EEDG/CE 6303: Testing and Testable Design

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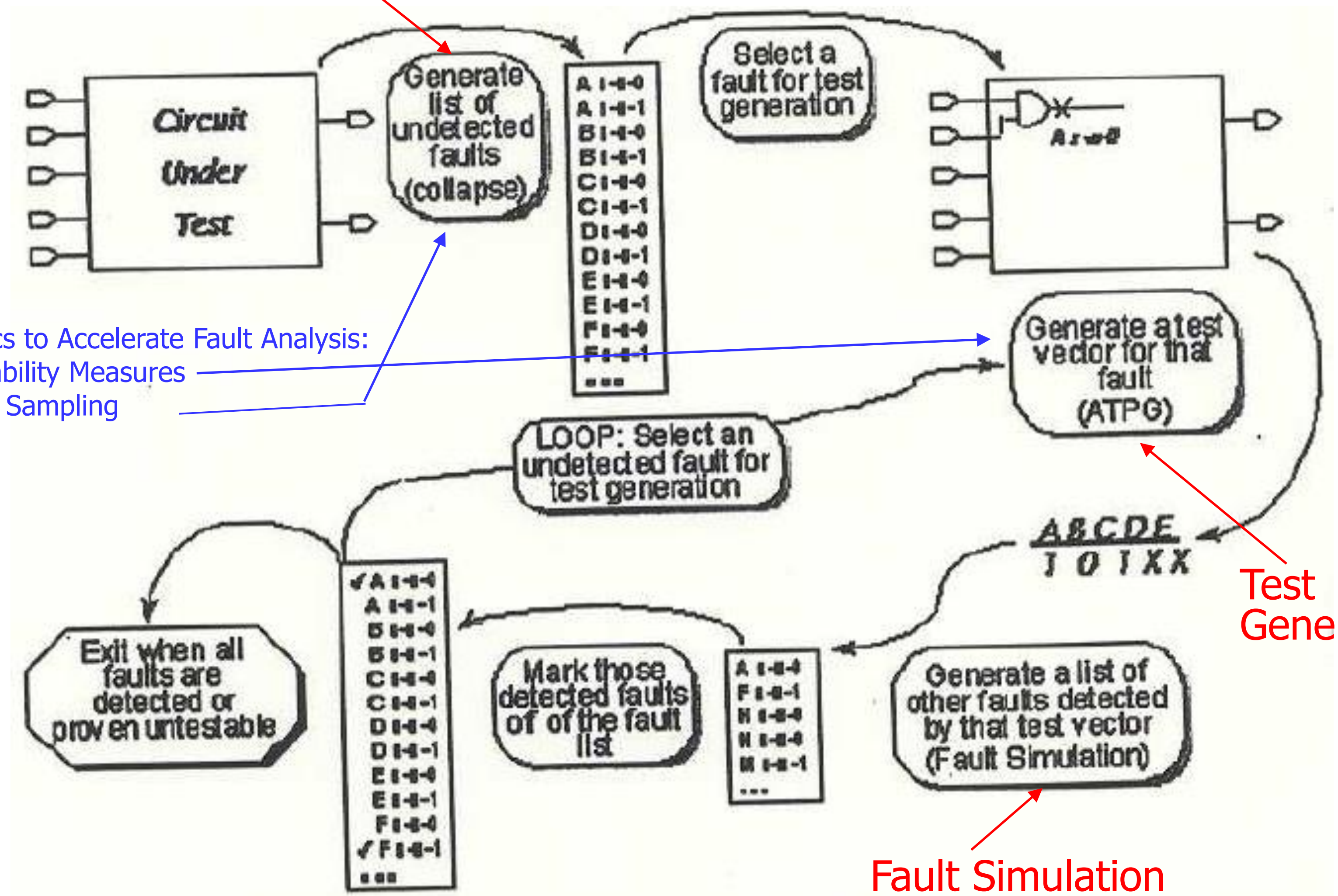
Session 05

Acceleration Heuristics for Test Generation

Fault Analysis System (Review)

Fault Collapsing



Heuristics to Accelerate Fault Analysis:

- Testability Measures
- Fault Sampling

Test Generation

Fault Simulation

Accelerating Test Generation

- There are many approaches in the literature trying to speed up the test generation process.
- Two main categories
  - **Deterministic**: Guaranteed to reduce search complexity
  - **Heuristic**: Likely to reduce search complexity
  - Even a deterministic technique may not reduce overall complexity if the complexity required to implement the technique **exceeds** the reduction in search complexity

Testability Measures

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

Origin

- 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

SCOAP and Its Metrics

- 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 (not discussed here):
  - *SC0*
  - *SC1*
  - *SO*

SCOAP and Its Metrics

- These metrics reflect the **level of difficulty**
- 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 (not discussed here):
  - —Roughly proportional to # times a flip-flop must be clocked to control or observe given line

Metrics Computation

- AND gate O/P 0 controllability:

  output_controllability = min (input_controllabilities) + 1

- AND gate O/P 1 controllability:

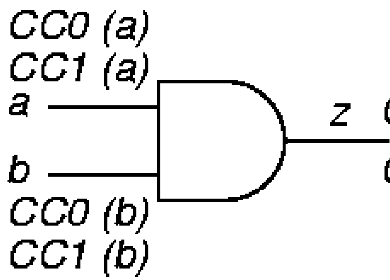
  output_controllability = Σ (input_controllabilities)+ 1

- XOR gate O/P controllability

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

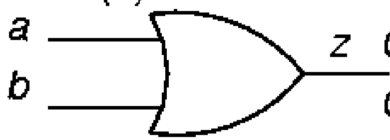
- To observe a gate input, observe output and make other input values non-controlling
- To observe a fanout stem, observe it through branch with best observability
- Fanout Stem observability:
  - Σ or min (some or all fanout branch observabilities)

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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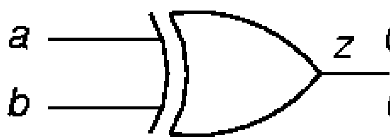
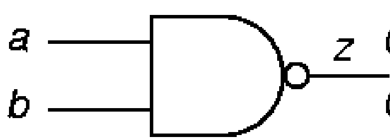


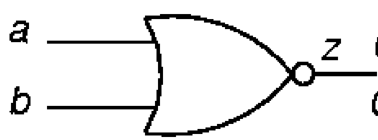
$CC0\ (z) = \min\ (CC0\ (a) + CC0\ (b), CC1\ (a) + CC1\ (b)) + 1$

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



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

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



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

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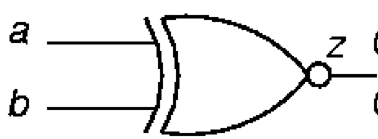
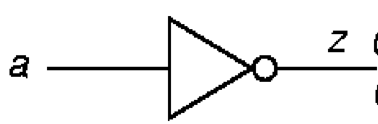


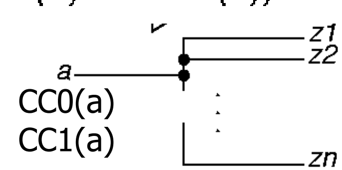
$CC0\ (z) = \min\ (CC1\ (a) + CC0\ (b), CC0\ (a) + CC1\ (b)) + 1$

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



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

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



$CC0(z_i)=CC0(a)$

$CC1(z_i)=CC1(a)$

Observability Examples

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

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

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

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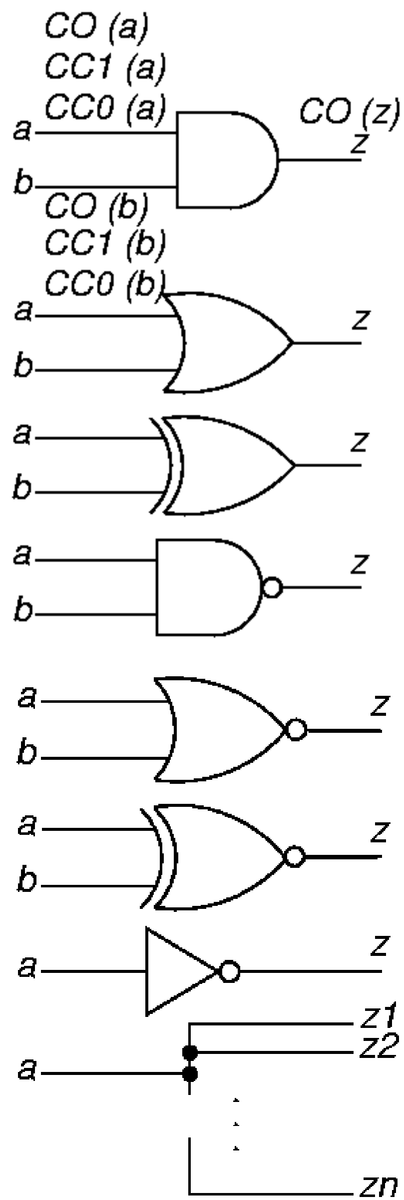
$$CO(a) = CO(z) + \min(CC0(b), CC1(b)) + 1$$
$$CO(b) = CO(z) + \min(CC0(a), CC1(a)) + 1$$

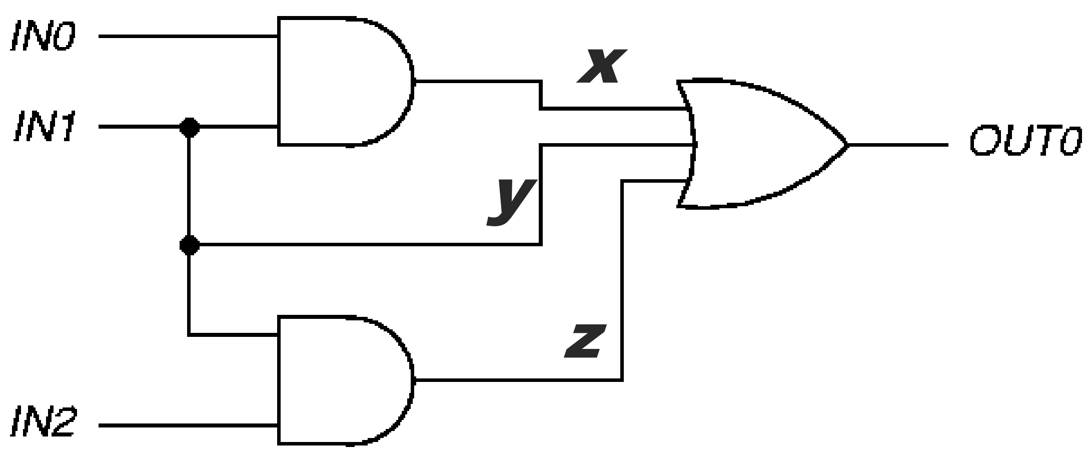
$$CO(a) = CO(z) + 1$$

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



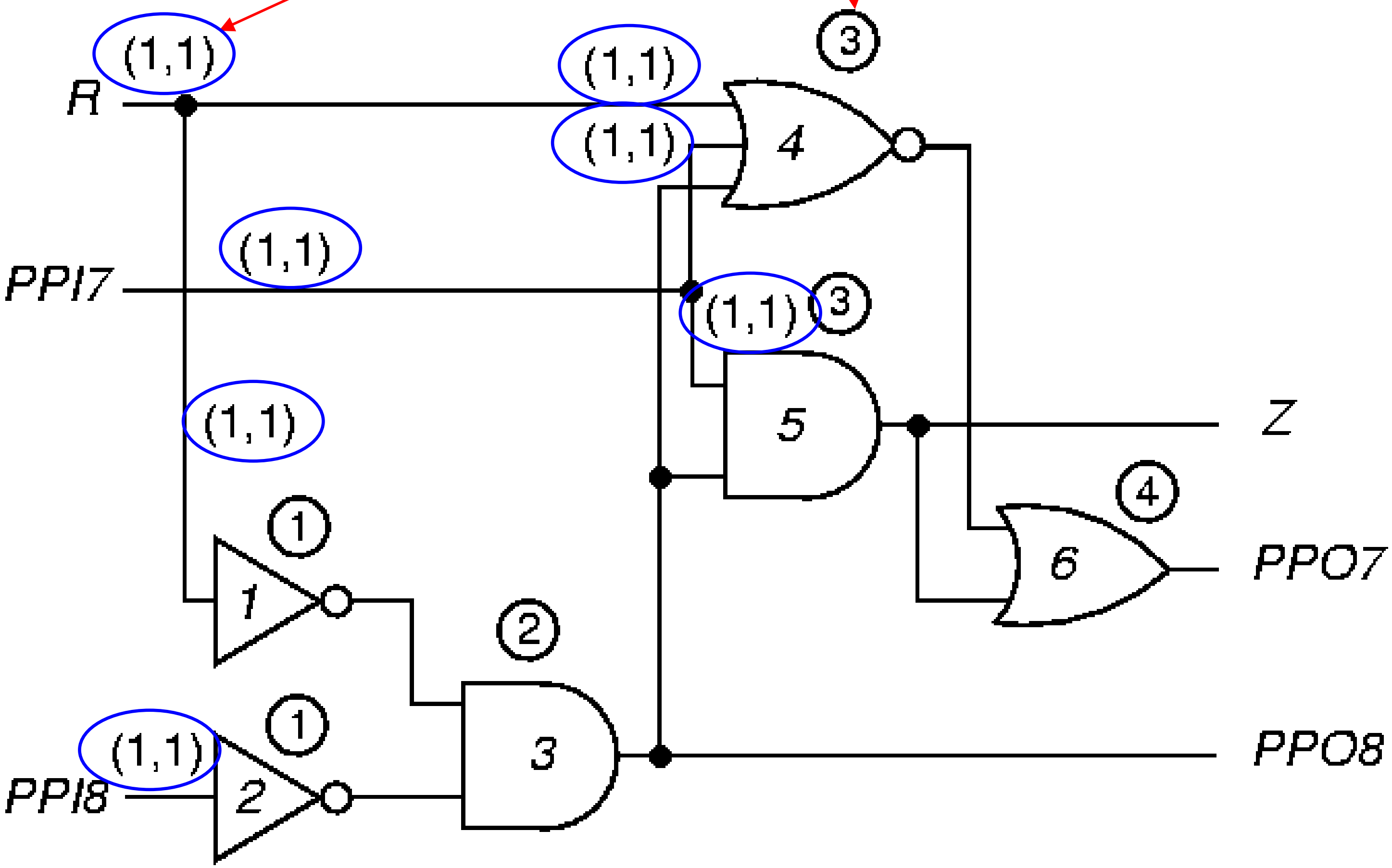
Errors Due to Reconverging Fanouts

- Exact computation of measures is NP-complete and impractical.
- SCOAP measures **wrongly** assume that controlling or observing *x*, *y*, *z* are independent events
  - *CC0 (x), CC0 (y), CC0 (z)* correlate
  - *CC1 (x), CC1 (y), CC1 (z)* correlate
  - *CO (x), CO (y), CO (z)* correlate

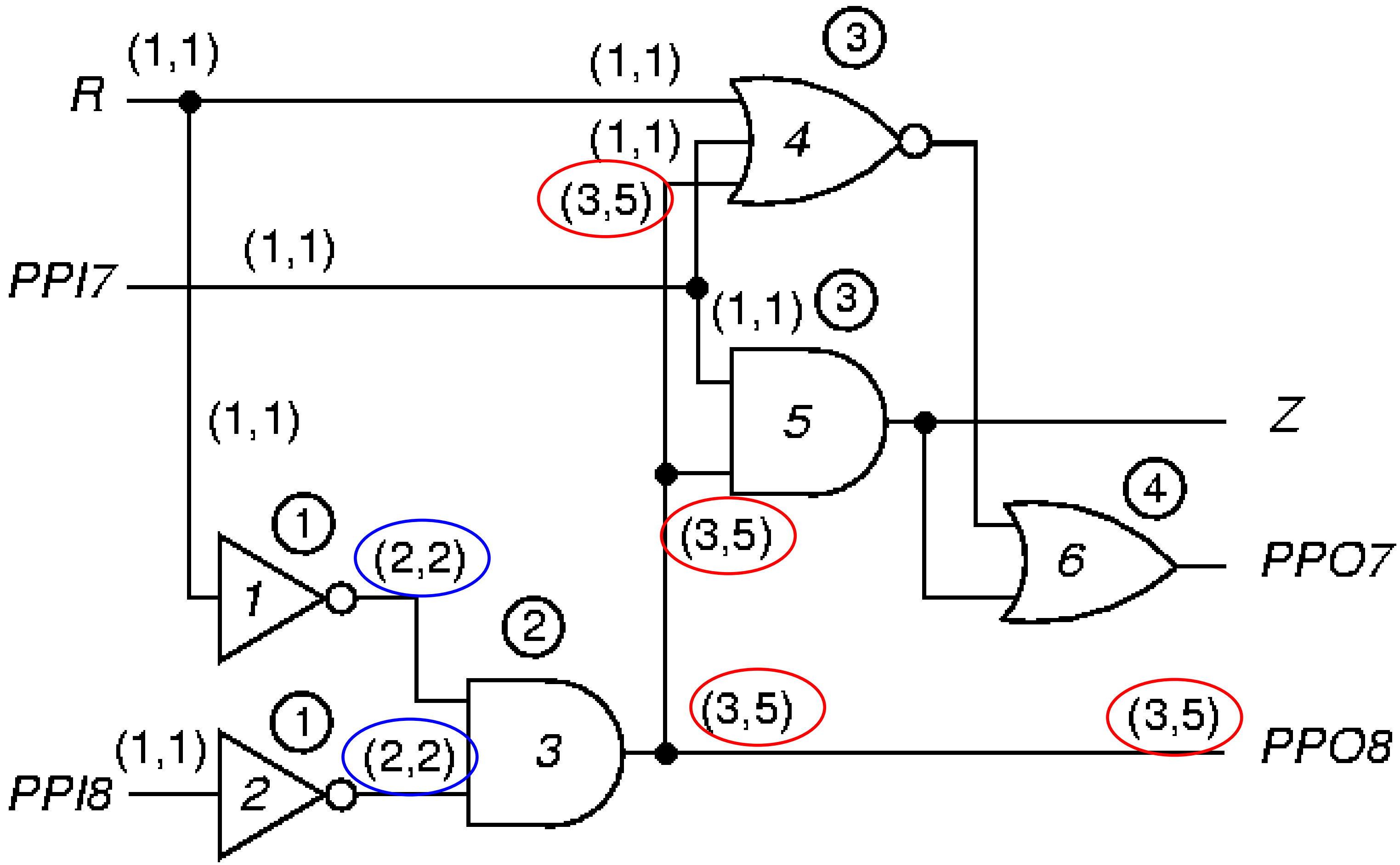


Controllability Example - Level 0

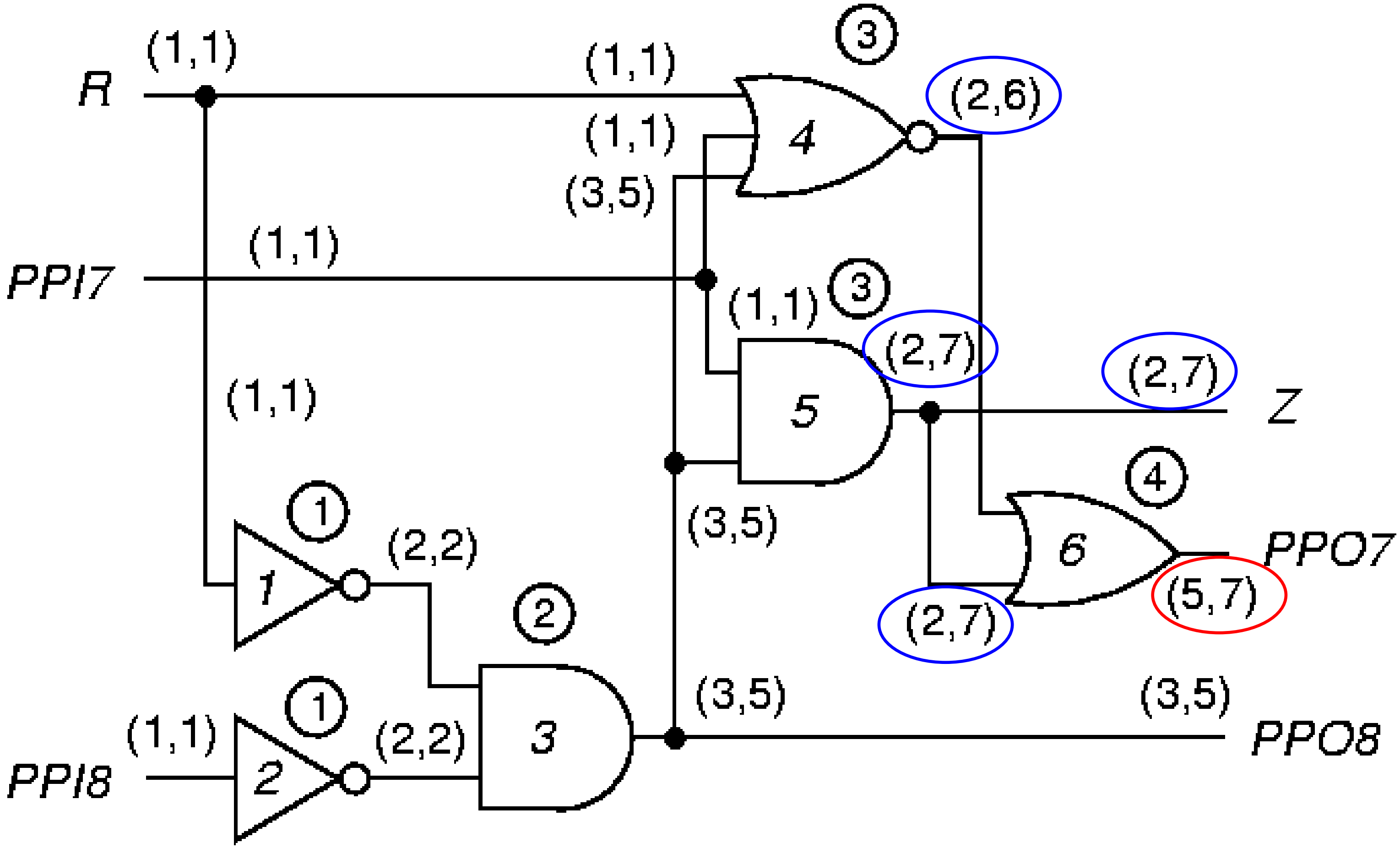
- Circled numbers give level number.
- Notation is: (CC0, CC1)



Controllability Example - Level 1 and 2

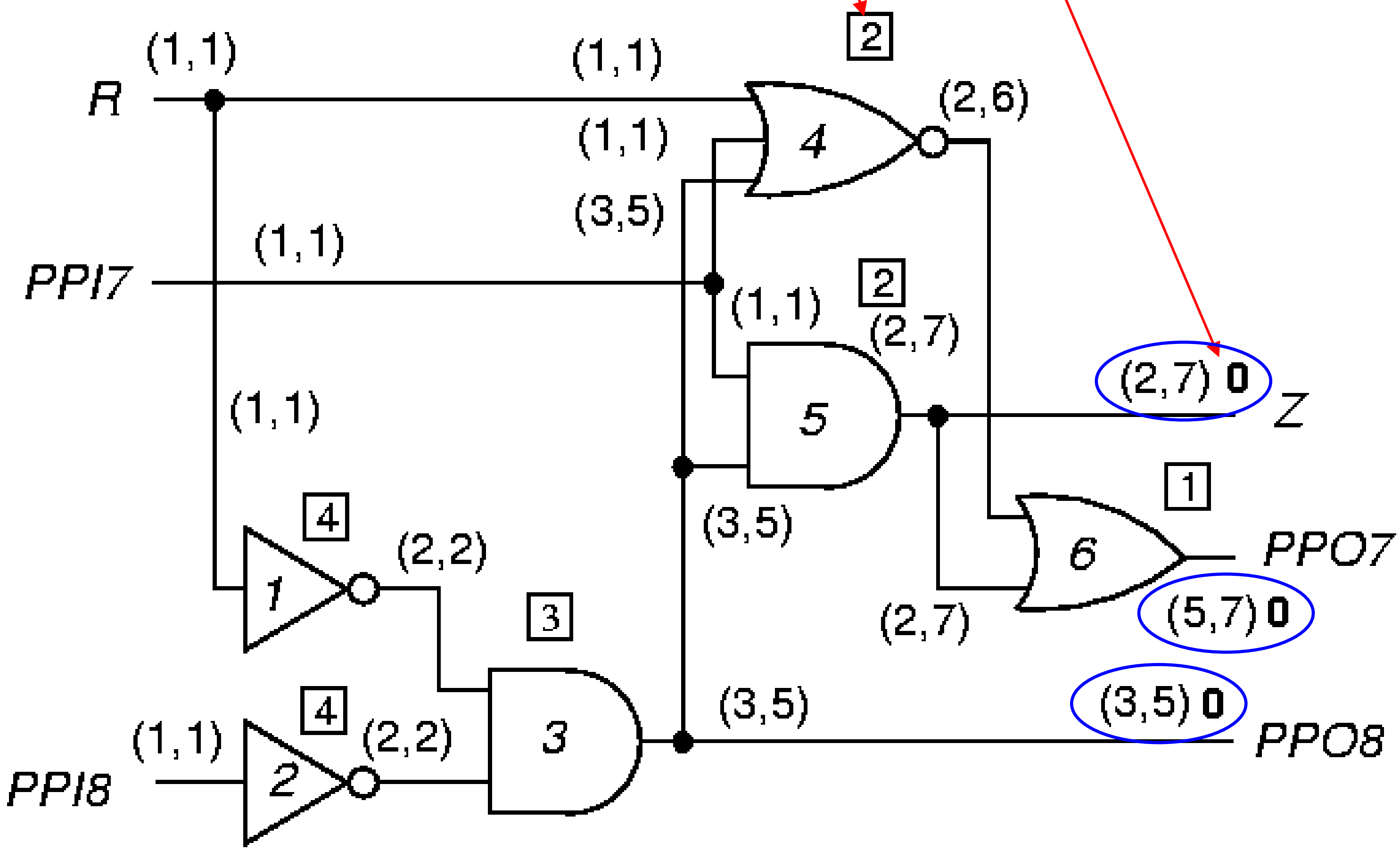


Controllability Example - Level 3 and 4

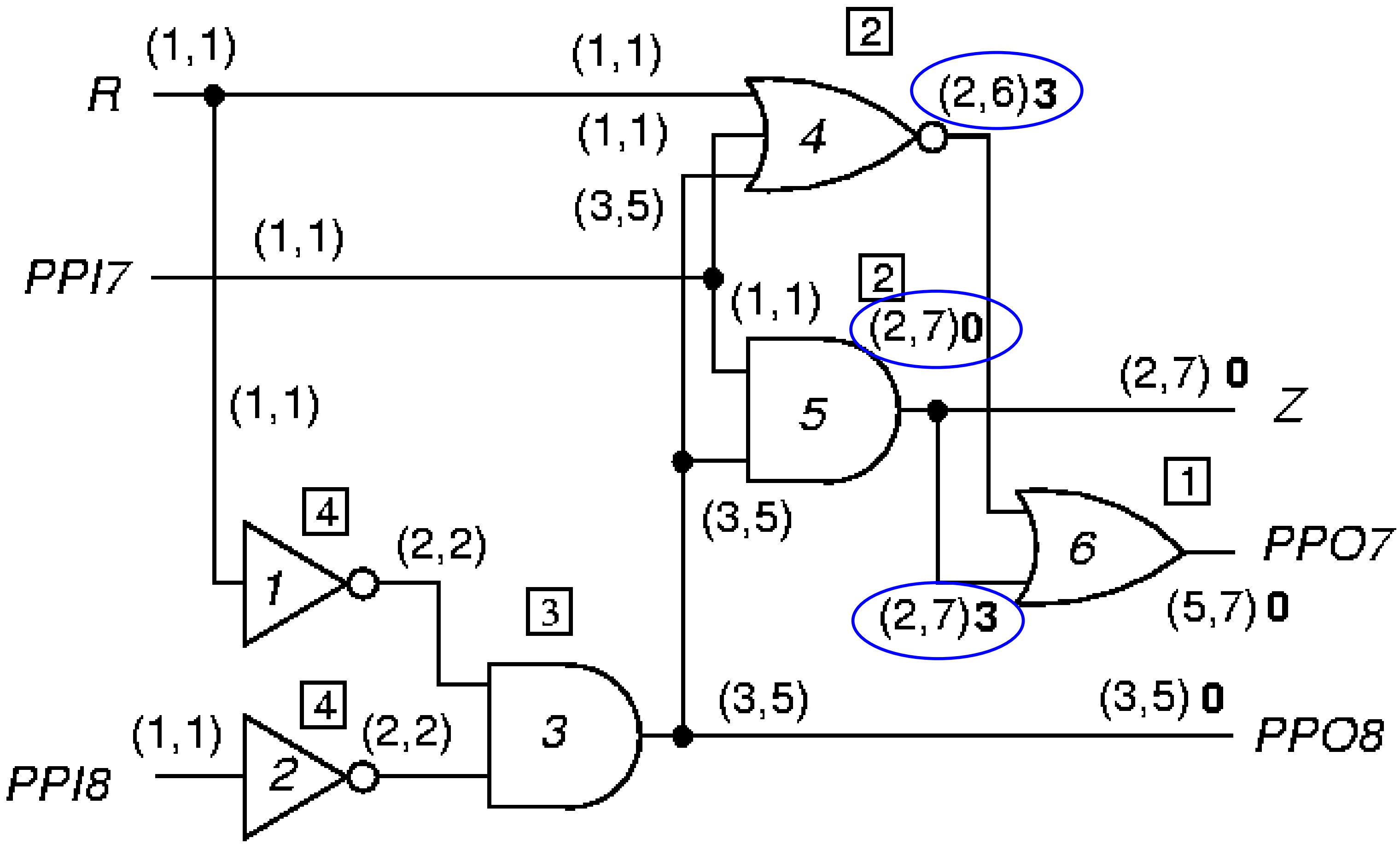


Observability Example – Level 1

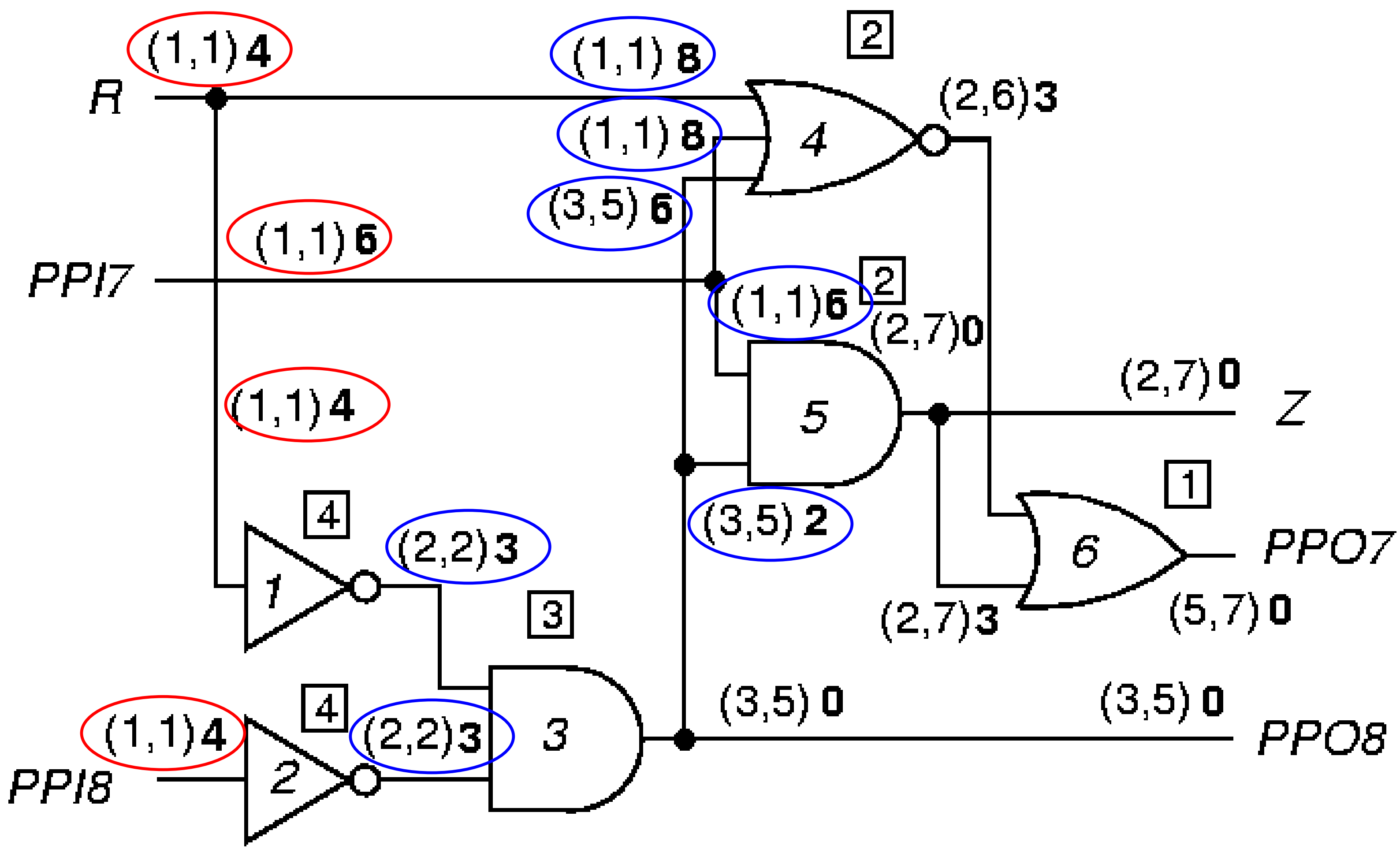
- Squared numbers give level number.
- Notation is: (CC0, CC1) **CO**



Observability Example – Level 2



Observability Example – Level 3 & 4



Sequential Measure Differences

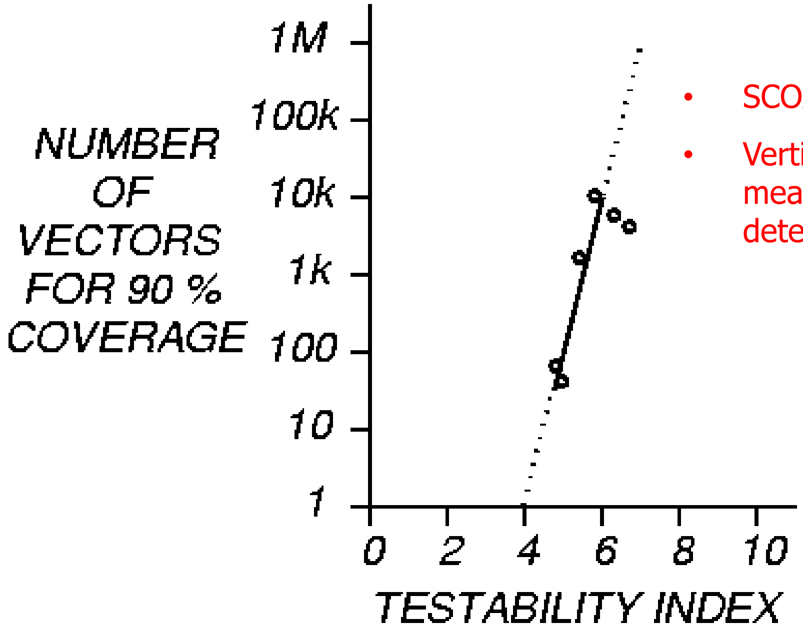
- Combinational
  - Increment *CC0, CC1, CO* whenever you pass through a gate, either forwards or backwards
- Sequential (not discussed here)
  - Increment *SC0, SC1, SO* only when you pass through a flip-flop, either forwards or backwards, to Q, $\overline{Q}$, D, C, *SET*, or *RESET*
- Both
  - Must iterate on feedback loops until controllabilities stabilize

Testability Computation Algorithm

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

Test Vector Length Prediction

- To detect a fault at x, we need to
  - Set x to the opposite value from the fault
  - Observe x at PO
- Compute *testabilities* for stuck-at faults
  - T(x sa0) = $CC1(x) + CO(x)$
  - T(x sa1) = $CC0(x) + CO(x)$
  - *Testability index* = log Σ T (f_i) , i.e. computed for all faults f_i (after collapsing – e.g. to avoid considering equivalent faults multiple times)



- SCOAP is a Linear complexity algorithm
- Vertical axis is exponential (higher index means much more difficulty and patterns to detect all faults)