High Level Synthesis

Virendra Singh

Computer Architecture and Dependable Systems Lab

Department of Electrical Engineering

Indian Institute of Technology Bombay

http://www.ee.iitb.ac.in/~viren/

E-mail: viren@ee.iitb.ac.in

EE-677: Foundations of VLSI CAD

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CADSL

Architectural Synthesis

Architectural Level Abstraction

- Datapath
- Controller

Architectural Synthesis

- Constructing the macroscopic structure of a digital circuit starting from behavioural models that can be captured from Data flow or Sequencing Graph

Architectural Synthesis

Computation: Differential Equation Solver

xl = x + dx

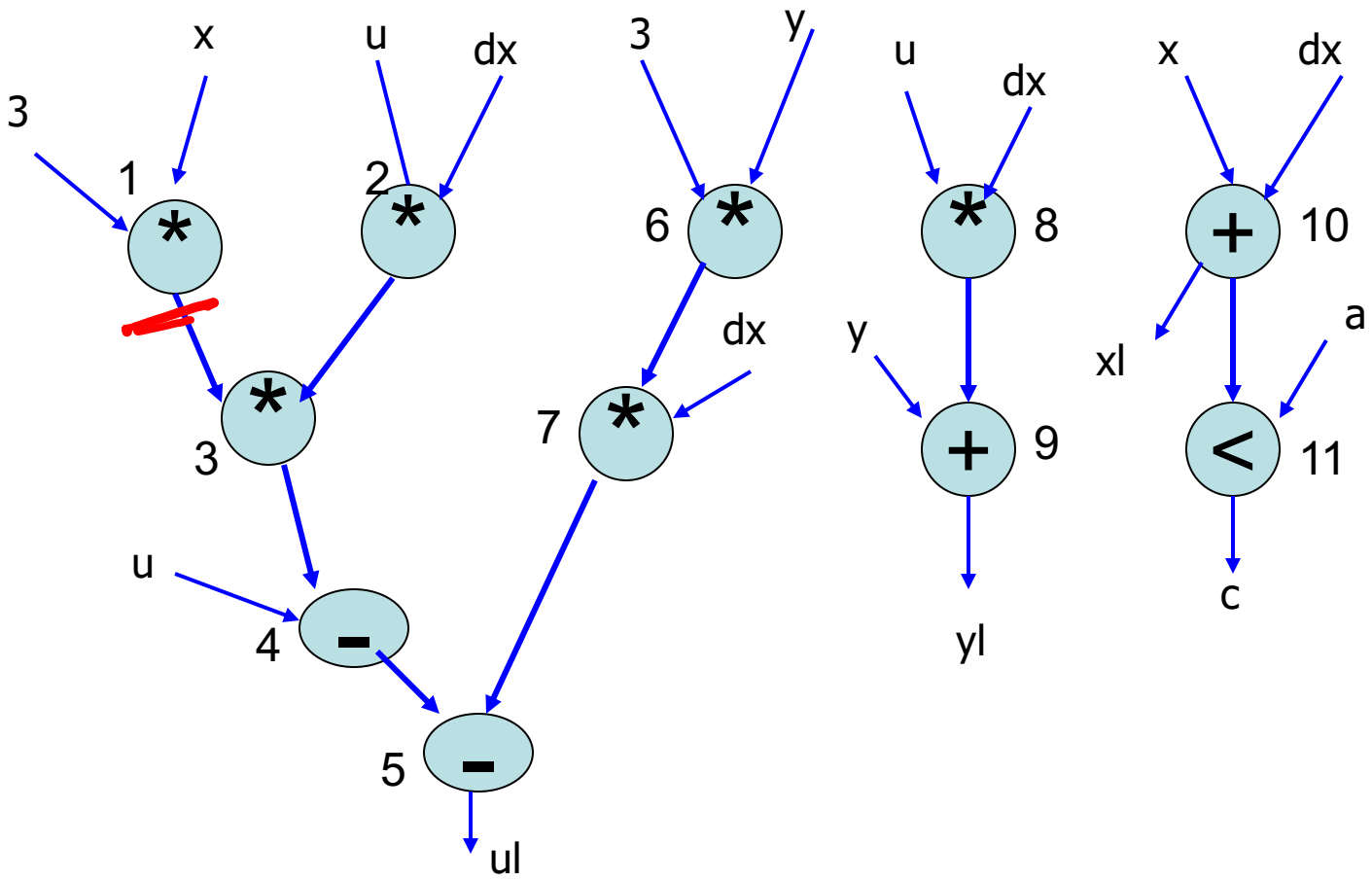
ul = u – (3*x*u*dx) – (3*y*dx)

yl = y + (u*dx);

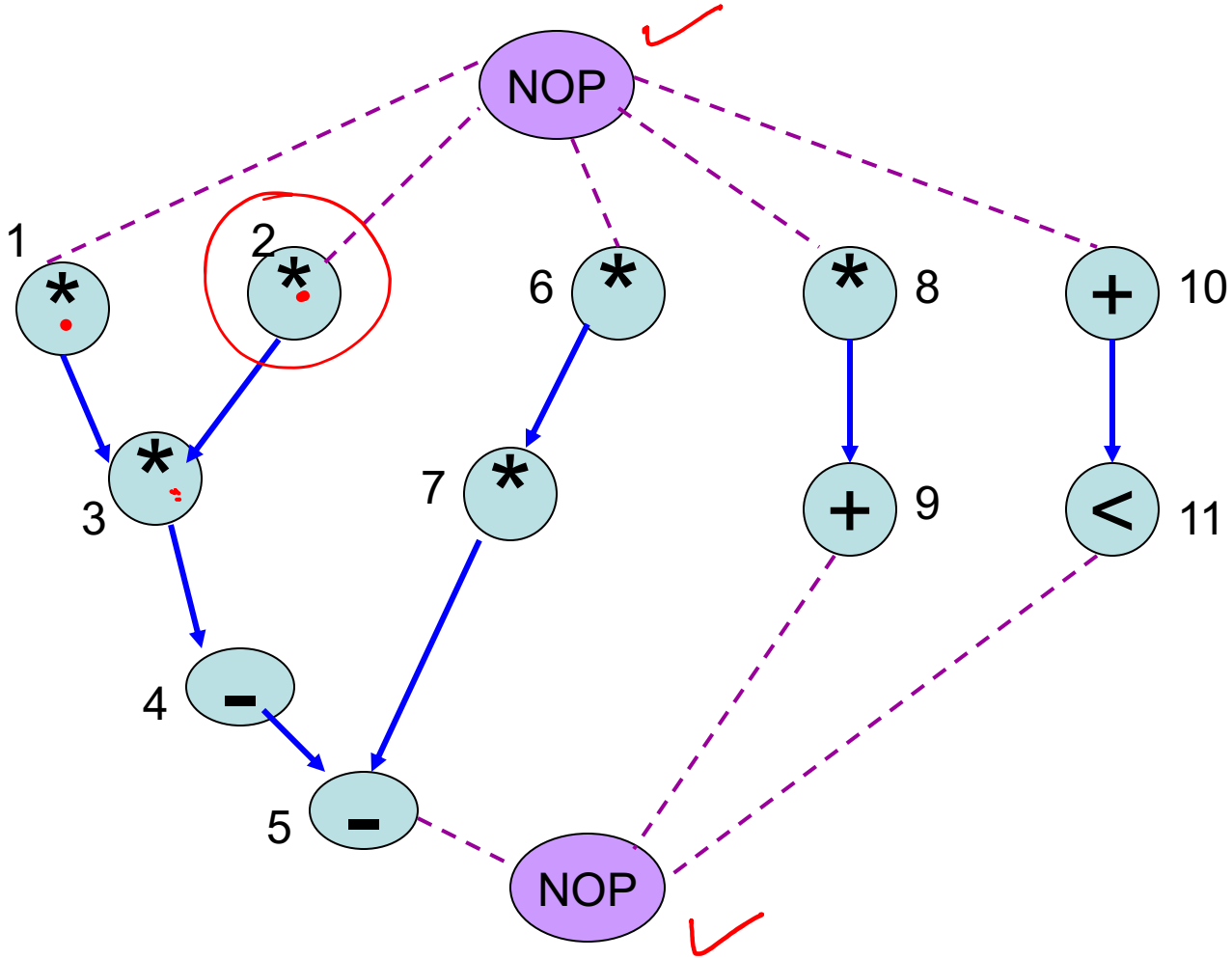
c = xl < a

Data Flow Graph (DFG): represent operation and data dependencies

Data Flow Graph



Sequencing Graph



Architectural Synthesis

Architectural Synthesis and optimization consists of two stages

1. Placing the operation in time and in space, i.e., determining their time interval of execution and binding to resources
2. Determining detailed interconnection of the datapath and the logic-level specifications of the control unit

Temporal Domain: Scheduling

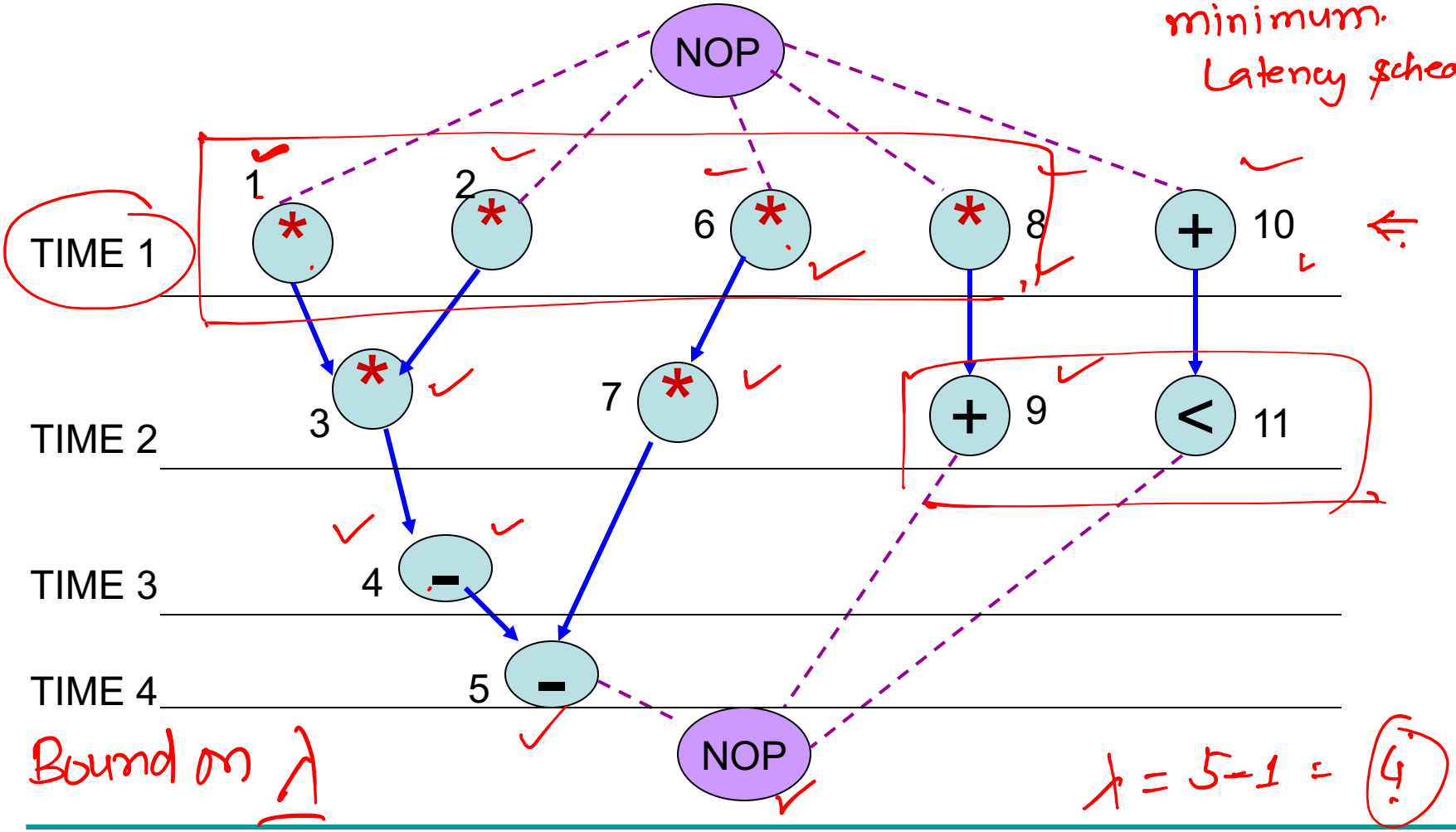
Delay **D** = $\{d_i; i = 0,1, 2, \ldots. n\}$

Start time T =$\{t_i; i= 0, 1, \ldots., n)$

Scheduling: Task of determining the start timing, subject to preceding constraints specified by sequencing graph

Latency $\lambda = t_n - t_0$

ASAP Scheduling



ASAP Scheduling

ASAP($G_s(V,E)$){

Schedule v_0 by setting $t_0^s = 1$;

repeat{

select vertex v_i whose predecessors are all scheduled;

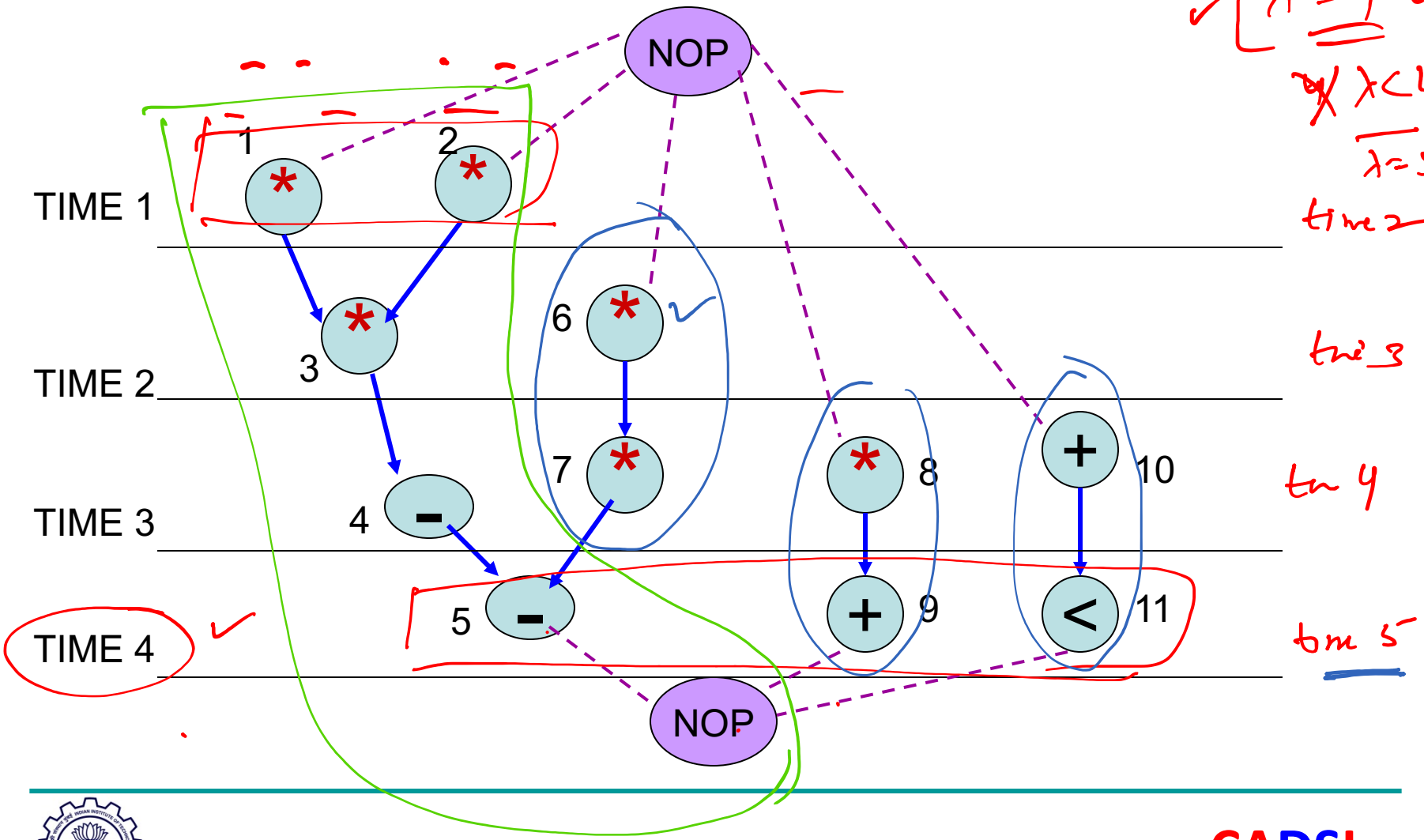
schedule v_i by setting $t_i^s = \max\{t_j^s + d_j\}$

} untill (v_n is scheduled)

return (t^s);

}

ALAP Scheduling



ALAP Scheduling

ALAP($G_s(V,E)$, λ){

Schedule v_n by setting $t_n^L = \lambda$;

repeat{

select vertex v_i whose successors are all scheduled;

schedule v_i by setting $t_i^L = \min\{t_j^L - d_j\}$

} untill (v_0 is scheduled)

return (t^L);

}

Scheduling with Resource Constraint

Scheduling under resource constraints

- computing area/latency trade-off points

Problems

- Intractable problem
- Area-performance trade-off points are affected by the other factors - non-resource dominated circuits

Optimization → min $(\alpha \cdot \text{latency} + \beta \cdot \text{area})$, $\alpha+\beta=1$.

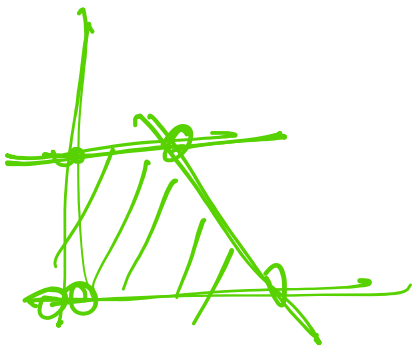
Area / Latency

Integer Linear Programming (ILP)

linear → $\min f(x)$

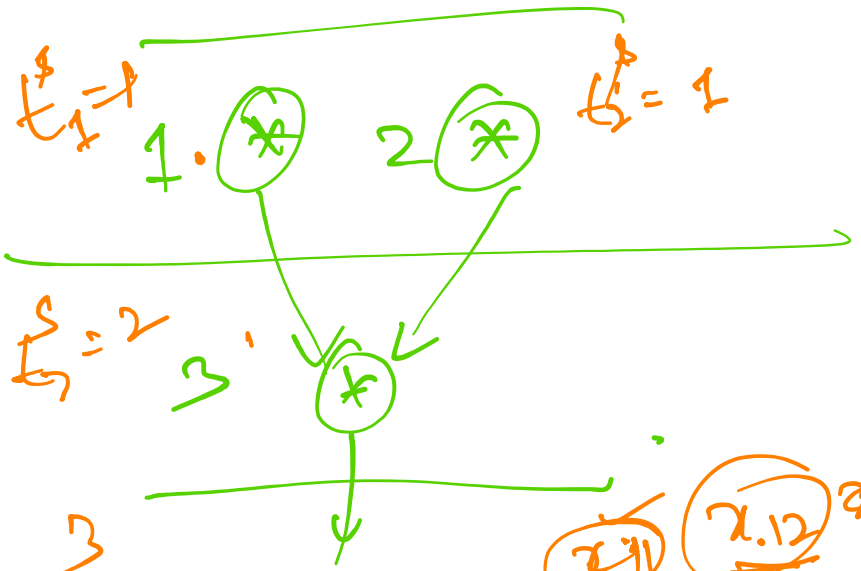
linear → $h(x) = 0$ (equality), $g(x) \leq 0$ (in-equality)

$X = x_1, x_2, \ldots, x_n$



Scheduling

decide start time of an operation



$2 \times 3 = 6$

λ - latency

n - operations

$n \times \lambda$

$n = 11$

$\lambda = 4$

$11 \times 4 = 44$

x_{11} x_{12} x_{13} x_{14} x_{22} x_{31} x_{32}

Boolean variable

$\{0, 1\}$

$x_{11} = 1$

$x_{11} + x_{12} = 1$

$x_{21} + x_{22} = 1$

$x_{31} + x_{32} = 1$

Scheduling with Resource Constraint

ILP Formulation

Binary decision variable $X = \{x_{il}\}$

i^{th} operation is scheduled in l^{th} time step

1. Start time of each operation is unique

$$\Sigma_l x_{il} = 1$$

2. Sequencing relations represented by $G_s(V,E)$ must be satisfied

$$\Sigma_l l x_{il} \geq \Sigma_l l x_{jl} + d_j$$

3. Resource bound must be met at every schedule step

$$\Sigma_k \Sigma_m x_{im} \leq a_k$$

ILP Formulation

All operation must start only once

$x_{0,1} = 1$

$x_{1,1} = 1$

$x_{2,1} = 1$

$x_{3,2} = 1$

$x_{4,3} = 1$

$x_{5,4} = 1$

$x_{6,1} + x_{6,2} = 1$

$x_{7,2} + x_{7,3} = 1$

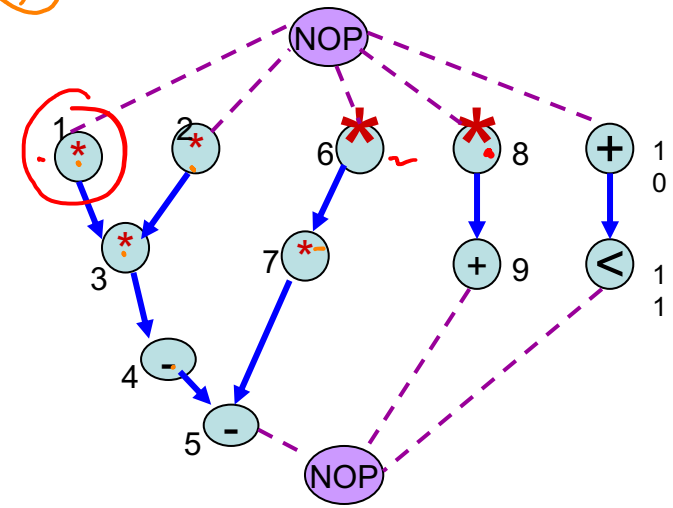
$x_{8,1} + x_{8,2} + x_{8,3} = 1$

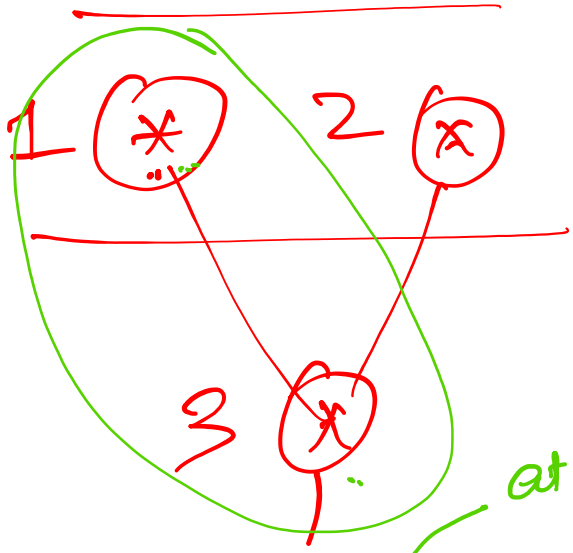
$x_{9,2} + x_{9,3} + x_{9,4} = 1$

$x_{10,1} + x_{10,2} + x_{10,3} = 1$

$x_{11,2} + x_{11,3} + x_{11,4} = 1$

$x_{n,5} = 1$





x_{11} x_{12}

x_{21} x_{22}

x_{31} x_{32}

{ 3 can start one time step after 1 starts — at least

$2 x_{32} + 3 x_{33} - x_{11} - 2x_{12} - 1 \geq 0$

If $x_{32} = 1$

$2 \cdot x_{32} \geq 1 \cdot x_{11} + 1$

$x_{12} = 0$

$x_{11} = 1$

$2 \cdot x_{32} + 3 \cdot x_{33} \geq 1 \cdot x_{11} + 2 \cdot x_{12} + 1$

$2 \geq 1 \cdot x_{11} + 2 x_{12} + 1$

ILP Formulation

Constraints – based on sequencing

(more than one starting time for at least one operation)

$$2\,x_{7,2} + 3\,x_{7,3} - x_{6,1} - 2\,x_{6,2} - 1 \geq 0$$

$$2\,x_{9,2} + 3\,x_{9,3} + 4\,x_{9,4} - x_{8,1} - 2\,x_{8,2} - 3\,x_{8,3} - 1 \geq 0$$

$$2\,x_{11,2} + 3\,x_{11,3} + 4\,x_{11,4} - x_{10,1} - 2\,x_{10,2} - 3\,x_{10,3} - 1 \geq 0$$

$$4\,x_{5,4} - 2\,x_{7,2} - 3\,x_{7,3} - 1 \geq 0$$

$$5\,x_{n,5} - 2\,x_{9,2} - 3\,x_{9,3} - 4\,x_{9,4} - 1 \geq 0$$

$$5\,x_{n,5} - 2\,x_{11,2} - 3\,x_{11,3} - 4\,x_{11,4} - 1 \geq 0$$

ILP Formulation

Resource Constraints

MULT

$$x_{1,1} + x_{2,1} + x_{6,1} + x_{8,1} \leq 2$$

$$x_{3,2} + x_{6,2} + x_{7,2} + x_{8,2} \leq 2$$

$$x_{7,3} + x_{8,3} \leq 2$$

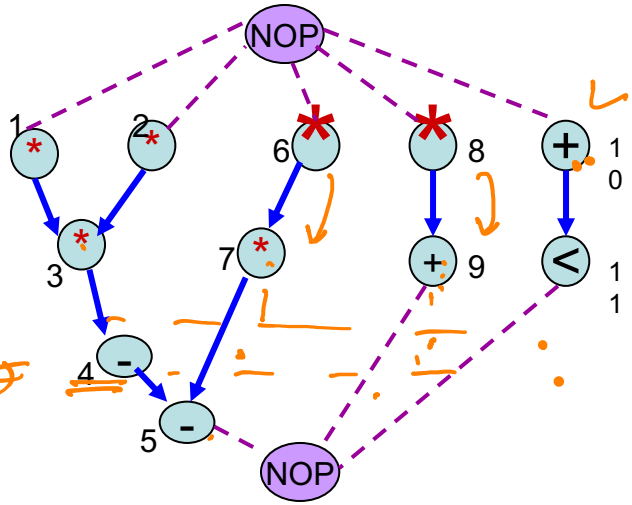
ALU

$$x_{10,1} \leq 2$$

$$x_{9,2} + x_{10,2} + x_{11,2} \leq 2$$

$$x_{4,3} + x_{9,3} + x_{10,3} + x_{11,3} \leq 2$$

$$x_{5,4} + x_{9,4} + x_{11,4} \leq 2$$



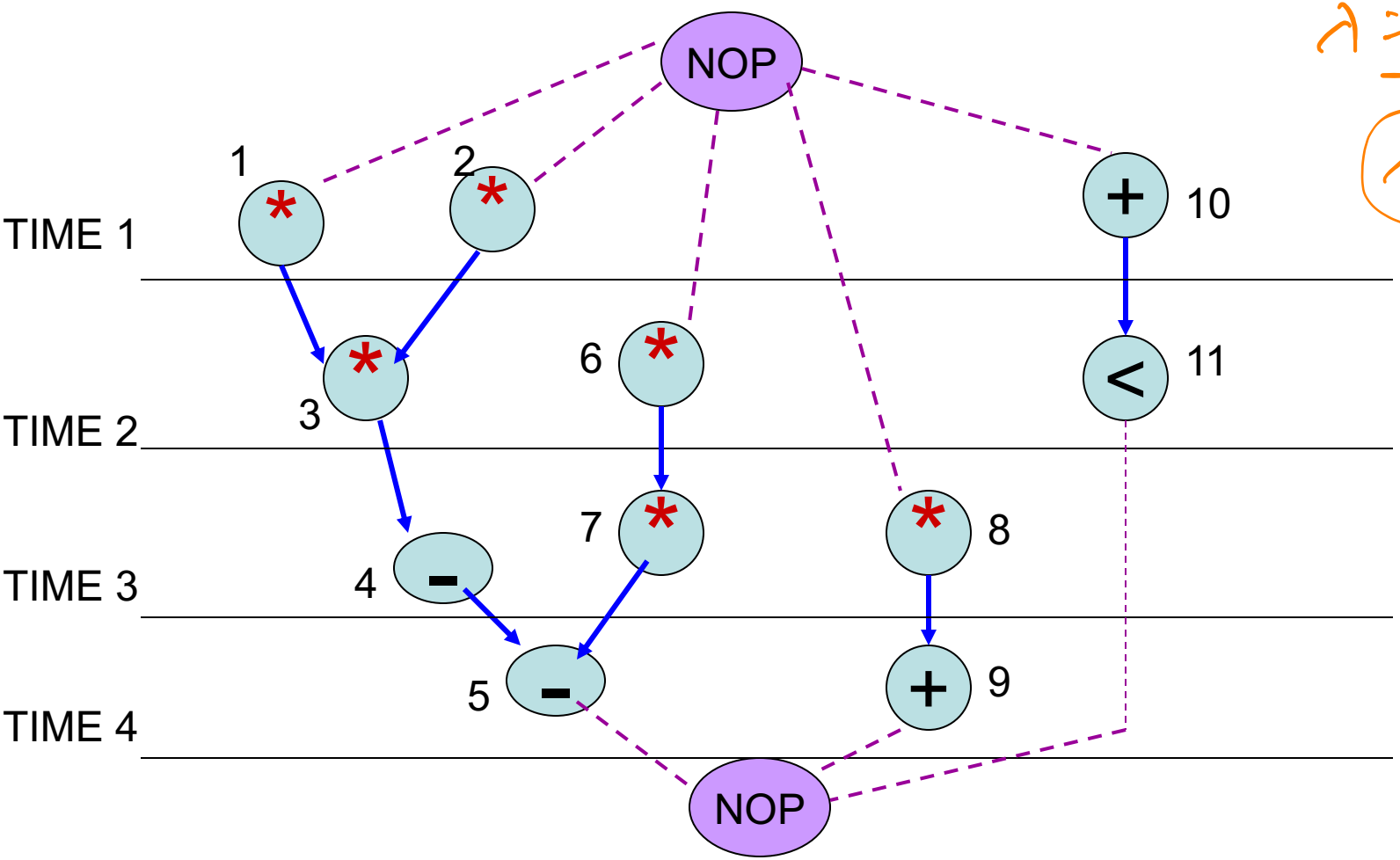
ILP Formulation

Optimize $\Sigma_i \Sigma_l \, l.x_{il}$

$\Sigma l \cdot x_{il}$

$$x_{6,1} + 2\,x_{6,2} + 3\,x_{7,2} + 3\,x_{7,3} + x_{8,1} + 2\,x_{8,2} + 3\,x_{8,3}$$
$$+ 2\,x_{9,2} + 3\,x_{9,3} + 4\,x_{9,4} + x_{10,1} + 2\,x_{10,2} + 3\,x_{10,3}$$
$$+ 2\,x_{11,2} + 3\,x_{11,3} + 4\,x_{11,4}$$

Optimum Scheduling under Resource Constraint



Thank You