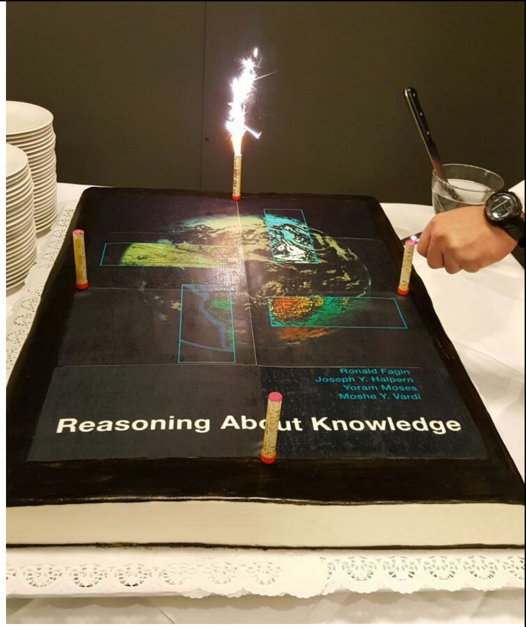
Knowledge and Distributed Coordination

Yoram Moses

Technion

FMAI 2019

Background



- Knowledge affects action in multi-agent systems
- We apply epistemic reasoning to the design and analysis of distributed protocols
- Basic tool – modelling using interpreted systems [HM’90, FHMV’95]
- The protocol (or strategies) agents use play a major role
- Today – a discussion on the value of silence

Silence

Guy Goren & Yoram Moses

PODC 2018

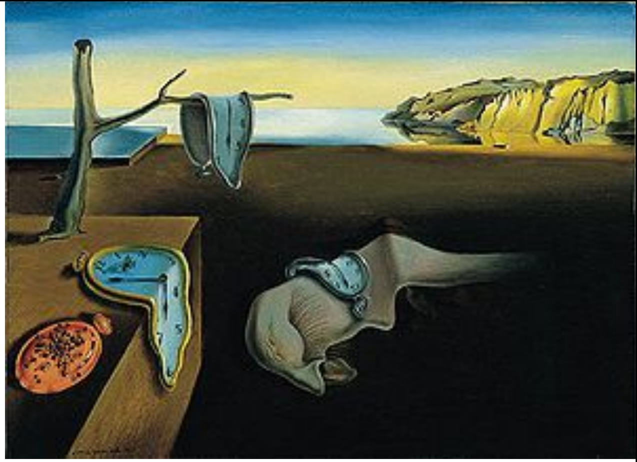
best student paper presentation

Communication is Expensive

The number of messages sent over the network

is a hindering factor for large scale systems

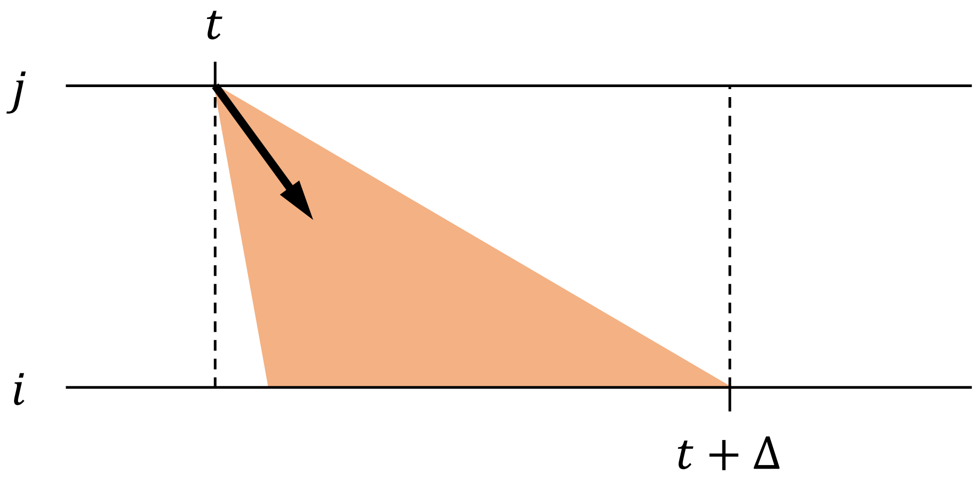
Clocks and Bounded Communication



i receives no message from j by time $t + \Delta$

$\Longrightarrow$ i receives a "null message" from j at time t.

[Lamport '85]



Δ – upper bound on message transmission

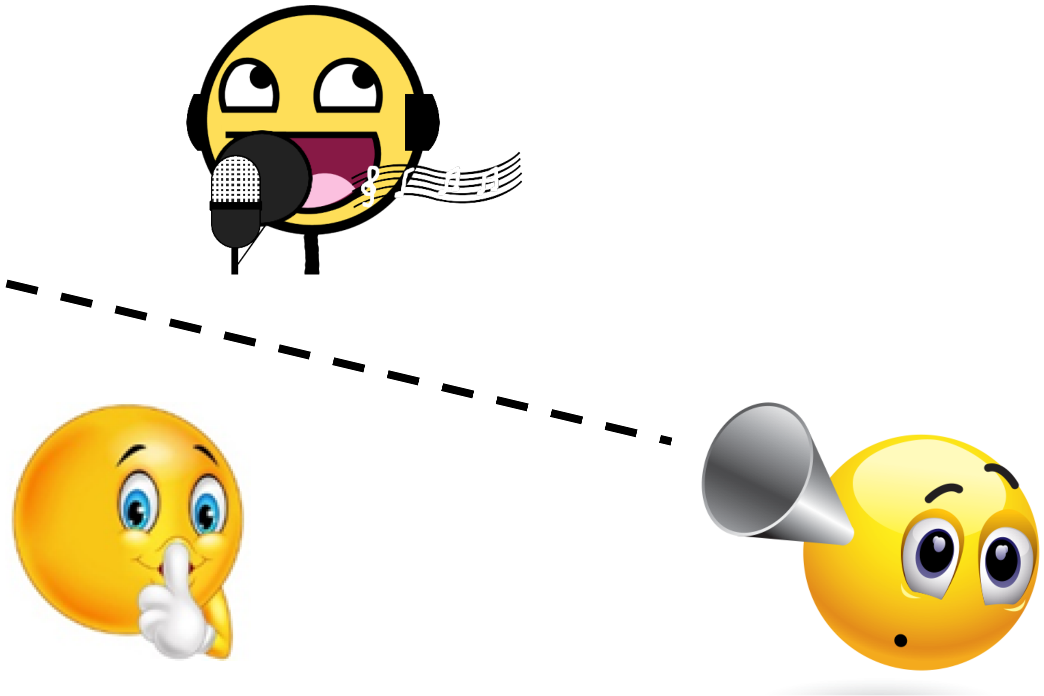
The “Sound” of Silence

i receives no message from j by time $t + \Delta$
$\Longrightarrow$ i receives a “null message” from j at time t.

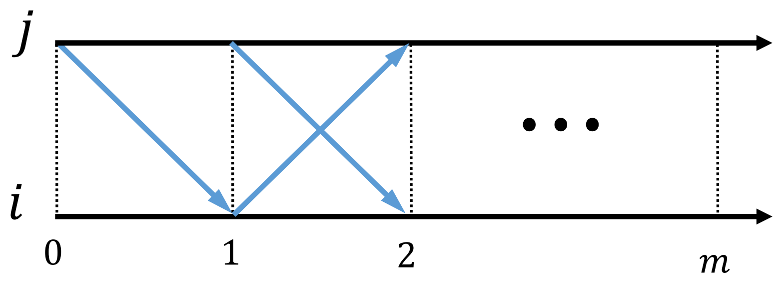
A null message provides knowledge

But only when an alternative exists

Silence can serve to transfer costs among scenarios



The "Sound" of Silence

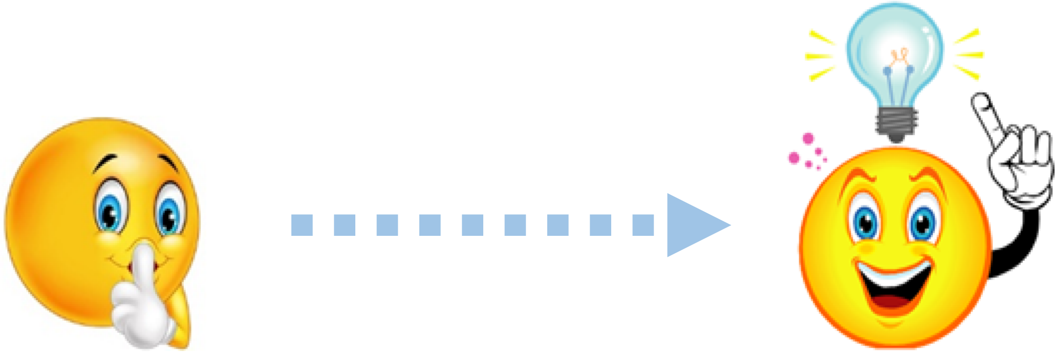


Assume a bound of $\Delta = 1$ time unit

- Suppose j always sends i a message at time m iff φ is false.

- If i hears nothing from j at time $m + 1$,

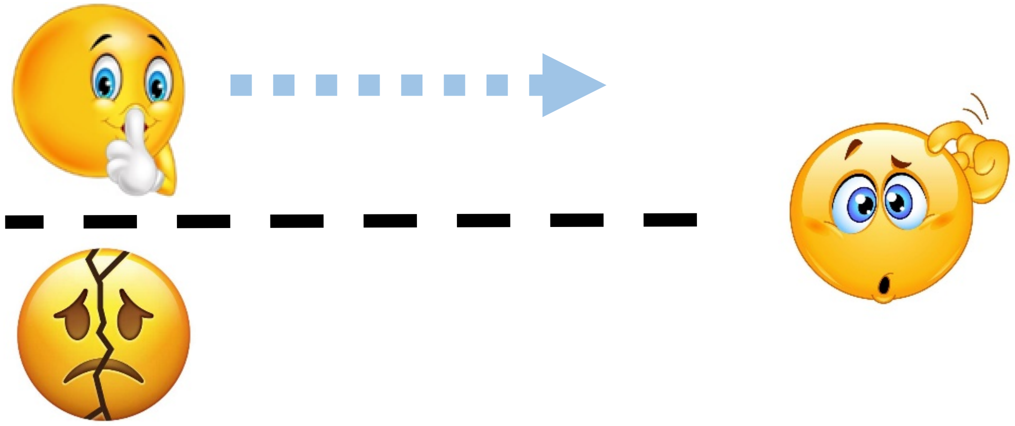
  then i *knows* φ. $(K_i\varphi)$



The Effect of **Possible** Failures

If i hears nothing from j at time $m + 1$ ... $\Longrightarrow$ $\boldsymbol{K_i \varphi}$??

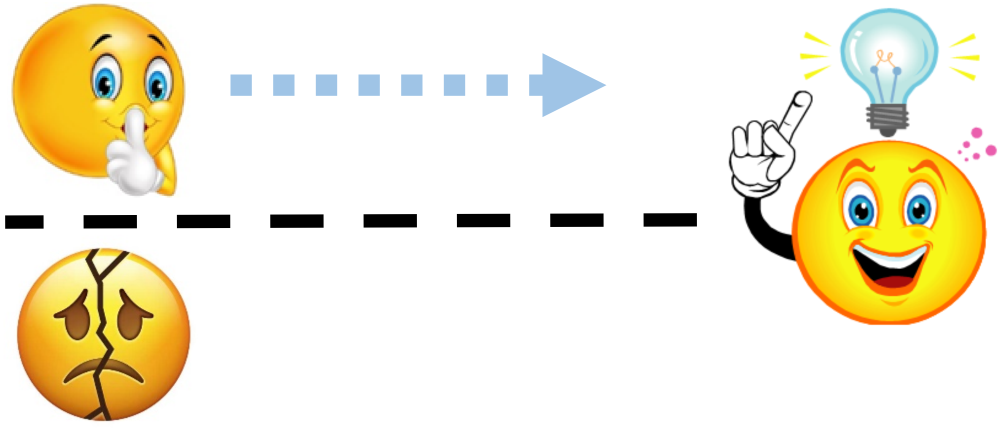
j may be silent because it is faulty



~~$\boldsymbol{K_i \varphi}$~~

The Effect of **Possible** Failures

From j's silence we learn: $\boldsymbol{K}_i(\varphi$ OR j is faulty$)$

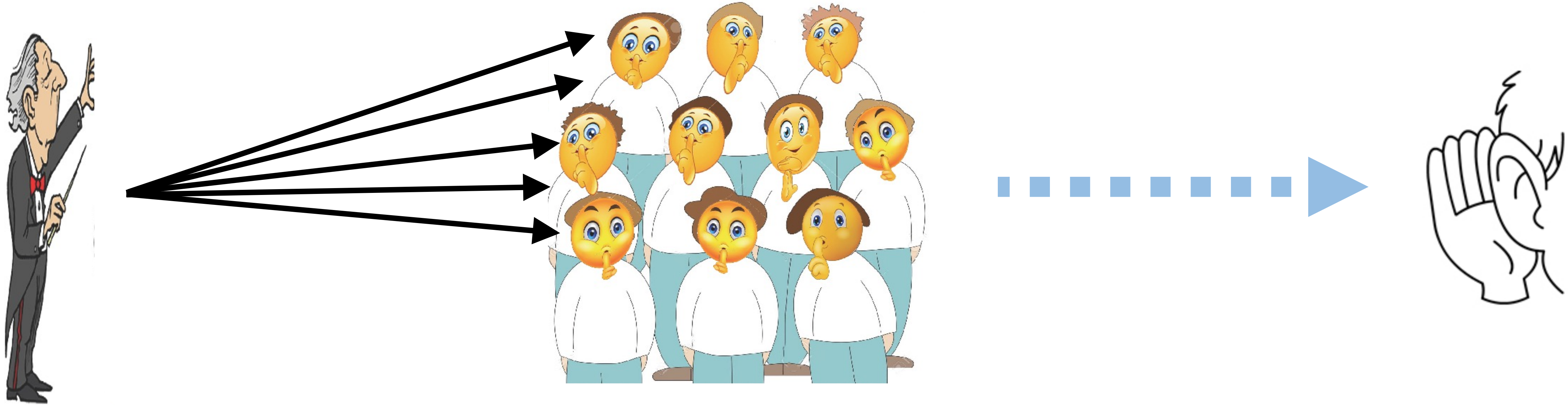


Can we silently transmit a fact φ ?

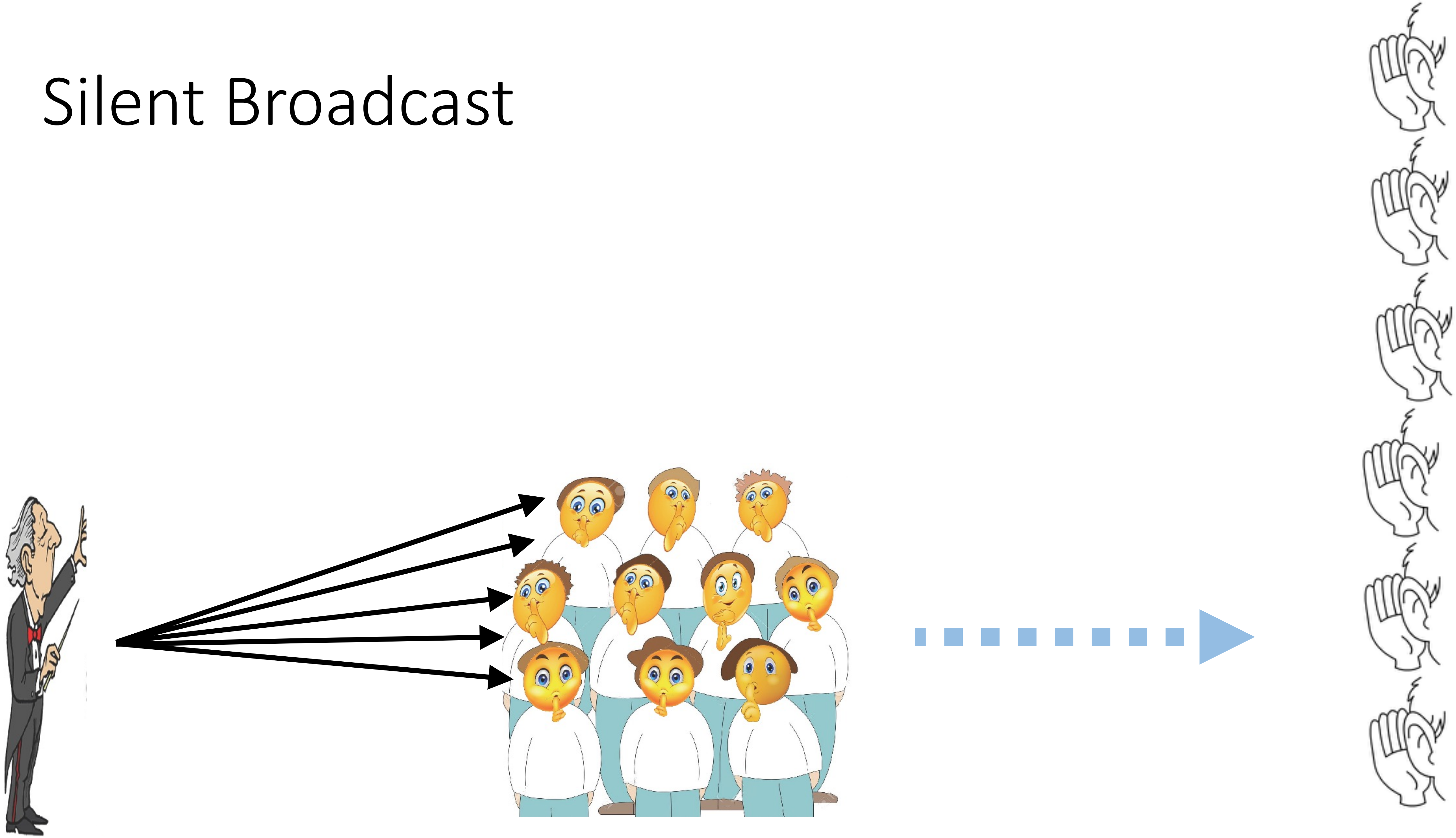
Silent Choirs

Assume a bound of $\boldsymbol{f}$ on the number of possible failures

($\boldsymbol{f} + 1$ cannot all fail)



Silent Broadcast



The Silent Choir Theorem

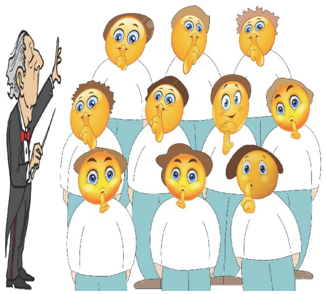
Theorem: If $K_i(v_j = 1)$ holds at time m then

a) A message chain from process j to i has been completed,

or

b) A **silent choir** of processes who know $v_j = 1$ is constructed by time $m - 1$.

OR



Silent Choirs in the Literature

- Byzantine agreement: Amdur, Weber, Hadzilacos [AWH'92]
  Hadzilacos & Halpern [HH'93]
- Atomic commitment: Guerraoui & Wang [GW'17]

An Application: Atomic Commitment (AC)

Each process starts with a vote in favor of commit (1) or abort (0), and every process that does not crash must decide. Moreover,

- **Agreement** - All decisions must be identical;
- If any of the votes is **0** then decisions must be to **0**;
- If all of the votes are **1** and nobody crashes, then decisions must be **1**.

Optimizing for the Common Case

Nice runs: all votes are **1** and no failure occurs

We optimize **AC** for nice runs

Silence in Message-Optimal AC

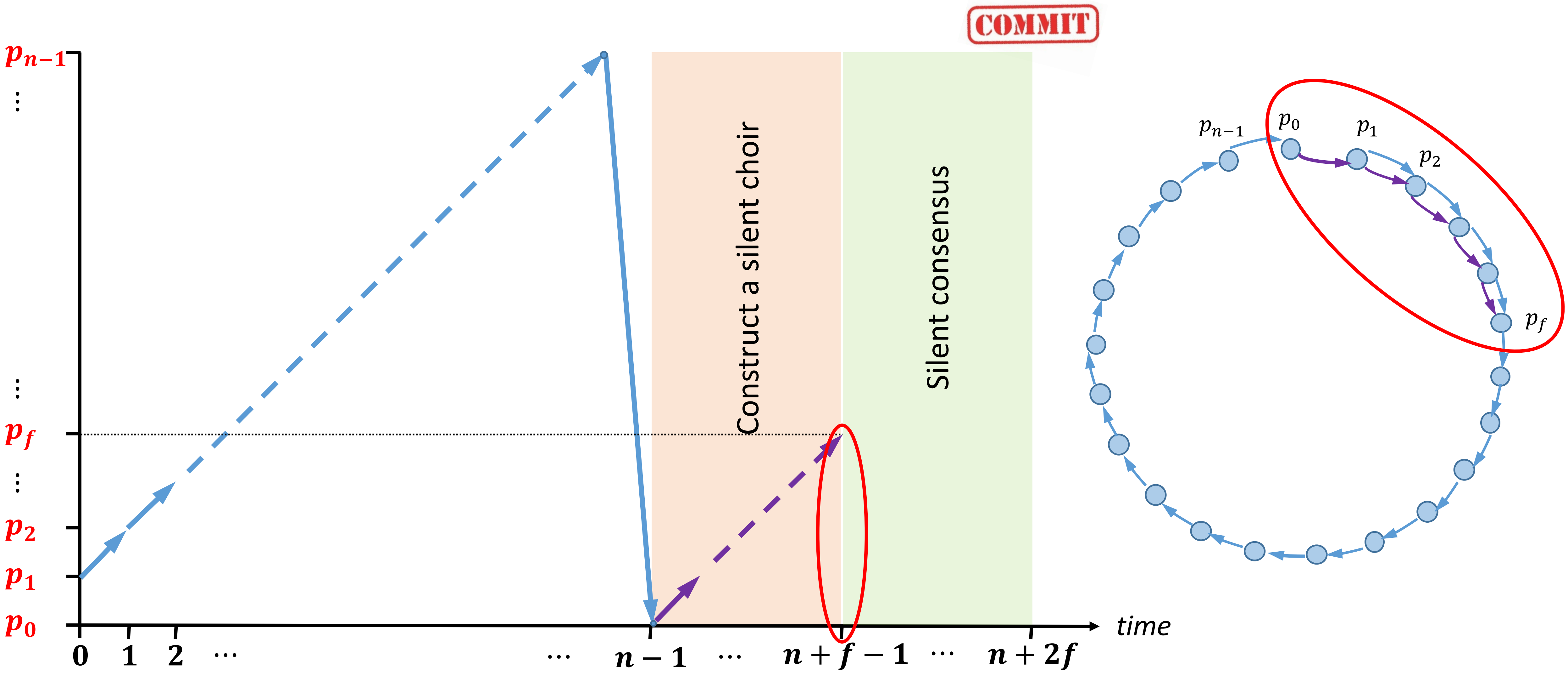
Theorem [GW '17]: $(\boldsymbol{n} + \boldsymbol{f} - \mathbf{1})$ messages must be sent in nice runs of AC

[Guerraoui and Wang '17]

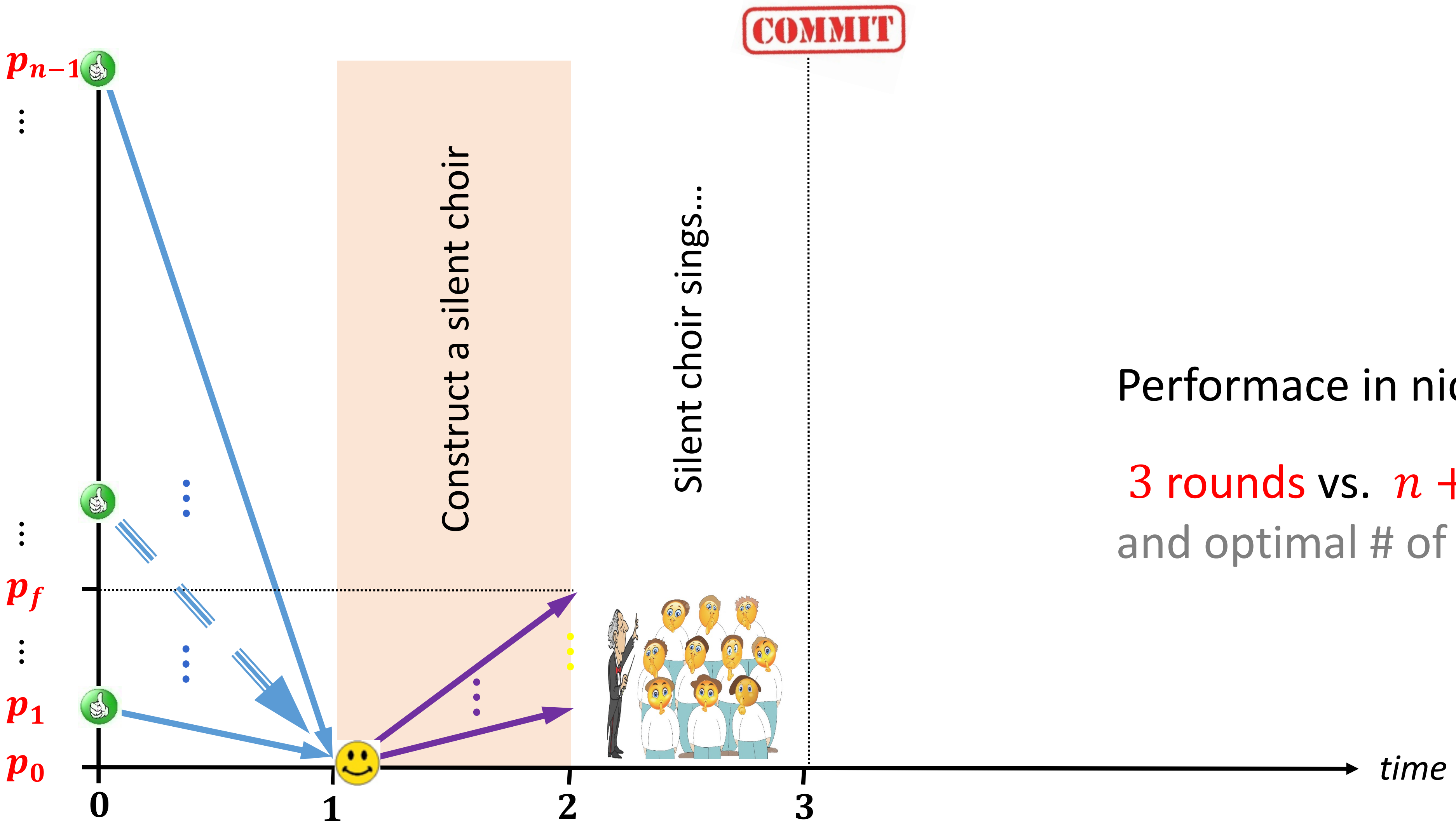
Theorem: Any message-optimal **AC** protocol must use silent choirs

- Every committing process must know the initial values of all others
- All-to-all message chains require at least $2n - 2$ messages ($\geq n + f - 1$)
- By the silent choir theorem, some knowledge is attained through silent choirs

Message-Optimal AC [GW '17]



STEALTH: Time-Optimal Message-Optimal AC



Performace in nice runs:

3 rounds vs. $n + 2f$ rounds of [GW'17]

and optimal # of messages

Summary

- Knowledge can be transmitted silently in the presence of failures
- Silent choirs can be used to obtain optimally efficient protocols

More generally:

- There are many models of distributed computing
- Studying problems in terms of knowledge applies to many models
- We study the interaction between knowledge, time, communication and strategic behavior

Thanks!