



# An Introduction to Synchronous Data Flow Model

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# Outline

- Synchronous Data Flow Model
  - Definition
  - Example
- Periodic Schedule and Consistency
- Stream Programming Language
  - Structured SDF
- Apply SDF to Bigdata

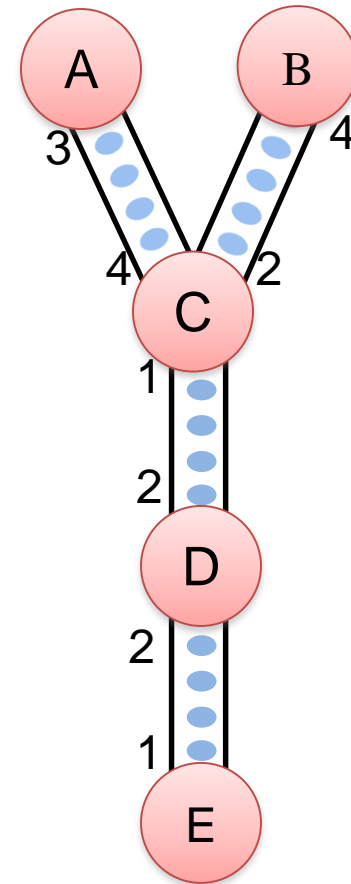


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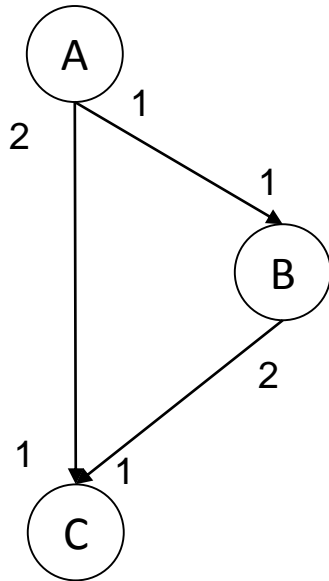
# Synchronous Data Flow Model

- Synchronous Data Flow (SDF) is represented as a graph
  - Node (actor): Computation
  - Edge: First In First Out (FIFO) Queue
- Each edge has two weights: produce rate and consume rate
- Each edge can also have initial data
- Formal: Tuple  $\langle N, E, E_{p,c,i} \rangle$ ,
  - N: node
  - E: edge
  - $E_{p,c,i}$ : Produce rate, consume rate and initial data

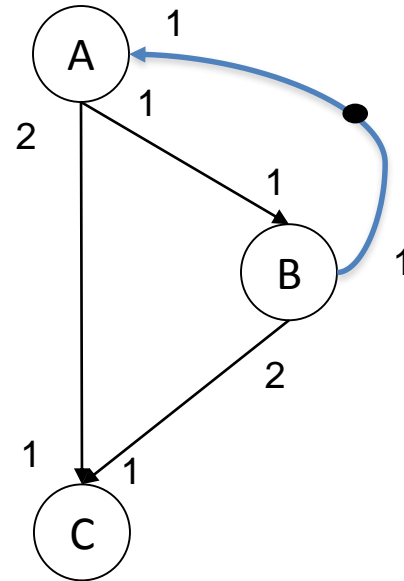




# Synchronous Data Flow Model



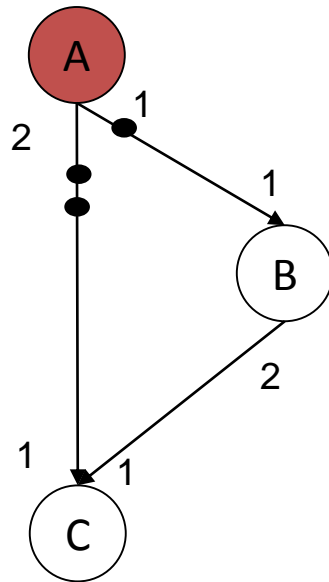
SDF with no initial tokens



SDF with initial token and loop



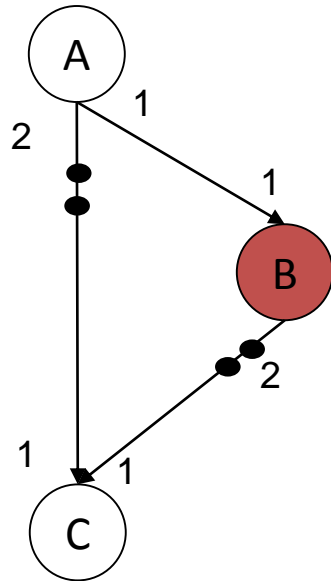
# Synchronous Data Flow Model



A firing



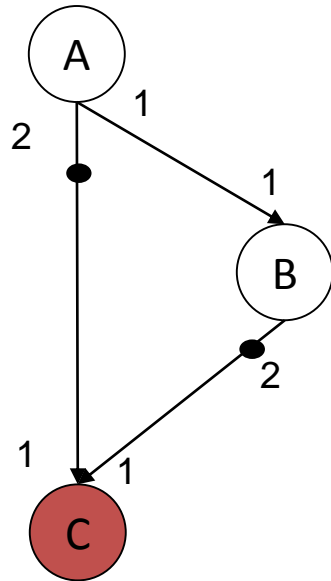
# Synchronous Data Flow Model



A firing, B firing



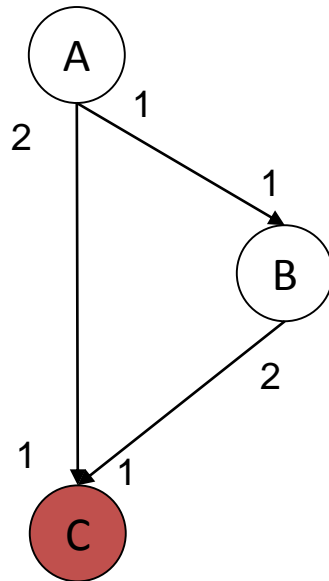
# Synchronous Data Flow Model



A firing, B firing, C firing

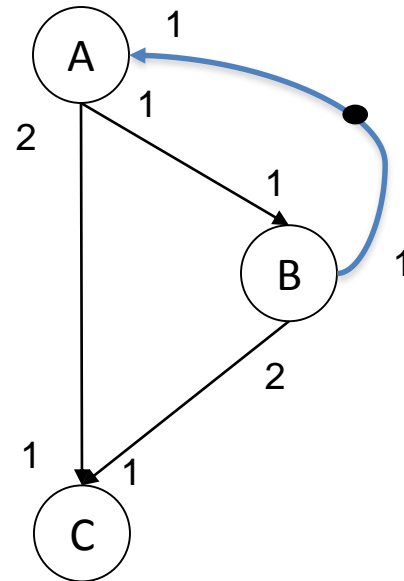


# Synchronous Data Flow Model



A firing, B firing, C firing, C firing

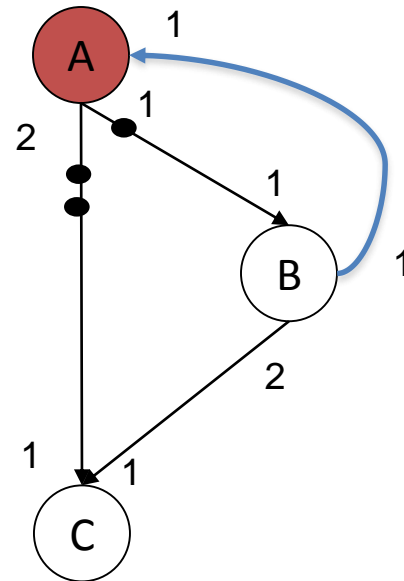
# Synchronous Data Flow Model



SDF with initial token and loop



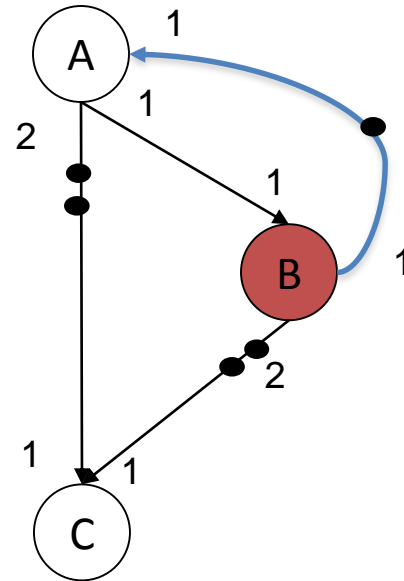
# Synchronous Data Flow Model



A firing



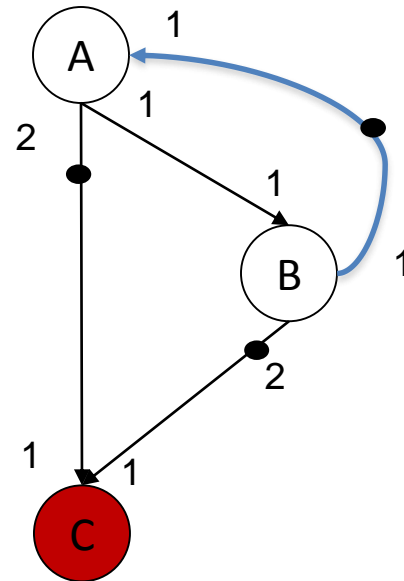
# Synchronous Data Flow Model



A firing, B firing

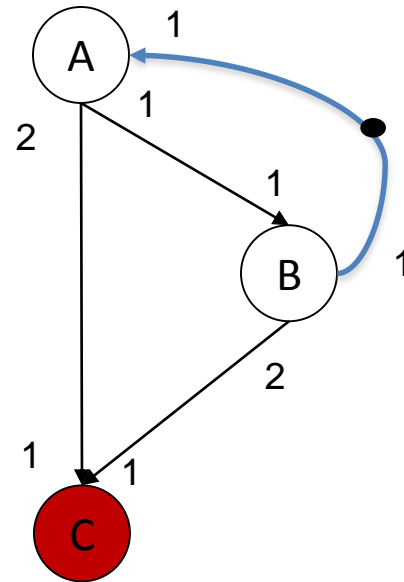


# Synchronous Data Flow Model



A firing, B firing, C firing

# Synchronous Data Flow Model



A firing, B firing, C firing, C firing



# Synchronous Data Flow Model

- Question: Can any SDF graph find a firing sequences that makes the state of the graph no changed?
  - State of the graph means: the tokens on each edge are clean, no more no less.
  - Which leads to SDF Consistency Problem



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- Stream Programming Language
  - Structured SDF in StreamIt
- Apply SDF to Bigdata



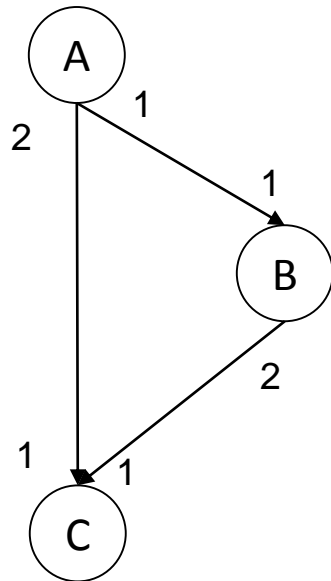


# Periodic Schedule and Consistency

- Firing sequence of a SDF is called a *schedule*
- A *periodic schedule* of an SDF clears all channels and return to its initial status after each node repeats execution a specified finite number of times
- Periodic schedule, permit SDF can process unbounded data with bounded memory
- *A SDF is Consistent* if a periodic schedule exists



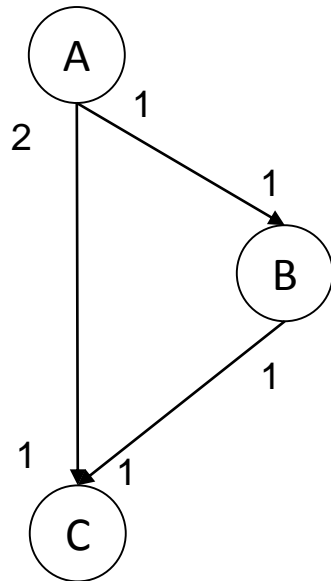
# Periodic Schedule and Consistency



Periodic Schedule: ABCC  
AB2C



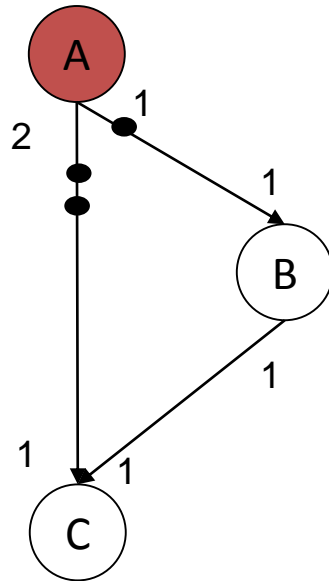
# Periodic Schedule and Consistency



Can you find the periodic schedule?



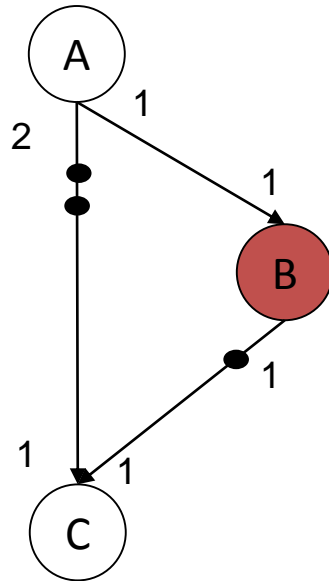
# Periodic Schedule and Consistency



A



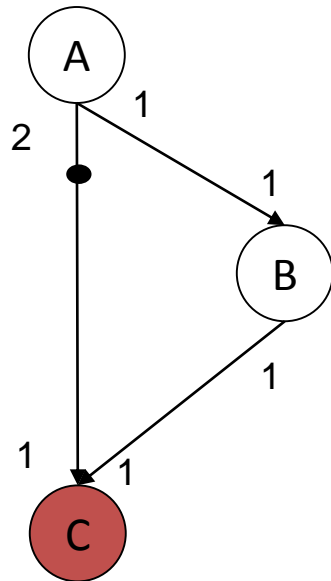
# Periodic Schedule and Consistency



A, B



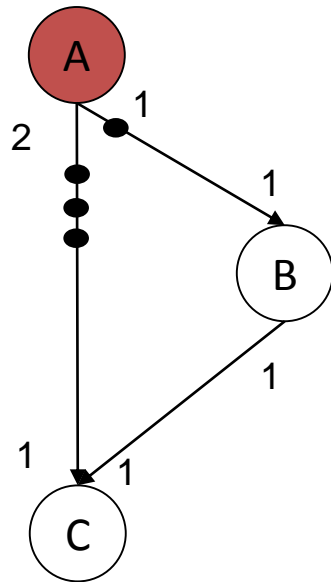
# Periodic Schedule and Consistency



A, B, C



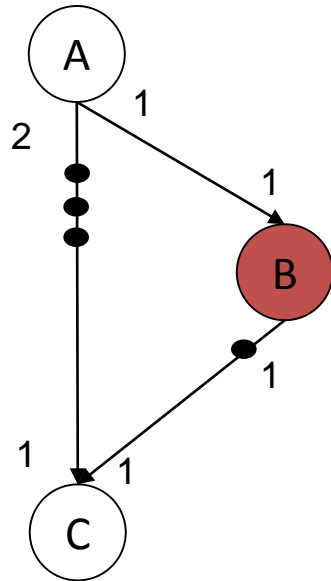
# Periodic Schedule and Consistency



A, B, C, A



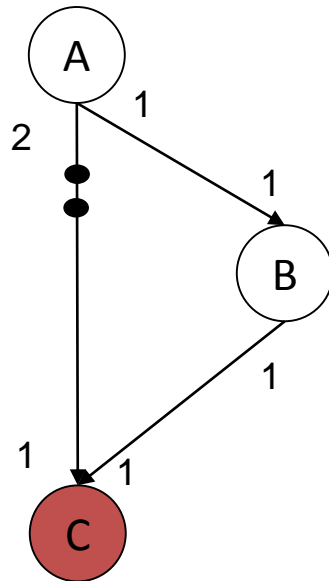
# Periodic Schedule and Consistency



A, B, C, A, B



# Periodic Schedule and Consistency

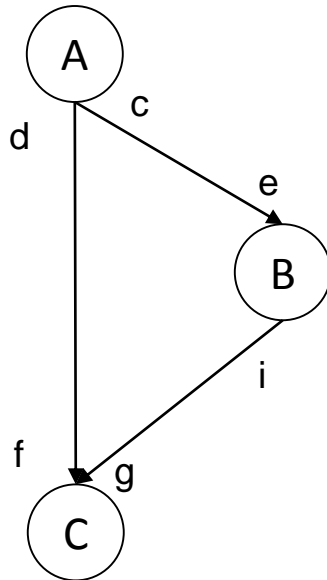


A, B, C, A, B, C

Tokens in channel (A-C) is accumulating  
which makes the channel unbounded

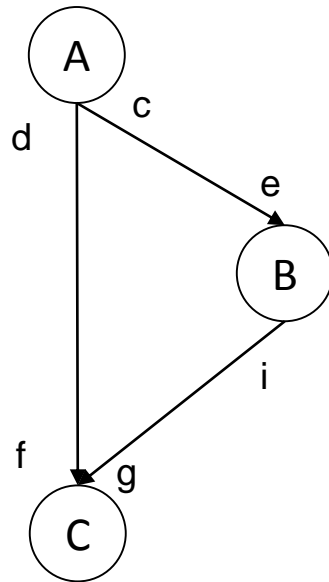
**Inconsistent!**

# Periodic Schedule and Consistency



Problem: Given a general SDF, how can we know it has periodic schedule or not?

# Periodic Schedule and Consistency



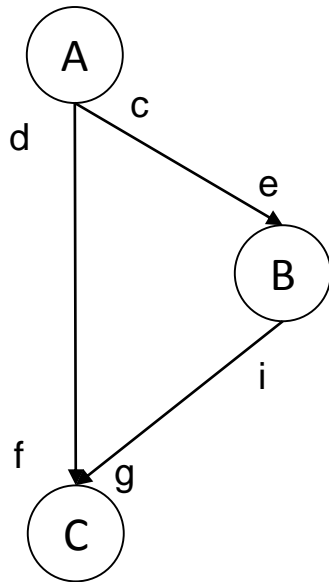
## Topology Matrix

- Each row presents the edge
- Each column presents a node
- $(i, j)$ : the number of data items placed on  $i$  after each invocation of  $j$
- If  $i$  is an input channel for  $j$ , element  $(i, j)$  is negative

$$\begin{array}{ccc} & A & B & C \\ \left( \begin{array}{ccc} c & -e & 0 \\ d & 0 & -f \\ 0 & i & -g \end{array} \right) & \begin{array}{l} A \rightarrow B \\ A \rightarrow C \\ B \rightarrow C \end{array} \end{array}$$



# Periodic Schedule and Consistency



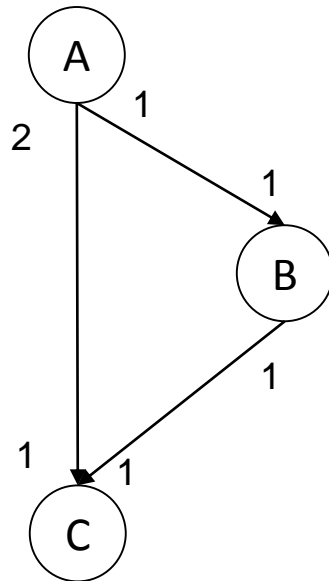
A necessary condition for the existence of a periodic schedule

- the rank of the topology matrix is  $s - 1$ , where  $s$  is the number of nodes
- Proof: please refer to “Lee’s 87 paper: Synchronous Data Flow”

$$\begin{array}{ccc} & A & B & C \\ \left( \begin{array}{ccc} c & -e & 0 \\ d & 0 & -f \\ 0 & i & -g \end{array} \right) & \begin{array}{l} A \rightarrow B \\ A \rightarrow C \\ B \rightarrow C \end{array} \end{array}$$



# Periodic Schedule and Consistency



A necessary condition for the existence of a periodic schedule

- the rank of the topology matrix is  $s - 1$ , where  $s$  is the number of nodes
- Proof: please refer to “Lee’s 87 paper: Synchronous Data Flow”

	A	B	C	
$\begin{pmatrix} 1 & -1 & 0 \\ 2 & 0 & -1 \\ 0 & 1 & -1 \end{pmatrix}$				A→B
				A→C
				B→C

Rank=3 > 2



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# An Stream Example—Average Pairs



```
while ( true ) {  
  int itm = geneDataItem ();  
  push(itm);  
}
```

```
while(inStream.moreData()) {  
  int first=peek(0);  
  int second=peek(1);  
  push ((first+second)/2);  
  pop(0);  
}
```

```
while (inStream .moreData ())  
{  
  print(pop(0));  
}
```



# Average Pairs to Synchronous Dataflow Graph



Extend the SDF to support “peek” sematic





# Average Pairs to Synchronous Dataflow Graph





# Average Pairs to Synchronous Dataflow Graph





# Average Pairs to Synchronous Dataflow Graph





# Average Pairs to Synchronous Dataflow Graph





# Average Pairs to Synchronous Dataflow Graph

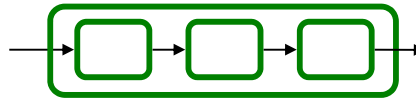


# Structured SDF In StreamIt

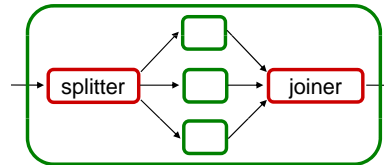
- Filter



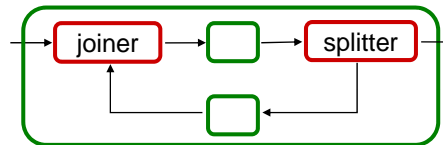
- Pipeline



- Split-Join



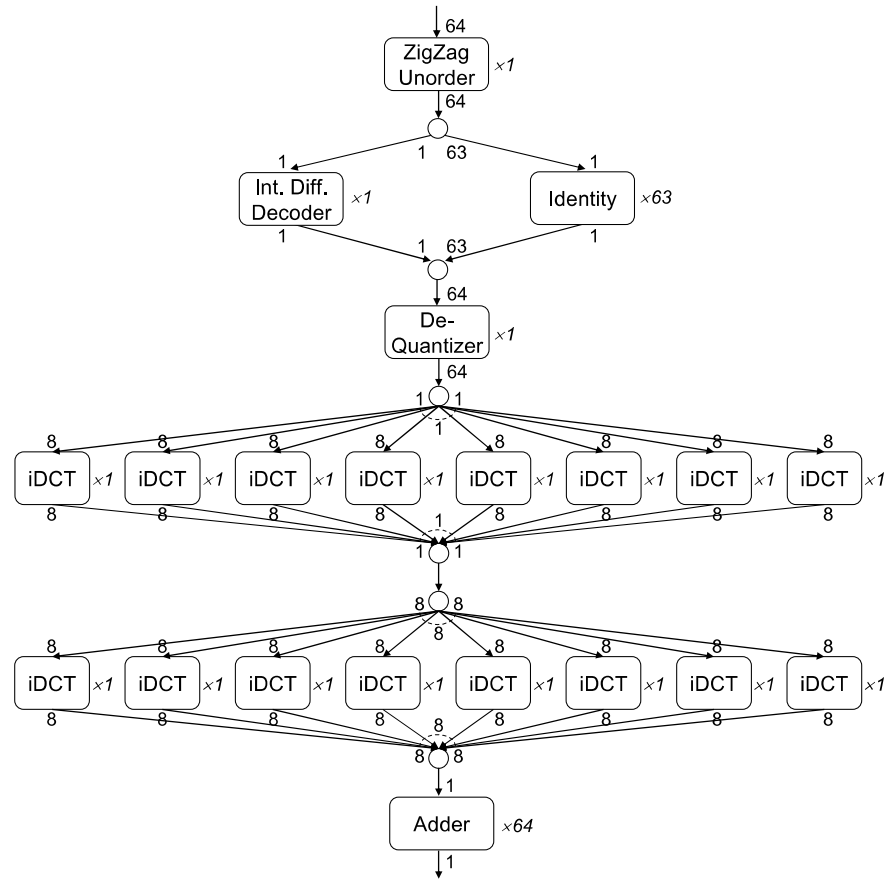
- Feedback Loop



Courtesy by: PACT 2010 paper of streamit: "An Empirical Characterization of Stream Programs and its Implications for Language and Compiler Design "



# Part of JPEG transcoder



Courtesy by: PACT 2010 paper of streamit: "An Empirical Characterization of Stream Programs and its Implications for Language and Compiler Design "



## Weakness of SDF

- Does not support condition (branch)
- Does not support recursion—because it is a static dataflow model
- But still the model is used widely in many application fields





## Some Projects Based on SDF model

- Early Ptolemy Project at UC Berkeley
  - Software Synthesis for Embedded system
- StreamIt at MIT
  - streaming program language and compiler
- InforStream and SPL
  - IBM streaming computing product
- Our work COStream
  - hierarchical data flow programming language and compiler
- OpenStream
  - language and compiler support for streaming in OpenMP



# Homework

- Write a Fibonacci number generator using Synchronous Data Flow Model
  - Pseudo code for each node in SDF using “peek, push and pop” statements
  - Push Token: PPT animation to show how the tokens flow in SDF graph
  - Periodic Schedule of the SDF



## Reference

[1] Early Ptolemy Project at UC Berkeley

– <http://ptolemy.eecs.berkeley.edu/projects/index.htm>

[2] StreamIt at MIT

– <http://groups.csail.mit.edu/cag/streamit/>

[3] InforStream and SPL

– <http://www-03.ibm.com/software/products/en/infosphere-streams>

[4] COStream

– <http://www.capsl.udel.edu/pub/doc/papers/dfm12.pdf>

[5] OpenStream

– <http://openstream.info/>