Look-Ahead SLP: Auto-vectorization in the Presence of Commutative Operations

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Background

SLP: The Straight-Line Code vectorizer

- Superword Level Parallelism
- Vectorizes across instructions

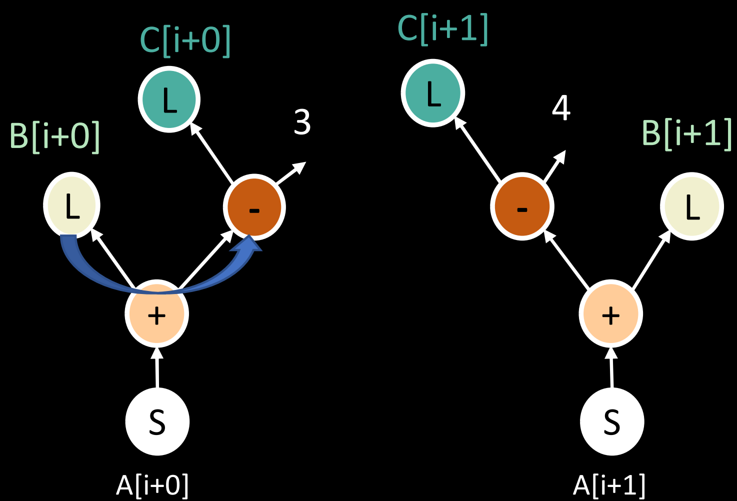
```
A[i] = B[i];
A[i+1] = B[i+1];
A[i+2] = B[i+2];
A[i+3] = B[i+3];
```

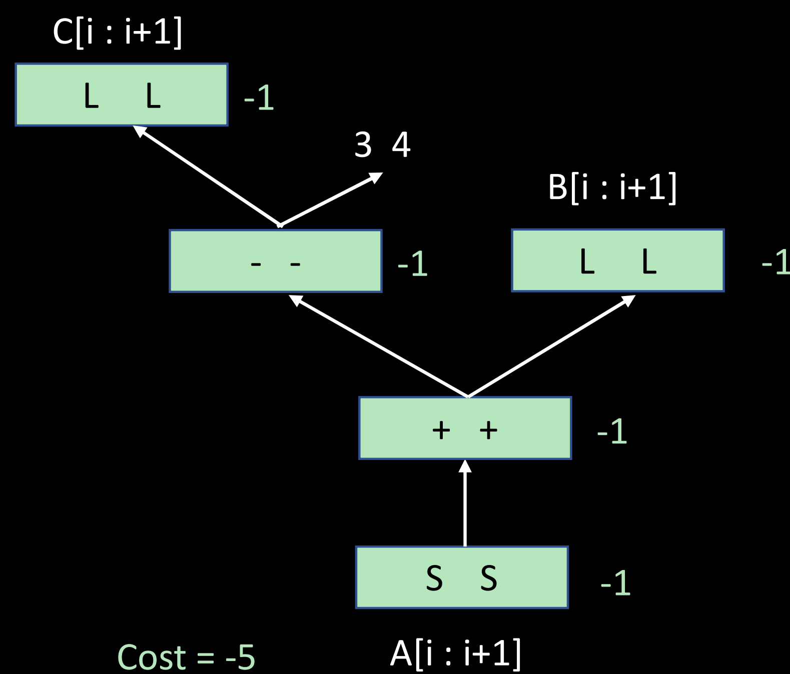
$\xrightarrow{\text{SLP}}$

```
A[i:i+3] = B[i:i+3];
```

How SLP works

```
long A[], B[], C[];
A[i+0] = B[i+0]         +  (C[i+0] – 3);
A[i+1] = (C[i+1] – 4)  +  B[i+1];
```





Motivation

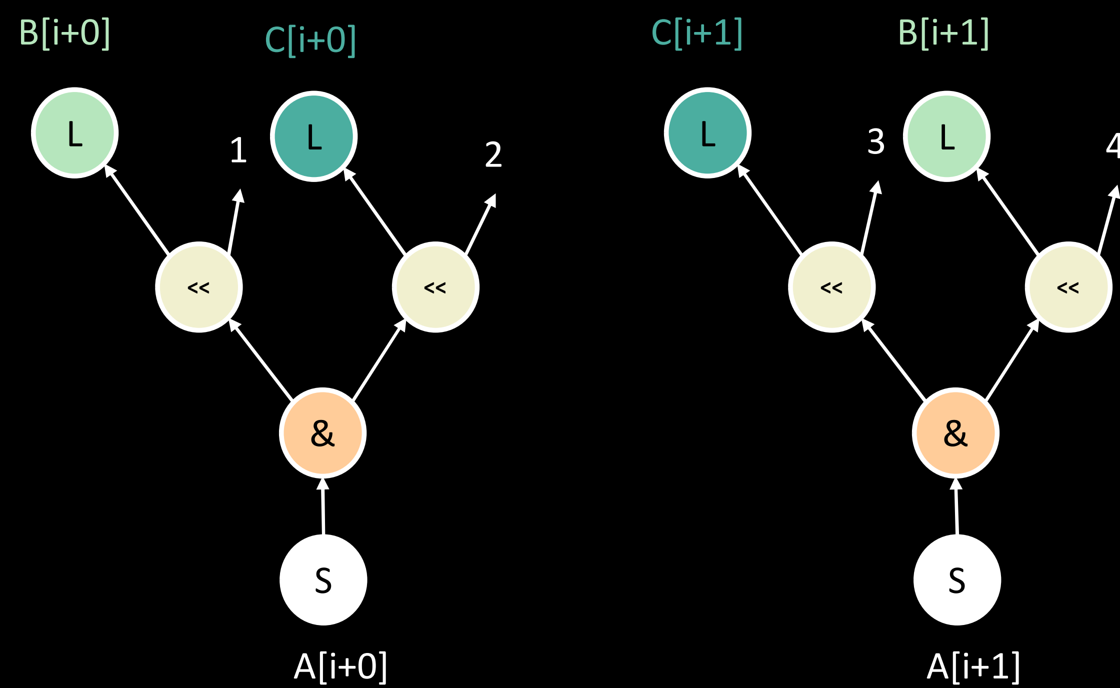
- Load Address Mismatch
- Opcode Mismatch
- Associativity Mismatch and Multi-Node

SLP Failure: Load Address Mismatch

```
long A[], B[], C[];
A[i+0] = (B[i+0] << 1) & (C[i+0] << 2);
A[i+1] = (C[i+1] << 3) & (B[i+1] << 4);
```

SLP Failure: Load Address Mismatch

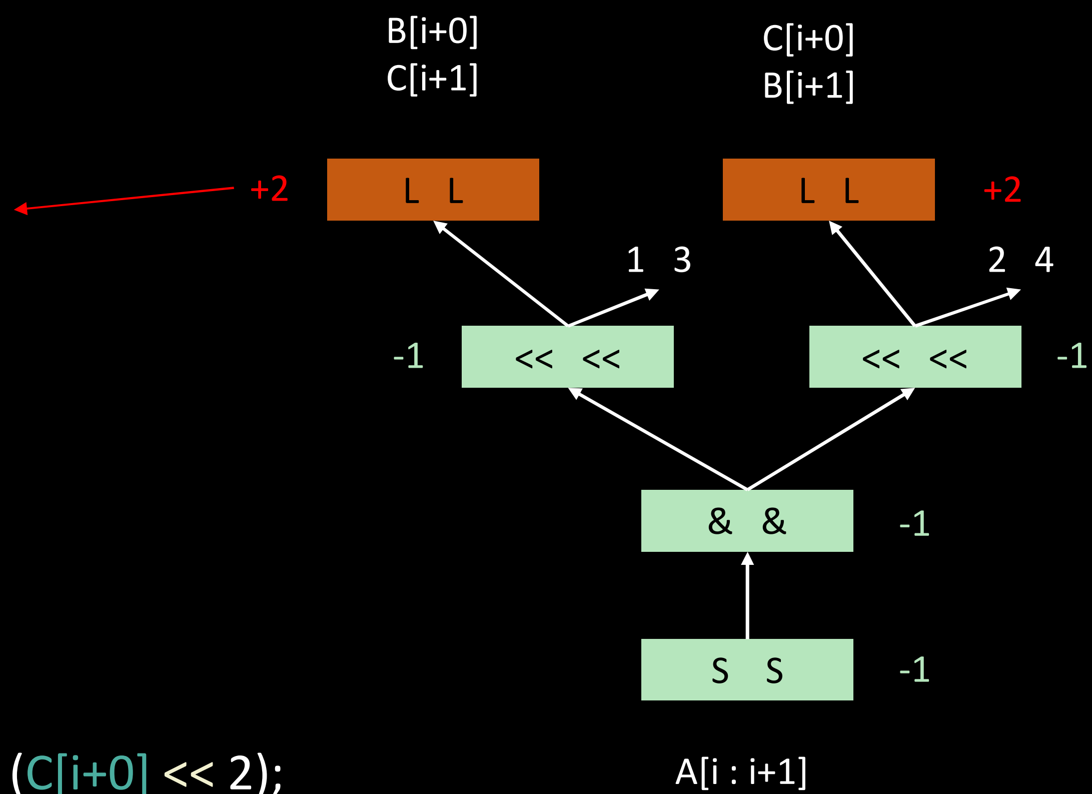
Use-def Chains DAG




```
1 long A[], B[], C[];
2 A[i+0] = (B[i+0] << 1) & (C[i+0] << 2);
3 A[i+1] = (C[i+1] << 3) & (B[i+1] << 4);
```

SLP Failure: Load Address Mismatch

Extra cost for gathering and aggregating



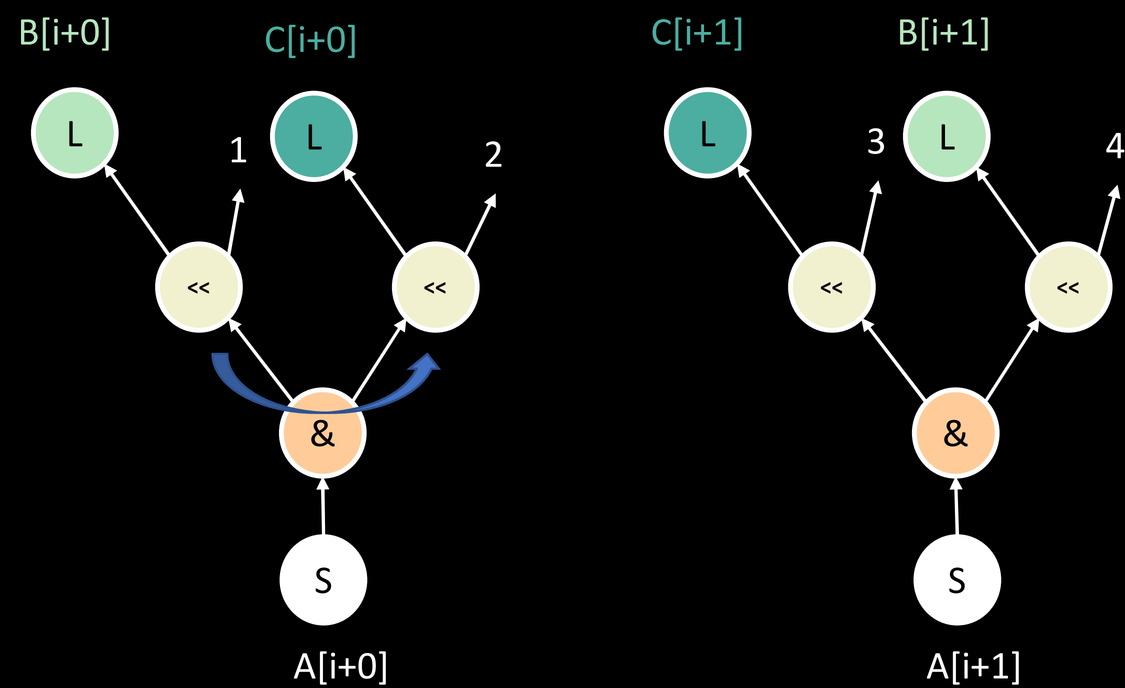
Total cost: 0

```
long A[], B[], C[];
A[i+0] = (B[i+0] << 1) & (C[i+0] << 2);
A[i+1] = (C[i+1] << 3) & (B[i+1] << 4);
```

SLP

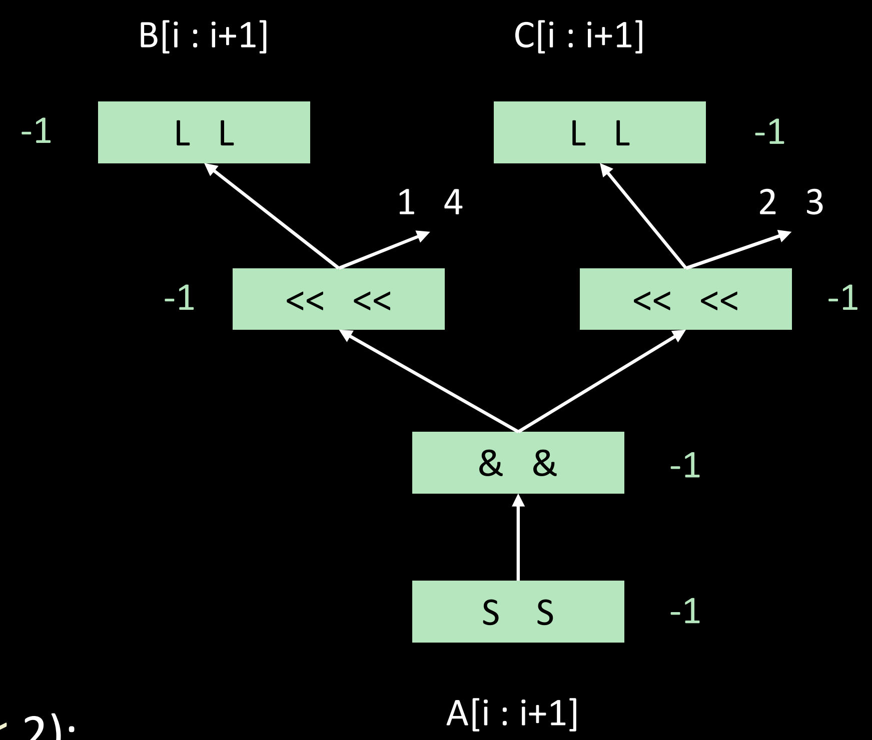
SLP Failure: Load Address Mismatch

Use-def Chains DAG




```
long A[], B[], C[];
A[i+0] = (B[i+0] << 1) & (C[i+0] << 2);
A[i+1] = (C[i+1] << 3) & (B[i+1] << 4);
```

SLP Failure: Load Address Mismatch



Total cost: -6

```
long A[], B[], C[];
A[i+0] = (B[i+0] << 1) & (C[i+0] << 2);
A[i+1] = (C[i+1] << 3) & (B[i+1] << 4);
```

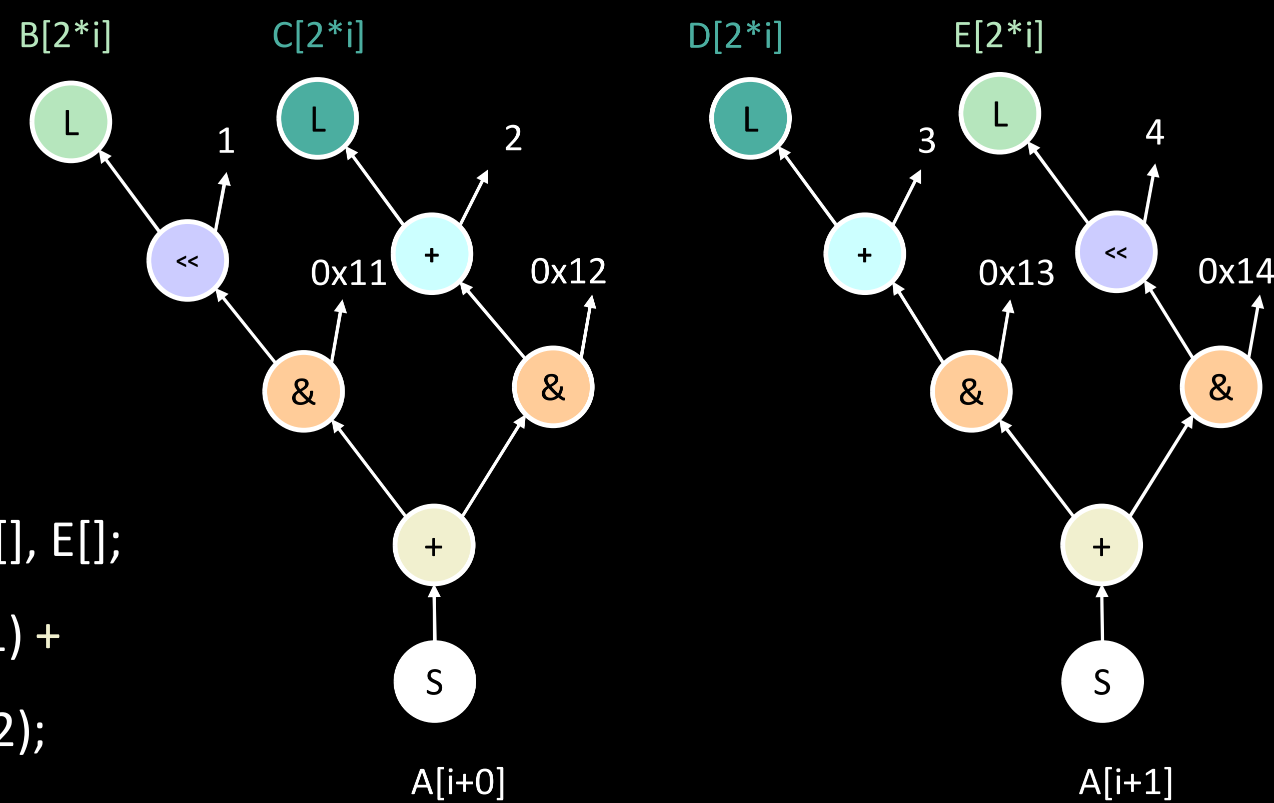
LSLP

SLP Failure: Opcode Mismatch

```
unsigned long A[], B[], C[], D[], E[];
A[i+0] = ((B[2*i] << 1) & 0x11) +
         ((C[2*i]  +   2) & 0x12);
A[i+1] = ((D[2*i]  +   3) & 0x13) +
         ((E[2*i] << 4) & 0x14);
```

SLP Failure: Opcode Mismatch

Use-def Chains DAG

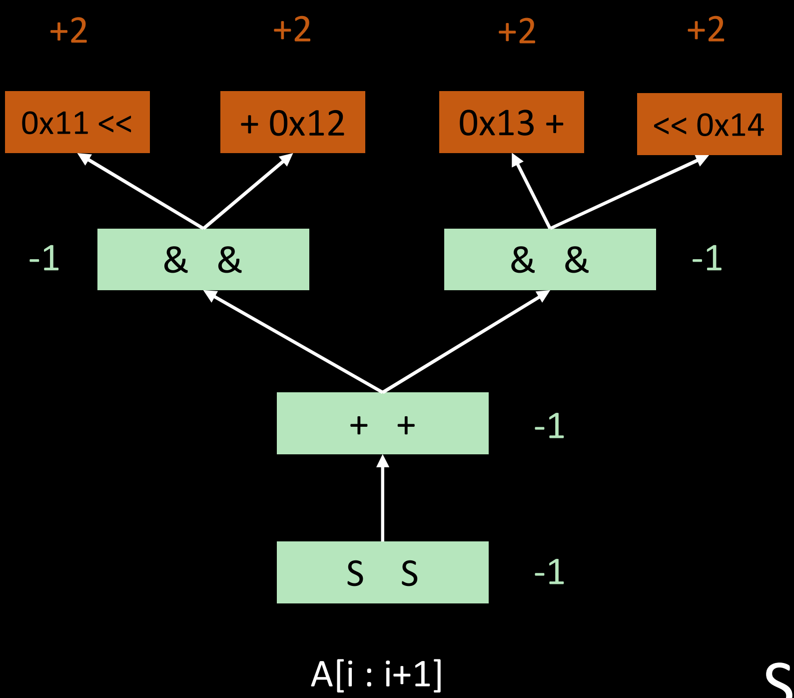



```
1 unsigned long A[], B[], C[], D[], E[];
2 A[i+0] = ((B[2*i] << 1) & 0x11) +
           ((C[2*i]  +   2) & 0x12);
3 A[i+1] = ((D[2*i]  +   3) & 0x13) +
           ((E[2*i] << 4) & 0x14);
```

SLP Failure: Opcode Mismatch

Total cost: +4

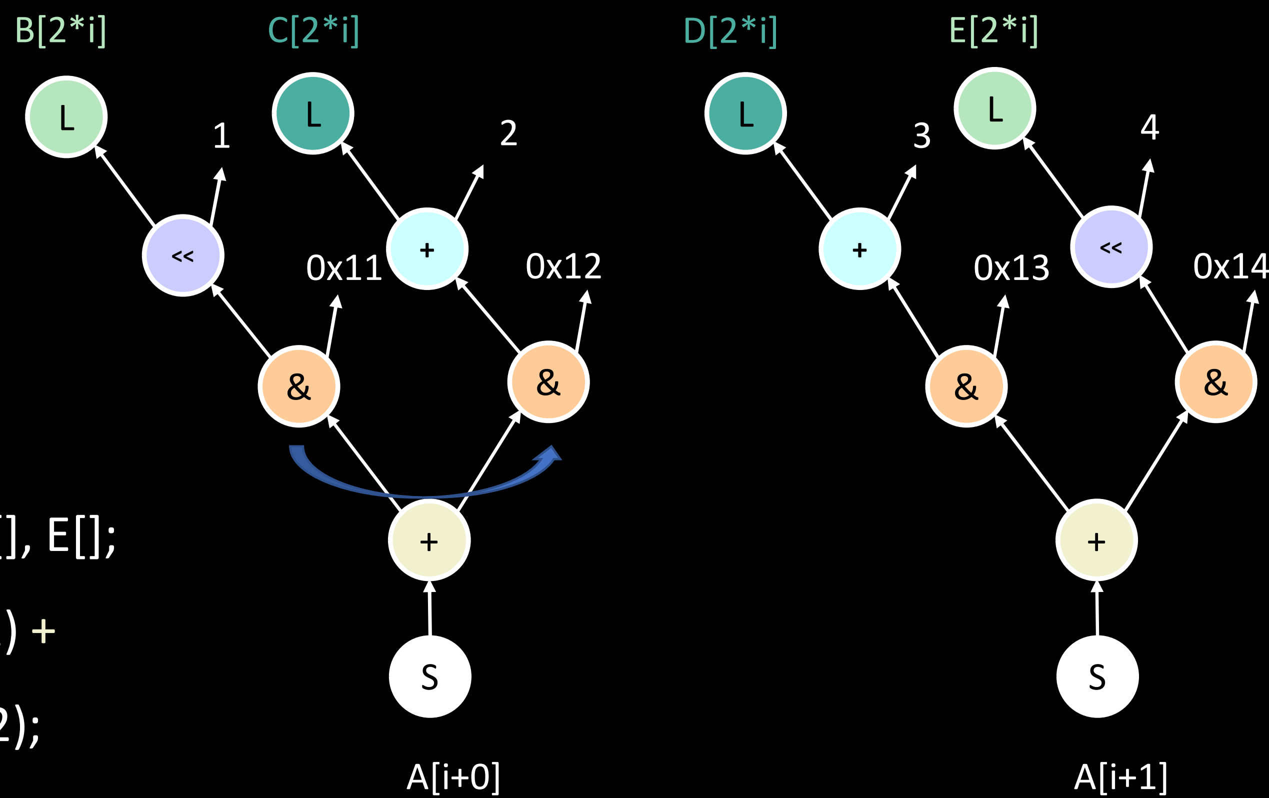
```
1  unsigned long A[], B[], C[], D[], E[];
2  A[i+0] = ((B[2*i] << 1) & 0x11) +
            ((C[2*i]  +  2) & 0x12);
3  A[i+1] = ((D[2*i]  +  3) & 0x13) +
            ((E[2*i] << 4) & 0x14);
```



SLP

SLP Failure: Opcode Mismatch

Use-def Chains DAG

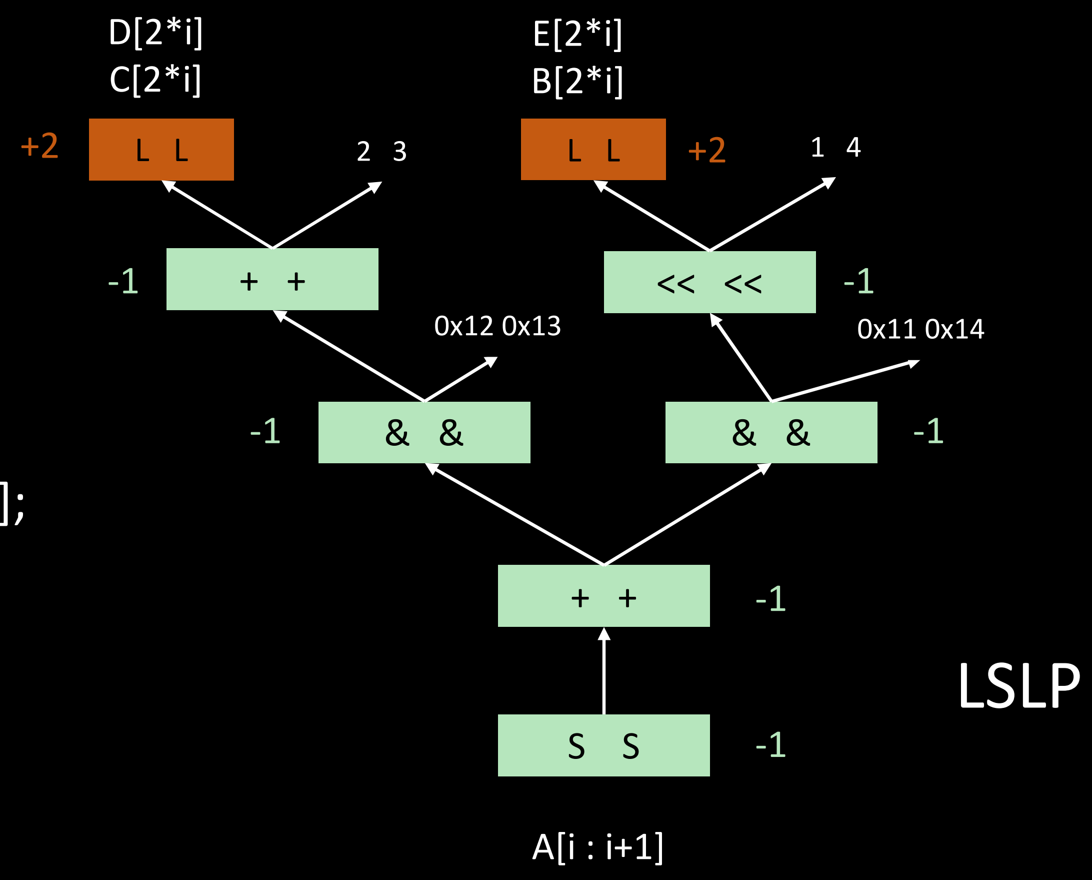



```
unsigned long A[], B[], C[], D[], E[];
A[i+0] = ((B[2*i] << 1) & 0x11) +
         ((C[2*i]  +  2) & 0x12);
A[i+1] = ((D[2*i]  +  3) & 0x13) +
         ((E[2*i] << 4) & 0x14);
```

SLP Failure: Opcode Mismatch

Total cost: -2

```
1 unsigned long A[], B[], C[], D[], E[];
2 A[i+0] = ((B[2*i] << 1) & 0x11) +
           ((C[2*i]  +  2) & 0x12);
3 A[i+1] = ((D[2*i]  +  3) & 0x13) +
           ((E[2*i] << 4) & 0x14);
```

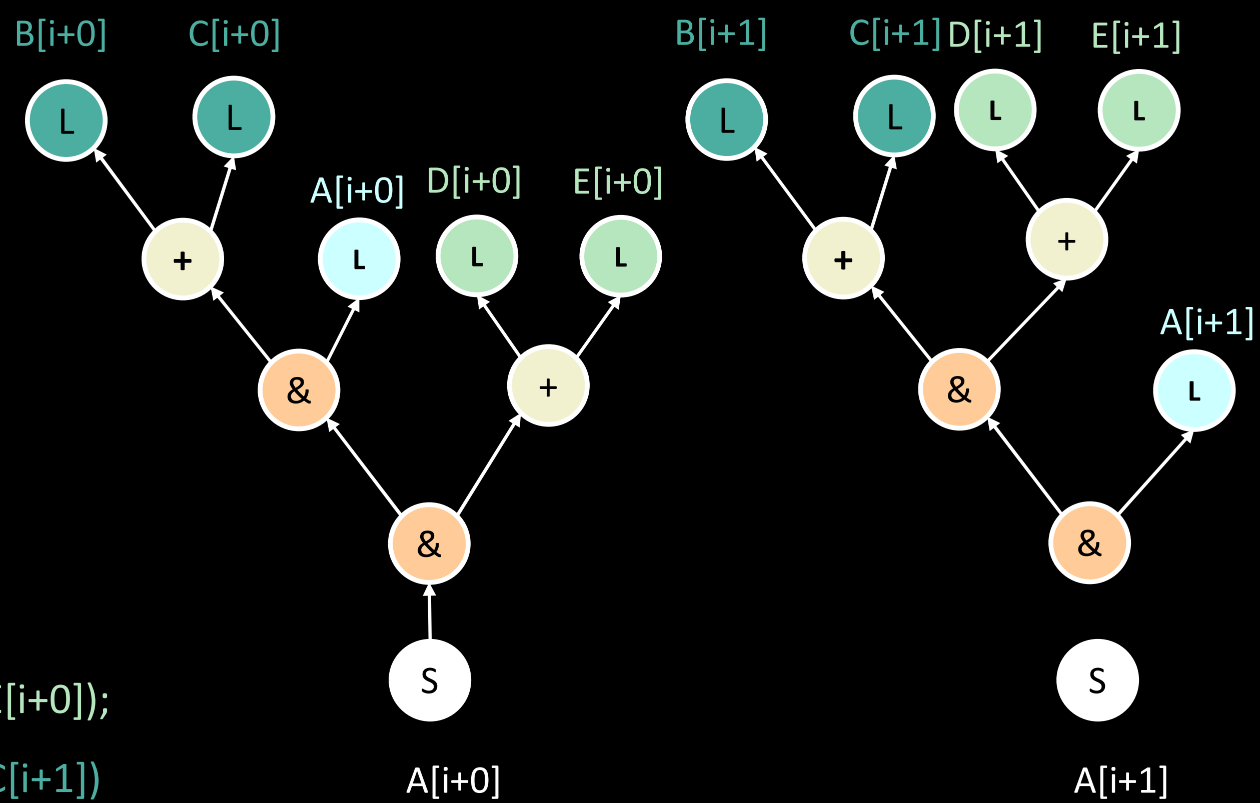


SLP Failure: Associativity Mismatch and Multi-Node

```
unsigned long A[], B[], C[], D[], E[];
A[i+0] = A[i+0] &
            (B[i+0] + C[i+0]) & (D[i+0] + E[i+0]);
A[i+1] = (D[i+1] + E[i+1]) & (B[i+1] + C[i+1])
            & A[i+1];
```

SLP Failure: Associativity Mismatch and Multi-Node

Use-def Chains DAG

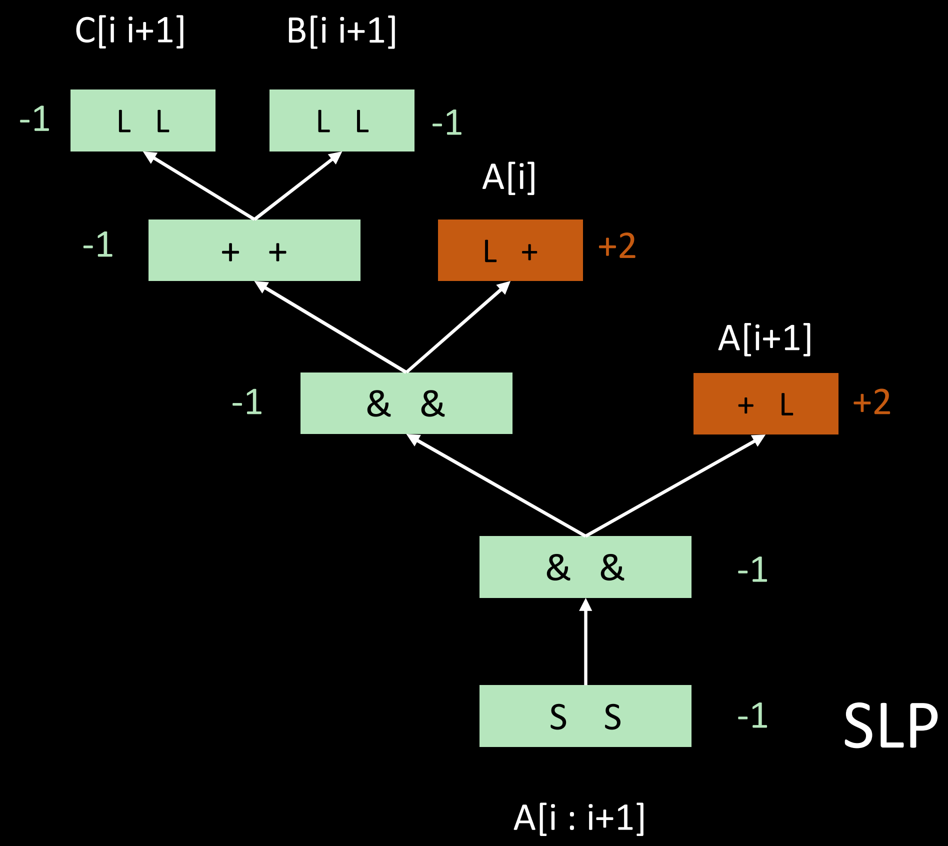



```
1 unsigned long A[], B[], C[], D[], E[];
2 A[i+0] = A[i+0] &
          (B[i+0] + C[i+0]) & (D[i+0] + E[i+0]);
3 A[i+1] = (D[i+1] + E[i+1]) & (B[i+1] + C[i+1])
          & A[i+1];
```

SLP Failure: Associativity Mismatch and Multi-Node

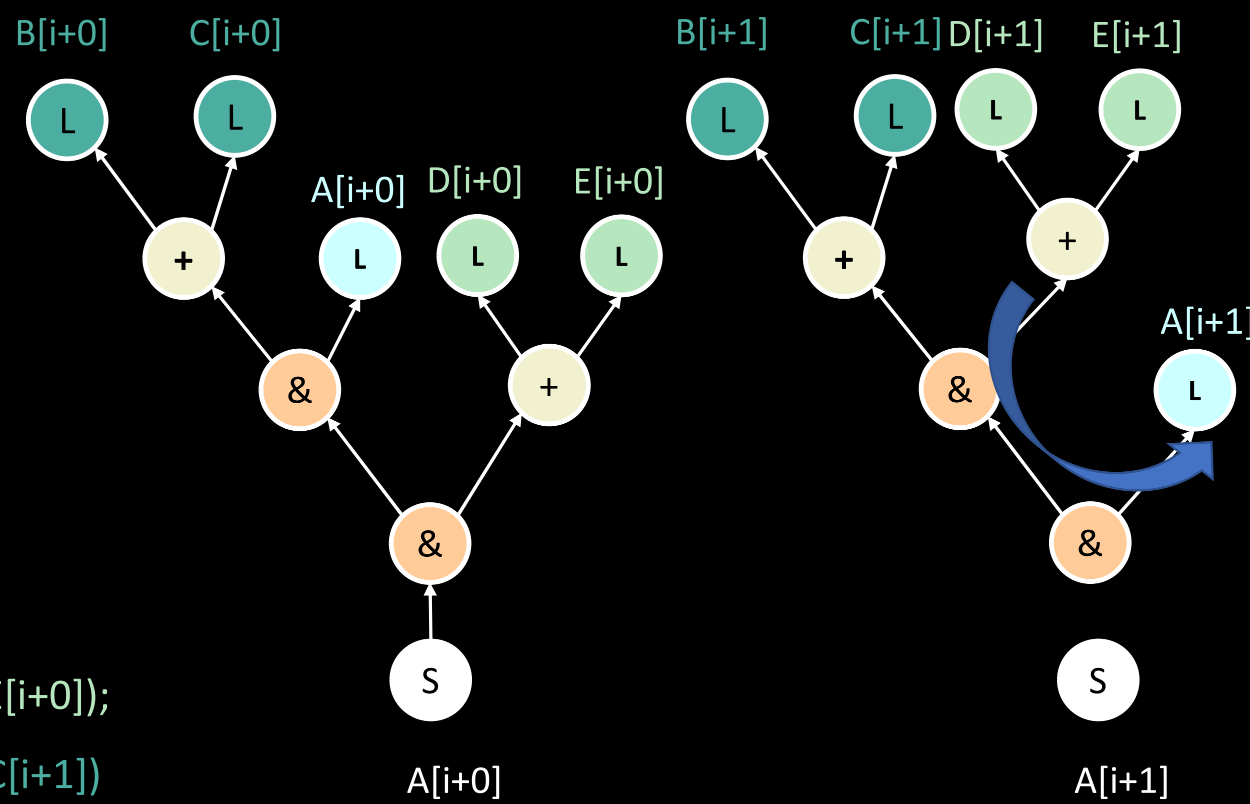
Total cost: -2

```
1 unsigned long A[], B[], C[], D[], E[];
2 A[i+0] = A[i+0] &
          (B[i+0] + C[i+0]) & (D[i+0] + E[i+0]);
3 A[i+1] = (D[i+1] + E[i+1]) & (B[i+1] + C[i+1])
          & A[i+1];
```



SLP Failure: Associativity Mismatch and Multi-Node

Use-def Chains DAG

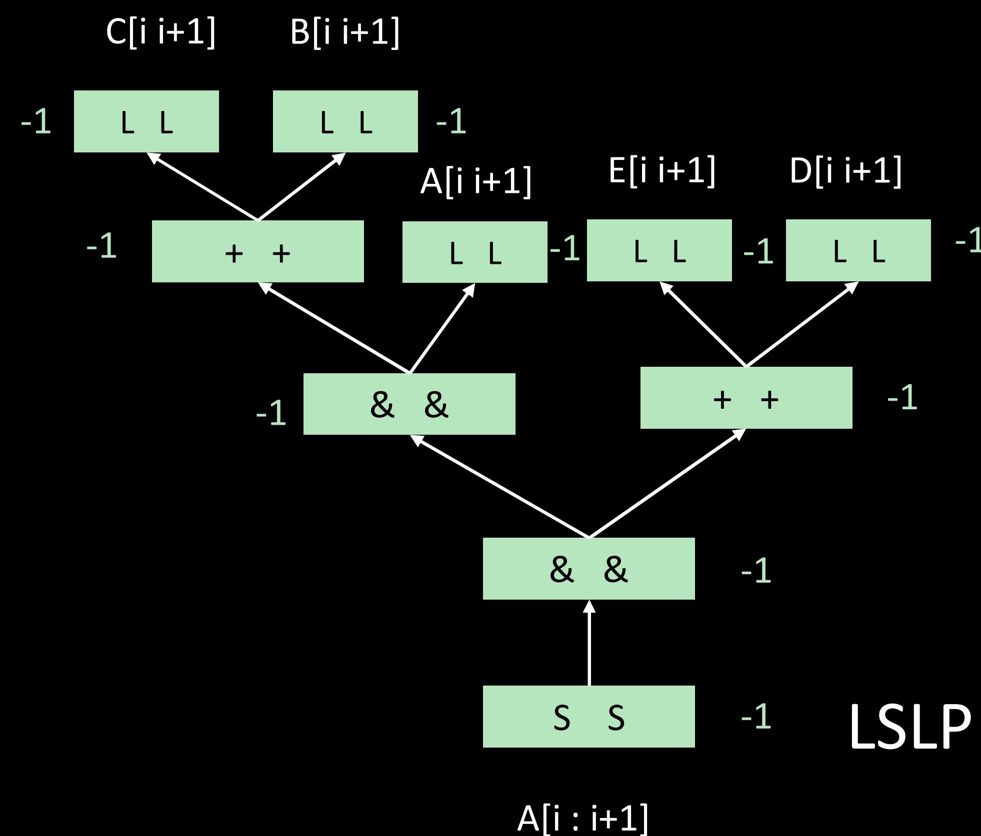



```
unsigned long A[], B[], C[], D[], E[];
A[i+0] = A[i+0] &
        (B[i+0] + C[i+0]) & (D[i+0] + E[i+0]);
A[i+1] = (D[i+1] + E[i+1]) & (B[i+1] + C[i+1])
        & A[i+1];
```

SLP Failure: Associativity Mismatch and Multi-Node

Total cost: -10

```
1 unsigned long A[], B[], C[], D[], E[];
2 A[i+0] = A[i+0] &
           (B[i+0] + C[i+0]) & (D[i+0] + E[i+0]);
3 A[i+1] = (D[i+1] + E[i+1]) & (B[i+1] + C[i+1])
           & A[i+1];
```



LSLP

Motivation

- Load Address Mismatch

  SLP: 0 LSLP: -6
- Opcode Mismatch

  SLP: +4 LSLP: -2
- Associativity Mismatch and Multi-Node

  SLP: -2 LSLP: -10

Look-Ahead SLP – Overview

1. Multi-Node Formation
   - Multi-Node: Chained multiple commutative operations;
   - e.g.: A[i+0] & (B[i+0] + C[i+0]) & (D[i+0] + E[i+0])
2. Top-Level Operand Reordering
   - Use Look-Ahead score for non-trivial case;
3. Run (1) recursively on reordered operands.

Multi-Node Formation

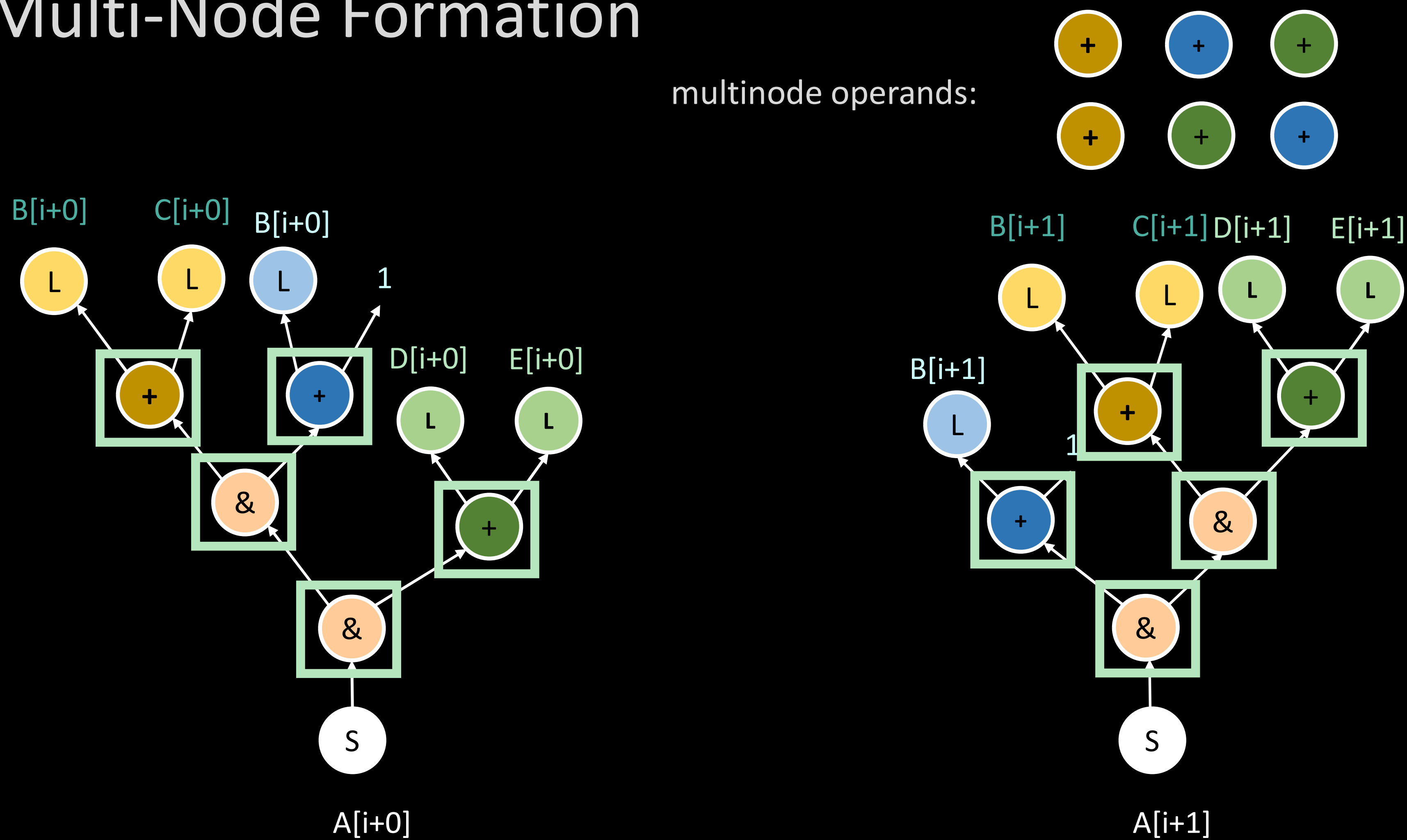
```
build_graph(values):
  if values are non-vectorizable: return
  if values are commutative:
    foreach operands of values:
      if opcode matches
        and not escape multi-node:
         build_graph(operands)
      else:
         add operands to multimode-operands
     if values are root of multi-node:
        // reorder and build_graph recursively
  else:
     // build_graph recursively
```

Core Idea:

1. Given a commutative operation at the root;
2. Find connected component with same opcode in the children;
3. Group the operands of the members of connected component together.

Multi-Node Formation

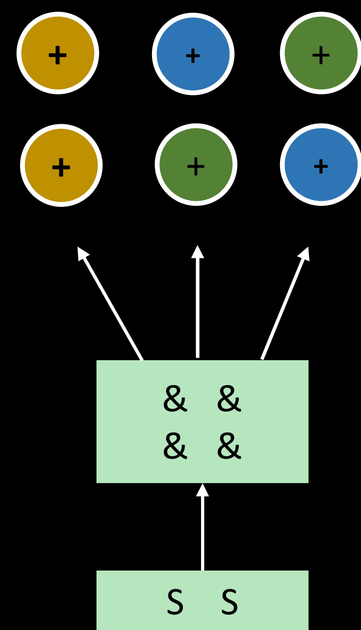
multinode operands:



Multi-Node Formation - Result

multinode operands:

Every operand can be reordered inside its lane

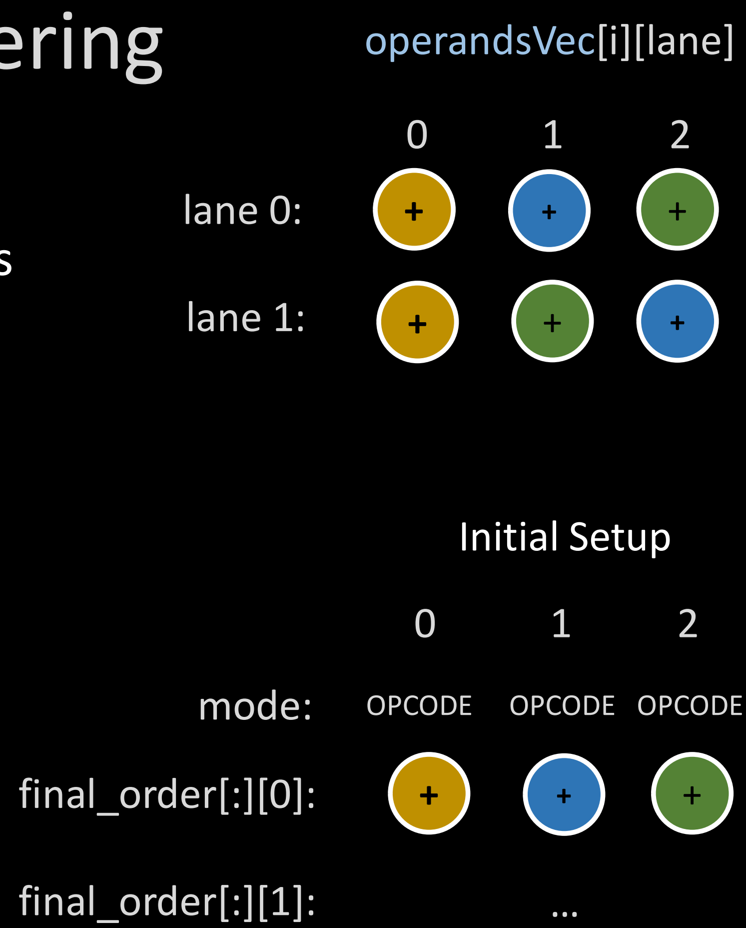


A chain of & operations

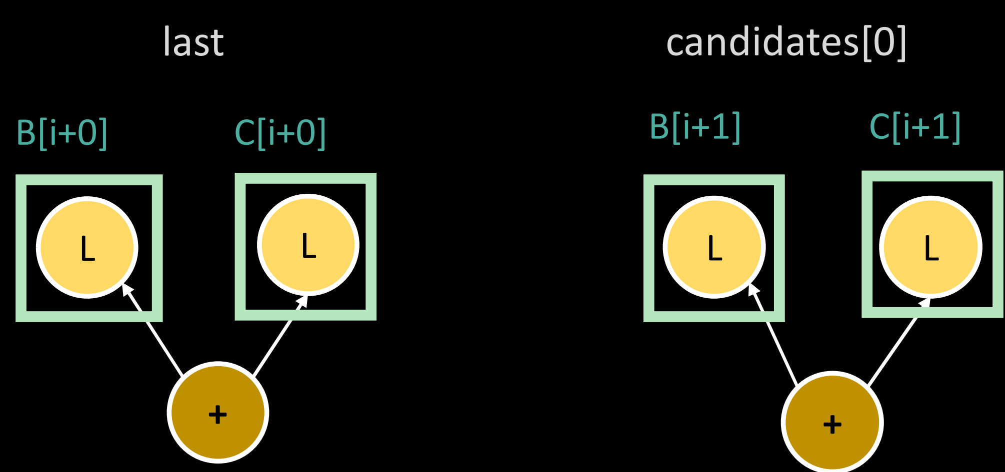
A[i : i+1]

Top-Level Operand Reordering

```
reorder_operands(operandsVec):
  setup mode and final_order for operands
based on first lane
  foreach lane:
    foreach i in {0..numOperands}
      if mode[i] is FAILED: continue
        last = final_order[i][lane - 1]
        get_best(mode[i], last,
operandsVec[:][lane])
        update final_order
  return final_order
```

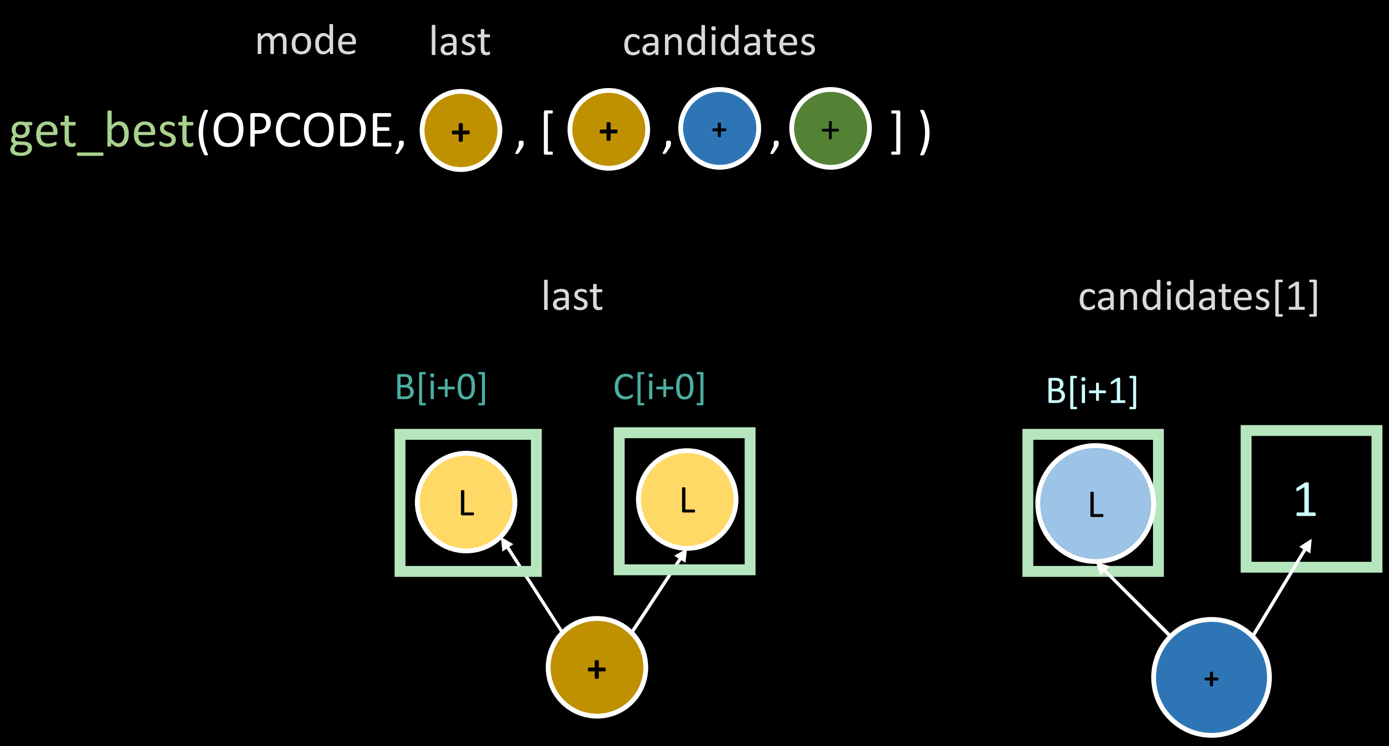


Top-Level Operand Reordering – get_best



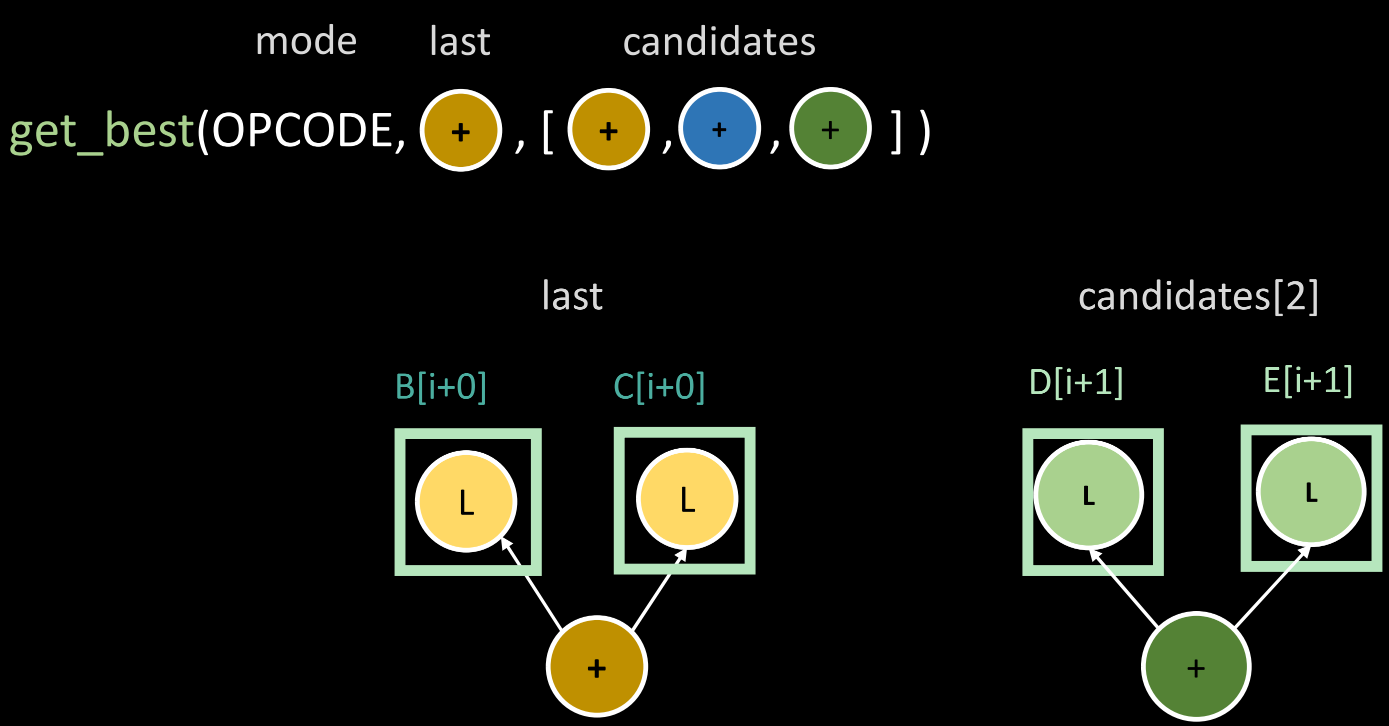
LAScore: 1+0+0+1 = 2

Top-Level Operand Reordering – get_best



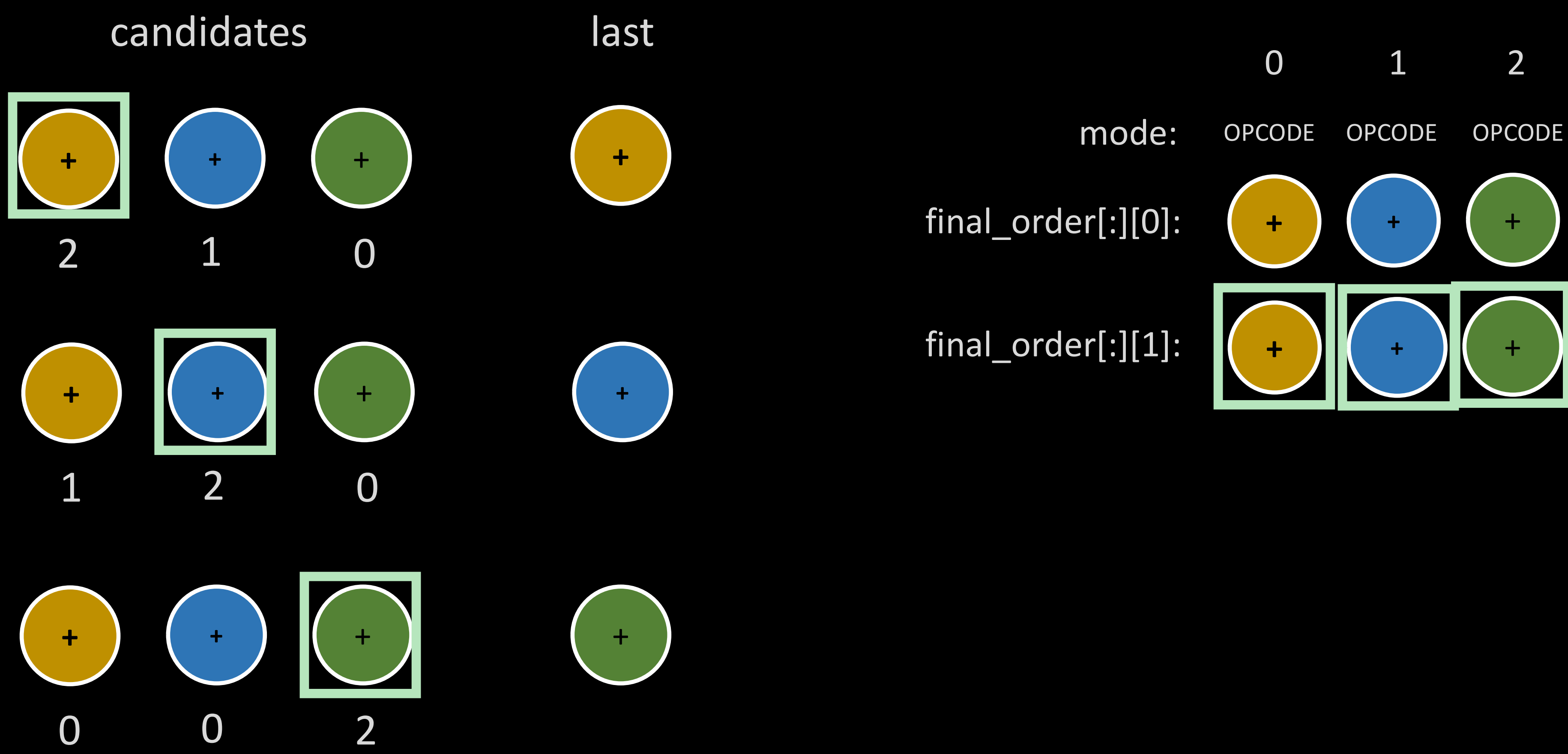
LAScore: 1+0+0+0 = 1

Top-Level Operand Reordering – get_best



LAScore: 0+0+0+0 = 0

Top-Level Operand Reordering – Result



Experimental Setup

Evaluated the following cases:

- Baseline: All Loop, SLP and LSLP vectorizers disabled (O3)
- O3 + SLP enabled but No Operand Reordering(SLP-NR)
- O3 + SLP enabled (SLP)
- O3 + LSLP enabled (LSLP)

Evaluation – Speedup

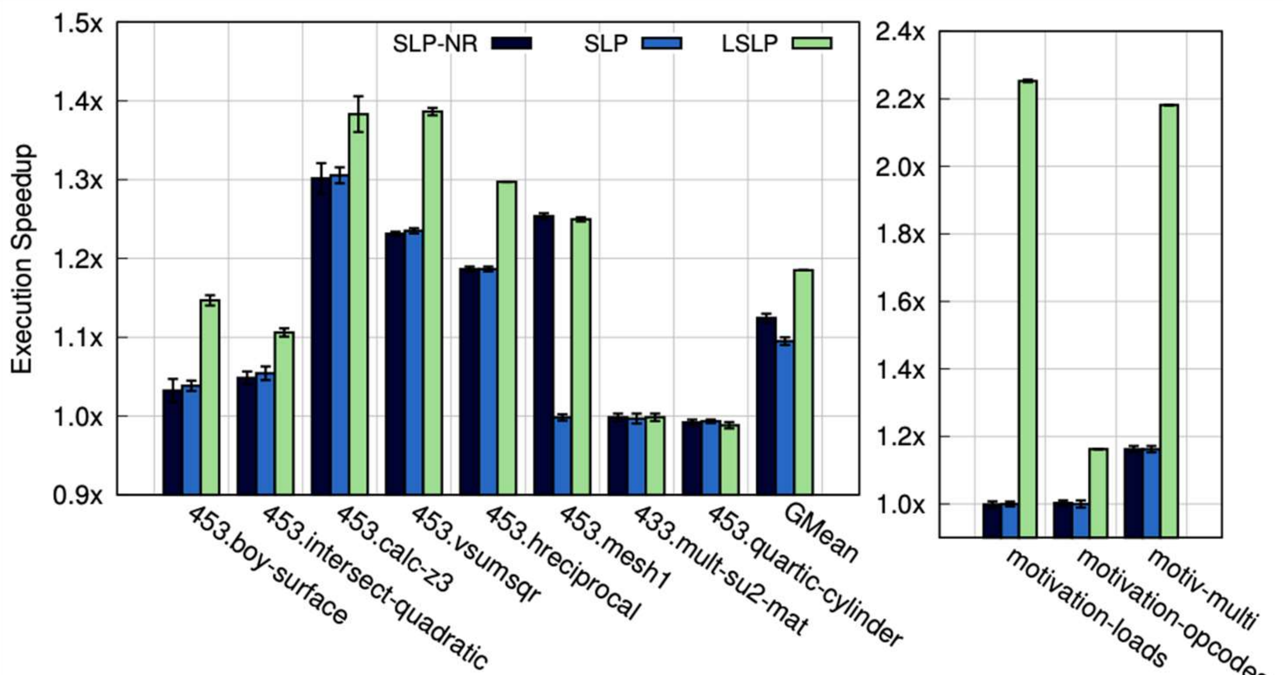


Figure 9. Speedup of LSLP, SLP and SLP-NR over O3.

Evaluation – Total Static Cost Seen by Each Scheme

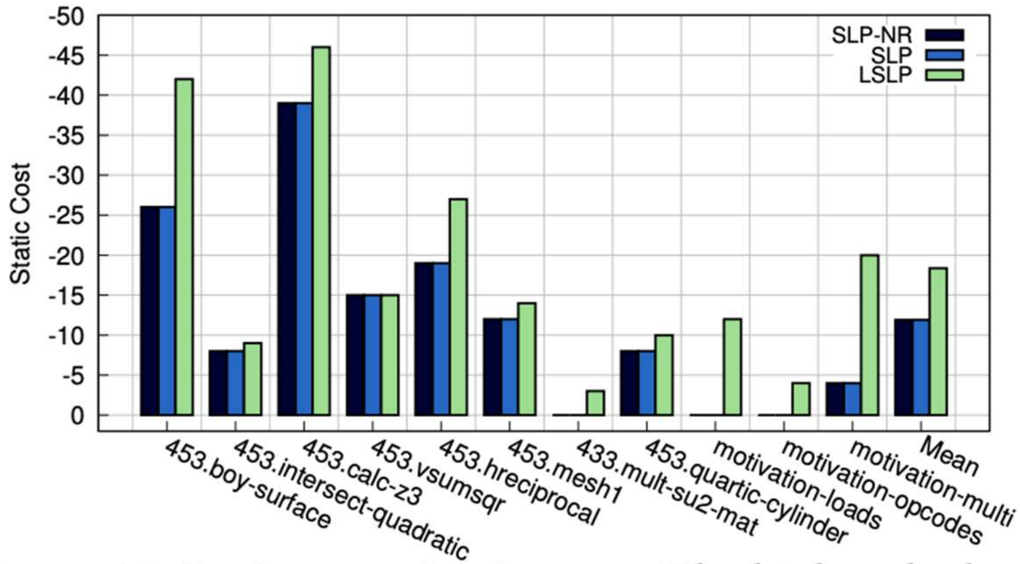


Figure 10. Static vectorization cost. The higher the better.

LSLP can locally improve individual vectorization regions compared to both SLP and SLP-NR

Evaluation – Compilation Time

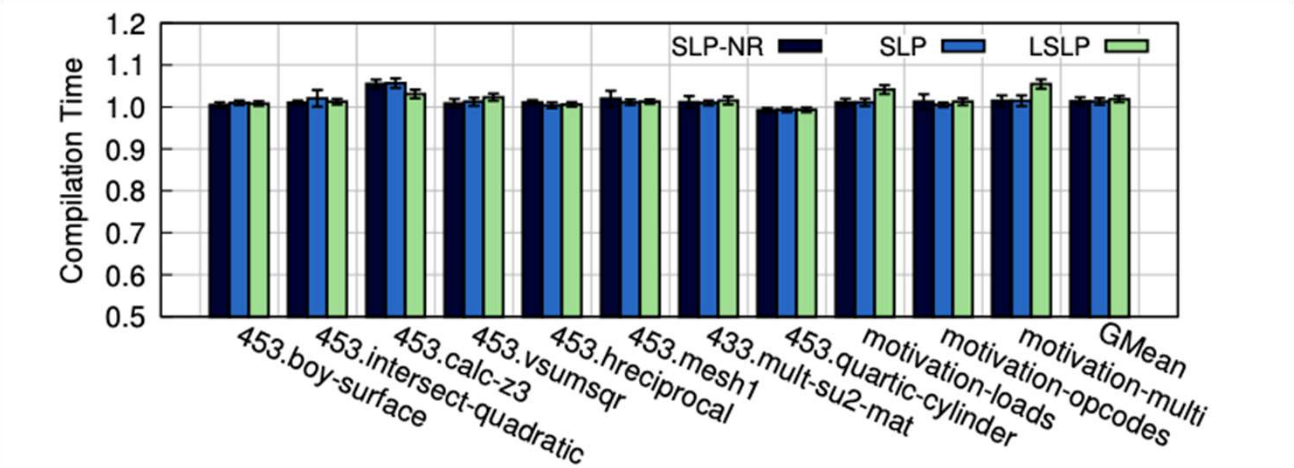


Figure 14. Compilation time, normalized to O3 (LA=8).

On average, LSLP increases the compilation over SLP slightly, by less than 1%

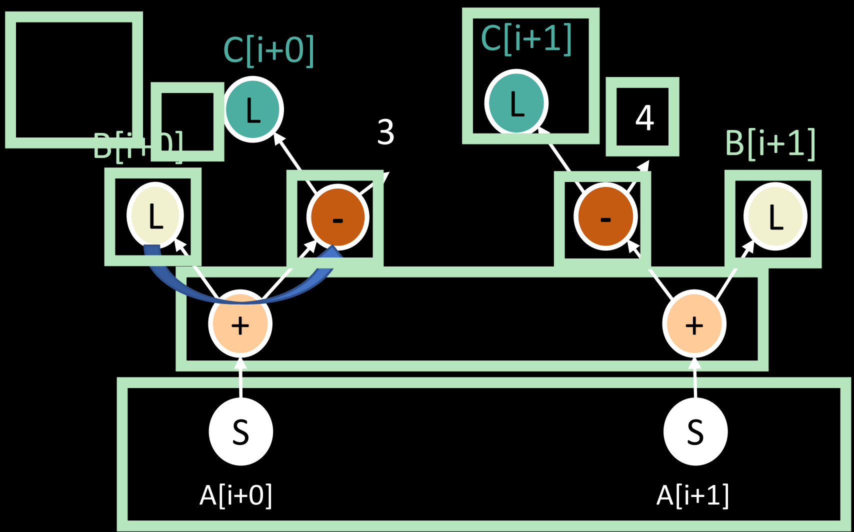
Discussion

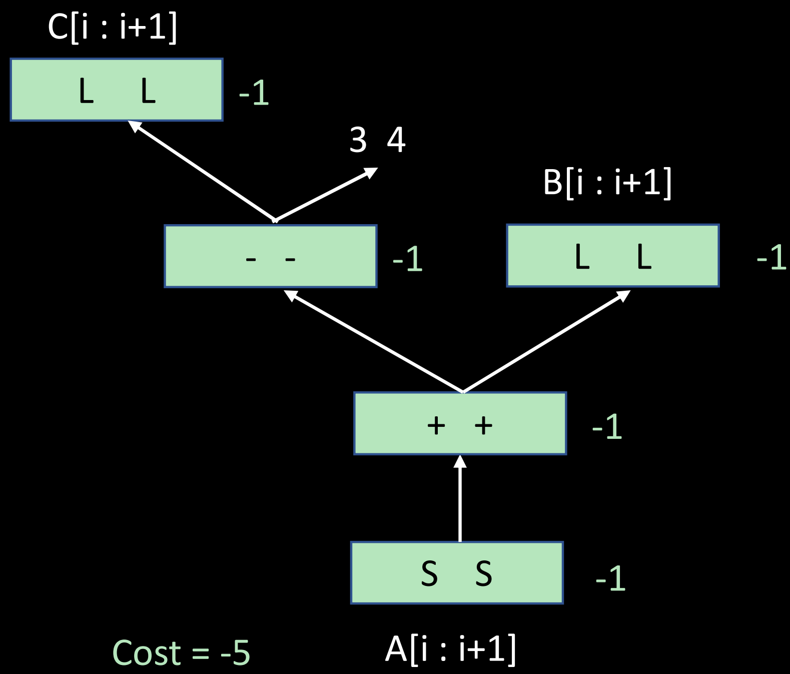
- LSLP introduces an effective scheme for dealing with commutative operations with little compilation time overhead.
- There are certain cases that LSLP can fail, which can be further improved.

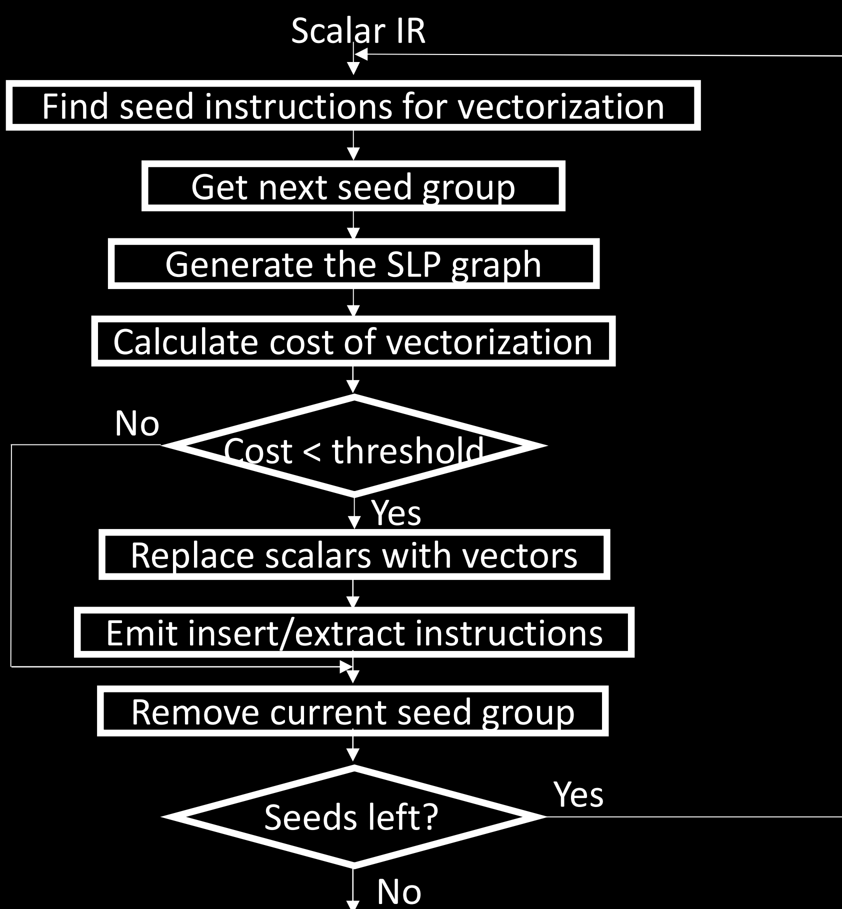
Q&A

How SLP works

```
long A[], B[], C[];
A[i+0] = B[i+0]         +  (C[i+0] – 3);
A[i+1] = (C[i+1] – 4)  +  B[i+1];
```








```
long A[], B[], C[];
A[i+0] = B[i+0]         +  (C[i+0] – 3);
A[i+1] = (C[i+1] – 4)  +  B[i+1];
```