TSLP Throttling Automatic Vectorization: When Less is More

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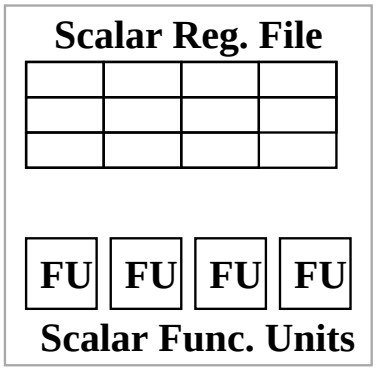
University of Cambridge

LLVM Developer's Meeting 2015


UNIVERSITY OF CAMBRIDGE

Why SIMD Vectorization?

- Scalable parallelism



a. ILP

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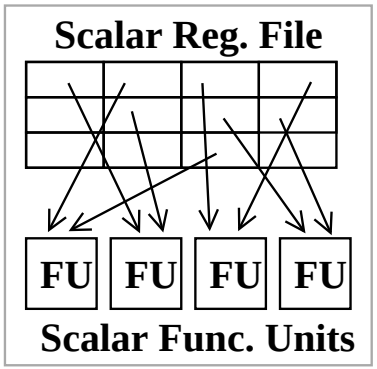

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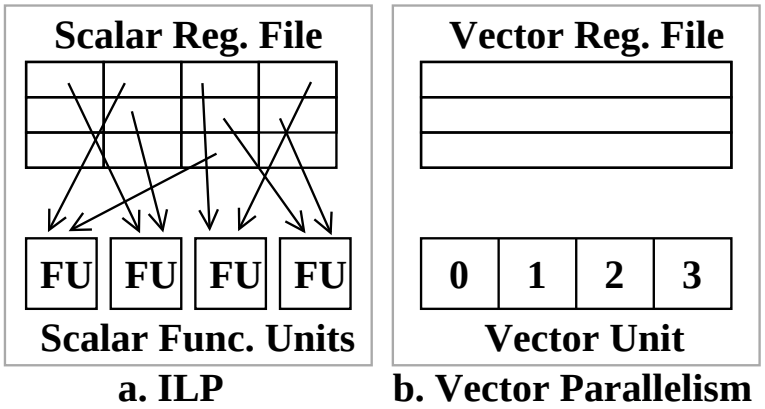

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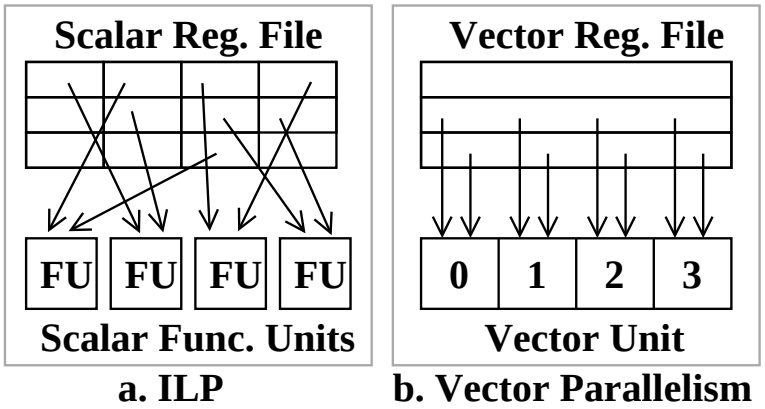

Why SIMD Vectorization?

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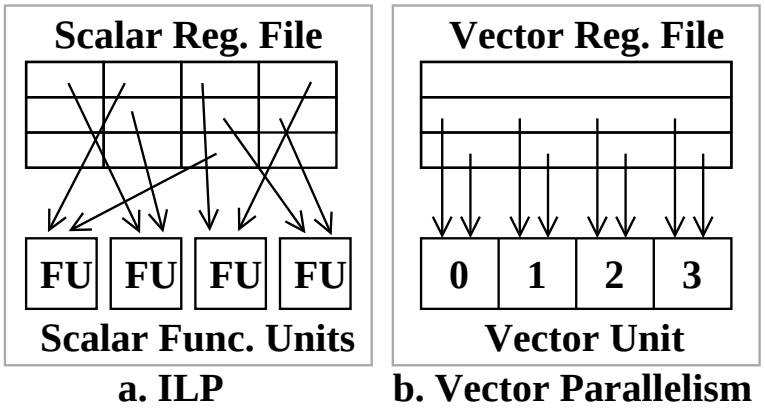

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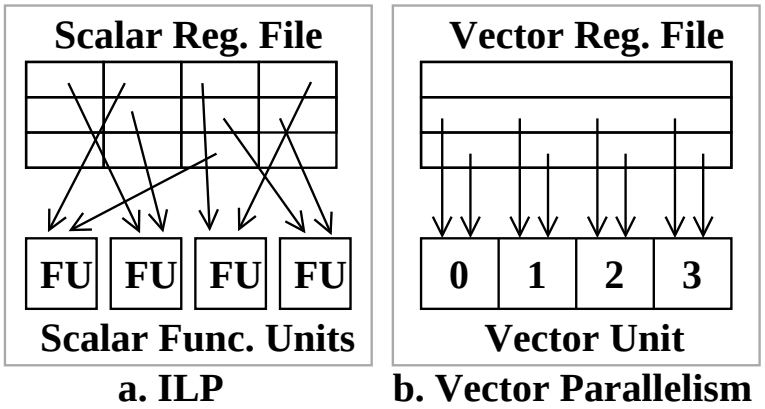

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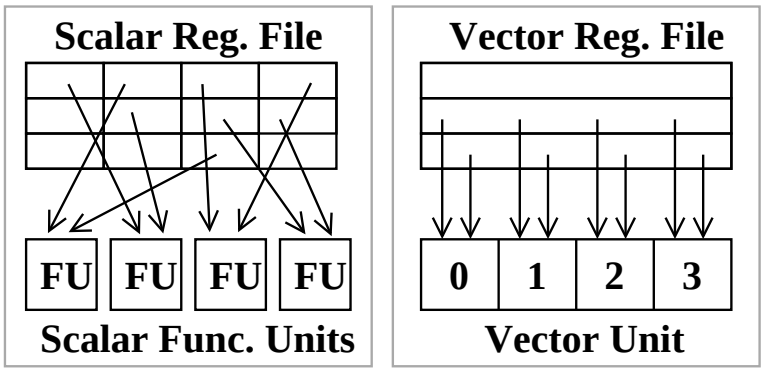
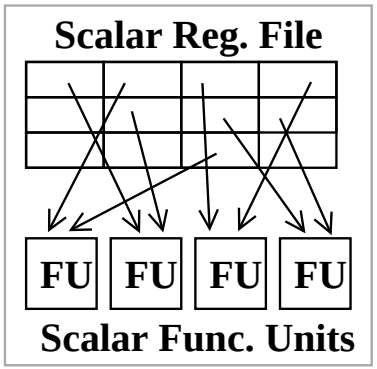
- Supported since mid 90's
- Frequent updates of vector ISAs



a. ILP b. Vector Parallelism

Why SIMD Vectorization?

- Scalable parallelism
- High Performance
- Energy efficiency
- Supported since mid 90's
- Frequent updates of vector ISAs
- Vector generation not done in hardware
- Low-level programming or capable compiler



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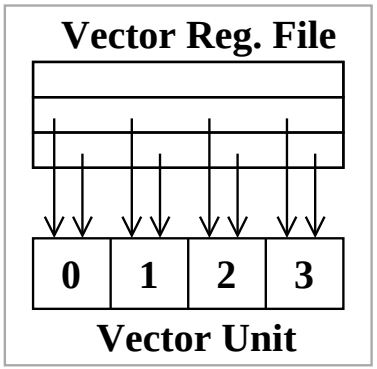

b. Vector Parallelism

SLP Straight-Line Code Vectorizer

- Superword Level Parallelism [Larsen PLDI'00]

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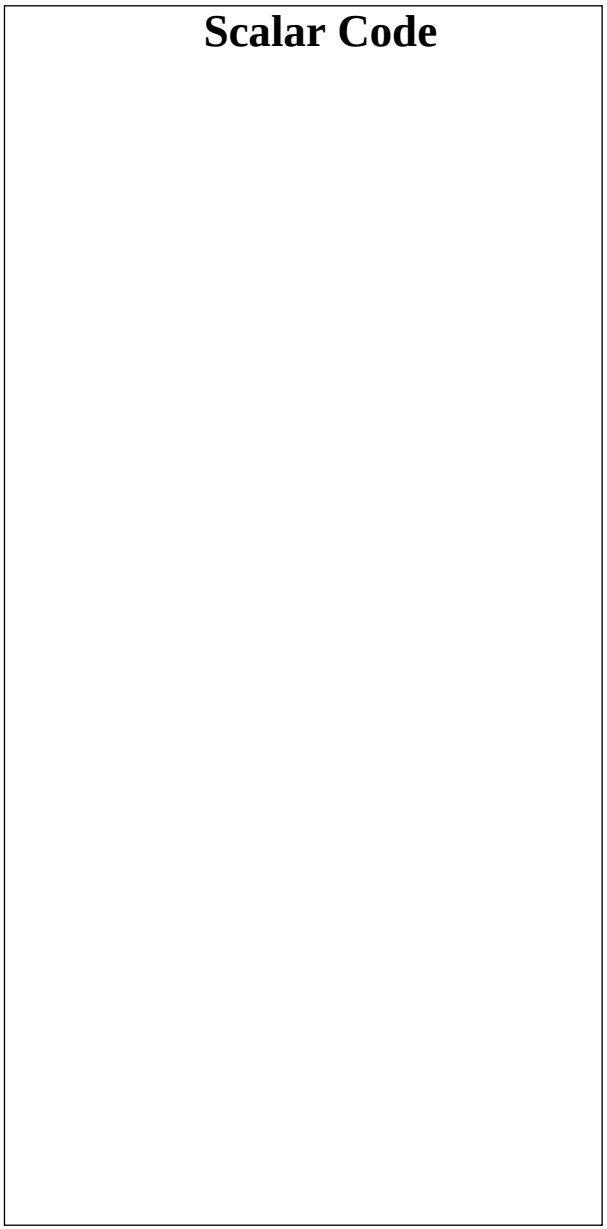
- In theory it should be a superset of loop-vectorizer
  - Unroll loop and vectorize with SLP
  - Even if loop-vectorizer fails, SLP could partly succeed
- In practice it is missing features present in the Loop vectorizer (Interleaved Loads, Predication)

SLP Vectorization Algorithm

- Input is scalar IR



SLP Vectorization Algorithm

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  1. Consecutive Stores
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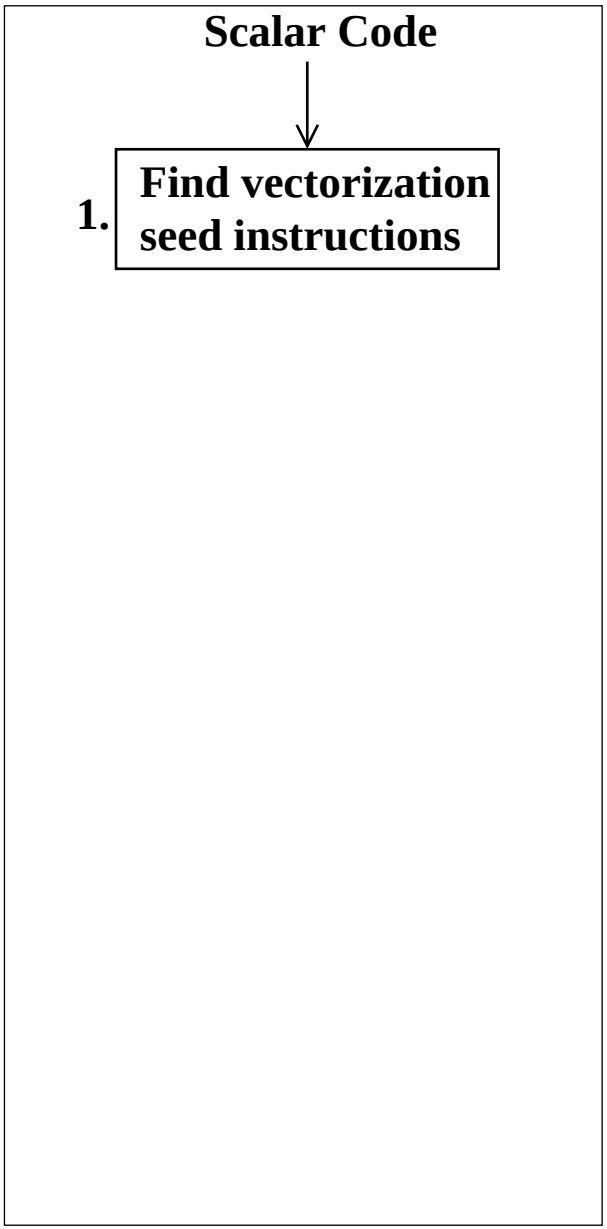

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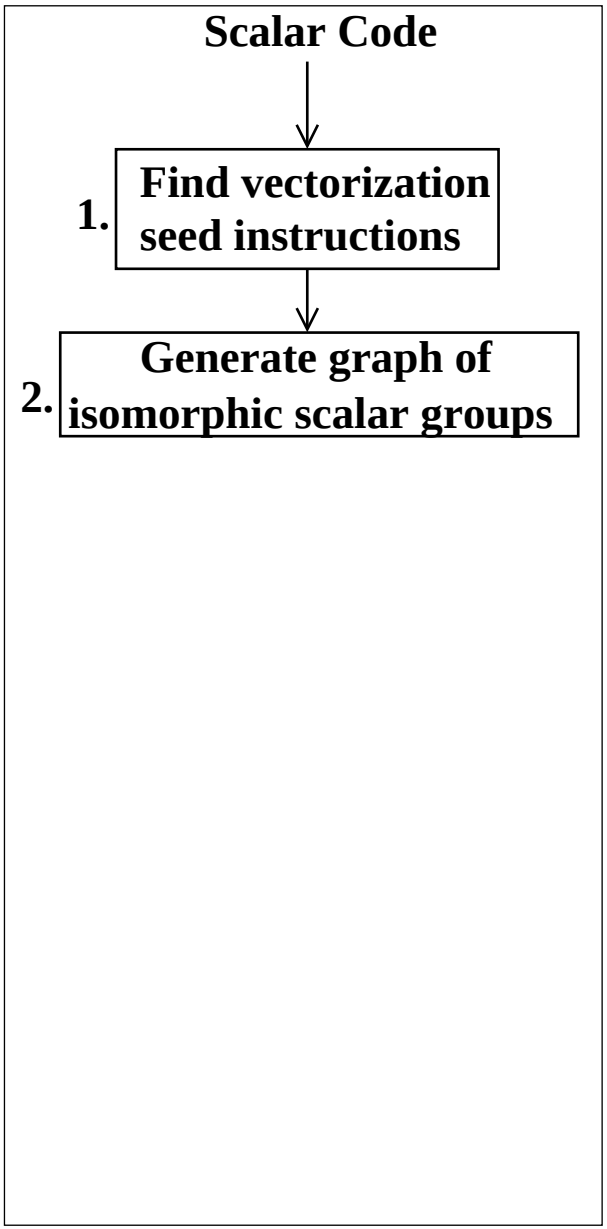

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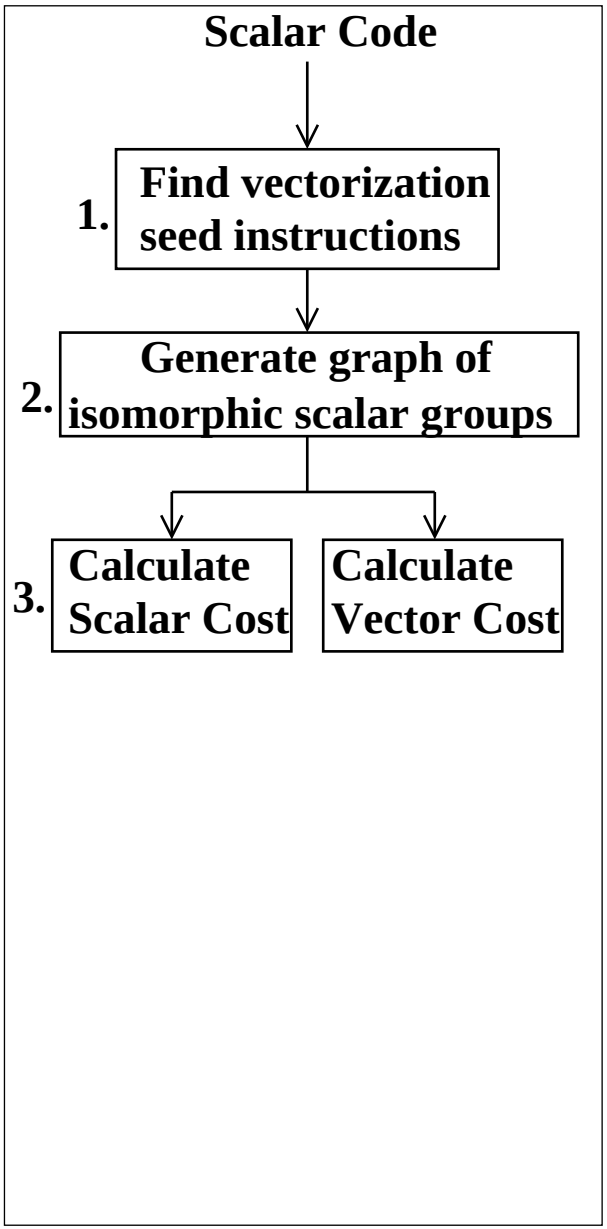

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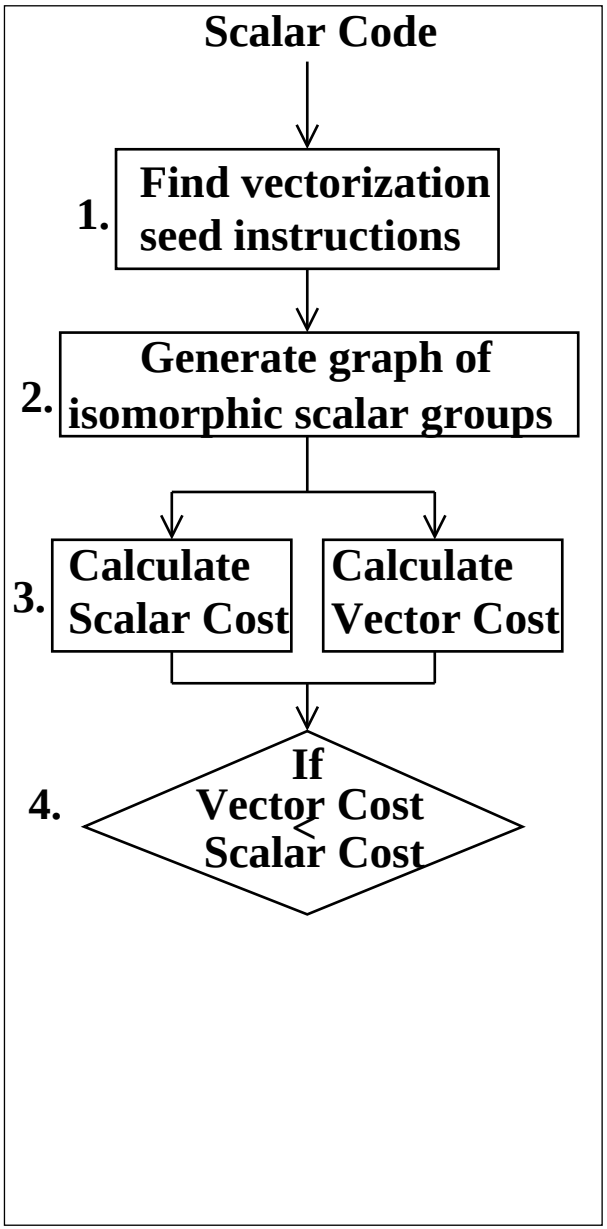

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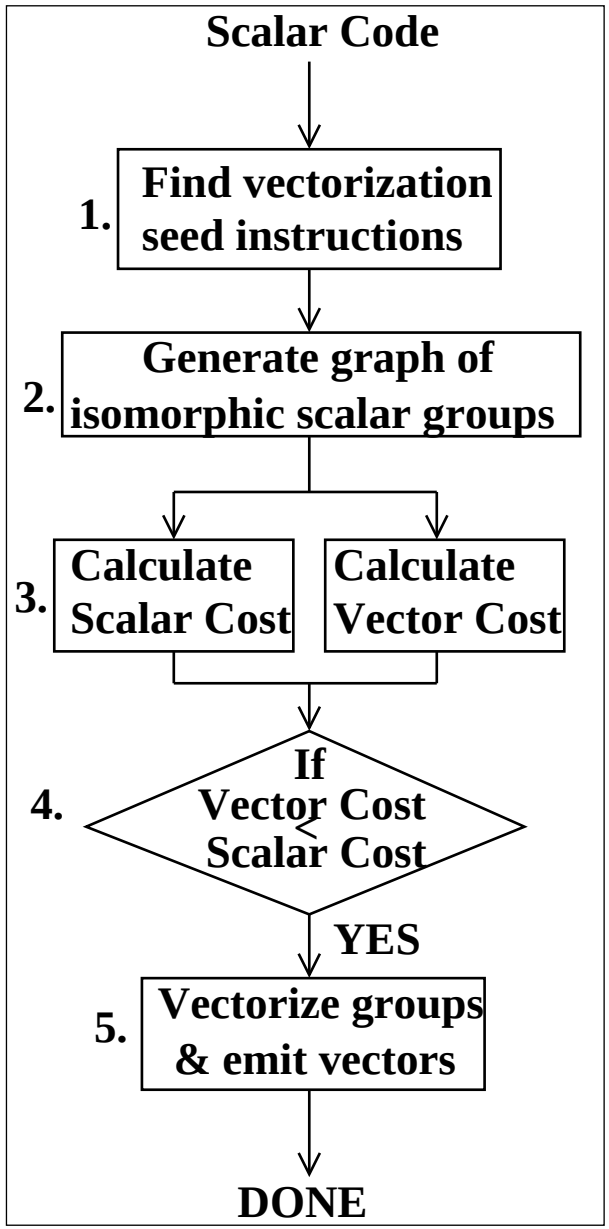

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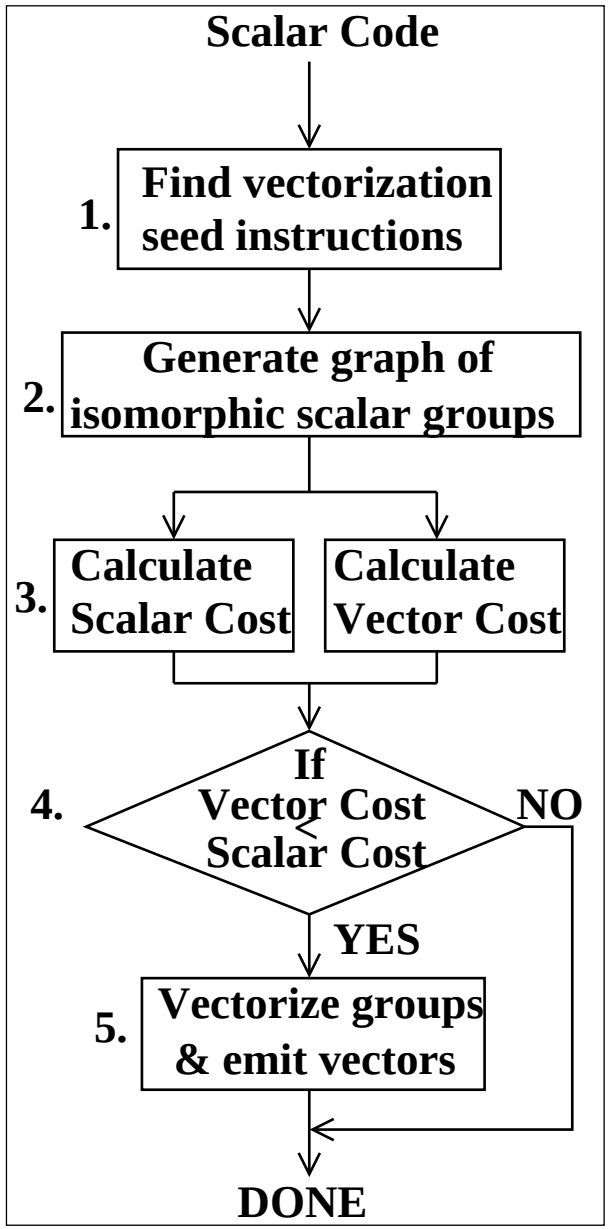

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- Costs outweigh the benefits: E.g. too many gather/scatter instructions

Original	Vectorized
ADD1	
ADD2	
ADD3	
ADD4	

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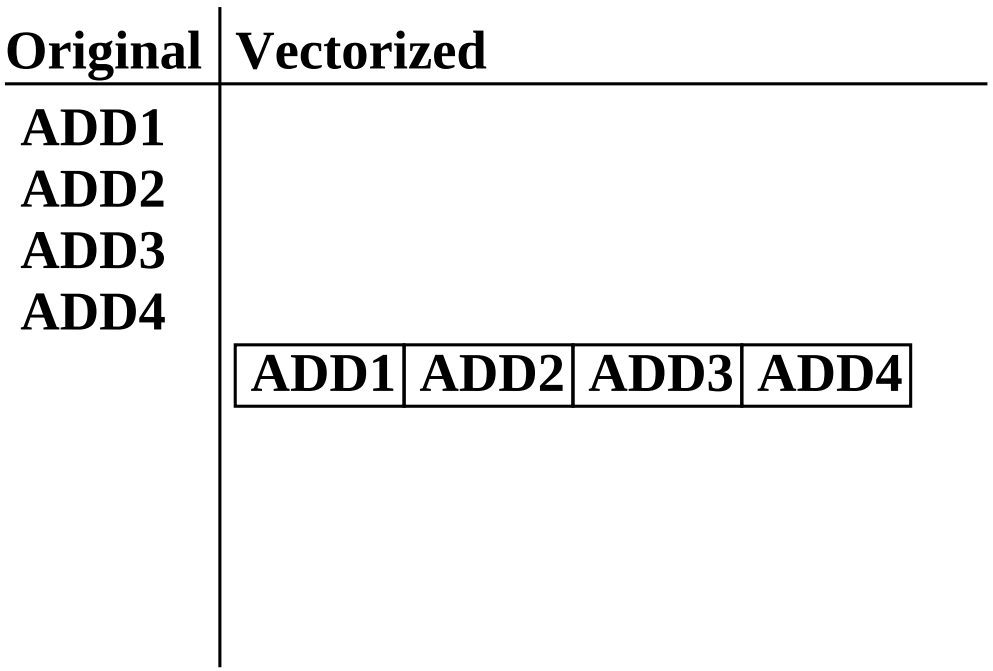

When SLP is not profitable

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Original	Vectorized
ADD1	Insert1
ADD2	Insert2
ADD3	Insert3
ADD4	Insert4
	ADD1 | ADD2 | ADD3 | ADD4
	Extract1
	Extract2
	Extract3
	Extract4

SLP not profitable for whole graph

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A[i]  =B[i]   + (C[2*i]*(D[2*i]+(E[2*i]*C[2*i])))
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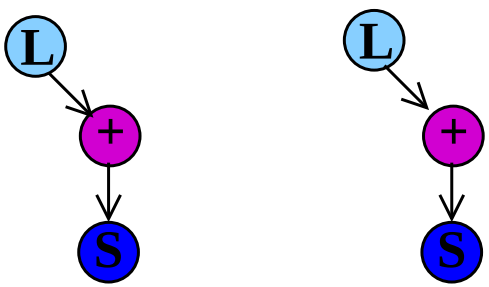

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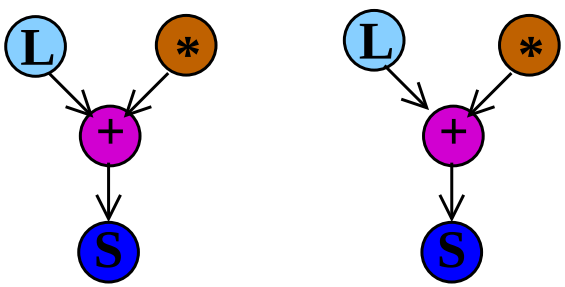

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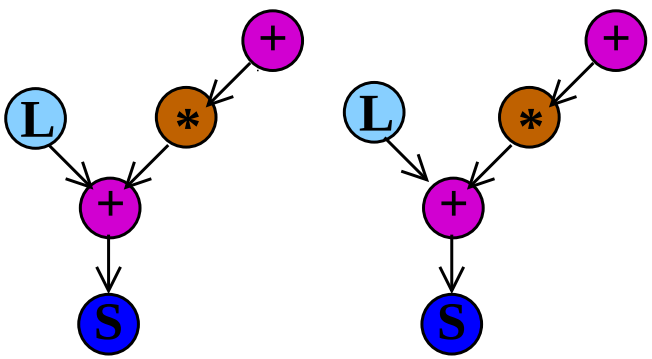

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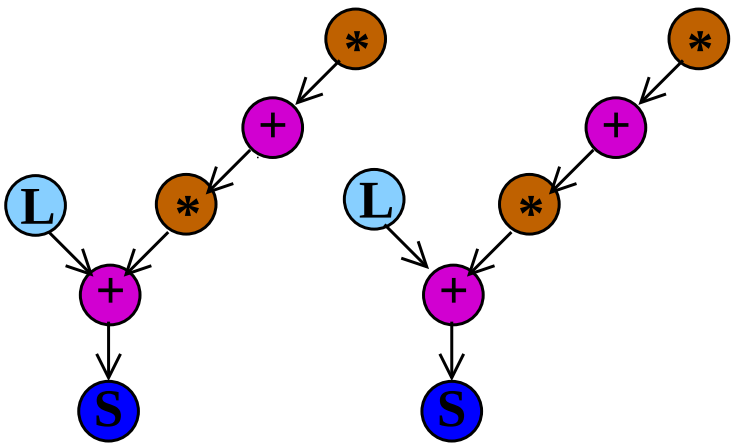

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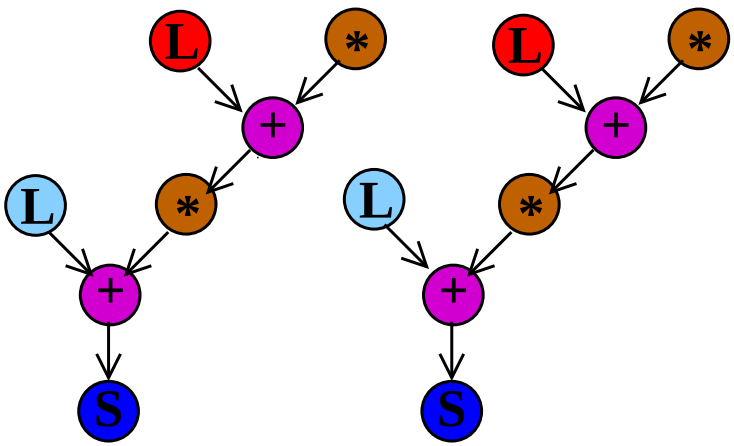

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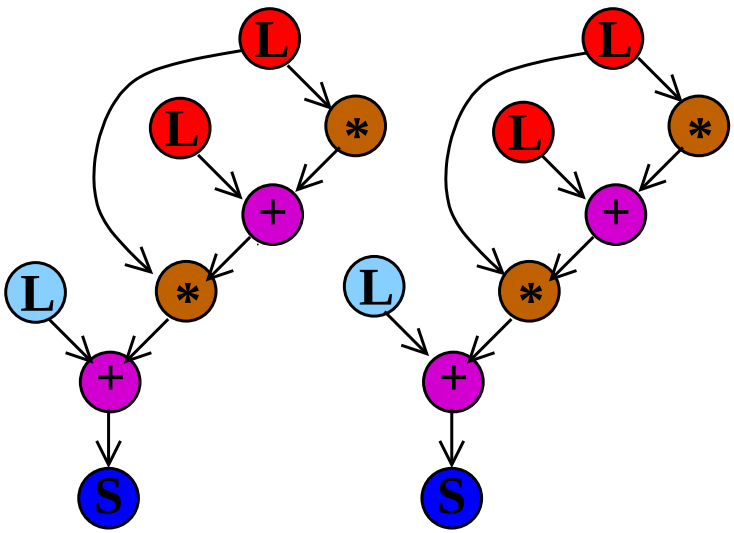

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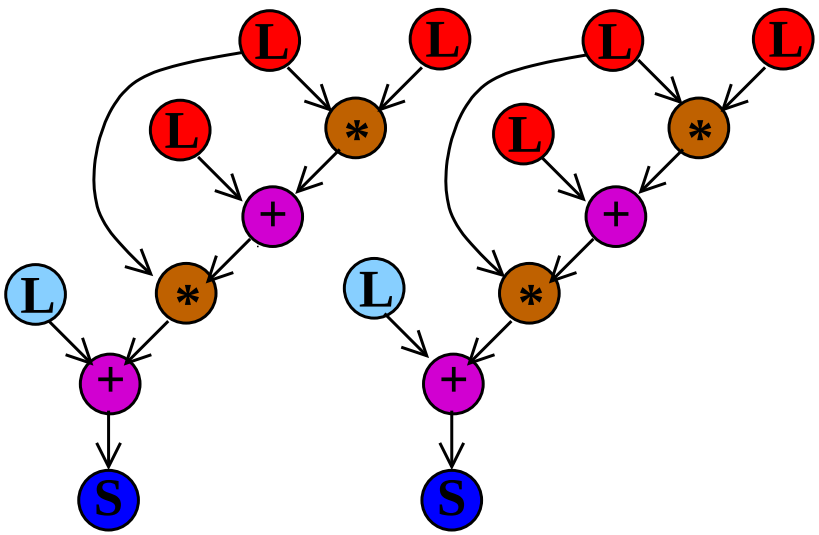

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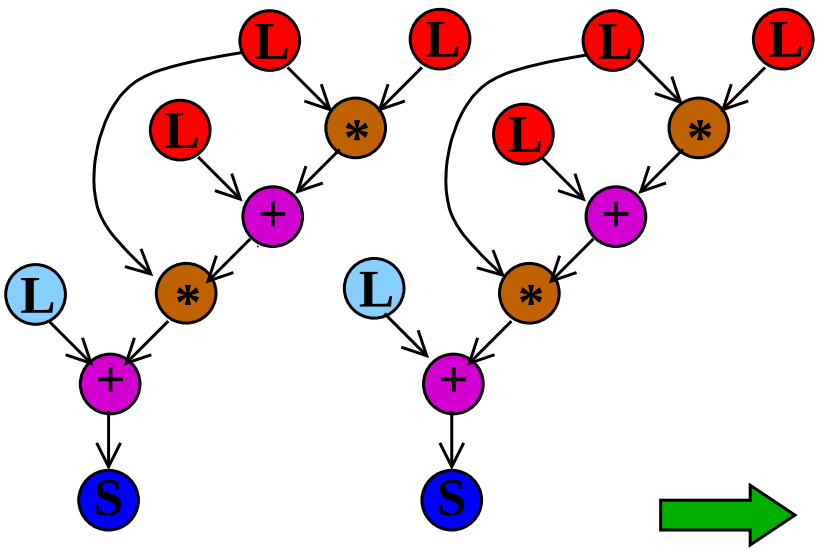

S S −1

Total Cost: −1

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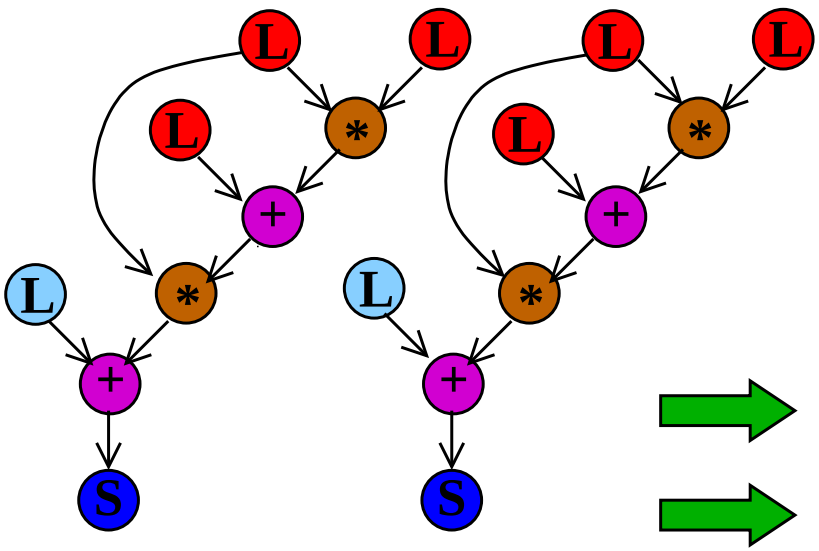

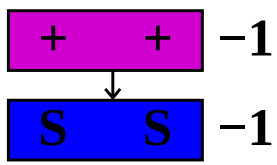

−1

−1

Total Cost: −2

SLP not profitable for whole graph

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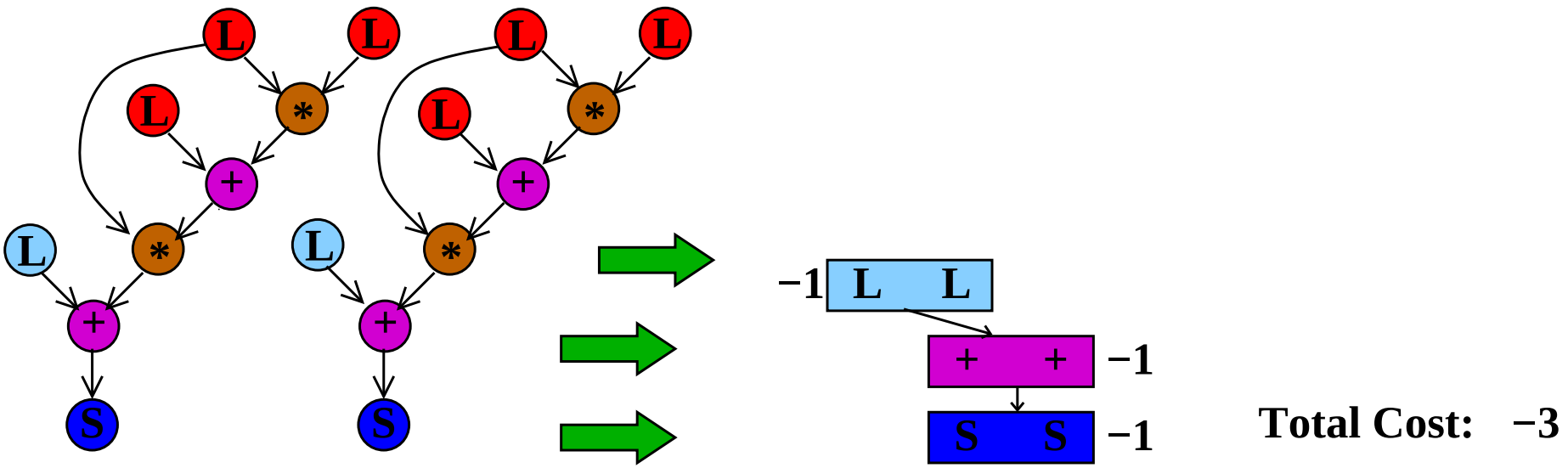

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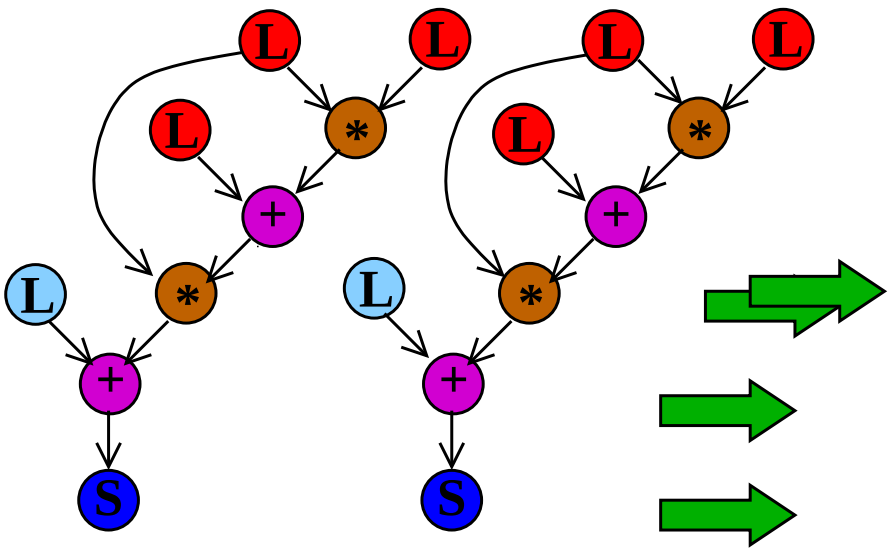

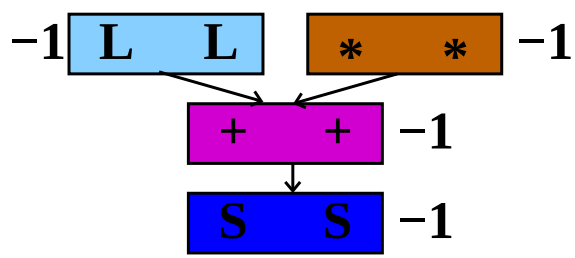

Total Cost: −4

SLP not profitable for whole graph

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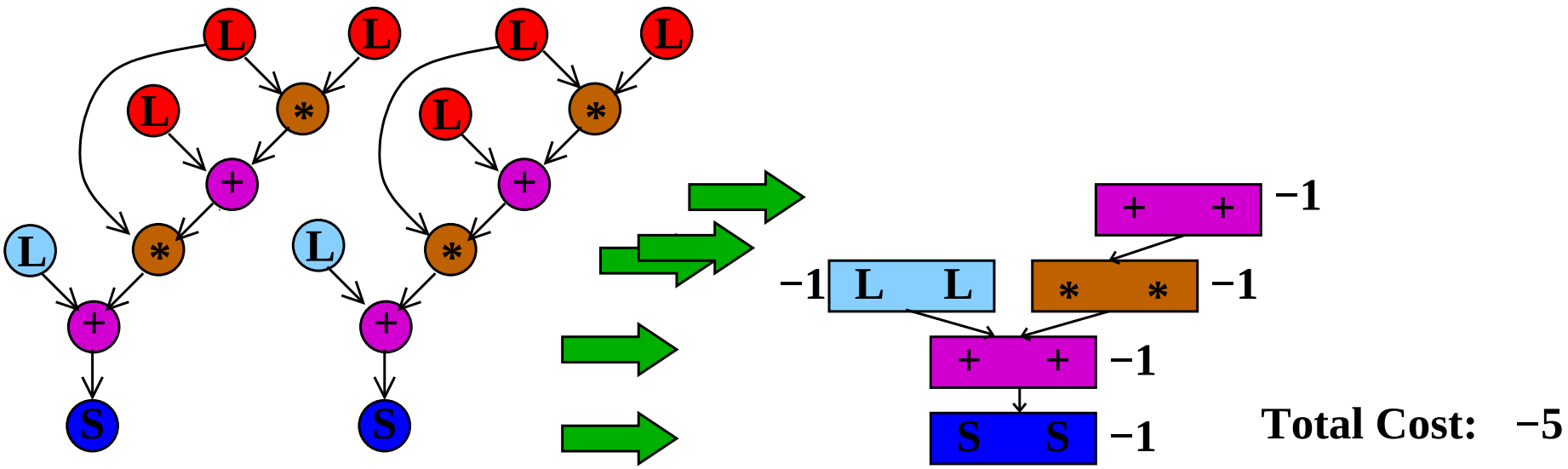

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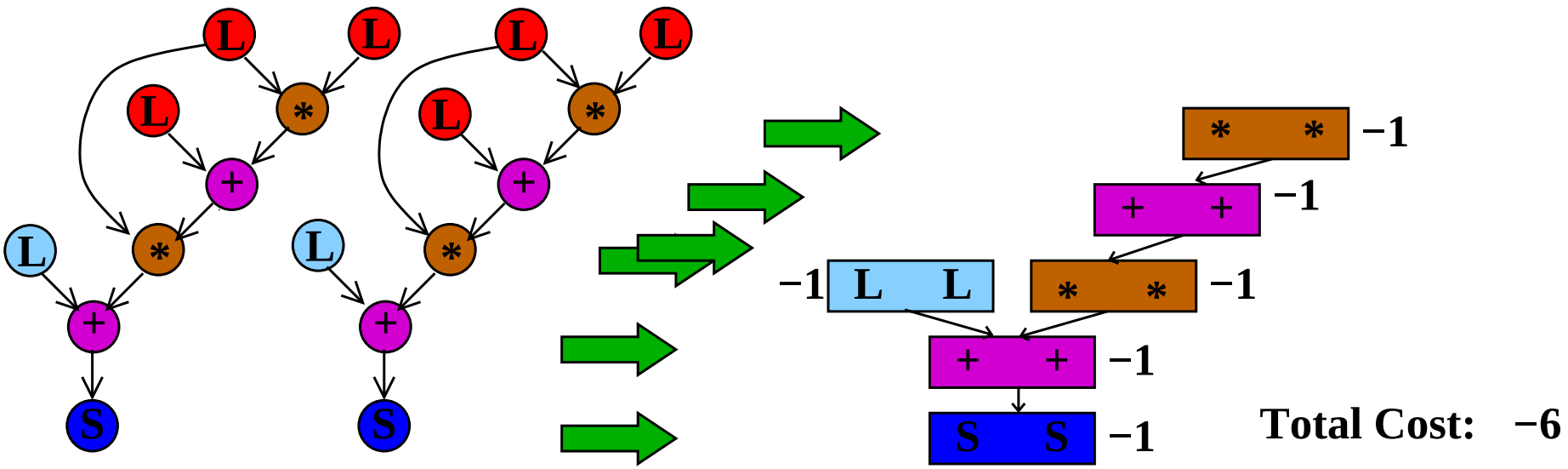

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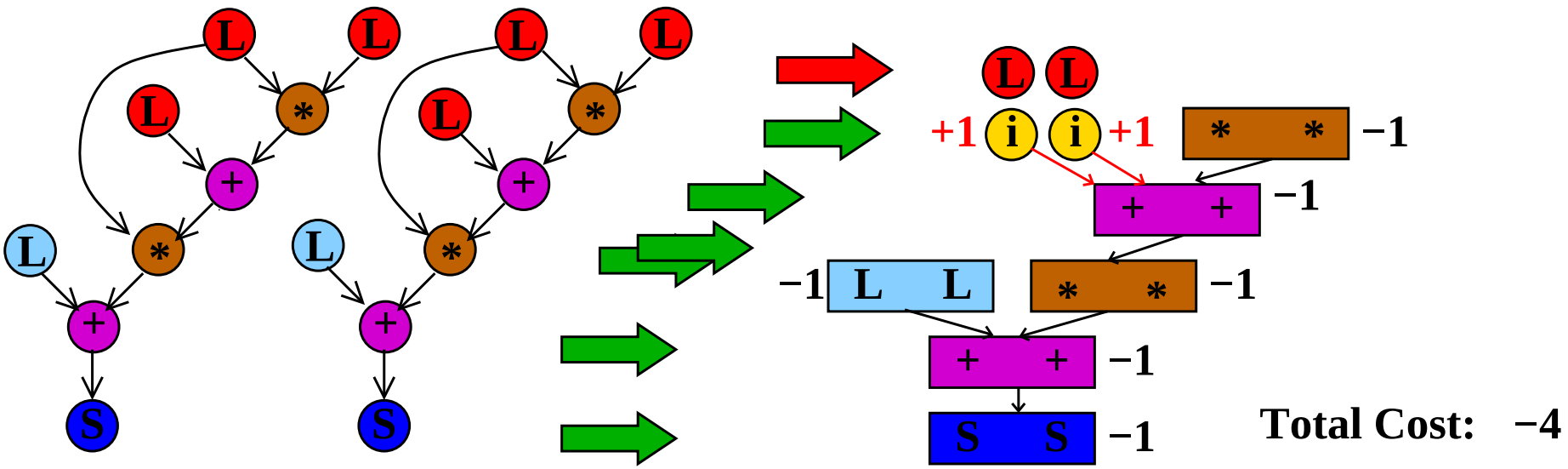

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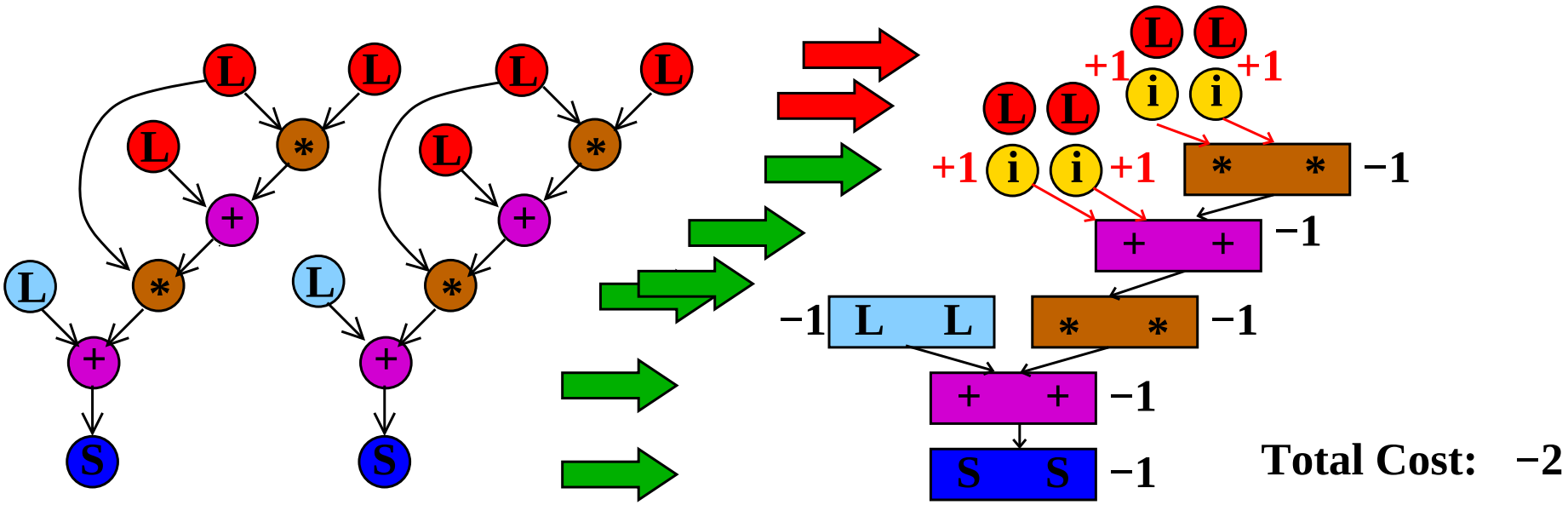

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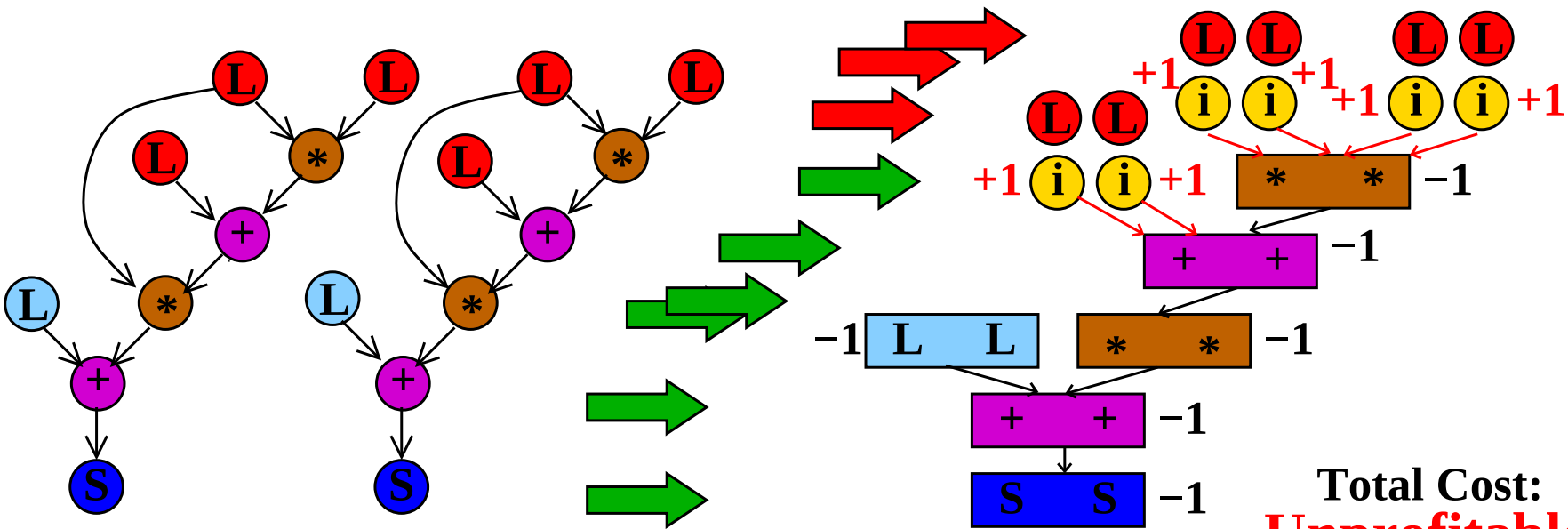
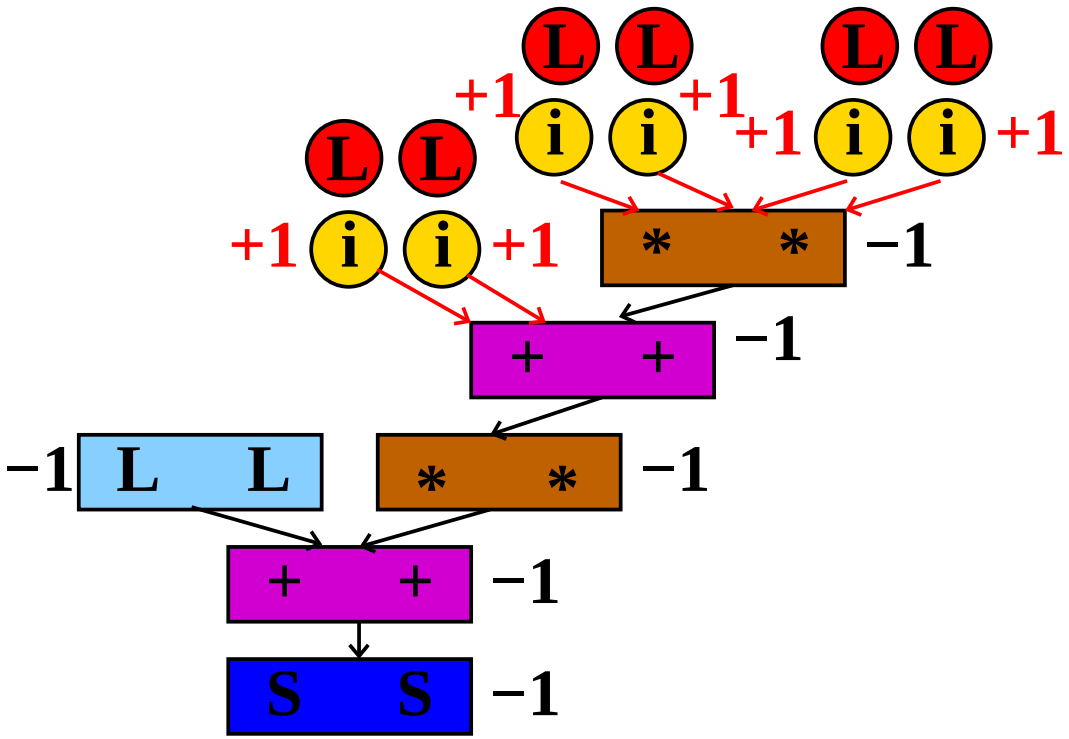


TSLP removes unprofitable region

SLP

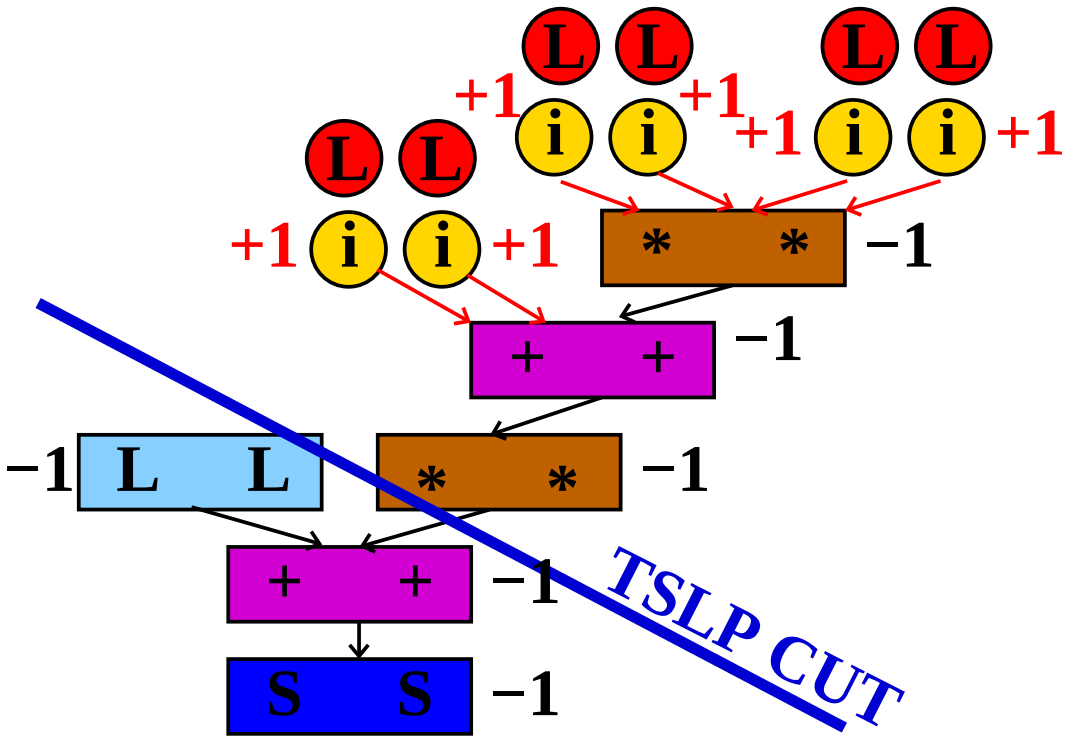


Total Cost: 0

Unprofitable!

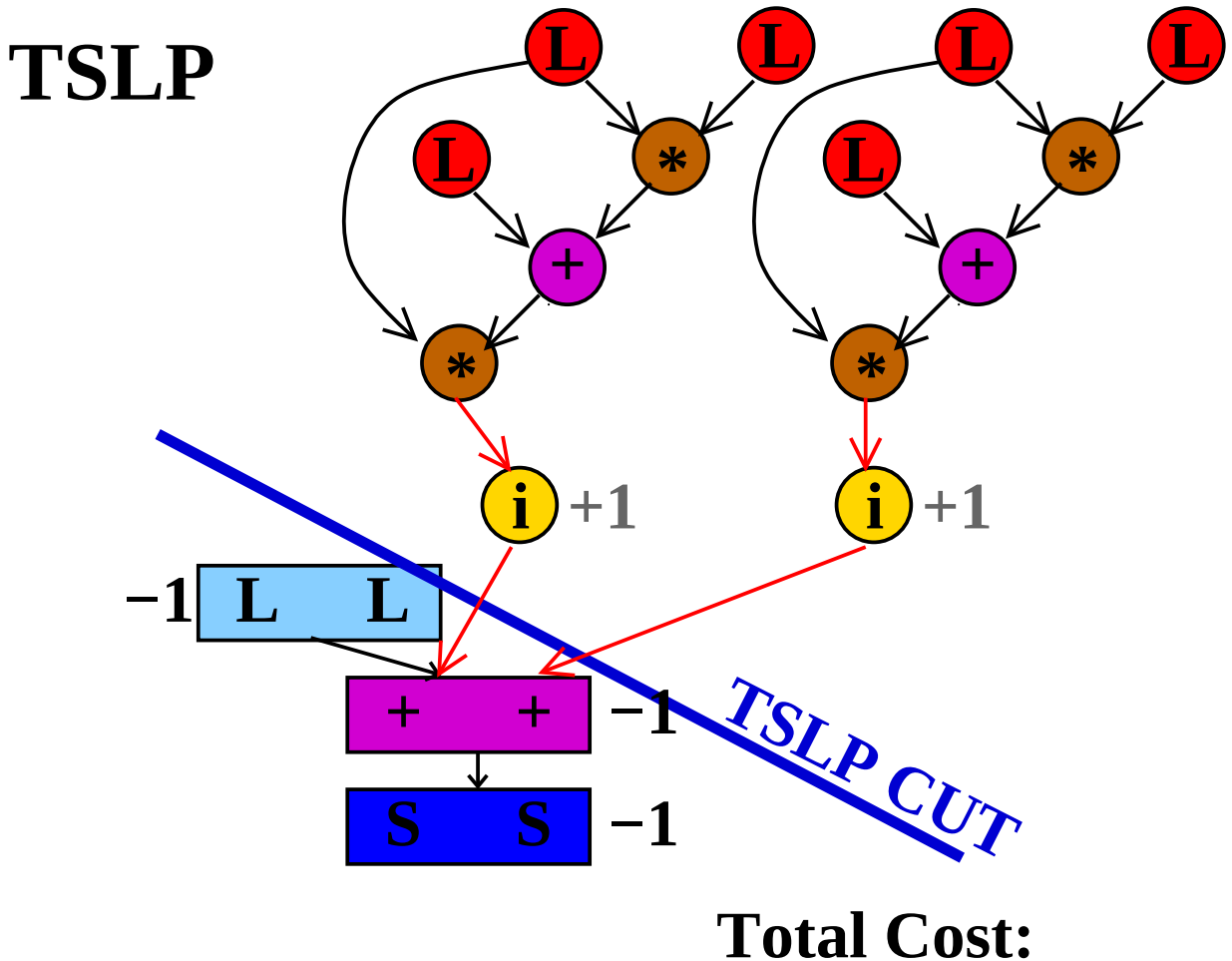
TSLP removes unprofitable region

TSLP

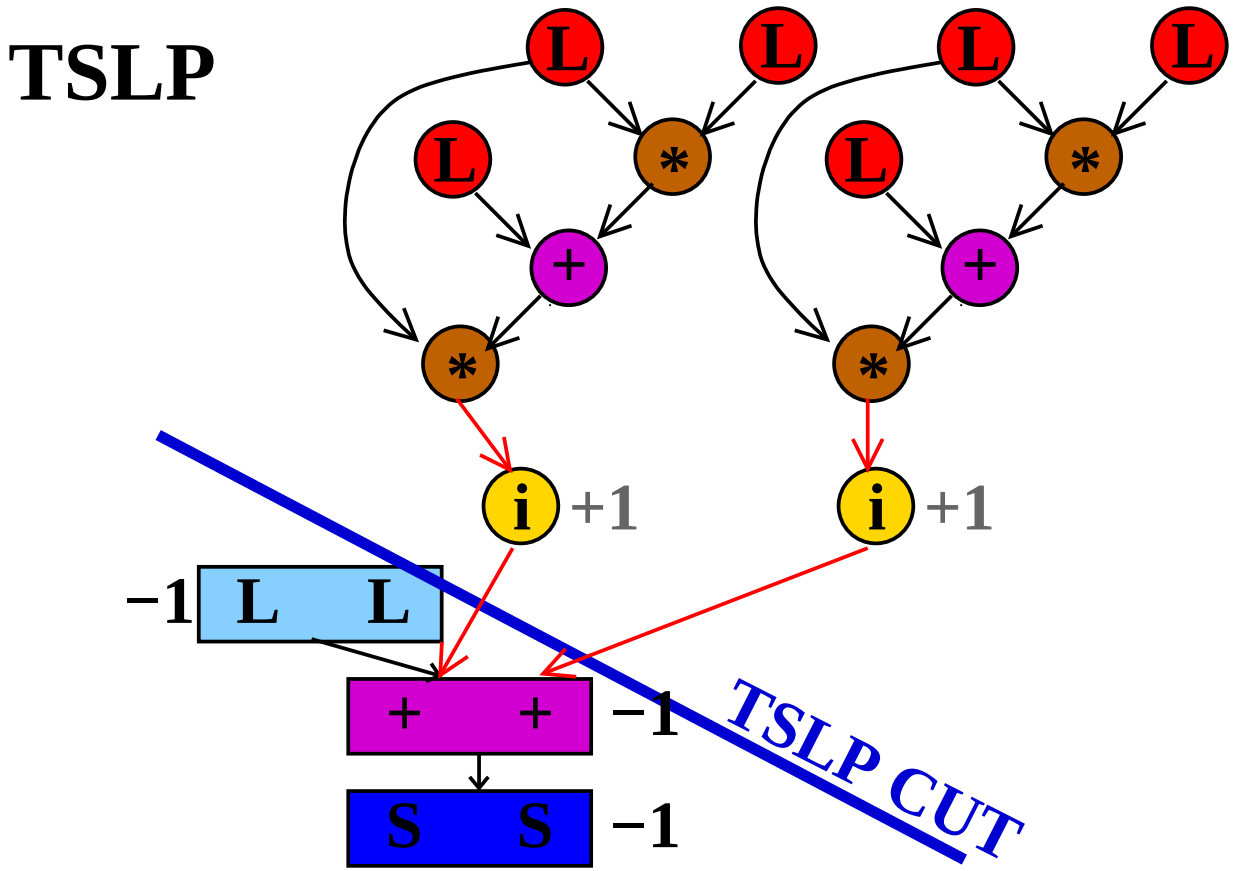


Total Cost:

TSLP removes unprofitable region



TSLP removes unprofitable region

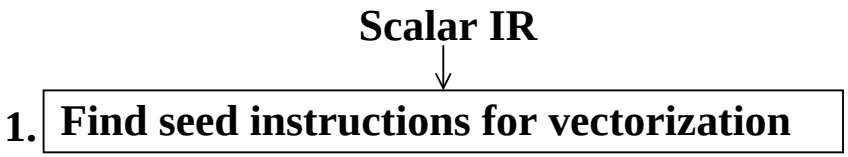


Total Cost: −1

Profitable !

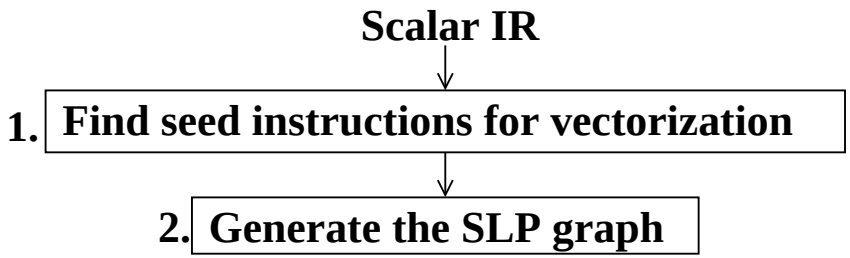
TSLP Algorithm

- Extension to SLP



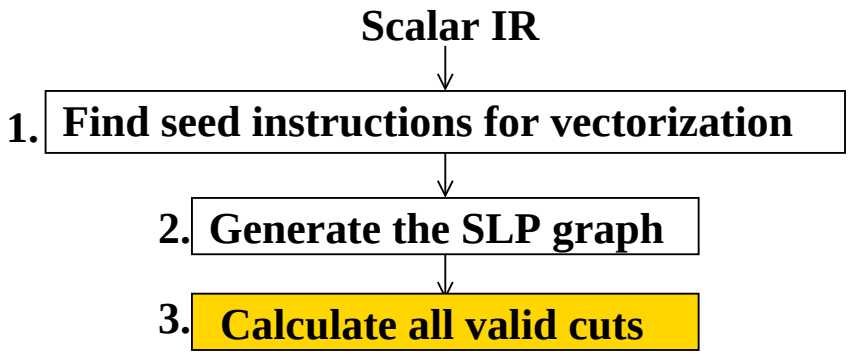
TSLP Algorithm

- Extension to SLP



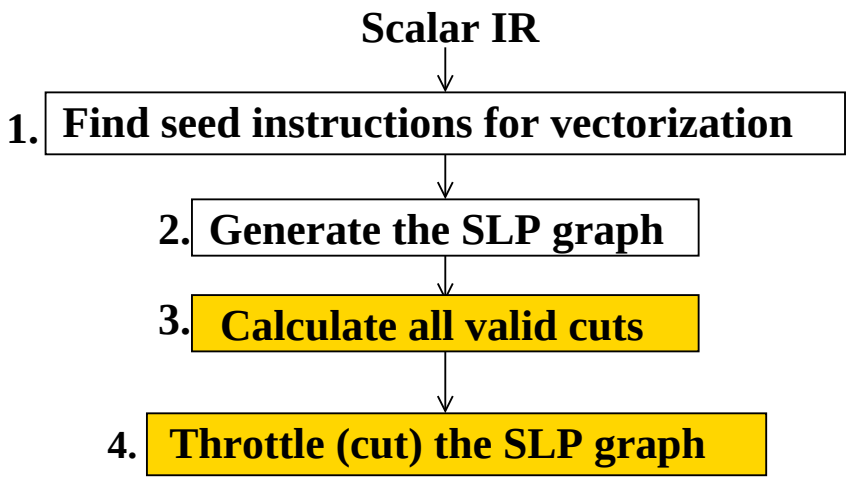
TSLP Algorithm

- Extension to SLP
- Try out many cuts



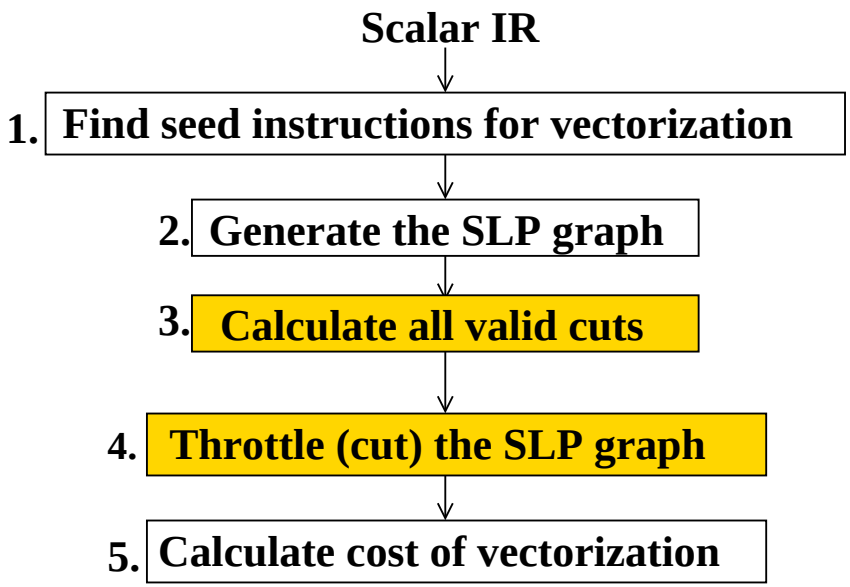
TSLP Algorithm

- Extension to SLP
- Try out many cuts



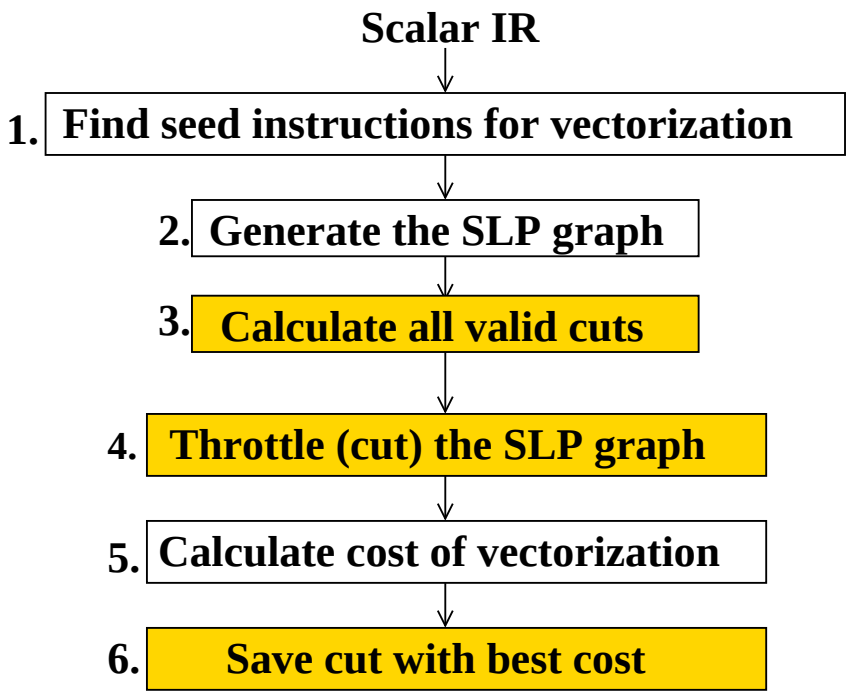
TSLP Algorithm

- Extension to SLP
- Try out many cuts



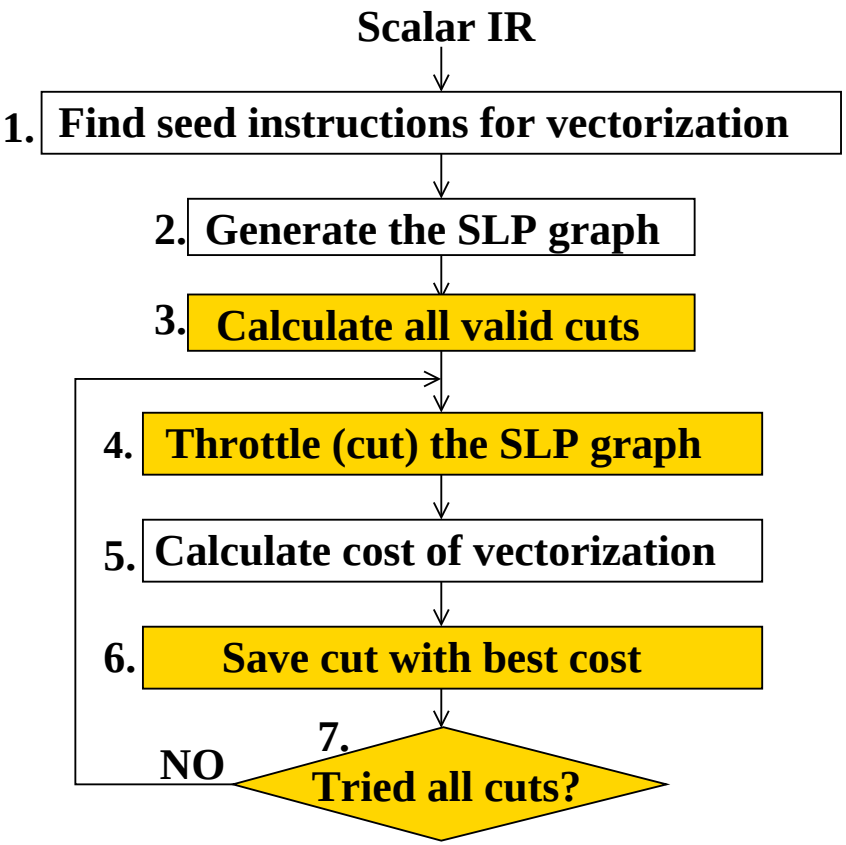
TSLP Algorithm

- Extension to SLP
- Try out many cuts
- Keep best cut



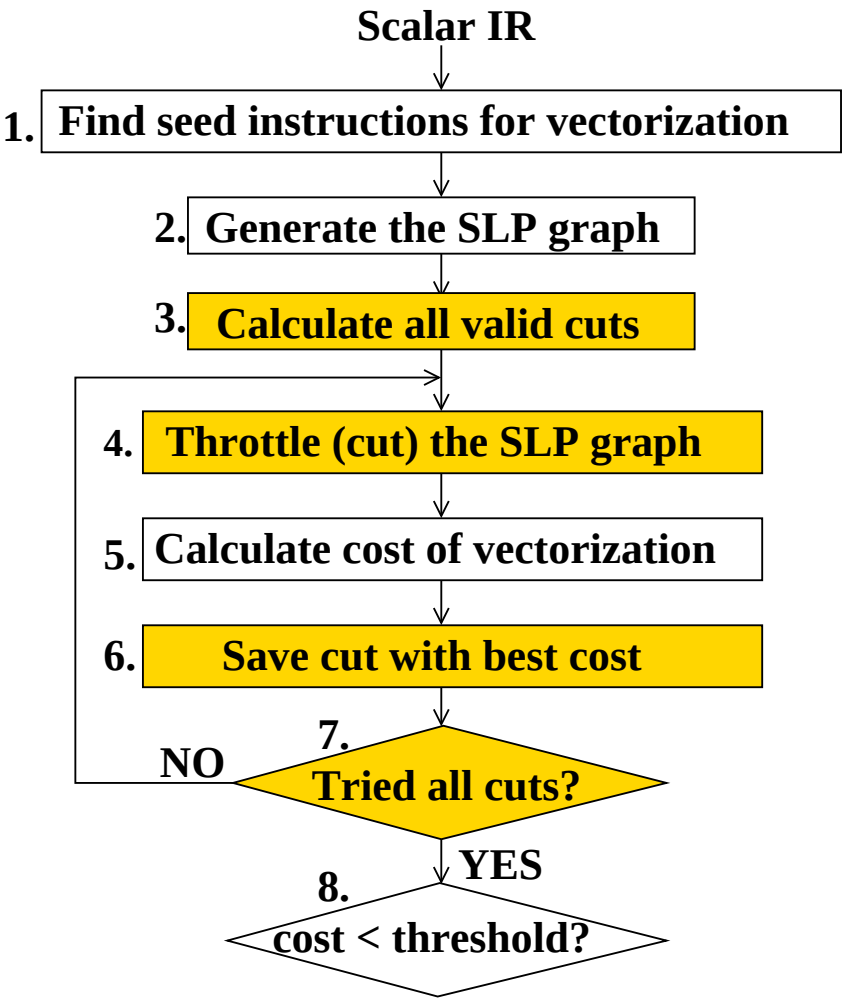
TSLP Algorithm

- Extension to SLP
- Try out many cuts
- Keep best cut



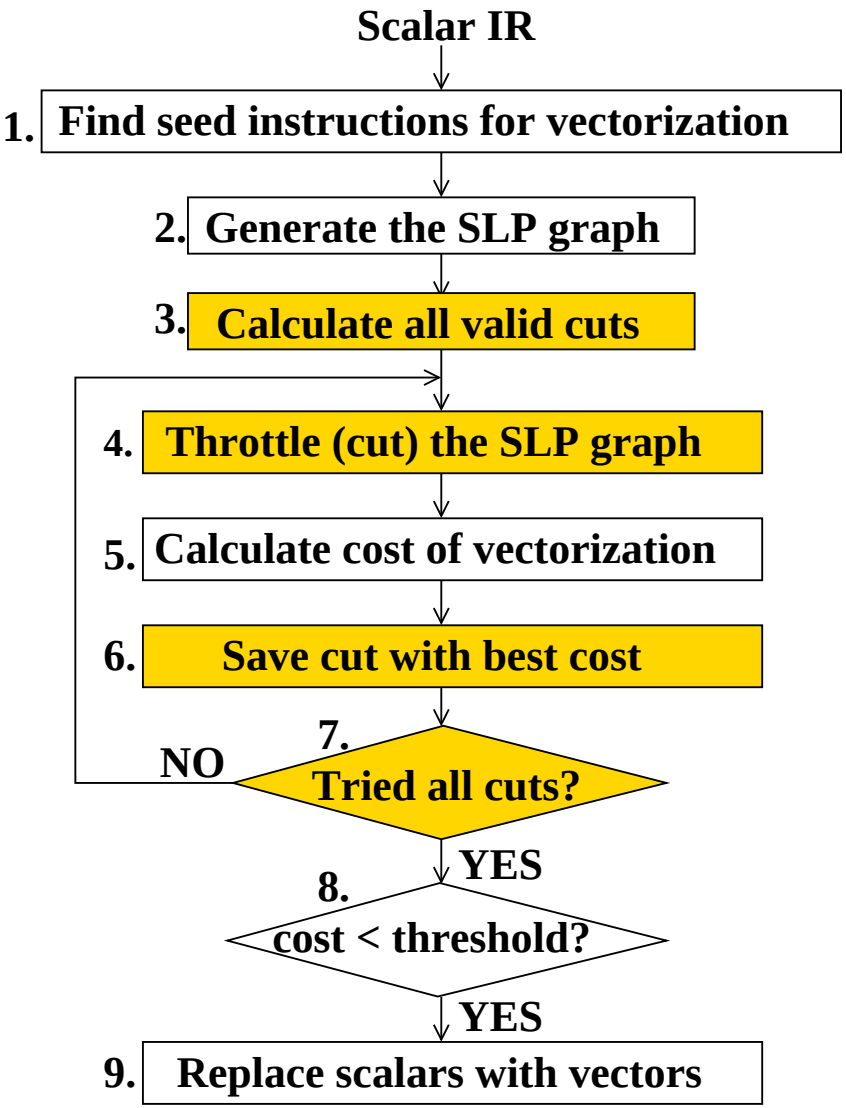
TSLP Algorithm

- Extension to SLP
- Try out many cuts
- Keep best cut
- Vanilla SLP



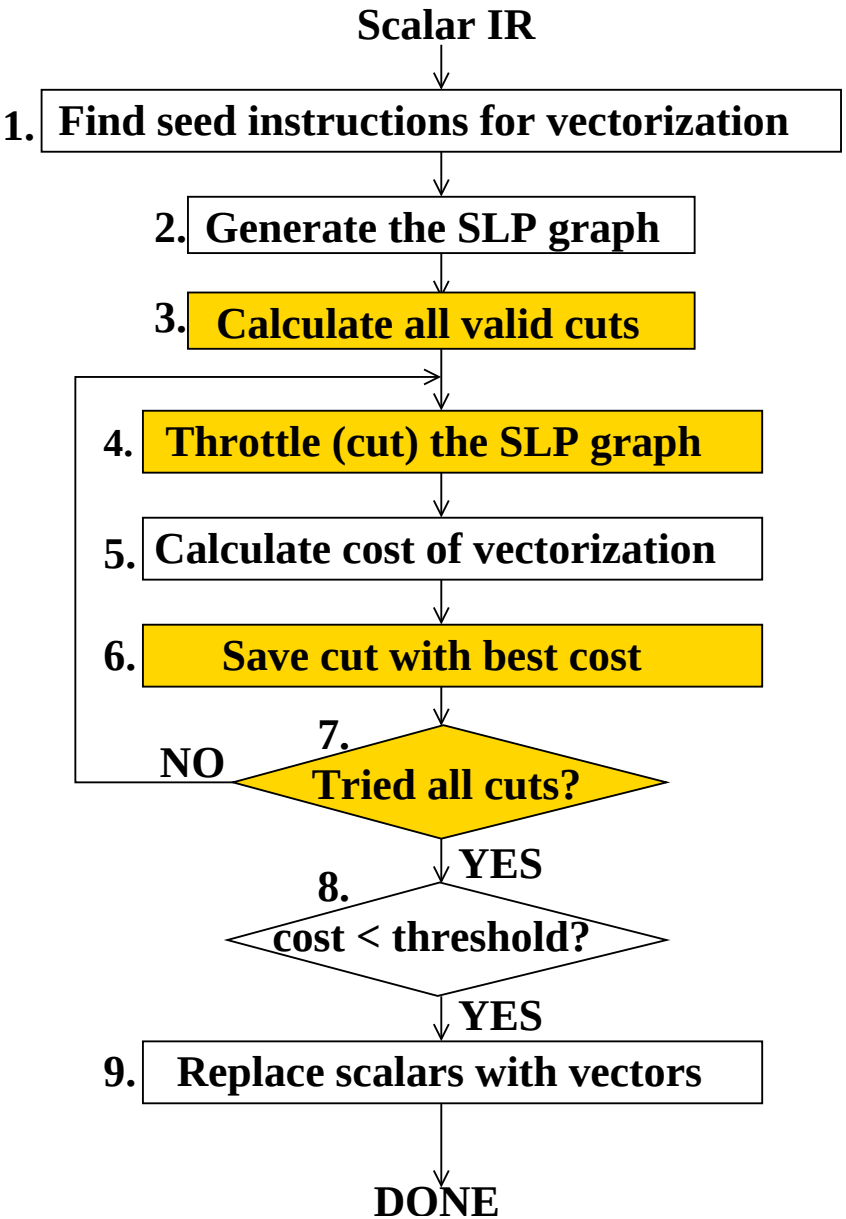
TSLP Algorithm

- Extension to SLP
- Try out many cuts
- Keep best cut
- Vanilla SLP



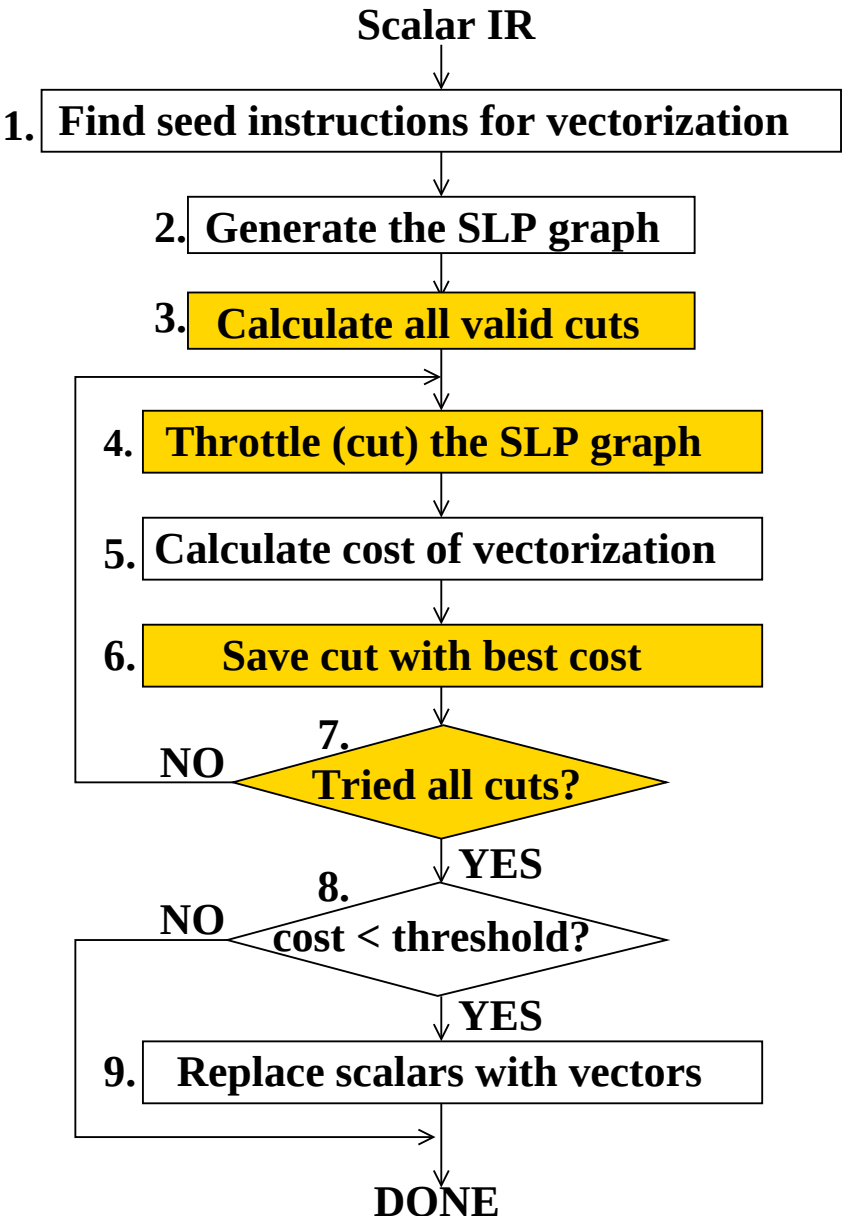
TSLP Algorithm

- Extension to SLP
- Try out many cuts
- Keep best cut
- Vanilla SLP

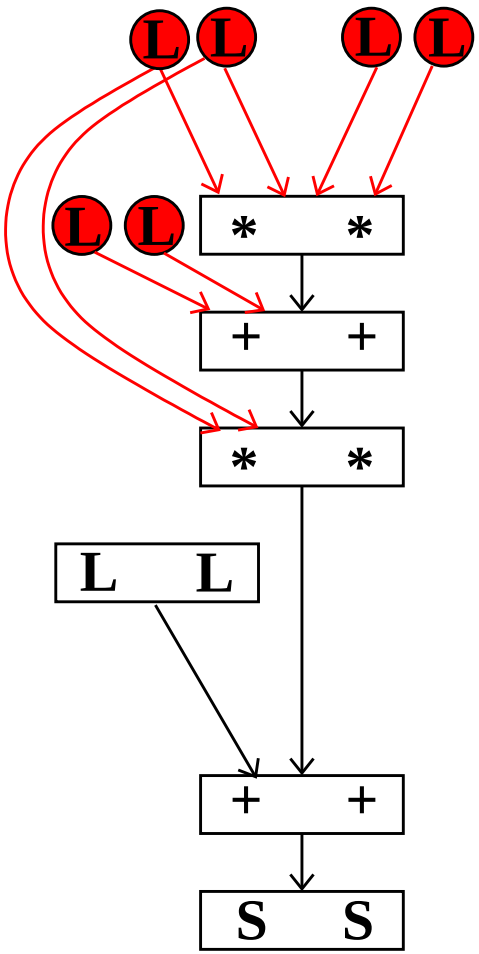


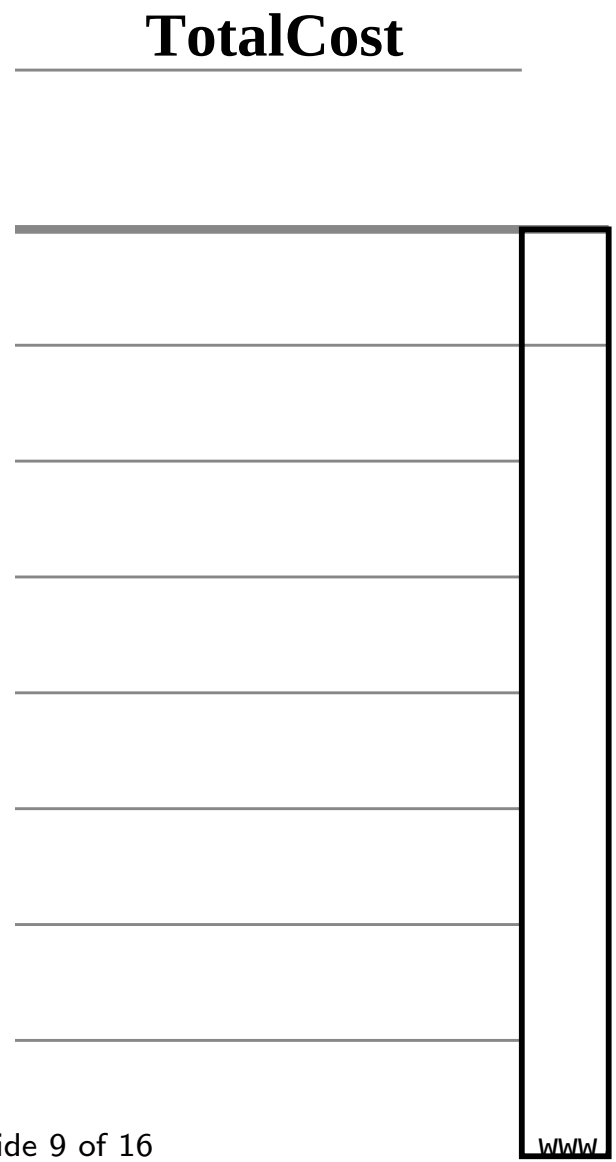
TSLP Algorithm

- Extension to SLP
- Try out many cuts
- Keep best cut
- Vanilla SLP

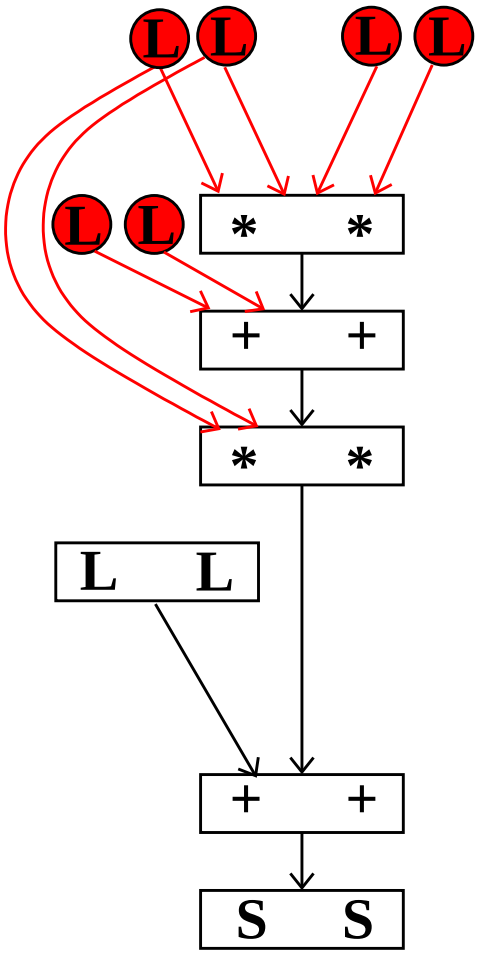


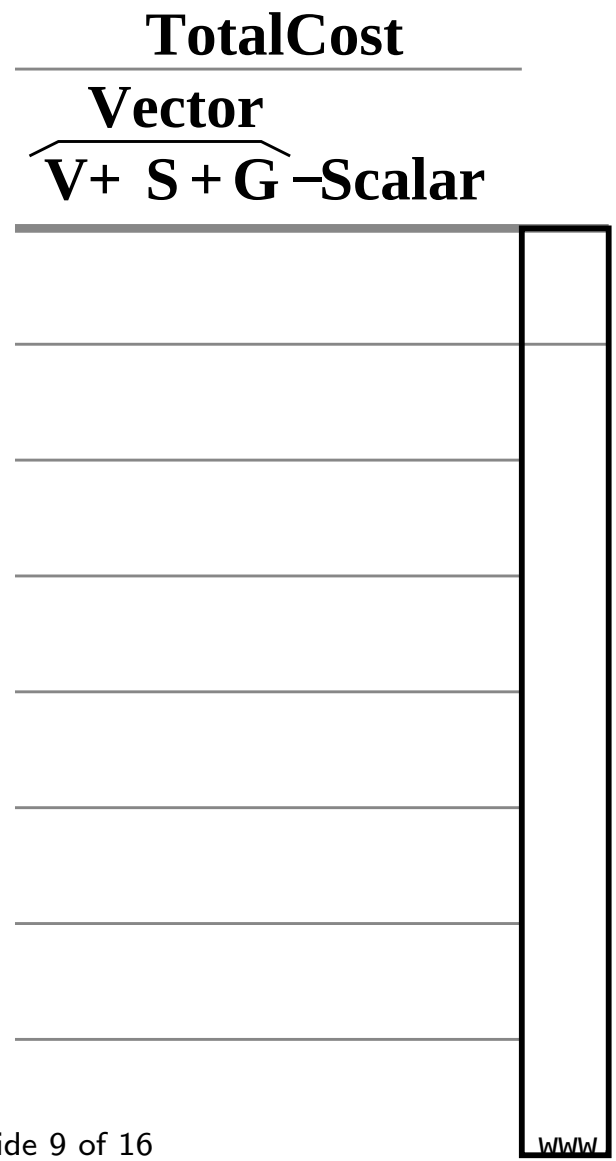
Cost calculation example



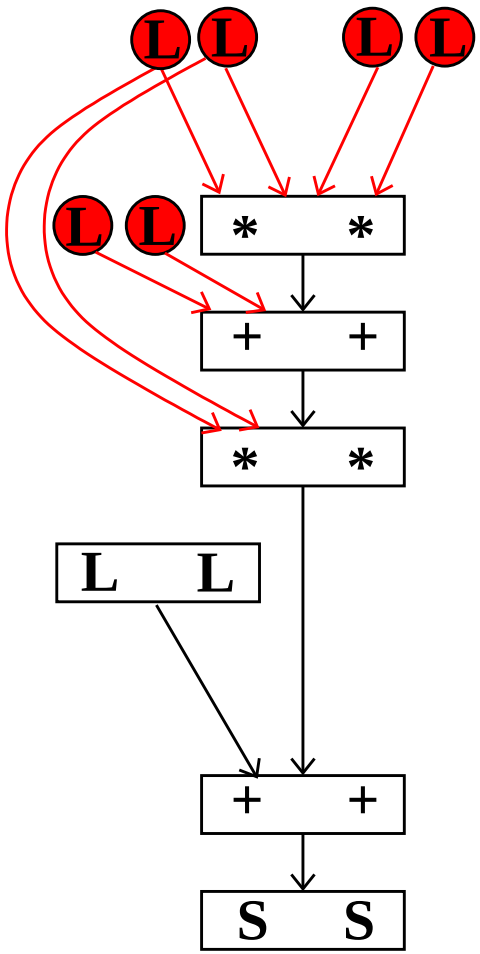


Cost calculation example



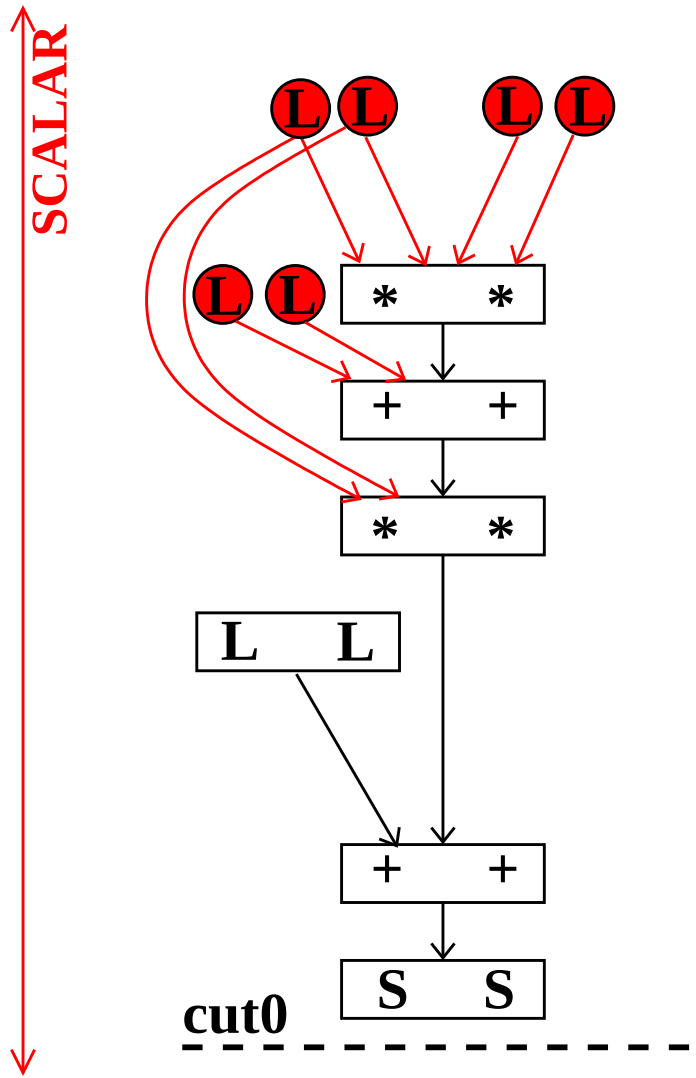


Cost calculation example



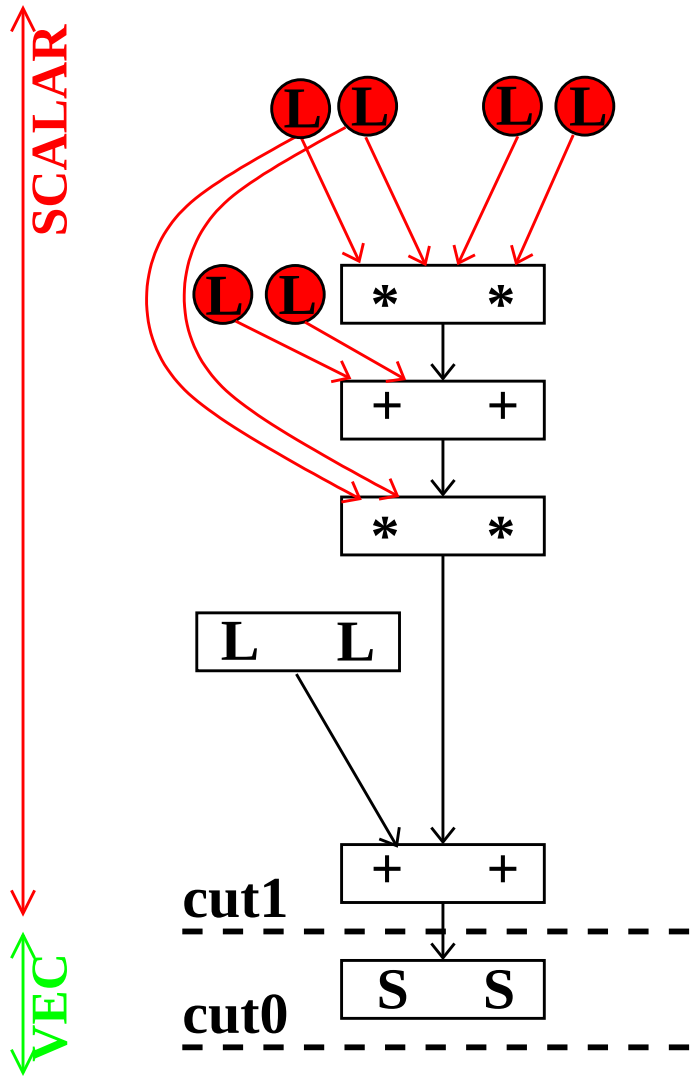
TotalCost	
Vector V+ S+G	Scalar
– 18	
– 18	
– 18	
– 18	
– 18	
– 18	
– 18	
– 18	

Cost calculation example



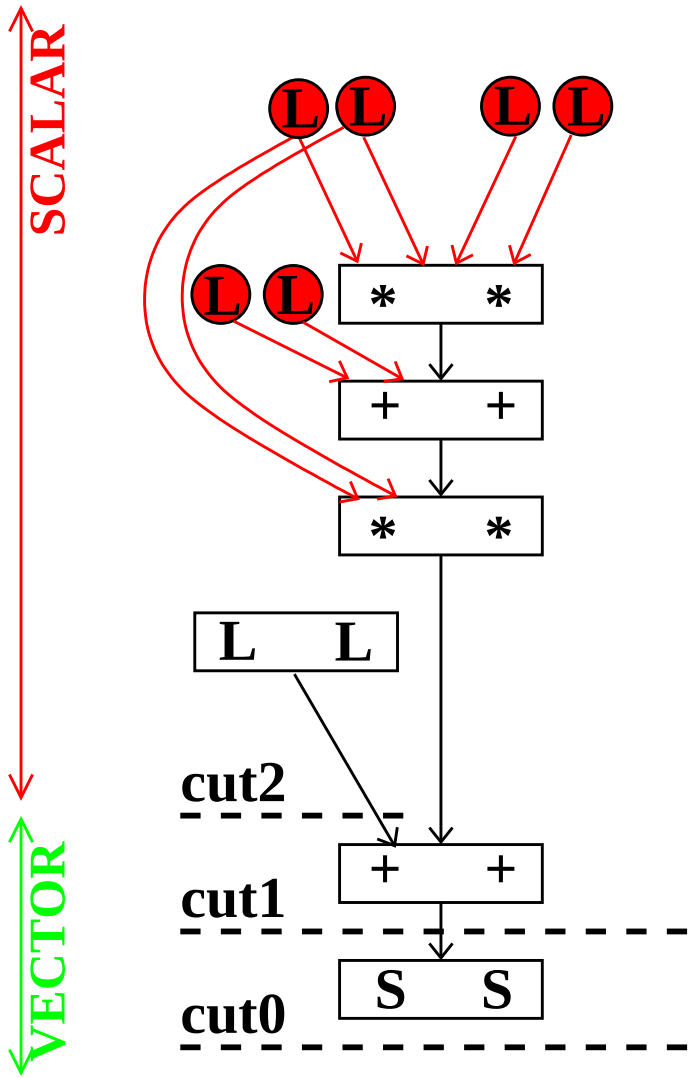
TotalCost	
Vector V+ S+G – Scalar	
– 18	
– 18	
– 18	
– 18	
– 18	
– 18	
– 18	
0 + 18 + 0 – 18 =	0

Cost calculation example



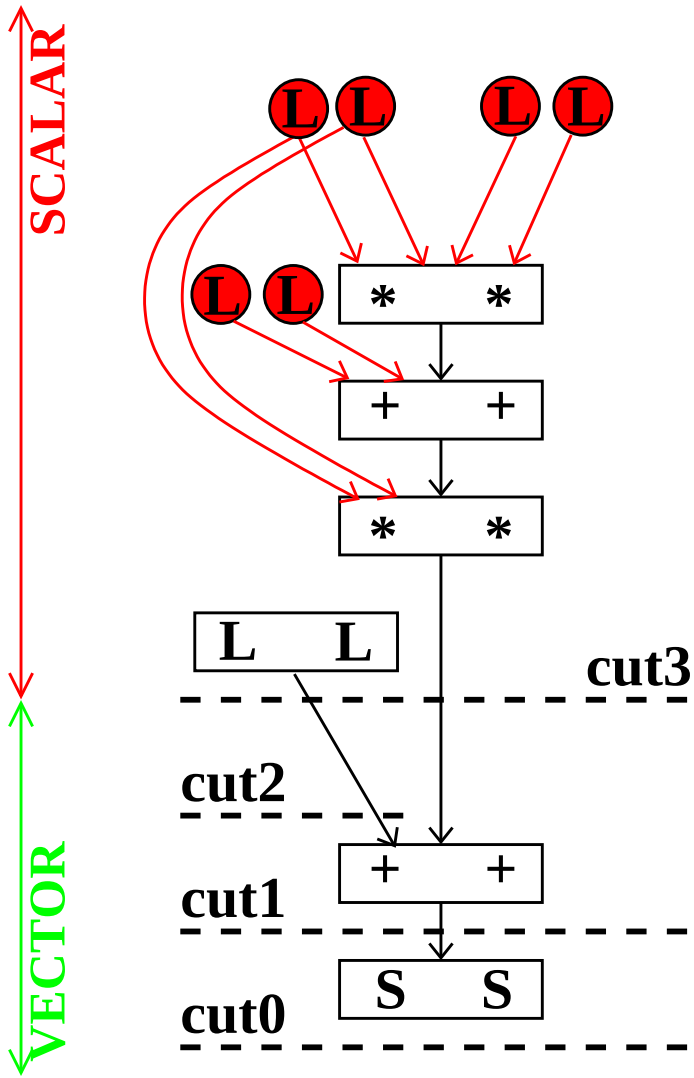
TotalCost					
Vector					
V+	S+	G	−	Scalar	
			−	18	
			−	18	
			−	18	
			−	18	
			−	18	
			−	18	
1 +	16+	2	−	18	= +1
0 +	18+	0	−	18	= 0

Cost calculation example



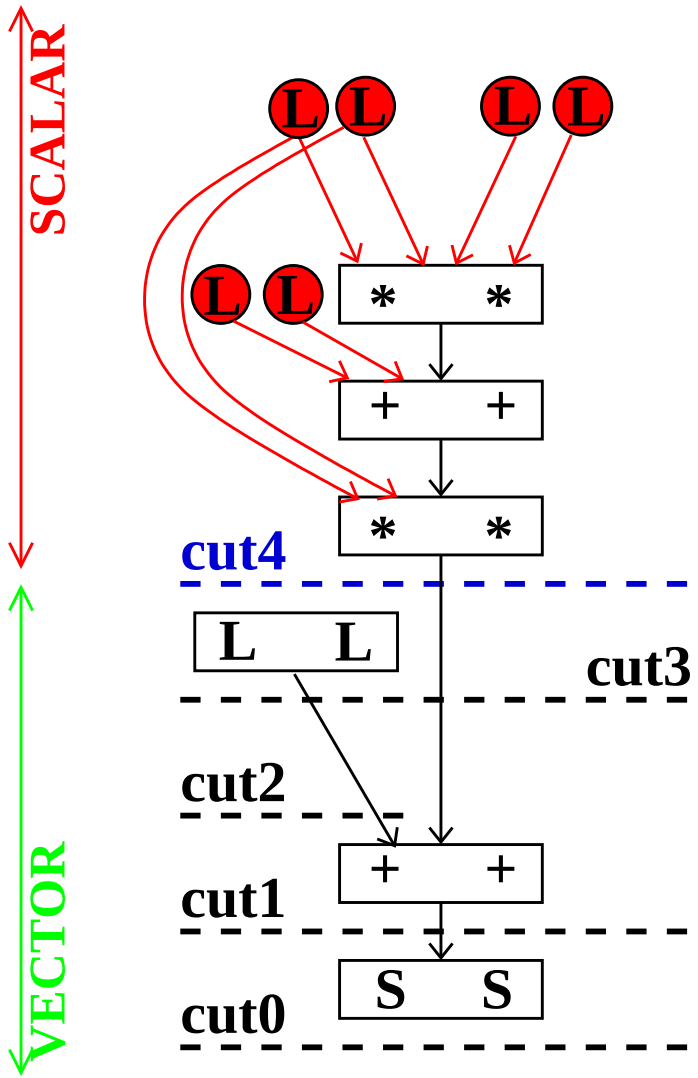
TotalCost				
Vector				
V+ S + G		Scalar		
	− 18			
	− 18			
	− 18			
	− 18			
	− 18			
5 + 8 + 8	− 18	=	+3	
1 + 16 + 2	− 18	=	+1	
0 + 18 + 0	− 18	=	0	

Cost calculation example



TotalCost					
Vector					
V+	S +	G	− Scalar		
			− 18		
			− 18		
			− 18		
			− 18		
2 +	14 +	4	− 18	=	+2
5 +	8 +	8	− 18	=	+3
1 +	16 +	2	− 18	=	+1
0 +	18 +	0	− 18	=	0

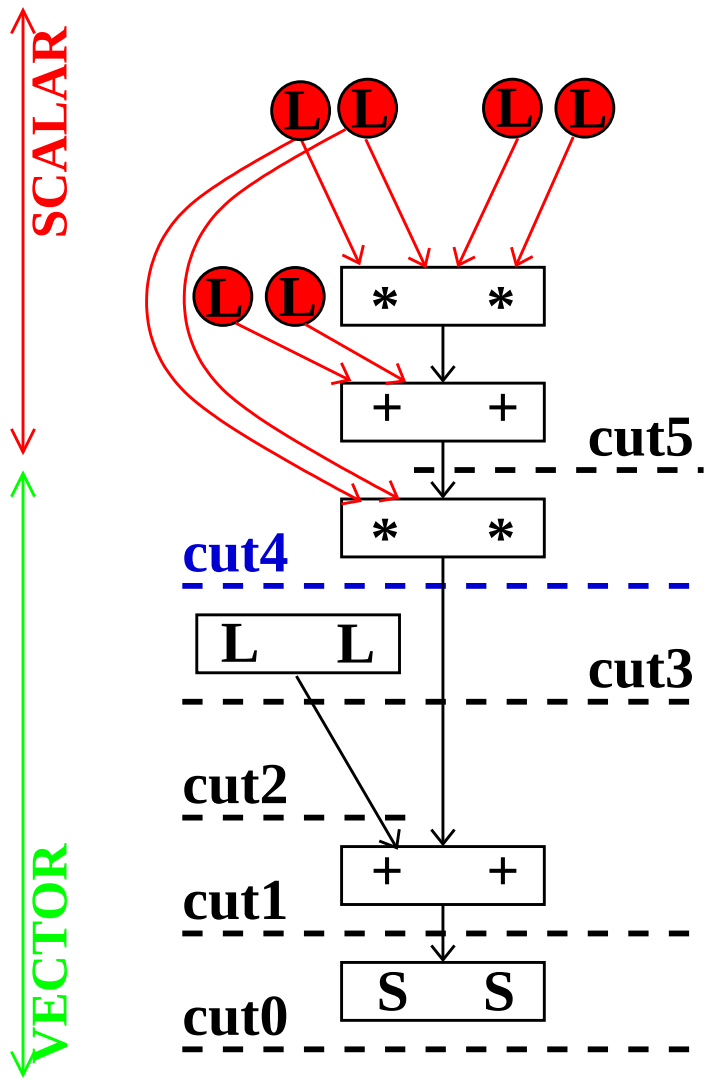
Cost calculation example



TotalCost					
Vector				Scalar	
V+	S +	G	−		
			− 18		
			− 18		
			− 18		
3 +	12 +	2	− 18	=	−1
2 +	14 +	4	− 18	=	+2
5 +	8 +	8	− 18	=	+3
1 +	16 +	2	− 18	=	+1
0 +	18 +	0	− 18	=	0

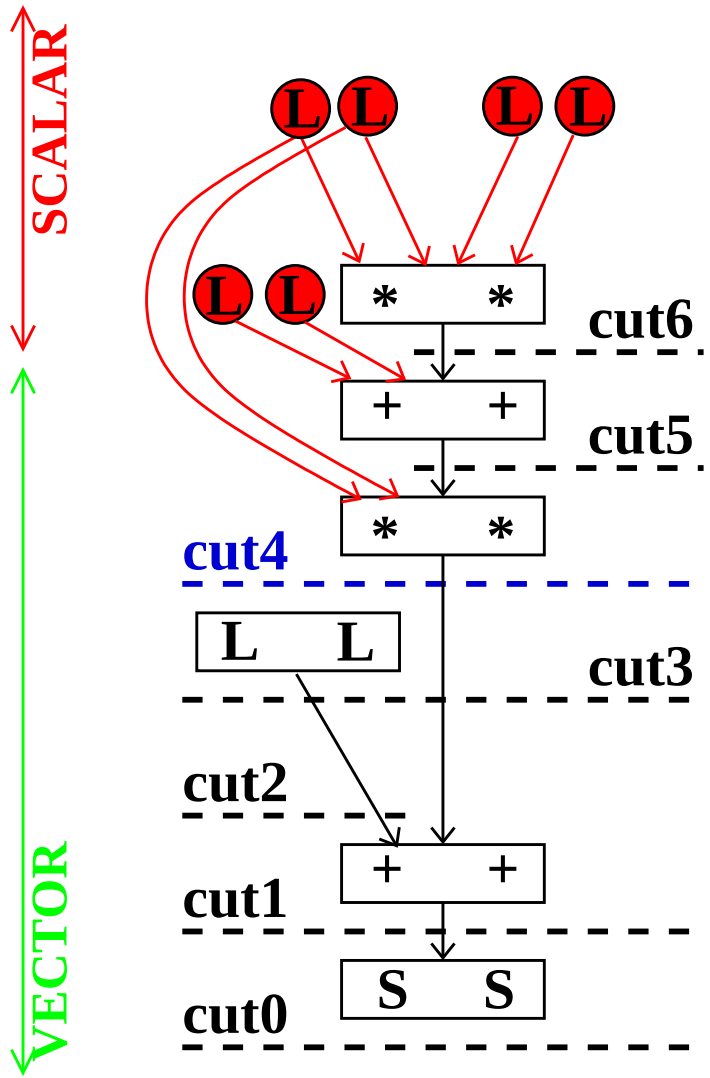
TSLP

Cost calculation example



TotalCost				
Vector				
V+ S + G	– Scalar			
	– 18			
	– 18			
4 + 10 + 4	– 18	=	0	
3 + 12 + 2	– 18	=	–1	TSLP
2 + 14 + 4	– 18	=	+2	
5 + 8 + 8	– 18	=	+3	
1 + 16 + 2	– 18	=	+1	
0 + 18 + 0	– 18	=	0	

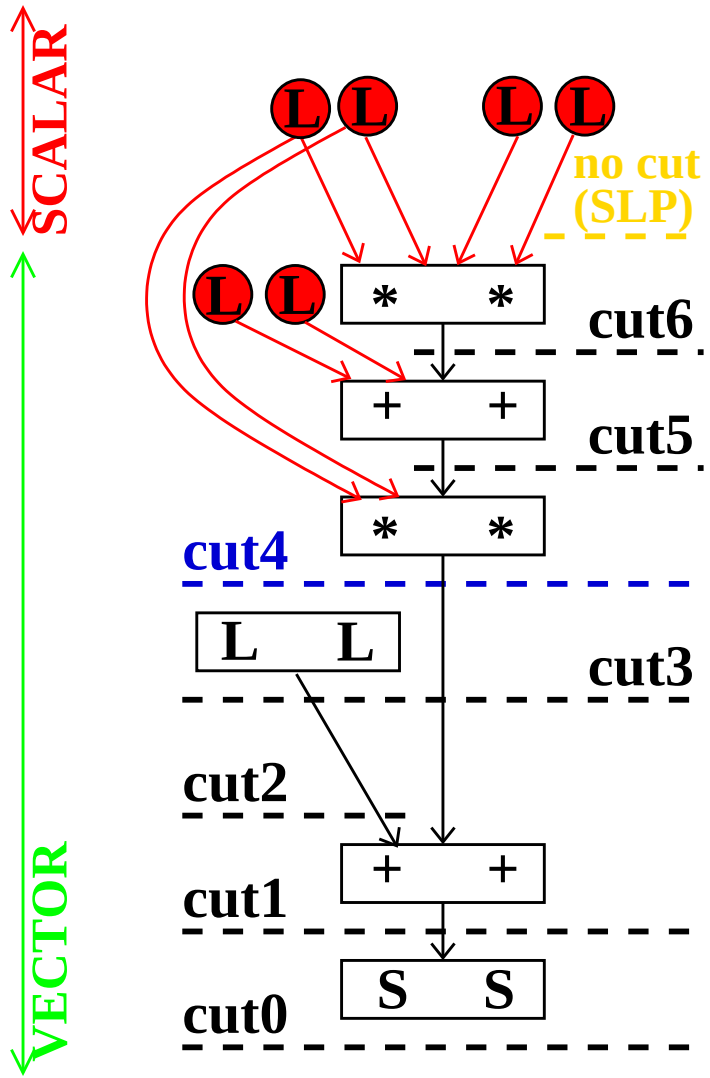
Cost calculation example



TotalCost			
Vector			
V+ S + G	– Scalar		
	– 18		
5 + 8 + 6	– 18	=	+1
4 + 10 + 4	– 18	=	0
3 + 12 + 2	– 18	=	–1
2 + 14 + 4	– 18	=	+2
5 + 8 + 8	– 18	=	+3
1 + 16 + 2	– 18	=	+1
0 + 18 + 0	– 18	=	0

TSLP

Cost calculation example

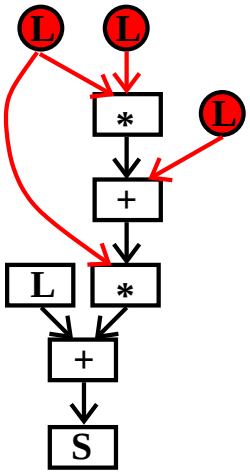


TotalCost					
Vector					
V+	S+	G	−Scalar		
6 +	6 +	6 −	18	=	0
5 +	8 +	6 −	18	=	+1
4 +	10+	4 −	18	=	0
3 +	12+	2 −	18	=	−1
2 +	14+	4 −	18	=	+2
5 +	8 +	8 −	18	=	+3
1 +	16+	2 −	18	=	+1
0 +	18+	0 −	18	=	0

SLP

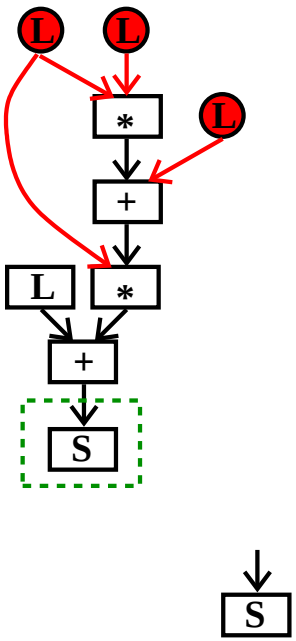
TSLP

Subgraph (Cuts) Generation Algorithm



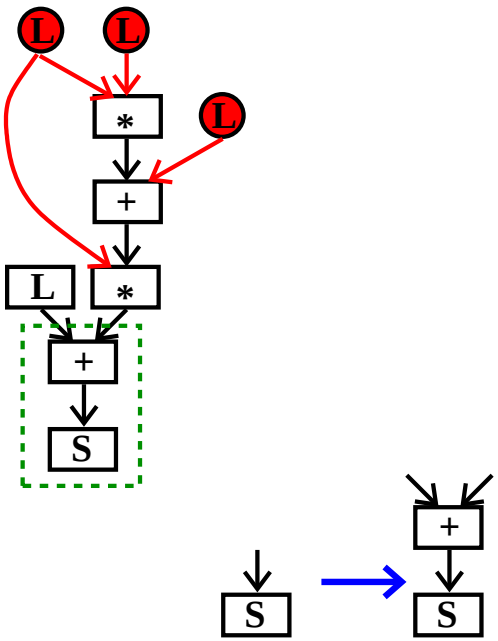
- Only connected subgraphs that include the root

Subgraph (Cuts) Generation Algorithm



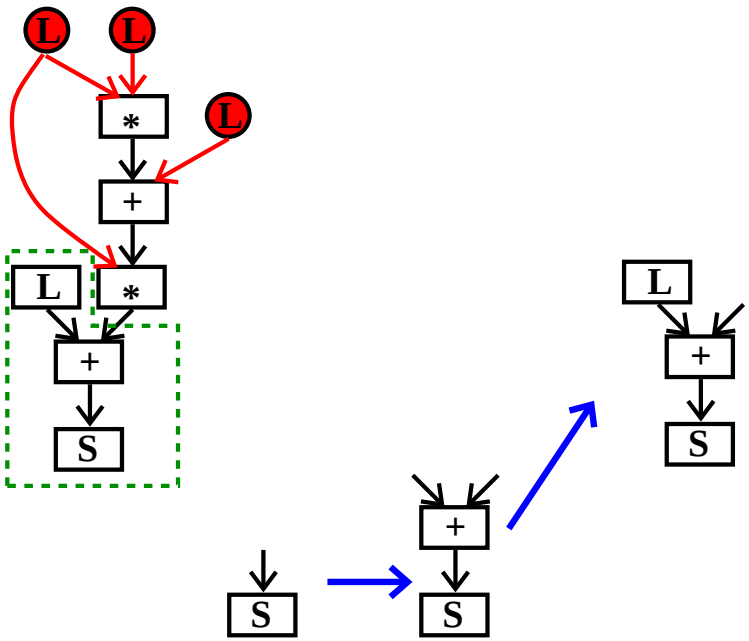
- Only connected subgraphs that include the root

Subgraph (Cuts) Generation Algorithm



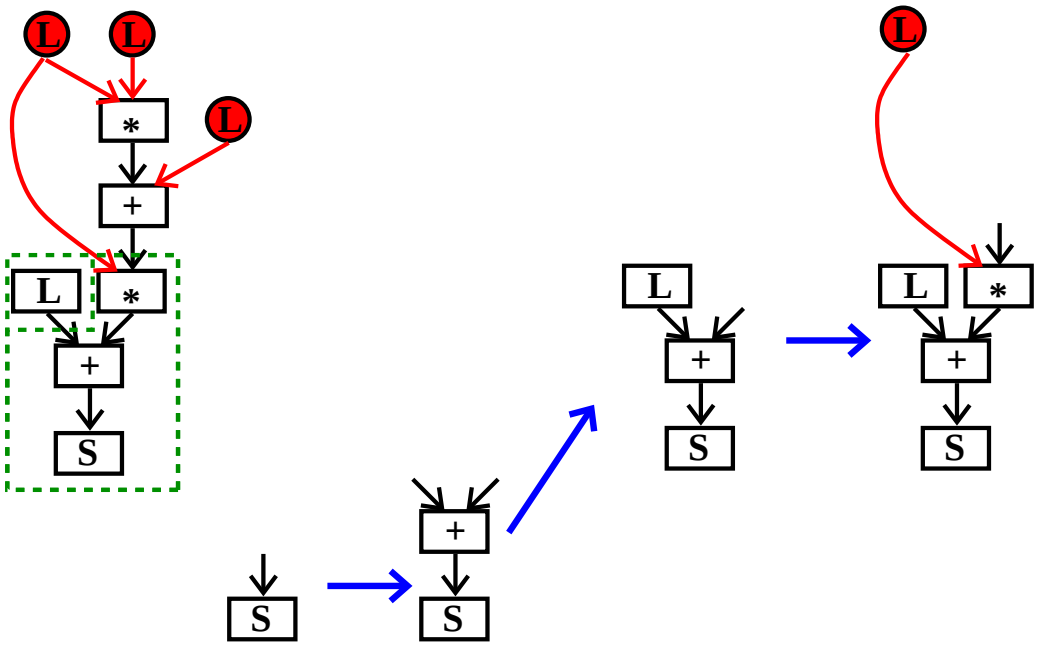
- Only connected subgraphs that include the root

Subgraph (Cuts) Generation Algorithm



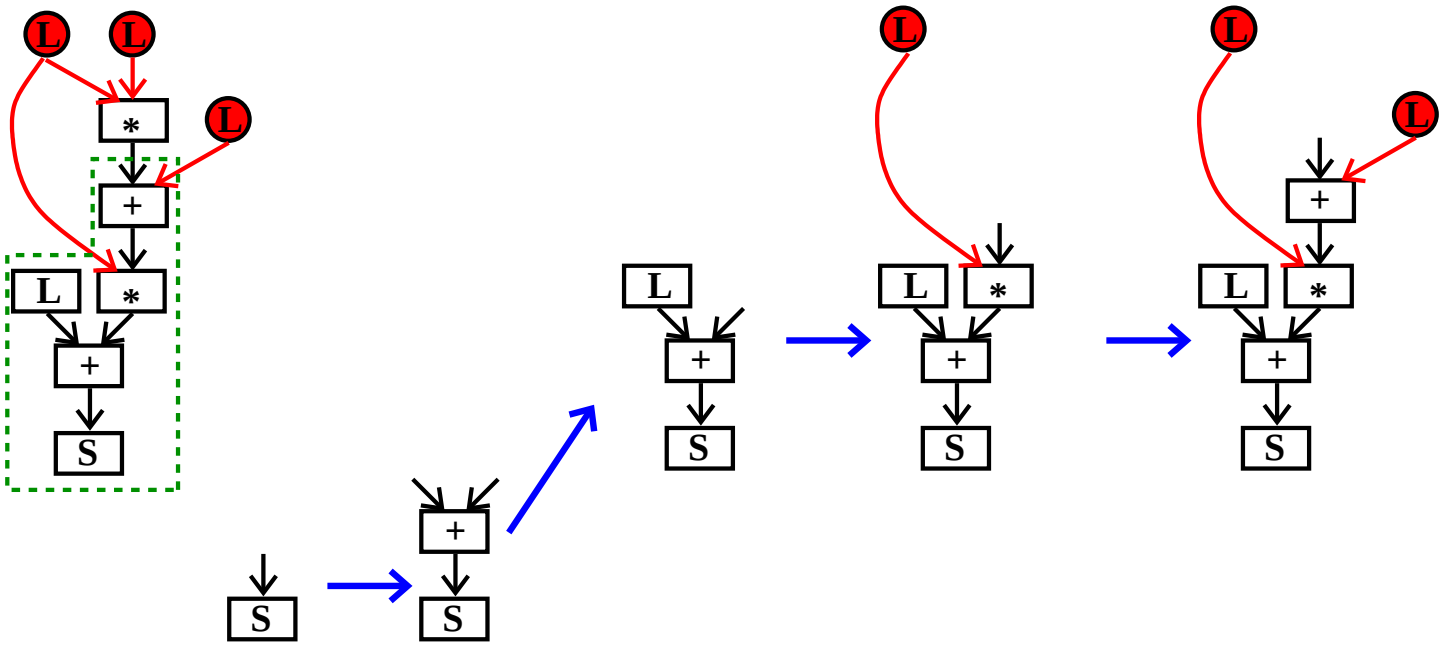
- Only connected subgraphs that include the root

Subgraph (Cuts) Generation Algorithm



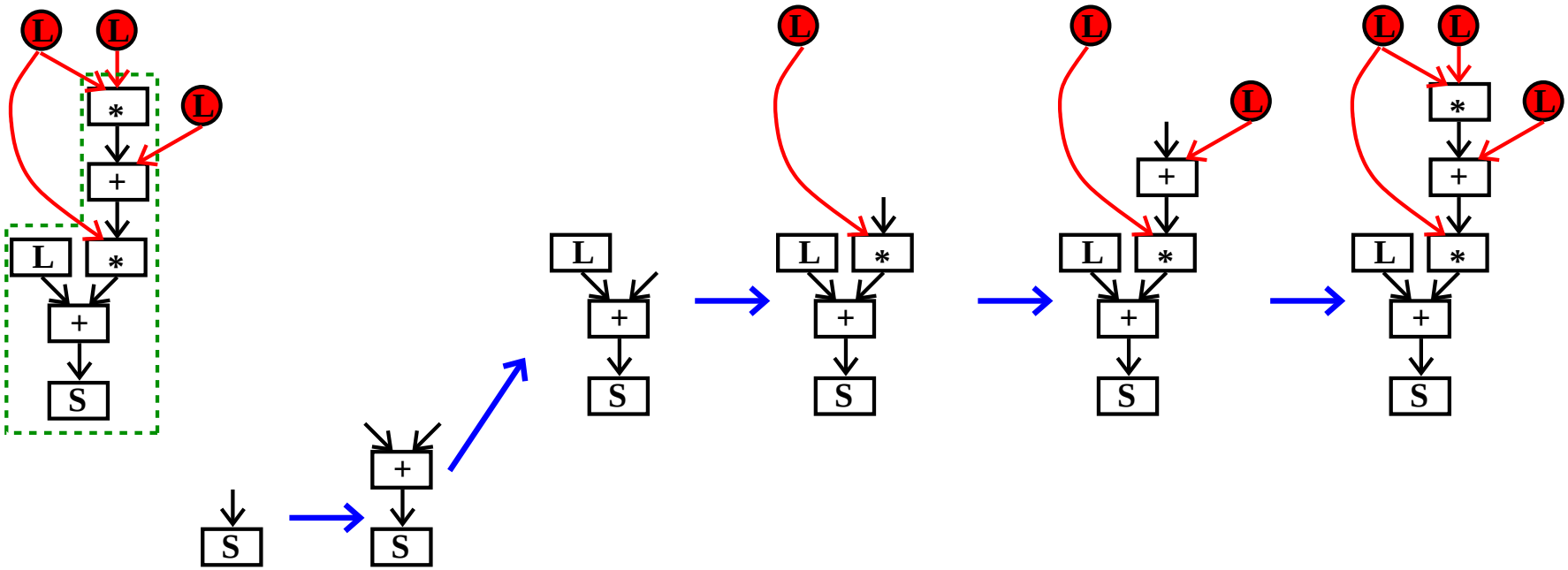
- Only connected subgraphs that include the root

Subgraph (Cuts) Generation Algorithm



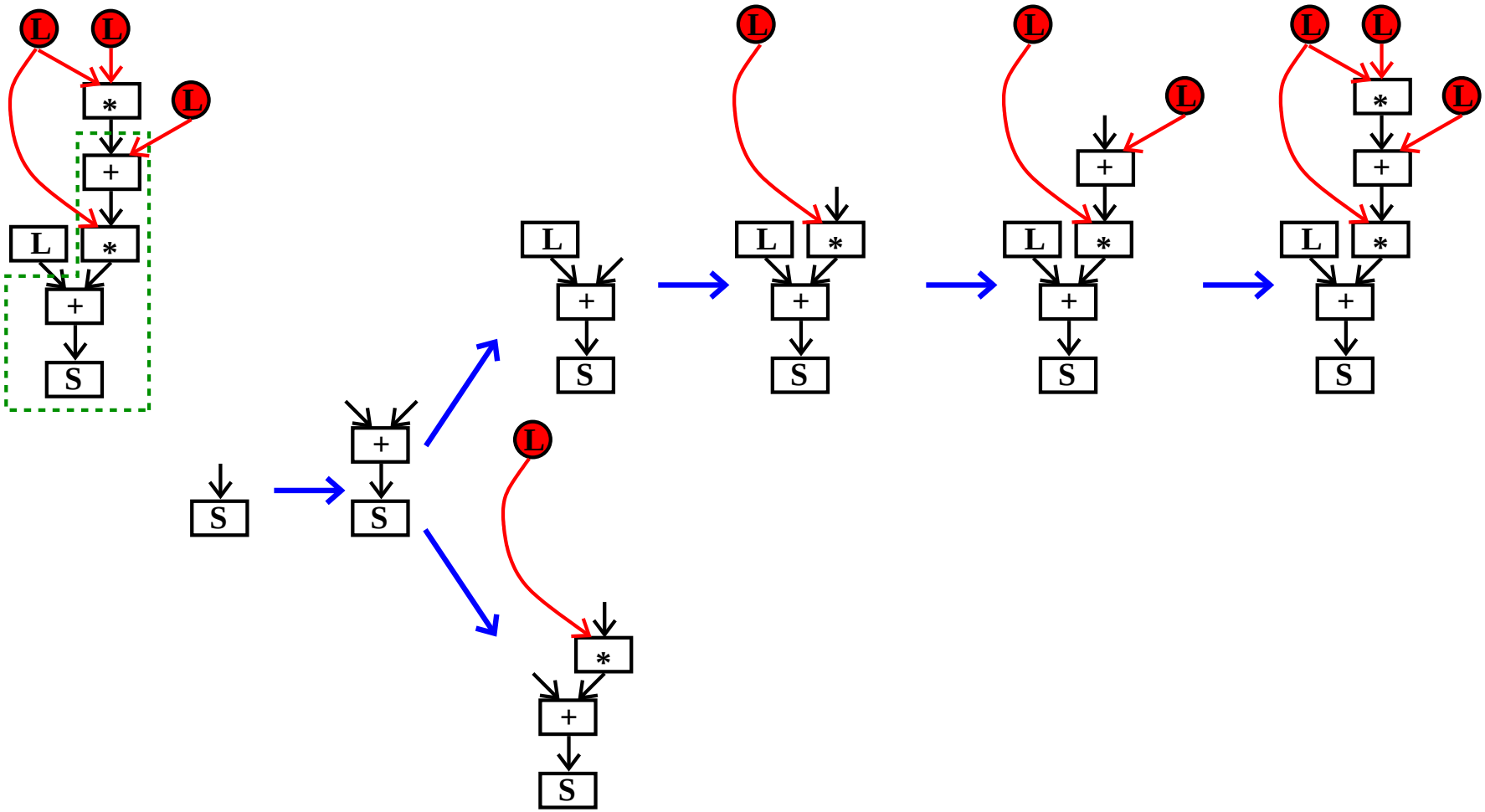
- Only connected subgraphs that include the root

Subgraph (Cuts) Generation Algorithm



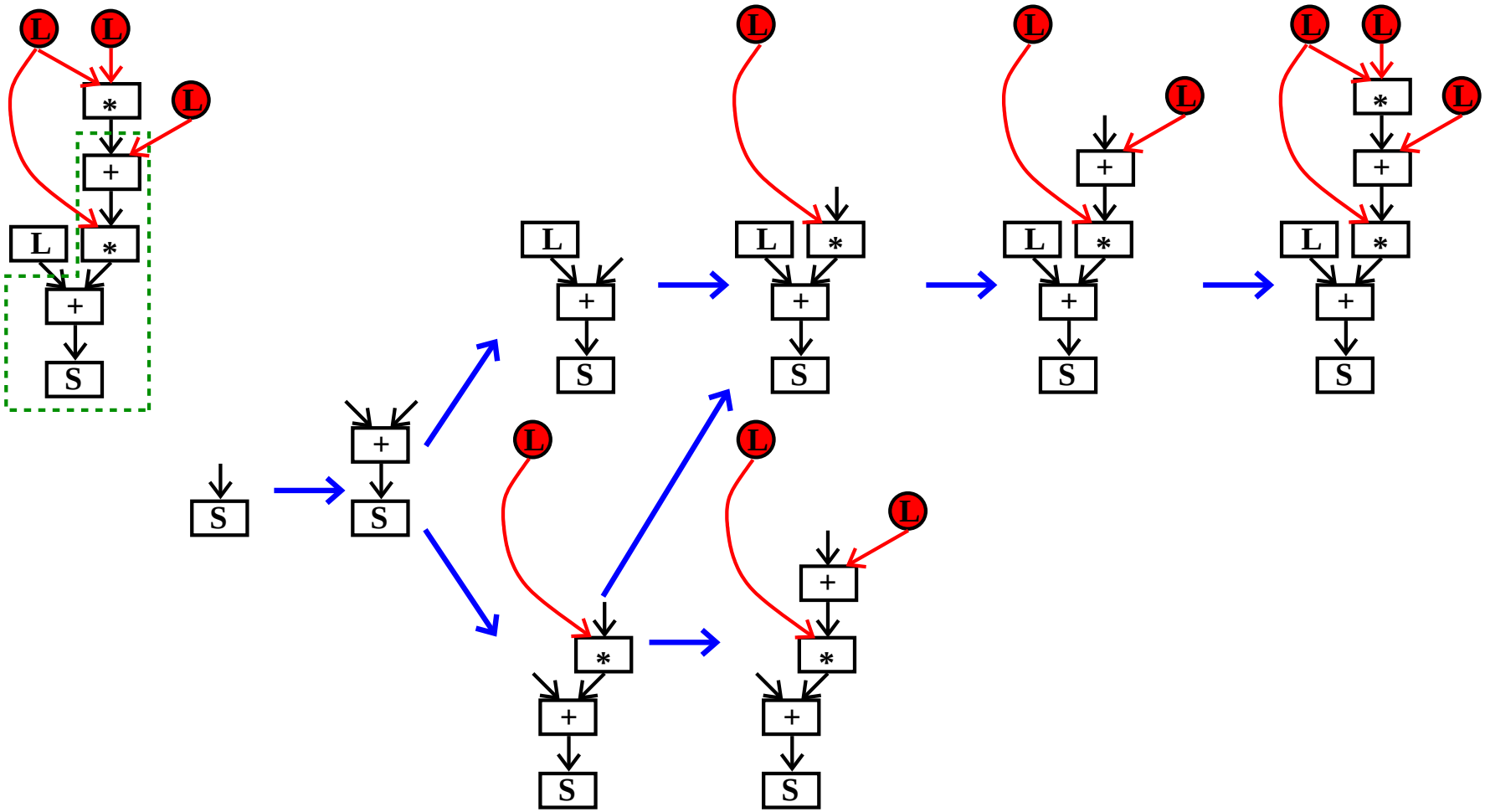
- Only connected subgraphs that include the root

Subgraph (Cuts) Generation Algorithm



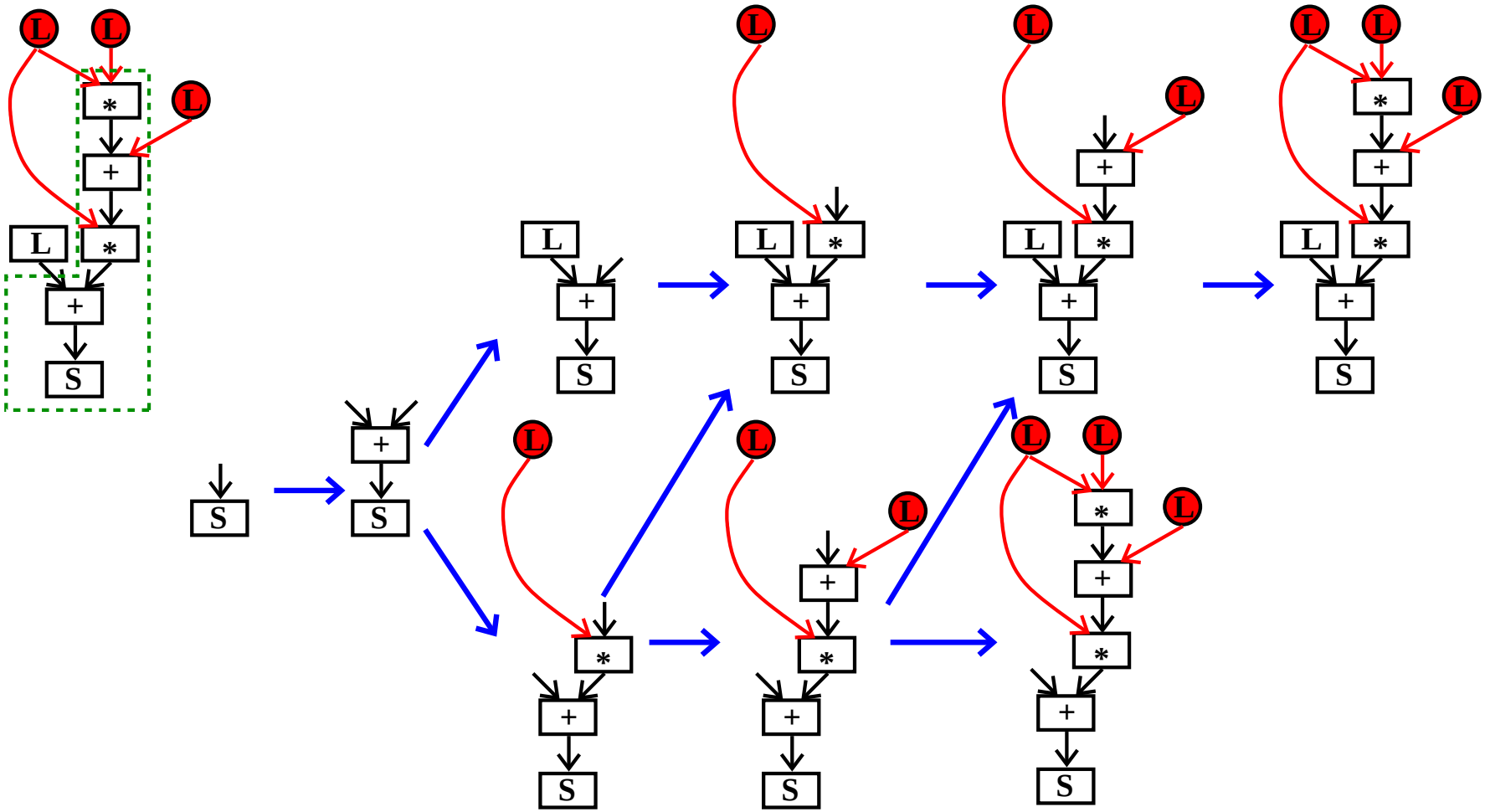
- Only connected subgraphs that include the root

Subgraph (Cuts) Generation Algorithm



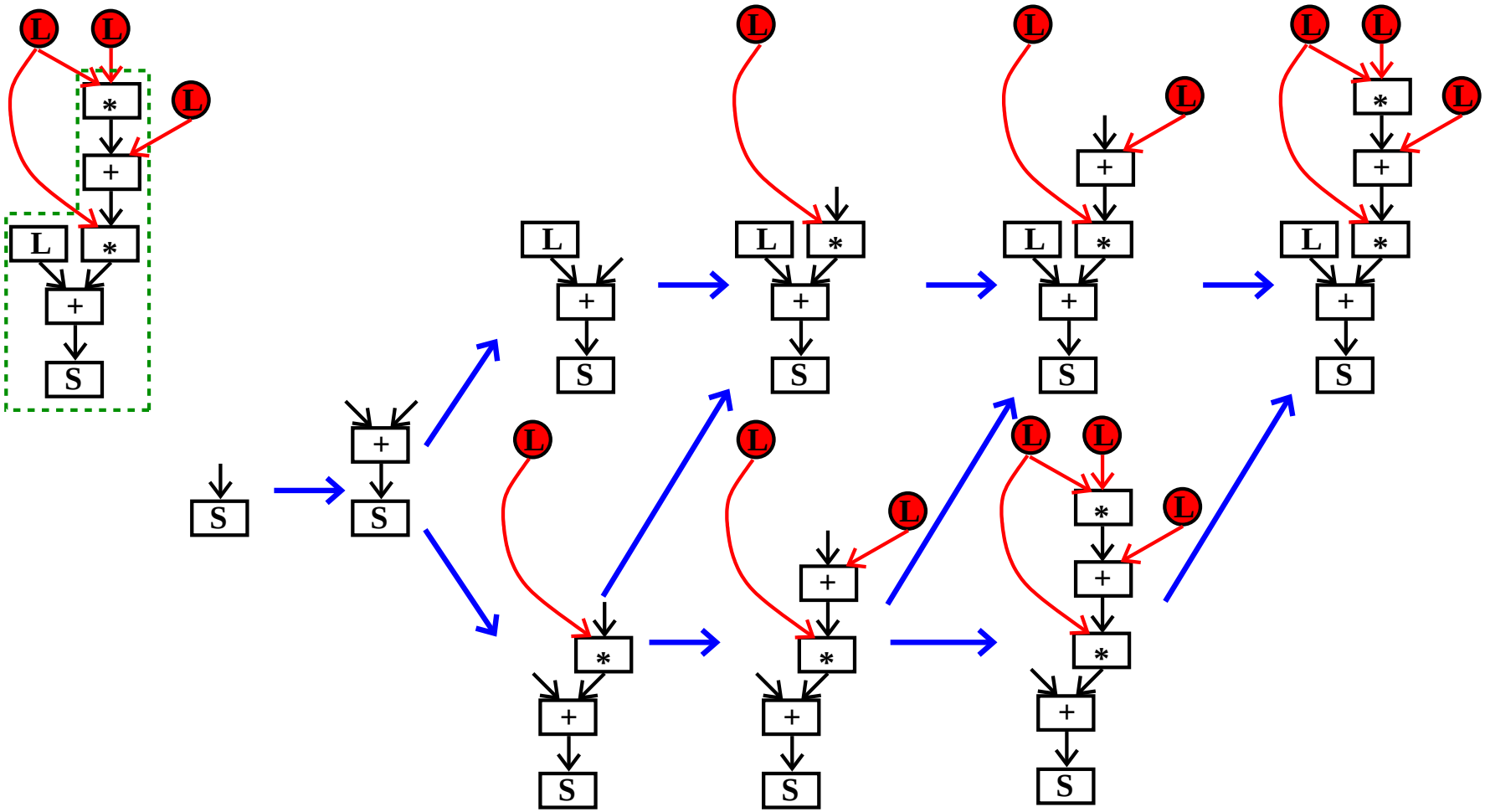
- Only connected subgraphs that include the root

Subgraph (Cuts) Generation Algorithm



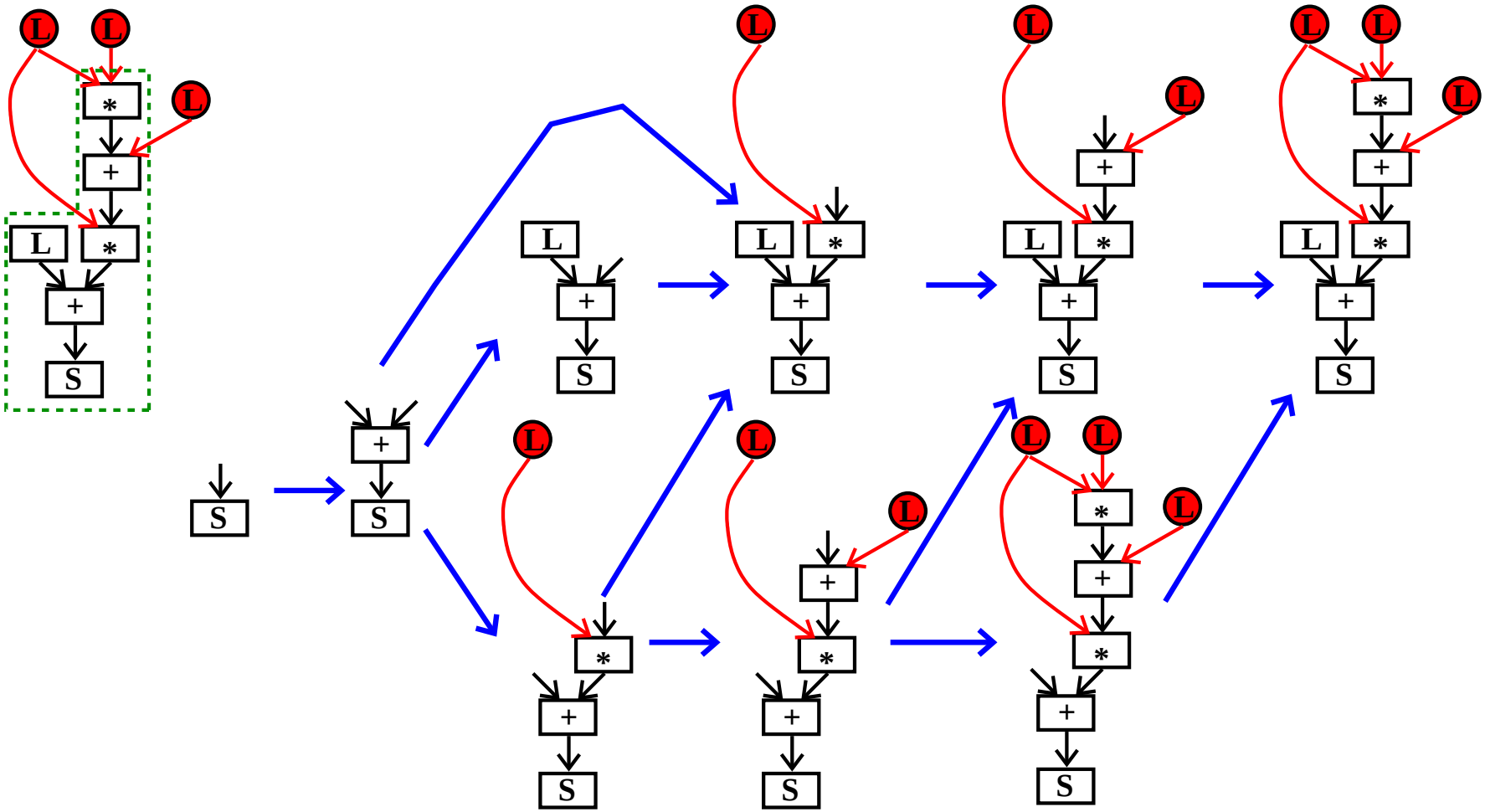
- Only connected subgraphs that include the root

Subgraph (Cuts) Generation Algorithm



- Only connected subgraphs that include the root

Subgraph (Cuts) Generation Algorithm



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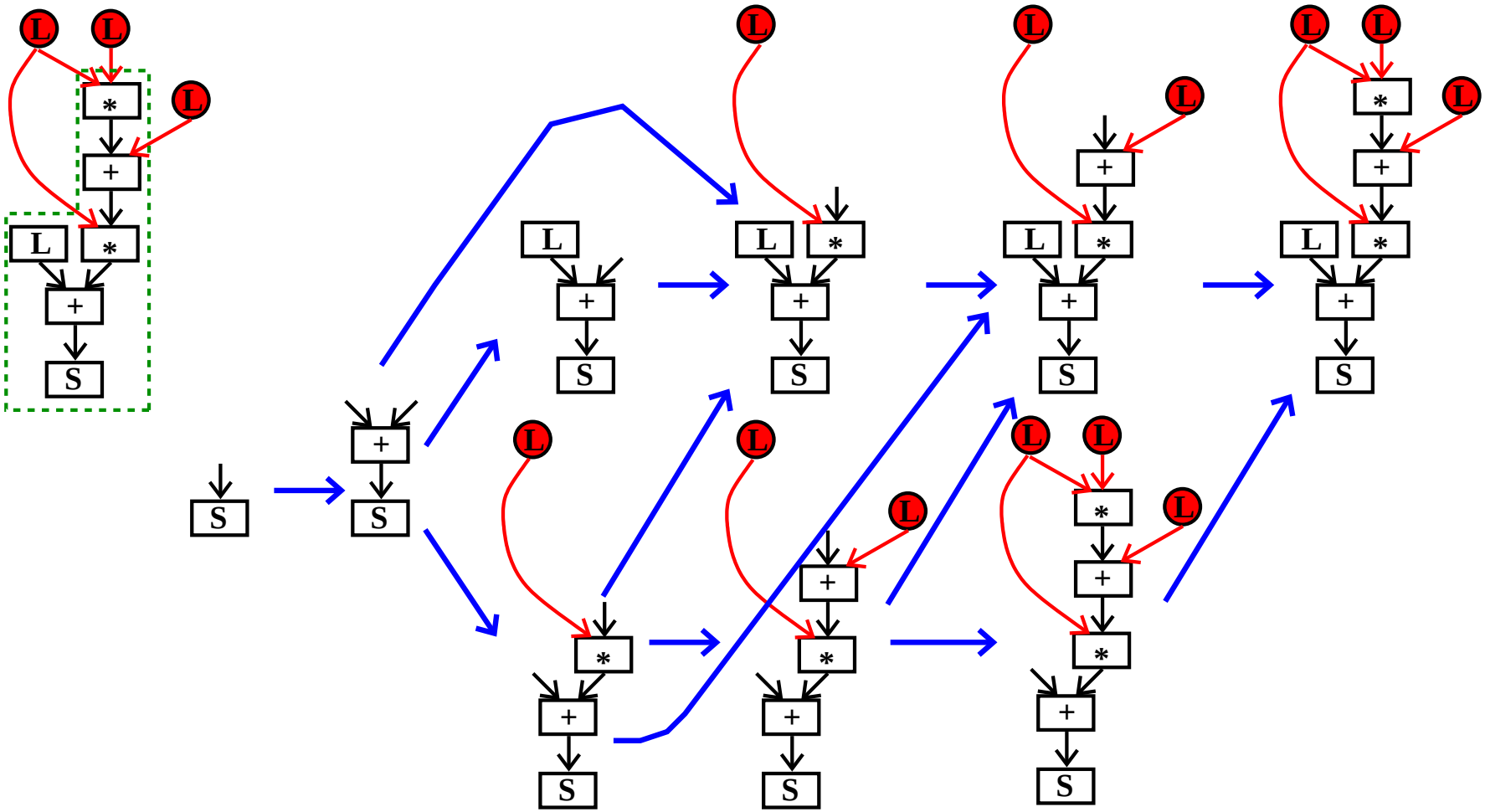
Subgraph (Cuts) Generation Algorithm



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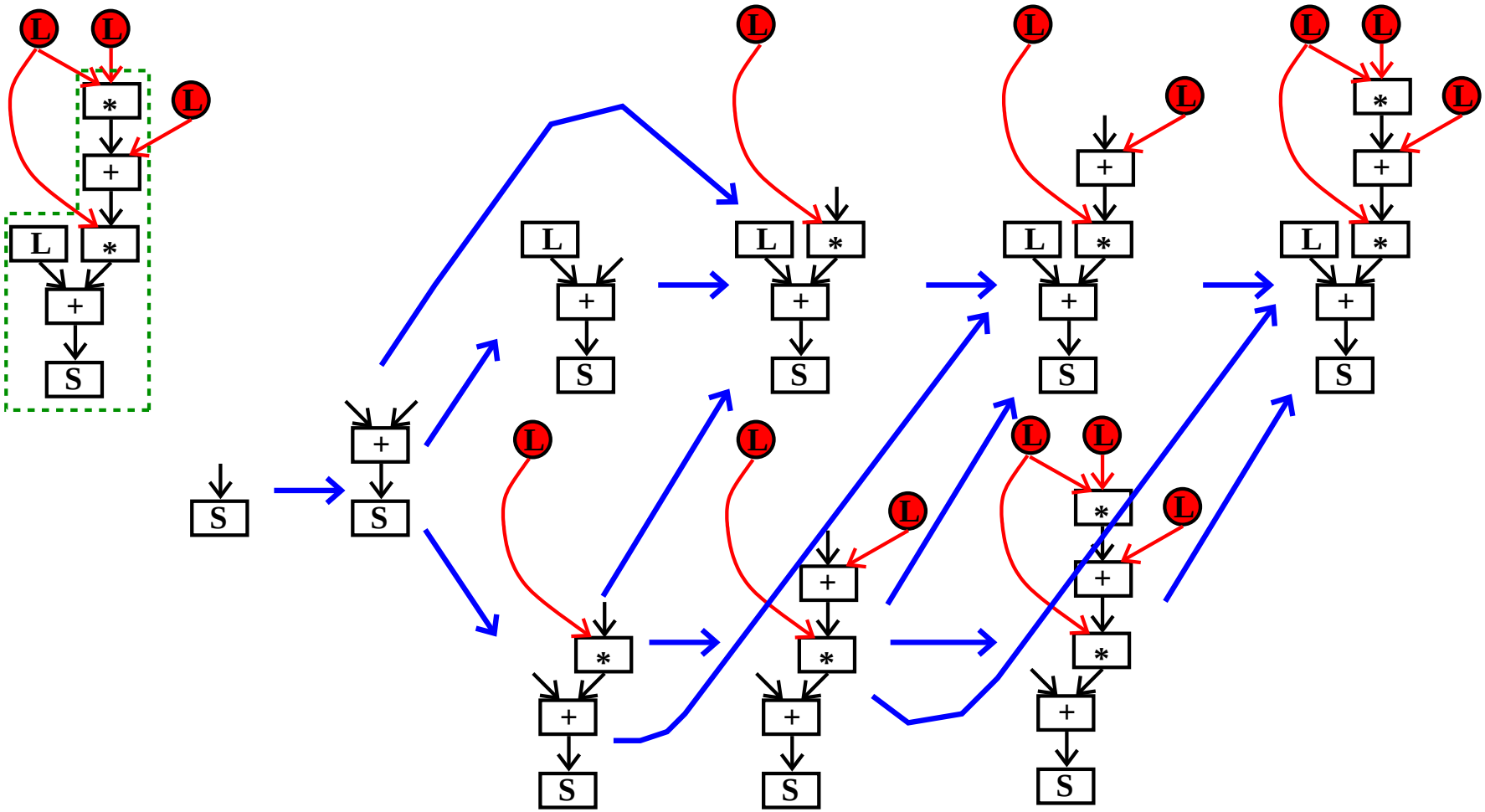
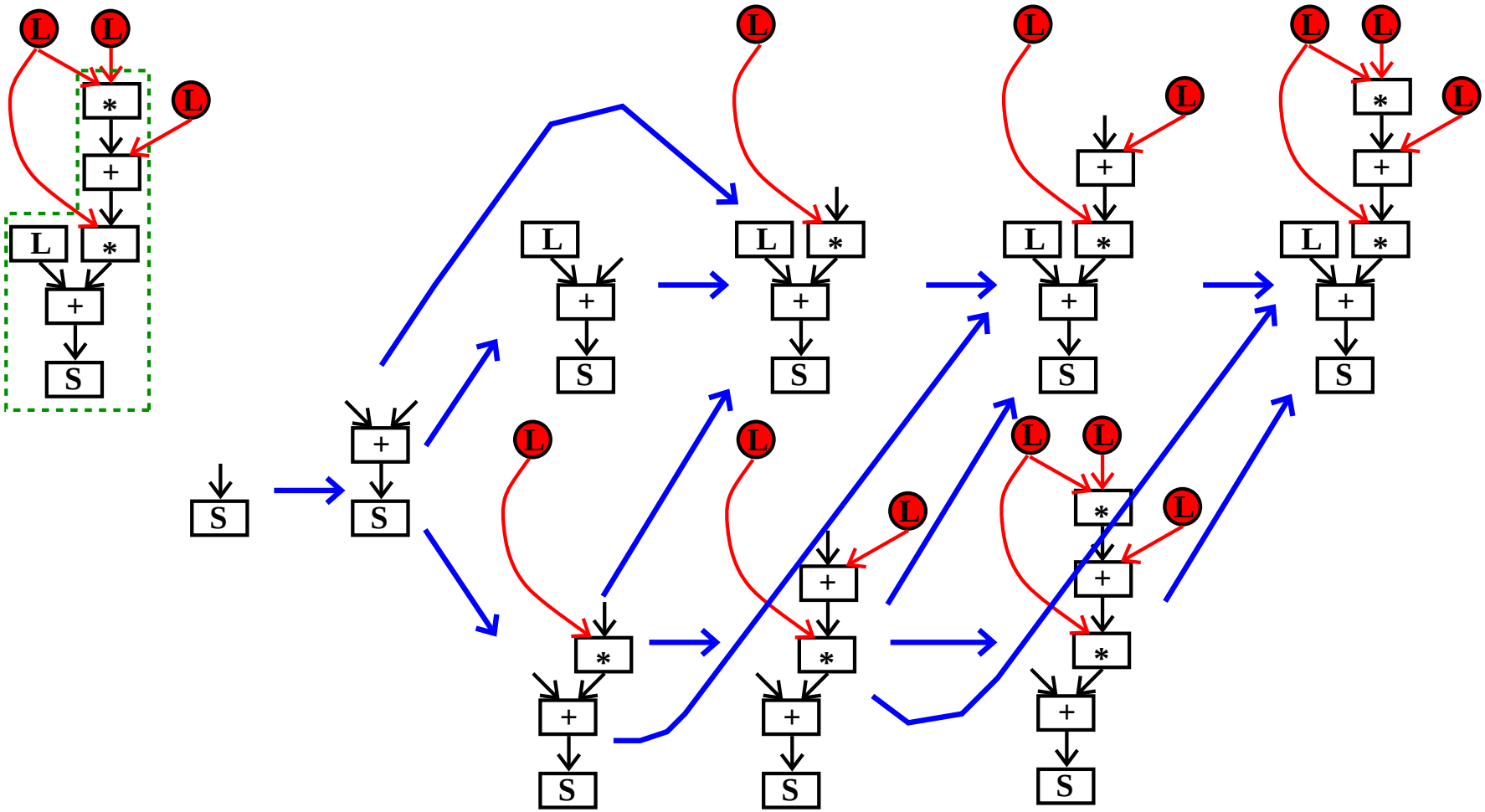
Subgraph (Cuts) Generation Algorithm



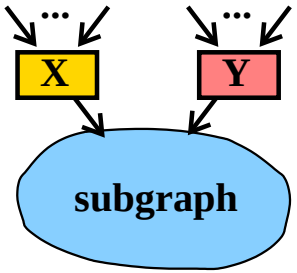
- Only connected subgraphs that include the root

Subgraph (Cuts) Generation Algorithm

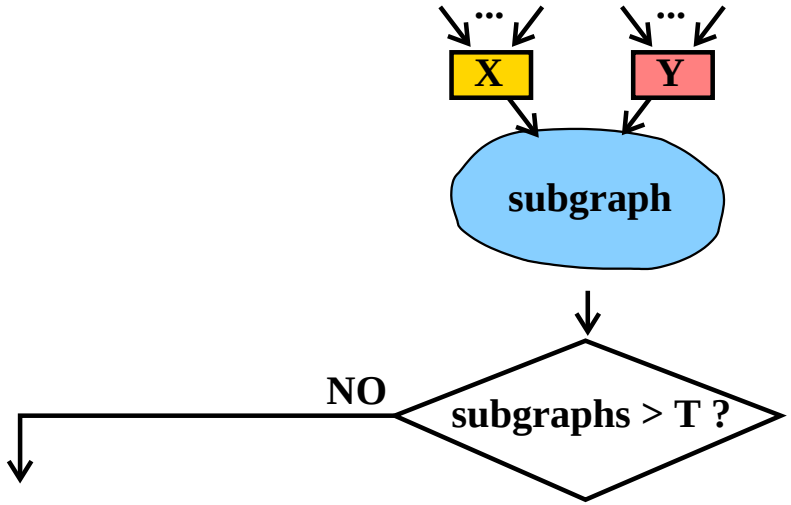


- Only connected subgraphs that include the root
- Worst time complexity $O(2^B xN)$ (N=Nodes, B=Neighbors)

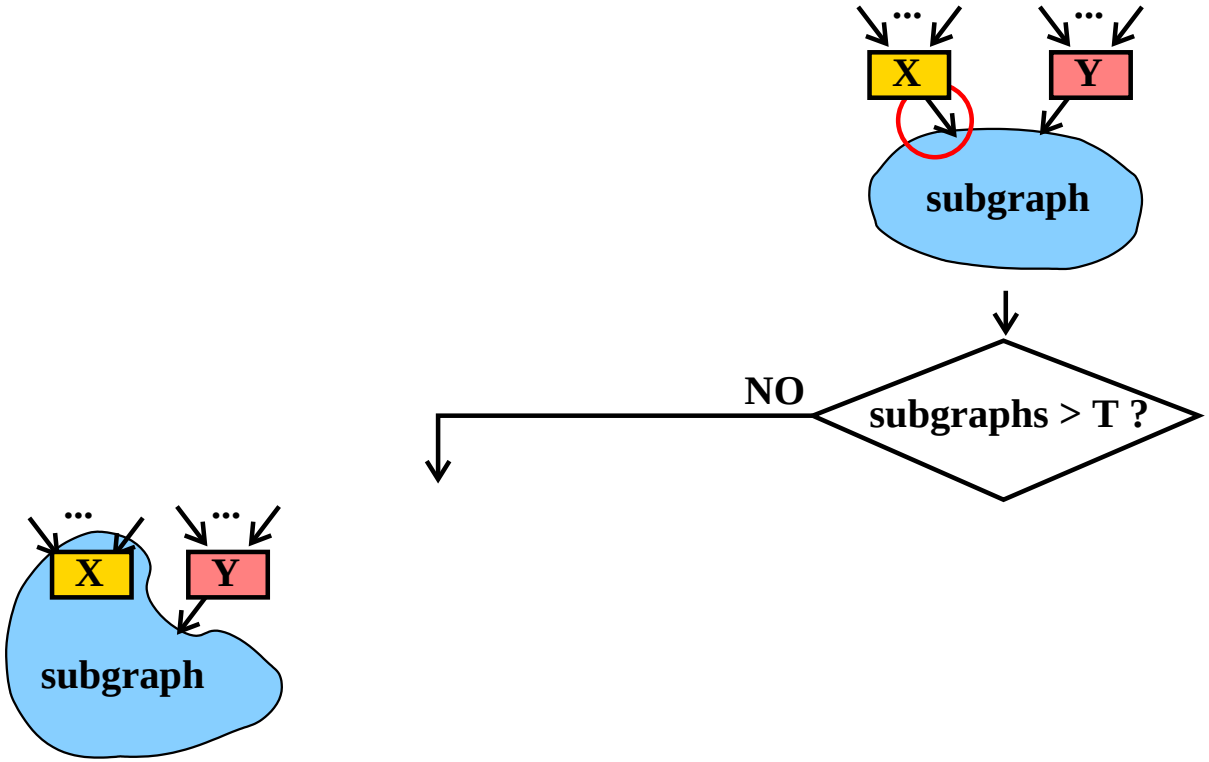
Fast Subgraph (Cuts) Generation Algorithm



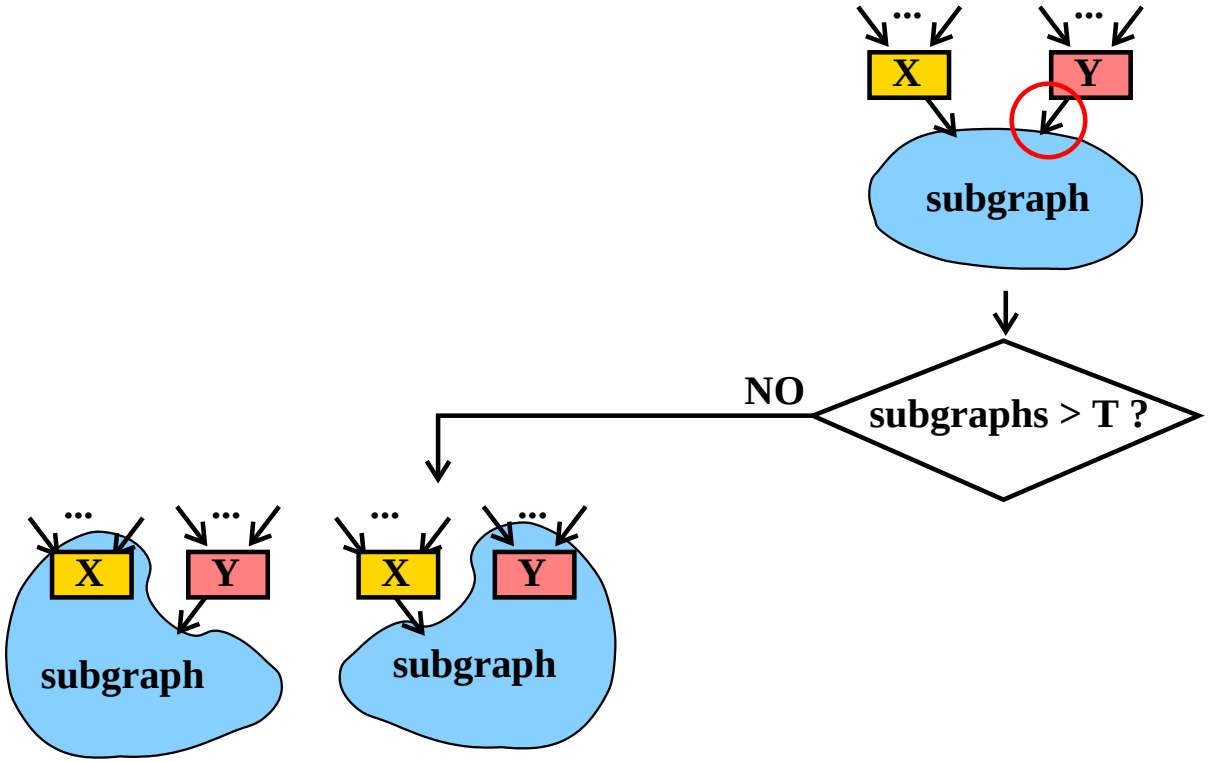
Fast Subgraph (Cuts) Generation Algorithm



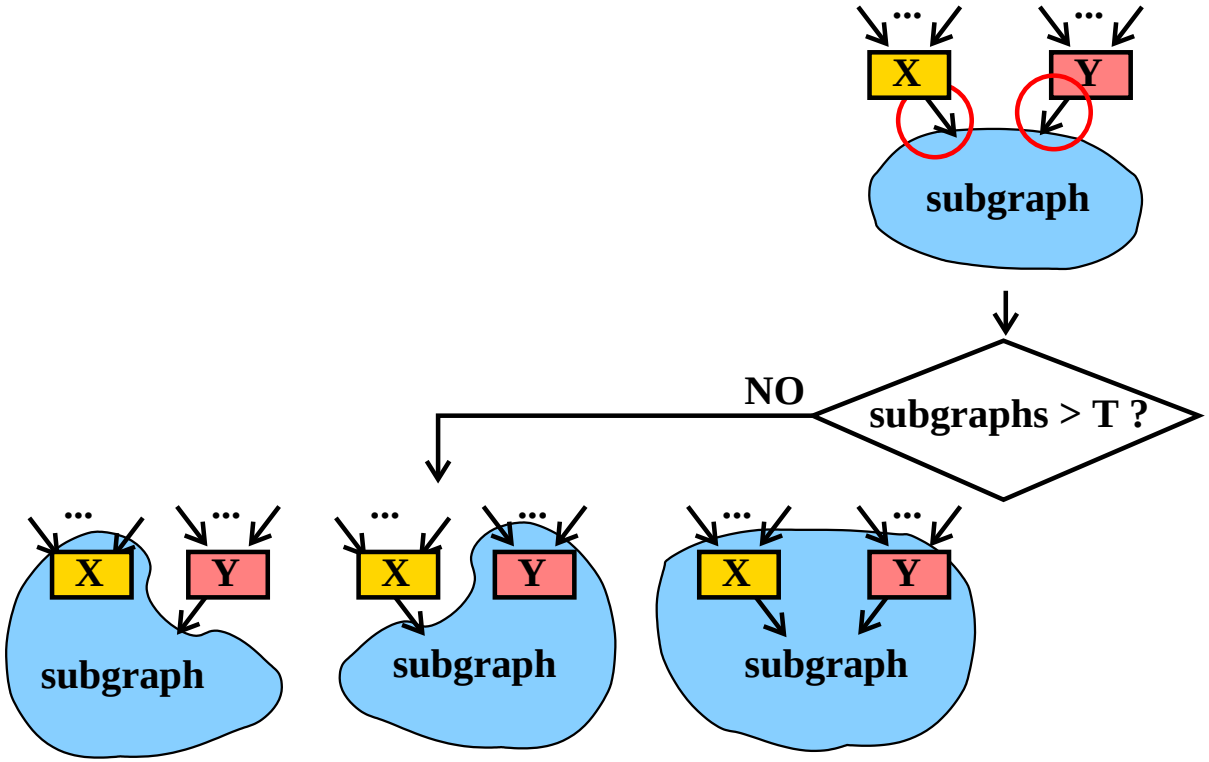
Fast Subgraph (Cuts) Generation Algorithm



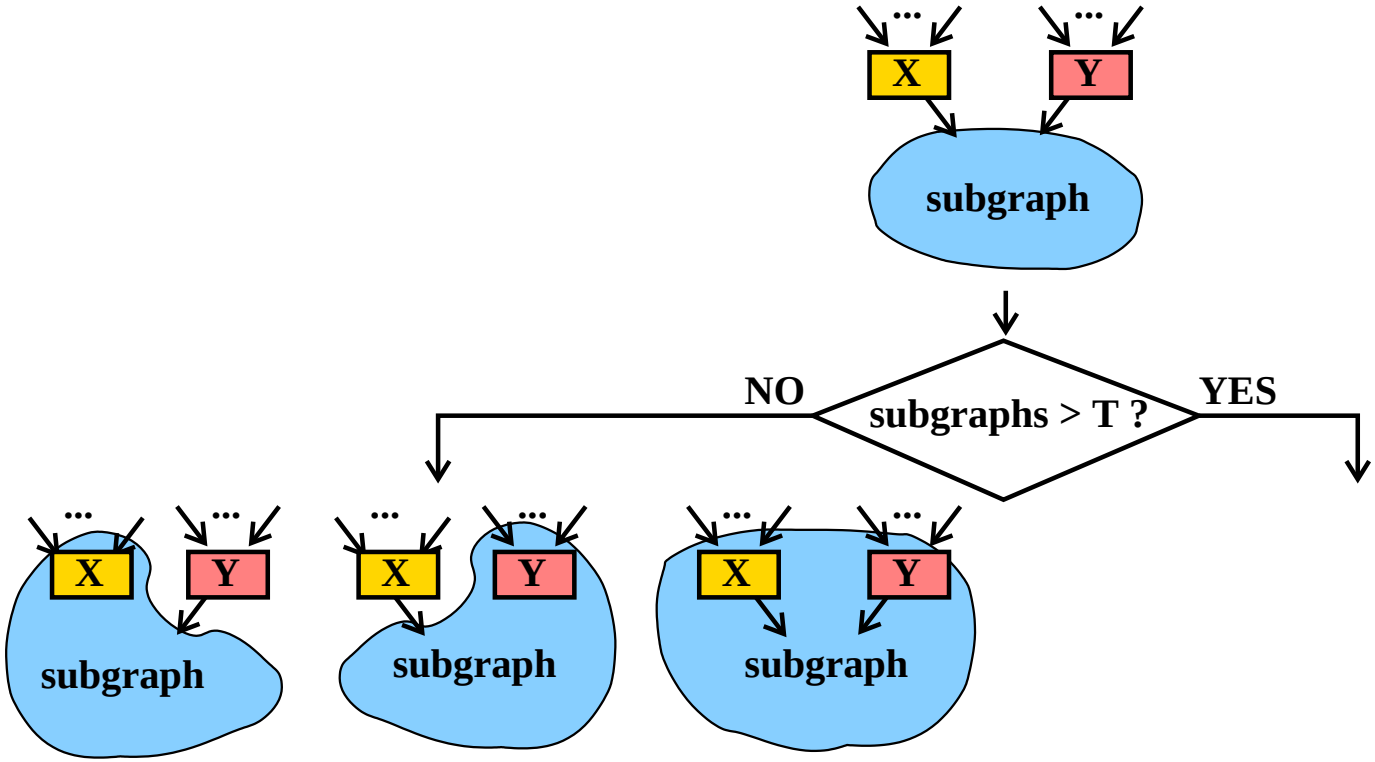
Fast Subgraph (Cuts) Generation Algorithm



Fast Subgraph (Cuts) Generation Algorithm

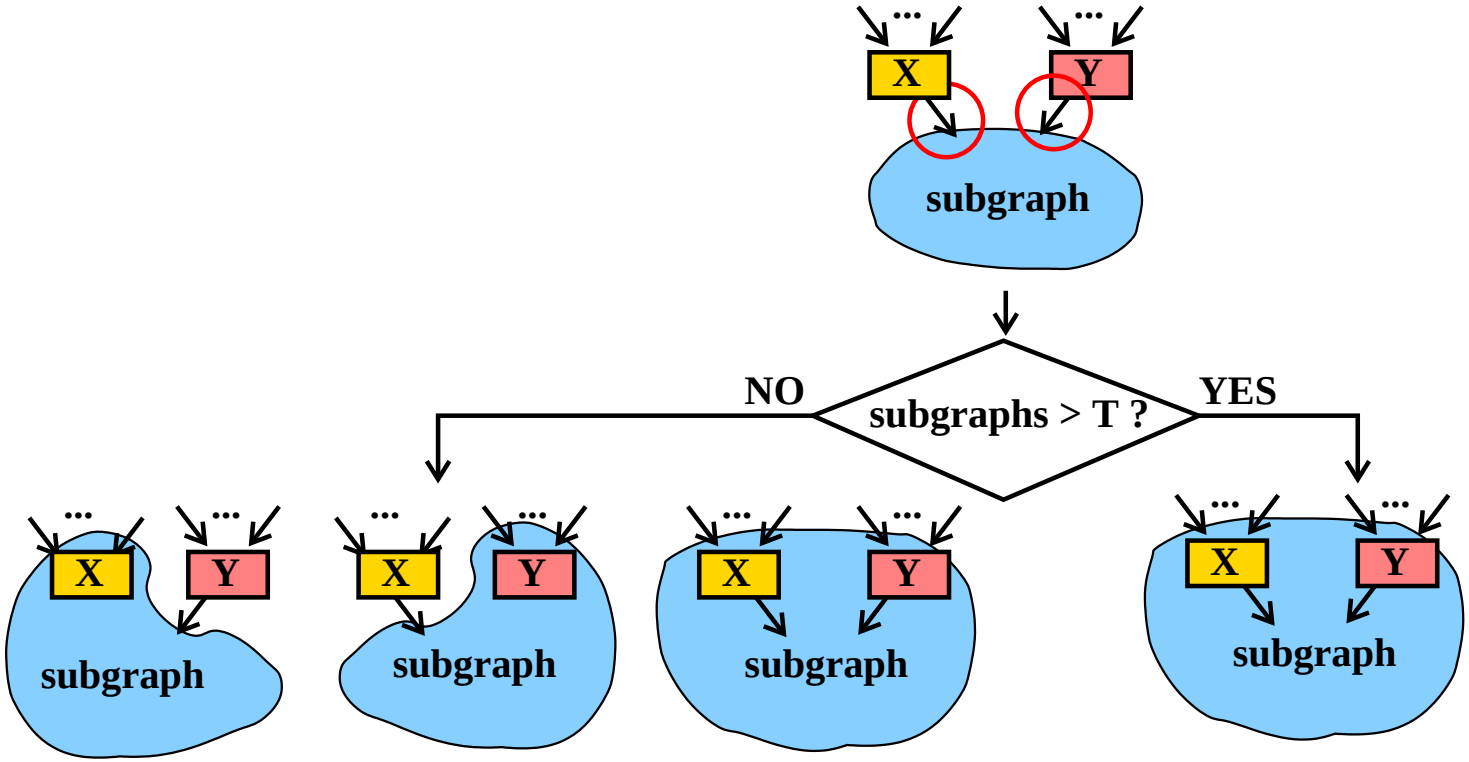


Fast Subgraph (Cuts) Generation Algorithm



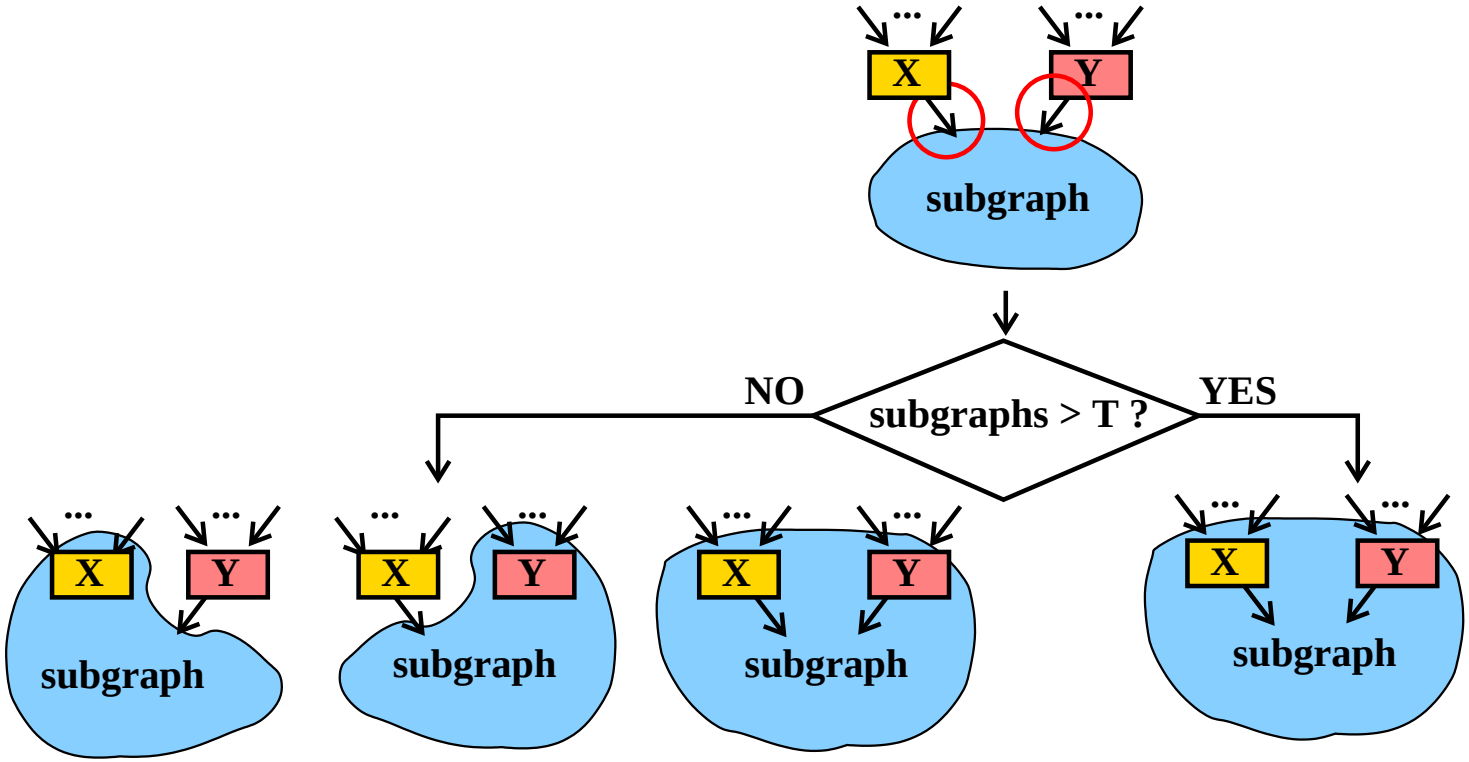
- After T subgraphs, attach all neighbors

Fast Subgraph (Cuts) Generation Algorithm



- After T subgraphs, attach all neighbors

Fast Subgraph (Cuts) Generation Algorithm



- After T subgraphs, attach all neighbors
- Complexity reduced to linear $O(T + N)$

Experimental Setup

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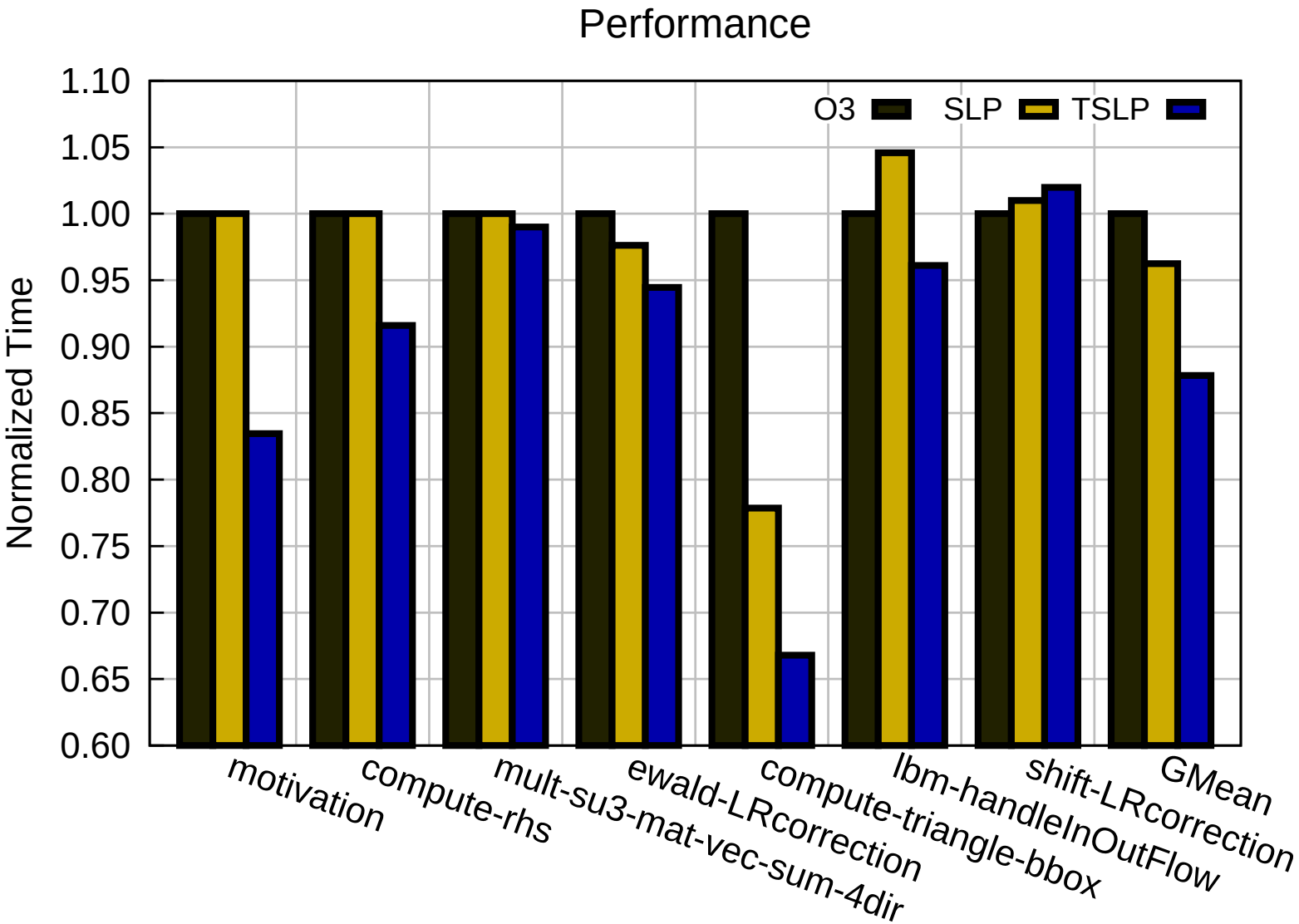
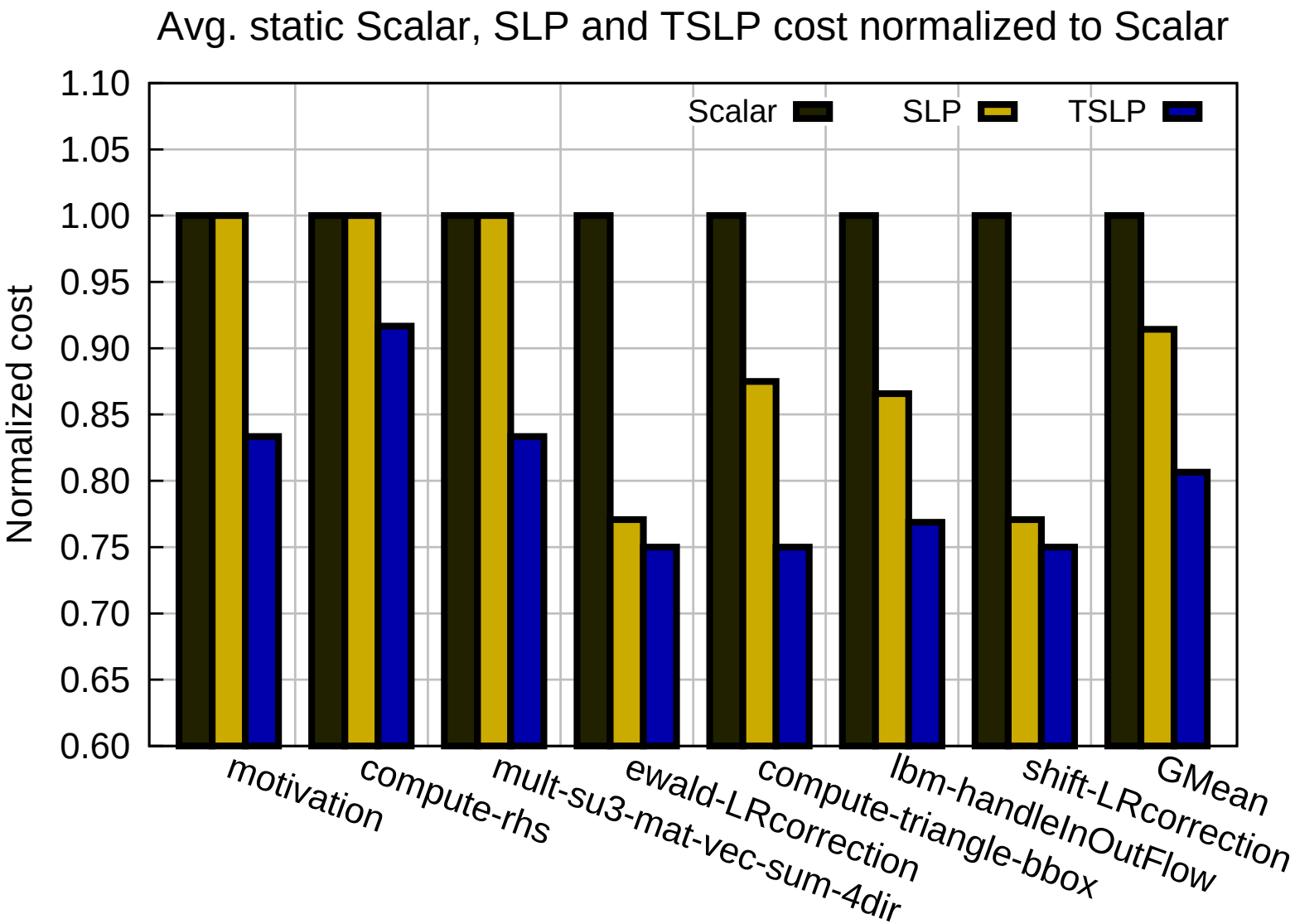
  3. O3 + TSLP enabled (TSLP)

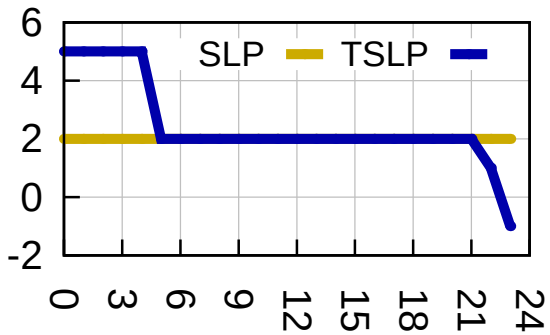
TSLP increases performance



TSLP static cost savings



TSLP TotalCost exploration



mult-su3-mat-vec-sum

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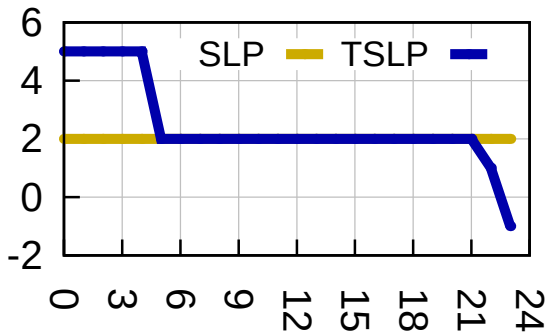

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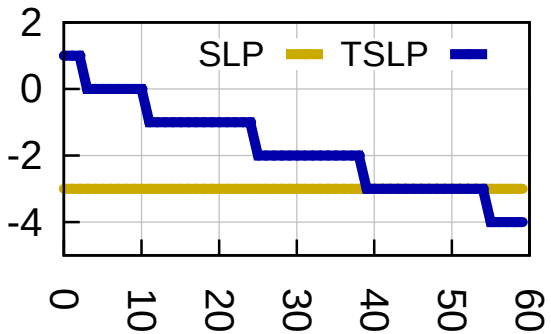

lbm-handleInOutFlow-3

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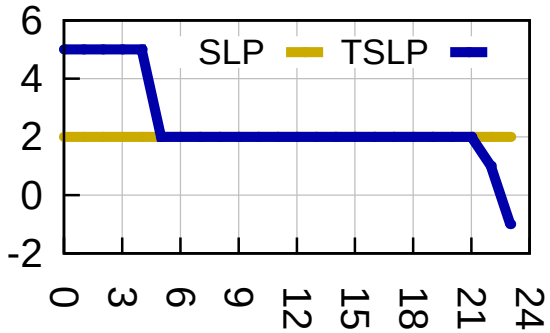

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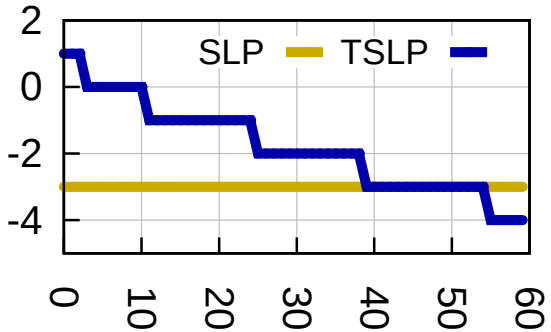
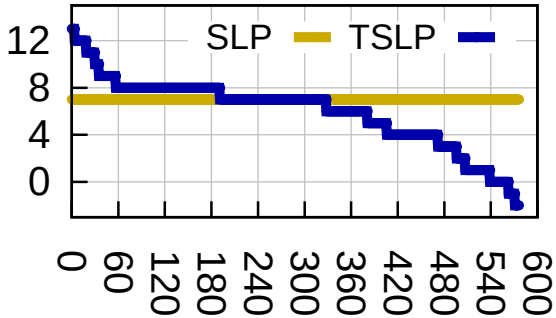


lbm-handleInOutFlow-3



lab-handleInOutFlow-5

- SLP non-profitable, TSLP profitable
- SLP profitable, but TSLP more profitable
- TSLP exploration gradually improves cost

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- PACT'15 paper: `http://www.cl.cam.ac.uk/~vp331/`