Your Optimizing Compiler is not Optimizing Enough. To hell with Multiple Recursions!

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Milan, Italy – 25 November 2025

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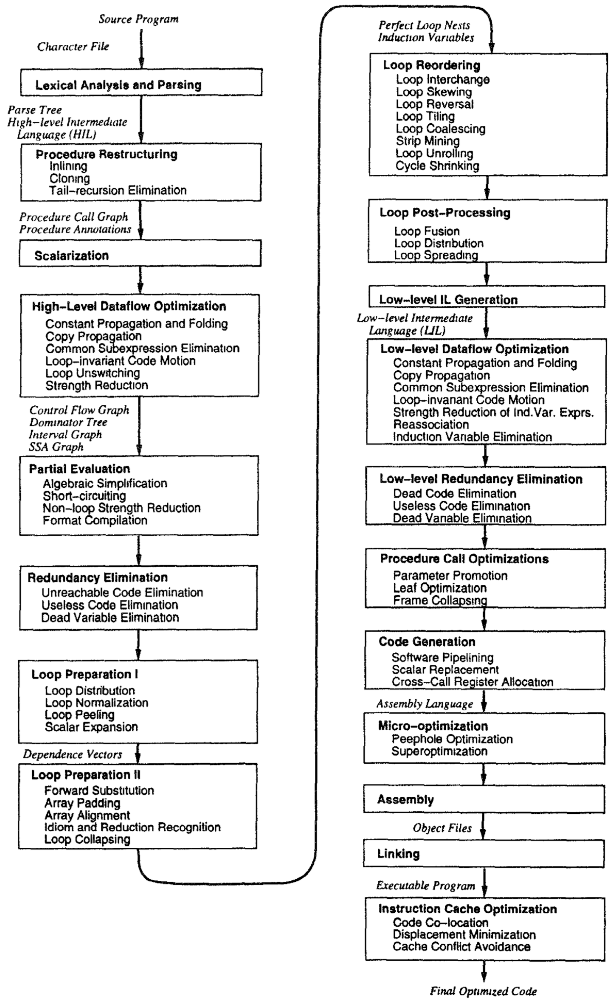
Compilers as Musical Compositions

Compilers are frequently perceived as intricate musical compositions—like the unfinished *J. S. Bach's Art of Fugue*—where mathematical precision and logical interplay guide each part.

Every module enters in perfect timing, weaving together a structure that only the keenest ears can fully grasp.

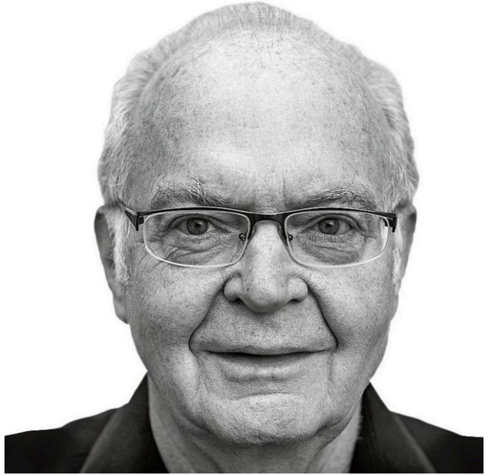


Bacon *et al.*, CSUR 1994 [1]

Premature Optimizations

Donald E. Knuth warned in 1974 about the dangers of **premature optimization** in programming [2]:

We should forget about small efficiencies, say about 97% of the time: premature optimization is the root of all evil. Yet we should not pass up our opportunities in that critical 3%.



In the absence of either empirically measured or theoretically justified performance issues, programmers should **avoid** making optimizations based **solely** on assumptions about potential performance gains.

Optimizing Compilers

Compilers use information collected during analysis passes to guide transformations [3], [4].

Compiler optimizations are such transformations (say *meaning-preserving mappings* [5]) applied to the input code to improve certain aspects—such as performance, resource utilization, and power consumption—without altering its observable behavior.

In accordance with the literature [6], [7], such compilers are referred to as **optimizing compilers**.

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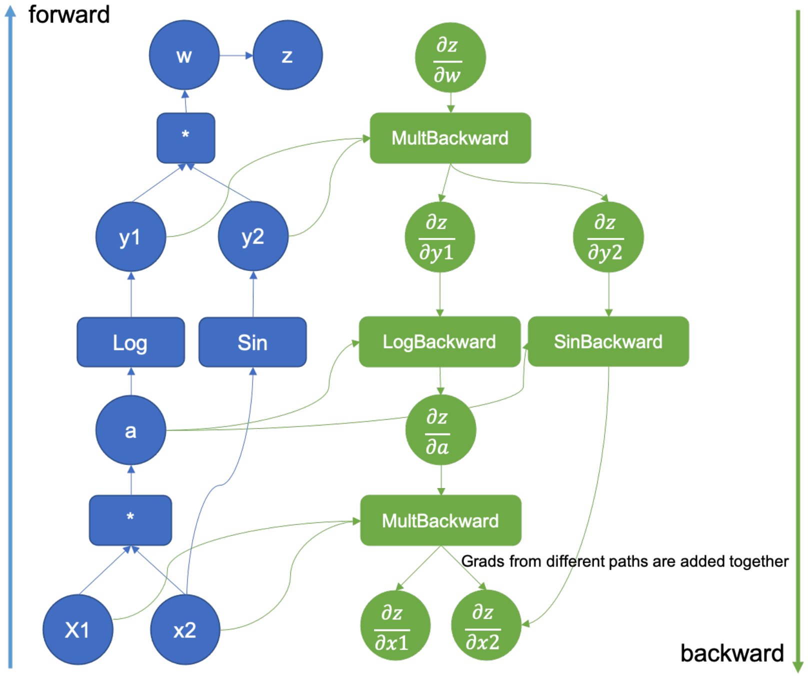
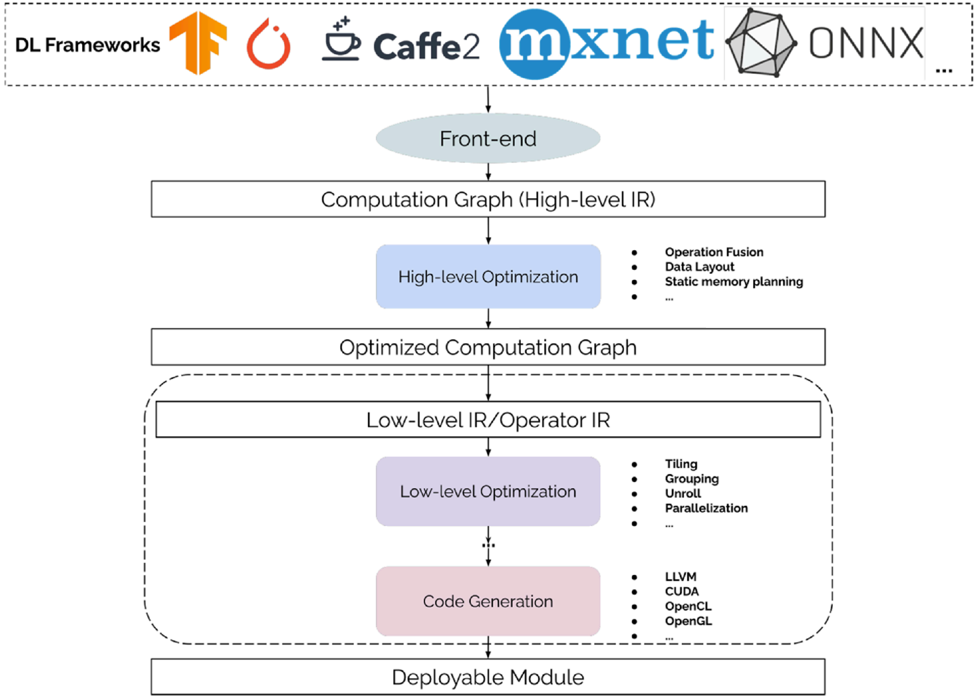
Machine Learning Framework are Just Optimizing Compilers[2]





[2]Li *et al.*, CSUR 2020, [8] compiled a comprehensive survey on deep learning compilers.

Peephole Optimizations (cf. [9], [10])

```asm
; x = x * 2
LOAD R1, 0       ; load from 0
MUL R1, 2        ; multiply R1 by 2
STORE R1, 0      ; store R1 back to 0
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The optimized version replaces the multiplication by 2 with a **more efficient** binary shift operation.

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```

The optimized version removes the **unnecessary** addition operation.

$\Downarrow$

```asm
LOAD R1, 0
STORE R1, 0
```

Loop Nest Optimizations — Loop Tiling (cf. [11], [12])

C++
```cpp
for (int i=0; i<n; ++i) {
  for (int j=0; j<m; ++j) {
      c[i][j] = a[i] * b[j];
  }
}
```

The vector `b` **may not** fit into a line of CPU cache, causing multiple cache misses during the inner loop.

It implies multiple **fetches** from the main memory, which is **slow**.

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```cpp
int TS = 16; // Tile Size
for (int jj=0; jj<m; jj+=TS) {
  for (int i=0; i<n; ++i) {
      for (int j=jj; j<MIN(jj + TS, m); ++j) {
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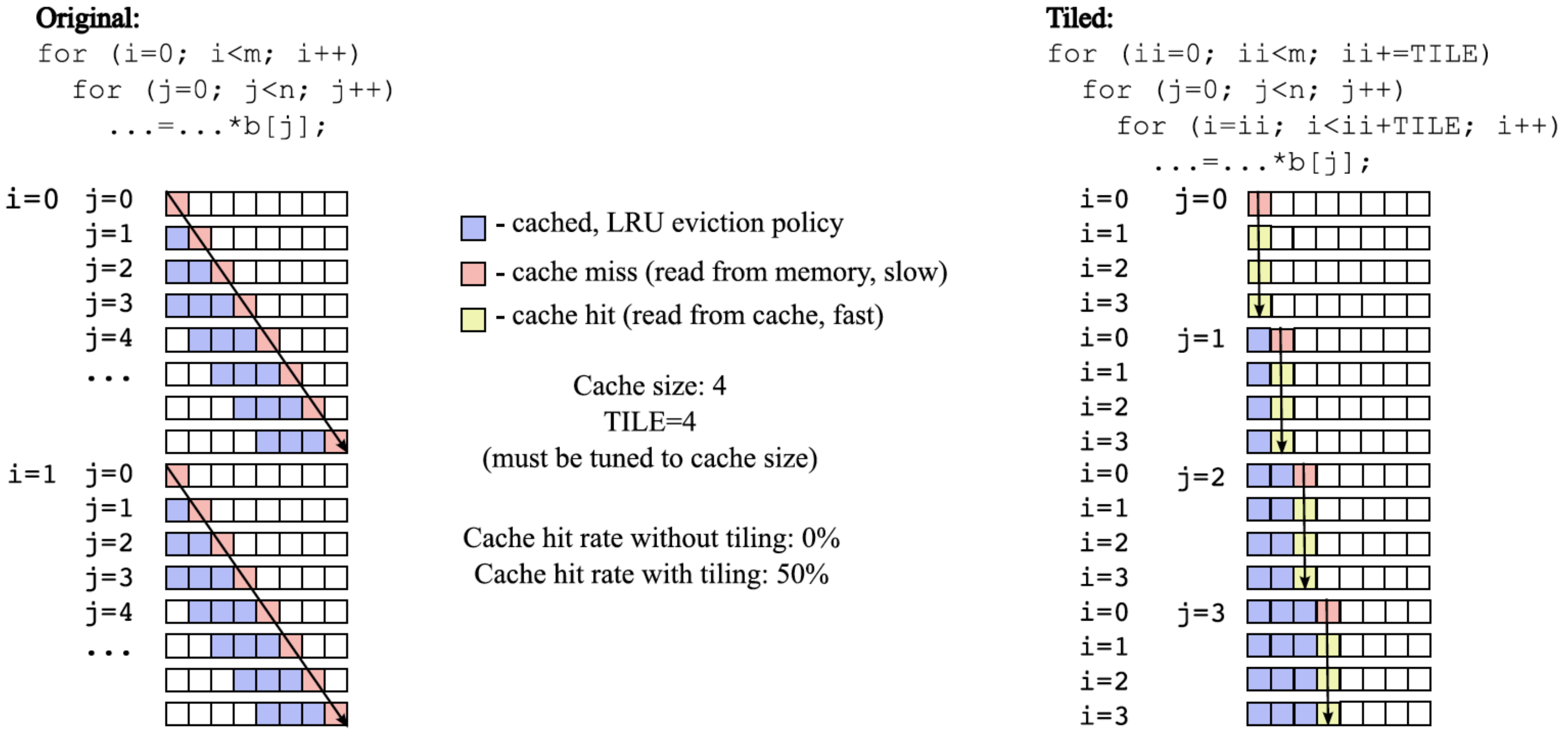
But, the values for the array `a` will be read `m / TS` times!

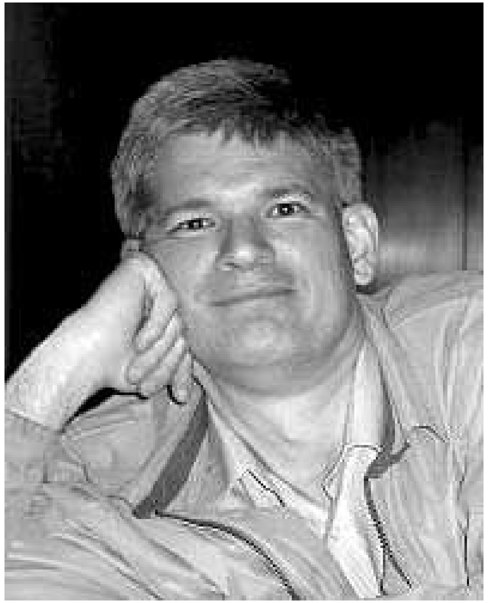
Loop Tiling Visualization



Tail Call/Recursion Optimization (cf. [3], [13], [14])

Guy L. Steele, Jr. in 1977 observed that **tail-recursive procedure calls** can be optimized to avoid growing the call stack [15]:

In general, procedure calls may be usefully thought of as GOTO statements which also pass parameters, and can be uniformly coded as [machine code] JUMP instructions.



Tail-recursive Factorial Function

C++

```cpp
int fact(int n) {
    if (n == 0) {
        return 1;
    }
    return n * fact(n - 1);
}
```

```llvm
define i32 @fact(int)(i32 %n)  {
entry:
  %cmp3 = icmp eq i32 %n, 0
  br i1 %cmp3, label %return, label %if.else ; label %if.else.preheader
; if.else.preheader -> vector.ph -> vector.body -> middle.block -> if.else.preheader7
if.else:
  %n.tr5 = phi i32 [ %sub, %if.else ], [ %n.tr5.ph, %if.else.preheader7 ]
  %acc.tr4 = phi i32 [ %mul, %if.else ], [ %acc.tr4.ph, %if.else.preheader7 ]
  %sub = add nsw i32 %n.tr5, -1
  %mul = mul nsw i32 %n.tr5, %acc.tr4
  %cmp = icmp eq i32 %sub, 0
  br i1 %cmp, label %return, label %if.else
return:
  %acc.tr.lcssa = phi i32 [ 1, %entry ], [ %4, %middle.block ], [ %mul, %if.else ]
  ret i32 %acc.tr.lcssa
}
```

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