VW-SLP: Auto-Vectorization with Adaptive Vector Width

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THE UNIVERSITY of EDINBURGH
informatics

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What is Vector-Width (VW) ?

- Wikipedia: In Computer Science a **vector** is
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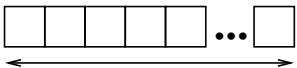
- Vector-Width is the size of the vector



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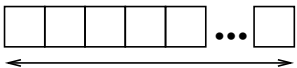

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- Aka Vector Length (VL) or Vector Factor (VF)

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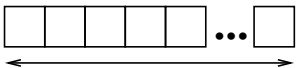
- Vector-Width is the size of the vector
- Aka Vector Length (VL) or Vector Factor (VF)
- VW == VL == VF



Vector Width
Vector Length
Vector Factor

SLP: The Straight-Line Code Vectorizer

- Superword Level Parallelism

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for (i=0; i<N; i+=4)
  A[i] = B[i]
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Loop Vectorization (LV) with VF = 4

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for (i=0; i<N; i+=16)
```

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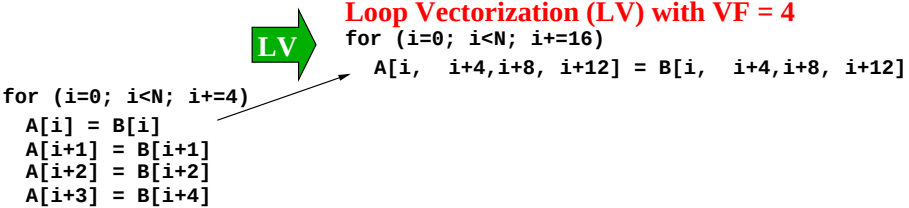

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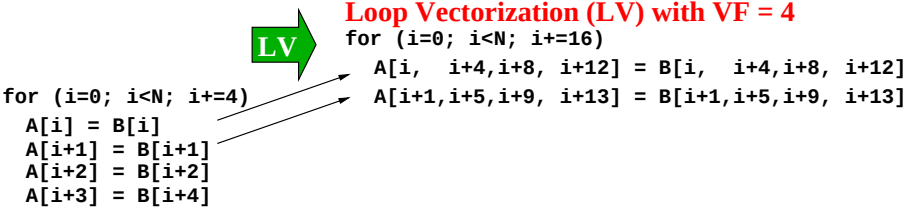

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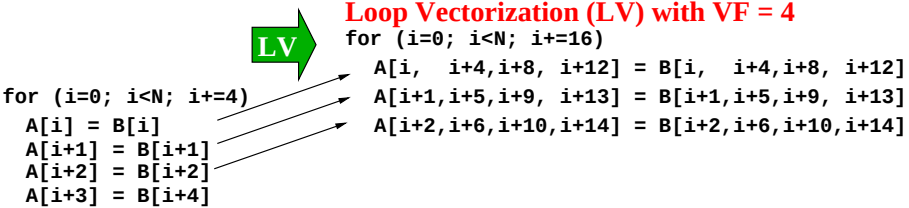

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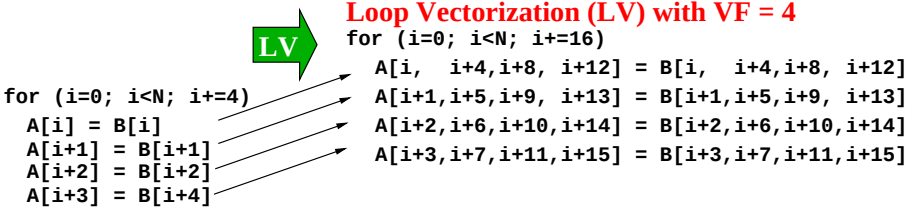

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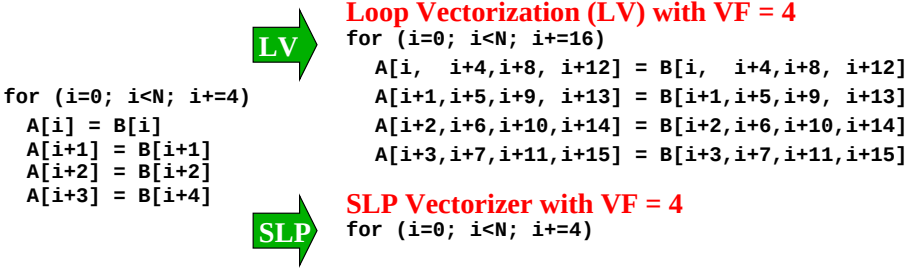

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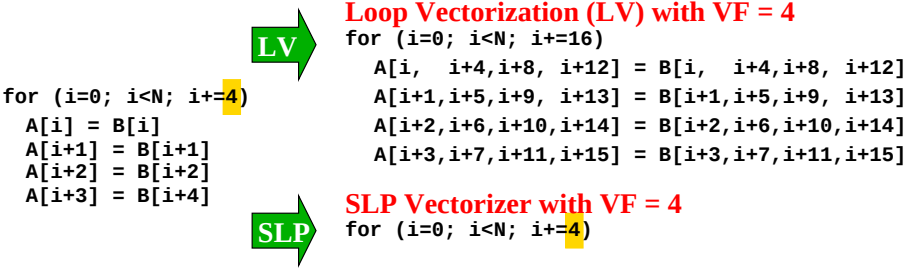

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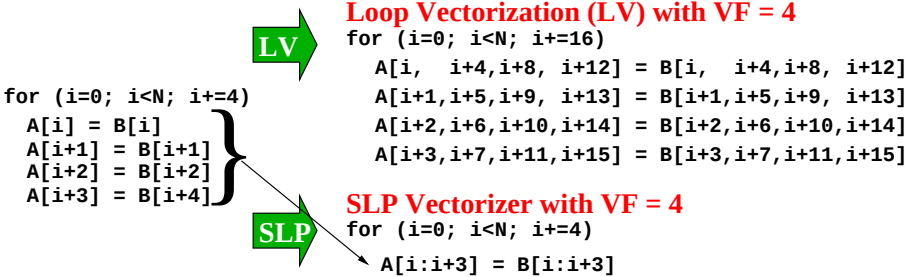

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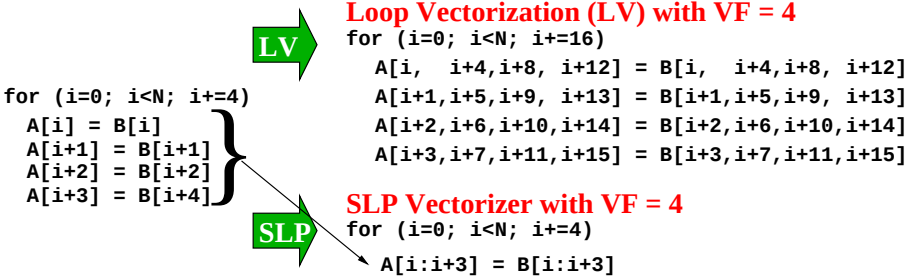
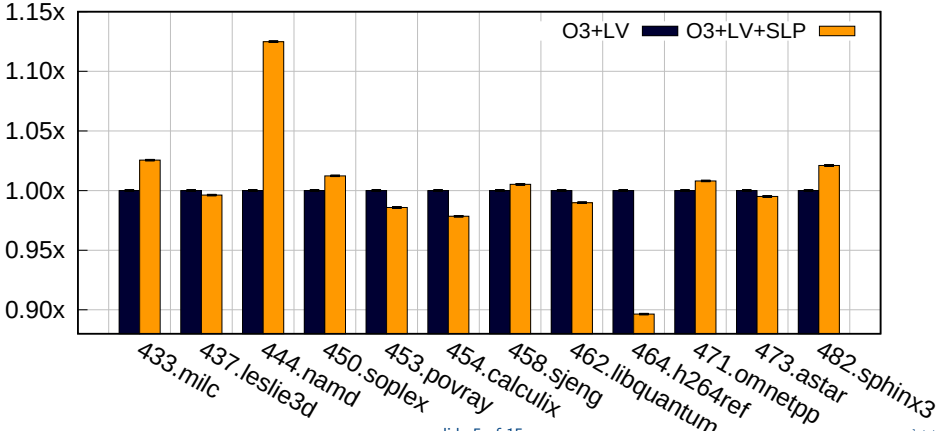


- Note: LV may be able to optimize the interleaved loads/stores

Isn't the Loop Vectorizer (LV) good enough ?

- SPEC 2006, 10 runs, Intel® Core™ i7-4790
- LLVM runs both LV and SLP



How SLP Works

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
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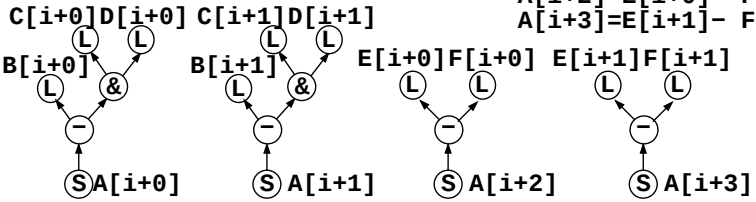

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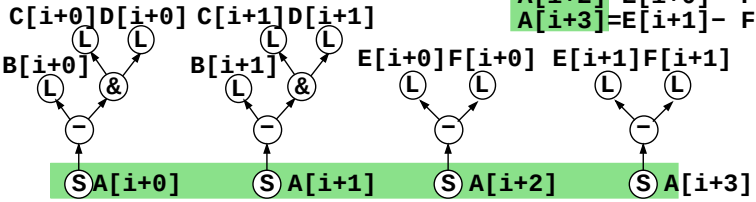


```
S S S S
A[i:i+3]
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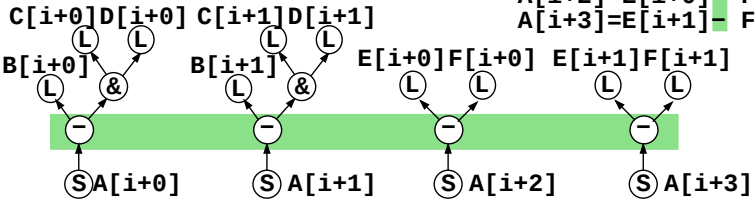

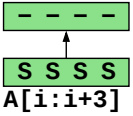

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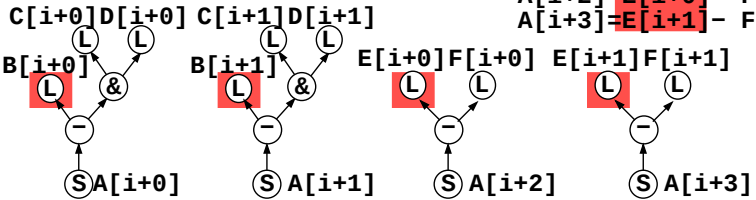

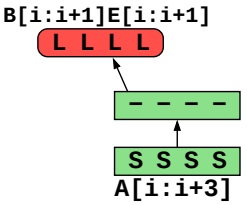

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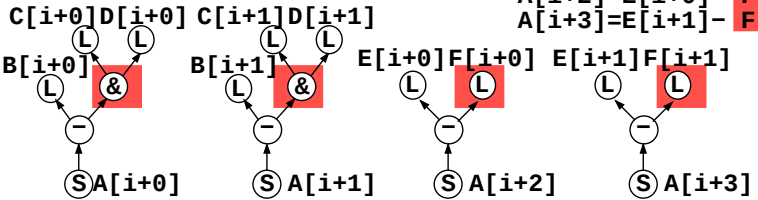

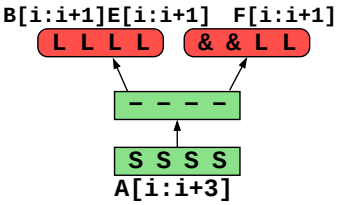

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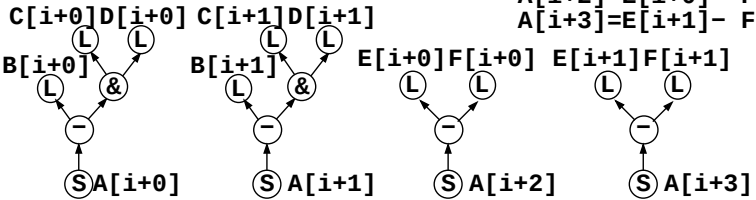

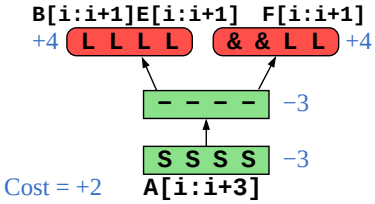

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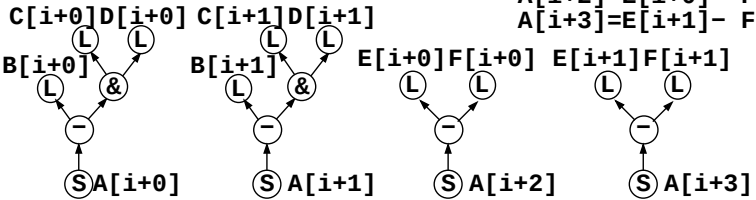

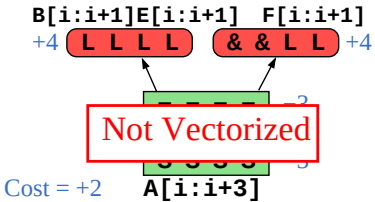

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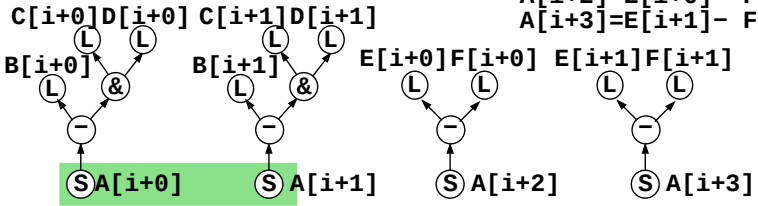

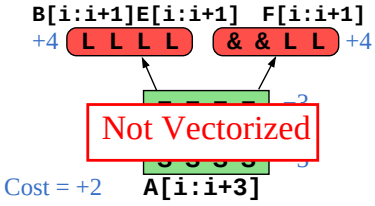

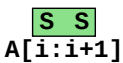

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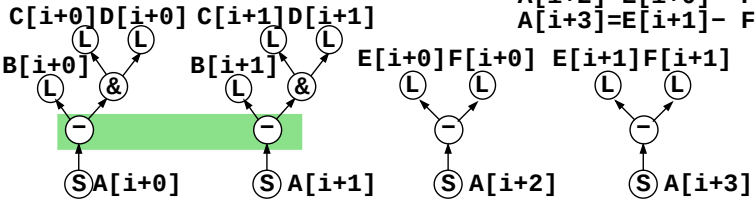

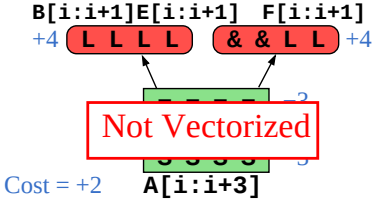

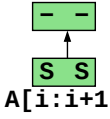

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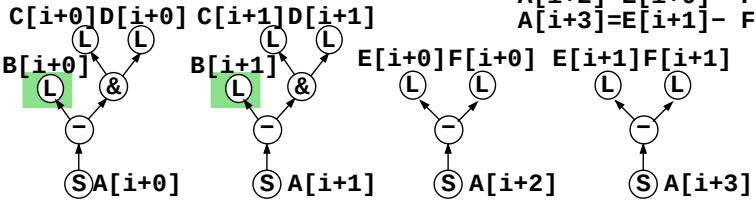

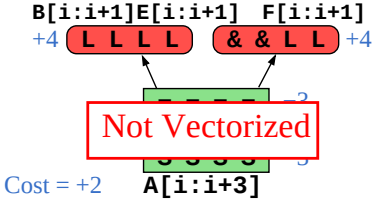

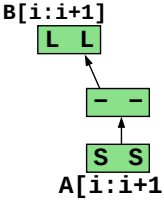

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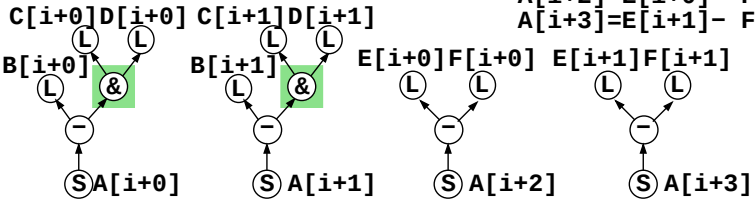
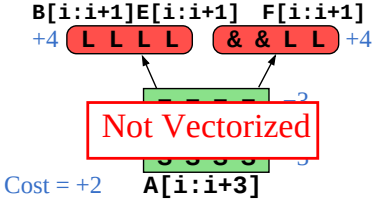
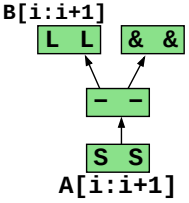
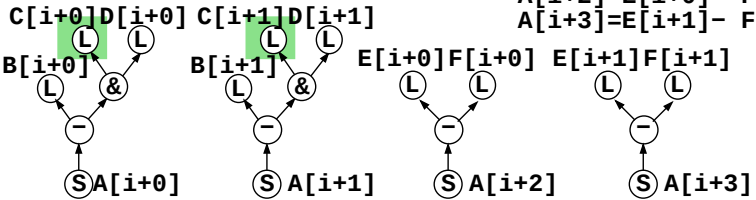


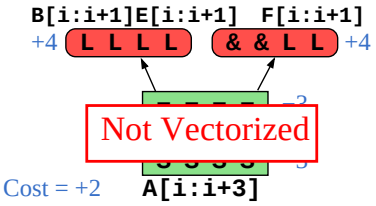


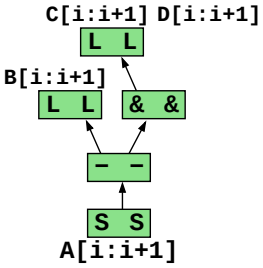


How SLP Works

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
```







How SLP Works

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uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
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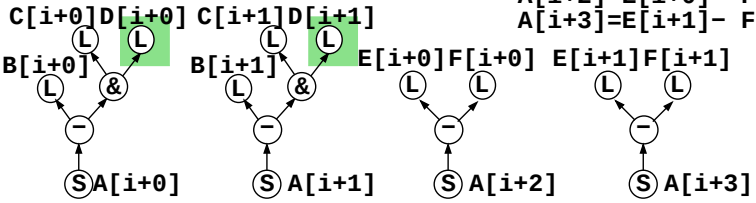
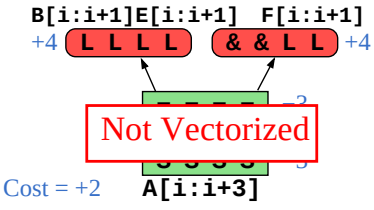
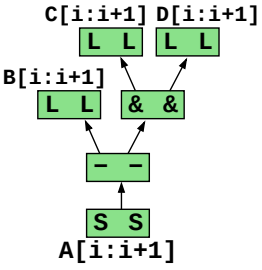
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
```







How SLP Works

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A[i+0]=B[i+0]-(C[i+0]&D[i+0])
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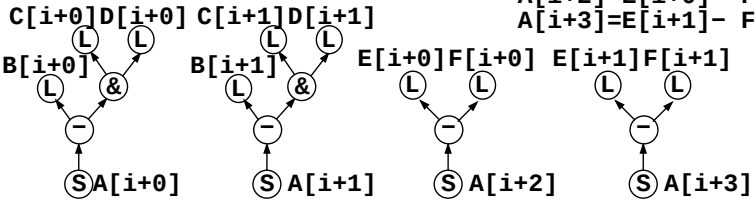
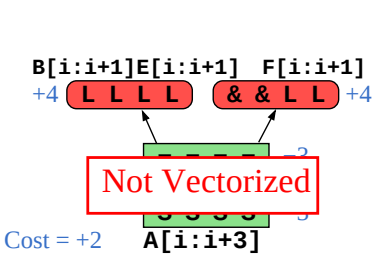
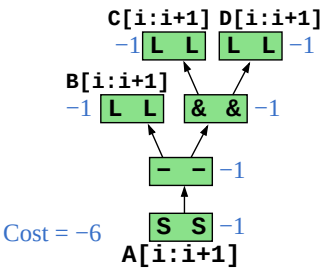
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
```







How SLP Works

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uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
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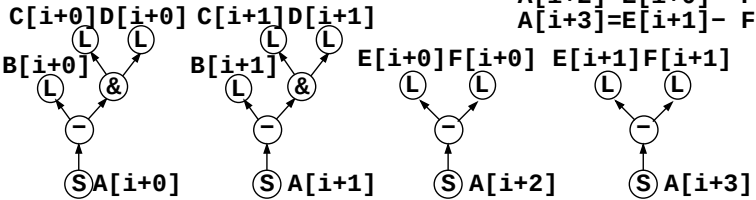
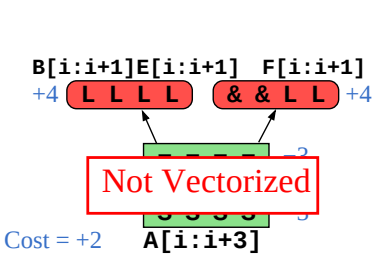
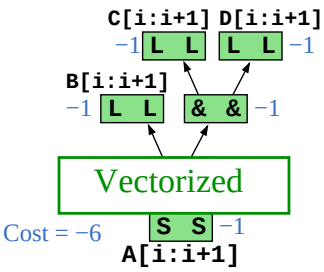
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
```







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uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
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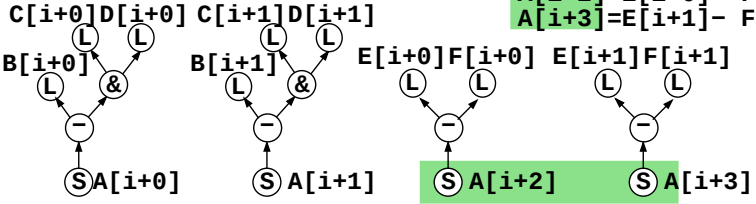
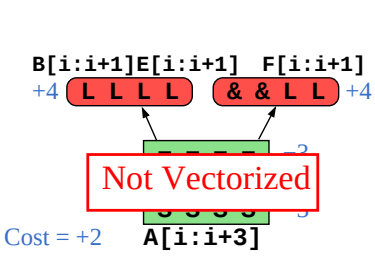
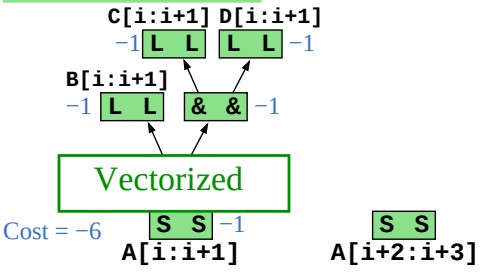
A[i+3]=E[i+1]- F[i+1]
```







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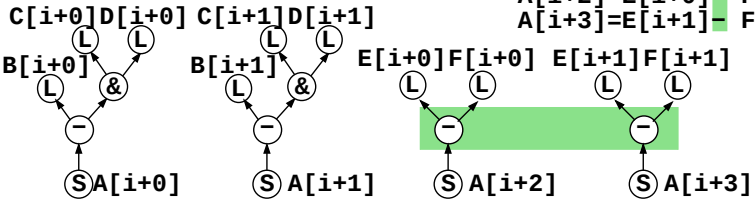
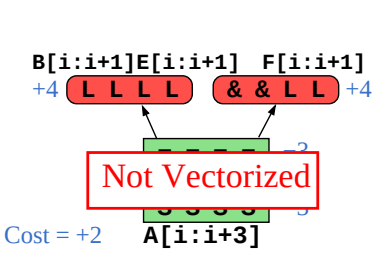
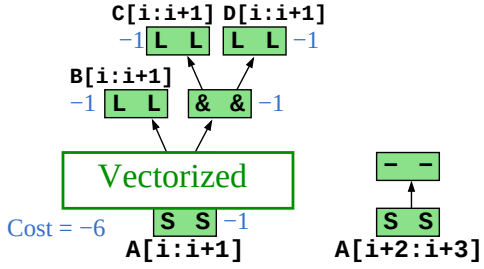
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
```







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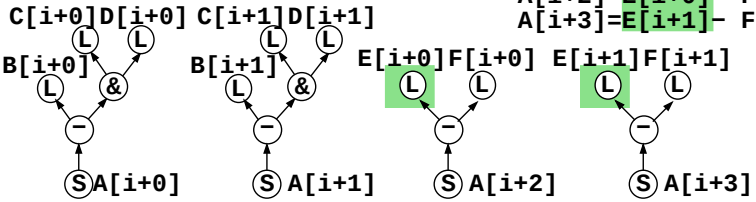
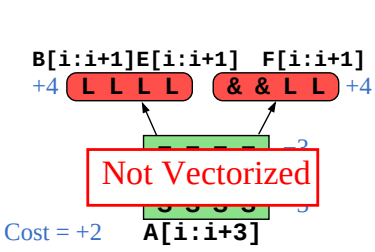
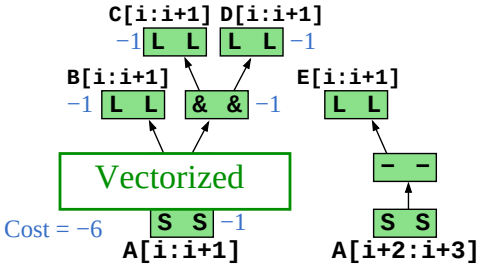
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
```







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A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
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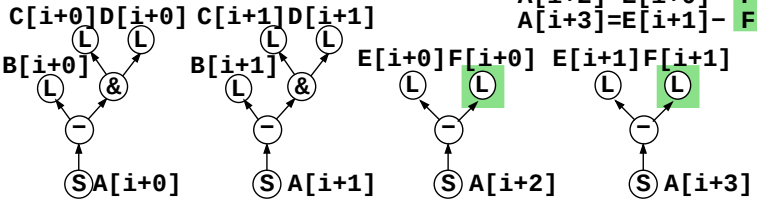

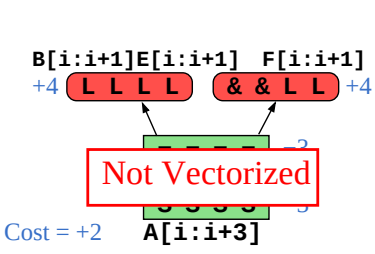

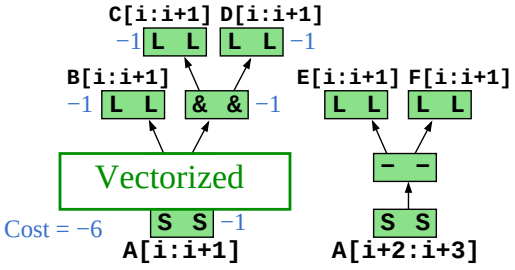

How SLP Works

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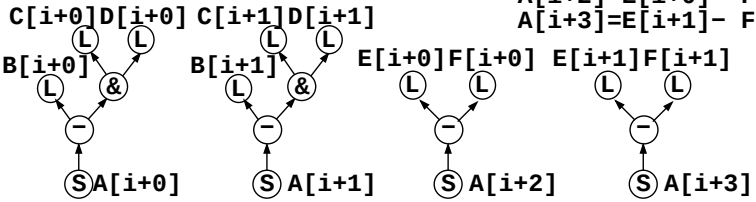
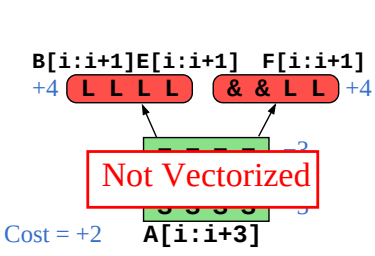
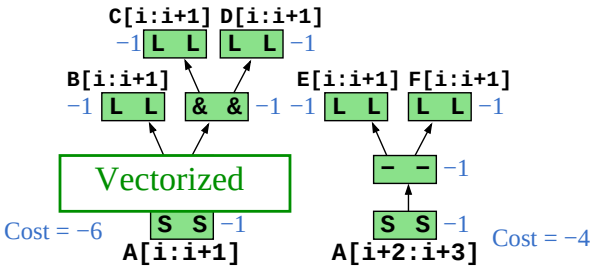
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
```







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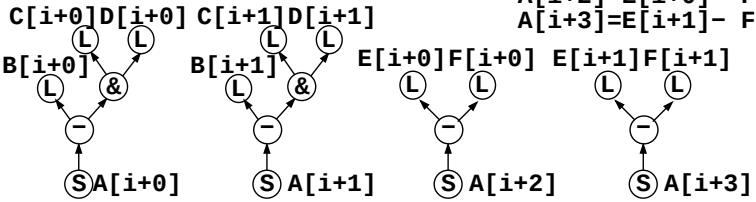

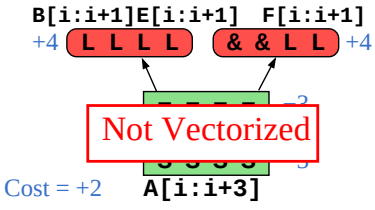

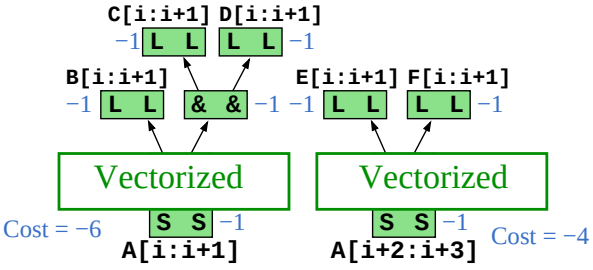

Scalar IR

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
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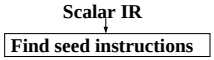
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
  ...
```




```
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A[i+0]=B[i+0]-(C[i+0]&D[i+0])
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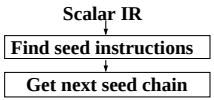
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
  ...
```

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uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
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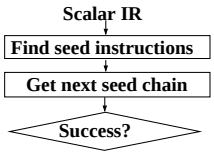
```

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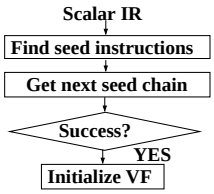
  ...
```

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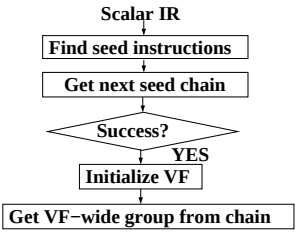
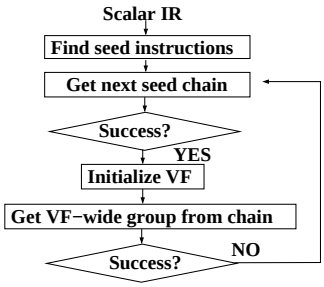
A[i+3]=E[i+1]- F[i+1]
  ...
```

VF=4




```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
  ...
```

VF=4




```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
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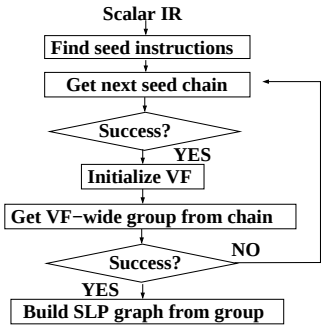
  ...
```

VF=4




```
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A[i+0]=B[i+0]-(C[i+0]&D[i+0])
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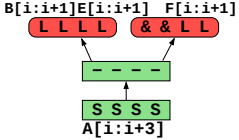
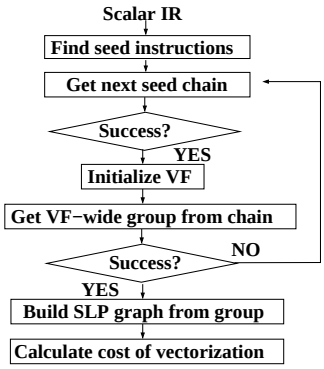
  ...
```

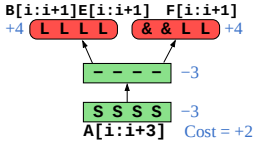
VF=4

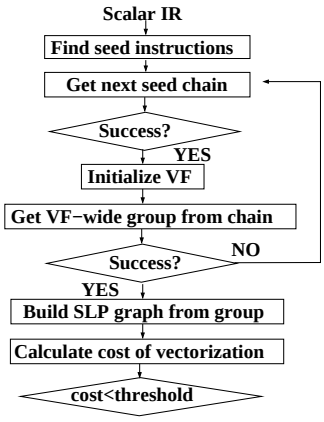





```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
  ...
```

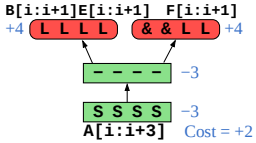
VF=4

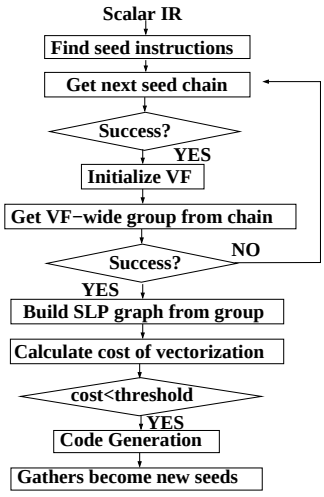





```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
  ...
```

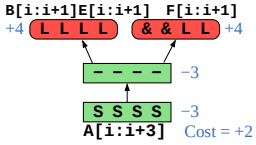
VF=4

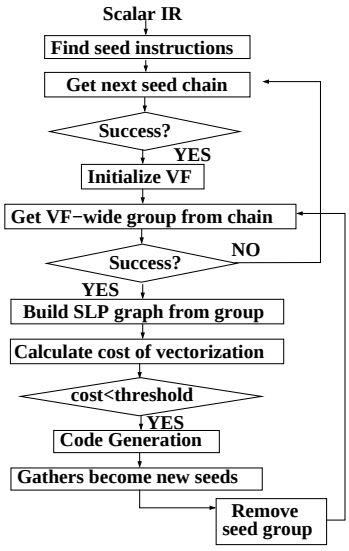





```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
  ...
```

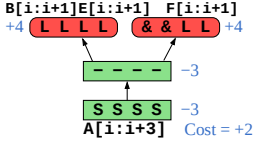
VF=4

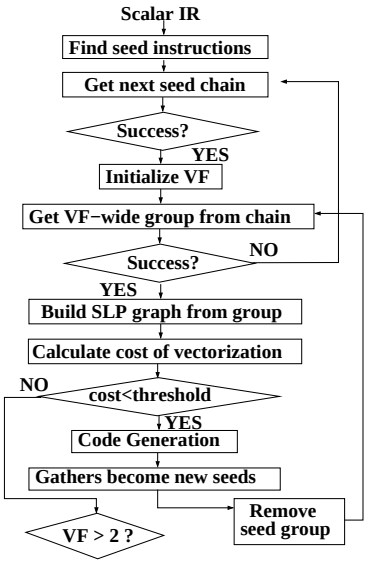





```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
  ...
```

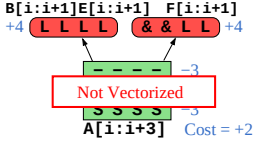
VF=4

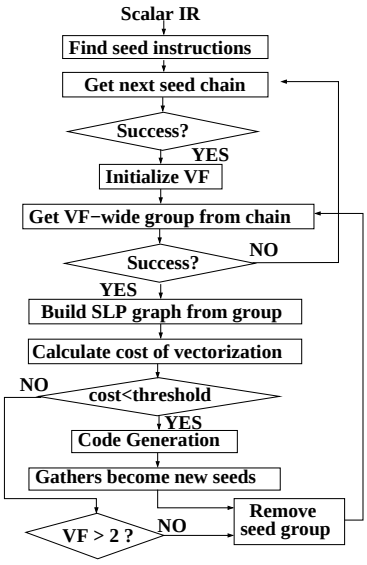





```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
  ...
```

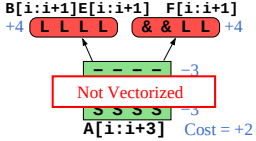
VF=4

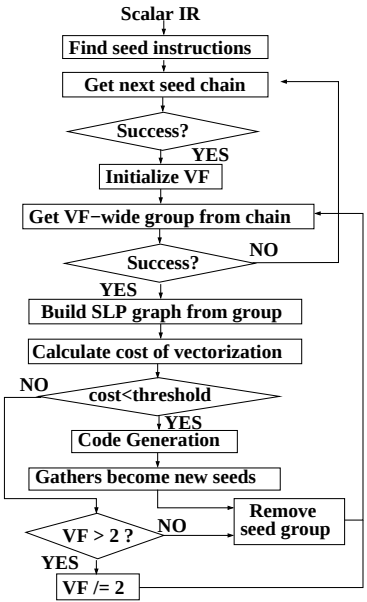





```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
  ...
```

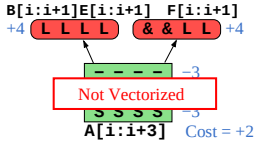
VF=4



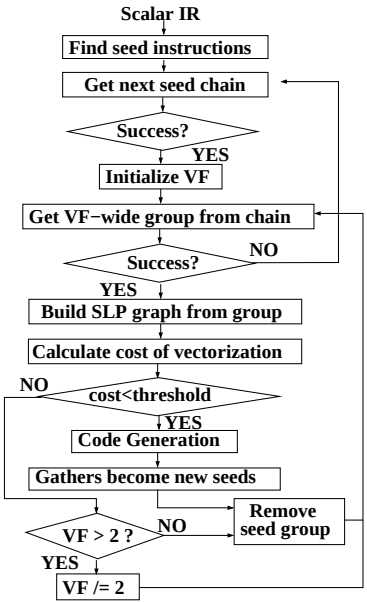



```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
  ...
```

VF=4

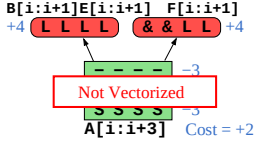


VF=2

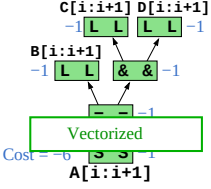


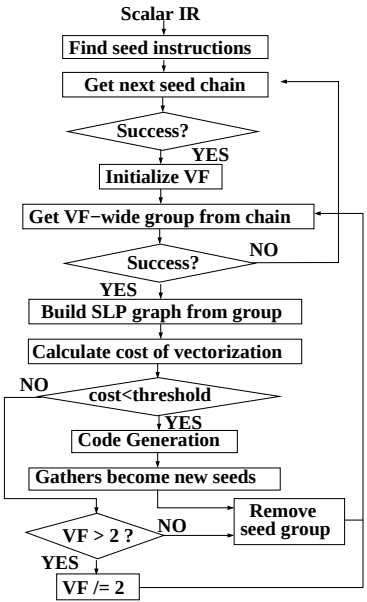

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
  ...
```

VF=4



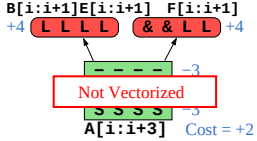
VF=2



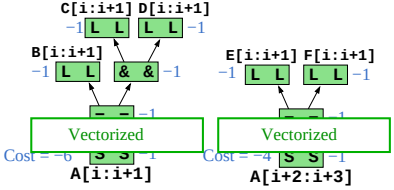


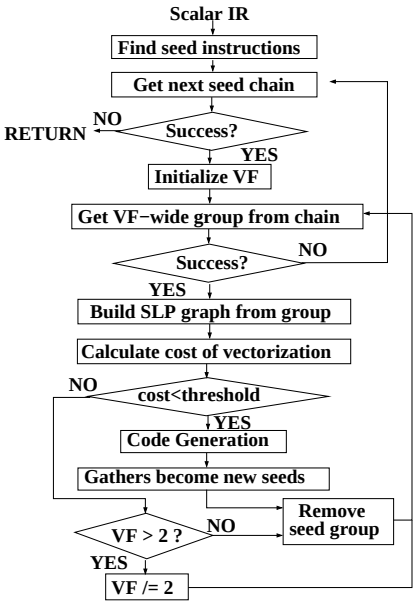

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]−(C[i+0]&D[i+0])
A[i+1]=B[i+1]−(C[i+1]&D[i+1])
A[i+2]=E[i+0]− F[i+0]
A[i+3]=E[i+1]− F[i+1]
  ...
```

VF=4



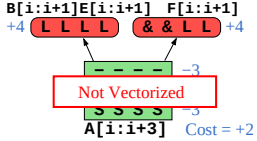
VF=2



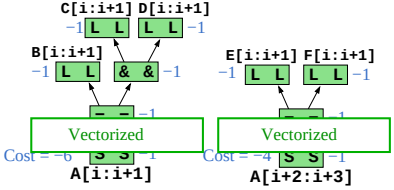



```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
  ...
```

VF=4



VF=2



Variable Width SLP

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
```

Variable Width SLP

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
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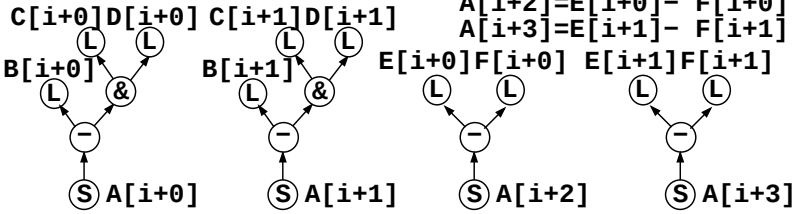
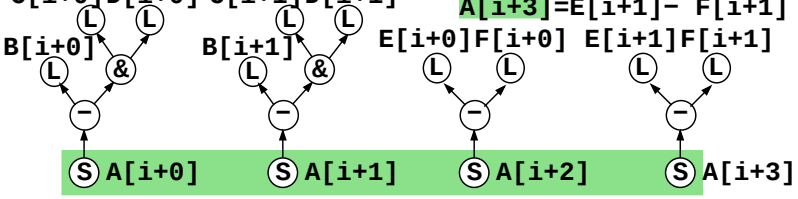


Variable Width SLP

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
```



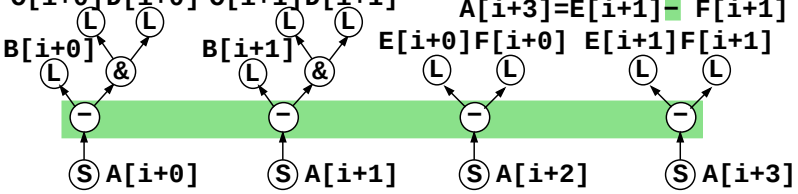
VF=4

S S S S A[i:i+3]

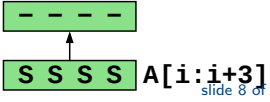
VW−SLP

Variable Width SLP

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
```



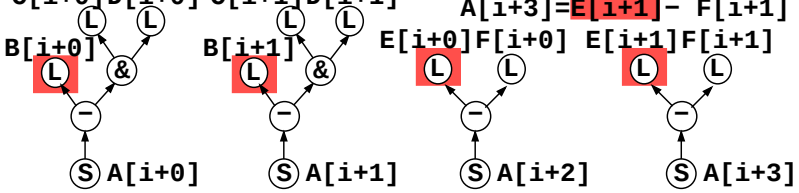
VF=4



VW−SLP

Variable Width SLP

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
```



VF=4

VW−SLP

Variable Width SLP

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
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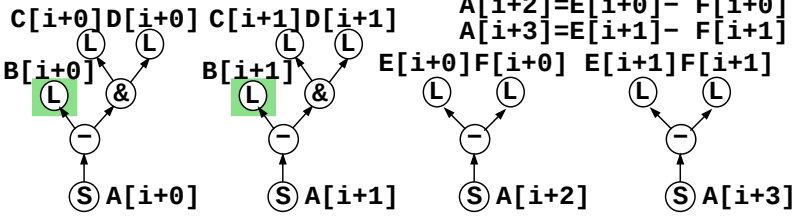
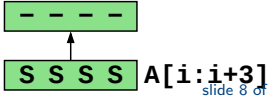


VF=2

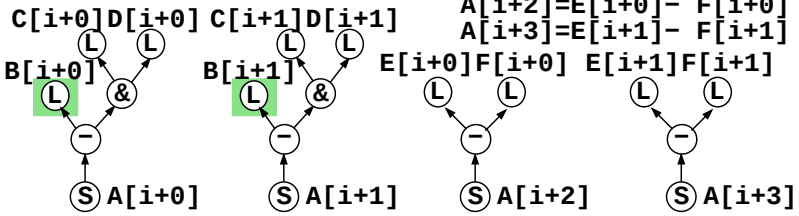
VF=4



VW−SLP

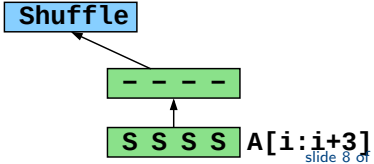
Variable Width SLP

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
```



VF=2

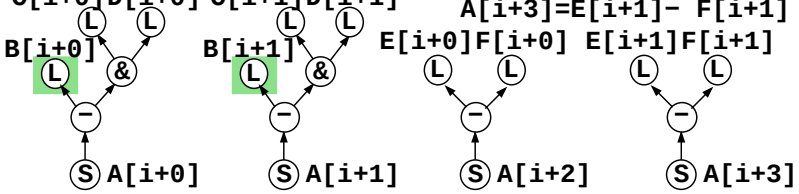
VF=4

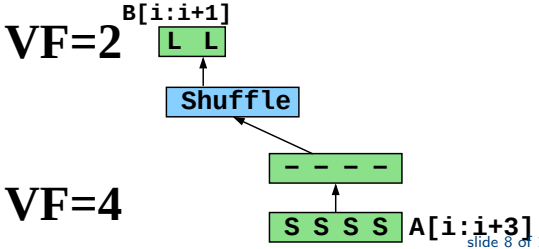


VW−SLP

Variable Width SLP

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
```

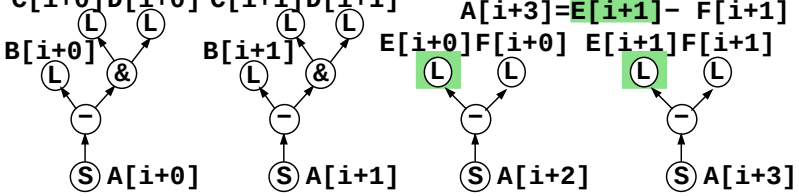


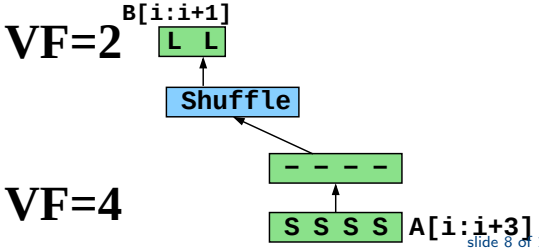


VW−SLP

Variable Width SLP

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
```

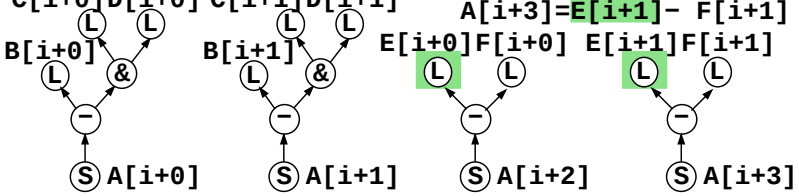


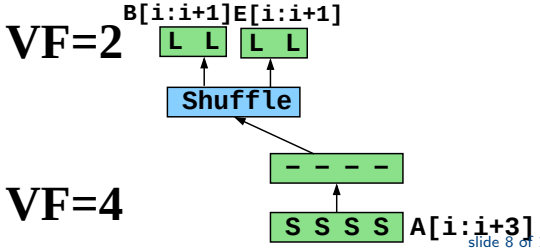


VW−SLP

Variable Width SLP

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
```

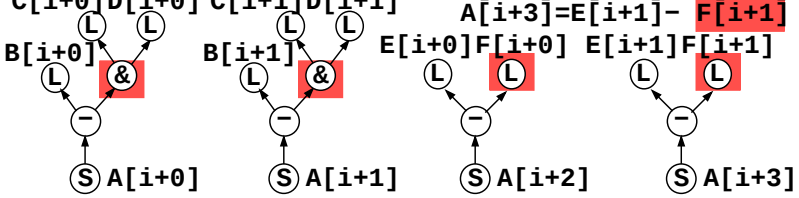


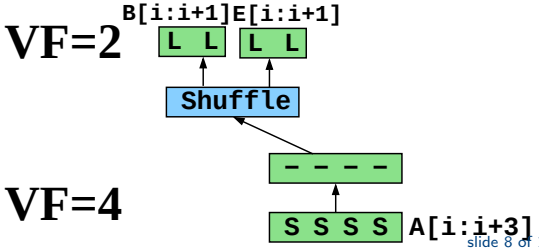


VW−SLP

Variable Width SLP

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
```

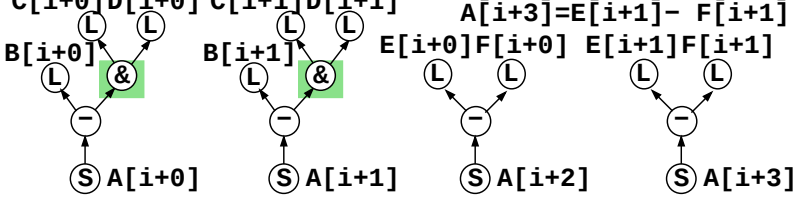


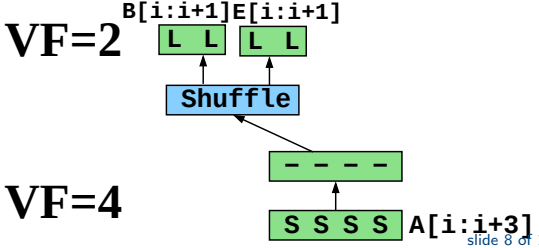


VW−SLP

Variable Width SLP

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
```

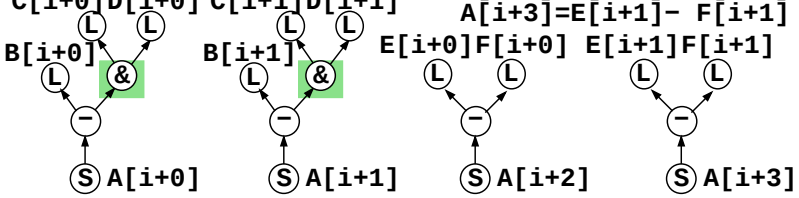


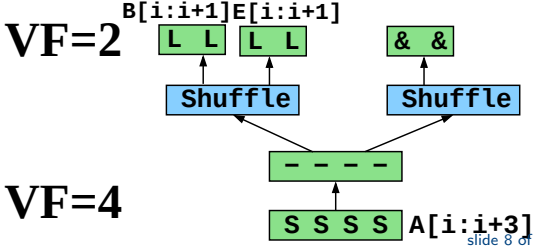


VW−SLP

Variable Width SLP

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
```





VW−SLP

Variable Width SLP

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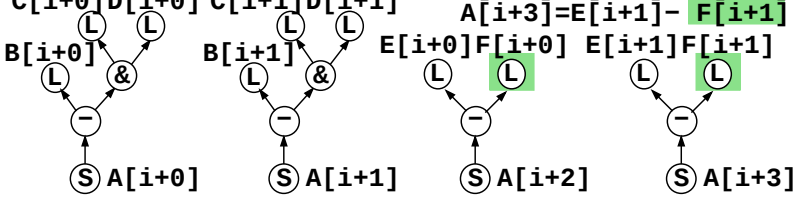
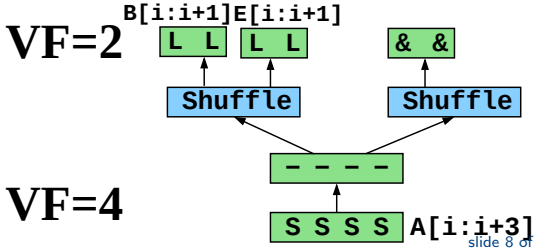
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
```

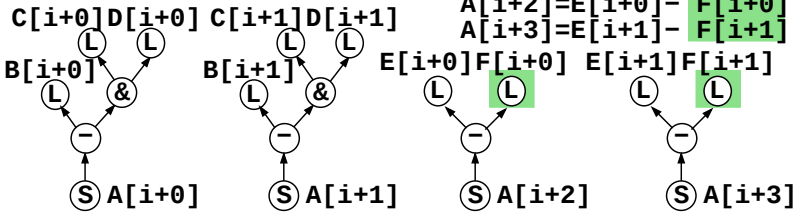


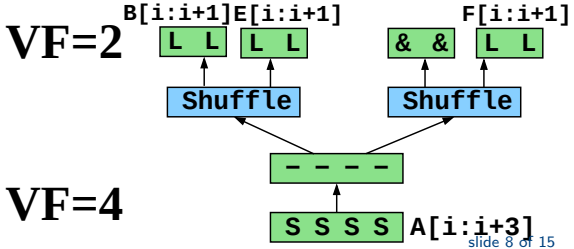


VW−SLP

Variable Width SLP

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
```

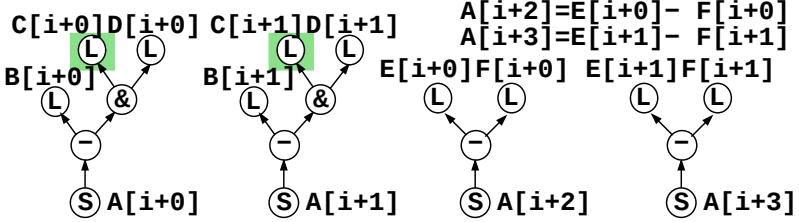


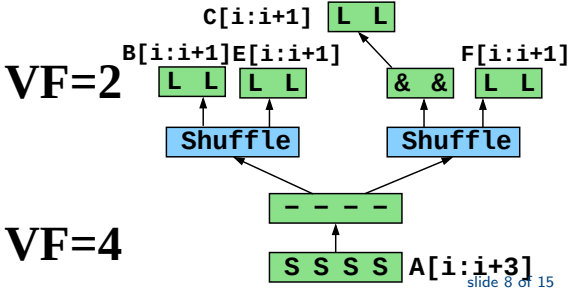


VW−SLP

Variable Width SLP

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
```

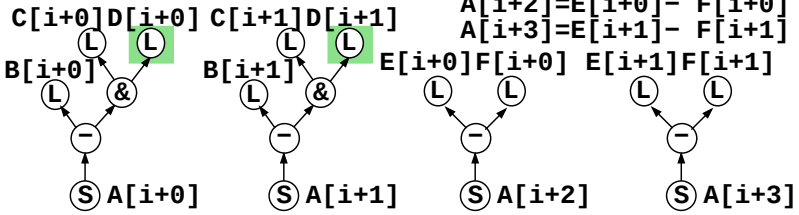


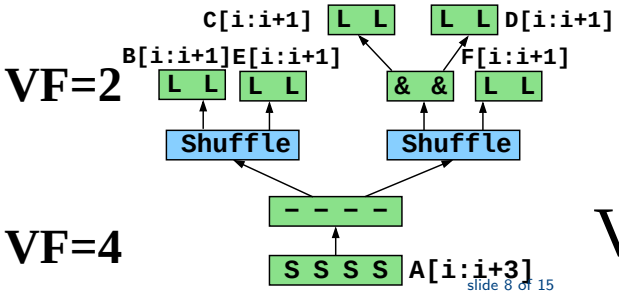


VW−SLP

Variable Width SLP

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
```

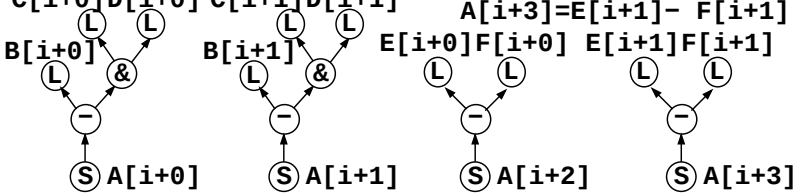


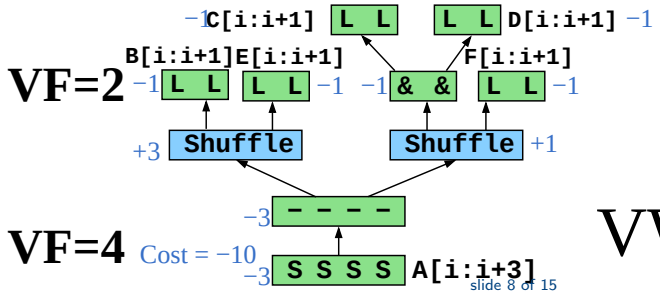


VW−SLP

Variable Width SLP

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
```

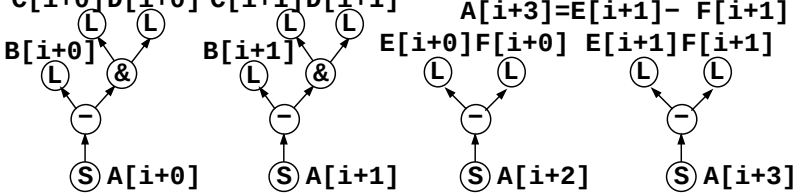


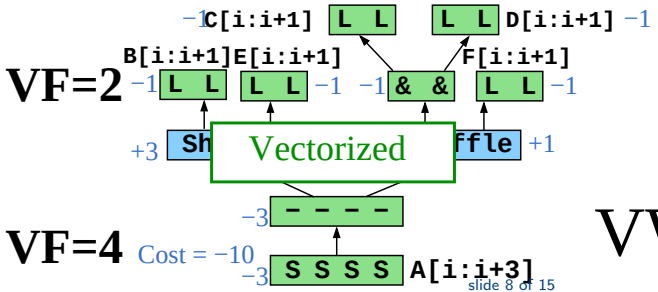


VW−SLP

Variable Width SLP

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+0]&D[i+0])
A[i+1]=B[i+1]-(C[i+1]&D[i+1])
A[i+2]=E[i+0]- F[i+0]
A[i+3]=E[i+1]- F[i+1]
```

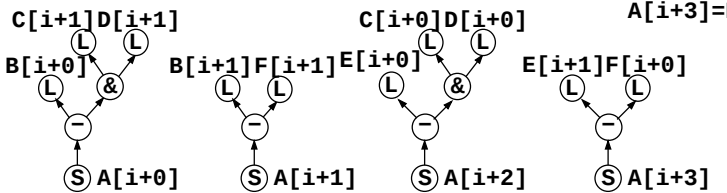




VW−SLP

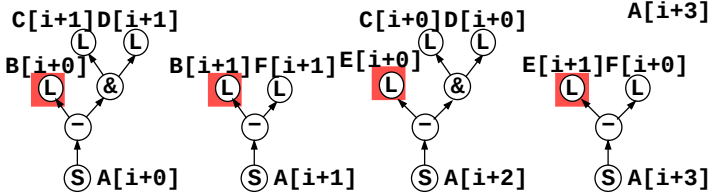
Variable Width + Permutations

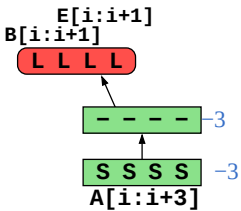
```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+1]&D[i+1])
A[i+1]=B[i+1]- F[i+1)
A[i+2]=E[i+0]-(C[i+0]&D[i+0])
A[i+3]=E[i+1]- F[i+0]
```



Variable Width + Permutations

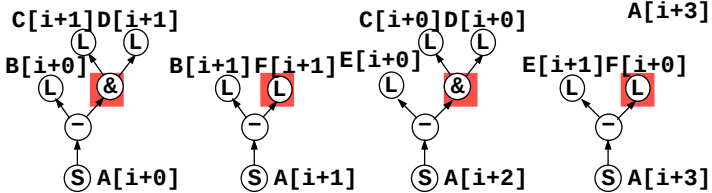
```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+1]&D[i+1])
A[i+1]=B[i+1]- F[i+1)
A[i+2]=E[i+0]-(C[i+0]&D[i+0])
A[i+3]=E[i+1]- F[i+0]
```

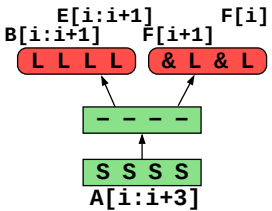




Variable Width + Permutations

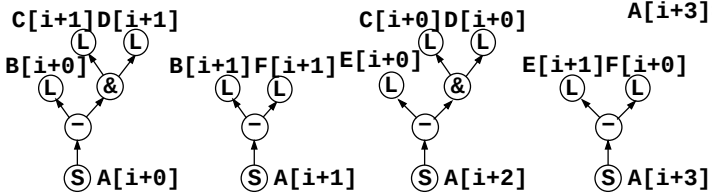
```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+1]&D[i+1])
A[i+1]=B[i+1]- F[i+1)
A[i+2]=E[i+0]-(C[i+0]&D[i+0])
A[i+3]=E[i+1]- F[i+0]
```

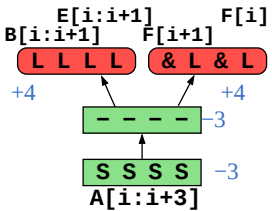




Variable Width + Permutations

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+1]&D[i+1])
A[i+1]=B[i+1]- F[i+1)
A[i+2]=E[i+0]-(C[i+0]&D[i+0])
A[i+3]=E[i+1]- F[i+0]
```

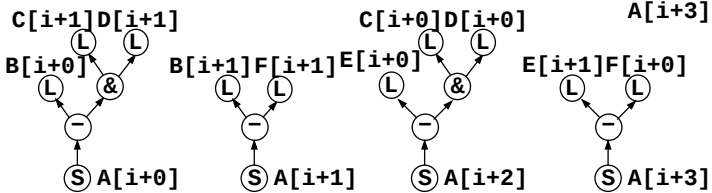


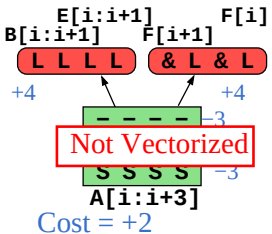


Cost = +2

Variable Width + Permutations

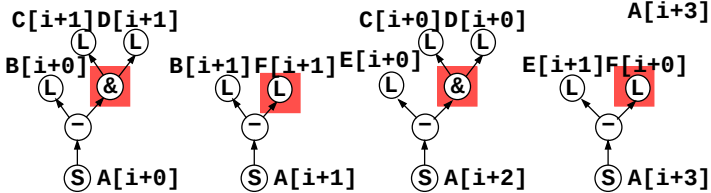
```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+1]&D[i+1])
A[i+1]=B[i+1]- F[i+1)
A[i+2]=E[i+0]-(C[i+0]&D[i+0])
A[i+3]=E[i+1]- F[i+0]
```

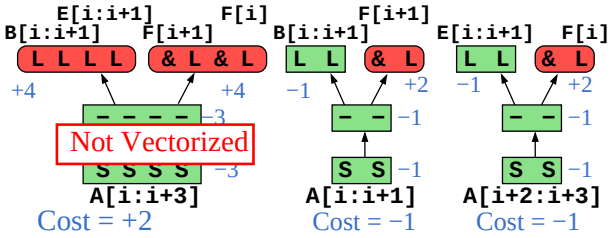




Variable Width + Permutations

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+1]&D[i+1])
A[i+1]=B[i+1]- F[i+1)
A[i+2]=E[i+0]-(C[i+0]&D[i+0])
A[i+3]=E[i+1]- F[i+0]
```





Variable Width + Permutations

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+1]&D[i+1])
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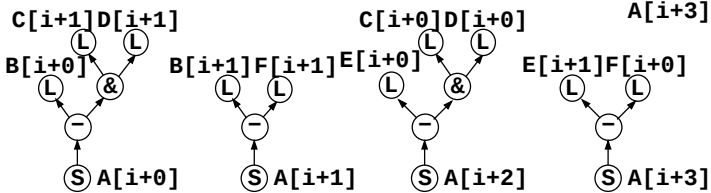
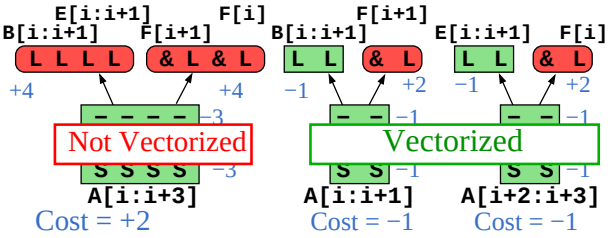
A[i+2]=E[i+0]-(C[i+0]&D[i+0])
A[i+3]=E[i+1]- F[i+0]
```





Variable Width + Permutations

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+1]&D[i+1])
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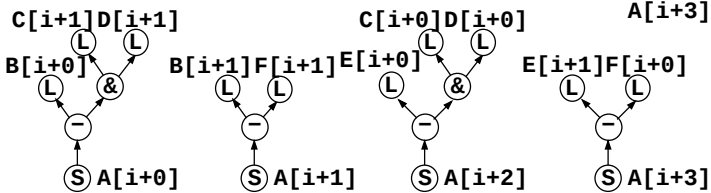
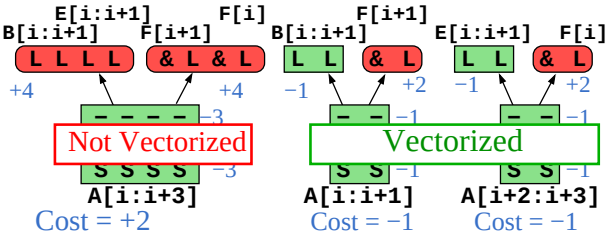
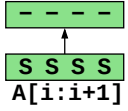
A[i+2]=E[i+0]-(C[i+0]&D[i+0])
A[i+3]=E[i+1]- F[i+0]
```



VW−SLP





Variable Width + Permutations

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+1]&D[i+1])
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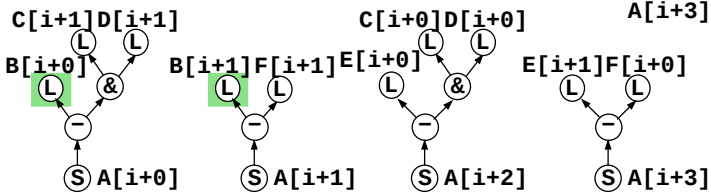
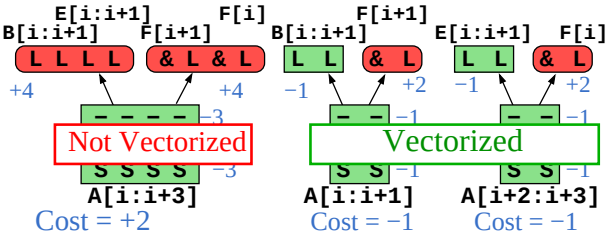
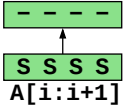
A[i+2]=E[i+0]-(C[i+0]&D[i+0])
A[i+3]=E[i+1]- F[i+0]
```



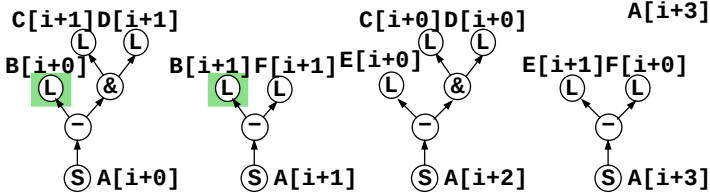
VW−SLP



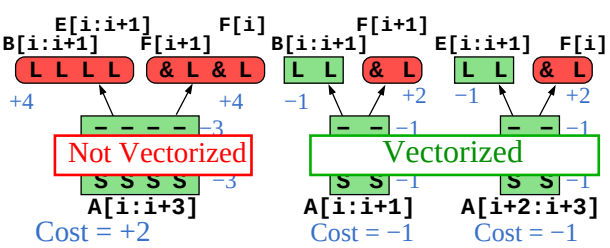


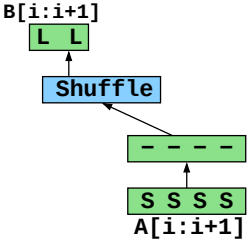
Variable Width + Permutations

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+1]&D[i+1])
A[i+1]=B[i+1]- F[i+1)
A[i+2]=E[i+0]-(C[i+0]&D[i+0])
A[i+3]=E[i+1]- F[i+0]
```



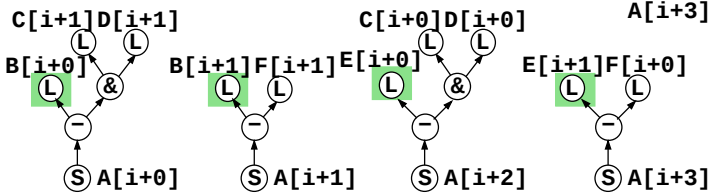
VW−SLP



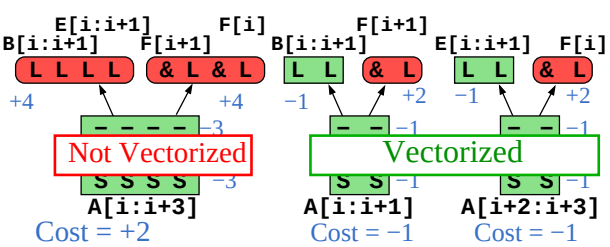


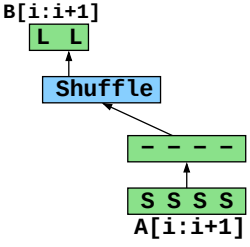
Variable Width + Permutations

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+1]&D[i+1])
A[i+1]=B[i+1]- F[i+1)
A[i+2]=E[i+0]-(C[i+0]&D[i+0])
A[i+3]=E[i+1]- F[i+0]
```



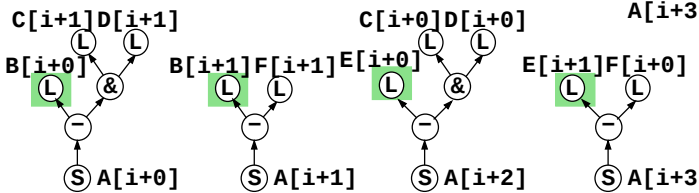
VW−SLP



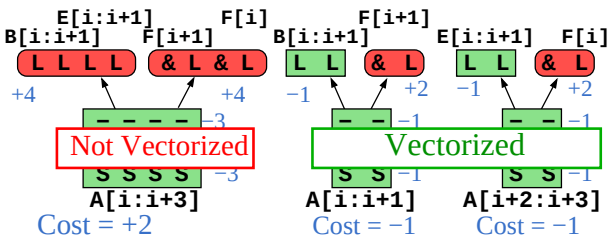


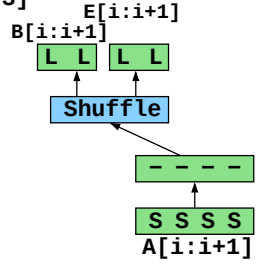
Variable Width + Permutations

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+1]&D[i+1])
A[i+1]=B[i+1]- F[i+1)
A[i+2]=E[i+0]-(C[i+0]&D[i+0])
A[i+3]=E[i+1]- F[i+0]
```



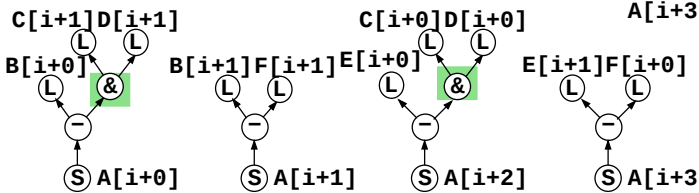
VW−SLP



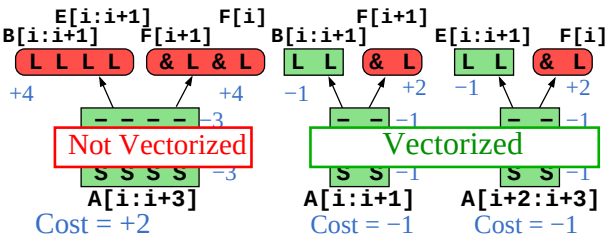


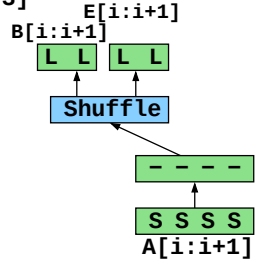
Variable Width + Permutations

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+1]&D[i+1])
A[i+1]=B[i+1]- F[i+1)
A[i+2]=E[i+0]-(C[i+0]&D[i+0])
A[i+3]=E[i+1]- F[i+0]
```



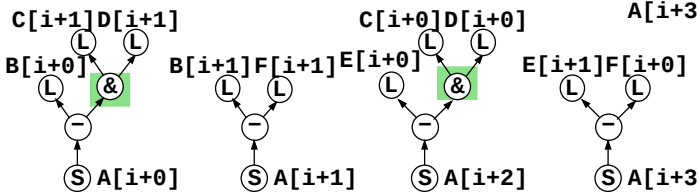
VW−SLP



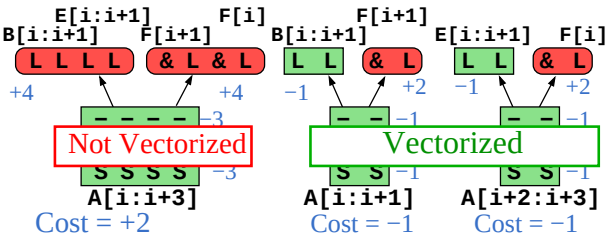


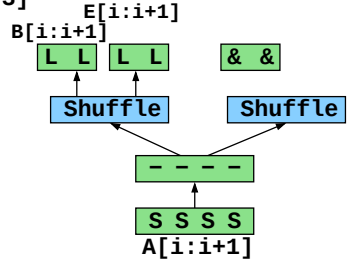
Variable Width + Permutations

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+1]&D[i+1])
A[i+1]=B[i+1]- F[i+1)
A[i+2]=E[i+0]-(C[i+0]&D[i+0])
A[i+3]=E[i+1]- F[i+0]
```



VW−SLP





Variable Width + Permutations

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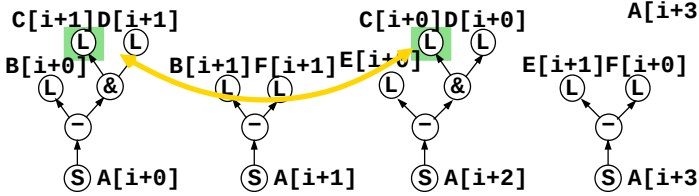
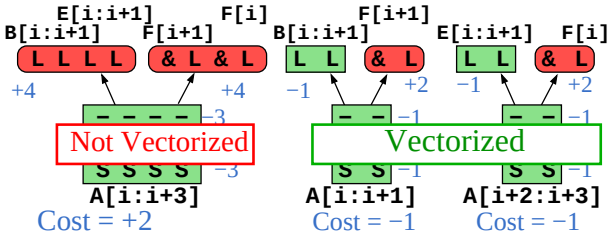
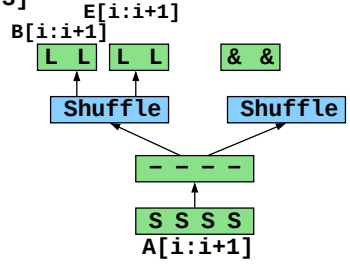
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+1]&D[i+1])
A[i+1]=B[i+1]- F[i+1)
A[i+2]=E[i+0]-(C[i+0]&D[i+0])
A[i+3]=E[i+1]- F[i+0]
```



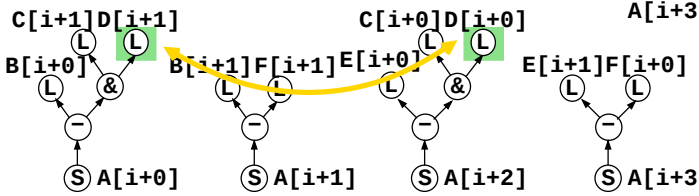
VW−SLP



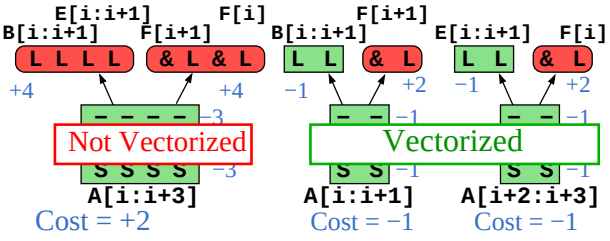


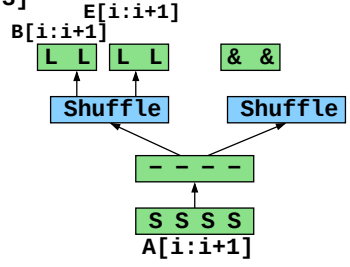
Variable Width + Permutations

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+1]&D[i+1])
A[i+1]=B[i+1]- F[i+1)
A[i+2]=E[i+0]-(C[i+0]&D[i+0])
A[i+3]=E[i+1]- F[i+0]
```



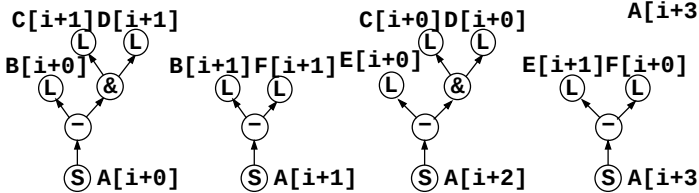
VW−SLP

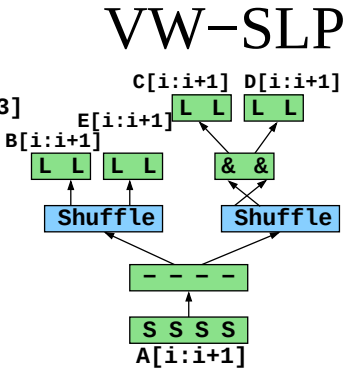




Variable Width + Permutations

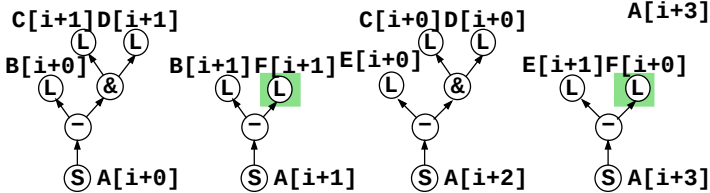
```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+1]&D[i+1])
A[i+1]=B[i+1]- F[i+1)
A[i+2]=E[i+0]-(C[i+0]&D[i+0])
A[i+3]=E[i+1]- F[i+0]
```

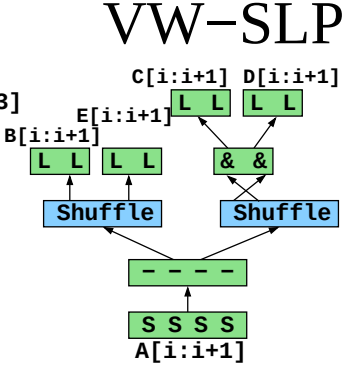




Variable Width + Permutations

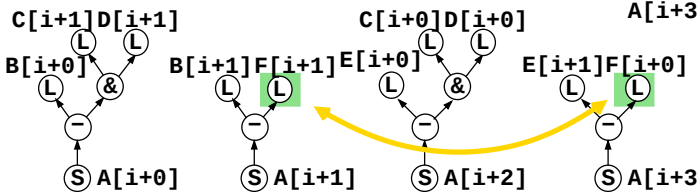
```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+1]&D[i+1])
A[i+1]=B[i+1]- F[i+1)
A[i+2]=E[i+0]-(C[i+0]&D[i+0])
A[i+3]=E[i+1]- F[i+0]
```

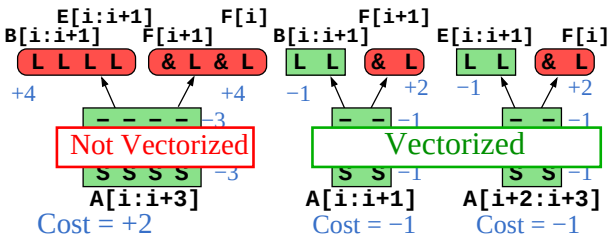




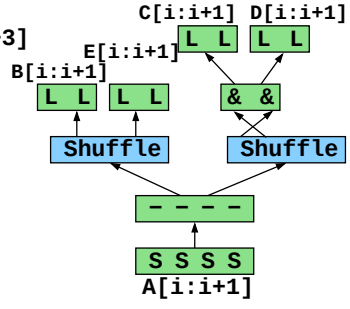
Variable Width + Permutations

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+1]&D[i+1])
A[i+1]=B[i+1]- F[i+1)
A[i+2]=E[i+0]-(C[i+0]&D[i+0])
A[i+3]=E[i+1]- F[i+0]
```



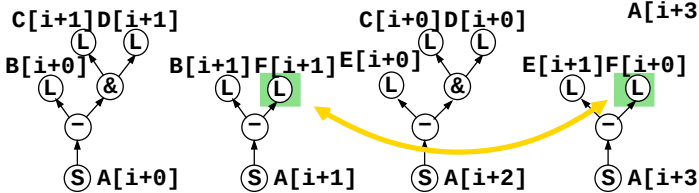


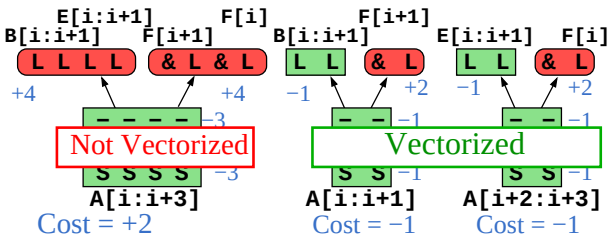
VW−SLP



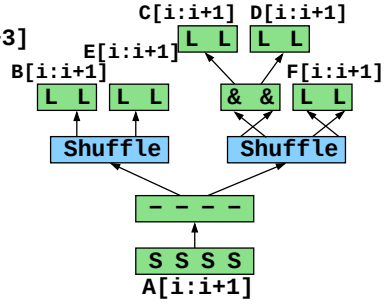
Variable Width + Permutations

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+1]&D[i+1])
A[i+1]=B[i+1]- F[i+1)
A[i+2]=E[i+0]-(C[i+0]&D[i+0])
A[i+3]=E[i+1]- F[i+0]
```



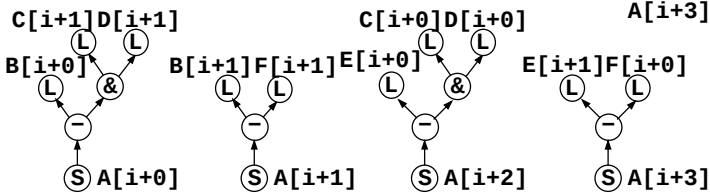


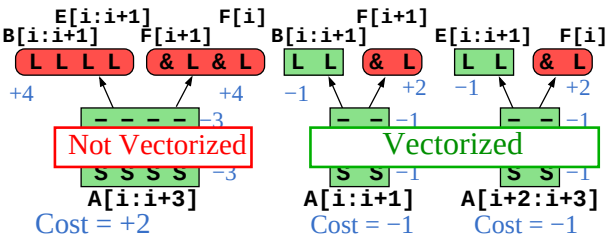
VW−SLP



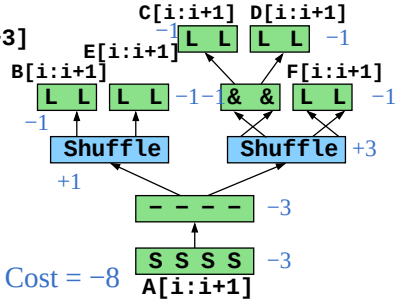
Variable Width + Permutations

```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+1]&D[i+1])
A[i+1]=B[i+1]- F[i+1)
A[i+2]=E[i+0]-(C[i+0]&D[i+0])
A[i+3]=E[i+1]- F[i+0]
```



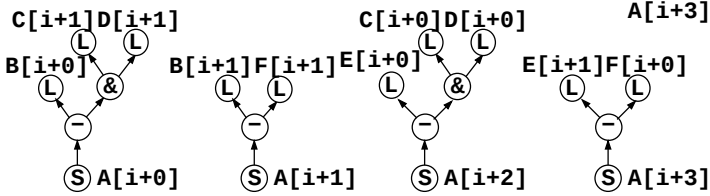


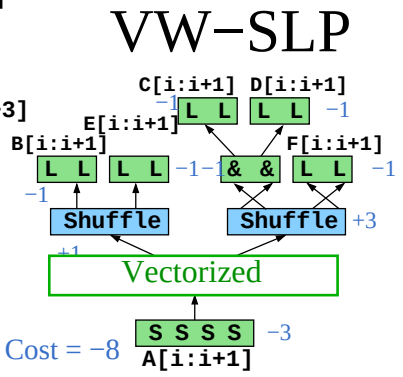
VW−SLP



Variable Width + Permutations

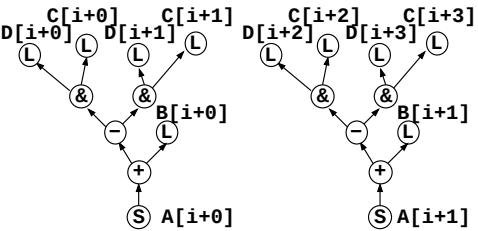
```
uint64_t A[],B[],C[],D[],E[],F[]
A[i+0]=B[i+0]-(C[i+1]&D[i+1])
A[i+1]=B[i+1]- F[i+1)
A[i+2]=E[i+0]-(C[i+0]&D[i+0])
A[i+3]=E[i+1]- F[i+0]
```





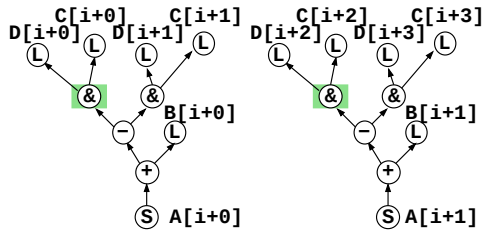
Widening the Vector Width

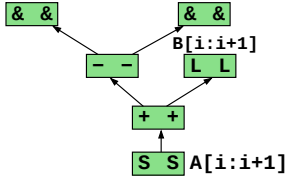
```
uint64_t A[],B[],C[],D[]
uint64_t tmp0=C[i+0]&D[i+0]
uint64_t tmp1=C[i+1]&D[i+1]
uint64_t tmp2=C[i+2]&D[i+2]
uint64_t tmp3=C[i+3]&D[i+3]
A[i+0]=B[i+0]+(tmp0-tmp1)
A[i+1]=B[i+1]+(tmp2-tmp3)
```



Widening the Vector Width

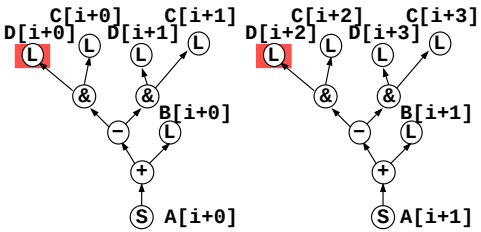
```
uint64_t A[],B[],C[],D[]
uint64_t tmp0=C[i+0]&D[i+0]
uint64_t tmp1=C[i+1]&D[i+1]
uint64_t tmp2=C[i+2]&D[i+2]
uint64_t tmp3=C[i+3]&D[i+3]
A[i+0]=B[i+0]+(tmp0-tmp1)
A[i+1]=B[i+1]+(tmp2-tmp3)
```

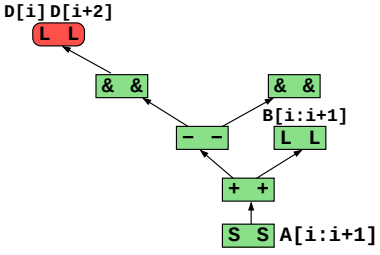




Widening the Vector Width

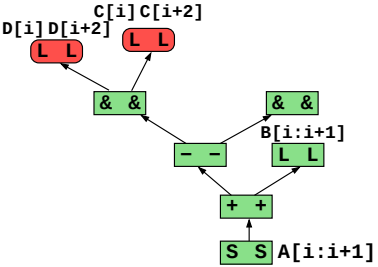
```
uint64_t A[],B[],C[],D[]
uint64_t tmp0=C[i+0]&D[i+0]
uint64_t tmp1=C[i+1]&D[i+1]
uint64_t tmp2=C[i+2]&D[i+2]
uint64_t tmp3=C[i+3]&D[i+3]
A[i+0]=B[i+0]+(tmp0-tmp1)
A[i+1]=B[i+1]+(tmp2-tmp3)
```

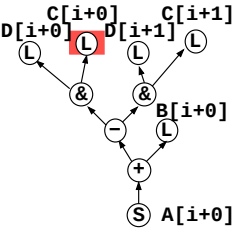


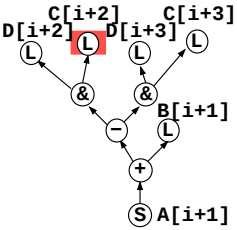


Widening the Vector Width

```
uint64_t A[],B[],C[],D[]
uint64_t tmp0=C[i+0]&D[i+0]
uint64_t tmp1=C[i+1]&D[i+1]
uint64_t tmp2=C[i+2]&D[i+2]
uint64_t tmp3=C[i+3]&D[i+3]
A[i+0]=B[i+0]+(tmp0−tmp1)
A[i+1]=B[i+1]+(tmp2−tmp3)
```

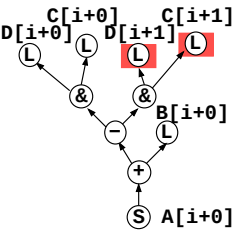


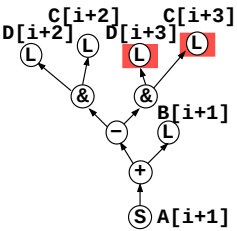


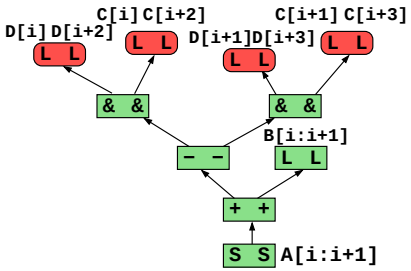


Widening the Vector Width

```
uint64_t A[],B[],C[],D[]
uint64_t tmp0=C[i+0]&D[i+0]
uint64_t tmp1=C[i+1]&D[i+1]
uint64_t tmp2=C[i+2]&D[i+2]
uint64_t tmp3=C[i+3]&D[i+3]
A[i+0]=B[i+0]+(tmp0-tmp1)
A[i+1]=B[i+1]+(tmp2-tmp3)
```

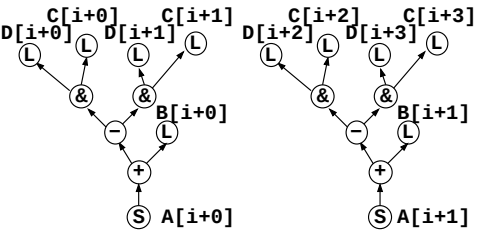


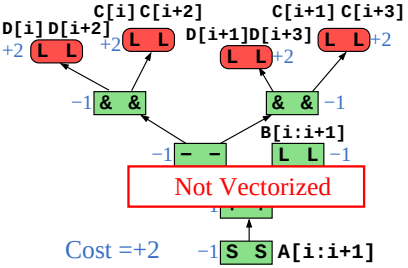




Widening the Vector Width

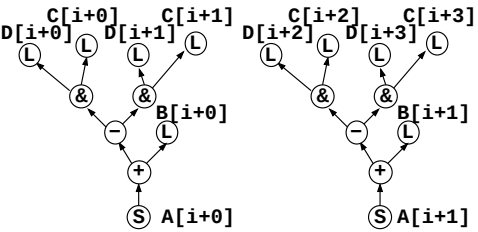
```
uint64_t A[],B[],C[],D[]
uint64_t tmp0=C[i+0]&D[i+0]
uint64_t tmp1=C[i+1]&D[i+1]
uint64_t tmp2=C[i+2]&D[i+2]
uint64_t tmp3=C[i+3]&D[i+3]
A[i+0]=B[i+0]+(tmp0-tmp1)
A[i+1]=B[i+1]+(tmp2-tmp3)
```

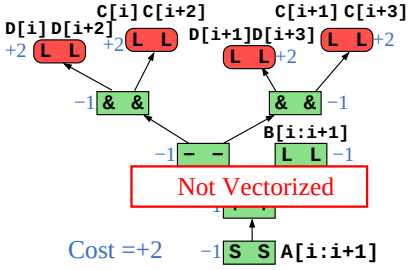




Widening the Vector Width

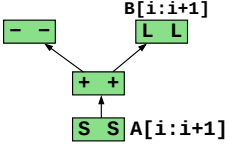
```
uint64_t A[],B[],C[],D[]
uint64_t tmp0=C[i+0]&D[i+0]
uint64_t tmp1=C[i+1]&D[i+1]
uint64_t tmp2=C[i+2]&D[i+2]
uint64_t tmp3=C[i+3]&D[i+3]
A[i+0]=B[i+0]+(tmp0-tmp1)
A[i+1]=B[i+1]+(tmp2-tmp3)
```





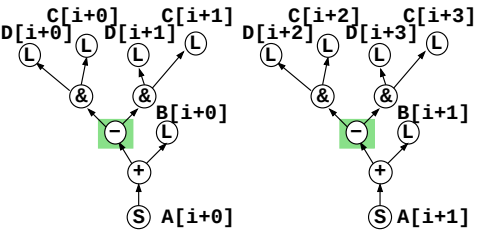
VW=SLP

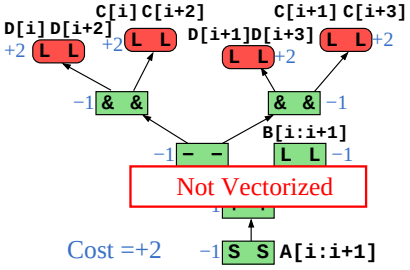
VF=2



Widening the Vector Width

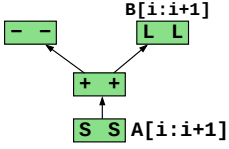
```
uint64_t A[],B[],C[],D[]
uint64_t tmp0=C[i+0]&D[i+0]
uint64_t tmp1=C[i+1]&D[i+1]
uint64_t tmp2=C[i+2]&D[i+2]
uint64_t tmp3=C[i+3]&D[i+3]
A[i+0]=B[i+0]+(tmp0-tmp1)
A[i+1]=B[i+1]+(tmp2-tmp3)
```





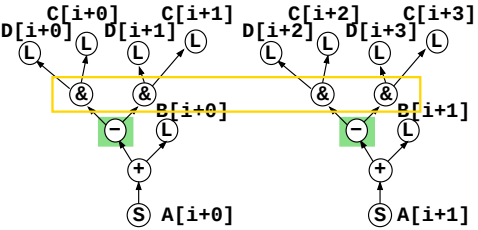
VW−SLP

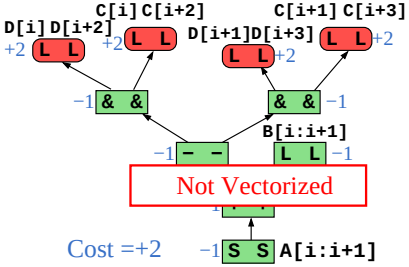
VF=2



Widening the Vector Width

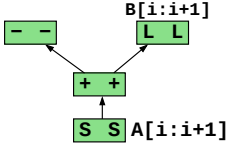
```
uint64_t A[],B[],C[],D[]
uint64_t tmp0=C[i+0]&D[i+0]
uint64_t tmp1=C[i+1]&D[i+1]
uint64_t tmp2=C[i+2]&D[i+2]
uint64_t tmp3=C[i+3]&D[i+3]
A[i+0]=B[i+0]+(tmp0-tmp1)
A[i+1]=B[i+1]+(tmp2-tmp3)
```





VW−SLP

VF=2



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```
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uint64_t tmp0=C[i+0]&D[i+0]
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A[i+0]=B[i+0]+(tmp0-tmp1)
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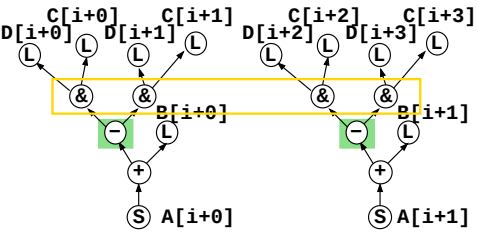
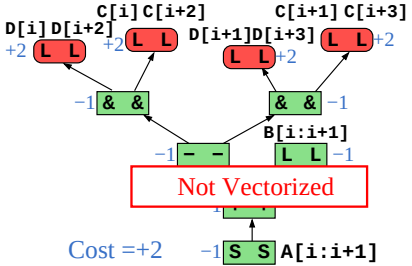
```

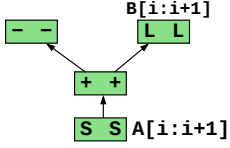




VW−SLP

VF=4

VF=2



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uint64_t A[],B[],C[],D[]
uint64_t tmp0=C[i+0]&D[i+0]
uint64_t tmp1=C[i+1]&D[i+1]
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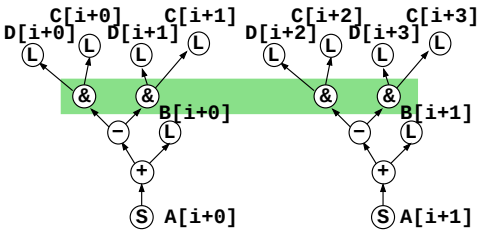

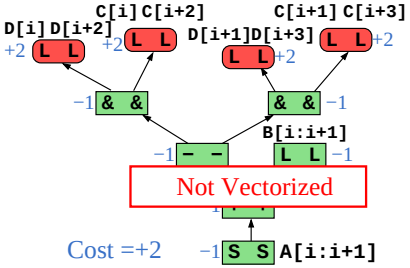

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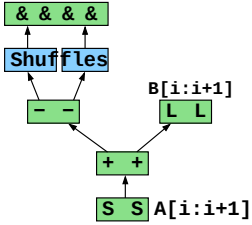

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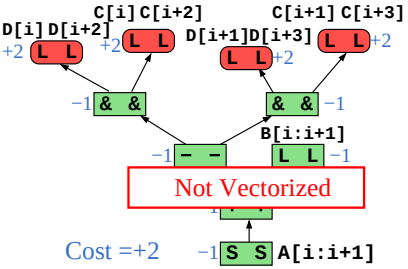
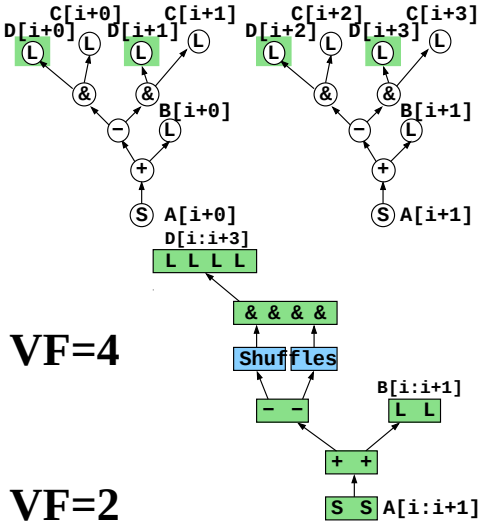
```



VW−SLP



Widening the Vector Width

```
uint64_t A[],B[],C[],D[]
uint64_t tmp0=C[i+0]&D[i+0]
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A[i+0]=B[i+0]+(tmp0-tmp1)
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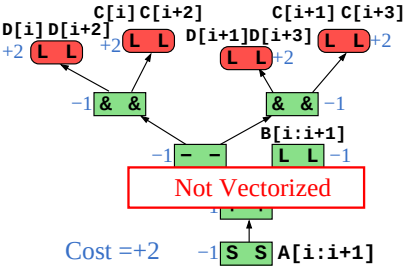
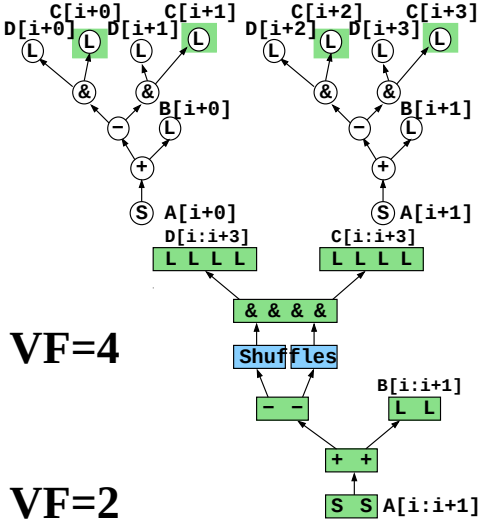
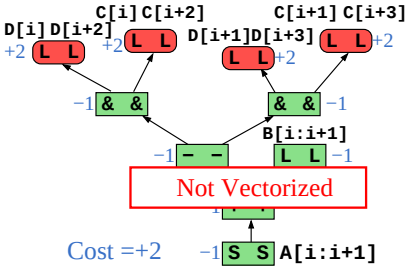


VW−SLP



Widening the Vector Width

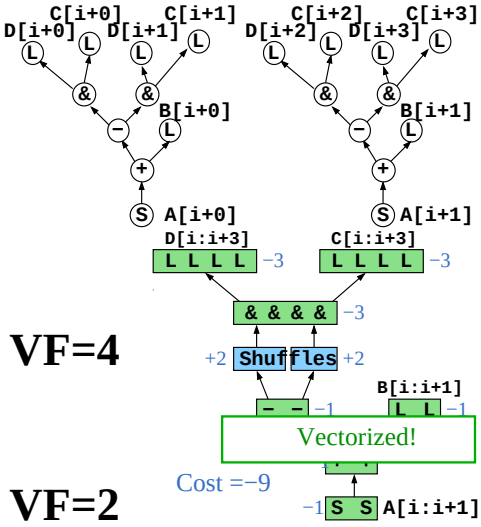
```
uint64_t A[],B[],C[],D[]
uint64_t tmp0=C[i+0]&D[i+0]
uint64_t tmp1=C[i+1]&D[i+1]
uint64_t tmp2=C[i+2]&D[i+2]
uint64_t tmp3=C[i+3]&D[i+3]
A[i+0]=B[i+0]+(tmp0-tmp1)
A[i+1]=B[i+1]+(tmp2-tmp3)
```



VW-SLP

VF=4

VF=2



Implementation

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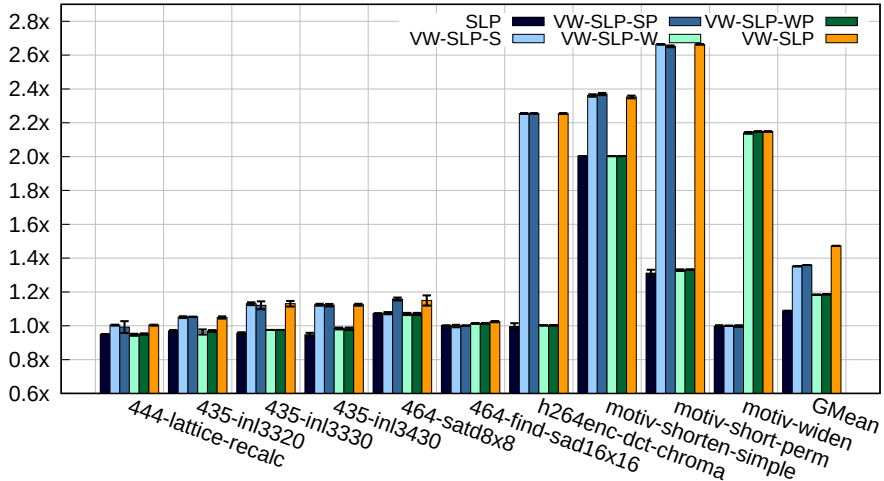
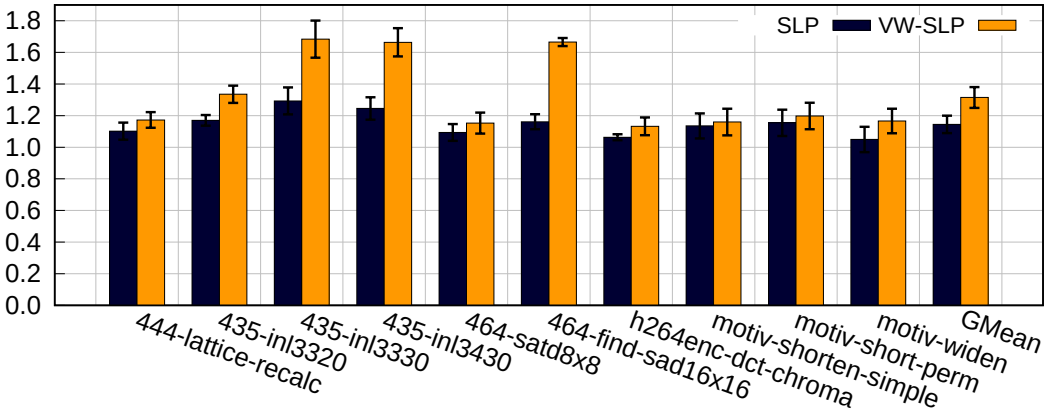
- Added scheduler support for roll-back and replay
- Code generation changes in `vectorizeTree()` for variable-width support and the `shufflevector` instructions

Performance



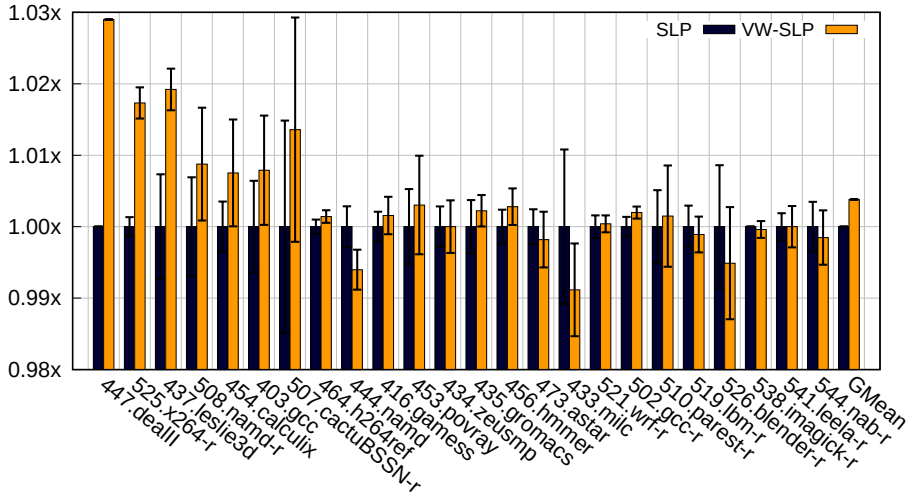
- Functions extracted from SPEC'06 and MediabenchII, Normalized to O3 and tested on a Core™ i5-6440HQ

Compilation Time



- Core™ i5-6440HQ

Performance on SPEC



- SPEC 2006/2017 SLP(No LV), VW-SLP(No LV), on Core™ i5-6440HQ

Conclusion

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- Better performance and coverage
- Very small increase in compilation time