CDA 5140
N-Modular Redundancy

- have introduced the concept of N-modular Redundancy (NMR) previously but have not gone into detail

- in this chapter investigate this means of error correction or detection

- in particular, useful for hardware but similar concepts can be used for software

- if have two modules and both outputs same, then either can be that both are correct or both have failed in the same way, the former being more likely

- if 2 modules differ in outputs, detect that there is an error but does not indicate which one in error

- if have three modules, and all agree much more likely that all correct than all three have failed identically

- if one of three modules disagrees with the other two, most likely that this one is in error, and hence have error correction

- if however, two of the three fail, it is possible that the hardware in both has failed identically and hence the majority would be in error

- history of NMR is quite lengthy in terms of computer history as an exercise in making reliable computing machines out of unreliable components

TMR – Triple Modular Redundancy

- most well known version of NMR – Figure 4.1

- typically assume that all modules are identical in terms of digital logic

- this model assumes the *voter does not fail*

- reliability (probability of no failures) then given as:

$$R = P(AB + AC + BC)$$

- if all digital circuits in figure 4.1 are independent and identical with probability of success *p*, then the above probability is that of all 3 being correct or at least two being correct, which reduces to

$$R = p^2 (3 - 2p)$$

System Error Rate

- above considered probability of no failures, but also of interest to consider error rate

- this is of interest in digital communications systems for example where temporary equipment malfunctions or noise can allow for continued service if infrequent

- similarly, as discussed in coding section, digital computer processing non-critical data can tolerate an error

- third example is that of rocket control, where can recover from small error during mid-flight

- Figure 4.2 demonstrates the probability of such success as element reliability gradually becomes worse

Where to test?

- often have information on a system malfunctioning, in which case can lock out such a system and continue with reduced number of systems

- as N is increased in NMR, and everything is on single chip, then problem of testing becomes only inputs and outputs

- further issue if each system has, for example, 3 subcomponents, A, B, C, then should there be one voter for the results of $A_1B_1C_1$, $A_2B_2C_2$, $A_3B_3C_3$ or is there a voter for $A_1A_2A_3$ and $B_1B_2B_3$ and $C_1C_2C_3$ for three voters?

- can extend this to *m* series subsystems as in Figure 4.5

Voter Reliability

- so far have assumed that voter cannot fail, which obviously is inaccurate

- in fact, system reliability can not exceed the reliability of the voter

- series set up as in figure 4.5 makes it even worse
- Figure 4.8 replicates the voters at each level, so that errors do not propagate more than one level (e.g. if B_1 fails, fault contained) and voter errors only propagate one level but are stopped (e.g. V_1" fails)

Model Limitations

- some interesting observations on developing models of fault systems arise
- note that some of the most common permanent errors are s-a-1 and s-a-0
- for TMR, if circuit computes one bit, then if one circuit fails as s-a-1 and one as s-a-0, then if the correct output is a 1 (correctly determined by one circuit) then two circuits will give the correct output, as will be done for a correct output of 0
- thus have the correct output when there are 2 faults
- another situation that can be corrected but which would not fit into the model of correcting only a single error is described when output is 4 bits, and the correct output should be 0110 and is obtained by the first circuit
- 2nd circuit has an error in the first bit and produces 1110
- 3rd circuit has an error in the last bit and produces 0111
- if the vote is on three 4-bit words, all disagree
- if vote is a bit at a time, then correct value will be obtained, again with 2 errors

Voter Logic

- will have a brief look at the construction of a voter
- Table 4.2 and corresponding Karnaugh maps in Tables 4.3 and 4.4 produce the circuits in Figure 4.9

Alternate Voting Systems

Voting with Lockout

- with N > 3 can use alternate approaches
- for N = 4, have the design used for Space Shuttle (Figure 5.19) for the first 4 computers
- failures can be permanent or transient
- if assume fault is permanent, no point in maintaining its vote, so can lockout
- reason behind this is that if left in and 2nd fault occurs which agrees with the first, and the 2 good elements agree, it is at a standoff
- on space shuttle, astronaut can disconnect the faulty unit
- this is called fail-safe-fail-operational by NASA

Adjudicator Algorithms

- version of NMR such that have $n + 1$ of $2n + 1$ = N elements agree, n an integer > 0 (usually 1 or 2)
- for N even, describe as an *m-out-of-N* voter, where $m \geq \lceil (N+1)/2 \rceil$

Consensus Voting

- if the majority do not agree, yet there is a definite consensus, in certain situations that can be used
- one example is allowing the consensus approach to run to check if it is functioning appropriately (in software this is the acceptance test)
- another example is to take the consensus and run a problem with a stored solution and if correct, take the consensus value for the original

Test and Switch Techniques

- approach is if you have valid tests, then test and as long as the result is valid stay with that element
- on failure, switch to the other element

Pairwise Comparison

- for an even number of elements, set them up in pairs
- outputs compared in pairs
- if pairs do not check, they are switched out of circuit

Adaptive Voting

- can be used for situations where there are intermittent failures
- in such situations don’t want to lockout the system
- can add weights to the voting for units based on statistics on behavior
- can again used pre-computed results to test this
- in general, use human operators to manage some of this, although with advances on agents and AI techniques could become automatic
- interesting observations about adding GPS to commercial airliners as prices on such units decrease
- comparable situation occurred in the 1780s when pocket chronometers dropped in price to 65 pounds and ship captains in East India Company and Royal Navy bought them to calculate longitude when at sea!