TESTABILITY ANALYSIS

TEST SCREEN

PRECEED TEST GENERATION

GOALS:

1. TESTABILITY COMPUTATIONS
2. PREDICT COMPLEXITY OF TEST GENERATION
3. IDENTIFY BOTTLENECKS FOR TEST GENERATION
4. IDENTIFY LOCATIONS FOR ADDITIONAL INPUTS AND OUTPUTS
5. LINEAR COMPLEXITY FOR TESTABILITY ANALYSIS.

∴ COMBINATIONAL NETWORKS

∴ SSFs

∴ SEPARATE MEASURES FOR:

PATH SENSITIZATION

RANDOM TEST

TESTABILITY is a function OF

OBSERVABILITY AND CONTROLLABILITY

TESTABILITY ANALYSIS

CONTROLLABILITY, OBSERVABILITY

TESTABILITY

TESTABILITY MEASURES

- SCOAP
- CAMELOT
- TMEAS
- TEST/80
- FUNCTIONAL
- COMET
- TEST SCREEN
- VICTOR *
- COP *

* COMBINATIONAL CIRCUITS ONLY

Reference: Bennetts chapter 2

Controllability - measure of a difficulty to set a line at a given logical value

Observability - measure of a difficulty to observe at output a change of a signal at a given line.

Testability is related to controllability and observability C/O values are topology dependent

SCOAP

- SEPARATE COMBINATIONAL AND SEQUENTIAL MEASURES
- SEPARATE 0 AND 1 CONTROLLABILITY MEASURES
- VARIABLE CELL WEIGHTING

Controllability computed from input to output (forward pass)

Observability computed from output to input (backward pass)

FEATURES OF TESTABILITY MEASURES

1. COMPUTATION HAS LINEAR COMPLEXITY
   ($ATG \propto KN^3$; $TESTABILITY \propto KN$)

2. CORRELATION BETWEEN TEST MEASURE
   AND TEST GENERATION / IMPLEMENTATION

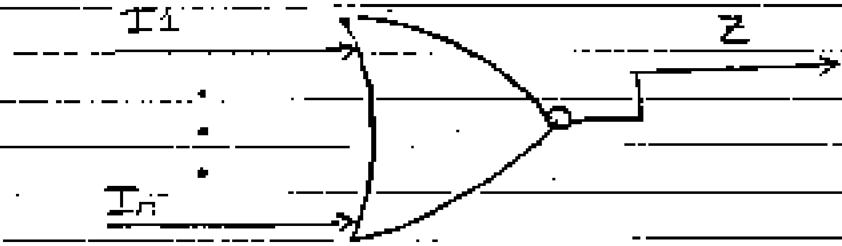
3. MEASURES USEFUL TO SUGGEST
   TOPOLOGICAL "CHANGES" OF LOGIC

4. MEASURES MAY BE USEFUL TO "GUIDE"
   ATG SOFTWARE

Observability analysis may be useful for introduction of additional observation points

TESTABILITY ANALYSIS FOR PATH SENSITIZATION

SCOAP

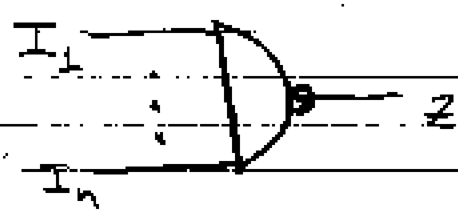


NOR

$$CC^1(Z) = CC^0(I1) + CC^0(I2) + \cdots + CC^0(In) + (\text{cell depth})_{=1}$$

$$CC^0(Z) = \min[CC^1(I1), CC^1(I2), \ldots, CC^1(In)] + (\text{cell depth})$$

$$CO(I1) = CO(Z) + CC^0(I2) + CC^0(I3) + \cdots + CC^0(In) + (\text{cell depth})$$



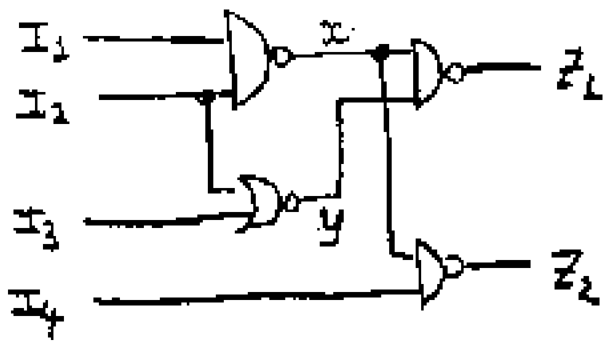
NAND

$$CC^1(Z) = \min[CC^0(I_1), CC^0(I_2), \ldots, CC^0(I_n)] + (\text{cell depth})$$

$$CC^0(Z) = CC^1(I_1) + CC^1(I_2) + \ldots + CC^1(I_n) + (\text{cell depth})$$

$$CO(I_1) = CO(Z) + CC^1(I_2) + CC^1(I_3) + \ldots + CC^1(I_n) + (\text{cell dept}$$

Example



Controllability

$CC^0(I_1) = CC^0(I_2) = CC^0(I_3) = CC^0(I_4) = 1$

$CC^1(I_1) = CC^1(I_2) = CC^1(I_3) = CC^1(I_4) = 1$

$CC^0(x) = CC^1(I_1) + CC^1(I_2) + (\text{cell depth}) = 3$

$CC^1(x) = \min[CC^0(I_1), CC^0(I_2)] + (\text{cell depth}) = 2$

$CC^0(y) = \min[CC^1(I_2), CC^1(I_3)] + (\text{cell depth}) = 2$

$CC^1(y) = CC^0(I_2) + CC^0(I_3) + (\text{cell depth}) = 3$

$CC^0(Z_1) = CC^1(x) + CC^1(y) + (\text{cell depth}) = 6$

$CC^1(Z_1) = \min[CC^0(x), CC^0(y)] + (\text{cell depth}) = 3$

$CC^0(Z_2) = CC^1(x) + CC^1(I_4) + (\text{cell depth}) = 4$

$CC^1(Z_2) = \min[CC^0(x), CC^0(I_4)] + (\text{cell depth}) = 2$

Conclusion: Line Z_1 has highest 0-controllability $\Rightarrow$ most difficult to set Z_1 at 0

Example (Cont'd)

Observability

$CO(Z_1) = CO(Z_2) = 1$

$CO(x) = \min[CO(Z_1) + CC^1(y) + (\text{cell depth}), CO(Z_2) + CC^1(I_4) + (\text{cell depth})] = \min[5, 3] = 3$

fanout

$CO(y) = CO(Z_1) + CC^1(x) + (\text{cell depth}) = 4$

$CO(I_1) = CO(x) + CC^1(I_2) + (\text{cell depth}) = 5$

$CO(I_2) = \min[CO(x) + CC^1(I_1) + (\text{cell depth}), CO(y) + CC^0(I_3) + (\text{cell depth})] = \min[5, 6] = 5$

fanout

$CO(I_3) = CO(y) + CC^0(I_3) + (\text{cell depth}) = 6$

$CO(I_4) = CO(Z_2) + CC^1(x) + (\text{cell depth}) = 4$

Conclusion: most difficult line to observe I_3

Testability

$$T(a) = CC^0(a) + CC^1(a) + CO(a)$$

Example

$T(I_1) = 1 + 1 + 5 = 7$

$T(I_2) = 1 + 1 + 5 = 7$

$T(I_3) = 1 + 1 + 6 = 8$

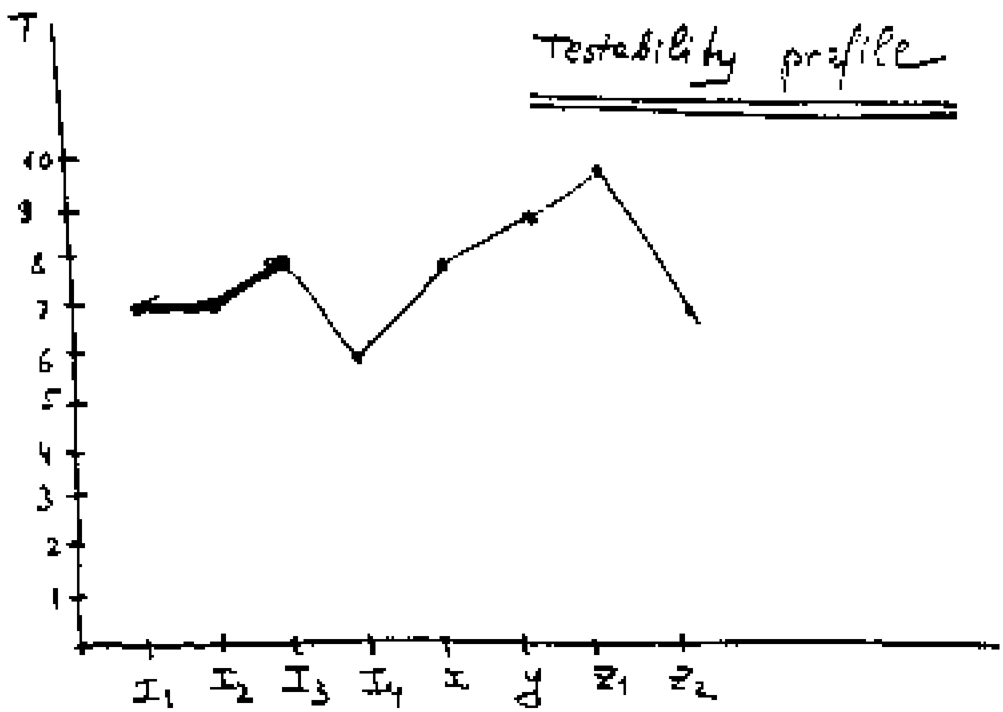
$T(I_4) = 1 + 1 + 4 = 6$

$T(x) = 3 + 2 + 3 = 8$

$T(y) = 2 + 3 + 4 = 9$

$T(Z_1) = 6 + 3 + 1 = 10$

$T(Z_2) = 4 + 2 + 1 = 7$



Line Z_1 is most difficult to test

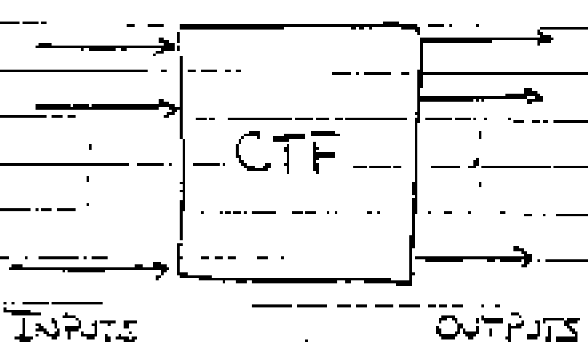
Testability analysis for random testing

TMEAS & CAMELOT

TRANSFER FUNCTIONS - CONTROLLABILITY

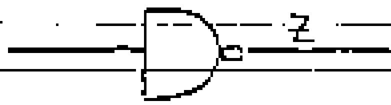
$$CTF \equiv 1 - \left| \frac{N(0) - N(1)}{N(0) + N(1)} \right|$$

= Avg. measure of mapping uniformity

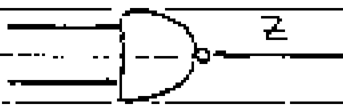


MULTIPLE OUTPUTS MAY HAVE DIFFERENT CTFs

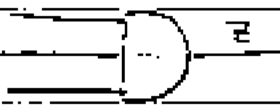
TYPICAL CTFs



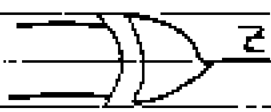
$N(0) = 1$
$N(1) = 1$
CTF $= 1$



$N(0) = 1$
$N(1) = 3$
CTF $= 0.5$



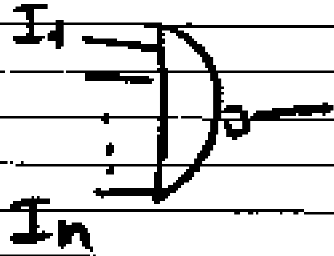
$N(0) = 7$
$N(1) = 1$
CTF $= 0.25$



$N(0) = 2$
$N(1) = 2$
CTF $= 1$

$N(0) = 15$
$N(1) = 1$
CTF $= 0.125$

$C(Z) =$ CTF $\cdot$ (Arithmetic Mean of Input CTFs)

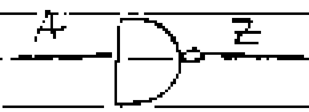


$N(0) = 1$
$N(1) = 2^n - 1$
CTF $= 2^{-n+1}$

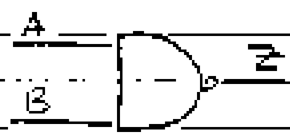
OBSERVABILITY TRANSFER FUNCTION

$$OTF(I \to O) \equiv \frac{\#\text{ OF SENSITIVE } I \to O \text{ PATHS}}{\text{TOTAL }\#\text{ OF } I \to O \text{ PATHS}}$$

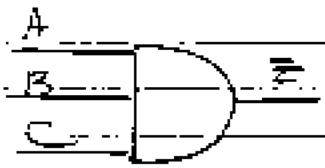
$$= \frac{NSP(I \to O)}{NTP(I \to O)}$$



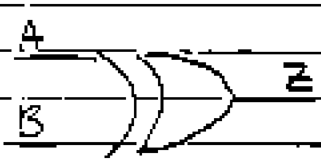
$NSP(A \to Z) = 1$
$NTP(A \to Z) = 1$
$OTF(A \to Z) = 1$



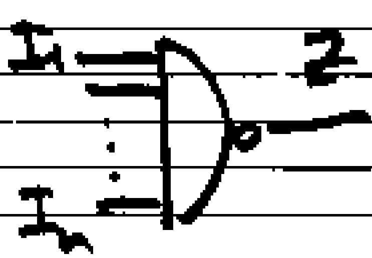
$NSP(A \to Z) = 1$
$NTP(A \to Z) = 2$
$OTF(A \to Z) = 0.5$
$OTF(B \to Z) = 0.5$



$NSP(A \to Z) = 1$
$NTP(A \to Z) = 4$
$OTF(A \to Z) = 0.25$
$OTF(B \to Z) = 0.25$



$NSP(A \to Z) = 2$
$NTP(A \to Z) = 2$
$OTF(A \to Z) = 1$
$OTF(B \to Z) = 1$

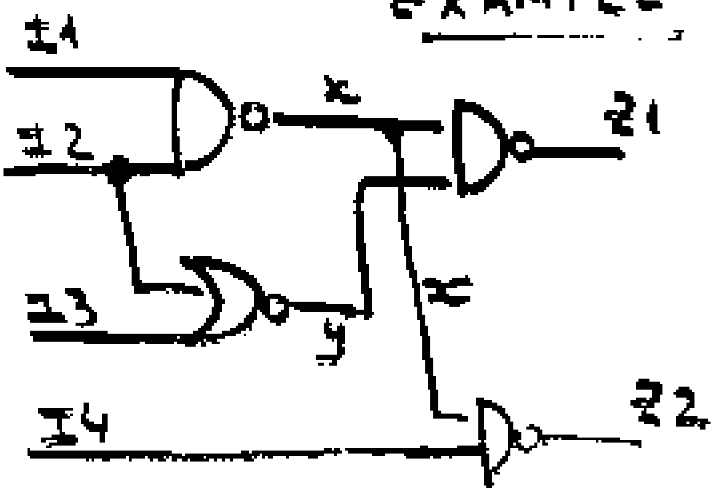


$NTP(I_1 \to Z) = 2^{n-1}$

$NSP(I_1 \to Z) = 1$

$OTF(A \to Z) = 2^{-n+1}.$

EXAMPLE



CONTROLLABILITY

CTF (I1) = CTF (I2) = CTF (I3) = CTF (I4) = 1

CTF (x) = MEAN [CTF (I1), CTF (I2)] · 0.5

CTF (y) = MEAN [CTF (I2), CTF (I3)] · 0.5 = 0.5

= 0.5

CTF (Z1) = MEAN [CTF (x), CTF (y)] · 0.5 = 0.25

CTF (Z2) = MEAN [CTF (x), CTF (I4)] · 0.5 = 3/8

LINE Z1 is most difficult to CONTROL FOR UNBIASED RANDOM TESTING

OBSERVABILITY

$OTF(Z1) = OTF(Z2) = 1$

$OTF(x) = MAX[OTF(Z1) \cdot CTF(y) \cdot 0.5,$
'FANOUT
$OTF(Z2) \cdot CTF(I4) \cdot 0.5] =$
$= MAX[1 \cdot 0.5 \cdot 0.5, 1 \cdot 1 \cdot 0.5] = 0.5$

$OTF(y) = OTF(Z1) \cdot CTF(x) \cdot 0.5 =$
$= 1 \cdot 0.5 \cdot 0.5 = 0.25$

$OTF(I1) = OTF(x) \cdot CTF(I2) \cdot 0.5 =$
$= 0.5 \cdot 1 \cdot 0.5 = 0.25$

$OTF(I2) = MAX[OTF(x) \cdot CTF(I1) \cdot 0.5,$
$OTF(y) \cdot CTF(I3) \cdot 0.5]$
$= MAX[0.5 \cdot 1 \cdot 0.5, 0.25 \cdot 1 \cdot 0.5] =$
$= 0.25$

$OTF(I3) = OTF(y) \cdot CTF(I2) \cdot 0.5 =$
$= 0.25 \cdot 1 \cdot 0.5 = 0.125$

$OTF(I4) = OTF(Z2) \, CTF(x) \cdot 0.5 =$
$= 1 \cdot 0.5 \cdot 0.5 = 0.25$

Conclusion: Line I3 is most difficult to observe for random testing.

TESTABILITY TRANSFER FUNCTION

FOR RANDOM TESTING

$$TTF(a) = CTF(a)\ OTF(a)$$