Fault Tolerance for Highly Available Internet Services: Concept, Approaches, and Issues

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Outlines

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    - FT Concepts & Challenges

2. Fault Models & Failure Detection

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3. Service Replications

    - Concepts, Approaches & Issues

4. Failure Recovery

    - Network, Transport, Session/Application Level Failovers

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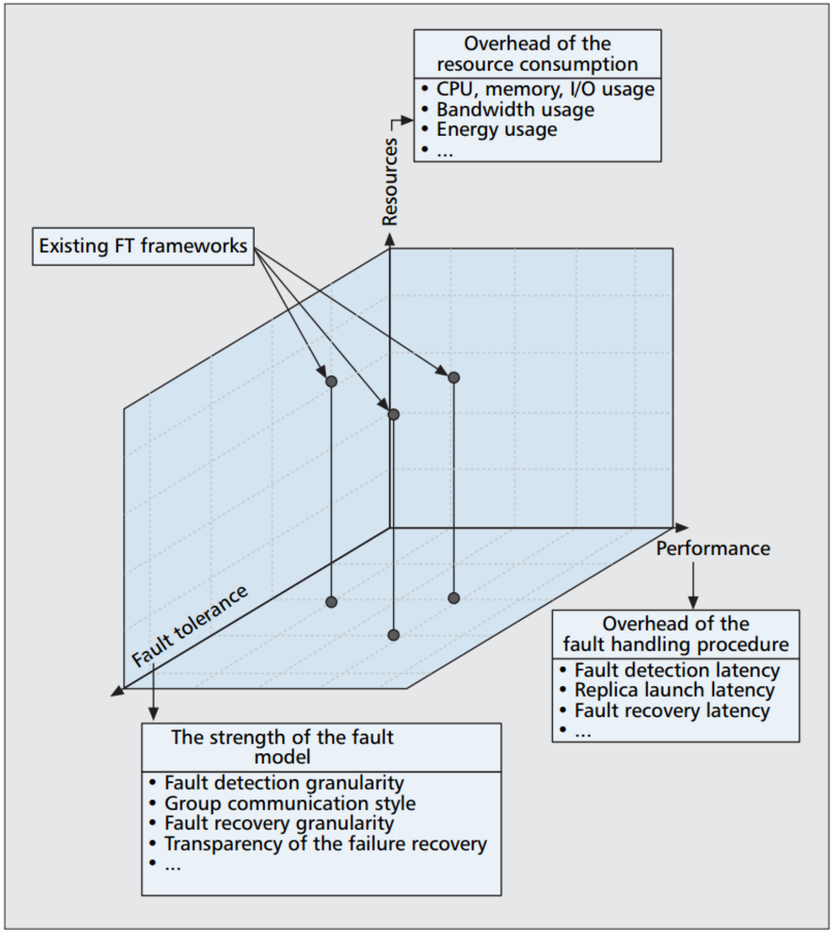
Intro

Fault Tolerance Framework

- ❑ FT Frameworks uses **Resource Redundancy** to Ensure Availability

- ❑ Two Concepts
  - **Fault Detection**
  - **Fault Recovery**

- ❑ Three Challenges
  - **Resource Consumption**
  - **Strength of Fault Tolerance**
  - **Performance**



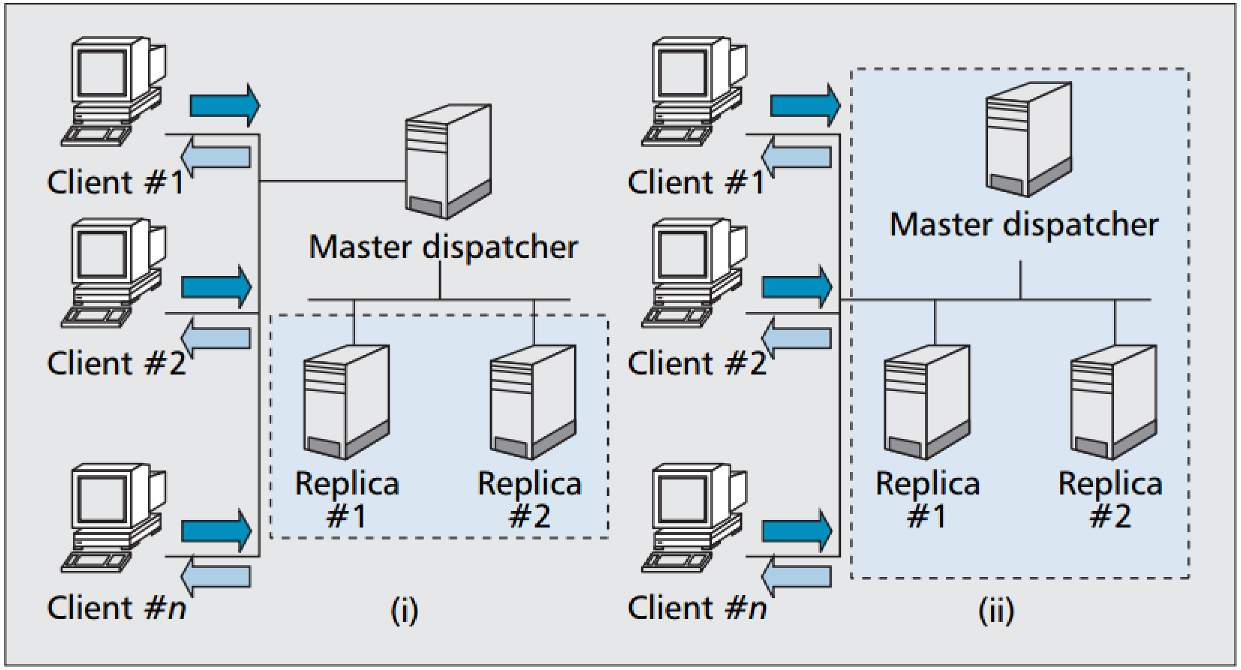
Overhead of the resource consumption
• CPU, memory, I/O usage
• Bandwidth usage
• Energy usage
• ...
Resources
Existing FT frameworks
Performance
Fault tolerance
Overhead of the fault handling procedure
• Fault detection latency
• Replica launch latency
• Fault recovery latency
• ...
The strength of the fault model
• Fault detection granularity
• Group communication style
• Fault recovery granularity
• Transparency of the failure recovery
• ...

Credit: Ayari, Narjess, et al. "Fault tolerance for highly available internet services: concepts, approaches, and issues." *Communications Surveys & Tutorials, IEEE* 10.2 (2008): 34-46.

Intro

Redundancy in Cluster-based Architecture

- ❑ Two Redundancy Scenarios
  - **Passive Scenario**
  - **Active Scenario**



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Fault Types and Models

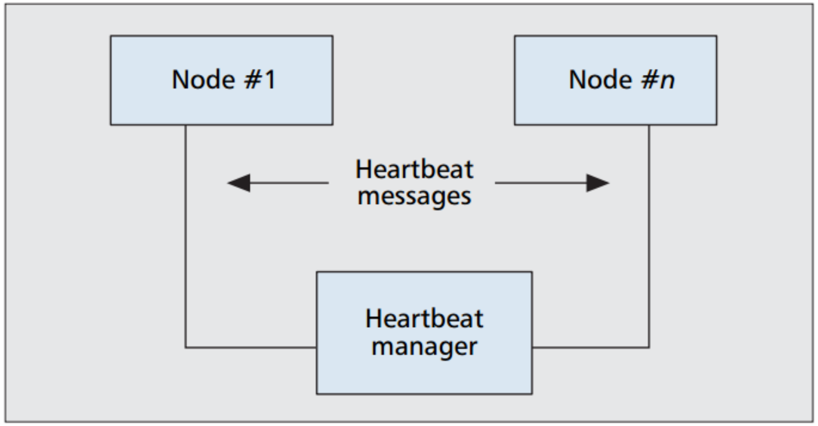
- **Fault Types**
  - Client-side fault
    - concerns the client device
  - Network-side fault
    - includes corruption, delay, reordering, duplication, and loss of packets
  - Server-side fault
    - results in the silence or malfunctioning of the processing server

- **Fault Models**
  - Byzantine fault
    - occurs arbitrarily and maliciously, causing the system to behave incorrectly
  - Fail-stop fault
    - has a deterministic impact on a subsystem component, causing it die silently
    - inactive during failure

Failure Detection Approaches

- ❑ **Requirement**
  - It should detect failures as soon as they occur so that the framework can quickly trigger the failure recovery procedure.
  - It must be robust enough to ensure that only one error-free instance of the service is running at once.

- ❑ **Heartbeat Monitoring**
  - Based on the explicit and periodic exchange of heartbeat messages between replicas.



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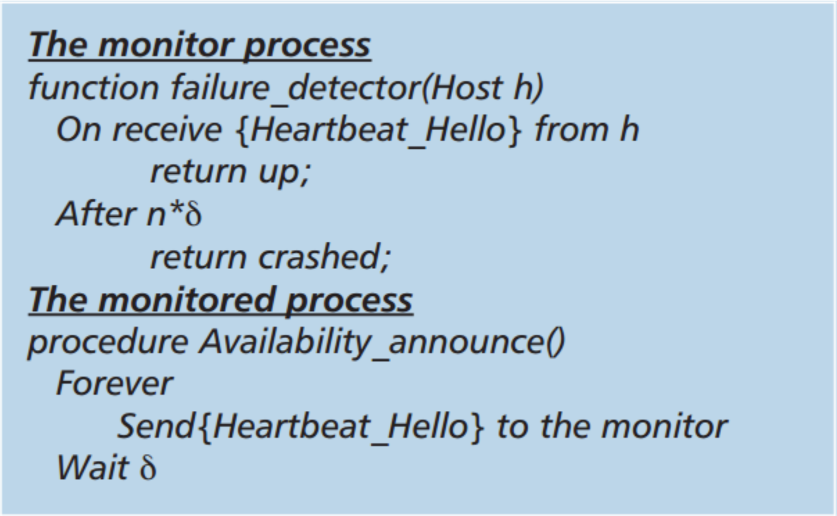
Fault Models

Failure Detection Approaches (Con’t)

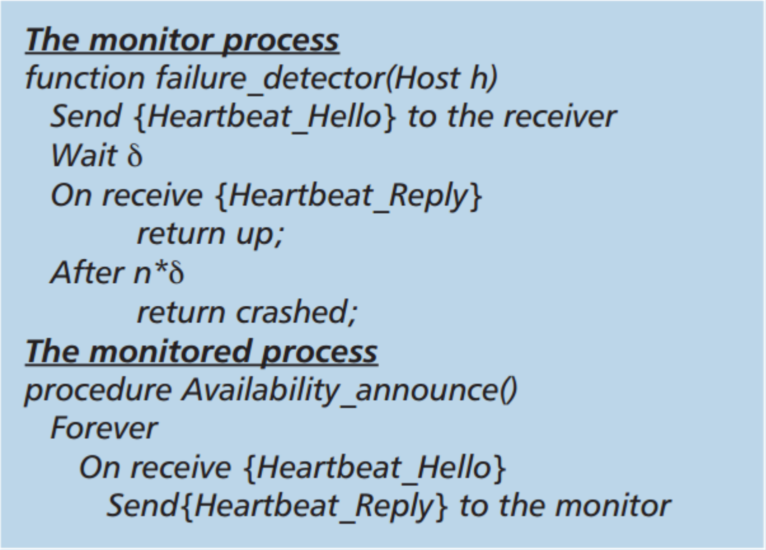
❑ Heartbeat Monitoring

- Two monitoring types:



```
The monitor process
function failure_detector(Host h)
  On receive {Heartbeat_Hello} from h
         return up;
  After n*δ
         return crashed;
The monitored process
procedure Availability_announce()
  Forever
      Send{Heartbeat_Hello} to the monitor
  Wait δ
```

Push-based heartbeat monitoring



```
The monitor process
function failure_detector(Host h)
  Send {Heartbeat_Hello} to the receiver
  Wait δ
  On receive {Heartbeat_Reply}
        return up;
  After n*δ
        return crashed;
The monitored process
procedure Availability_announce()
  Forever
    On receive {Heartbeat_Hello}
      Send{Heartbeat_Reply} to the monitor
```

Pull-based heartbeat monitoring

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Failure Detection Approaches (Con't)

❑ Problem with Heartbeat Monitoring

- Heartbeat monitoring is generally used to detect a node or link failure
- Failure could occur at a smaller level
  - such as at process level

❑ Solution

- **Watchdog timer** is an inexpensive solution
  - process being monitored must reset a timer before it expires
  - otherwise, it is assumed to have failed
- Problems with Waterdog
  - only deterministic runtime process can be monitored
  - partially failed process can still reset the timer

Service Replication Concept

- ❑ **Replication Concept**
  - ▪ Recovery of a service by replicating its related states
  - ▪ When failure occurs The traffic is taken over by an elected backup node
- ❑ **Requirements**
  - ▪ Transparency
    - needs to achieve a client-side transparent failover, already established sessions need to be recovered in case of failure
  - ▪ Overhead
    - measured by the cost of replication process during failure-free period
  - ▪ Consistency
    - needs replicas to maintain same view of the replicated states

- ❑ **Replication Approaches**
  - ▪ Leader/follower
  - ▪ Active Replication
  - ▪ Checkpointing
  - ▪ Message Logging
  - ▪ Hybrid Approach

Replication

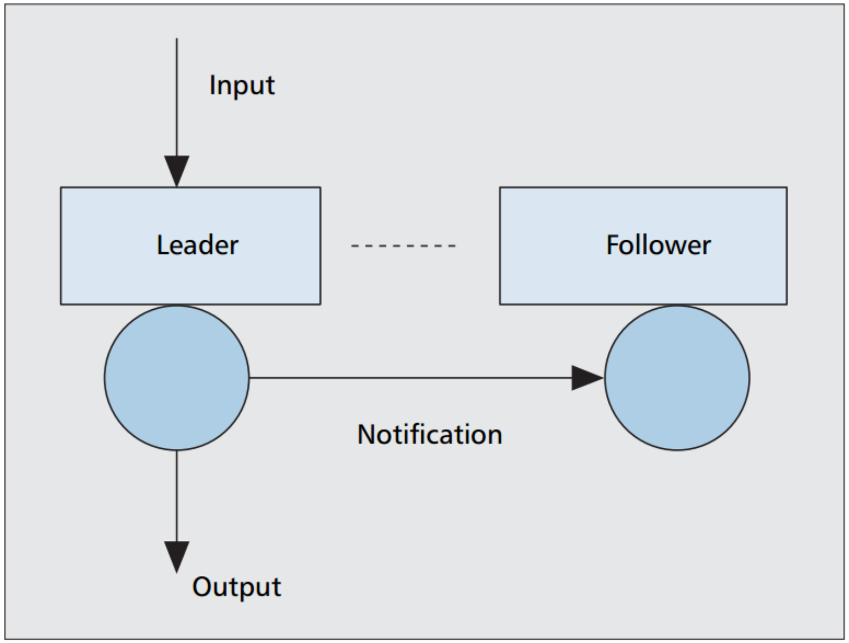
Leader/follower Approach

❑ **Idea**

- Let a replica (leader) perform action first;
- Then leader notifies followers the results;
- Replicas update their state.

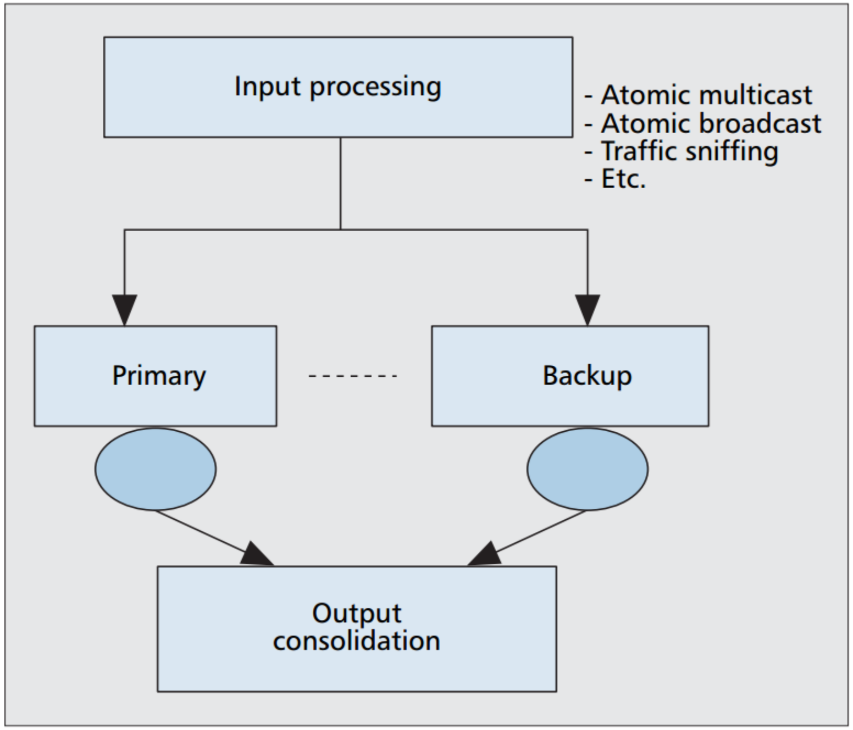
❑ **Evaluation**

- Performs well with read-only files
- Not appropriate for processes modifying files concurrently
- Performs poorly when large volumes of info involved



Active Approach

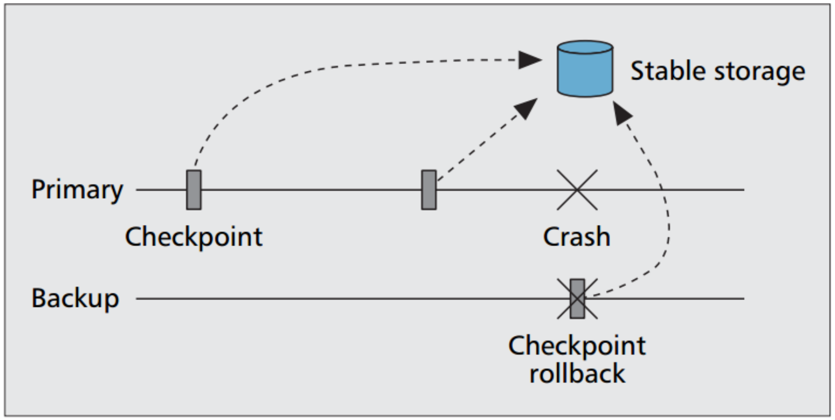
- ❑ **Idea**
  - All nodes to receive and concurrently process the offered network traffic
  - Its objective is to ensure all replicas maintain same state and guarantee only one server replies to client



- ❑ **Evaluation**
  - Leader does not need to forward data to followers
  - Further processing is required to ensure consistency
    - Atomic Multicast Protocol
    - Intermediate Gateway or Proxy
    - etc.

Checkpointing Approach

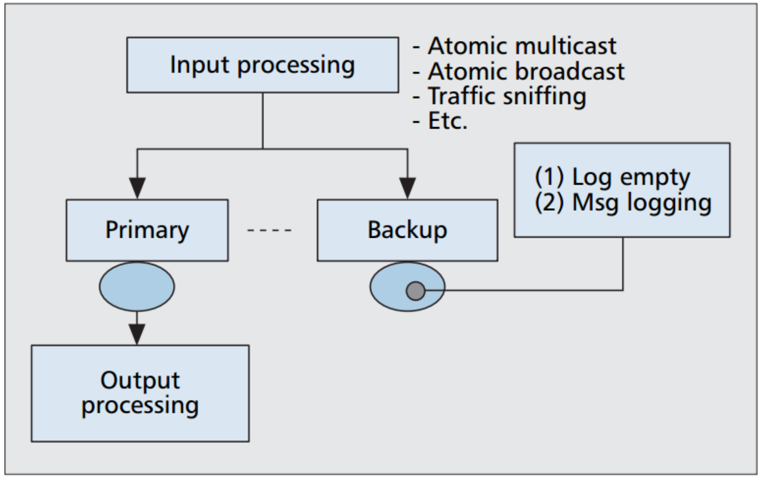
- ❑ **Idea**
  - State is periodically copied either to standby servers or to a stable storage
  - **Incremental Checkpointing** checkpoints each time change occurs
  - **Time-line Checkpointing** checkpoints state periodically



- ❑ **Evaluation**
  - Aggressive approach has high cost and adds latency
  - Time-line approach’s time-to-check value affects overhead and number of rollback operations

Message Logging Approach

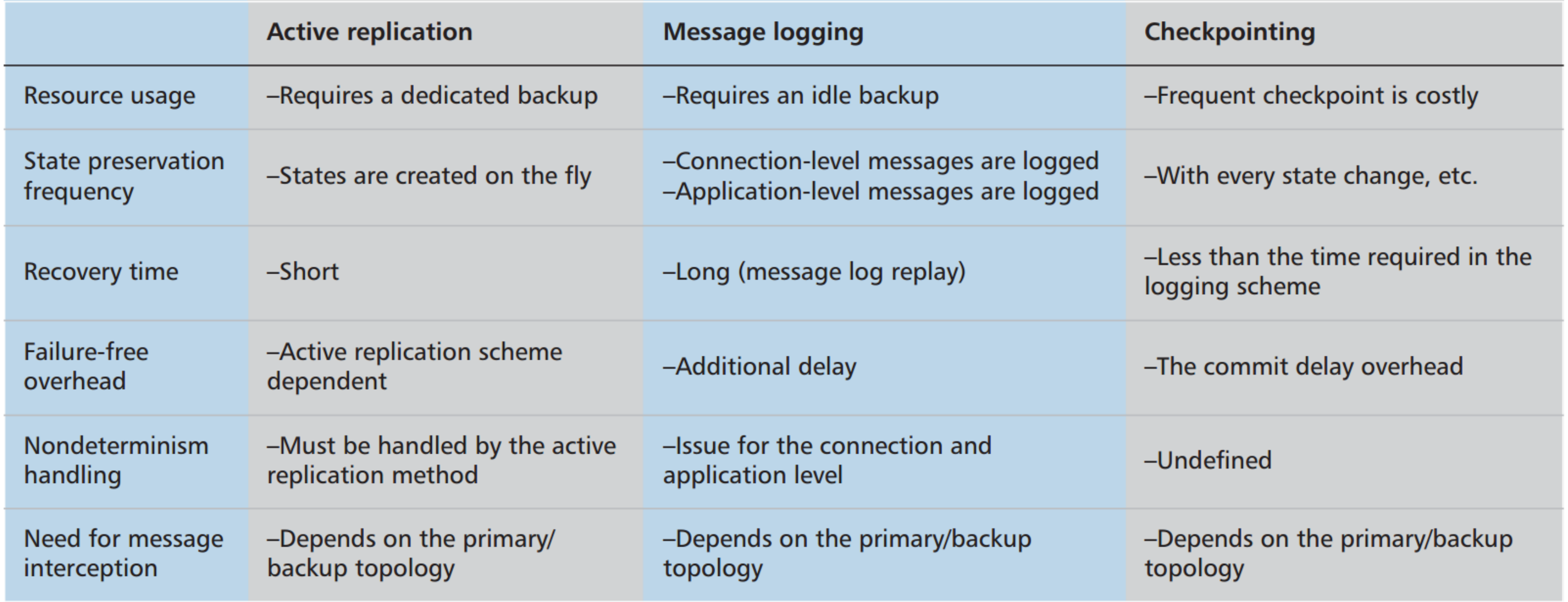
- **Idea**
  - To store or log all the messages delivered to the primary server on stable storage or a replica
  - **Dependency-based Logging** flushes the log space once full
  - **Optimistic Logging** flushes periodically or at a given threshold



- **Evaluation**
  - Recover time takes longer than checkpointing approach

Replication Approaches Compare

- Active replication and Message logging need server to be deterministic
- Active replication has the best recovery time
- Message logging needs longest recovery time



	Active replication	Message logging	Checkpointing
Resource usage	–Requires a dedicated backup	–Requires an idle backup	–Frequent checkpoint is costly
State preservation frequency	–States are created on the fly	–Connection-level messages are logged –Application-level messages are logged	–With every state change, etc.
Recovery time	–Short	–Long (message log replay)	–Less than the time required in the logging scheme
Failure-free overhead	–Active replication scheme dependent	–Additional delay	–The commit delay overhead
Nondeterminism handling	–Must be handled by the active replication method	–Issue for the connection and application level	–Undefined
Need for message interception	–Depends on the primary/ backup topology	–Depends on the primary/backup topology	–Depends on the primary/backup topology

Failure Recovery Concept

- Failure recovery is followed by detection
  - Its objective is to increase both availability and reliability
  - **Network identity takeover** is the first step
  - Further steps needed to meet reliability requirement
    - Transport-level failover
    - Session/Application level failover

Network-level Failover

❑ **Idea**

- Provide replicas the means to take over the network identity of the legitimate processing server if it fails.
- It provides an acceptable level of service availability

❑ **Approaches**

- Link Aggregation Protocol
  - allows the use of multiple Ethernet network interfaces or links in parallel
- ARP-Spoofing-based network Identify Takeover
  - backup node takes over the virtual IP by flooding gratuitous ARP message
- Virtual Router Redundancy Protocol
  - virtual router abstracts a cluster of routers servicing hosts in the same network
- Static NAT-based IP takeover
  - traffic first offered to the entry point before assigning to a server

Failover

Transport-level failover

- ❑ **Idea**
  - Should the primary server fail, the already established flow is taken over by an elected backup while avoiding its interruption.
- ❑ **Approaches**
  - FT-TCP
  - Transparent Connection Failover
  - ST-TCP

Session/Application Level Failover

- ❑ **Idea**
  - Require the elected replica to failback each associated state
- ❑ **Approaches**
  - Synchronize the primary node’s system call at each replica
  - Identify nondeterministic behaviour at the application level and synchronizing at those point
  - Use checkpointing to save the primary’s application level state

Conclusion

Paper Conclusion

❑ This paper provides a comprehensive overview of the building blocks of fault tolerance frameworks.

- Fault model and failure detection approaches

  - different existing Internet server fault models

  - state-of-art failure detection approaches

- Service replication concepts, approaches and issues

  - different states required to be replicated

  - replication approaches and their major limitations

- Failure recovery approaches and issues

  - failover at Network, Transport, Session and Application level

Conclusion

Questions Raised

- □ Why, as shown in FT framework constraints figure, the increase of resource does not affect the performance and fault tolerance?

- □ Why the current FT frameworks lacks transport- nor session/application level failover support despite of the increasing need of next-generation Internet services?

- □ How content inspection can be used to identify the source of nondeterministic behavior at Application level failover?