Computer Systems

Exercise 6

Now with 300% more quizzes

REMINDER: Exam question

vs

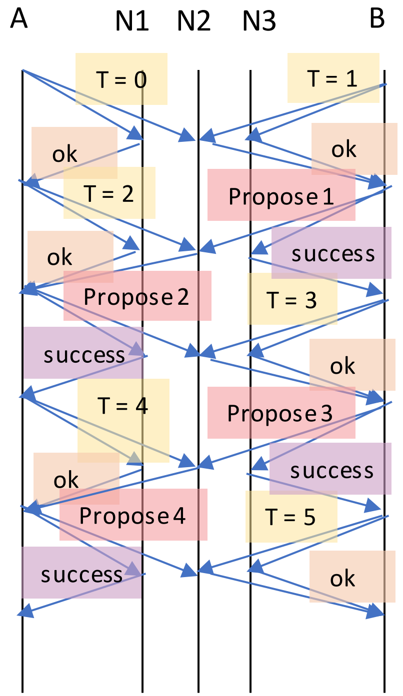
https://hanslodge.com/clipart/8Txr4xdoc.htm
http://clipartmag.com/angel-cartoon-clipart

Bonus Exam Question

- Deadline: Nov. 1st
- Upload through Polybox
- See the course website for details + Polybox link

Last last exercise

- Example where Paxos does not terminate does not work if same ticket number! But with ticket A = ticket B -1 it works!



Algorithm 7.13 Paxos

Client (Proposer) | **Server (Acceptor)**

Initialization ....

c ◁ *command to execute*
$t = 0$ ◁ *ticket number to try*

$T_{\max} = 0$ ◁ *largest issued ticket*

$C = \perp$ ◁ *stored command*
$T_{\text{store}} = 0$ ◁ *ticket used to store C*

Phase 1 ....

Clients asks for a specific ticket ***t***

$t = t + 1$
Ask all servers for ticket t

if $t > T_{\max}$ then
    $T_{\max} = t$
    Answer with ok(T_{store}, C)
end if

Server only issues ticket ***t*** if ***t*** is the largest ticket requested so far

Phase 2 ....

If client receives majority of tickets, it proposes a command

if a majority answers ok then
    Pick (T_{store}, C) with largest T_{store}

    if $T_{\text{store}} > 0$ then
        $c = C$
    end if
    Send propose(t, c) to same majority
end if

if $t = T_{\max}$ then
    $C = c$
    $T_{\text{store}} = t$
    Answer success
end if

When a server receives a proposal, if the ticket of the client is still valid, the server stores the command and notifies the client

Phase 3 ....

If a majority of servers store the command, the client notifies all servers to execute the command

if a majority answers success then
    Send execute(c) to every server
end if

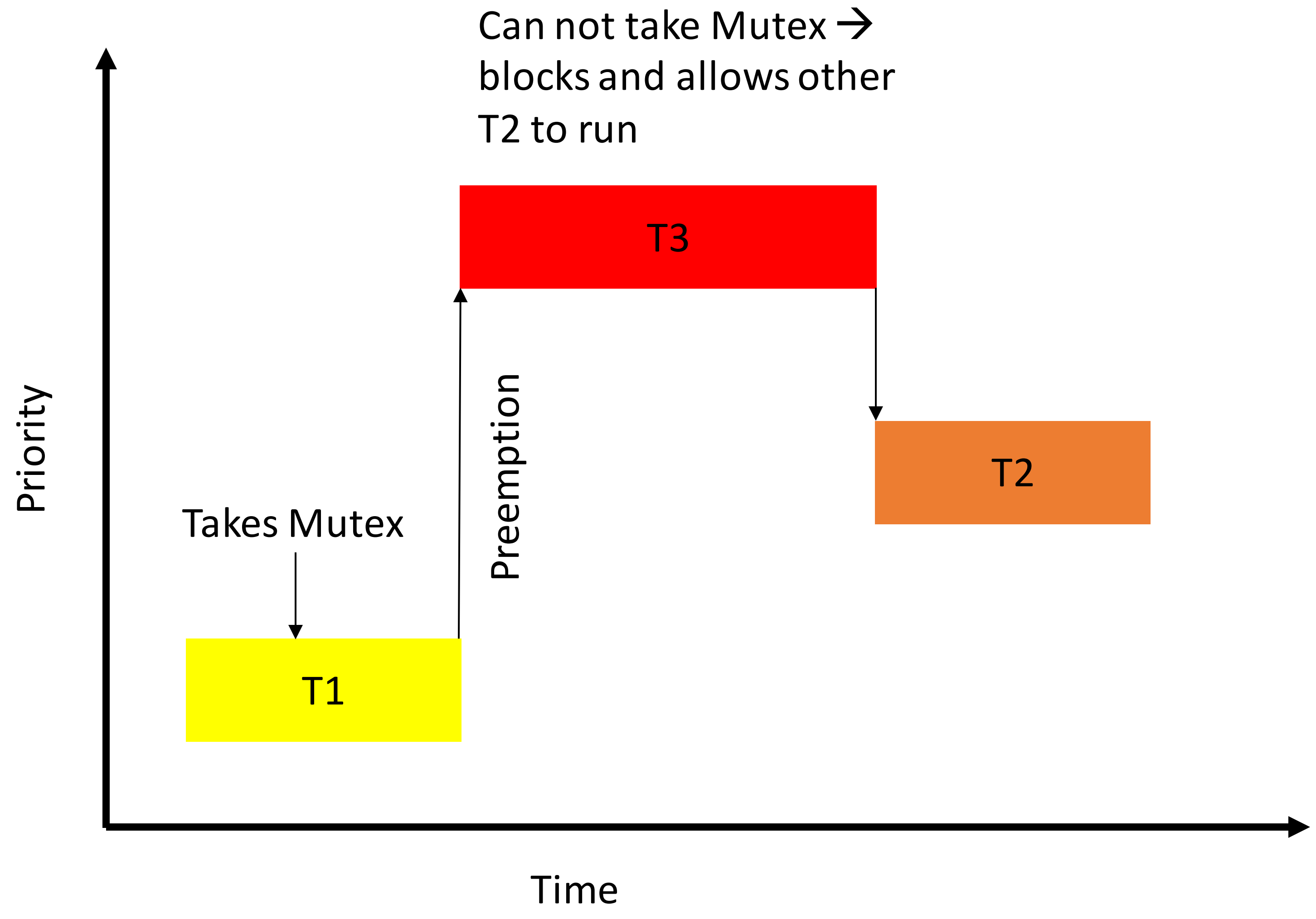
Last Exercise

- What is the problem with shortest job first (SJF)?
  - *Answer: Long jobs are potentially never scheduled*
- What is the advantage of shortest job first (SJF)?
  - *Answer: It minimizes the average time a task is waiting to be scheduled (and therefore the average turnaround time)*
- What is the benefit of round robin(RR)?
  - *Answer: It has a good response time. (And is easy to implement/understand/analyze)*

Last Exercise

- Why do hard realtime systems often don’t have dynamic scheduling?
  - *Answer: In a dynamic setup, the feasibility of a correct schedule is often not guaranteed -> we don’t want that for hard realtime systems.*
- What is priority inversion?
  - *Answer: A lower priority task is running and holding a lock for A, it gets preempted by a higher priority task which can’t proceed because the lower priority thread is still holding the lock and gives up the scheduler to a medium priority thread.*

Priority Inversion



Last exercise

- What is the problem with priority inversion?
  - *Answer: High-priority tasks cannot proceed because low-priority tasks are running.*
- What preconditions must hold to achieve priority inversion?
  - *Answer: There must be at least three runnable tasks of different priorities. The lowest one must hold a lock that the highest one needs to proceed.*
- How can this problem be solved?
  - *Answer: This can be solved by the priority inheritance scheme. The task holding the lock temporarily inherits the priority of the task which wants to acquire the lock.*

Last exercise

- How many levels of priority inheritance do you need?
  - *You need as many levels as possible priority levels.*
- Why?
  - *Because the low priority thread has to inherit the priority of the high priority thread that wants to acquire the priority.*
- How could you implement that?
  - *Problem: A low priority thread holding multiple locks that multiple high priority tasks want. So after releasing one lock and one high priority task running, the priority shouldn't be reset to the original level, but to the one of the other thread needing the lock.*
  - *Solution: A linked list of priorities that the thread will get reset to.*
  - *Easier Solution: priority ceiling*

Last exercise

- State three advantages/disadvantages of placing functionality in the device controller (hardware), rather than in the kernel (software)?
  - *Advantages:*
    - *Bugs are less likely to cause an operating system crash*
    - *Performance can be improved by utilizing dedicated hardware and hard-coded algorithms*
    - *The kernel is simplified by moving algorithms out of it*
  - *Disadvantages*
    - *Bugs are harder to fix- a new firmware version or new hardware is needed*
    - *Improving algorithms likewise require hardware update rather than just a kernel or device driver update*
    - *Embedded algorithms could conflict with application’s use of the device, causing decreased performance*

Last exercise

- Why might a system use interrupt-driven I/O to manage a single serial port(character device), but polling I/O to manage a front-end processor, such a terminal concentrator?
    - *Polling can be more efficient than interrupt-driven I/O when I/O is frequent and of short duration.*
- Describe a hybrid strategy that combines polling and interrupts for I/O device service. What kind of I/O patterns could this be useful for?

Last exercise

- How does DMA increase system concurrency? How does it complicate the hardware design?
  - *DMA increases system concurrency by allowing the CPU to perform tasks while the DMA system transfers data via the system and memory buses.*
  - *Hardware design is complicated because the DMA controller must be integrated into the system and the system must allow the DMA controller to be a bus master.*

Byzantine nodes

- Node which has arbitrary behavior
- So it can:
  - Decide not to send messages
  - Send wrong messages
  - Send correct messages
  - Send different messages to different nodes
  - Lie about input values
- If an algorithm works with f byzantine nodes, it is f-resilient

Different Validities

- Any-input validity:
  - The decision value must be input of any node
  - That includes byzantine nodes, might not make sense
- Correct-input validity:
  - The decision value must be input of a correct node
  - Difficult because byzantine node could behave like normal one just with different value
- All-same validity:
  - if all correct nodes start with the same value, the decision must be that value
- Median validity:
  - If input values are orderable, byzantine outliers can be prevented by agreeing on a value close to the median value of the correct nodes

Byzantine agreement in the synchronous model

- Assumption: nodes operate in synchronous rounds. In each round, each node may send a message to each other node, receive the message by other nodes and do some computation.
    - -> runtime is easy, since it is only the number of rounds

King Algorithm (synchronous byzantine agreement)

Idea:
If not all correct input nodes have the same value, decide on value of one correct input node. Ensure this by doing f+1 rounds, since there must be at least one correct input node.

Algorithm 11.14 King Algorithm (for $f < n/3$)

x = my input value
for phase = 1 to $f + 1$ **do**

Round 1

Broadcast value(x)

Round 2

if some value(y) received at least $n - f$ times **then**
Broadcast propose(y)
end if
if some propose(z) received more than f times **then**
$x = z$
end if

Round 3

Let node v_i be the predefined king of this phase i
The king v_i broadcasts its current value w
if received strictly less than $n - f$ propose(y) **then**
$x = w$
end if
end for

Do until at least one correct input node

Send out own value

If some value received from all nodes but byzantine ones (or at least ((n – f)- f) correct ones), propose that value

If some value proposed by at least one correct node, set your value to that value

King of this phase broadcasts its value

If didn’t get propose from all nodes but byzantine ones (or at least ((n – f)- f) correct ones), set your value to value of king

King Algorithm (synchronous byzantine agreement)

Why f+1?

- Because there are f byzantine nodes, at least one of the kings will be a correct node

Algorithm 11.14 King Algorithm (for $f < n/3$)

```
x = my input value
for phase = 1 to f + 1 do
    Round 1
    Broadcast value(x)
    Round 2
    if some value(y) received at least n − f times then
        Broadcast propose(y)
    end if
    if some propose(z) received more than f times then
        x = z
    end if
    Round 3
    Let node v_i be the predefined king of this phase i
    The king v_i broadcasts its current value w
    if received strictly less than n − f propose(y) then
        x = w
    end if
end for
```

King Algorithm (synchronous byzantine agreement)

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    end if
    if some propose(z) received more than f times then
        x = z
    end if
    Round 3
    Let node v_i be the predefined king of this phase i
    The king v_i broadcasts its current value w
    if received strictly less than n − f propose(y) then
        x = w
    end if
end for
```

King Algorithm (synchronous byzantine agreement)

Why n-f?

- Because if there are n-f correct nodes, so we can't wait for more. If we wait for less than f + 1 nodes, all the input values could be fake. Because 3f < n, n – f > f.
- Ensures only one proposal: If one node sees n-f values v, then every other node sees at least n-2f times v. Because n-(n-2f) = 2f < n-f, there can be no proposal for another value.
- All same validity ensured here!

Algorithm 11.14 King Algorithm (for $f < n/3$)

```
x = my input value
for phase = 1 to f + 1 do
    Round 1
    Broadcast value(x)
    Round 2
    if some value(y) received at least n − f times then
        Broadcast propose(y)
    end if
    if some propose(z) received more than f times then
        x = z
    end if
    Round 3
    Let node v_i be the predefined king of this phase i
    The king v_i broadcasts its current value w
    if received strictly less than n − f propose(y) then
        x = w
    end if
end for
```

King Algorithm (synchronous byzantine agreement)

Why more than f?

- If we just waited for <= f propose messages, they all could be byzantine.

Algorithm 11.14 King Algorithm (for $f < n/3$)

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x = my input value
for phase = 1 to f + 1 do
  Round 1
  Broadcast value(x)
  Round 2
  if some value(y) received at least n − f times then
    Broadcast propose(y)
  end if
  if some propose(z) received more than f times then
    x = z
  end if
  Round 3
  Let node v_i be the predefined king of this phase i
  The king v_i broadcasts its current value w
  if received strictly less than n − f propose(y) then
    x = w
  end if
end for
```

King Algorithm (synchronous byzantine agreement)

Why n-f propose messages?

- Similar as for n-f broadcast messages. We can wait for at most n-f ones because those are the correct nodes, and we have to wait for at least f+1 ones.

After a correct king, the correct nodes will not change their values anymore! Why?

- If all of them have less than n-f propose messages, all correct nodes will have the king value and then “all same validity” holds. If one does not adapt, this means that it got n-f propose messages. This means, every other message got at least n-f-f > f propose messages, so it adapted its value to the propose. So the king also adapted it’s value and again all nodes have the same value.

Algorithm 11.14 King Algorithm (for $f < n/3$)

x = my input value
for phase = 1 to $f+1$ **do**

Round 1

Broadcast value(x)

Round 2

if some value(y) received at least $n-f$ times **then**
Broadcast propose(y)
end if
if some propose(z) received more than f times **then**
$x = z$
end if

Round 3

Let node v_i be the predefined king of this phase i
The king v_i broadcasts its current value w
if received strictly less than $n-f$ propose(y) **then**
$x = w$
end if
end for

King Algorithm (synchronous byzantine agreement)

- Does it solve byzantine agreement?
  - Validity: All same validity!
  - Agreement: They agree at least after the first correct king.
  - Termination: After (f+1)*3 rounds

Algorithm 11.14 King Algorithm (for $f < n/3$)

```
x = my input value
for phase = 1 to f + 1 do
  Round 1
  Broadcast value(x)
  Round 2
  if some value(y) received at least n − f times then
    Broadcast propose(y)
  end if
  if some propose(z) received more than f times then
    x = z
  end if
  Round 3
  Let node v_i be the predefined king of this phase i
  The king v_i broadcasts its current value w
  if received strictly less than n − f propose(y) then
    x = w
  end if
end for
```

Asynchronous Byzantine Agreement

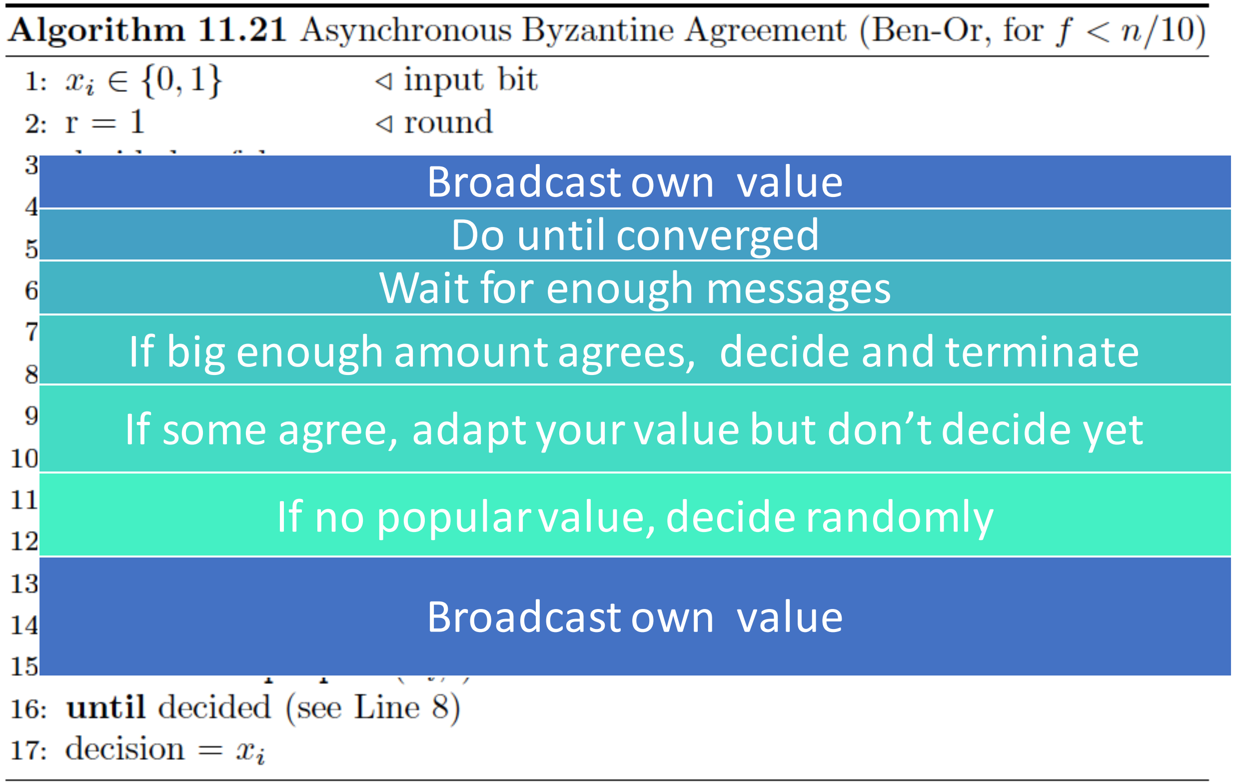
- Assumption: Messages do not need to arrive at the same time anymore. They have variable delays.

-> Also works, but is a lot more complicated.

-> Algorithm in script is proof of concept, so don’t worry about it too much.

->Asynchronity changes messages you have to wait for, but not principle

- Problem: slow! (exponential runtime)



Asynchronous Byzantine Agreement with oracle

- Now, if no popular value, all correct nodes will decide on same oracle value.
- Constant runtime
- Problem: oracle does not exist

Algorithm 11.21 Asynchronous Byzantine Agreement (Ben-Or, for $f < n/10$)

$x_i \in \{0, 1\}$ ◁ input bit
r = 1 ◁ round

Broadcast own value
Do until converged
Wait for enough messages
If big enough amount agrees, decide and terminate
If some agree, adapt your value but don't decide yet
If no popular value, ask oracle
Broadcast own value

until decided (see Line 8)
decision = x_i

Asynchronous Byzantine Agreement with random bitstring

- New idea: generate a random bitstring and take next value of bitstring instead of asking oracle
- Problem: byzantine nodes know "random" value and can adapt their behavior

Algorithm 11.21 Asynchronous Byzantine Agreement (Ben-Or, for $f < n/10$)

$x_i \in \{0, 1\}$ ◁ input bit
r = 1 ◁ round

Broadcast own value
Do until converged
Wait for enough messages
If big enough amount agrees, decide and terminate
If some agree, adapt your value but don't decide yet
If no popular value, ask look at bitstring
Broadcast own value

until decided (see Line 8)
decision = x_i

Asynchronous Byzantine Agreement with blackboard

- Back to the roots! – shared coin
- Implement it by writing values to a public blackboard, after seeing a certain amount of values nodes decide on coin value
- Constant probability that value is the same for all
- Similar to shared coin but works asynchronously
- Byzantine nodes don't know value of shared coin in advance

Algorithm 11.21 Asynchronous Byzantine Agreement (Ben-Or, for $f < n/10$)

1: $x_i \in \{0, 1\}$ ◁ input bit
2: r = 1 ◁ round

Broadcast own value
Do until converged
Wait for enough messages
If big enough amount agrees, decide and terminate
If some agree, adapt your value but don't decide yet
If no popular value, generate shared coin
Broadcast own value

16: **until** decided (see Line 8)
17: decision = x_i

Reliable Broadcast

- **Best effort broadcast**
  - Messages broadcast by correct nodes will arrive at other correct nodes eventually
- **Reliable broadcast**
  - Correct nodes will eventually agree on all accepted messages (including those sent by byzantine nodes!)
- **FIFO (reliable) broadcast**
  - All messages sent out by a node v are accepted by other nodes in the order they were sent out.
- **Atomic broadcast**
  - All nodes agree on the order of all messages

Reliable Broadcast

Algorithm 4.15 Asynchronous Reliable Broadcast (code for node u)

Broadcast own value

If message received from node directly, broadcast it together with your own name

If you do not get message from node directly, but from a reasonable amount of others also broadcast with own name

If you get enough forwarded messages, accept message

Reliable Broadcast

Guarantees:

- If a node broadcasts a message reliably, all correct nodes will eventually accept that value
- If a correct node has not broadcast a message, it will not be accepted by any other correct node
- If a correct node accepts a message from a (byzantine) node, it will be eventually accepted by every correct node

Cryptography

- Public key cryptography for message authentication
- Cryptographic hashes can help weaken byzantine nodes
  - E.g. for shared coin
  - Controlling the hash value is impractical if a good hash function is used

Quiz

- Can byzantine nodes collaborate?
  - *Yes*
- Can byzantine nodes forge a sender address?
  - *No, otherwise one could impersonate all correct ones.*
- In all-same validity, what values can we decide if not all correct nodes have the same input?
  - *Anything, even a value from a byzantine node*
- Can there be any algorithm that can solve synchronous byzantine agreement in less than f+1 rounds?
  - *No, because the node with the smallest value might propagate its value to one other node which then passes it to one node and crashes and so on. So in the last round, one node knows about the new value but has no chance to propagate it.*

2.1 What is the Average?

Assume that we are given 7 nodes with input values $\{-3, -2, -1, 0, 1, 2, 3\}$. The task of the nodes is to establish agreement on the average of these values. As always, our system might be faulty - nodes could crash or even be byzantine.

a) Show that in the presence of even one failure (crash or byzantine), the nodes cannot agree on the average of all input values.

Since we cannot establish agreement on the exact value, it would be great to understand how close we can get to the average value. Let us begin by only considering crash failures in the system. Assume that at most 2 of the 7 given nodes can crash.

b) In which range do you expect the consensus value to be?

From now on, we will consider byzantine failures as well. Assume that we have 9 nodes in total. 7 of these nodes are correct and have the input values specified above. The remaining two nodes are byzantine. We will start with a synchronous system.

c) Show that the consensus values can be basically anything now.

d) Suggest a rule that a node could use to locally choose a value as an approximation to the average.

e) What is the range of all possible local approximations of the average?

f) Suggest a validity condition that can be used to determine a consensus value.

Now assume that the system is asynchronous. Keep in mind that the scheduling is worst-case.

g) How does the range of all possible local approximations of the average change in this case?

h) Suggest a new validity condition that can be used to determine a consensus value.

Quiz

1.1 Synchronous Consensus in a Grid

In the lecture you learned how to reach consensus in a fully connected network where every process can communicate directly with every other process. Now consider a network that is organized as a 2-dimensional grid such that every process has up to 4 neighbors. The width of the grid is w, the height is h. Width and height are defined in terms of edges: A 2×2 grid contains 9 nodes! The grid is big, meaning that $w + h$ is much smaller than $w \cdot h$. We use the synchronous time model; i.e., in every round every process may send a message to each of its neighbors, and the size of the message is not limited.

a) Assume every node knows w and h. Write a short protocol to reach consensus.

b) From now on the nodes do not know the size of the grid. Write a protocol to reach consensus and optimize it according to runtime.

c) How many rounds does your protocol from **b)** require?

Assume there are Byzantine nodes and that you are the adversary who can select which nodes are Byzantine.

d) What is the smallest number of Byzantine nodes that you need to prevent the system from reaching agreement, and where would you place them?