- what should the loyal participants do?
- we need a default action e.g. "retreat"

- solution for 1 disloyal general
  - there must be $n \geq 3d+1$ ($e.g. \geq 4$) generals
  - the commander issues command v to all lieutenants
  - lieutenants tell each other what they heard and they each store these v_is in a vector
  - each lieutenant acts on $v = \text{majority}\{v_i\}$

e.g. 4 generals, $v = a$ (attack), lieutenant 3 is disloyal

lt. 1's vector

1	2	3
a	a	X

, $v = \text{majority}\{a, a, X\} = a$

- solution for 2 disloyal generals
  - need at least $n=7$ generals
  - the lieutenants share their vectors with each other and store in a table
  - each lt. takes the majority heard by each lt.

e.g. 7 generals, $v = a$, lt. 3 & lt. 6 are disloyal

lt. 1's table

i \ j	1	2	3	4	5	6
1	-	a	X	a	a	X
2	a	-	X	a	a	X
3	X	X	-	X	X	X
4	a	a	X	-	a	X
5	a	a	X	a	-	X
6	X	X	X	X	X	-

row 1 what lieutenant 1 heard

row 2 what lt. 2 heard

column majority: | a | a | X | a | a | X |

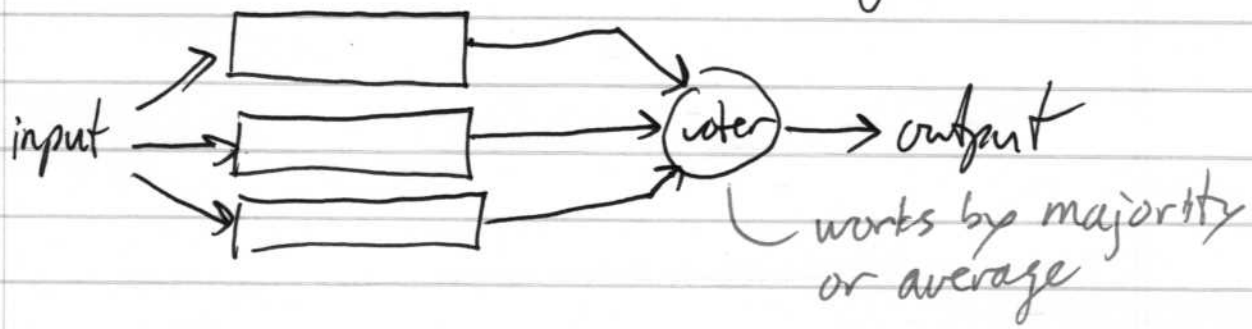
↑ consensus on what lt. 4 heard

v = majority{a, a, X, a, a, X}

= a

- summarize
  - there must be $n = 3d+1$ generals where d = # of disloyal generals
  - # of rounds of communication = d
  - runtime complexity = $O(n^{d+1})$

- fault tolerant systems
  - use redundant sensors, redundant busses, redundant processors
  - their outputs are combined using voters



- Apollo rockets: Triple Modular Redundancy (TMR)
  - 3 computers all doing same thing

- Dual-Dual systems: used in satellites
  - 2 pairs of identical processors all doing same thing
  - if 1 pair disagrees, then the other takes over

- early autolanders in jets:
  Boeing 747: TMR
  Lockheed L-1011: Dual-Dual

- Boeing 777 flight computers
  - 3 groups of 3 computers
  - each group has a command computer, a monitor computer and a standy computer

- each group has different processors: Motorola 68040, Intel 80486, AMD 29030
- all software was in Ada but compiled with 3 different compilers

A380 - uses a dual-dual system with a standby pair