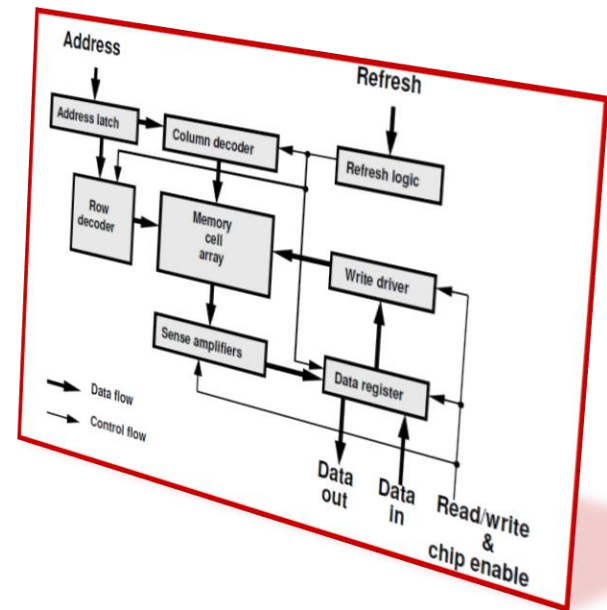


Outline

- Introduction
- Memory Fault Model
- Memory Test Algorithms
- Memory Fault Simulation (*not in exam)
- Memory Test Generation (*not in exam)
- Memory BIST (*not in exam)



Memory Fault Simulation

- What is *memory fault simulation*?
 - ◆ Given test algorithm, memory architecture
 - * find fault coverage of different fault models
- Why fault simulation?
 - ◆ Evaluate fault coverage efficiently,
 - * especially when many fault models
 - ◆ Help test algorithm design and optimization
 - ◆ Fault dictionary can be constructed for easy diagnosis

Sequential Memory Fault Simulation

```
For each fault  /*  $N^2$  for 2-cell CF */  
Inject fault;  
For each test element  /*  $N$  for March */  
    {  
        Apply test element;  
        Report error output  
    }
```

- Complexity is N^3 for 2-cell CF
 - ♦ This is very slow

Parallel Fault Simulation [Wu 02]

- Random Access Memory Simulator for Error Screening (RAMSES)
- Consider all faults at a time
- Complexity N^2

```
# S/1
AGR := w0
SPT := @      /* Single-cell fault */
VTM := r0
RCV := w1
```

```
# CFst <0;s/1>
AGR := v0
SPT := *      /* All other cells are suspects */
VTM := r0
RCV := w1
```

AGR=aggressor
SPT=suspects
VTM=victim
RCV=recover
@=this cell
*=all cells

For each test operation

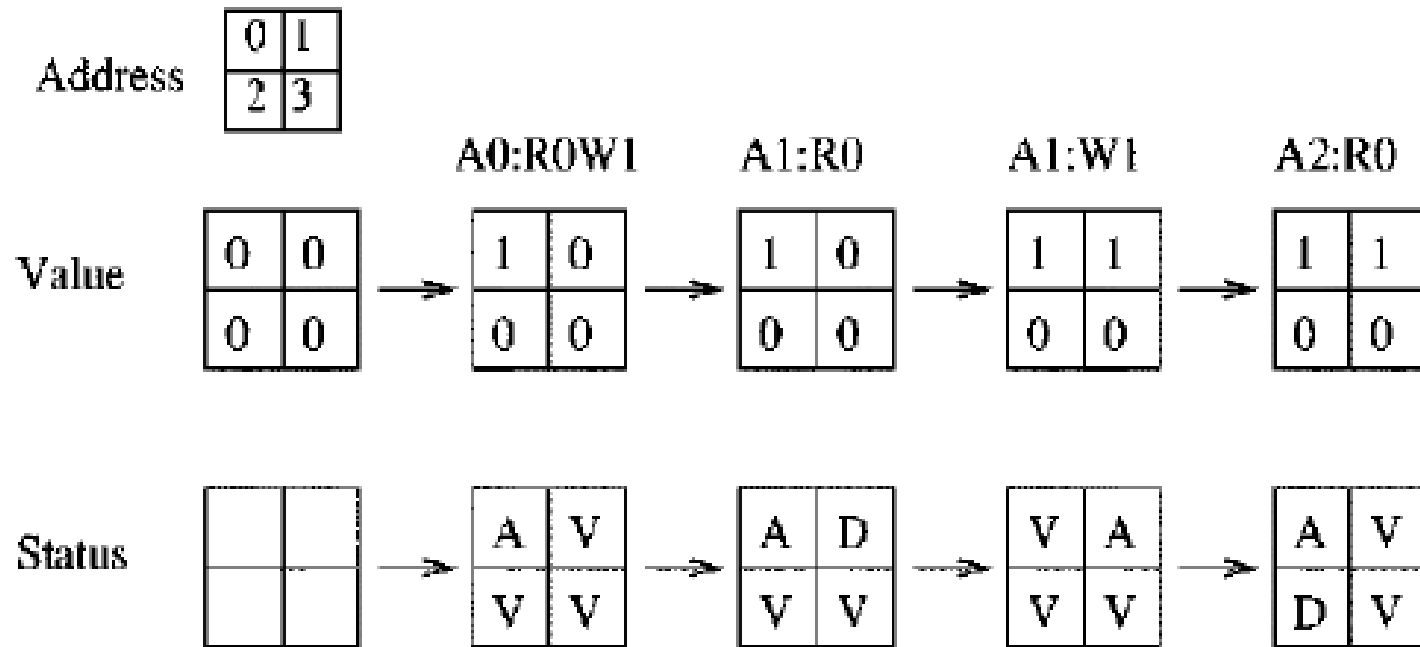
```
{
  If op is AGR then mark victim cells;
  If op is RCV then release victim cells;
  If op is VTM then report error;
}
```

RAMSES Algorithm

```
For each fault operation
  set op_flags;
  if (ARG  $\subset$  op_flags) {
    for each victim cell {
      set victim flags;
      set aggressor address;
    }
  }
  if (OP eq RCV) {
    clear victim flag;
    clear aggressor entry;
  }
  else if (OP eq VTM) {
    mark detected;
  }
}
```

RAMESE Example

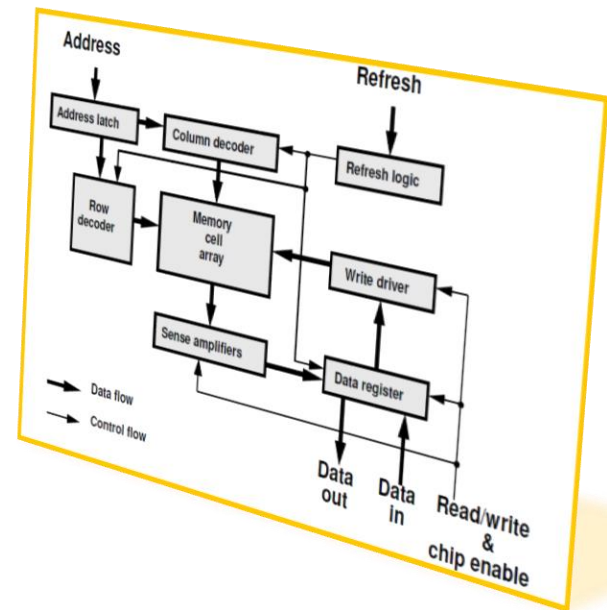
- $CF_{in} < \uparrow / \downarrow >$
- March element $\uparrow(r0, w1)$



D = detect; A = aggressor; V=victim

Outline

- Introduction
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Memory Test Generation

- What is memory test algorithm generation
 - ◆ Given a set of target fault models and a test length constraint,
 - * generate a test with the highest fault coverage
- Priority setting for fault models

TAGS [Wu 00]

- Test Algorithm Generation by Simulation (TAGS)

- March template abstraction:

$\uparrow (w0); \uparrow (r0, w1); \downarrow (r1, w0, r0)$



$\uparrow (w) \uparrow (r, w); \downarrow (r, w, r)$



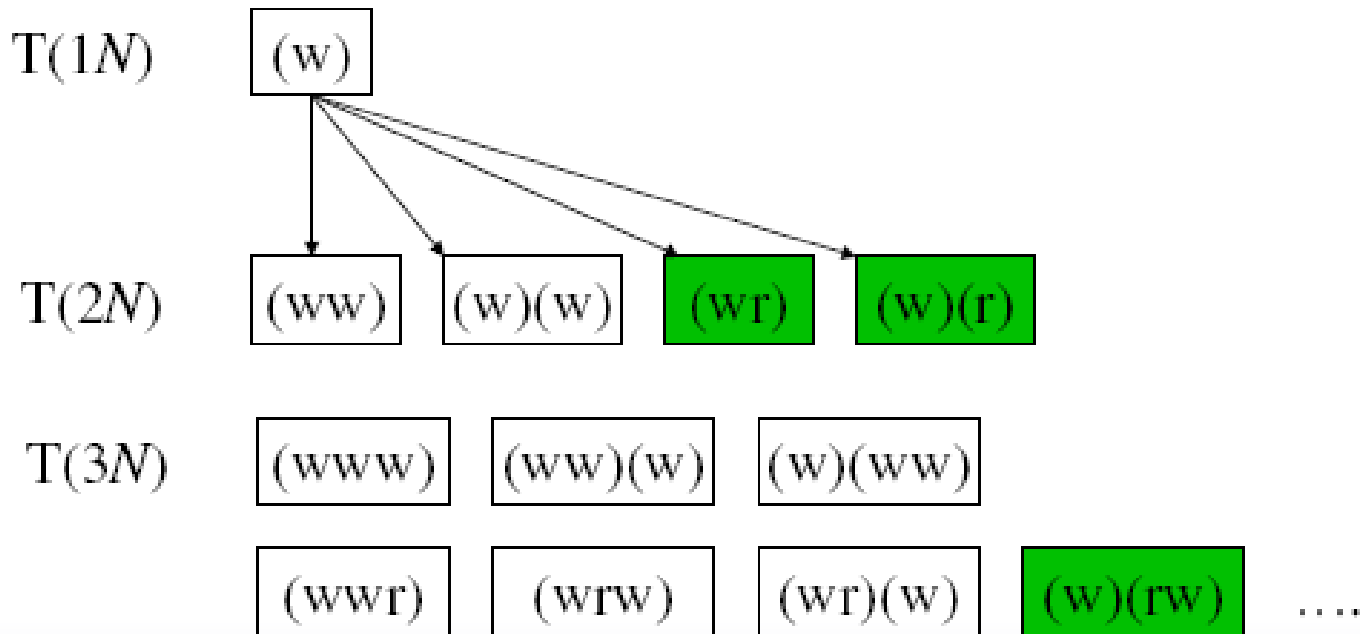
$(w)(rw)(rwr)$



March template

Template Set

- **Template set**
 - ♦ $T(cN)$ = a set of march templates of c read or write
- Exhaustive generation of template set is very expensive
 - ♦ e.g., 6.7 million templates when $N = 9$
- Heuristics should be developed to select useful templates



TAGS Procedure

- 1. Initialize test length as $1N$, $T(1N) = \{(w)\}$;
- 2. **Increase** test length by $1N$: apply generation options;
- 3. Apply *filtering* heuristics;
- 4. Assign **address orders** and **data backgrounds**;
- 5. **Fault simulation** using RAMSES;
- 6. Drop ineffective tests;
- 7. Repeat 2-6 using the new template set until constraints met;

Template Generation and Filtering

- **Generation** heuristics:
 - ♦ (r) insertion
 - ♦ (...r), (r...) expansion
 - ♦ (w) insertion
 - ♦ (...w), (w...) expansion
- **Filtering** heuristics:
 - ♦ Consecutive read: (...rr...)
 - ♦ Repeated read: (r)(r)
 - ♦ Tailing single write: ...(w)

3N March Test

- 3N March Test generated by TAGS after step 3

- ◆ WWW Table 8.7

	Test
1	$\uparrow\uparrow(w0) \uparrow\uparrow(w1, r1)$
2	$\uparrow\uparrow(w0) \downarrow\downarrow(w1, r1)$
3	$\uparrow\uparrow(w0) \uparrow\uparrow(w0, r0)$
4	$\uparrow\uparrow(w0) \downarrow\downarrow(w0, r0)$
5	$\uparrow\uparrow(w0) \uparrow\uparrow(r0, w1)$
6	$\uparrow\uparrow(w0) \downarrow\downarrow(r0, w1)$
7	$\uparrow\uparrow(w0) \uparrow\uparrow(r0) \uparrow\uparrow(r0)$
8	$\uparrow\uparrow(w0) \uparrow\uparrow(w1) \uparrow\uparrow(r1)$

- 3N March test selected by RAMSES

- ◆ WWW Table 8.8

	Test
3	$\uparrow\uparrow(w0) \uparrow\uparrow(w0, r0)$
5	$\uparrow\uparrow(w0) \uparrow\uparrow(r0, w1)$
8	$\uparrow\uparrow(w0) \uparrow\uparrow(w1) \uparrow\uparrow(r1)$

TAGS Examples (1/2)

- WWW Table 8.9

$T(N)$	Name	Match algorithm
$1N$	M_1^1	$\uparrow (w_0)$
$2N$	M_1^2	$\uparrow (w_0) \uparrow (r_0)$
$3N$	M_1^3	$\uparrow (w_0) \uparrow (w_1) \uparrow (r_1)$
$3N$	M_2^3	$\uparrow (w_0) \uparrow (r_0, w_1)$
$3N$	M_3^3	$\uparrow (w_0) \downarrow (w_1) \uparrow (r_1)$
$3N$	M_4^3	$\uparrow (w_0) \downarrow (r_0, w_1)$
$4N$	M_1^4	$\uparrow (w_0) \downarrow (r_0, w_1) \uparrow (r_1)$
$4N$	M_2^4	$\uparrow (w_0) \downarrow (r_0, w_1, r_1)$
$5N$	M_1^5	$\uparrow (w_0) \uparrow (w_1) \uparrow (r_1, w_0) \uparrow (r_0)$
$5N$	M_2^5	$\uparrow (w_0) \downarrow (r_0, w_1) \uparrow (r_1, w_0)$
$5N$	M_3^5	$\uparrow (w_0) \uparrow (w_1) \uparrow (r_1, w_0, r_0)$
$6N$	M_1^6	$\uparrow (w_0) \uparrow (w_1) \uparrow (r_1, w_0) \downarrow (r_0, w_1)$
$6N$	M_2^6	$\uparrow (w_0) \downarrow (r_0, w_1) \uparrow (r_1, w_0) \uparrow (r_0)$
$6N$	M_3^6	$\uparrow (w_0) \uparrow (r_0, w_1) \uparrow (r_1, w_0) \uparrow (r_0)$
$6N$	M_4^6	$\uparrow (w_0) \uparrow (r_0, w_1) \uparrow (r_1, w_0, r_0)$
$6N$	M_5^6	$\uparrow (w_0) \downarrow (r_0, w_1) \uparrow (r_1, w_0, r_0)$
$7N$	M_1^7	$\uparrow (w_0) \uparrow (r_0, w_1) \uparrow (r_1, w_0) \downarrow (r_0, w_1)$

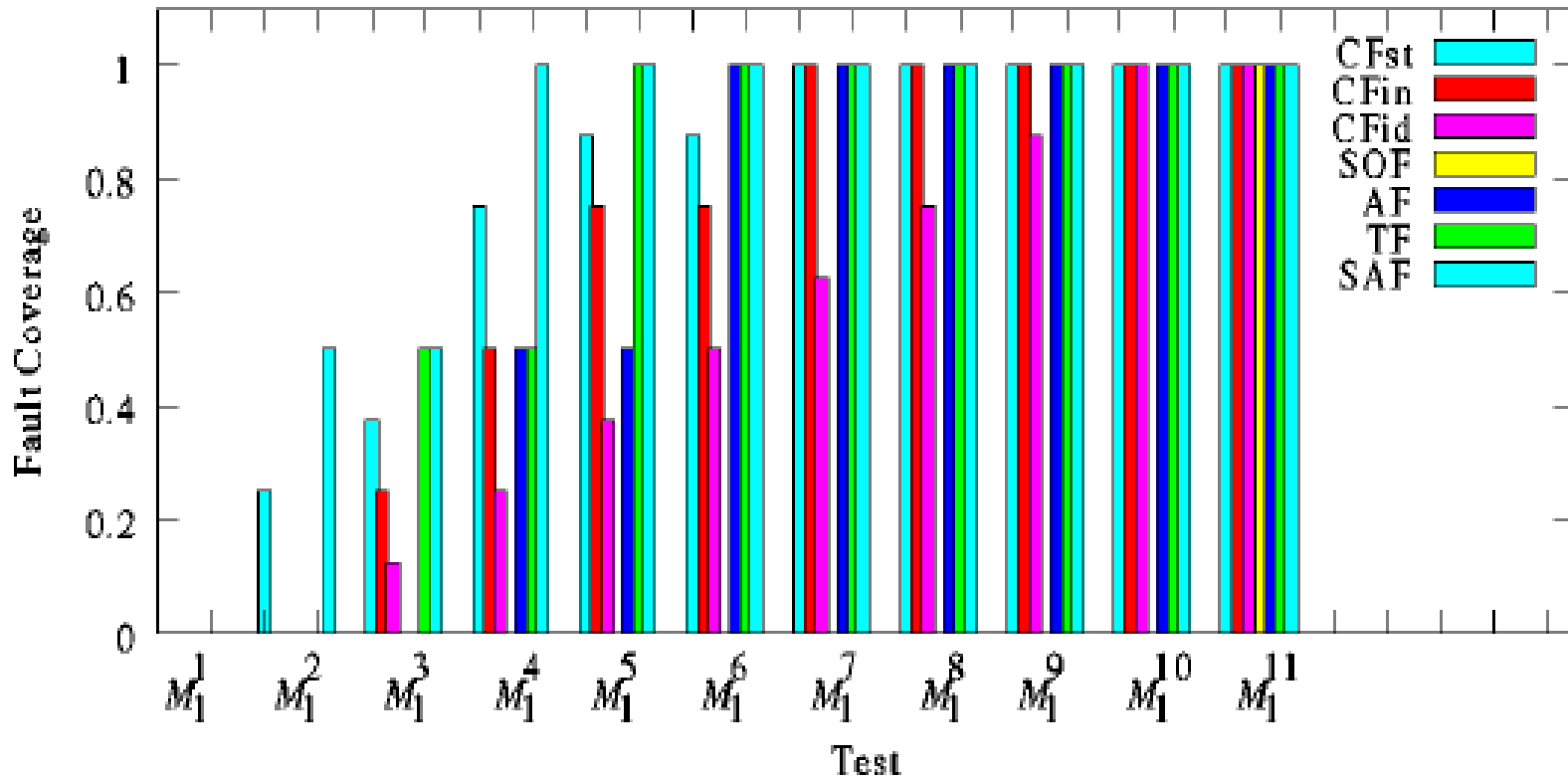
TAGS Examples (2/2)

- WWW Table 8.9 cont'd

7N	M_1^7	$\uparrow(w0) \uparrow(\tau0, w1) \uparrow(\tau1, w0) \downarrow(\tau0, w1)$
7N	M_2^7	$\uparrow(w0) \uparrow(w1) \downarrow(\tau1, w0) \uparrow(\tau0, w1, \tau1)$
7N	M_3^7	$\uparrow(w0) \downarrow(\tau0, w1) \uparrow(\tau1, w0, \tau0) \uparrow(\tau0)$
7N	M_4^7	$\uparrow(w0) \uparrow(\tau0, w1) \uparrow(\tau1, w0, \tau0) \uparrow(\tau0)$
8N	M_1^8	$\uparrow(w0) \uparrow(\tau0, w1) \uparrow(\tau1, w0) \downarrow(\tau0, w1)$ $\uparrow(\tau1)$
8N	M_2^8	$\uparrow(w0) \uparrow(\tau0, w1) \uparrow(\tau1, w0)$ $\downarrow(\tau0, w1, \tau1)$
9N	M_1^9	$\uparrow(w0) \uparrow(\tau0, w1) \uparrow(\tau1, w0) \downarrow(\tau0, w1)$ $\downarrow(\tau1, w0)$
9N	M_2^9	$\uparrow(w0) \uparrow(\tau0, w1) \uparrow(\tau1, w0)$ $\downarrow(\tau0, w1, \tau1) \uparrow(\tau1)$
10N	M_1^{10}	$\uparrow(w0) \uparrow(\tau0, w1) \uparrow(\tau1, w0) \downarrow(\tau0, w1)$ $\downarrow(\tau1, w0) \uparrow(\tau0)$
10N	M_2^{10}	$\uparrow(w0) \uparrow(\tau0, w1) \uparrow(\tau1, w0) \downarrow(\tau0, w1)$ $\downarrow(\tau1, w0, \tau0)$
11N	M_1^{11}	$\uparrow(w0) \uparrow(\tau0, w1) \uparrow(\tau1, w0) \downarrow(\tau0, w1)$ $\downarrow(\tau1, w0, \tau0) \uparrow(\tau0)$

RAMSES Simulation Results

- WWW Figure 8.13



RAMSES Simulation Results

- WWW Figure 8.14
 - ♦ Five different 6N tests

