

# Implementing the Consensus Object with Timing Assumptions

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# A modular approach

We implement *Wait-free Consensus (Consensus)*  
through:

*Lock-free Consensus (L-Consensus)*

and

*Registers*

We implement L-Consensus through

*Obstruction-free Consensus (O-Consensus)*

and

$\langle \rangle$ *Leader* (encapsulating timing assumptions and  
sometimes denoted by  $\Omega$ )

# A modular approach

## Consensus

### L-Consensus

**Registers**

**O-Consensus**

**<>Leader**

**<>Synchrony**

# Consensus

*Wait-Free-Termination*: If a correct process proposes, then it eventually decides

*Agreement*: No two processes decide differently

*Validity*: Any value decided must have been proposed

# L-Consensus

***Lock-Free-Termination:*** If a correct process proposes, then *at least one* correct process eventually decides

***Agreement:*** No two processes decide differently

***Validity:*** Any value decided must have been proposed

# O-Consensus

***Obstruction-Free-Termination:*** If a correct process proposes and *eventually executes alone*, then the process eventually decides

***Agreement:*** No two processes decide differently

***Validity:*** Any value decided must have been proposed





# O-Consensus algorithm (idea)

- ☛ A process that is eventually « left alone » to execute steps, eventually decides
- ☛ Several processes may keep trying to concurrently decide until some unknown time: agreement and validity should be preserved during this preliminary period

# O-Consensus algorithm (data)

- Each process  $p_i$  maintains a timestamp  $ts$ , initialized to  $i$  and incremented by  $n$
- The processes share an array of register pairs ***Reg[1,..,n]***; each element of the array contains two registers:
  - Reg[i].T*** contains a timestamp (init to 0)
  - Reg[i].V*** contains a pair (value,timestamp) (init to  $(\perp, 0)$ )

# O-Consensus algorithm (functions)

- To simplify the presentation, we assume two functions applied to  $\text{Reg}[1, \dots, N]$ 
  - ***highestTsp()*** returns the highest timestamp among all elements  $\text{Reg}[1].T$ ,  $\text{Reg}[2].T$ , ..,  $\text{Reg}[N].T$
  - ***highestTspValue()*** returns the value with the highest timestamp among all elements  $\text{Reg}[1].V$ ,  $\text{Reg}[2].V$ , ..,  $\text{Reg}[N].V$

# O-Consensus algorithm

- ☛ propose(v):
- ☛ while(true)
  - ☛ Reg[i].T.write(ts);
  - ☛ val := Reg[1,..,n].highestTspValue();
  - ☛ if val =  $\perp$  then val := v;
  - ☛ Reg[i].V.write(val,ts);
  - ☛ if ts = Reg[1,..,n].highestTsp() then return(val)
  - ☛ ts := ts + n

# O-Consensus algorithm

propose(v):

while(true)

    (1) Reg[i].T.write(ts);

    (2) val := Reg[1,..,n].highestTspValue();

    if val =  $\perp$  then val := v;

    (3) Reg[i].V.write(val,ts);

    (4) if ts = Reg[1,..,n].highestTsp() then return(val)

    ts := ts + n

# O-Consensus algorithm

- ☛ (1)  $p_i$  announces its timestamp
- ☛ (2)  $p_i$  selects the value with the highest timestamp (or its own if there is none)
- ☛ (3)  $p_i$  announces the value with its timestamp
- ☛ (4) if  $p_i$ 's timestamp is the highest, then  $p_i$  decides (i.e.,  $p_i$  knows that any process that executes line 2 will select  $p_i$ 's value)

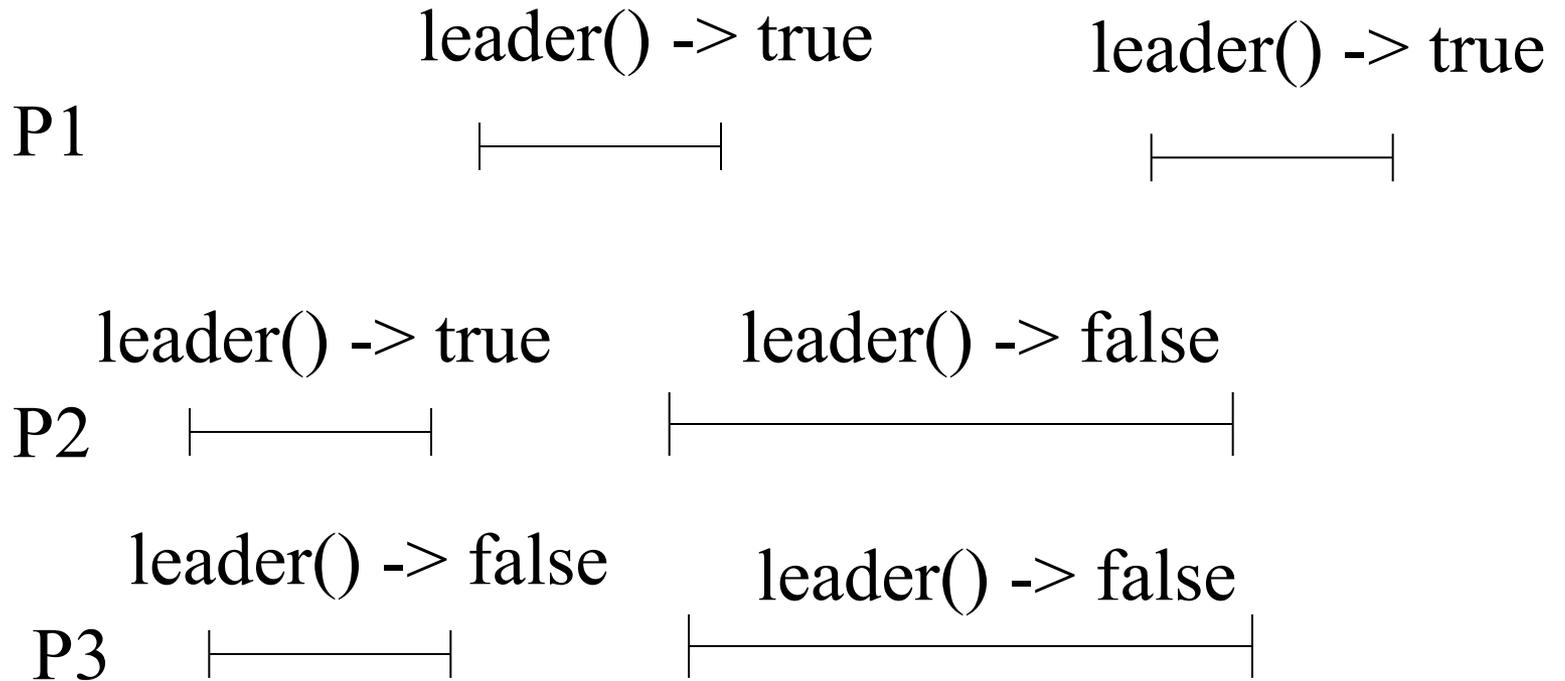
# L-Consensus

- We implement L-Consensus using  $\langle \rangle$ leader (leader()) and the O-Consensus algorithm
- The idea is to use  $\langle \rangle$ leader to make sure that, eventually, one process keeps executing steps alone, until that process decides

# <> Leader

- One operation ***leader()*** which does not take any input parameter and returns a boolean
- A process considers itself leader if the boolean ***leader()*** is true
- ✓ ***Property***: If a correct process invokes leader, then the invocation returns and *eventually*, some correct process is *permanently* the only leader

# Example



# L-Consensus

propose(v): while(true)

- if leader() then

  - Reg[i].T.write(ts);

  - val := Reg[1,..,n].highestTspValue();

  - if val =  $\perp$  then val := v;

  - Reg[i].V.write(val,ts);

  - if ts = Reg[1,..,n].highestTsp() then return(val)

  - ts := ts + n

# From L-Consensus to Consensus (helping)

- Every process that decides writes its value in a register ***Dec*** (init to  $\perp$ )
- Every process periodically seeks for a value in ***Dec***

# Consensus

- ☛ propose(v)
- ☛ while (**Dec**.read() =  $\perp$ )
- ☛ if leader() then
  - ☛ Reg[i].T.write(ts);
  - ☛ val := Reg[1,..,n].highestTspValue();
  - ☛ if val =  $\perp$  then val := v;
  - ☛ Reg[i].V.write(val,ts);
  - ☛ if ts = Reg[1,..,n].highestTsp() then Dec.write(val)
  - ☛ ts := ts + n;

return(**Dec**.read())

# <> Leader

- One operation ***leader()*** which does not take any input parameter and returns a boolean
  - A process considers itself leader if the boolean is true
- ✓ ***Property***: If a correct process invokes `leader()`, then the invocation returns and *eventually*, some correct process is *permanently* the only leader

# <>Leader: algorithm

- We assume that the system is <>synchronous
  - ✓ There is a time after which there is a lower and an upper bound on the delay for a process to execute a local action, a read or a write in shared memory
  - ✓ The time after which the system becomes synchronous is called the global stabilization time (GST) and is unknown to the processes
- This model captures the practical observation that distributed systems are usually synchronous and sometimes asynchronous

# <>Leader: algorithm (shared variables)

- Every process  $p_i$  elects (stores in a local variable leader) the process with the lowest identity that  $p_i$  considers as non-crashed; if  $p_i$  elects  $p_j$ , then  $j < i$
- A process  $p_i$  that considers itself leader keeps incrementing ***Reg[i]***, i.e., claiming leadership
- Eventually, only the leader keeps incrementing ***Reg[i]***

# <>Leader: algorithm (local variables)

- Every process periodically increments local variables **clock** and **check**, as well as a local variable **delay** whenever its leader changes
- Process  $p_i$  maintains **lasti[j]** to record the last value of **Reg[j]**  $p_i$  has read ( $p_i$  can hence know whether  $p_j$  has progressed)
- The next leader is the one with the smallest id that makes some progress; if no such process  $p_j$  such that  $j < i$  exists, then  $p_i$  elects itself (**noLeader** is true)

# <>Leader: algorithm (variables)

- ***check***, and ***delay*** are initialized to 1
- ***lasti[j]*** and ***Reg[j]*** are initialized to 0
  
- The next leader is the one with the smallest id that makes some progress; if no such process  $p_j$  such that  $j < i$  exists, then  $p_i$  elects itself (***noLeader*** is true)

# <>Leader: algorithm

leader(): return(leader=self)

- check, delay and leader init to 1
- lasti[j] and Reg[j] init to 0;
  
- Task:
  - clock := 0;
  - while(true) do
    - ✓ if (leader=self) then
      - ✓                   Reg[i].write(Reg[i].read()+1);
    - ✓ clock := clock + 1;
    - ✓ if (clock = check) then
      - ✓    elect();

# <>Leader: algorithm (cont'd)

elect():

- noLeader := true;
- for j = 1 to (i-1) do
  - ✓ if (Reg[j].read() > last[j]) then
  - ✓ last[j] := Reg[j].read();
  - ✓ if (leader ≠ pj) then delay:=delay\*2;
  - ✓ leader:= pj;
  - ✓ noLeader := false; break (for);
- check := check + delay
- if (noLeader) then leader := self;

# Consensus = Registers + $\langle \rangle$ Leader

- $\langle \rangle$ Leader has one operation ***leader()*** which does not take any input parameter and returns a boolean; a process considers itself leader if the boolean is true
  - ✓ ***Property***: If a correct process invokes leader, then the invocation returns and *eventually*, some correct process is *permanently* the only leader
- $\langle \rangle$ Leader encapsulates the following synchrony assumption: there is a time after which a lower and an upper bound hold on the time it takes for every process to execute a step (eventual synchrony)

# Minimal Assumptions

- Consensus is impossible in an asynchronous system with Registers (FLP83, LA88)
- Consensus is possible in an eventually synchronous system (i.e.,  $\langle \rangle$  Leader) with Registers (DLS88, LH95)