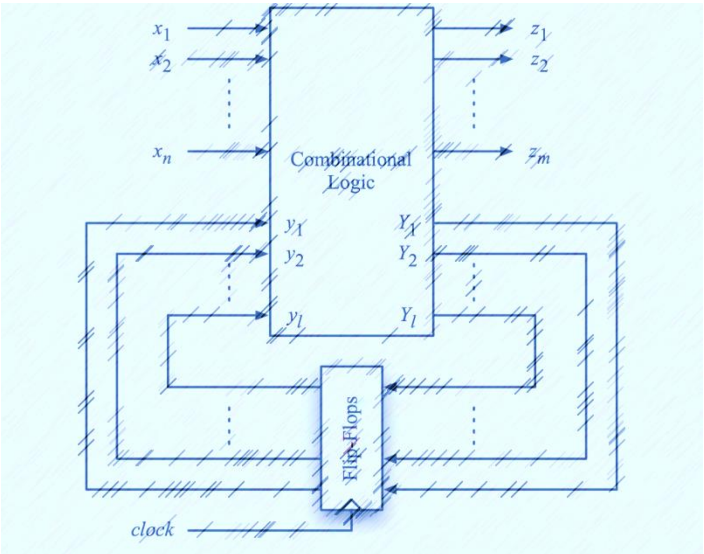
Sequential ATPG

- Introduction
- Time-frame expansion methods
- <u>Simulation-based methods (* not in exam)</u>
    - CONTEST [Agrawal & Cheng 88]
    - Genetic Algorithm
- Issues of Sequential ATPG
- Conclusions



Simulation-Based Methods

- **Idea: use logic/fault simulators to guide ATPG [Seshu 62]**
  - **Simulation is faster than ATPG**
- **Approach**
  - **Generate candidate test vectors**
  - ***Fitness**** **of candidates evaluated by logic or fault simulation**
  - **Select best candidate based on a certain *cost function***
- **Advantage:**
  - **No time frame expansion. Easy memory management**

Simulate Many Vectors and Choose Best

CONTEST– Concurrent Test Generator for Sequential Circuits [Agrawal & Cheng 89]

Based on event-driven concurrent fault simulator

- Search for test vectors guided by cost functions
- Three phases
  ① Initialization
  ② Concurrent fault detection
  ③ Single fault detection

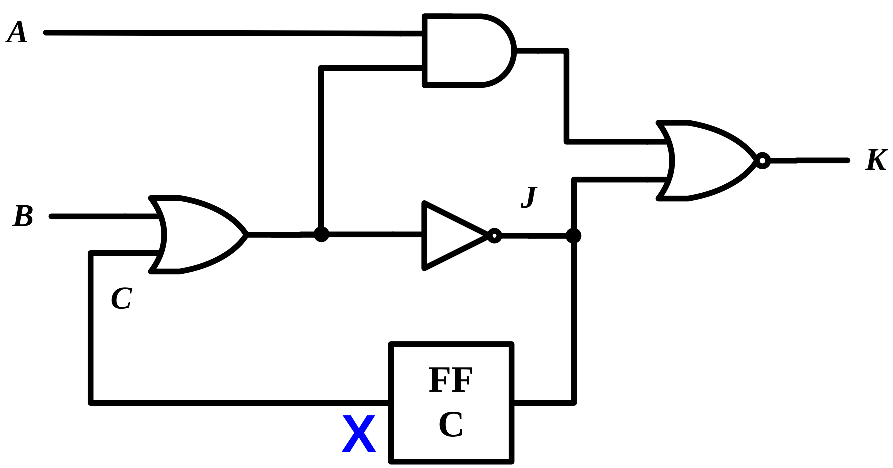
1. Initialization Phase

- **Start with arbitrary test vector**
  - **Start with FFs in unknown states**
- **Use logic simulation (not fault simulation)**
  - **Cost = number of FFs in unknown state**
  - ***Trial vectors* are generated by single-bit change of the current vector. A trial vector is accepted and becomes the current vector if it lowers the cost**
- **Stop this phase when cost drops below a desired value**

QUIZ

Q1: Initially the FF is unknown. Given three trial vectors, please simulate the circuit and decide their costs, where cost = number of unknown FF.

Q2: Which trial vector would you pick?

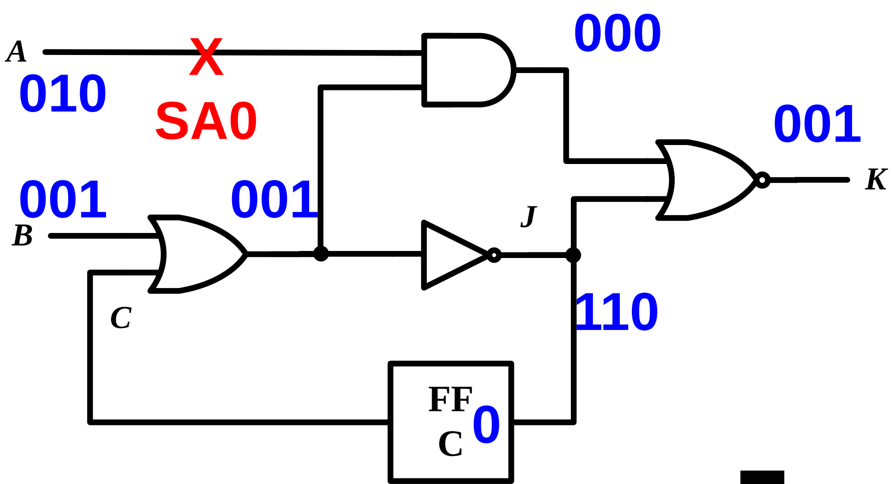


AB	**cost** = number of unknown FF
00	1
01	
10	

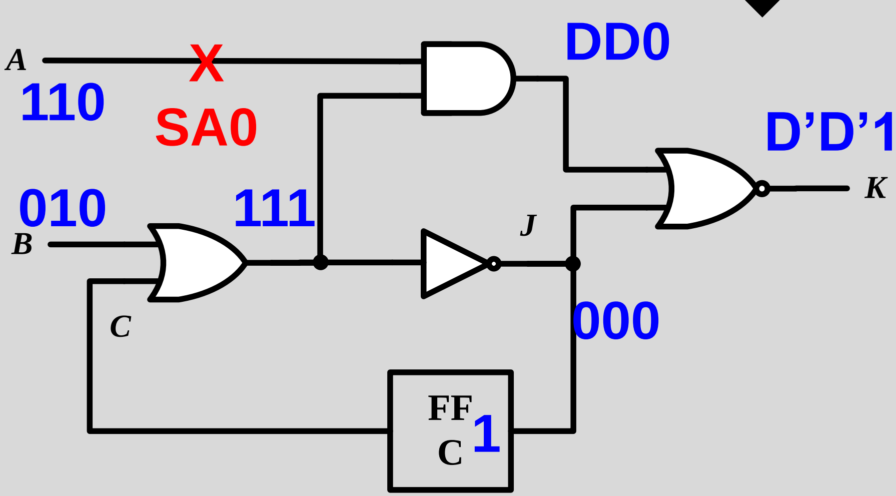
2. Concurrent Fault Detection Phase

- **Start with fault simulation of generated initialization sequence**
  - **Detected faults are dropped from the fault list**
- **Compute the cost of the last vector**
  - **Cost of an undetected fault *f***
    - **COST(*f*) = minimum distance of its fault effect to a PO**
    - **distance = level of logic gates**
  - **Cost of a vector**
    - **Sum of costs of all undetected faults**
- **Trial vectors are generated by single-bit change**
  - **Only accept the vectors that reduce the cost**

Example



AB	cost = distance of D or D' to PO
00	∞
10	2
01	∞



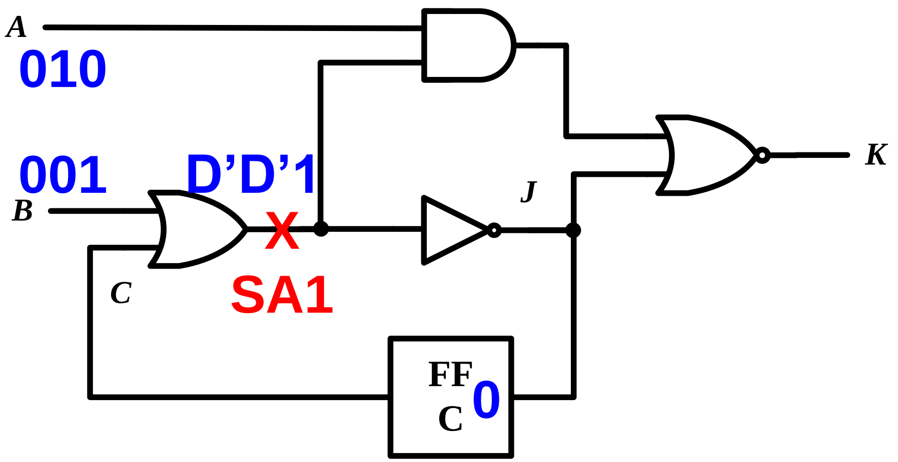
AB	cost = distance of D or D' to PO
10	0
11	0
00	∞

Test Vector Sequence: AB = (01), 10, 11

QUIZ

Q1: Given FF initial state is zero, please evaluate the cost of three trial vectors: 00, 10, 01

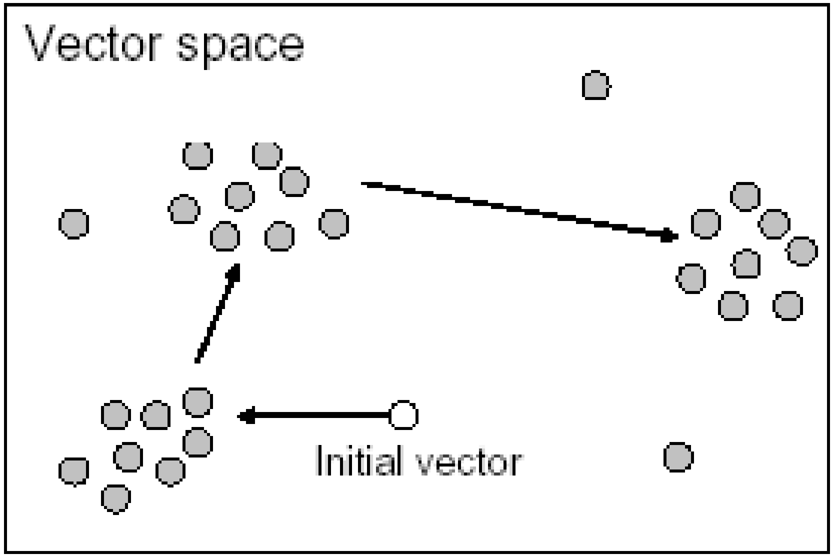
Q2: Which test vector would you pick?



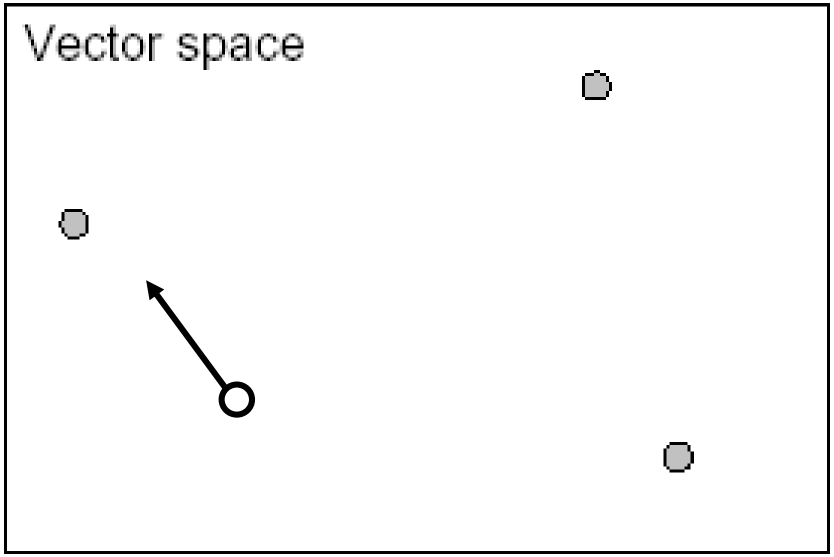
AB	cost = distance of D or D' to PO
00	
10	
01	

Need Phase 3

- **Experience shows test patterns for all stuck-at faults are usually clustered instead of being evenly distributed**
- **When only a few faults are left, their tests will be isolated vectors and we need a different test generation strategy**



Phase 2: Concurrent Fault Detection



Phase 3: Single Fault Detection

3. Single Fault Detection Phase

- Start with any vector
- Generate new vectors by single-bit change to reduce cost of the selected fault until it is detected
  - The lowest cost fault is picked first

- Cost of a fault f at signal line g is
  - If not activated yet:

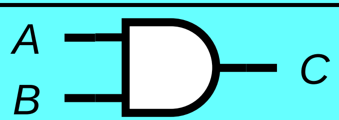
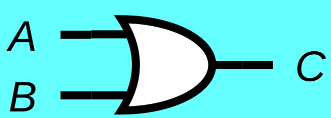
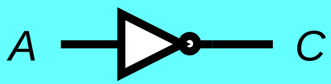
    $KC_A(f) + C_P(f)$

    K = constant ; C_A=activation ;C_p=propagation cost
  - If activated:

    $\mathrm{Min}(C_P(i))$, $i \in$ the set of inputs to signal g

C_A and DC

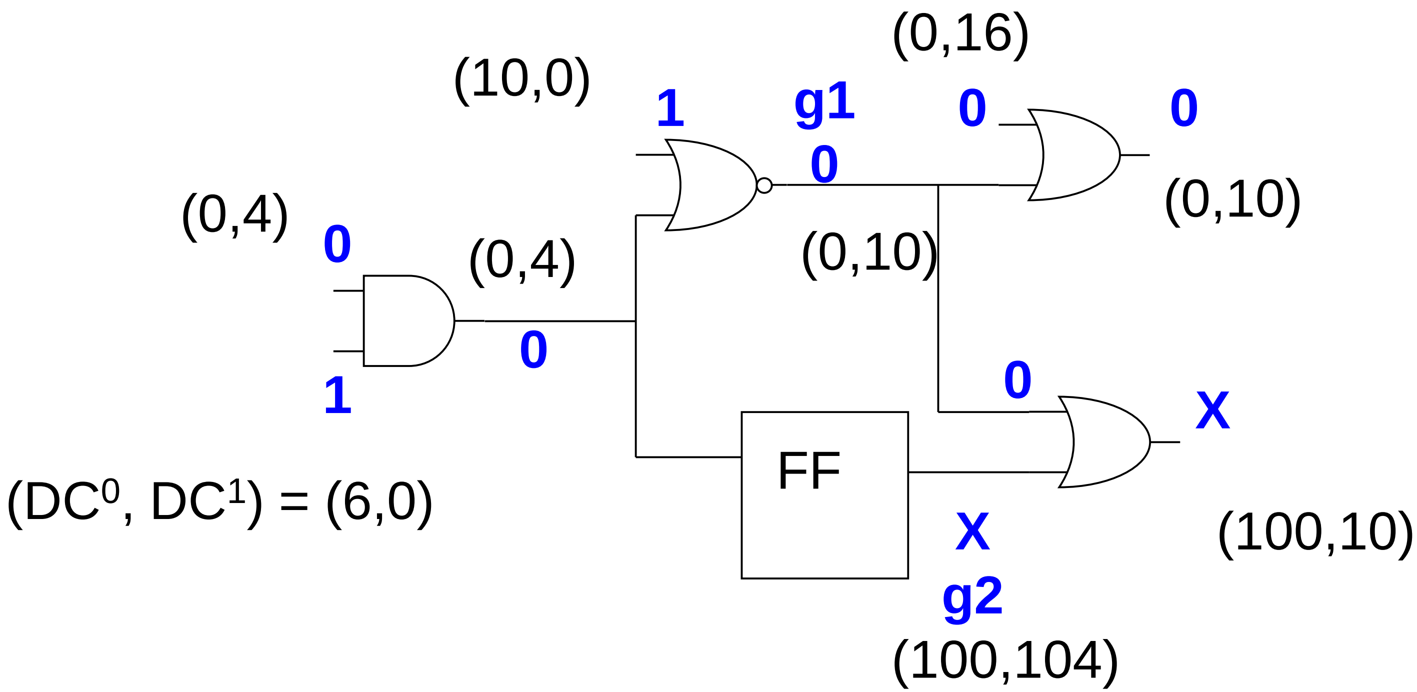
- ***Activation Cost, C_A***
  - C_A(*g* stuck-at-*v*) = $DC_{v'}$(*g*) = dynamic controllability of line *g* at *v'*
- ***Dynamic Controllability, DC***
  - Similar to sequential controllability in SCOAP except logic values known

	$DC^0(C)$	$DC^1(C)$
	$\min[DC^0(A),DC^0(B)]$, if C=1 or x 0 , if C=0	$DC^1(A) + DC^1(B)$, if C=0 or x 0 , if C=1
	$DC^0(A) + DC^0(B)$, if C=1 or x 0 , if C=0	$\min[DC^1(A),DC^1(B)]$, if C=0 or x 0 , if A=1
	$DC^1(A)$, if C=1 or x 0 , if C=0	$DC^0(A)$, if C=0 or x 0 , if C=1
Primary inputs	1 , if C=1 or x 0 , if C=0	1 , if C=0 or x 0 , if C=1
C = FF(A)	$DC^0(A)+K$, if C=1 or x 0 , if C=0	$DC^1(A)+K$* , if C=0 or x 0 , if C=1

* K is a chosen constant

C_A and DC Example

- **$C_A(g_1$ stuck-at 0) = $DC_1(g_1)$ =10 ← easier**
- **$C_A(g_2$ stuck-at 1) = $DC_0(g_2)$ =100**

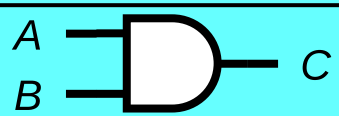
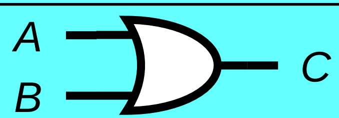
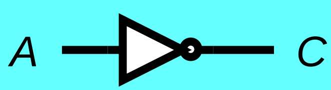
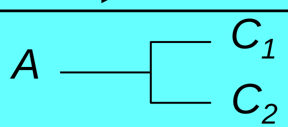


Propagation Cost, C_P

- **$C_p(g)$ = Dynamic Observability of node *g***
- **Dynamic observability (DO)**
  - **Similar to combinational observability in SCOAP**
  - **Measure the effort to observe the fault on a given node**
    - **the number of gates between *N* and PO's, and**
    - **the minimum number of PI assignments required to propagate the logical value on node *N* to a primary output.**

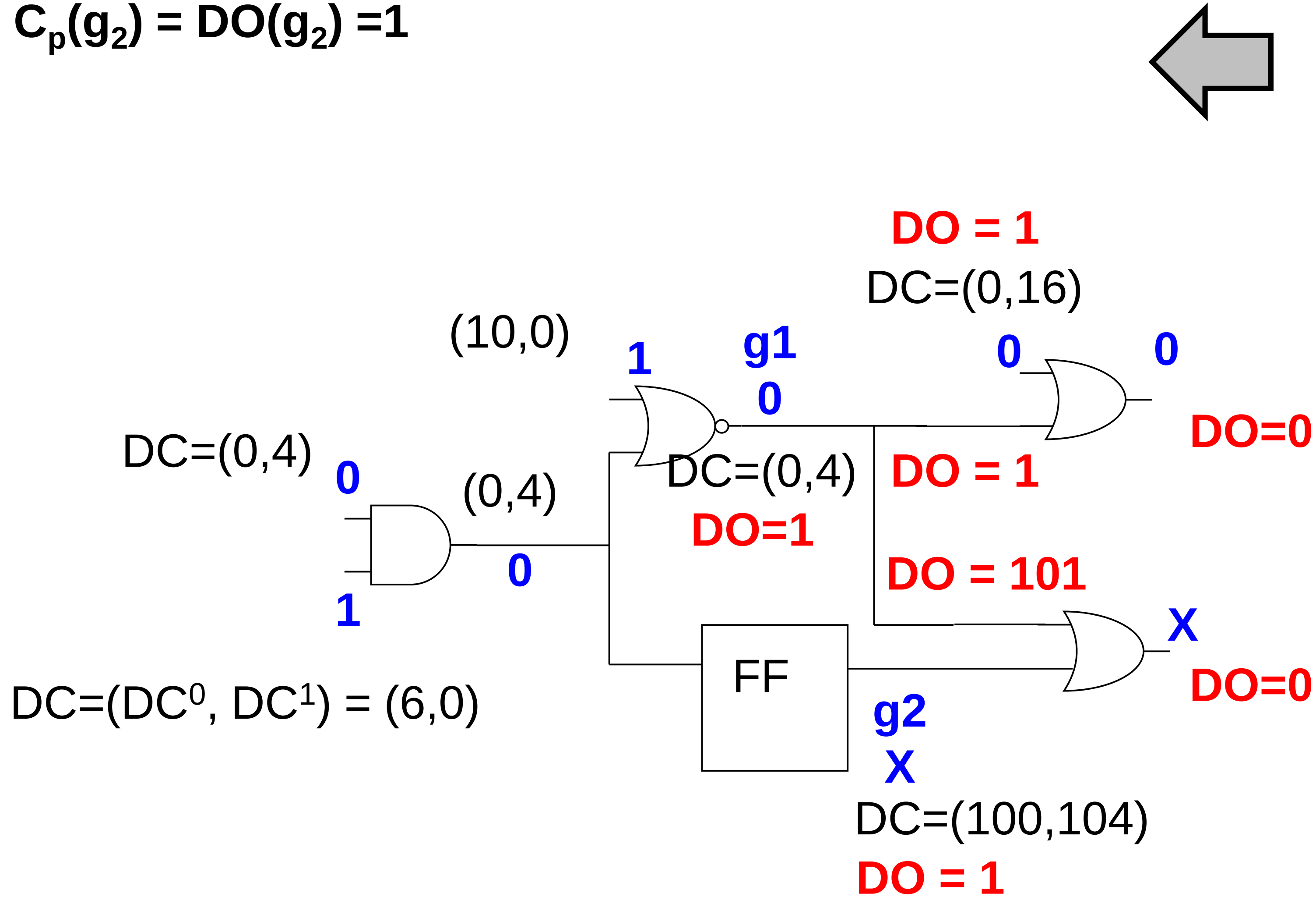
Dynamic Observability (DO)

- **Similar to combinational observability in SCOAP**

	DO(*A*)
	**DO(C) + DC^1(*B*) + 1**
	**DO(*C*) + DC^0(*B*) + 1**
	**DO(*C*) + 1**
	**min[DO(C_1),DO(C_2)]**
Primary outputs	**0**

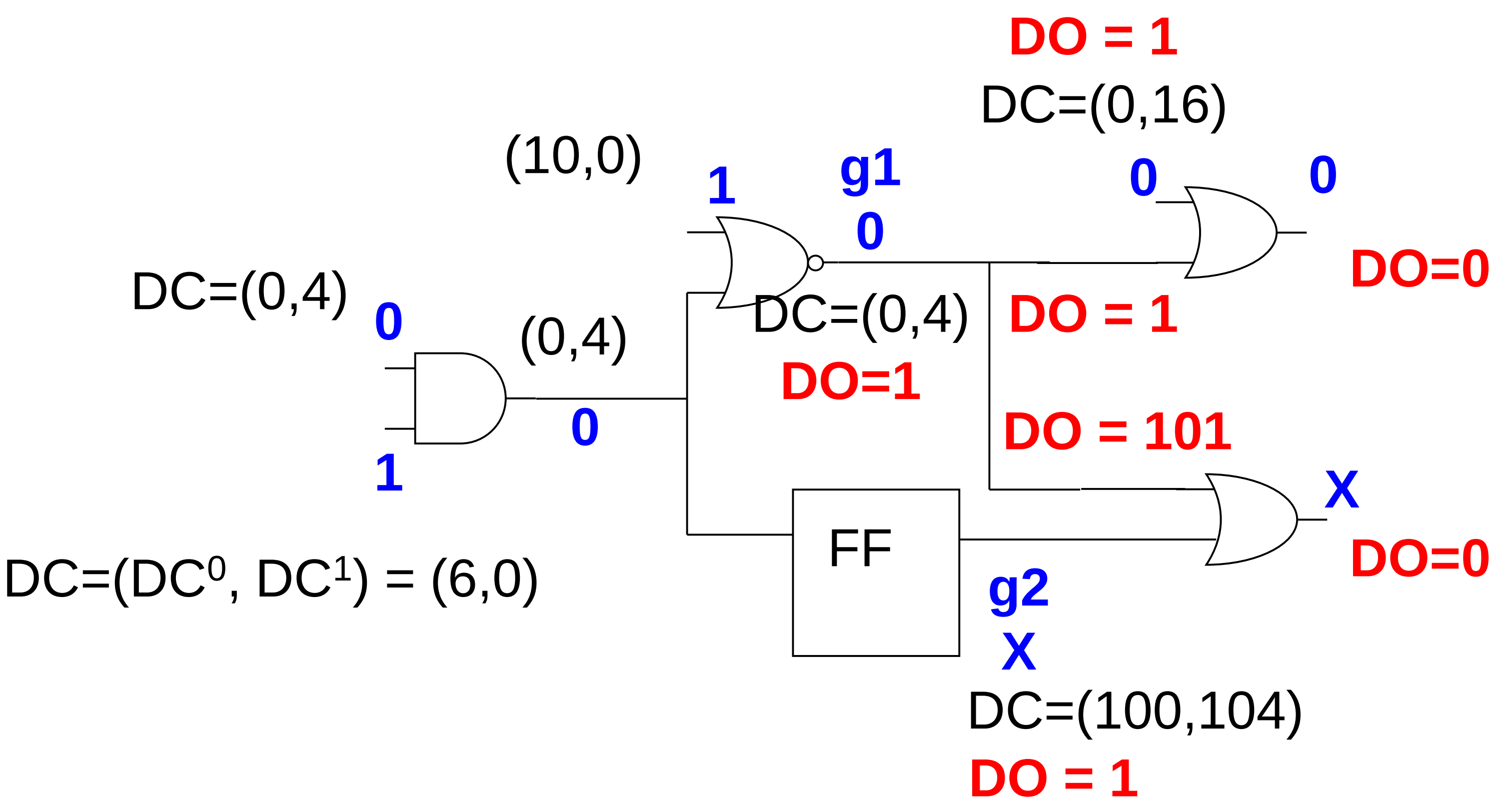
C_p and DO Example

- $C_p(g_1) = DO(g_1) = 1$
- $C_p(g_2) = DO(g_2) = 1$



Total Cost

- **Fault g_1: $C_A = 10$, $C_p = 1$**
- **Fault g_2: $C_A = 100$, $C_p = 1$**
- **Choose g1 SA0 as target fault to generate test vector**



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  - **Genetic Algorithm**
- Issues of Sequential ATPG*
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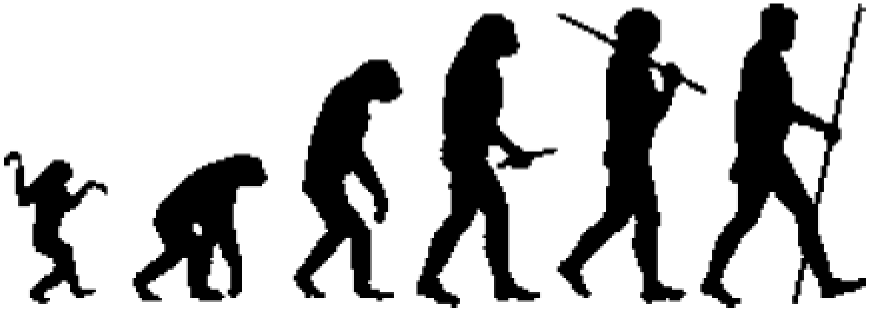
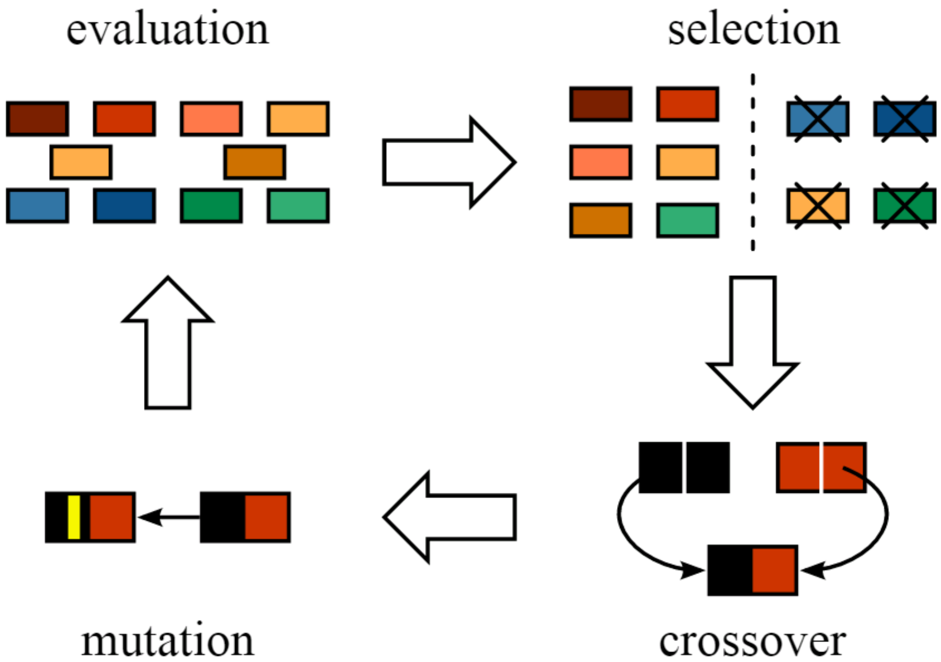


Genetic Algorithms (GA) [Holland 1975]

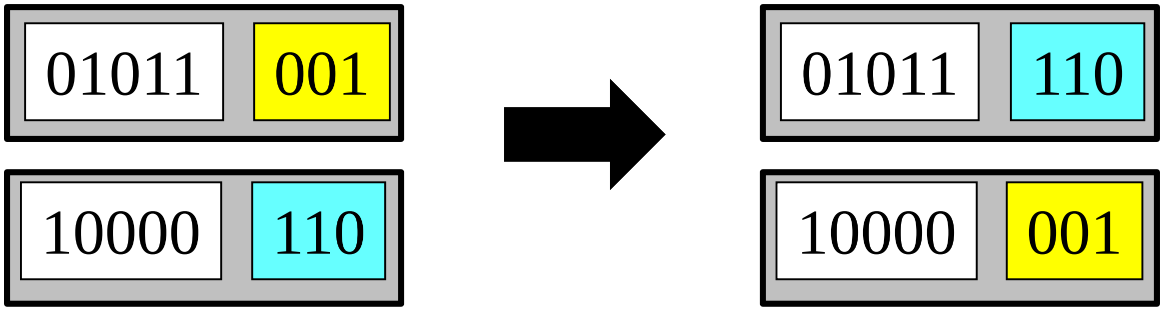
- General Principle: **Survival of fittest(s)**
  - Keep a ***population*** of feasible solutions, not just one
  - Parent population generates child population
    - by gene ***crossover, mutation*** etc
  - Select only best children, remove weak children
  - Repeat the above for many generations



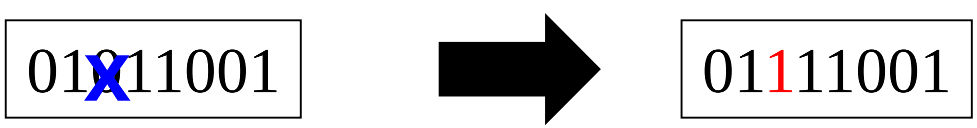
[www.jade-cheng.com]

Crossover and Mutation

- Test vectors are represented by **bit-stream "gene"**
- ***Crossover***: Two feasible solutions generate child by switching gene



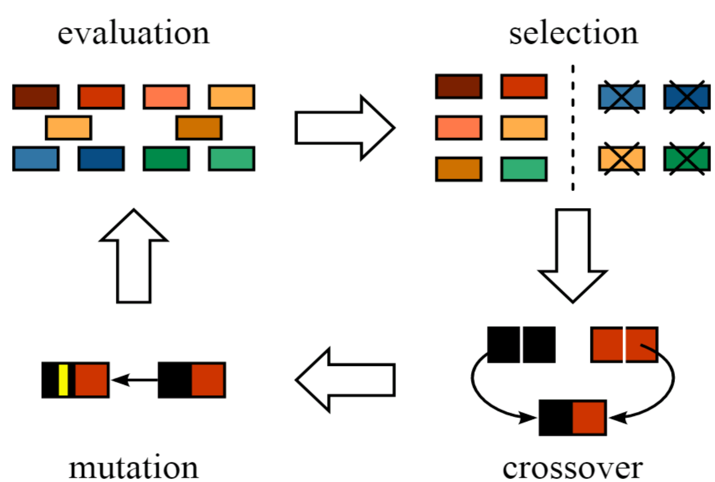
- ***Mutation***: some gene can change by a random probability



Pseudo Code of GA

```
GENETICALGORITHM
pop = set of initial solutions
do
   childpop = ∅
   for (i = 1 to (n x pop.size))  // n times size
       crossover = random 0 or 1
       if (crossover)
          parent1 = random_choose(pop)
          parent2 = random_choose(pop)
          child = crossover(parent1, parent2)
       else   // mutate
          parent = random_choose(pop)
          child = mutate(parent)
       childpop = childpop ∪{child}
   pop = evaluate&select(childpop)
while (!stop)
return (best solution)
```

- Need to decide
- 1. initial solution
- 2. corssover/ mutation
- 3. evaluate & select
- 4. stop criterion



Summary

- Simulation-based methods
  - Randomly generate many trial test vectors
  - Evaluate test vectors by simulation and pick the best
  - Need many testability measure to help smart decision
- Advantages
  - Better memory management than time frame expansion
  - Timing can be considered
  - Use genetic algorithm to optimize
- Disadvantages
  - Cannot identify untestable faults
  - Test length can be longer than time frame expansion