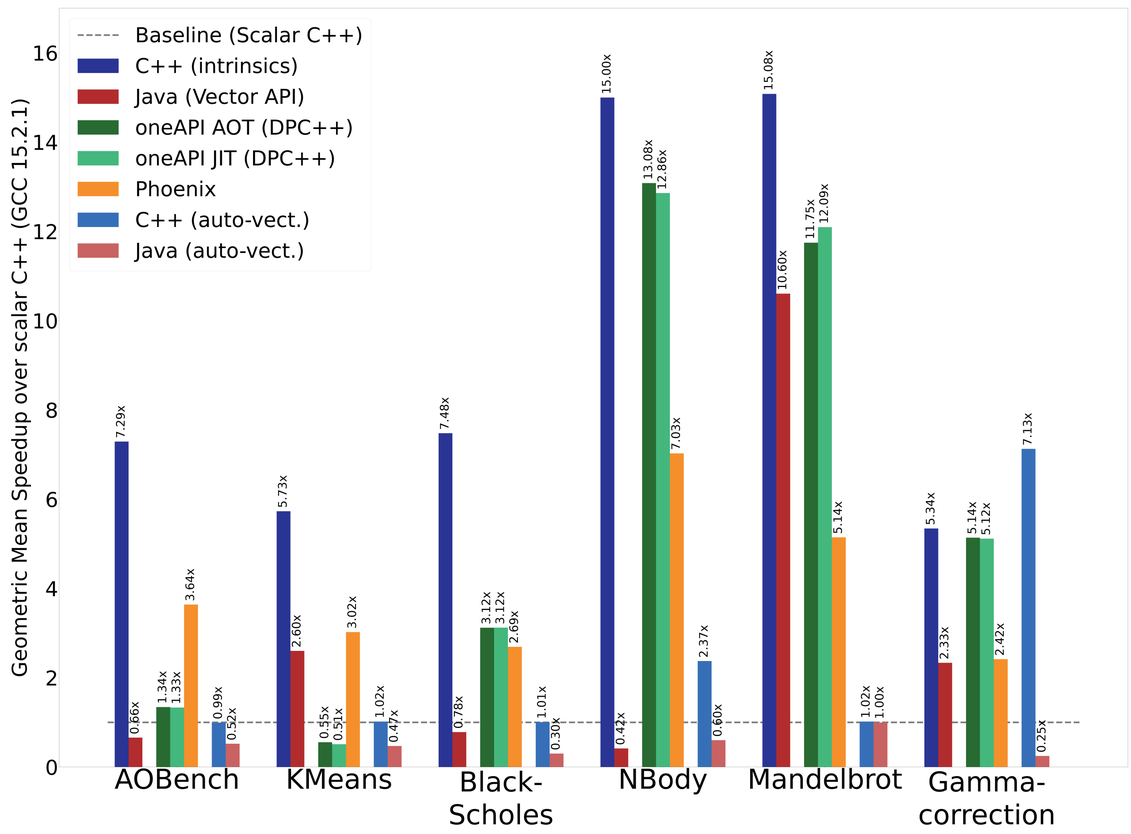
Phoenix's design eliminates compiler guesswork, guaranteeing vectorisability

4. Simplified Vectorisation Steps



5. Evaluation

We evaluated Phoenix through a benchmark suite with kernels from various application domains, showing that its expressivity is not hampered by its restrictions.



Complex control flow does not inhibit Phoenix's vectoriser.

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