Message Logging Protocol for Hierarchical Server Architectures

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Abstract— *Two-level hierarchical architecture consisting of a set of node groups is one of the most well-known organizations for managing a large scale distributed system in an efficient way. This network organization generally has the topological feature that inter-group communication overhead is considerably higher than intra-group one. This paper presents a new message logging protocol as lightweight fault-tolerance technique to reduce the number of in-group control messages and the number of inter-group control messages while distributing the load of logging of the message as evenly as possible compared to the existing sender-based message logging ones with high failure-free overhead and recovery inefficiency.*

Keywords: Hierarchical and Distributed Architecture, Fault-tolerance, Message Logging and Checkpointing, Recovery

1. Introduction

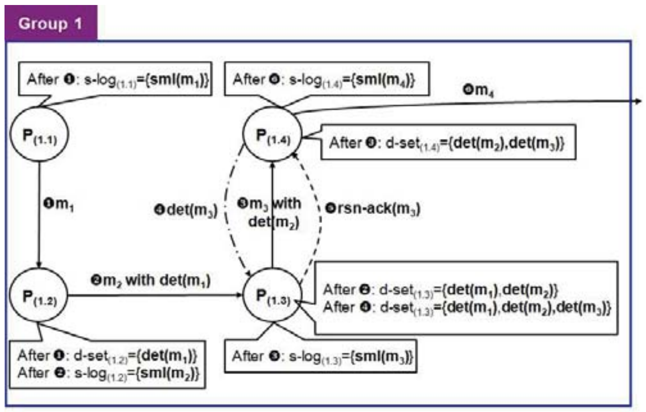
Distributed computing architectures require efficient fault-tolerance techniques for improving service availability in case of sequential node failures [3], [4], [5]. For this purpose, checkpointing and message logging may satisfy the requirement with much less computing resources during failure-free operation than process replication [2]. Among the message logging algorithms, Sender-Based Message Logging(SBML) can greatly reduce the cost of synchronous logging to the stable storage compared with receiver-based pessimistic message logging by maintaining the log information of each message onto the volatile memory buffer of its sender [3], [4], [5]. Also, if nodes or processes sequentially fail, they can obtain the contents and the receive sequence number(rsn) of each message from its sender, and replay it in a pre-failure order, recovering to reach their consistent states. However, most of the previous sender-based message logging protocols[1], [3], [4], [5] commonly have message senders get receive sequence numbers(RSNs) of the messages from their receivers and confirm them with the receivers. For this purpose, they essentially incur extra message transmissions respectively. This behavioral feature may cause the following performance problems in the two-level hierarchical and distributed architectures.

• A message transmission in a group makes two additional in-group control messages between its sender and receiver.
• A message transmission between two groups makes two additional inter-group control messages between its sender and receiver.
• If a recovering process received at least one inter-group message before failure, it should broadcast a request for its log information to every other group on starting recovery.

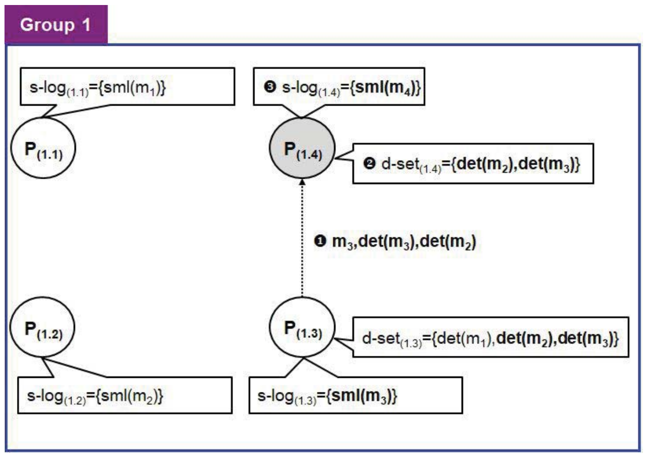
In this paper, we present a novel message logging protocol consisting of three modules for two-level hierarchical and distributed architectures to address the drawbacks of sender-based message logging. The first module reduces the number of in-group control messages and, the rest, the number of inter-group control messages while localizing recovery. Also, it can distribute the load of logging and keeping inter-group messages to group members as evenly as possible.

2. New Message Logging Protocol

The proposed protocol consists of three modules to address the three drawbacks of the original sender-based message logging. The first two modules are performed for intra group messages and, the last, for inter group messages. The first is called causal message logging; when the first member of group 1, $P_{(1,1)}$, sends message m_1 to the second member of the same group in figure 1(a), $P_{(1,2)}$, the log information of m_1 except its receive sequence number, $smi(m_1)$, is kept on its sender's volatile buffer, $s\text{-}log_{(1,1)}$. Here, $smi(m_1)$ is composed of the identifier of the receiver(rid), the send sequence number(ssn), and the data of the message($data$). Receiving m_1, $P_{(1,2)}$ assigns a receive sequence number(rsn) to it, and then, saves the determinant of the message, $det(m_1)$, in its buffer, $d\text{-}set_{(1,2)}$. Here, $det(m_1)$ consists of the identifier of the receiver(sid), ssn, rid, the receive sequence number of the message(rsn), and the identifier of the immediate dependent(did) which is the member having a copy of the determinant. When the receiver of m_1, $P_{(1,2)}$, sends message m_2 to the third group member, $P_{(1,3)}$, $det(m_1)$ is piggy-backed on m_2 to maintain in the buffer of the immediate dependent of m_1, $d\text{-}set_{(1,3)}$. Receiving m_3, the immediate dependent of m_2, $P_{(1,4)}$, also keeps $det(m_2)$ in its buffer $d\text{-}set_{(1,4)}$ in the same way. However, when the fourth member, $P_{(1,4)}$, attempts to send an inter group message m_4 to a member of group 2, $P_{(2,1)}$, the second module, named sender-based message logging, is executed to do group-wide output commit meaning, in case of $P_{(1,4)}$'s failure, it can obtain $det(m_3)$ from one of its own group members, in particular, the sender of m_3, $P_{(1,3)}$, not $P_{(2,1)}$, during recovery. This behavioral feature enables the in-group recovery for reducing the number of recovery control messages from other groups. Afterwards, if


Group 1
After ❶: s-log(1,1)={sml(m1)}
After ❹: s-log(1,4)={sml(m4)}
❹m4
P(1,1)
P(1,4)
After ❸: d-set(1,4)={det(m2),det(m3)}
❶m1
❺det(m3)
❸m3 with det(m2)
❹rsn-ack(m3)
❷m2 with det(m1)
P(1,2)
P(1,3)
After ❷: d-set(1,3)={det(m1),det(m2)}
After ❺: d-set(1,3)={det(m1),det(m2),det(m3)}
After ❶: d-set(1,2)={det(m1)}
After ❷: s-log(1,2)={sml(m2)}
After ❸: s-log(1,3)={sml(m3)}

(a) Message logging.

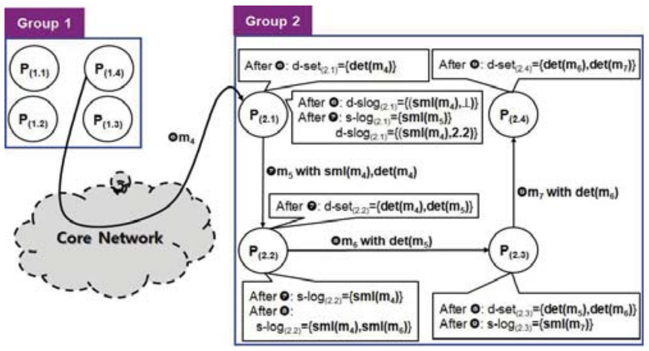


(b) Failure of process with group-wide output commit.

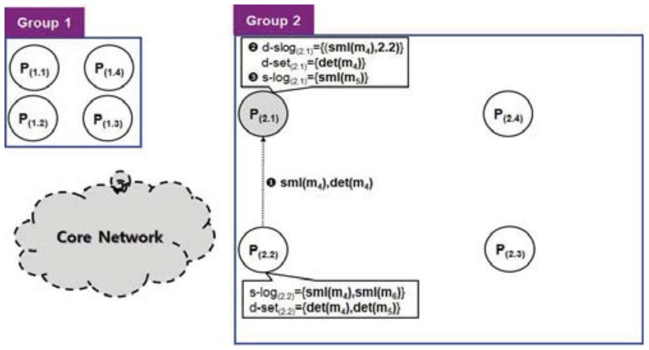
Fig. 1: In-group message logging and recovery execution

$P_{(1,4)}$ fails like in figure 1(b), sender-based logging allows $P_{(1,4)}$ to get m_3 and its rsn in $det(m_3)$ from $P_{(1,3)}$ to restore to its pre-failure state. In case of $P_{(1,3)}$'s failure, causal logging enables $P_{(1,3)}$ to attain m_2 from $P_{(1,2)}$ and its rsn in $det(m_2)$ from $P_{(1,4)}$. Therefore, our protocol can considerably alleviate the first drawback of the previous ones stated earlier.

When any message from a group is transmitted to another group, its receiver performs the third module, called immediate dependent message logging(IDML). Figure 2(a) shows an example of this case that $P_{(1,4)}$ sends message m_4 to $P_{(2,1)}$ and keeps $smi(m_4)$ in its buffer $s\text{-}log_{(1,4)}$. In this example, $P_{(2,1)}$ first saves $smi(m_4)$ in another send log buffer for inter-group messages directly received by itself, $d\text{-}slog_{(2,1)}$, and then, assigns a rsn to m_4 and records $det(m_4)$ in its buffer $d\text{-}set_{(2,1)}$. As it sends m_5 to another member of the same group, $P_{(2,2)}$, $smi(m_4)$ and $det(m_4)$ are transmitted with m_5. In this case, $P_{(2,2)}$ saves them in its buffers, $s\text{-}log_{(2,2)}$ and $d\text{-}set_{(2,2)}$, respectively. Afterwards, intra-group messages like m_5, m_6 and m_7 are handled by causal


Group 1
Group 2
P(1,1)
P(1,4)
P(1,2)
P(1,3)
❹m4
Core Network
After ❹: d-set(2,1)={det(m4)}
After ❼: d-set(2,4)={det(m6),det(m7)}
After ❹: d-slog(2,1)={(sml(m4),⊥)}
After ❺: s-log(2,1)={sml(m5)}
d-slog(2,1)={(sml(m4),2.2)}
P(2,1)
P(2,4)
❺m5 with sml(m4),det(m4)
❼m7 with det(m6)
After ❺: d-set(2,2)={det(m4),det(m5)}
❻m6 with det(m5)
P(2,2)
P(2,3)
After ❺: s-log(2,2)={sml(m4)}
After ❻: s-log(2,2)={sml(m4),sml(m6)}
After ❻: d-set(2,3)={det(m5),det(m6)}
After ❼: s-log(2,3)={sml(m7)}

(a) IDML with in-group interaction.



(b) Failure of process with in-group interaction.

Fig. 2: Inter-group message logging and recovery execution

message logging module as mentioned above. Thus, when $P_{(2,1)}$ crashes like in figure 2(b), $P_{(2,2)}$ can provide m_4 and its rsn in $det(m_4)$ to $P_{(2,1)}$ to recover consistently without any help of the sender of m_4, $P_{(1,4)}$. From this example, we can see our protocol allows the logging procedure of each inter-group message to be fulfilled at its own receiver, not the group leader, improving scalability in terms of message logging load and log information maintenance. In addition, the protocol can require no extra control messages during failure-free execution and localize recovery in this message exchanging pattern.

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