Memory Optimal Single Appearance Schedule with Dynamic Loop Count for Synchronous Dataflow Graphs

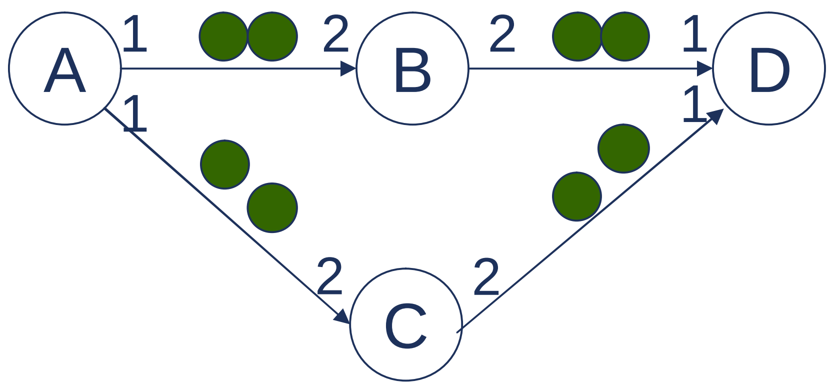
Hyunok Oh, ARM Inc.,
Nikil Dutt, UC Irvine,
Soonhoi Ha, Seoul National Univ.

Outline

- Code synthesis from synchronous dataflow model
- Single appearance schedule
- Dynamic loop count single appearance schedule
  - Algorithm
  - Example
- Experiment
- Conclusion

Synchronous Dataflow (SDF) Model

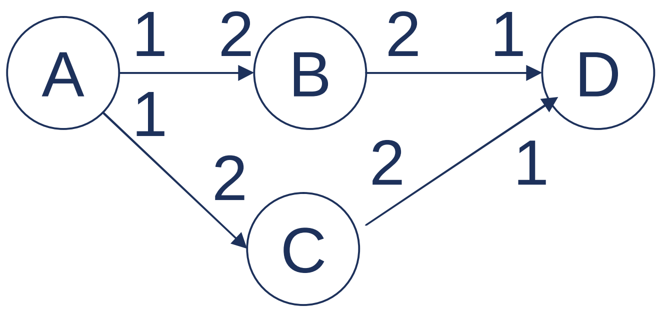
- Useful to describe DSP algorithms
- A node represents a function block (ex: FIR, DCT)
- An arc represents data dependency : FIFO queue of samples
- Statically scheduled at compile-time.



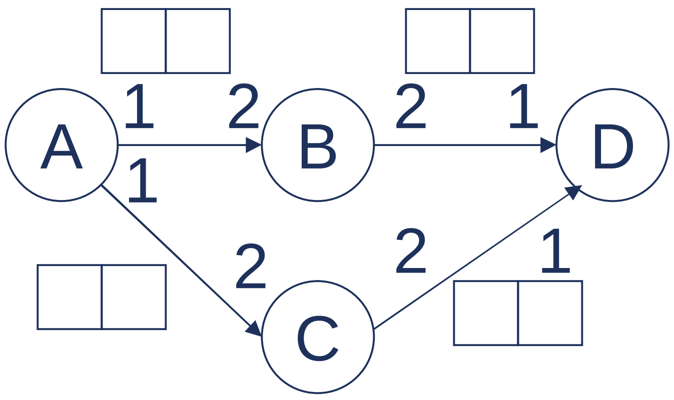
AACBDD

Software Synthesis Procedure

SDF(Synchronous Dataflow)



Buffer allocation



Schedule

= 2(A)CB2(D)

= …

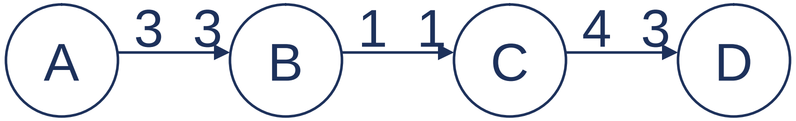
```
main() {
  int AB[2], AC[2], BD[2], CD[2];
  for(i=0;i<2;i++){A}
  {C}
  {B}
  for(i=0;i<2;i++){D}
}
```

Software Synthesis Problem

- Automatic code generation from data flow graph
  - The kernel code of a node is already optimized in the library.
  - Determine the schedule
  - Determine the buffer size
  - Codes are generated according to the scheduled sequence with buffer size
- Fundamental Question
  - Can we achieve the similar code quality as manually optimized code in terms of performance and memory requirement?

Memory Requirement

- Data memory: depends on schedule & buffer sharing & buffer management technique



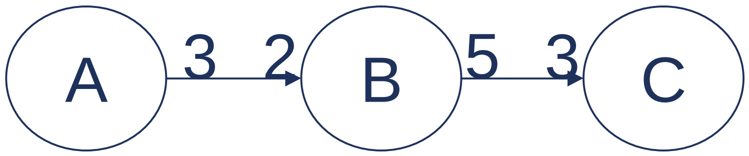
- <example>
  - < Schedule 1 > 3(ABC)4(D)
    - buffer size: 3 + 1 + 12 = 16
  - < Schedule 2 > (3A)(3B)(3C)(4D)
    - buffer size: 9 + 3 + 12 = 24
    - buffer sharing: 3 + max (9,12) = 15
  - < Schedule 3 > 3(ABCD)D
    - buffer size: 3 + 1 + 6 = 10

Single Appearance Schedule (SAS)

- Contains only one lexical appearance of each node
  - SAS : 3(ABC)4(D), (3A)(3B)(3C)(4D)
  - Non SAS : 3(ABCD)D
- Minimize code memory size
  - Each node has a single definition in a generated code

Problems of SAS (1/2)

- Large buffer size



- Buffer-optimal non SAS : ABC ABCC BCC
  - Buffer size on AB : 4
  - Buffer size on BC : 7
- SAS : (2A) (3B) (5C)
  - Buffer size on AB : 6
  - Buffer size on BC : 15

Buffer Memory Lower Bound

- For single appearance schedule,
  - a=produced(e), b=consumed(e), c=gcd{a,b}, d = delay(e)

multiplication

$$\mathrm{BMLB}(e) = \begin{cases} (\eta(e) + d) & \text{if } d < \eta(e) \\ d & \text{if } d \geq \eta(e) \end{cases}, \quad \text{where} \quad \eta(e) = \frac{ab}{c}$$

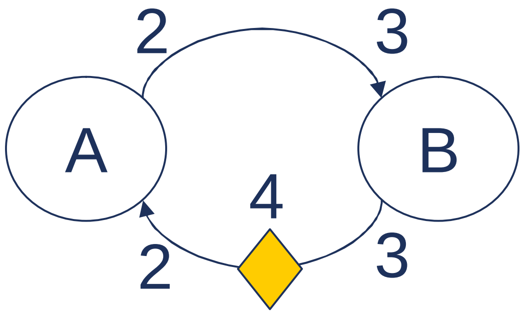
- For any schedule

addition

$$\mathrm{LB}(e) = \begin{cases} a + b - c + (d \bmod c) & \text{if } d < a + b - c \\ d & \text{otherwise} \end{cases}$$

Problems of SAS (2/2)

- Unschedulable for a graph with delay samples



- Buffer optimal non SAS : (2A)B AB
- SAS : N/A

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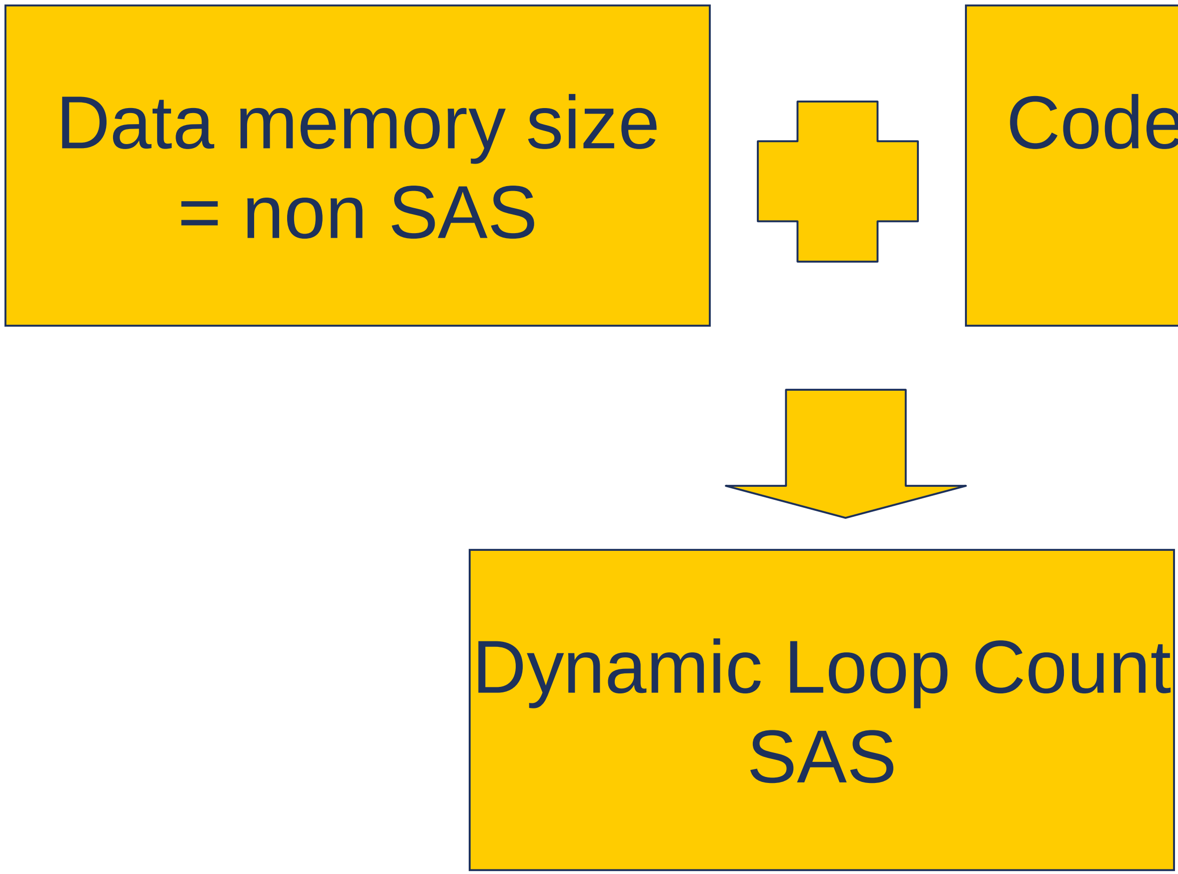
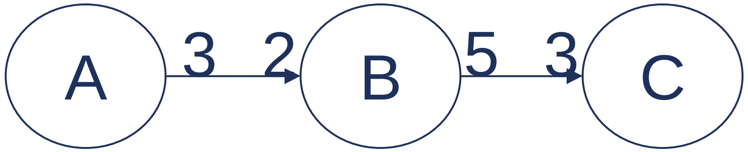
Dynamic Loop Count SAS (dlcSAS)



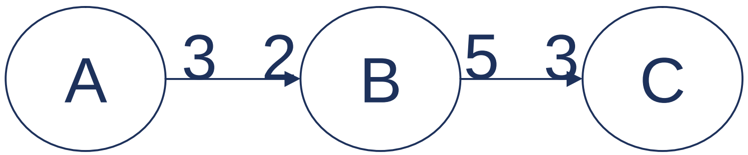
- Change loop count at run time
- Data memory size
  - Equal to buffer optimal non SAS
- Code memory size
  - Similar to SAS except codes for loop count computation

Example 1 : optimal data buffer size



- Buffer-optimal non SAS : ABC ABCC BCC
- Previous SAS : (2A) (3B) (5C)
- dlcSAS
  - AB A(2B) → A {1,2}B
  - BC B(2C) B(2C) → B {1,2,2}C
  - 2(A {1,2}(B {1,2,2}C))
  - = ABC ABCC BCC : buffer-optimal non SAS
  - Buffer size on AB : 4
  - Buffer size on BC : 7

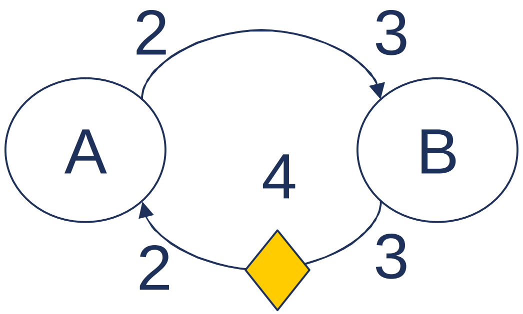
Generated Code



2(A {1,2}(B {1,2,2}C))

```
main()
{
 int n,i,j, a[4],b[7],iC=0;
 int lB[2]={1,2},lC[3]={1,2,2};
 for(;;) {
   for(n=0;n<2;n++) {
     /* A's code */
     for(i=0;i<lB[n];i++) {
      /* B's code */
      for(j=0;j<lC[iC];j++)
      { /* C's code */}
      iC=(iC+1)%3; }
}}}
```

Example 2 : graph with delays



- dlcSAS

  2({2,1}A B)

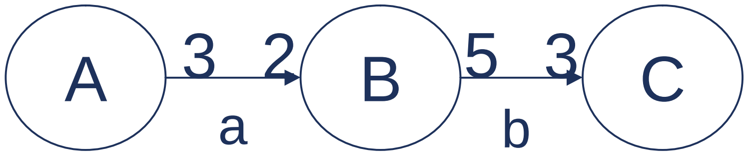
  = (2A)B AB

```
main()
{
 int i,j, a[4],b[4],lA[2]={2,1};
 for(;;) {
   for(i=0;i<2;i++) {
     for(j=0;j<lA[i];j++) {
       // A's code
     }
     // B's code
}}}
```

Algorithm

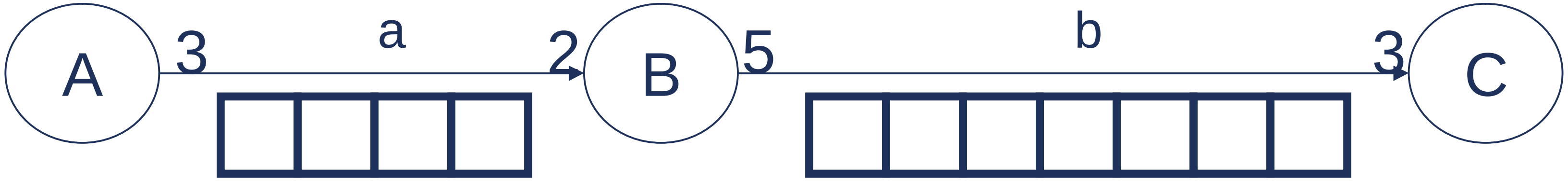
- Determine optimal buffer size on each arc at compile time
- Compute loop count of each node at run time
  - Loop count is dependent on the number of samples on accumulated on input arcs and the available buffer size on output arcs

Example



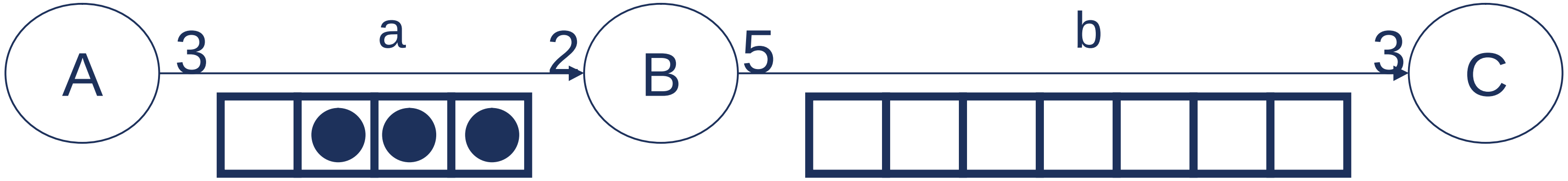
- Optimal buffer size
  - a : 4, b : 7
- Schedule
  - l = loop count and r = # of samples
  - $l_A A\ l_B B\ l_C C$
  - $l_A = (4 - r_a)/3$
  - $l_B = \min(r_a/2, (7 - r_b)/5)$
  - $l_C = r_b/3$

Example



$I_A = 4/3 = 1$

Example



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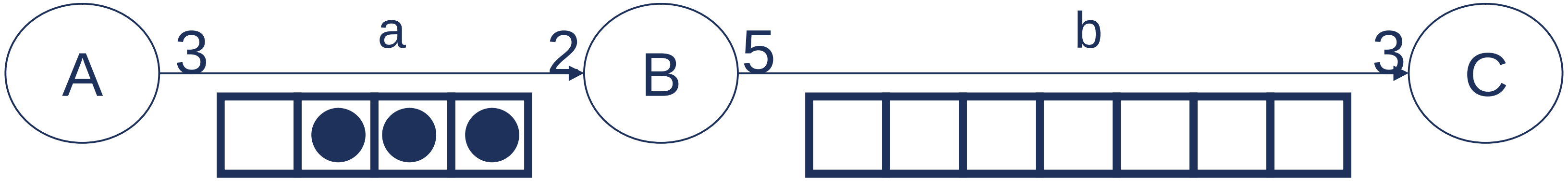
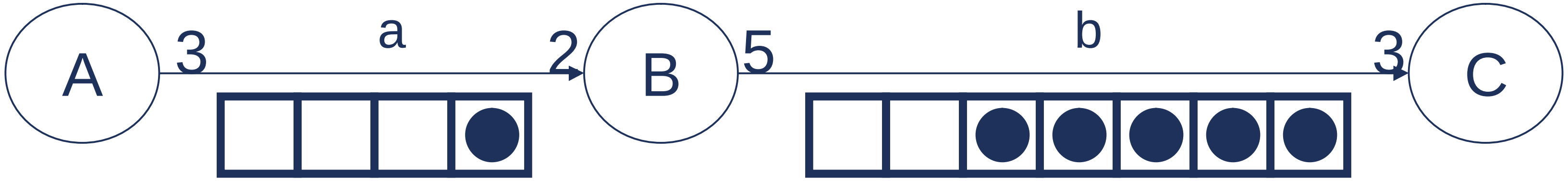


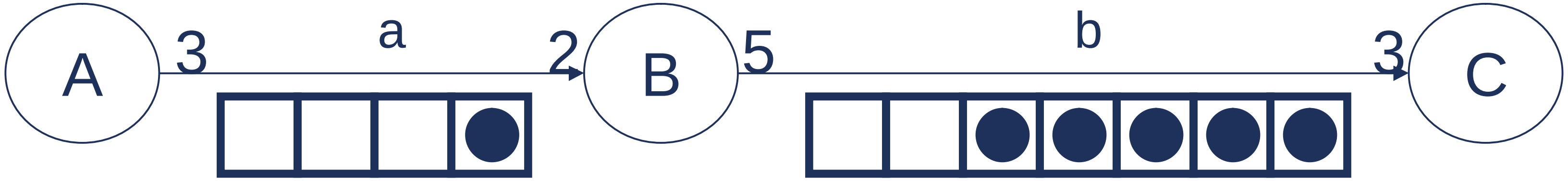
l_A= 4/3=1 l_B= min(3/2,7/5)=1

Example



$l_A = 4/3 = 1$ $l_B = \min(3/2, 7/5) = 1$

Example



$l_A = 4/3 = 1$ $l_B = \min(3/2, 7/5) = 1$ $l_C = 5/3 = 1$

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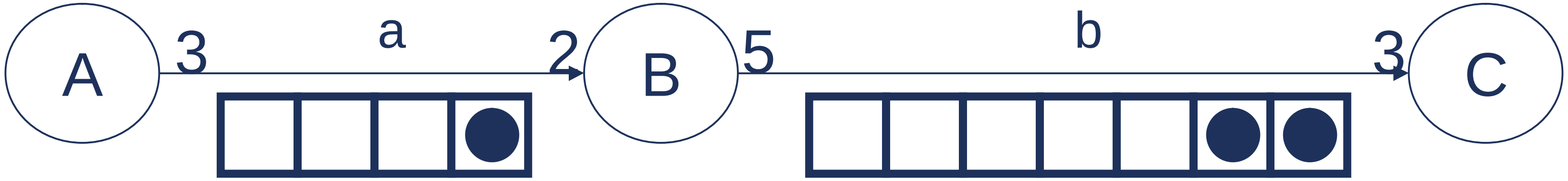

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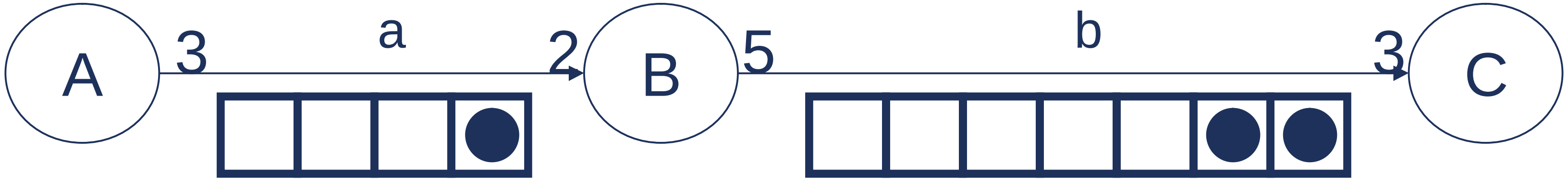
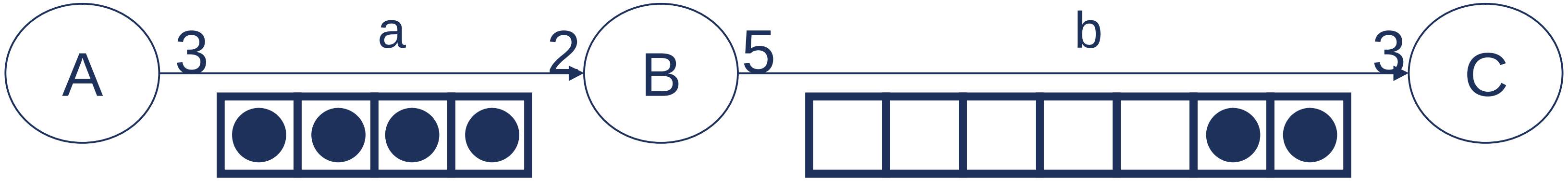


$l_A = 4/3 = 1$ $l_B = \min(3/2, 7/5) = 1$ $l_C = 5/3 = 1$

$l_A = 3/3 = 1$

Example



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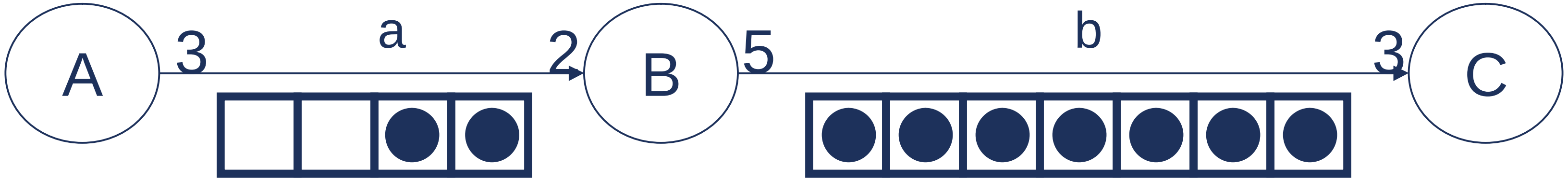

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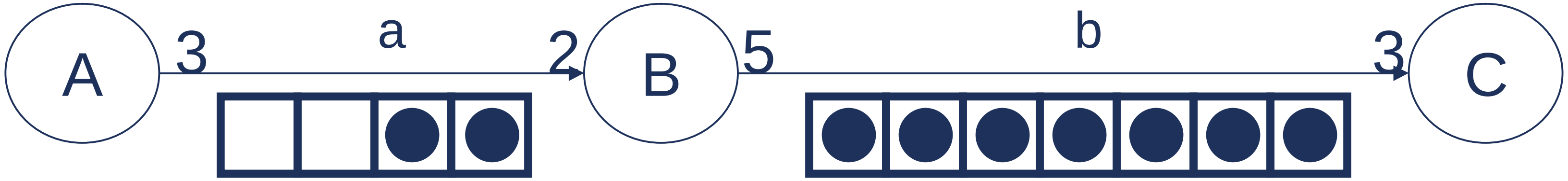

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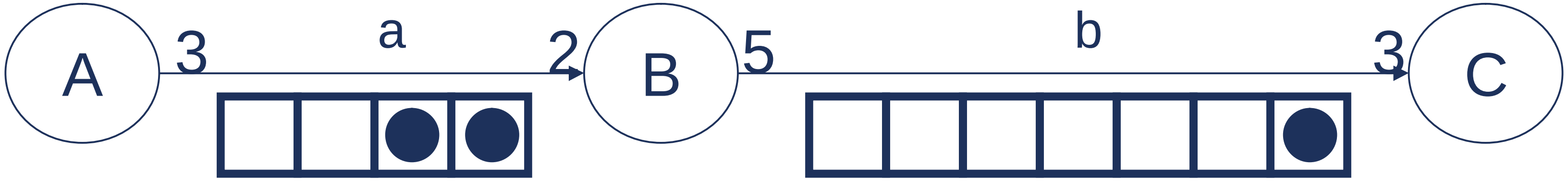
Example



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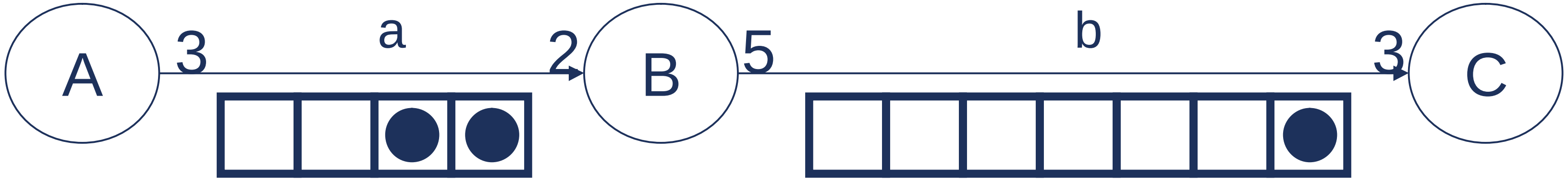

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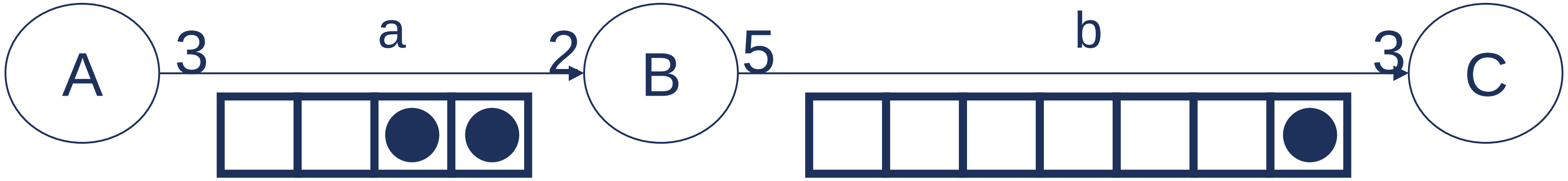
$l_A = 3/3 = 1$

$l_B = \min(4/2, 5/5) = 1$

$l_C = 7/3 = 2$

$l_A = 2/3 = 0$

Example



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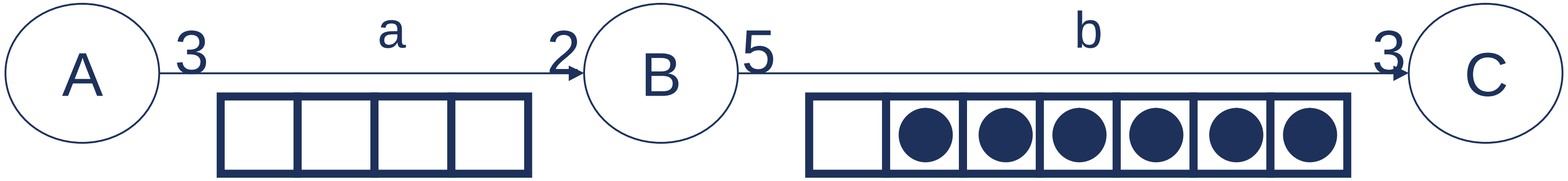
$l_A = 2/3 = 0$ $l_B = \min(2/2, 6/5) = 1$

Example



l_A= 4/3=1

l_A= 3/3=1

l_A= 2/3=0

l_B= min(3/2,7/5)=1

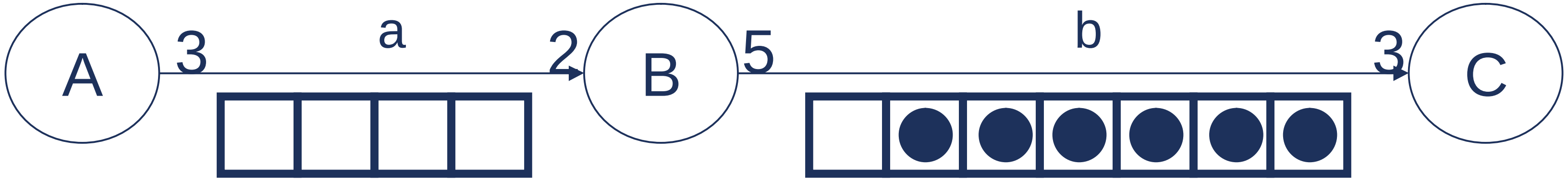
l_B= min(4/2,5/5)=1

l_B= min(2/2,6/5)=1

l_C= 5/3=1

l_C= 7/3=2

Example



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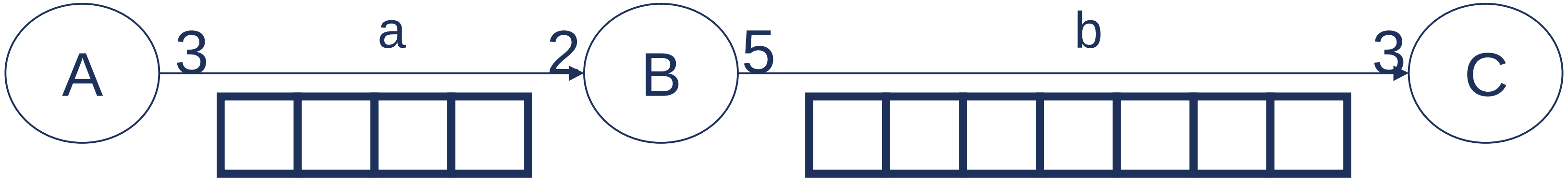
Example



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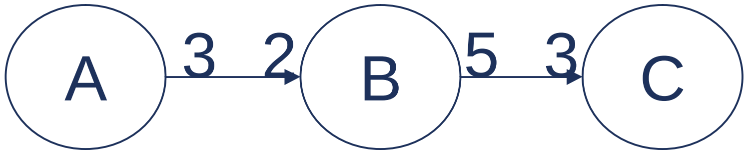
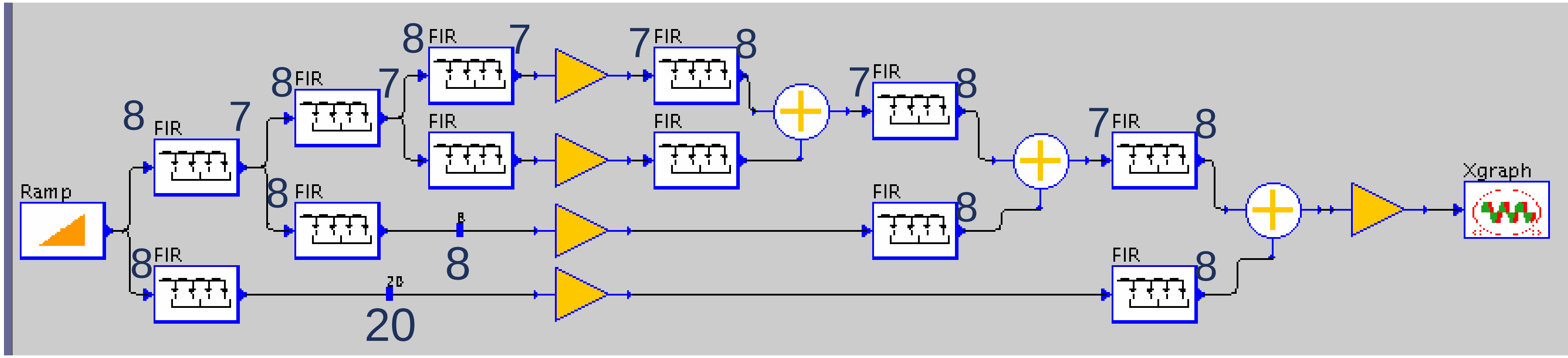
Code Generation




```
main() {
 int i,j,k a[4],b[7], lA,lB,lC, ra=0, rb=0;
 for(;;) {
   lA = (4-ra)/3;ra+=3*lA;
   for(i=0;n<lA;i++)
   { /* A's code */ }
   lB = min(ra/2,(7-rb)/5);
   ra-=2*lB; rb+=5*lB;
   for(j=0;j<lB;j++)
   { /* B's code */ }
   lC = rb/3; rb-= 3*lC;
   for(k=0;j<lC;k++)
   { /* C's code */ }
}}
```

Experiments



Filter Bank

	previous SAS	dlcSAS	Ratio (%)
code memory	13128 bytes	13540 bytes	3.14 %
data memory	15720 bytes	9664 bytes	-38.52 %
total memory	28848 bytes	23204 bytes	-19.56 %
cycles	71060 Kcycls	71363 Kcycls	0.43 %

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Conclusion

- A new single appearance schedule
  - Dynamic loop count single appearance schedule
  - Data buffer size is equal to buffer optimal non SAS
  - Code size is equal to single appearance schedule except loop count computation
  - 20% total memory reduction
  - Less than 1% performance overhead

Thanks!