Data Flow Graphs Intro

Sources: Gang Quan

Computational Models

- What:
  - A conceptual notion for expressing the function of a system
    - E.g. DFG, FSM, Petri net, Turing machine, etc.
- Computational Models & Languages
  - Models express the behavior, languages capture models
  - Models are conceptual, languages are concrete
- What is in a computational model
  - A set of objects
  - Rules
  - Semantics

Data Flow Graph (DFG)

- A modem communications system

  - Each box is a single function or sub systems
  - The activity of each block in the chain depends on the input of the previous block
  - Data driven
    - Each functional block may have to wait until it receives a "certain amount" of information before it begins processing
    - Some place to output the results

Data Flow Graph

- Definition
  - A directed graph that shows the data dependencies between a number of functions
  - G=(V,E)
    - Nodes (V): each node having input/output data ports
    - Arces (E): connections between the output ports and input ports
  - Semantics
    - Fire when input data are ready
    - Consume data from input ports and produce data to its output ports
    - There may be many nodes that are ready to fire at a given time

Data Flow Graph Construction

$$x_1 = \frac{-b + \sqrt{b^2 - 4ac}}{2a}$$

$$x_2 = \frac{-b - \sqrt{b^2 - 4ac}}{2a}$$

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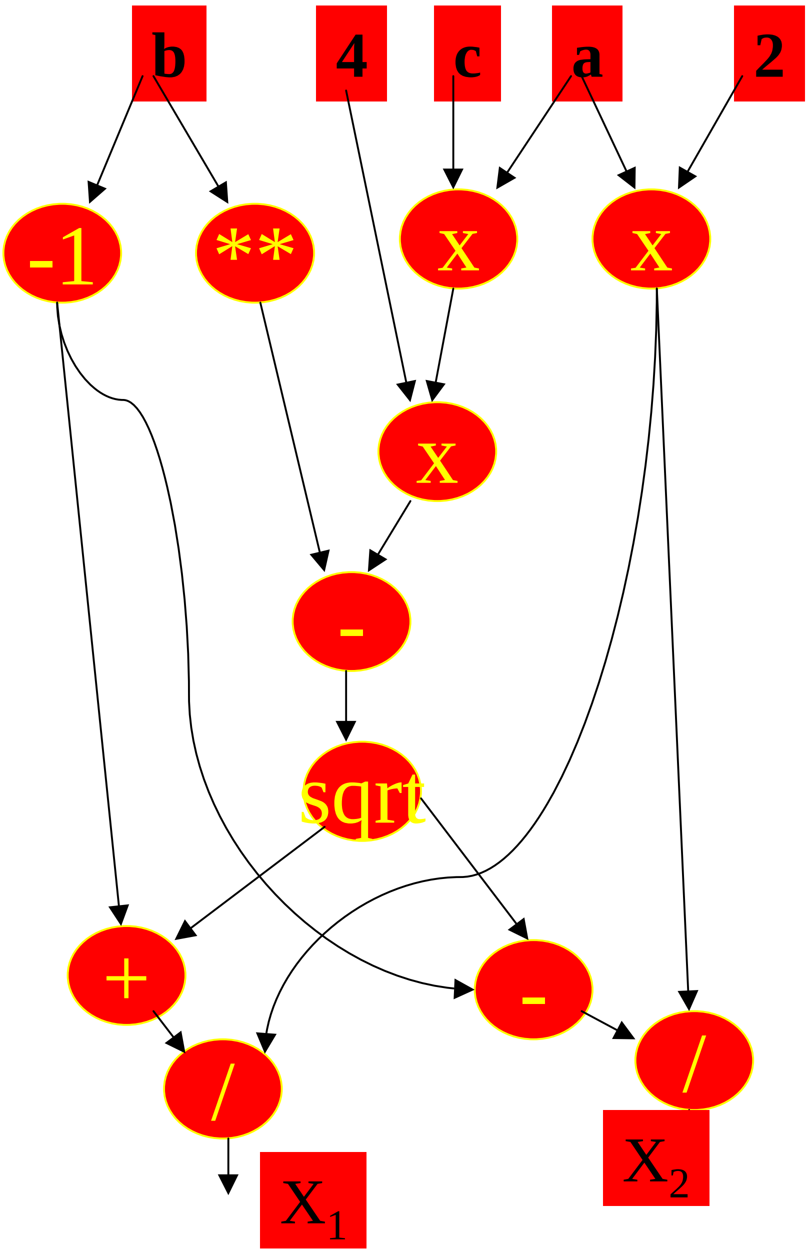
$$x_2 = \frac{-b - \sqrt{b^2 - 4ac}}{2a}$$



Data flow graph construction

original code:

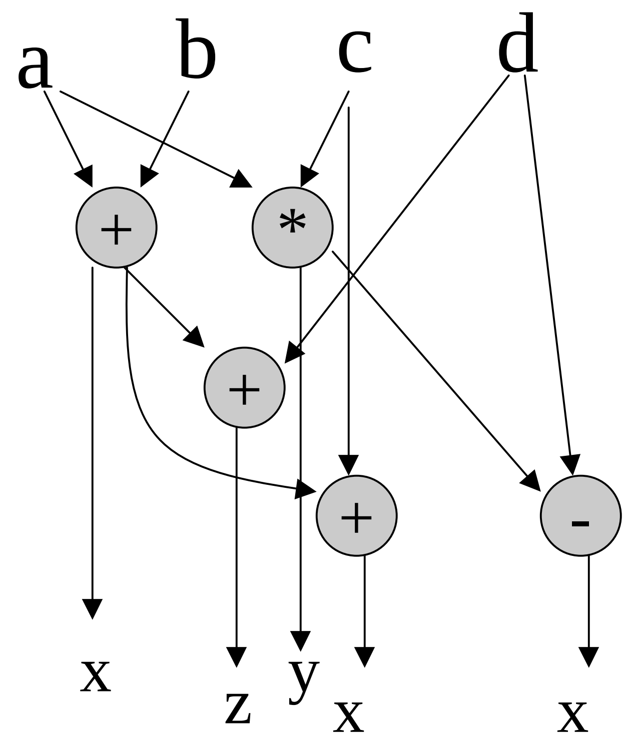
x <= a + b;

y <= a * c;

z <= x + d;

x <= y - d;

x <= x + c;



Data flow graph construction

original code:

```
x <= a + b;
y <= a * c;
z <= x + d;
x <= y - d;
x <= x + c;
```

single-assignment form:

```
x1 <= a + b;
y <= a * c;
z <= x1 + d;
x2 <= y - d;
x3 <= x2 + c;
```

Data flow graph construction

single-assignment form:

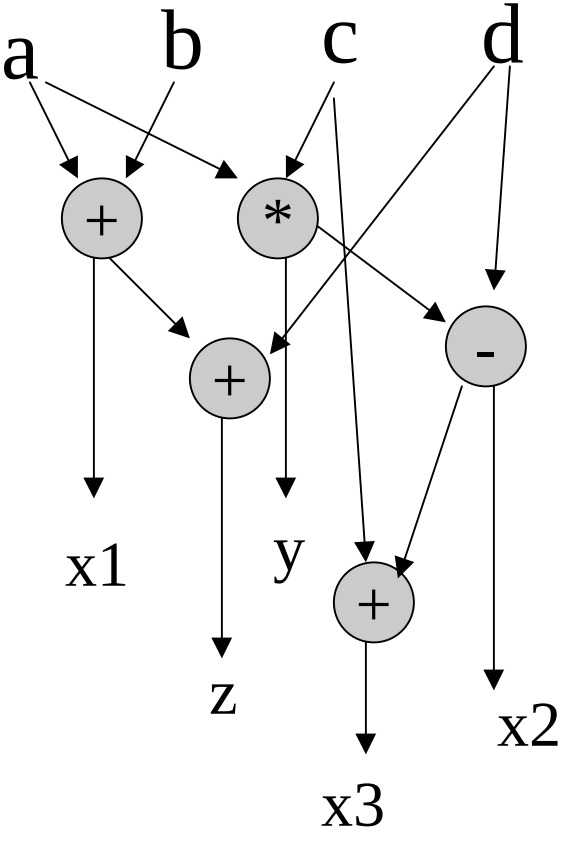
x1 <= a + b;

y <= a * c;

z <= x1 + d;

x2 <= y - d;

x3 <= x2 + c;



Design Issues

- Allocating
- Mapping
- Schedule
- Memory management
- Construction and usage of the queues

Goals

- Guarantee correct behavior
- Utilize hardware efficiently.
- Obtain acceptable performance.

Allocation

- Decide the numbers and types of different functional units
  - E.g. register allocation

```
….
x <= a + b;
y <= a + c;
x <= x - c;
….
….x …
….y….
```

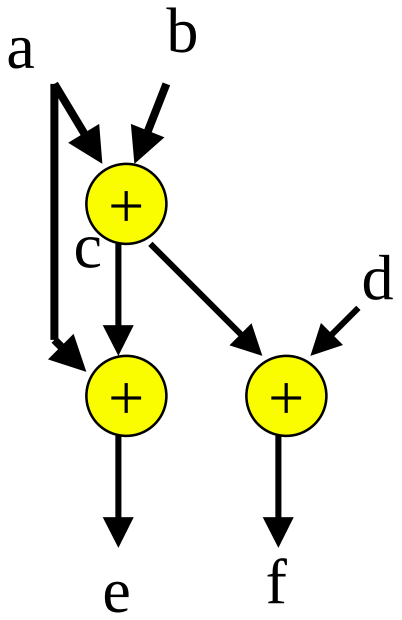
three registers

```
….
x <= a + b;
y <= a + c;
x <= x - c;
….
….x …
….y….
```

Mapping

- Distributing nodes to different functional units on which they will fire
  - Functional units may provide different functions
    - Adder or ALU, MUX or buses, etc
  - Functional units may have different delay
    - Ripple adder or look ahead adder
  - Determines area, cycle time.

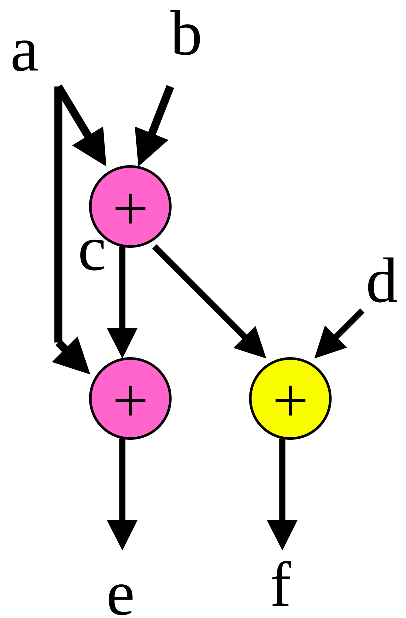
A Mapping Example

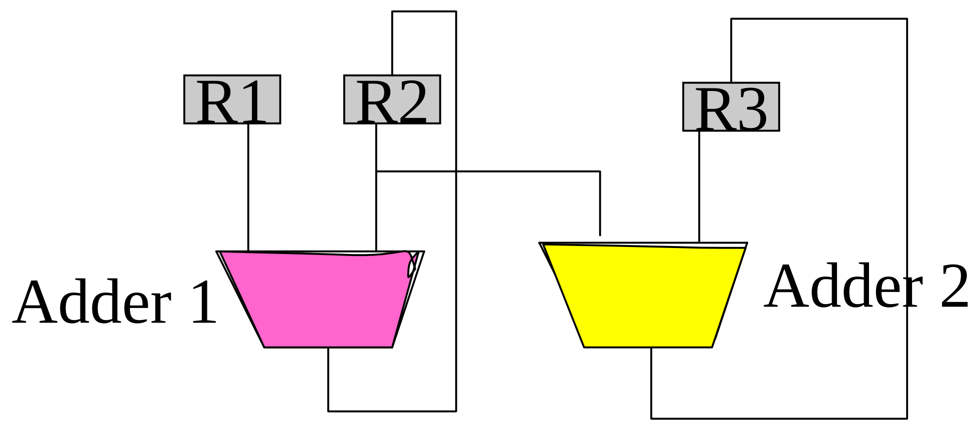


Subject to:

- Two adders
- Four registers
- b and e cannot be assigned to the same register

A Mapping Example





Subject to:

- **Two adders**
- **Three registers**
- **a and e cannot be assigned to the same register**

R1: a

R2: b, c, e

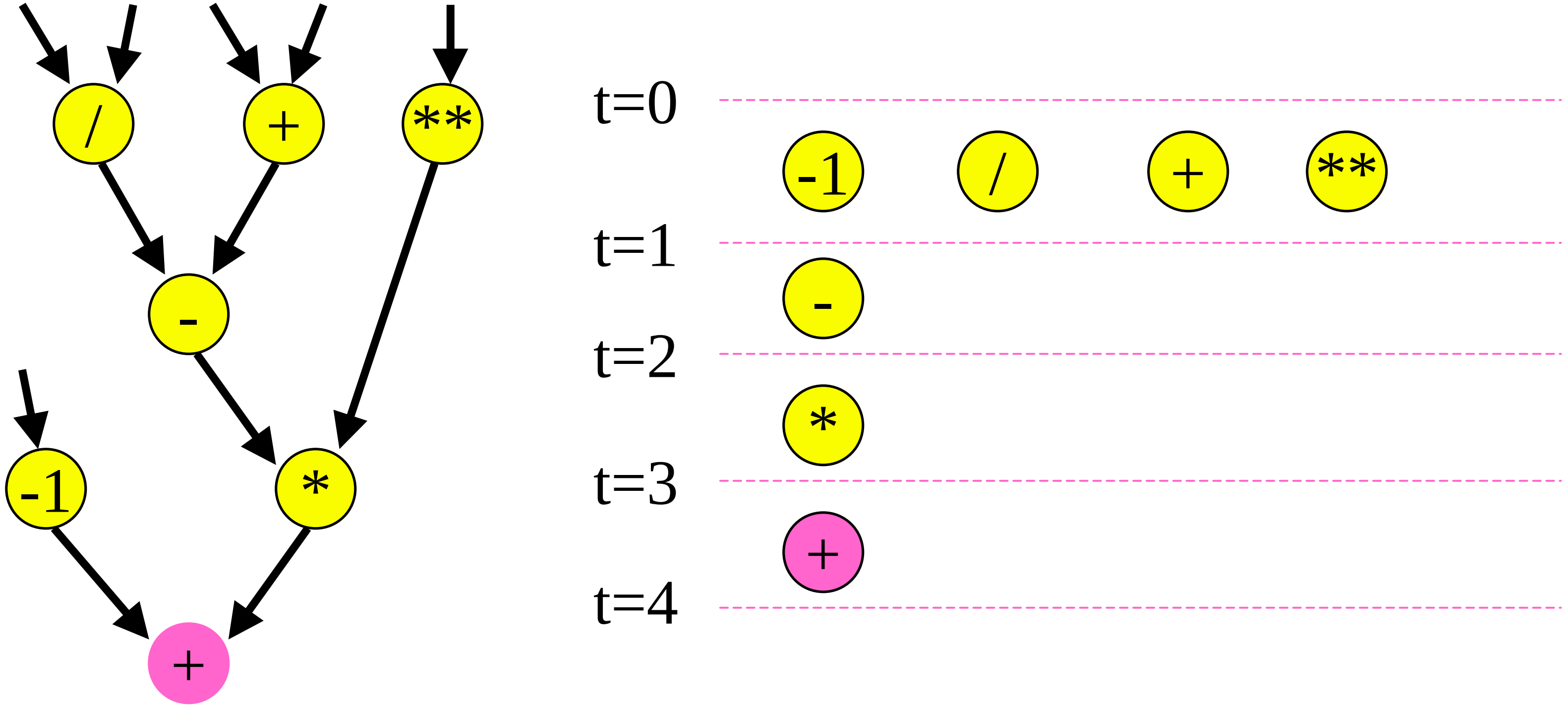
R3: d, f

Mapping may not be unique !

Scheduling of DFG

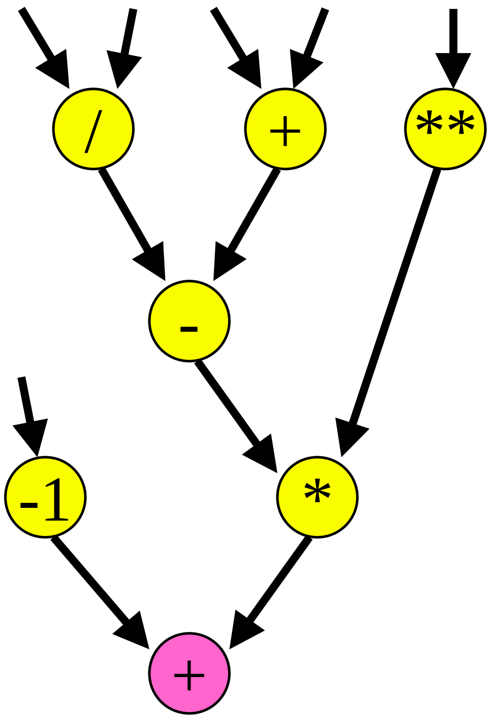
- Schedule
  - Creating the sequence in which nodes fire
  - Determines number of clock cycles required
- Two simple schedules:
  - As-soon-as-possible (ASAP) schedule puts every operation as early in time as possible
  - As-late-as-possible (ALAP) schedule puts every operation as late in schedule as possible

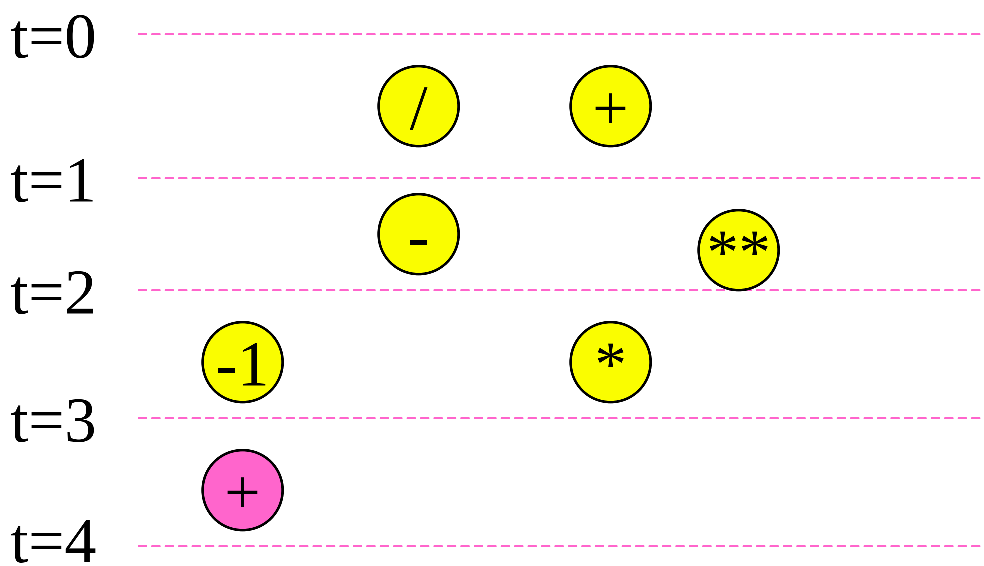
ASAP



Nodes fire whenever the input data are available.

ALAP





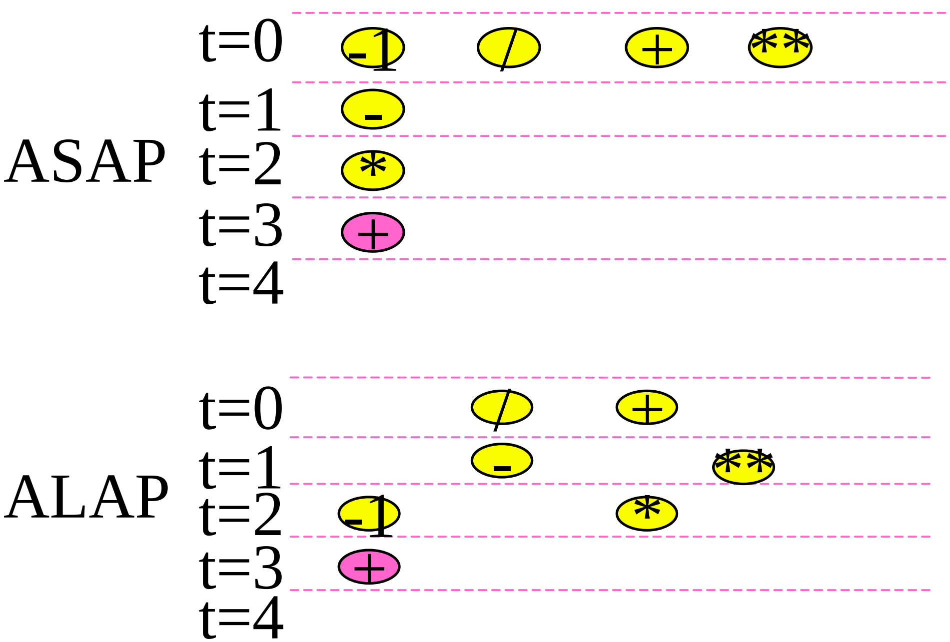
Nodes fire when absolutely necessary.

More about ASAP and ALAP

- Unlimited resources
  - No limit for the number of registers, adders, etc
- Longest path through data flow determines minimum schedule length
- Mobility
  - $t_L - t_S$

Mobility

- $u = t_L - t_S$



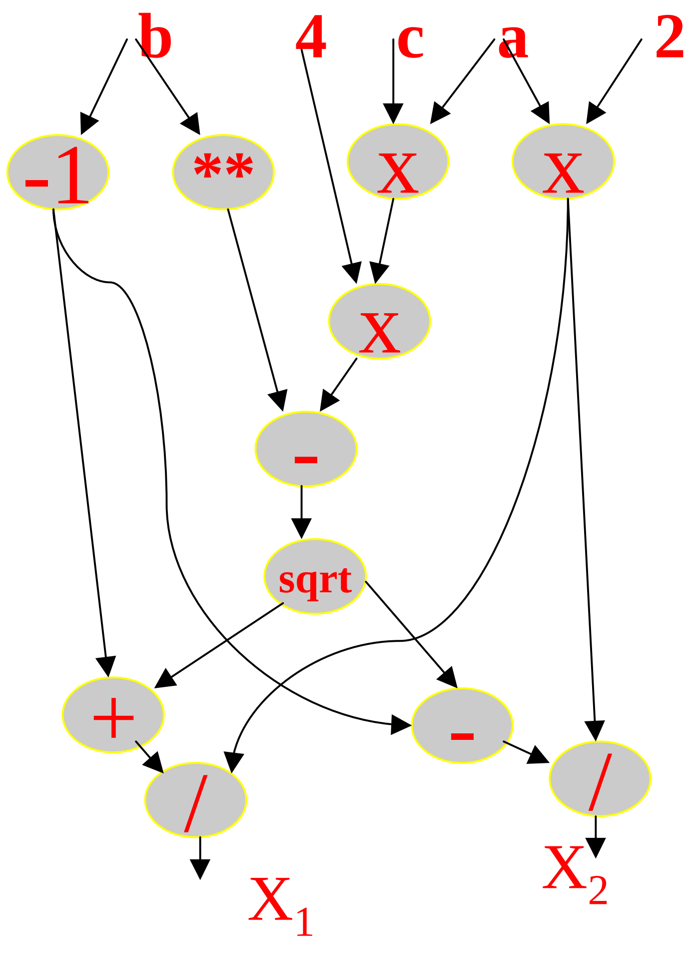
Node	u
+	0
/	0
-	0
**	1
*	0
-1	2
+	0

The node mobility represents its flexibility in the fire sequence.

Restrained Scheduling

- Time constraints
  - Time is given, minimize the resource
- Resource constraints
- NP problem

Time Constraints

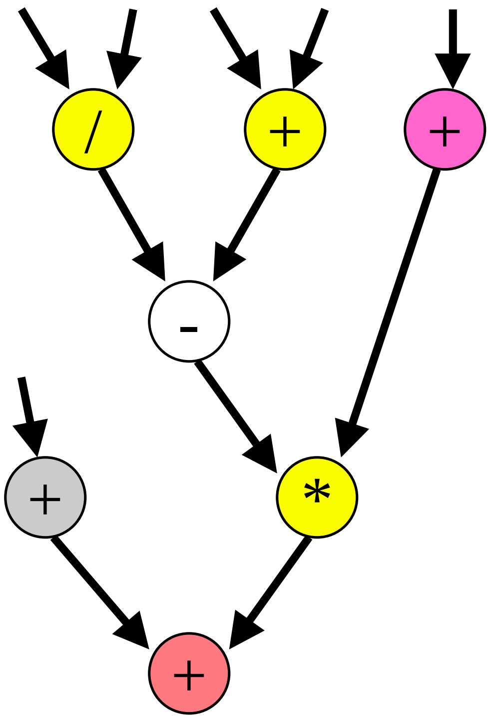


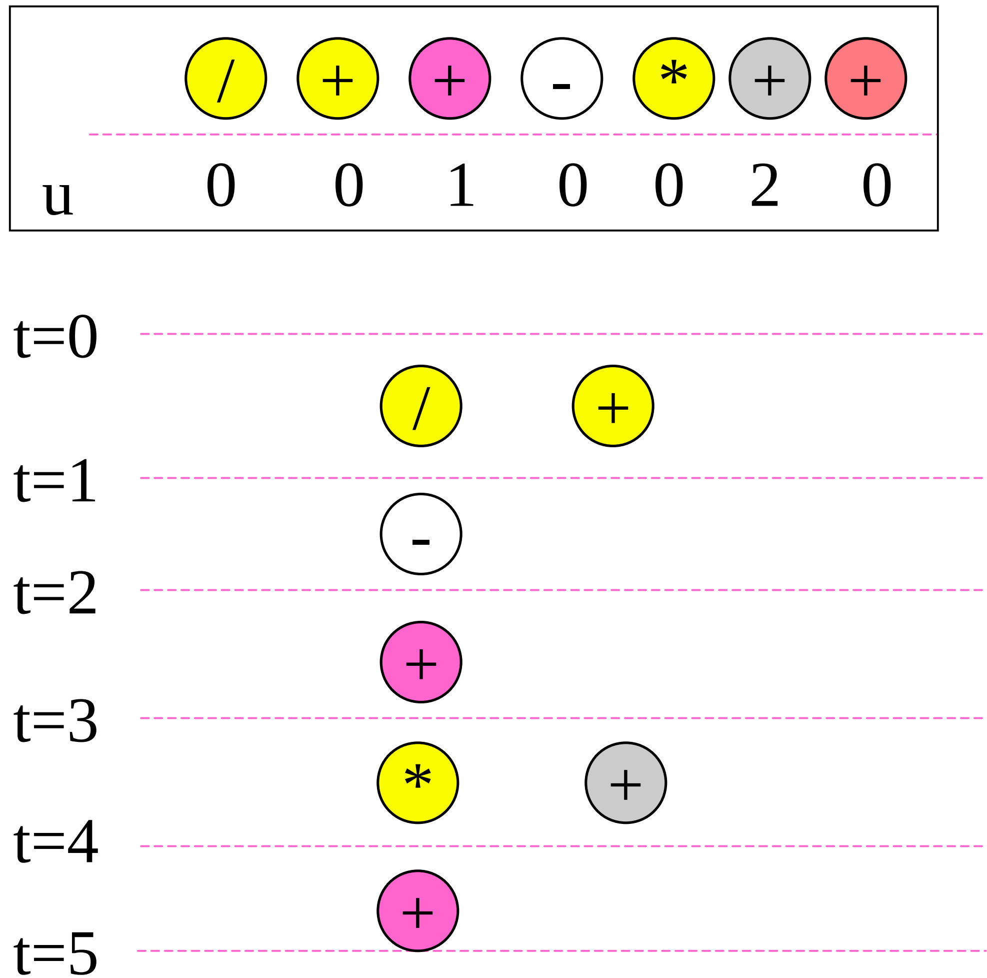
T	6	7	8
+/-	2	1	1
*//	2	2	1
**	1	1	1
sqrt	1	1	1
-1	1	1	1

Resource Constraints

- Resource is given, minimize the long time
- List based scheduling
  - Maintain a priority based ready list
    - The priority can be decide by mobility for example
  - Fire the nodes according to their priorities until all the resource are used in that stage

List Based Scheduling





S.t: one +/-, one */

List Based Scheduling

- A general ASAP
- Priority based ready list

Control/Data Flow Graph (CDFG)

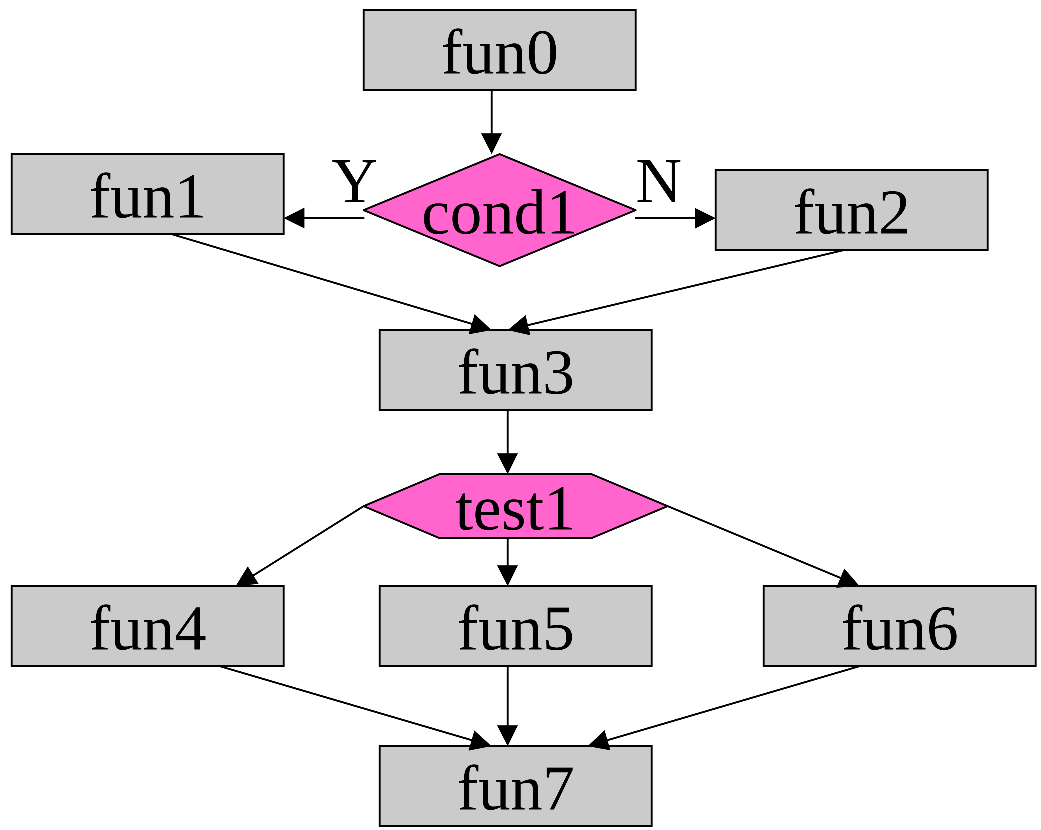
```
x <= a + b;
if ( x > 100)
   y <= a * c;
else
   y <= a + c;
endif
```

Control/Data Flow Graph

- Definition
  - A directed graph that represents the control dependencies among the functions
    - **branch**
    - **fall-through**
  - G=(V,E)
    - Nodes (V)
      - Encapsulated DFG
      - Decision
    - Arces (E)
      - flow of the controls

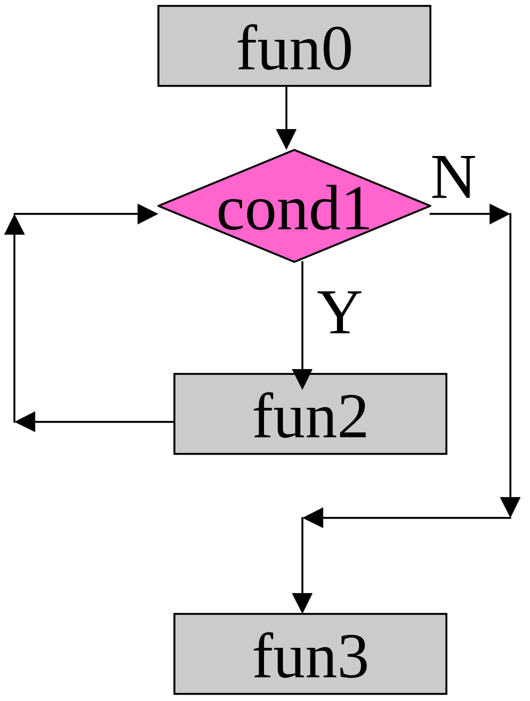
CDFG Example

```
fun0();
if (cond1) fun1();
else fun2();
fun3();
switch(test1) {
case 1: fun4();
    break;
case 2: fun5();
    break;
case 3: fun6();
    break;
}
fun7();
```



CDFG Example

```
fun0();
while(cond1) {
  fun1();
}
fun2();
```



Design Issues

- Code optimization
  - Loop optimization, dead code detection
- Register allocation

Summary

- Data Flow Graph (DFG)
  - models data dependencies.
  - Does not require that nodes be fired in a particular order.
  - Models operations in the functional model—no conditionals.
  - Allocation and Mapping
  - Scheduling – ASAP, ALAP, List-based scheduling
- Control/Data Flow Graph
  - Represents control dependencies