

# Distributed Systems

## Master of Science in Engineering in Computer Science

AA 2020/2021

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LECTURE 8: CONSENSUS

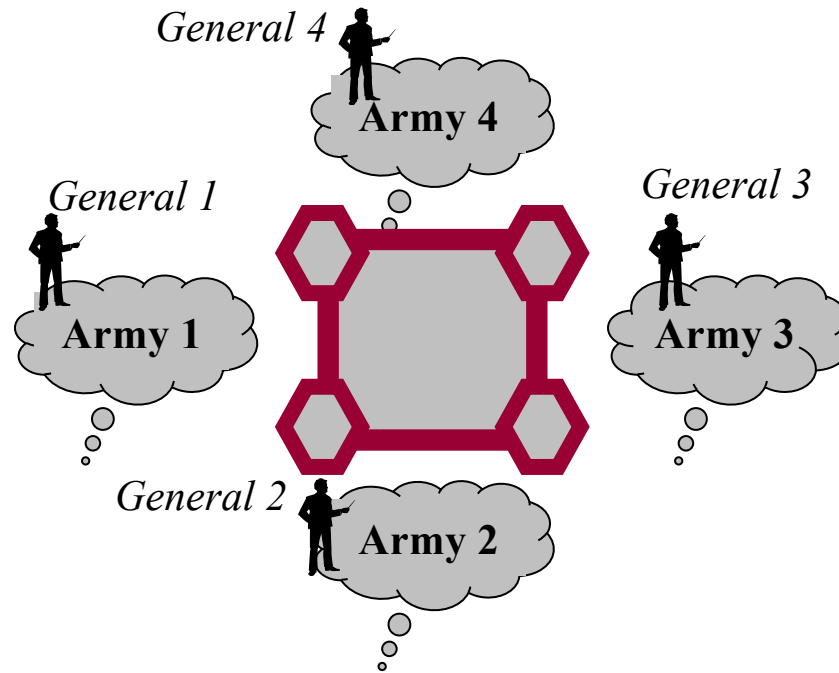
# Consensus Problem

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- A group of processes must agree on a value that has been proposed by one of them (e.g., commit/abort of a transaction).
- It is an abstraction of a class of problems where processes start with their opinion and then converge on one of them
- It is a fundamental problem
- We study algorithms working on weak models

# Consensus Example

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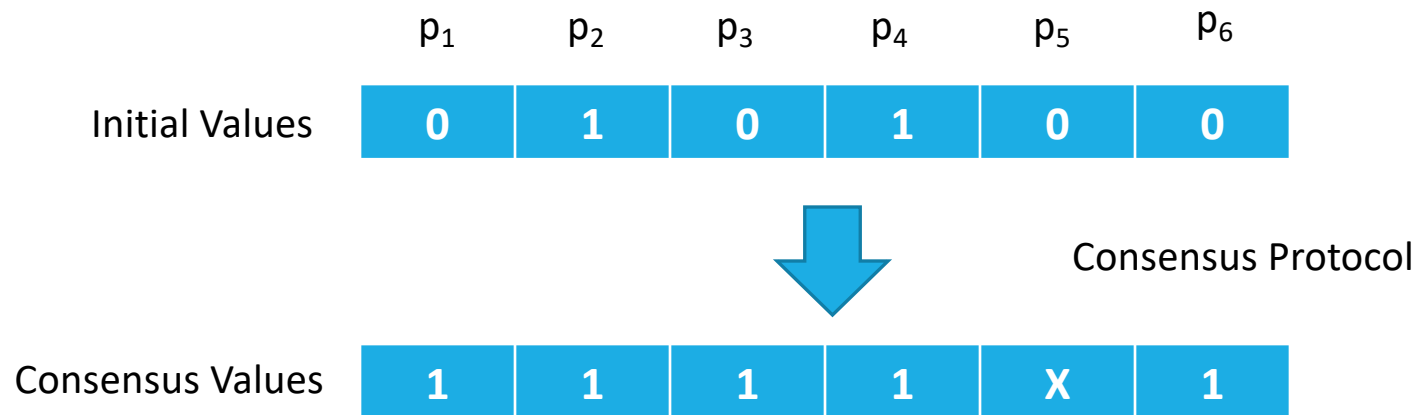


Generals have to reach consensus between attack and get back

# Consensus Definition

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- Set of initial values  $\in \{0,1\}$ .
- Every process has to decide the same value  $\in \{0,1\}$  based on the initial proposals.



# Consensus Specification

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**Module 5.1:** Interface and properties of (regular) consensus

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**Module:**

**Name:** Consensus, **instance**  $c$ .

**Events:**

**Request:**  $\langle c, \text{Propose} \mid v \rangle$ : Proposes value  $v$  for consensus.

**Indication:**  $\langle c, \text{Decide} \mid v \rangle$ : Outputs a decided value  $v$  of consensus.

**Properties:**

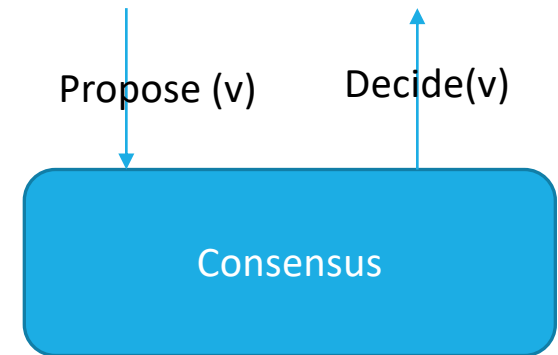
**C1: Termination:** Every correct process eventually decides some value.

**C2: Validity:** If a process decides  $v$ , then  $v$  was proposed by some process.

**C3: Integrity:** No process decides twice.

**C4: Agreement:** No two correct processes decide differently.

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# FLP Impossibility Result

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no algorithm can guarantee to reach consensus in an asynchronous system, even with one process crash failure.

Fisher, Lynch e Patterson (FLP result)  
Ref: Journal of the ACM, Vol. 32, No. 2, April 1985.

# A Consensus Implementation in Synchronous Systems: Flooding Consensus

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## Basic Idea:

- Processes exchange their values
- when all the proposals from correct processes are available a one value can be chosen

## Problem:

- due to failures, some values can be lost

## Solution:

- A value can be selected only when no failures happen during the communication

# A Consensus Implementation in Synchronous Systems: Flooding Consensus

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**Algorithm 5.1:** Flooding Consensus

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**Implements:**

Consensus, **instance**  $c$ .

**Uses:**

BestEffortBroadcast, **instance**  $beb$ ;  
PerfectFailureDetector, **instance**  $\mathcal{P}$ .

**upon event**  $\langle c, \text{Init} \rangle$  **do**

$correct := \Pi$ ;  
 $round := 1$ ;  
 $decision := \perp$ ;  
 $receivedfrom := [\emptyset]^N$ ;  
 $proposals := [\emptyset]^N$ ;  
 $receivedfrom[0] := \Pi$ ;

**upon event**  $\langle \mathcal{P}, \text{Crash} \mid p \rangle$  **do**

$correct := correct \setminus \{p\}$ ;

**upon event**  $\langle c, \text{Propose} \mid v \rangle$  **do**

$proposals[1] := proposals[1] \cup \{v\}$ ;  
**trigger**  $\langle beb, \text{Broadcast} \mid [\text{PROPOSAL}, 1, proposals[1]] \rangle$ ;

**upon event**  $\langle beb, \text{Deliver} \mid p, [\text{PROPOSAL}, r, ps] \rangle$  **do**

$receivedfrom[r] := receivedfrom[r] \cup \{p\}$ ;  
 $proposals[r] := proposals[r] \cup ps$ ;

**upon**  $correct \subseteq receivedfrom[round] \wedge decision = \perp$  **do**

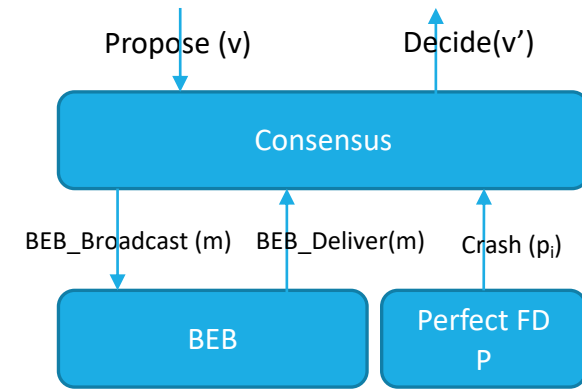
**if**  $receivedfrom[round] = receivedfrom[round - 1]$  **then**  
     $decision := \min(proposals[round])$ ;  
    **trigger**  $\langle beb, \text{Broadcast} \mid [\text{DECIDED}, decision] \rangle$ ;  
    **trigger**  $\langle c, \text{Decide} \mid decision \rangle$ ;

**else**

$round := round + 1$ ;  
    **trigger**  $\langle beb, \text{Broadcast} \mid [\text{PROPOSAL}, round, proposals[round - 1]] \rangle$ ;

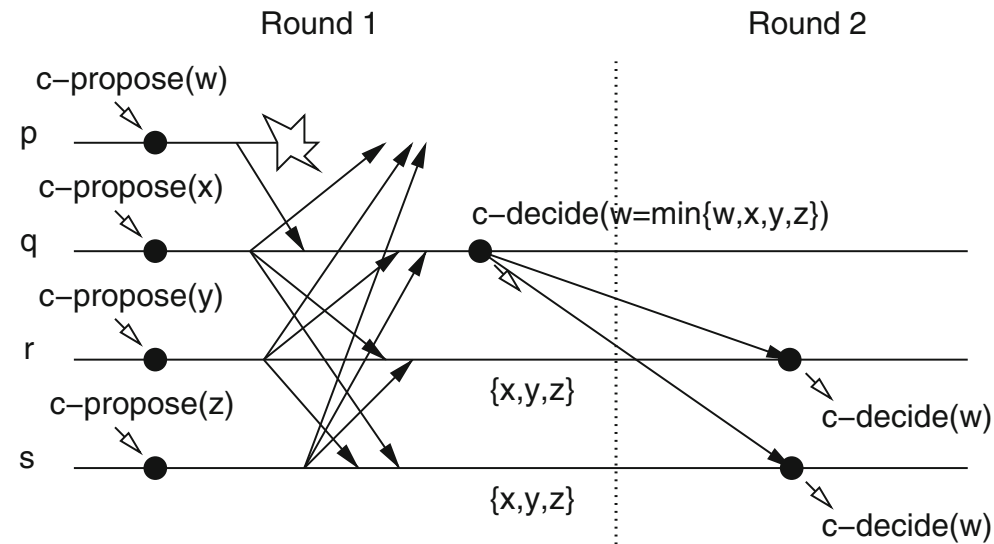
**upon event**  $\langle beb, \text{Deliver} \mid p, [\text{DECIDED}, v] \rangle$  **such that**  $p \in correct \wedge decision = \perp$  **do**

$decision := v$ ;  
    **trigger**  $\langle beb, \text{Broadcast} \mid [\text{DECIDED}, decision] \rangle$ ;  
    **trigger**  $\langle c, \text{Decide} \mid decision \rangle$ ;





# Example of Flooding Consensus



**Figure 5.1:** Sample execution of flooding consensus

# Correctness and Performance

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## Correctness

- Validity and integrity follow from the properties on the communication channels
- Termination. At most after  $N$  rounds processes decide
- Agreement. The same deterministic function is applied to the same values by correct processes

## Performance

- Best Case (No failures). One communication round ( $2N^2$  messages)
- Worst case ( $n-1$  failures).  $N^2$  messages exchanged for each communication step and at most  $N$  rounds  $\Rightarrow N^3$  messages

# Uniform Consensus Specification

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**Module 5.2:** Interface and properties of uniform consensus

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**Module:**

**Name:** UniformConsensus, **instance** *uc*.

**Events:**

**Request:**  $\langle uc, Propose \mid v \rangle$ : Proposes value  $v$  for consensus.

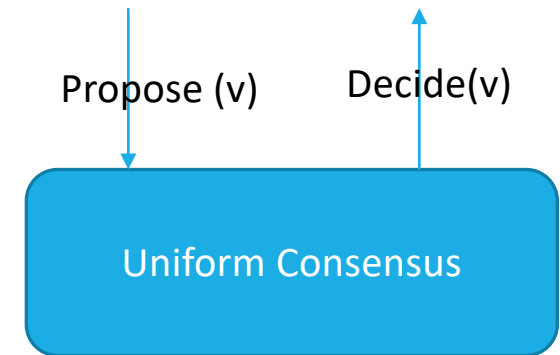
**Indication:**  $\langle uc, Decide \mid v \rangle$ : Outputs a decided value  $v$  of consensus.

**Properties:**

**UC1–UC3:** Same as properties C1–C3 in (regular) consensus (Module 5.1).

**UC4:** *Uniform agreement*: No two processes decide differently.

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# Uniform Consensus and Flooding Consensus algorithm

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Does the flooding consensus algorithm (described in the previous slides) satisfy the Uniform Consensus specification?

# Uniform Consensus Implementation in Synchronous Systems

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## Algorithm 5.3: Flooding Uniform Consensus

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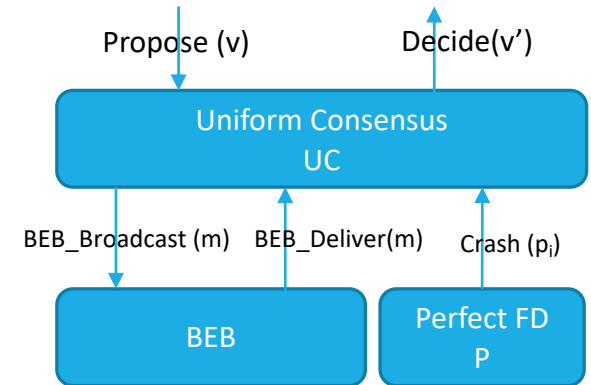
### Implements:

UniformConsensus, **instance** *uc*.

### Uses:

BestEffortBroadcast, **instance** *beb*;

PerfectFailureDetector, **instance**  $\mathcal{P}$ .



### upon event $\langle uc, Init \rangle$ do

```

correct :=  $\Pi$ ;
round := 1;
decision :=  $\perp$ ;
proposalset :=  $\emptyset$ ;
receivedfrom :=  $\emptyset$ ;
  
```

### upon event $\langle \mathcal{P}, Crash \mid p \rangle$ do

```

correct := correct  $\setminus$   $\{p\}$ ;
  
```

### upon event $\langle uc, Propose \mid v \rangle$ do

```

proposalset := proposalset  $\cup$   $\{v\}$ ;
trigger  $\langle beb, Broadcast \mid [PROPOSAL, 1, proposalset] \rangle$ ;
  
```

No more related to the round

### upon event $\langle beb, Deliver \mid p, [PROPOSAL, r, ps] \rangle$ such that $r = round$ do

```

receivedfrom := receivedfrom  $\cup$   $\{p\}$ ;
proposalset := proposalset  $\cup$  ps;
  
```

### upon $correct \subseteq receivedfrom \wedge decision = \perp$ do

#### if $round = N$ then

```

decision := min(proposalset);
trigger  $\langle uc, Decide \mid decision \rangle$ ;
  
```

#### else

```

round := round + 1;
receivedfrom :=  $\emptyset$ ;
trigger  $\langle beb, Broadcast \mid [PROPOSAL, round, proposalset] \rangle$ ;
  
```

Decision only at the end

Cleaned at the beginning of each round

# Correctness and Performance

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## Correctness

- The *validity* and *integrity* properties follow from the algorithm and from the properties of best-effort broadcast
- The *termination* property is ensured as all correct processes reach round N and decide in that round
  - the *strong completeness* property of the failure detector implies that no correct process waits indefinitely for a message from a process that has crashed, as the crashed process is eventually removed from *correct*.
- The *uniform agreement* holds because all processes that reach round N have the same set of values in their variable *proposalset*.

## Performance

- N communication steps and  $O(N^3)$  messages for all correct processes to decide

# References

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C. Cachin, R. Guerraoui and L. Rodrigues. Introduction to Reliable and Secure Distributed Programming, Springer, 2011

- Chapter 5, Sections 5.1.1, 5.1.2, 5.2.1, 5.2.2