ESE535: Electronic Design Automation

Day 8: February 11, 2009
Dataflow

Previously

- Behavioral model (C)
  - Based on sequential semantics
    - Control flow semantics
- Scheduling of concurrent operations

Control Flow Model

- Can extract some parallelism
  - "Instruction"-level parallelism within basic block (hyperblock)
- Must sequentialize blocks
  - Only one block run at a time
  - Limited Parallelism

Want to see

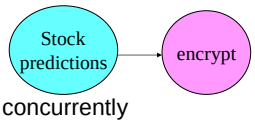
- There are other compute models
  - More natural for parallelism/hardware

Today

- Dataflow
- SDF
  - Single rate
  - Multirate
- Dynamic Dataflow
- Expression

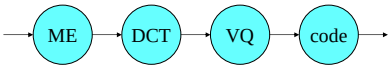
Parallelism Motivation

Producer-Consumer Parallelism



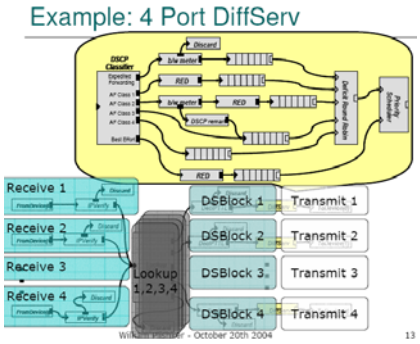
- Can run concurrently
- Just let consumer know when producer sending data
- Not described well in C
  - How put encryption tasks in same basic-block as prediction code?
    - Would prefer to develop separately
  - Tasks run own threads of control
    - Synchronize on data transfer

Pipeline Parallelism

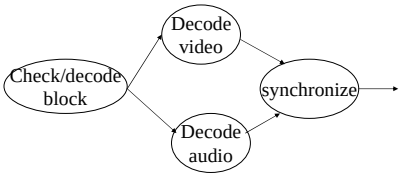


- Can potentially all run in parallel
- Like physical pipeline
- Useful to think about **stream** of data between operators

Plishker Task Example

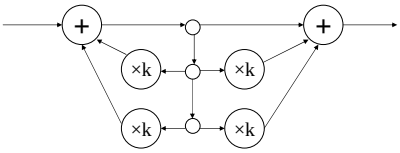


DAG Parallelism



- Doesn't need to be linear pipeline
- Synchronize inputs

Graphs with Feedback



- In general may hold state
- Very natural for many tasks

Definitions

Dataflow / Control Flow

Dataflow

- Program is a graph of operators
- Operator consumes **tokens** and produces tokens
- All operators run concurrently

Control flow

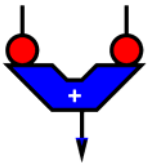
- Program is a sequence of operations
- Operator reads inputs and writes outputs into common store
- One operator runs at a time
  - Defines successor

Token

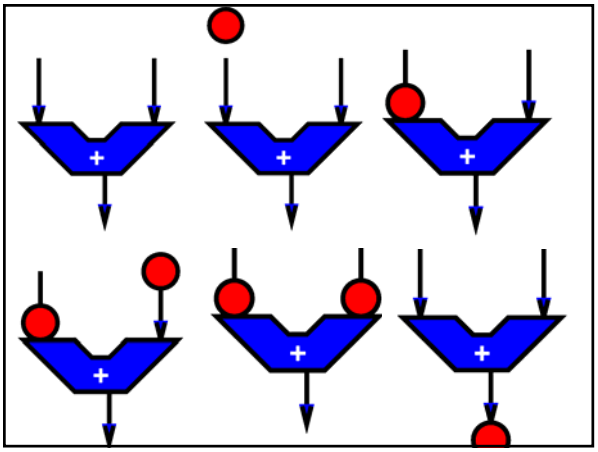
- Data value with presence indication
  - May be conceptual
    - Only exist in high-level model
    - Not kept around at runtime
  - Or may be physically represented
    - One bit represents presence/absence of data
    - Data comes in packets

Operator

- Takes in one or more inputs
- Computes on the inputs
- Produces a result

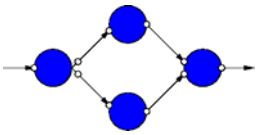


- Logically self-timed
  - "Fires" only when input set present
  - Signals availability of output

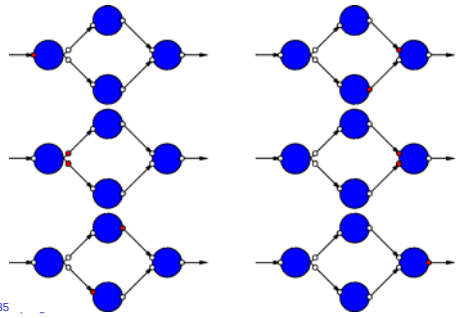


Dataflow Graph

- Represents
  - computation sub-blocks
  - linkage
- Abstractly
  - controlled by data presence



Dataflow Graph Example



Stream

- Logical abstraction of a persistent point-to-point communication link
  - Has a (single) source and sink
  - Carries data presence / flow control
  - Provides in-order (FIFO) delivery of data from source to sink

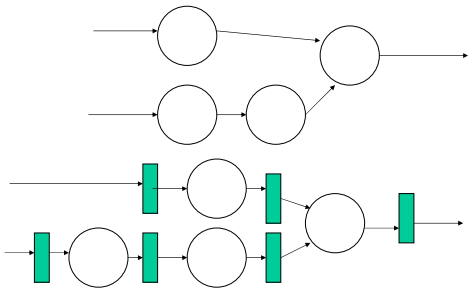
Streams

- Captures communications structure
  - Explicit producer→consumer link up
- Abstract communications
  - Physical resources or implementation
  - Delay from source to sink

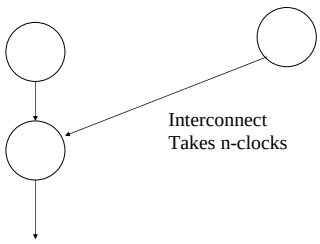
Dataflow Abstracts Timing

- Doesn't say
  - on which cycle calculation occurs
- Does say
  - What order operations occur in
  - How data interacts
    - i.e. which inputs get mixed together
- Permits
  - Scheduling on different # of resources
  - Operators with variable delay
  - Variable delay in interconnect

Difference: Dataflow Graph/Pipeline



Clock Independent Semantics



Semantics

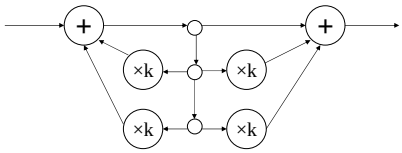
- Need to implement semantics
  - *i.e.* get same result as if computed as indicated
- But can implement any way we want
  - That preserves the semantics

Dataflow Variants

Synchronous Dataflow

- Particular, restricted form of dataflow
- Each operator
  - Consumes a fixed number of input tokens
  - Produces a fixed number of output tokens
  - When full set of inputs are available
    - Can produce output
  - Can fire any (all) operators with inputs available at any point in time

Synchronous Dataflow

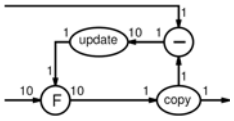


SDF: Execution Semantics

while (true)
  Pick up any operator
  If operator has full set of inputs
    Compute operator
    Produce outputs
    Send outputs to consumers

Multirate Synchronous Dataflow

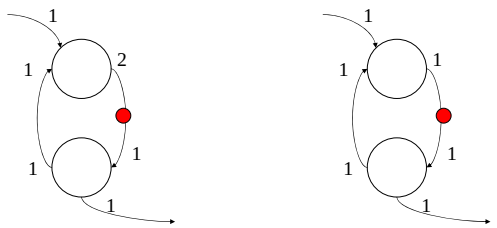
- Rates can be different
  - Allow lower frequency operations
  - Communicates rates to CAD
    - Something not clear in RTL
    - Use in scheduling, provisioning
  - Rates must be constant



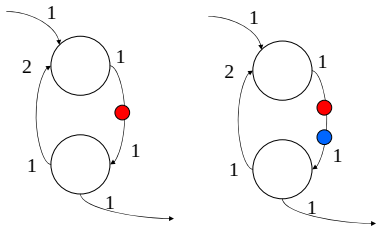
SDF

- Can validate flows to check legal
  - Like KCL → token flow must be conserved
  - No node should
    - be starved of tokens
    - Collect tokens
- Schedule onto processing elements
  - Provisioning of operators
- Provide real-time guarantees
- Simulink is SDF model

SDF: good/bad graphs



SDF: good/bad graphs

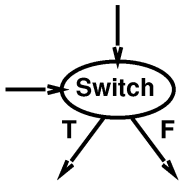


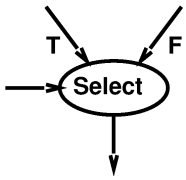
Dynamic Rates?

- When might static rates be limiting?
  - Compress/decompress
    - Lossless
    - Even Run-Length-Encoding
  - Filtering
    - Discard all packets from geraldo
  - Anything data dependent

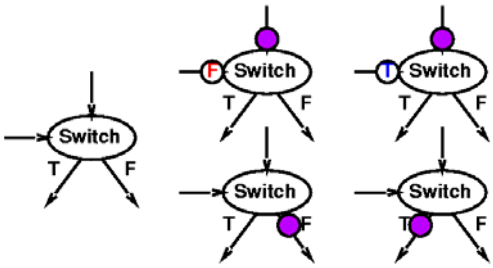
Data Dependence

- Add Two Operators
  - Switch
  - Select

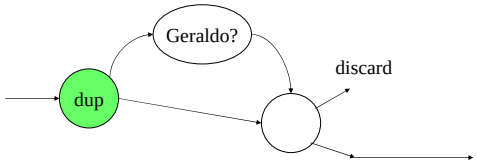




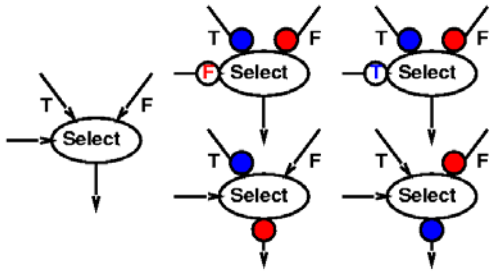
Switch



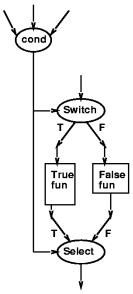
Filtering Example



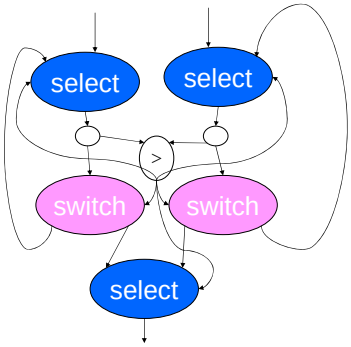
Select



Constructing If-Then-Else



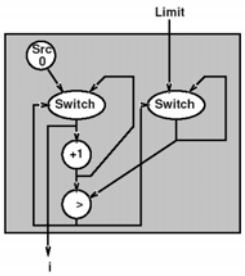
Select Example



In-Order Merge of Streams

Looping

- For (i=0;i<Limit;i++)



Dynamic Challenges

- In general, cannot say
  - If a graph is well formed
    - Will not deadlock
  - How many tokens may have to buffer in stream
  - Right proportion of operators for computation

Expression

Expression

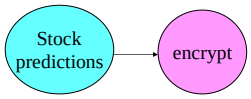
- Could express operators in C/Java
  - Each is own thread
- Link together with Streams
- *E.g.* SystemC

C Example

```
while (!(eos(stream_a) && !(eos(stream_b))
    A=stream_a.read();
    B=stream_b.read();
    Out=(a+b)*(a-b);
    stream_out.write(Out);
```


Connecting up Dataflow

```
stream stream1=new stream();
operator prod=new stock(stream1);
operator cons=new encrypt(stream1);
```



Summary

- Dataflow Models
  - Simple pipelines
  - DAGs
  - SDF (single, multi)-rate
  - Dynamic Dataflow
- Allow
  - express parallelism
  - freedom of implementation

Admin

- Reading
  - Monday online
- Assignment 2A due Monday

Big Ideas:

- Dataflow
  - Natural model for capturing computations
  - Communicates useful information for optimization
    - Linkage, operator usage rates
- Abstract representations
  - Leave freedom to implementation