MIC05: Teste de Circuitos Integrados

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Lecture 4 – Testability Measures

- Testability
  - Purpose, origins
  - Analysis, measures and computation
  - Summary

Purpose

- Need approximate measure of:
  - Difficulty of setting internal circuit lines to 0 or 1 by setting primary circuit inputs
  - Difficulty of observing internal circuit lines by observing primary outputs
- Uses:
  - Analysis of difficulty of testing internal circuit parts – redesign or add special test hardware
  - Guidance for algorithms computing test patterns – avoid using hard-to-control lines
  - Estimation of fault coverage
  - Estimation of test vector length

Origins

- Control theory
- Rutman 1972 -- First definition of controllability
- Goldstein 1979 -- SCOAP
  - First definition of observability
  - First elegant formulation
  - First efficient algorithm to compute controllability and observability
- Parker & McCluskey 1975
  - Definition of Probabilistic Controllability
- Brglez 1984 -- COP
  - 1st probabilistic measures
- Seth, Pan & Agrawal 1985 – PREDICT
  - 1st exact probabilistic measures

Testability Analysis

- Involves Circuit Topological analysis, but no test vectors and no search algorithm
    - Static analysis

- Linear computational complexity
    - Otherwise, is pointless – might as well use automatic test-pattern generation and calculate:
        - Exact fault coverage
        - Exact test vectors

Types of Measures

- SCOAP – Sandia Controllability and Observability Analysis Program
- Combinational measures:
  - *CC0* – Difficulty of setting circuit line to logic 0
  - *CC1* – Difficulty of setting circuit line to logic 1
  - *CO* – Difficulty of observing a circuit line
- Sequential measures – analogous:
  - *SC0*
  - *SC1*
  - *SO*

Range of SCOAP Measures

- Controllabilities – 1 (easiest) to infinity (hardest)
- Observabilities – 0 (easiest) to infinity (hardest)
- Combinational measures:
  - Roughly proportional to # circuit lines that must be set to control or observe given line
- Sequential measures:
  - Roughly proportional to # times a flip-flop must be clocked to control or observe given line

Goldstein's SCOAP Measures

- AND gate O/P 0 controllability:

  output_controllability = min (input_controllabilities) + 1

- AND gate O/P 1 controllability:

  output_controllability = S (input_controllabilities) + 1

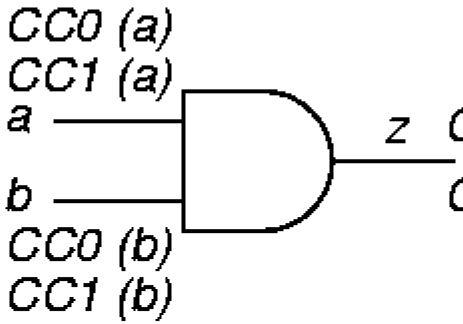
- XOR gate O/P controllability

  output_controllability = min (controllabilities of each input set) + 1

- Fanout Stem observability:

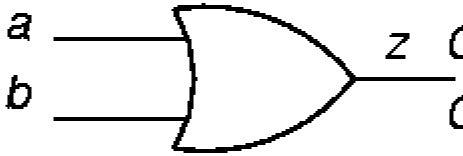
  S or min (some or all fanout branch observabilities)

Controllability Examples



$CC0(z) = \min(CC0(a), CC0(b)) + 1$

$CC1(z) = CC1(a) + CC1(b) + 1$



$CC0(z) = CC0(a) + CC0(b) + 1$

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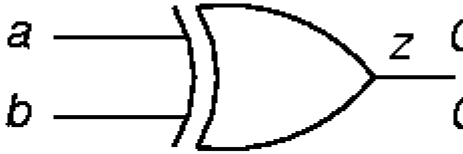
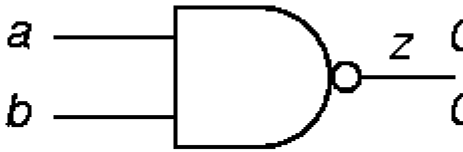


$CC0(z) = \min(CC0(a) + CC0(b), CC1(a) + CC1(b)) + 1$

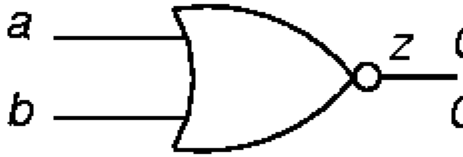
$CC1(z) = \min(CC1(a) + CC0(b), CC0(a) + CC1(b)) + 1$



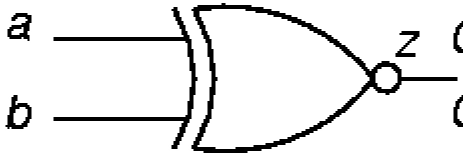
$CC0(z) = CC1(a) + CC1(b) + 1$

$CC1(z) = \min(CC0(a), CC0(b)) + 1$

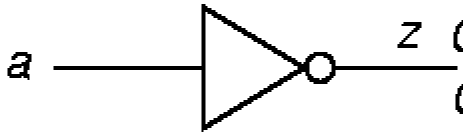
More Controllability Examples



$$CC0(z) = \min(CC1(a), CC1(b)) + 1$$
$$CC1(z) = CC0(a) + CC0(b) + 1$$



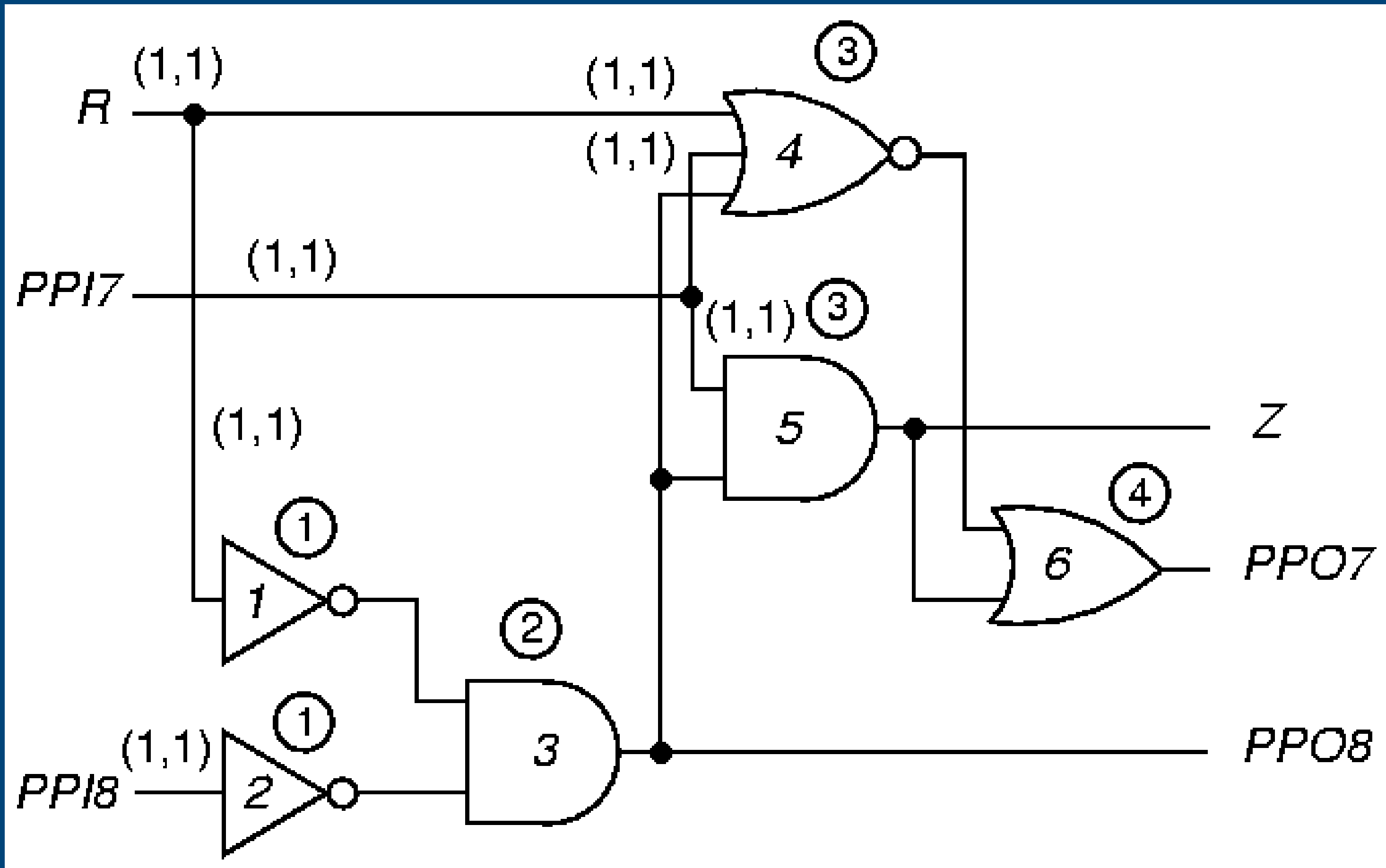
$$CC0(z) = \min(CC1(a) + CC0(b), CC0(a) + CC1(b)) + 1$$
$$CC1(z) = \min(CC0(a) + CC0(b), CC1(a) + CC1(b)) + 1$$



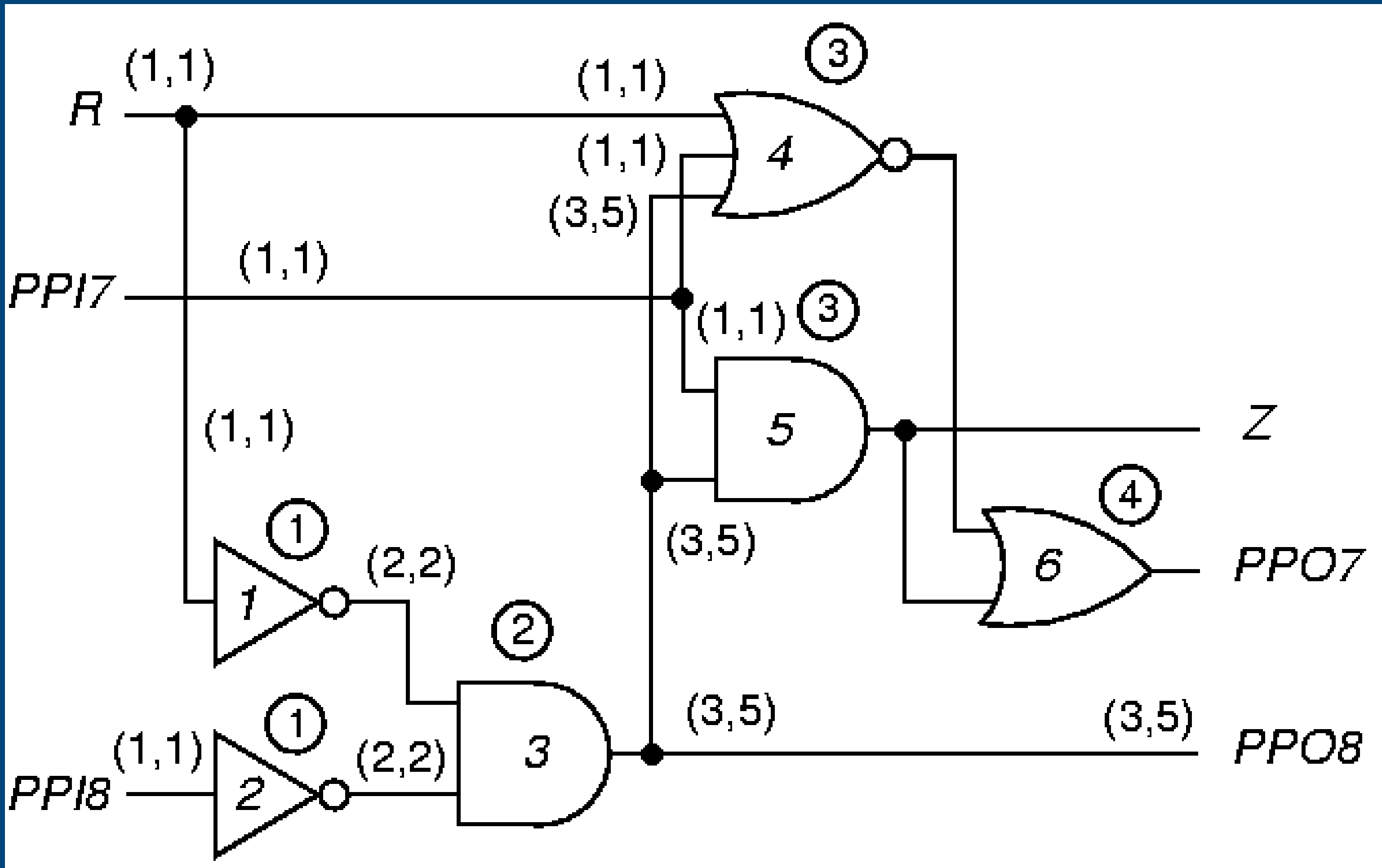
$$CC0(z) = CC1(a) + 1$$
$$CC1(z) = CC0(a) + 1$$

Controllability Through Level 0

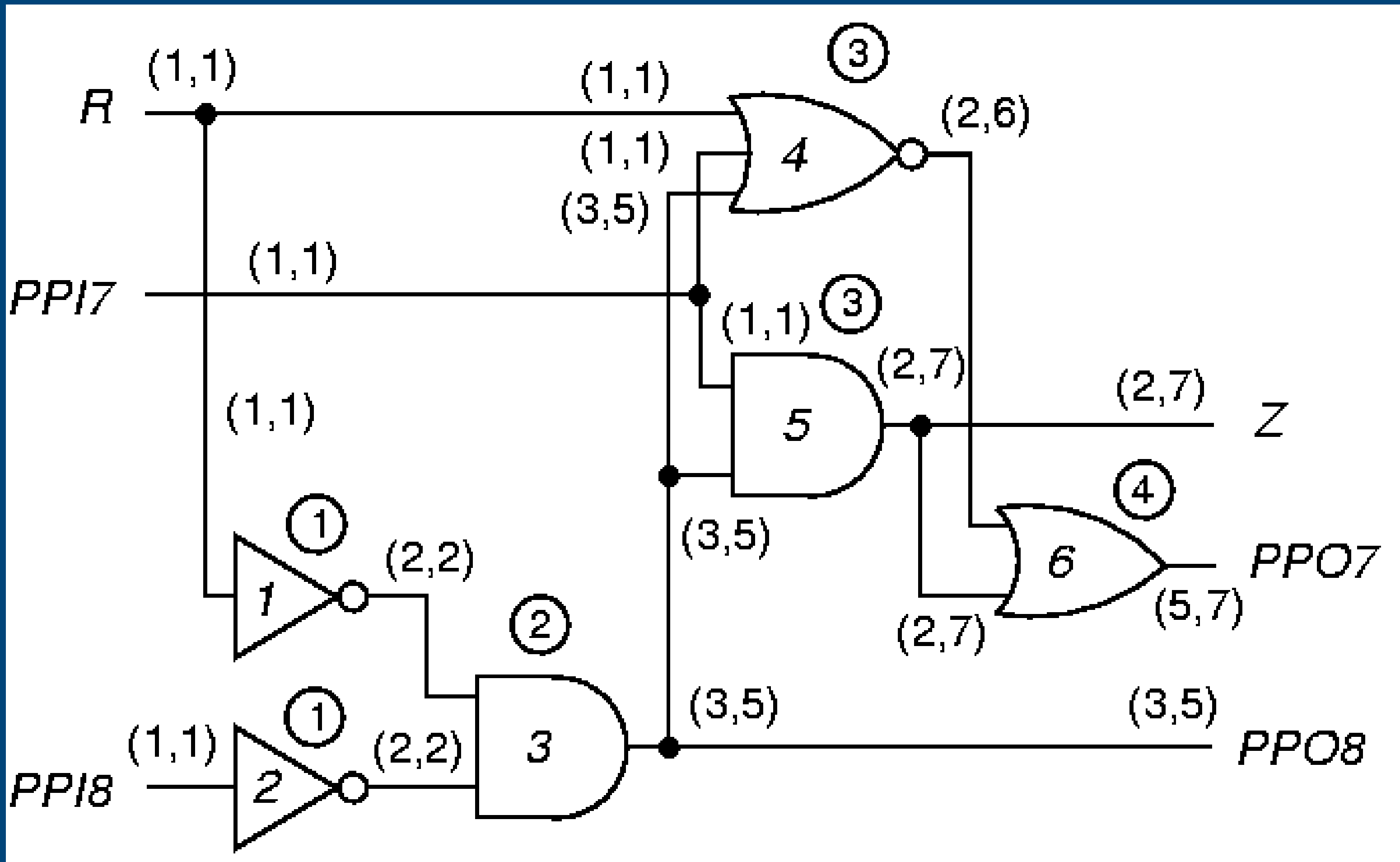
Circled numbers give level number. (CC0, CC1)



Controllability Through Level 2



Final Combinational Controllability



Observability Examples

To observe a gate input:

Observe output and make other input values non-controlling

$CO(a) = CO(z) + CC1(b) + 1$

$CO(b) = CO(z) + CC1(a) + 1$

$CO(a) = CO(z) + CC0(b) + 1$

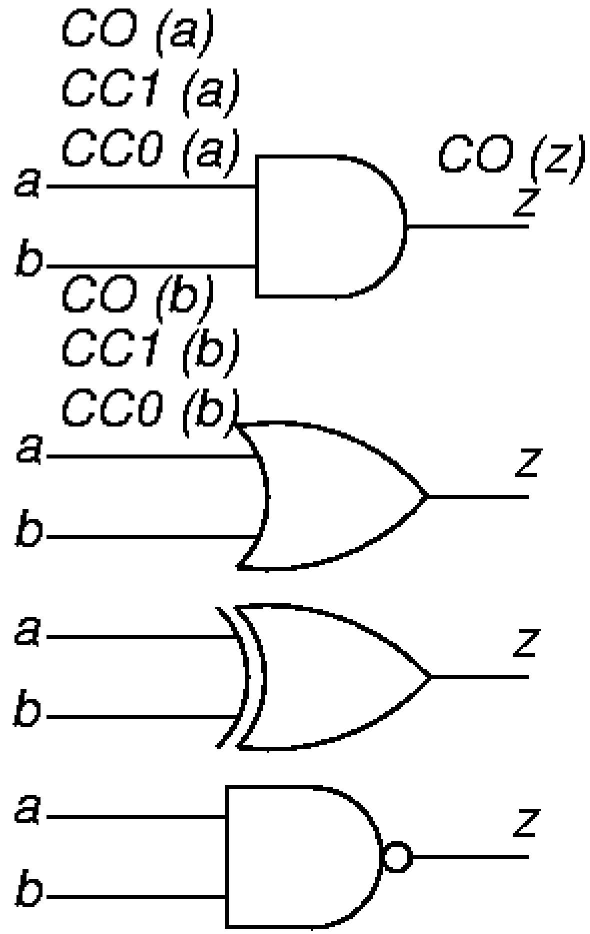
$CO(b) = CO(z) + CC0(a) + 1$

$CO(a) = CO(z) + \min(CC0(b), CC1(b)) + 1$

$CO(b) = CO(z) + \min(CC0(a), CC1(a)) + 1$

$CO(a) = CO(z) + CC1(b) + 1$

$CO(b) = CO(z) + CC1(a) + 1$

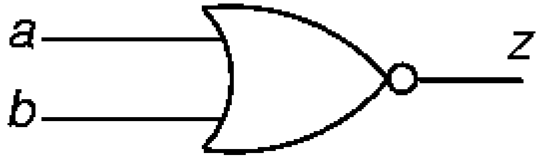


More Observability Examples

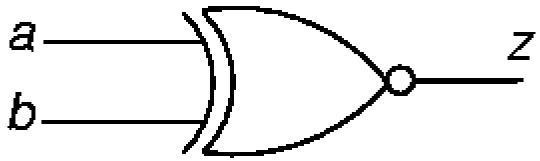
To observe a fanout stem:

Observe it through branch with best observability

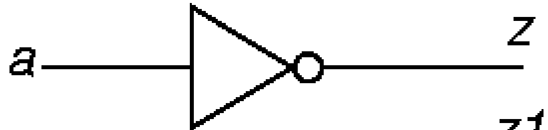
$$CO(a) = CO(z) + CC0(b) + 1$$
$$CO(b) = CO(z) + CC0(a) + 1$$



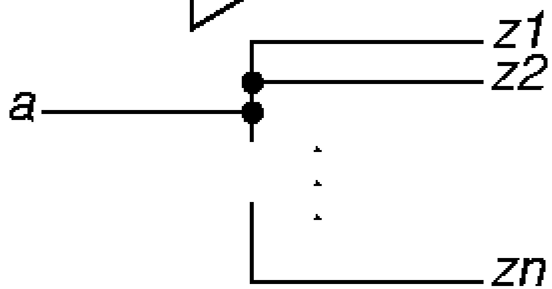
$$CO(a) = CO(z) + \min(CC0(b), CC1(b)) + 1$$
$$CO(b) = CO(z) + \min(CC0(a), CC1(a)) + 1$$



$$CO(a) = CO(z) + 1$$

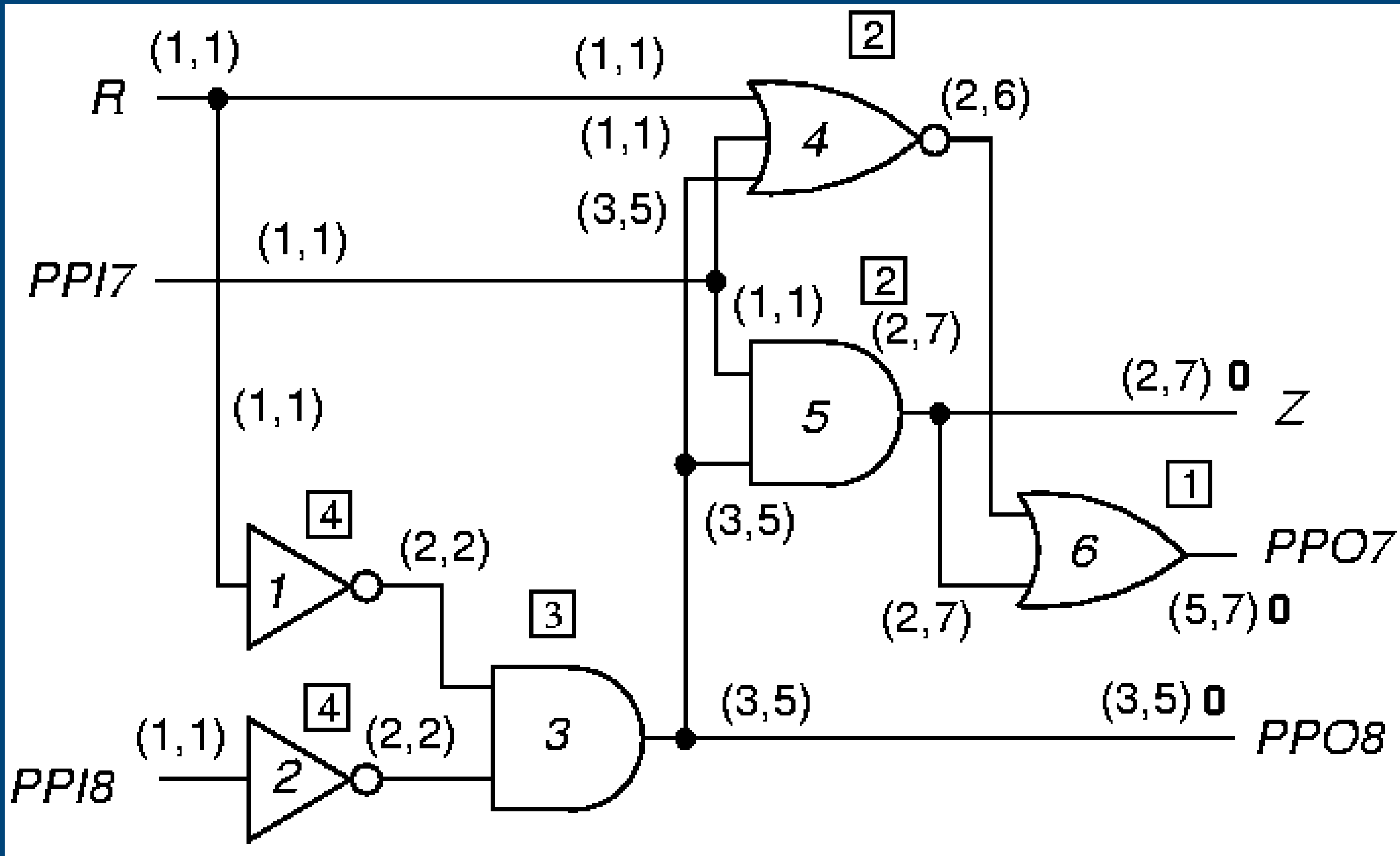


$$CO(a) = \min(CO(z1), CO(z2), \ldots, CO(zn))$$

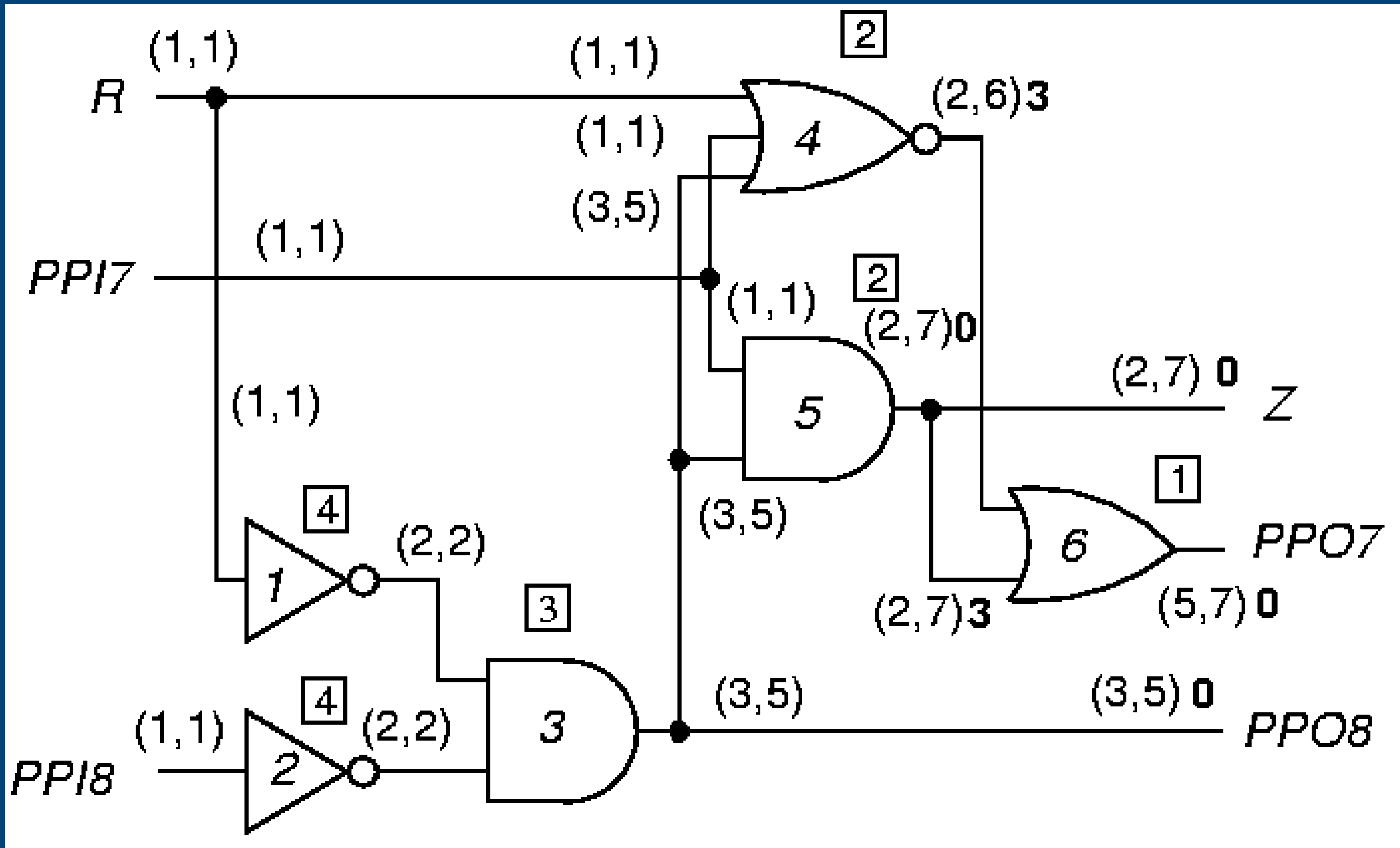


Combinational Observability for Level 1

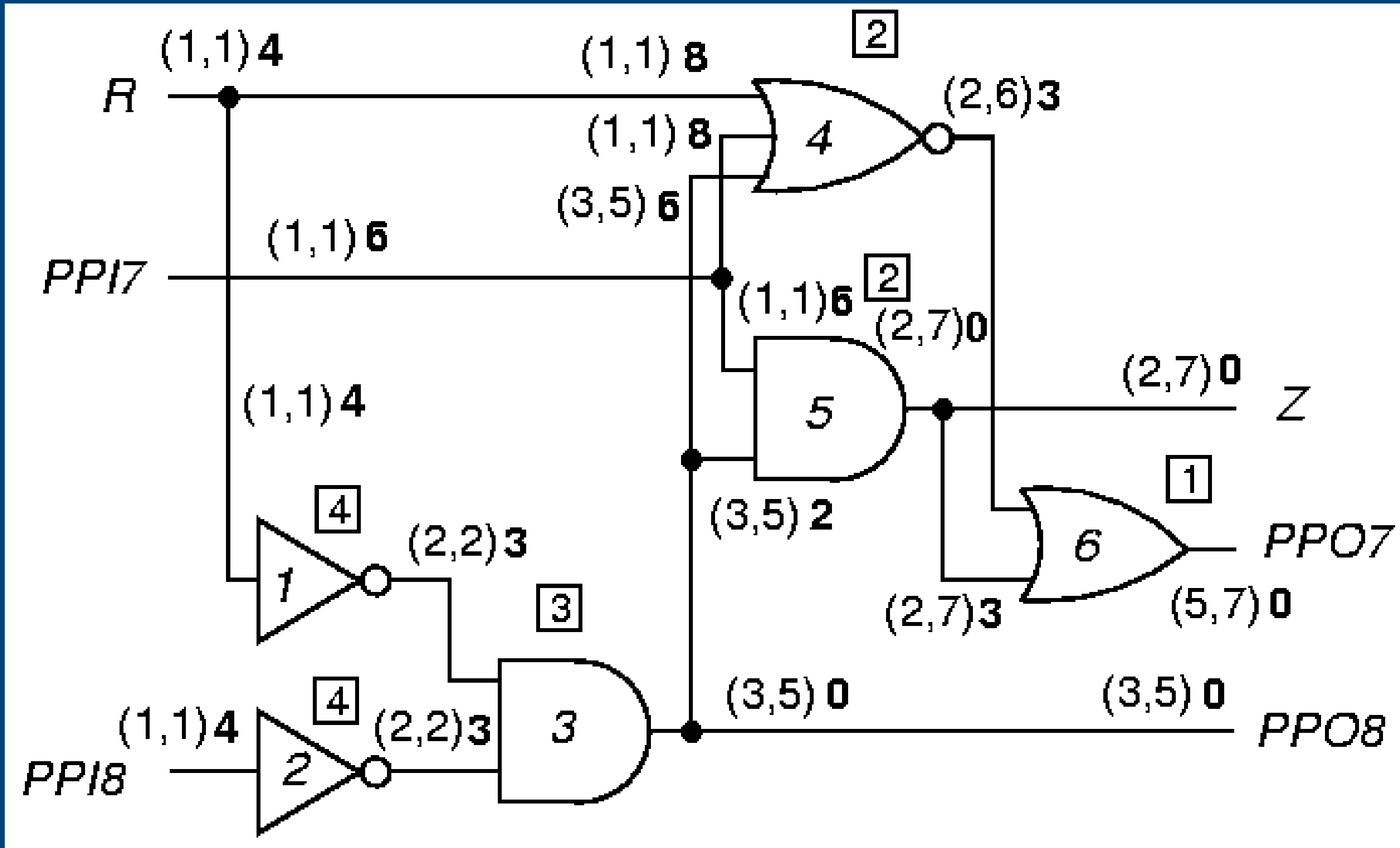
Number in square box is level from *primary outputs* (POs).
(CC0, CC1) CO



Combinational Observabilities for Level 2



Final Combinational Observabilities



Testability Computation

1. For all PIs, *CC0* = *CC1* = 1 and *SC0* = *SC1* = 0
2. For all other nodes, *CC0* = *CC1* = *SC0* = *SC1* = ∞
3. Go from PIs to POS, using *CC* and *SC* equations to get controllabilities -- Iterate on loops until *SC* stabilizes -- convergence guaranteed
4. For all POs, set *CO* = *SO* = ∞
5. Work from POs to PIs, Use *CO*, *SO*, and controllabilities to get observabilities
6. Fanout stem (*CO*, SO) = min branch (CO, SO)
7. If a *CC* or *SC* (*CO* or *SO*) is ∞ , that node is uncontrollable (unobservable)

Summary

- Testability approximately measures:
  - Difficulty of setting circuit lines to 0 or 1
  - Difficulty of observing internal circuit lines
- Uses:
  - Analysis of difficulty of testing internal circuit parts
  - Redesign circuit hardware or add special test hardware where measures show bad controllability or observability
  - Guidance for algorithms computing test patterns – avoid using hard-to-control lines
  - Estimation of fault coverage – 3-5 % error
  - Estimation of test vector length