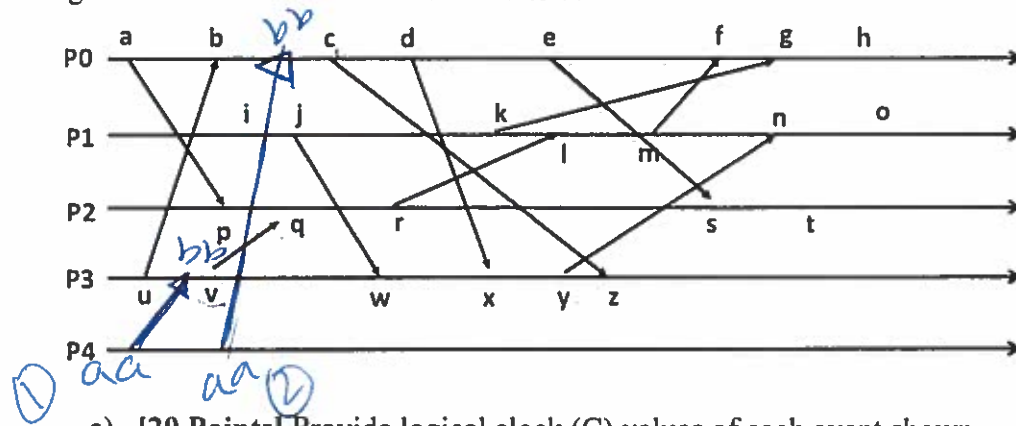


1. Consider the following figure that shows five processes (P_0, P_1, P_2, P_3, P_4) with events a, b, c, \dots and messages communicating between them. Assume that initial logical clock values are all initialized to 0.



a) [20 Points] Provide logical clock (C) values of each event shown.

a 0

b 1

c 2

d 3

e 4

f 6

g 7

h 8

i 0

j 1

k 2

l 4

m 5

n 6

o 7

p 1

q 2

r 3

s 5

t 6

u 0

v 1

w 2

x 4

y 5

z 6

Grading

① -1: if all numbers are 1 greater

② -2: for 1 error

③ -5: for up to 5 errors

④ -15: up to 10 errors

b) [20 Points] Provide vector clock (V) values of each event shown.

a [1 0 0 0 0]

b [2 0 0 1 0]

c [3 0 0 1 0]

d [4 0 0 1 0]

e [5 0 0 1 0]

f [6 5 3 2 0]

g [7 5 ~~2~~ 2 0]

h [8 5 ³ 2 0]

i [0 1 0 0 0]

j [0 2 0 0 0]

k [0 3 0 0 0]

l [1 4 3 2 0]

m [1 5 3 2 0]

n [4 6 3 5 0]

o [4 7 3 5 0]

p [1 0 1 0 0]

q [1 0 2 2 0]

r [1 0 3 2 0]

s [5 0 4 2 0]

t [5 0 5 2 0]

u [0 0 0 1 0]

v [0 0 0 2 0]

w [0 2 0 3 0]

x [4 2 0 4 0]

y [4 2 0 5 0]

z [4 2 0 6 0]

Grading

① -1: if all values are 1 less

② -2: for 1 error

③ -5: up to 5 errors

④ -15: up to 16 errors

- c) [10 Points] Identify two events a_i and a_j to show that $C(a_i) < C(a_j)$ does not necessarily imply $a_i \rightarrow a_j$.

There are lots of them.
 e.g. v and c
 i and b
 i and c ...

- d) [10 Points] Assuming $P_0 < P_1 < P_2 < P_3 < P_4$, provide the total ordering of all events constructed from the logical clock C . Is this total order unique?

$a \ i \ u \ b \ j \ p \ v \ c \ k \ z \ w$ -2: 100%
 $\rightarrow d \ r \ e \ l \ x \ m \ s \ y$ -5: up to 50%
 $\rightarrow f \ n \ t \ z \ g \ o \ h$ -15: up to 100%

Yes. This order is unique based on the logical clock and process ordering.

- e) [10 Points] Suppose process P_4 sends a message m (send event is aa and the corresponding receive event is bb). Show how $aa \rightarrow z$, $aa \rightarrow t$, and aa and b are concurrent. Identify an event a_i ($a_i \neq aa$) such that $a_i \rightarrow bb$.

Two possibilities) See figure } 8 points for identity 1 of 2
 ①: ~~$a \rightarrow bb$~~ $u \rightarrow bb$
 ②: $a \rightarrow bb$
 $b \rightarrow bb$ } 2 points

2. **[30 Points]** Browse the NTP project webpage (<http://www.ntp.org>). Explain how NTP computes filter dispersion.

Grade for completion