

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

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Milan, Italy – 24 November 2025

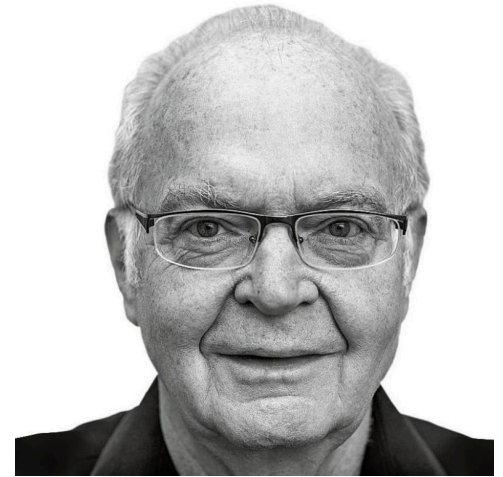
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# Premature Optimizations

Donald E. Knuth warned in 1974 about the dangers of **premature optimization** in programming [1]:

*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%.*

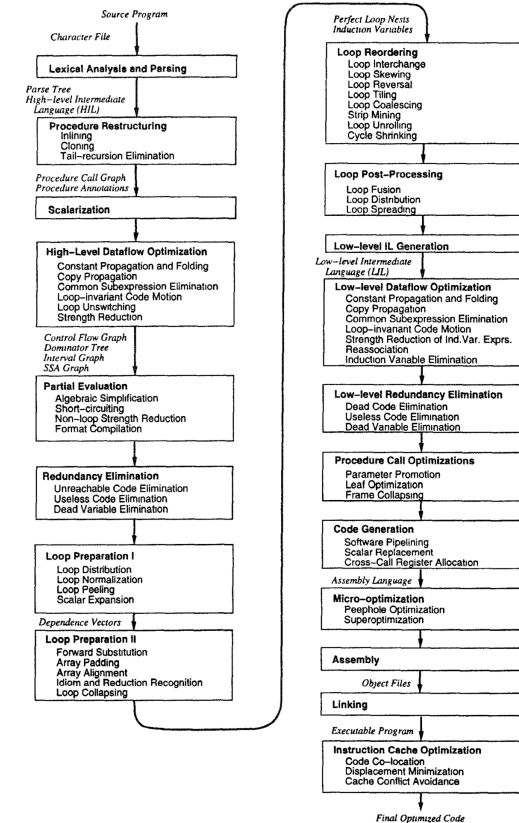


In the absence of either empirically measured or theoretically justified performance issues, programmers should **avoid** making optimizations based **solely** on assumptions about potential performance gains.

# Optimizing Compilers as Musical Compositions

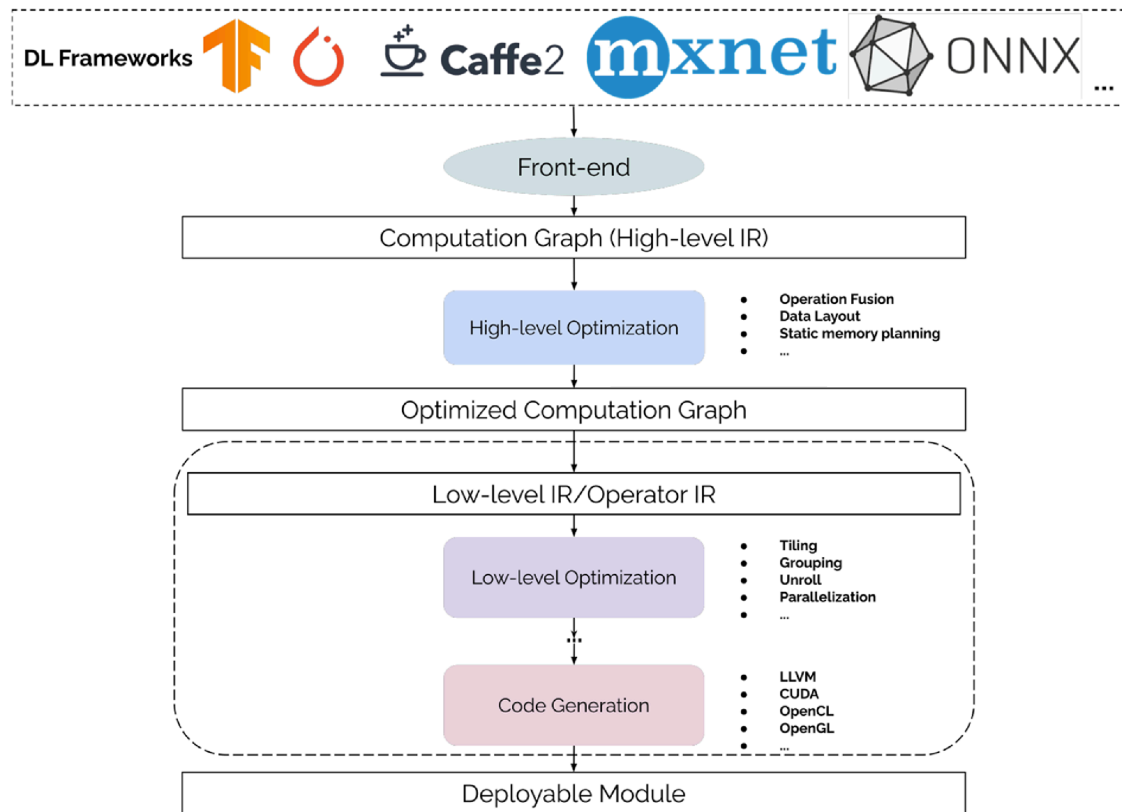
Compilers are frequently perceived as intricate musical compositions—like the unfinished *J. S. Bach's Art of Fugue*—where mathematical precision and logical interplay guide each part.

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

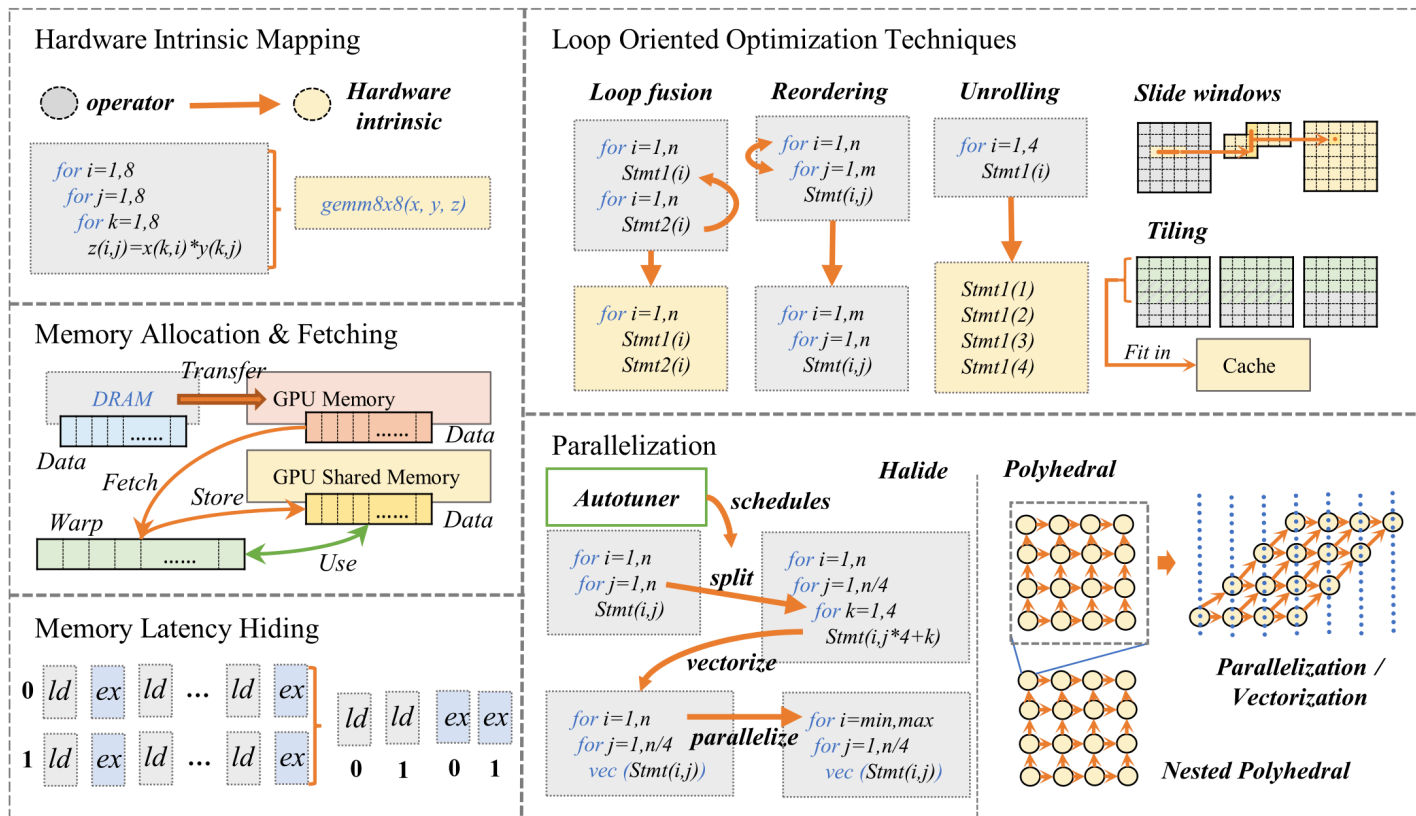


Bacon et al., CSUR 1994 [2]

# Machine Learning Framework are Just Optimizing Compilers



# Machine Learning Framework (Cont.)



Li et al., CSUR 2020, [3]

# Peephole Optimizations (cf. [4], [5])

```
; x = x * 2
```

asm

```
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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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.



```
LOAD R1, 0
```

asm

```
SHL R1, 1      ; shift left by 1
```

```
STORE R1, 0
```



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The optimized version replaces the multiplication by 2 with a **more efficient** binary shift operation.



```
LOAD R1, 0  
SHL R1, 1       ; shift left by 1  
STORE R1, 0
```

asm

```
; x = x + 0  
LOAD R1, 0  
ADD R1, 0       ; add 0 to R1  
STORE R1, 0
```

asm

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LOAD R1, 0
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```

asm

```
; x = x + 0
LOAD R1, 0
ADD R1, 0       ; add 0 to R1
STORE R1, 0
```

asm

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



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

asm

# Loop Nest Optimizations — Loop Tiling (cf. [6], [7])

```
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**.

# Loop Nest Optimizations — Loop Tiling (cf. [6], [7])

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```
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) {  
            c[i][j] = a[i] * b[j];  
        }  
    }  
}
```

The inner loop works on a **tile** of **b** that fits into the cache.

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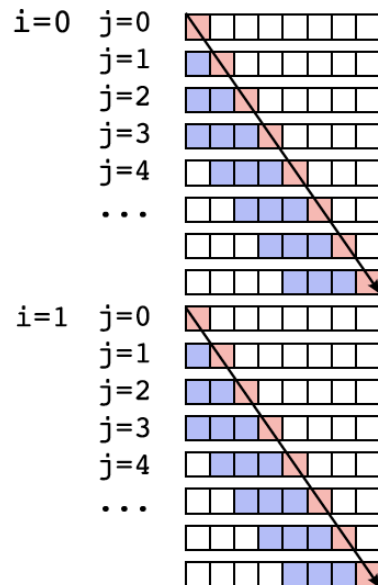
The inner loop works on a **tile** of **b** that fits into the cache.

But, the values for the array **a** will be read  $m / TS$  times!

# Loop Tiling Visualization

## Original:

```
for (i=0; i<m; i++)  
  for (j=0; j<n; j++)  
    ...=...*b[j];
```



- - cached, LRU eviction policy
- - cache miss (read from memory, slow)
- - cache hit (read from cache, fast)

Cache size: 4

TILE=4

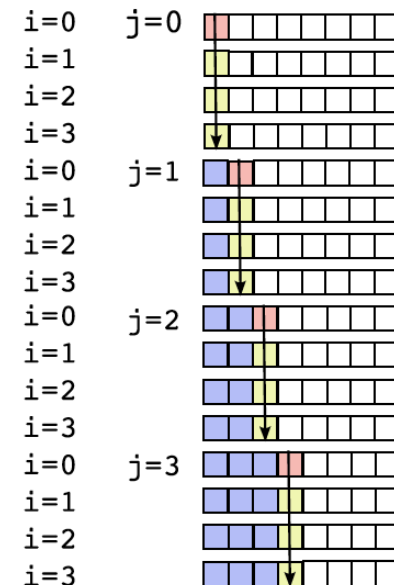
(must be tuned to cache size)

Cache hit rate without tiling: 0%

Cache hit rate with tiling: 50%

## Tiled:

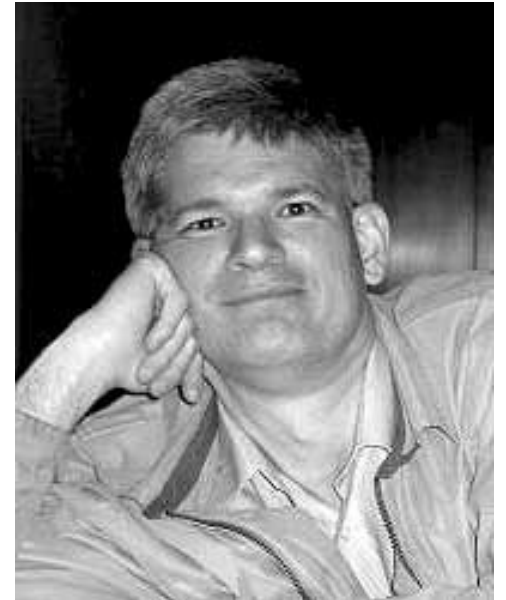
```
for (ii=0; ii<m; ii+=TILE)  
  for (j=0; j<n; j++)  
    for (i=ii; i<ii+TILE; i++)  
      ...=...*b[j];
```



# Tail Call/Recursion Optimization (cf. [8], [9], [10])

Guy L. Steele, Jr. in 1977 observed that **tail-recursive procedure calls** can be optimized to avoid growing the call stack [11]:

*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

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



```
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  
}
```



# Bibliography

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