Failure Detection

Outline

- Failure detectors
- Properties – completeness & accuracy
- Two failure detector algorithms
  - Heart-beating and Ping-Ack
- Distributed Failure Distribution through heart-beating algorithms
  - Centralized, Ring, All-to-all
- Accuracy metrics
- Other Types of Failures

Two Different System Models

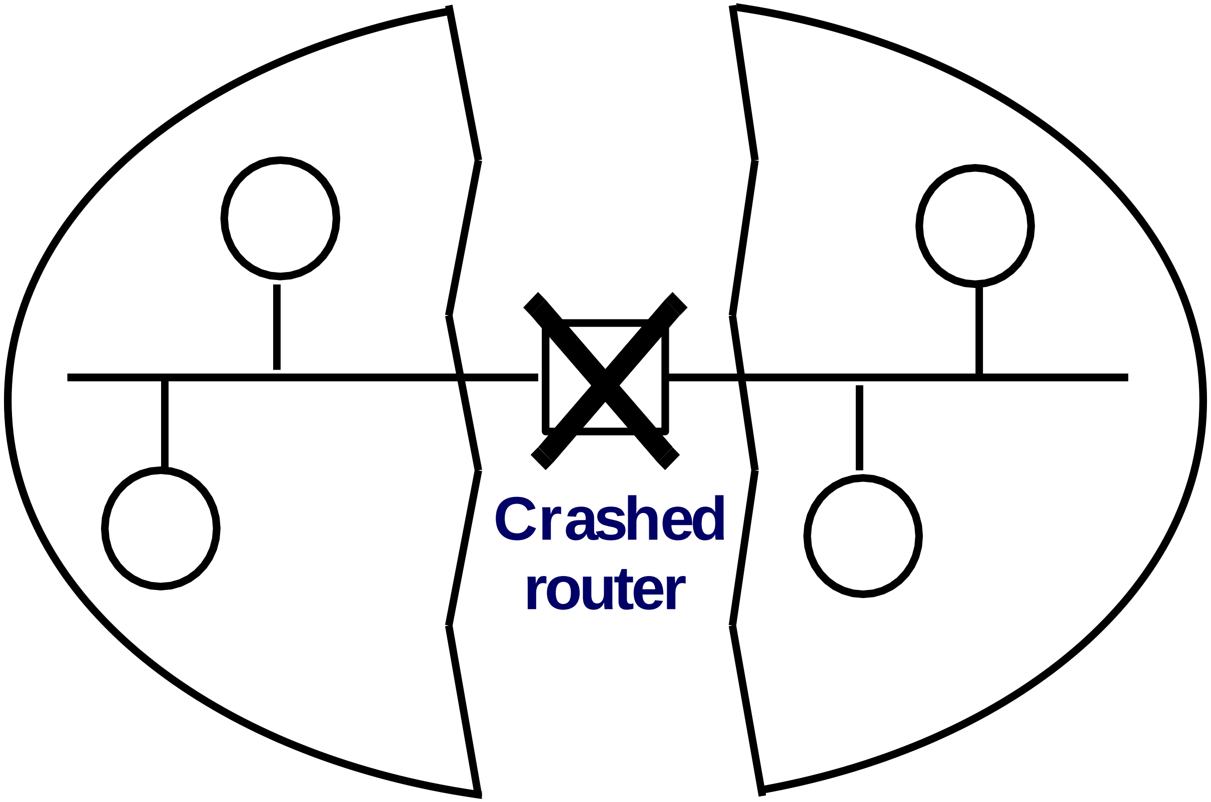
- Synchronous Distributed System
  - Each message is received within bounded time
  - Each step in a process takes *lb* < *time* < *ub*
  - (Each local clock's drift has a known bound)
- Asynchronous Distributed System
  - No bounds on process execution
  - No bounds on message transmission delays
  - (The drift of a clock is arbitrary)

The Internet is an asynchronous distributed system

Failure Model

- Process omission failure
  - Crash-stop (fail-stop) – a process halts and does not execute any further operations
  - Crash-recovery – a process halts, but then recovers (reboots) after a while
- *Crash-stop* failures can be detected in synchronous systems
- Next: detecting *crash-stop* failures in asynchronous systems

Network partition



What's a failure detector?

pi

pj

What's a failure detector?

Crash-stop failure
pi
X
pj

What's a failure detector?

needs to know about *pj*'s failure

pi

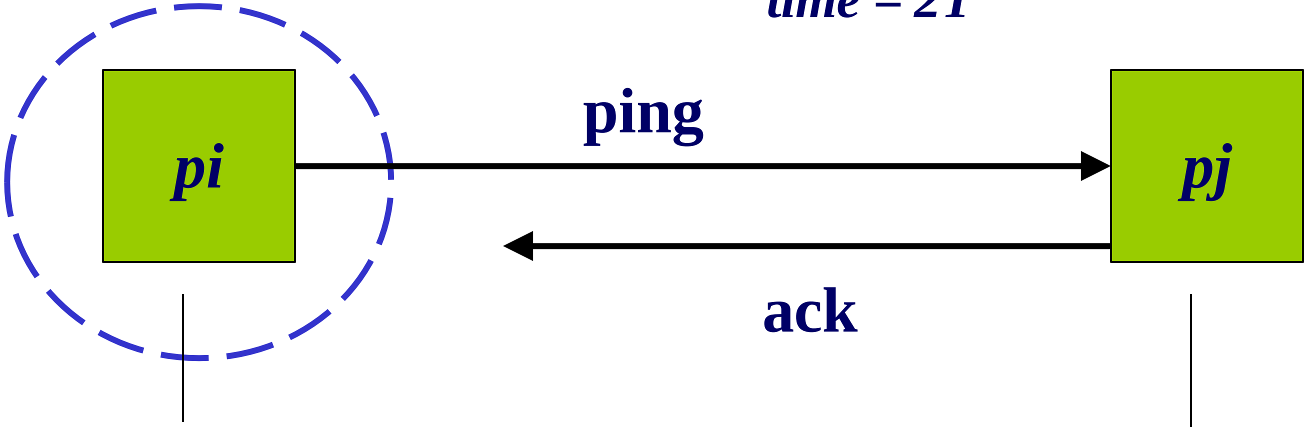
Crash-stop failure

X *pj*

I. Ping-Ack Protocol

If pj fails, within T time units, pi will send it a ping message, and will time out within another T time units. Detection time = 2T

needs to know about *pj*'s failure



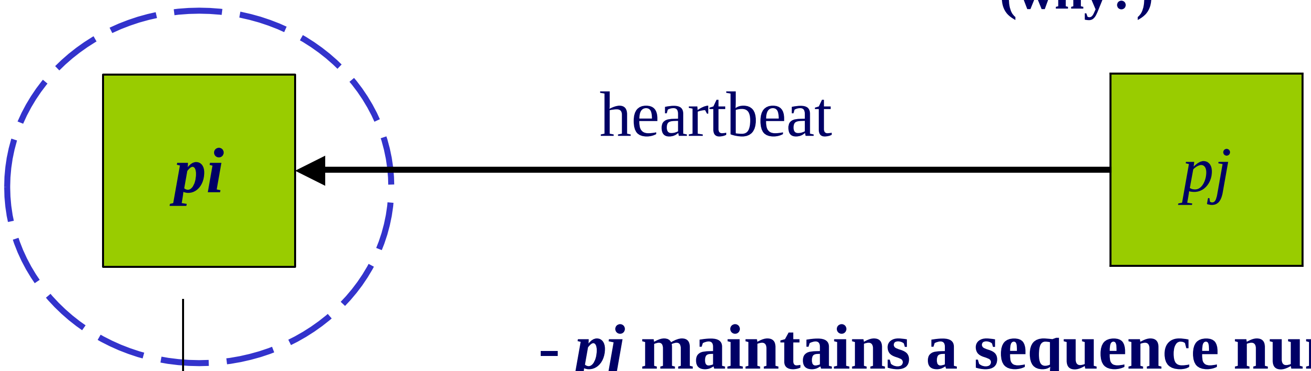
- *pi* queries *pj* once every *T* time units
- if *pj* does not respond within *T* time units, pi marks *pj* as failed

- *pj* replies

II. Heart-beating Protocol

needs to know about *pj*'s failure

In reality, detection time is also T time units (why?)



- ***pj* maintains a sequence number**
- ***pj* sends *pi* a heartbeat with incremented seq. number after every *T'(=T)* time units**

-if *pi* has not received a new heartbeat for the past *T* time units, *pi* declares *pj* as failed

Failure Detector Properties

- Completeness = every process failure is eventually detected (no misses)
- Accuracy = every detected failure corresponds to a crashed process (no mistakes)

Completeness or Accuracy?

- Most failure detector implementations are willing to tolerate some inaccuracy, but require 100% completeness
- Plenty of distributed apps designed assuming 100% completeness, e.g., p2p systems
  - "Err on the side of caution".
  - Other processes need to make repairs whenever a failure happens
- Heart-beating – satisfies completeness but not accuracy (why?)
- Ping-Ack – satisfies completeness but not accuracy (why?)

Completeness or Accuracy?

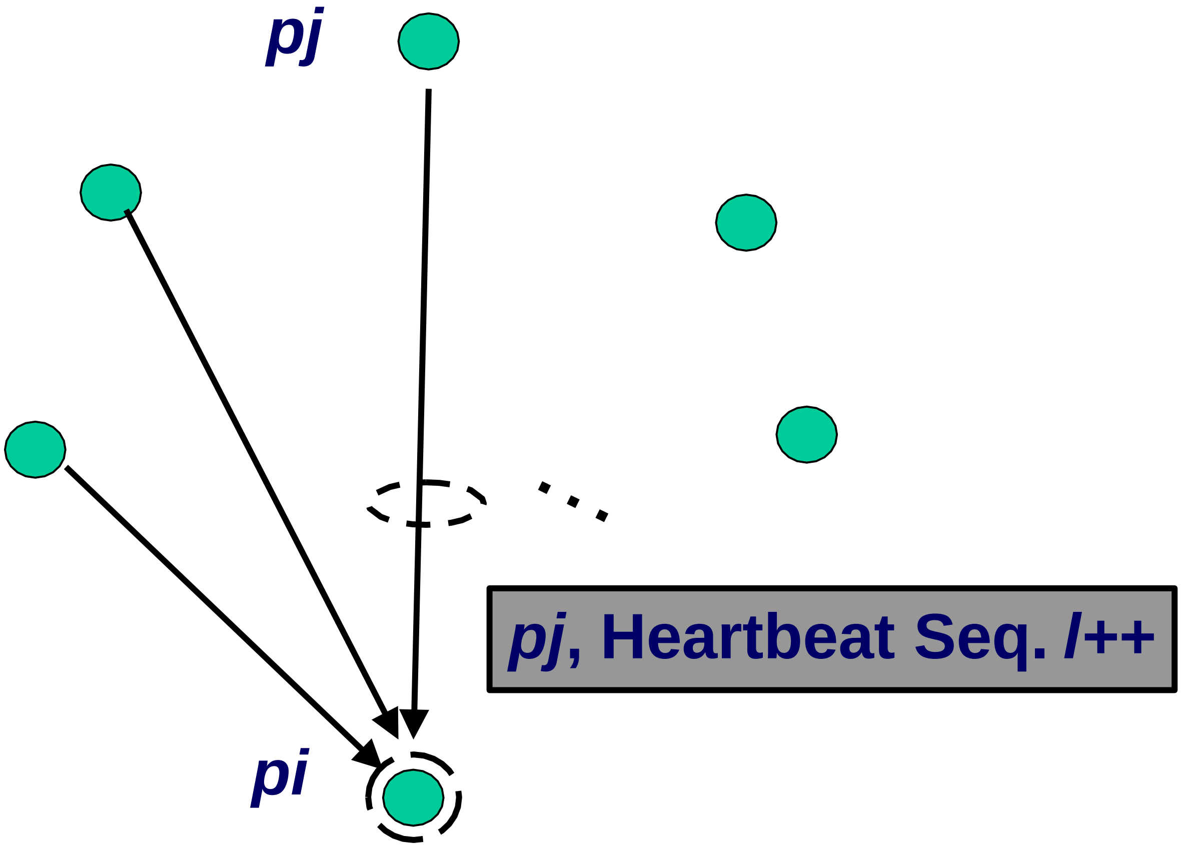
- Both Heart-beating and Ping-Ack provide
  - *Probabilistic* accuracy (for a process detected as failed, with some probability close to 1.0, it is true that it has actually crashed).
  - That was for asynchronous systems
- Heart-beating and Ping-ack can satisfy both completeness and accuracy in *synchronous* systems

Distributed System

- Difference from original failure detection is
  - we want not one process (*pi*), but *all* processes in system to know about failure
- May need to combine failure detection with *a dissemination protocol*
  - What's an example of a dissemination protocol?

    A reliable multicast protocol!

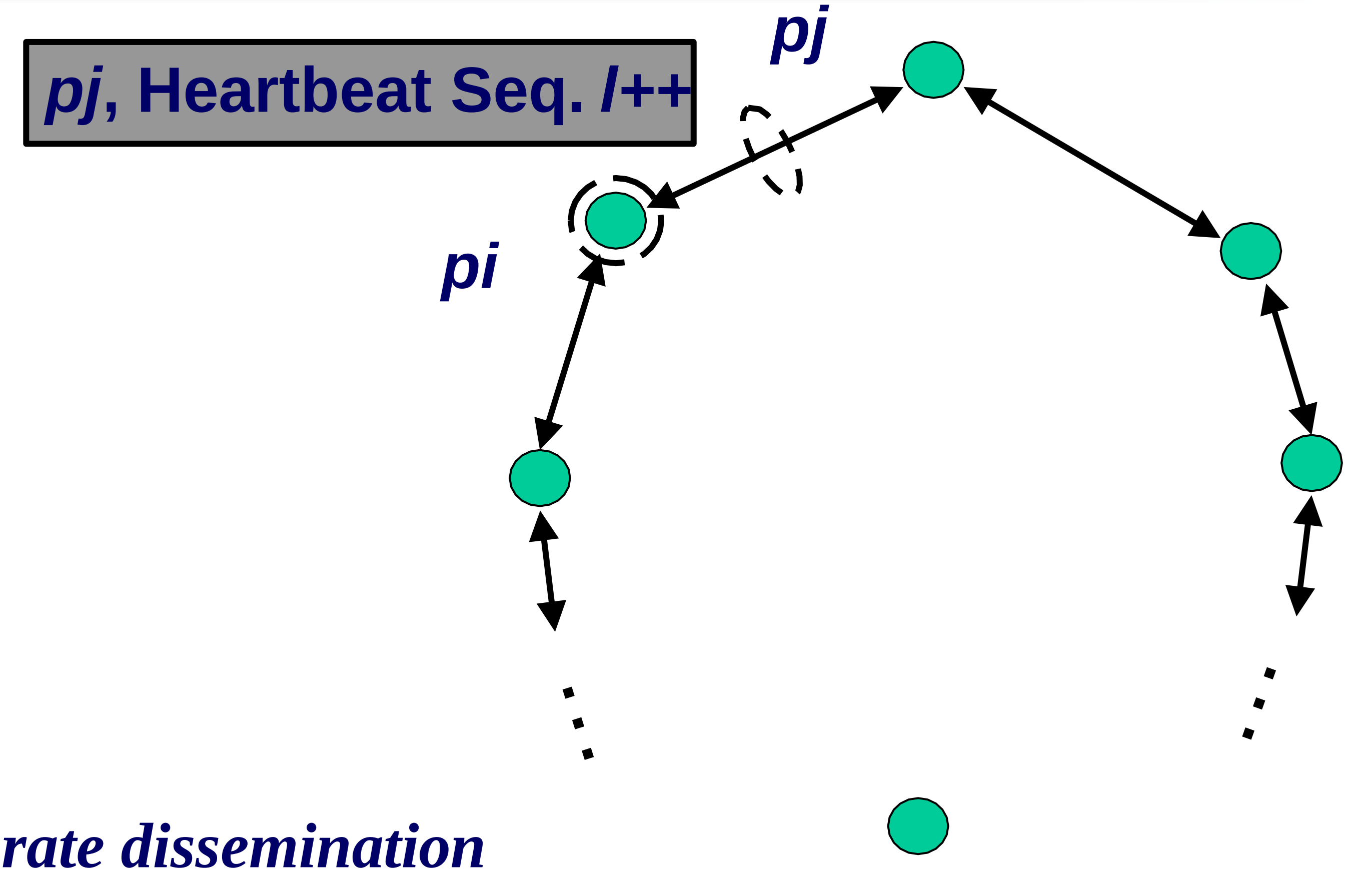
Centralized Heart-beating



pj, Heartbeat Seq. *l*++

Needs a separate dissemination component Downside?

Ring Heart-beating



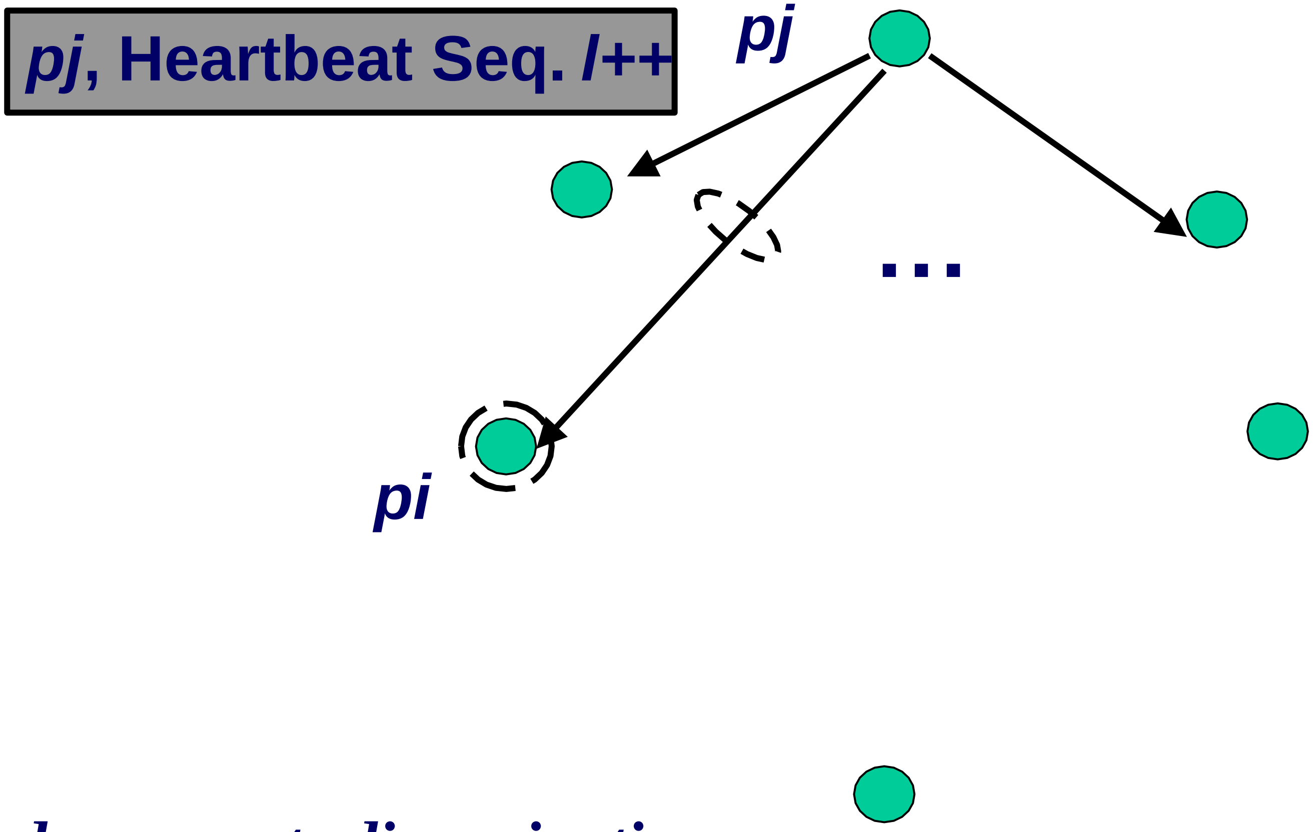
pj, Heartbeat Seq. *l*++

pj

pi

Needs a separate dissemination component Downside?

All-to-All Heart-beating



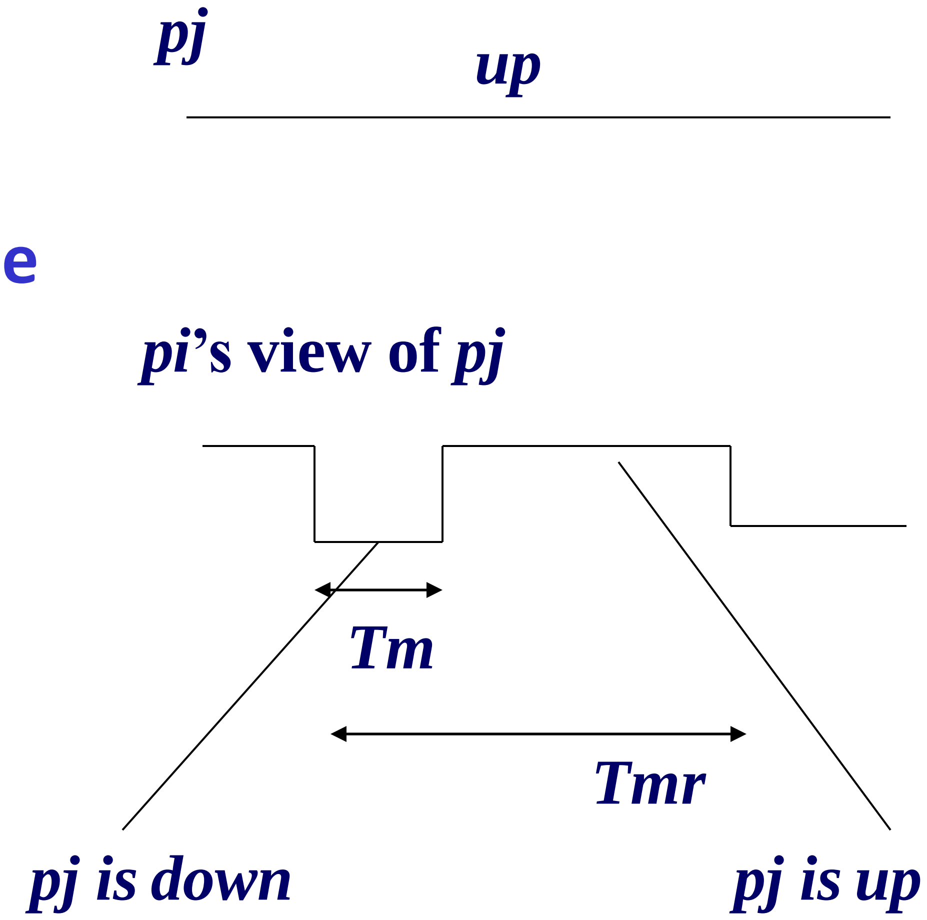
Does not need a separate dissemination component Downside?

Efficiency of Failure Detector: Metrics

- **Measuring Speed**: Detection Time
  - Time between a process crash and its detection
  - Determines speed of failure detector
- **Measuring Accuracy**: depends on distributed application

Accuracy Metrics

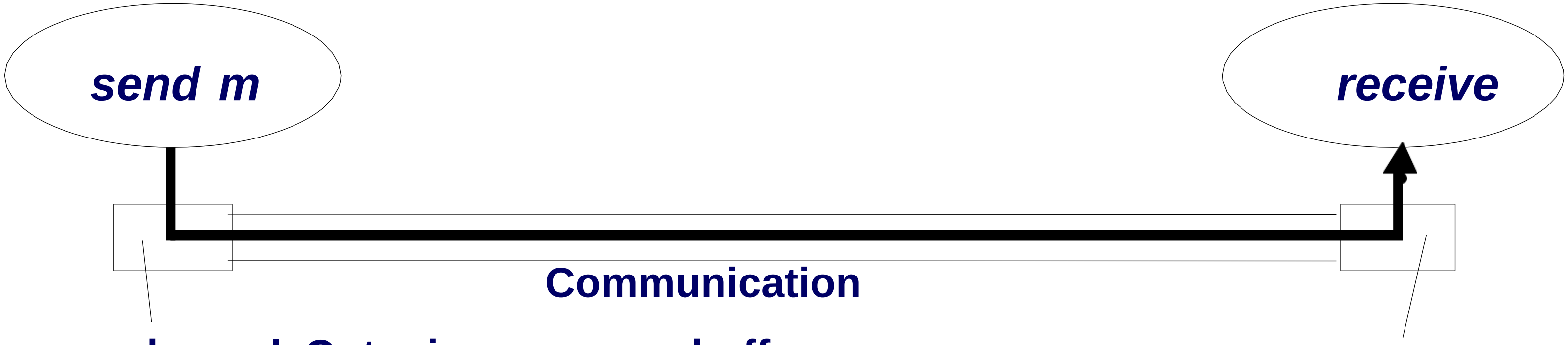
- ***Tmr***: **Mistake recurrence time**
  - Time between two consecutive mistakes
- ***Tm:*** **Mistake duration time**
  - Length of time for which correct process is marked as failed (for crash-recovery model)



More Accuracy Metrics

- Number of false failure detections per time unit (false positives)
  - System reported failure, but actually the process was up
  - Failure detector is inaccurate
- Number of not detected failures (false negatives)
  - System did not report failure, but the process failed
  - Failure detector is incomplete

Processes and Channels



process *p*

send m

process *q*

receive

Communication

channel Outgoing message buffer

Incoming message buffer

Other Failure Types

- Communication Omission Failures
  - Send-omission: loss of messages between the sending process and the outgoing message buffer (both inclusive)
    - What might cause this?
  - Channel omission: loss of message in the communication channel.
  - Receive-omission: loss of messages between the incoming message buffer and the receiving process (both inclusive)

Other Failure Types

- Arbitrary Failures (Byzantine)
  - Arbitrary process failure: arbitrarily omits intended processing steps or takes unintended processing steps.
  - Arbitrary channel failures: messages may be corrupted, duplicated, delivered out of order, incur extremely large delays; or non-existent messages may be delivered.

Timing Failures

- In synchronous distributed systems - applicable
  - Need time limits on process execution time, message delivery time, clock drift rate
- In asynchronous distributed systems- not applicable
  - Server may respond too slowly, but we cannot say if it is timing failure since no guarantee is offered
- In real-time OS - applicable
  - Need timing guarantees, hence may need redundant hardware
- In multimedia distributed systems – applicable
  - Timing important for multimedia computers with audio/video channels

Timing Failures

Class of Failure	Affects	Description
Clock	Process	Process's local clock exceeds the bounds on its rate of drift from real time
Performance	Process	Process exceeds the bounds on the interval between two steps
Performance	Channel	A message's transmission takes longer than the stated bound

Summary

- Failure detectors are required in distributed systems to maintain liveness in spite of process crashes
- Properties – completeness & accuracy, together unachievable in asynchronous systems
- Most apps require 100% completeness, but can tolerate inaccuracy
- 2 failure detector algorithms – Heart-beating and Ping-Ack
- Distributed Failure Distribution through heart-beating algorithms: Centralized, Ring, All-to-all
- Other Types of Failures