분산환경에서 거래관리를 위한 두단계 기부 잠금규약

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요 약

데이터베이스 기술의 적용분야가 점차 확대되어감에 따라 작업처리율을 증대시키기 위한 다양한 형태의 거래 처리 모형들을 필요로 하는 추세이다. 그러나 기존의 syntax위주의 직렬성 이론만 가지고서는 거래의 실행시간상 차별화 특성을 수용하면서 다수의 거래에 대한 단위시간당 처리 생산성을 높이기는 힘든 형편이다. 이러한 상황을 해결하기 위하여 이타적 잠금기법(altruistic locking: *AL*)은 거래가 객체를 사용한 다음 더이상 그 객체를 요구하지 않을 때 다른 거래들이 그 객체를 로크할 수 있도록 미리 객체에 대한 로크를 해제함으로써 거래들의 대기시간을 줄이기 위한 취지에서 제안된 것이다. 확장형 이타적 잠금(extended altruistic locking: *XAL*)기법은 *AL*을 자취의 확장 측면에서 개선한 잠금기법으로서 *AL*이 근본적으로 안고 있는 반드시 기부된 객체만을 처리해야 한다는 부담을 보다 완화한 기법이다. 본 논문에서는 우선 장기거래로 인한 단기거래의 장기적 대기현상 완화 측면에서의 *AL*과 *XAL*의 공통적 한계점을 분석하였다. 분산 환경하에서 장기거래로 인한 단기거래의 장기적 대기현상을 최소화하도록 줄임으로써 동시성 제어의 정도를 높이는 반면, 거래간의 평균 대기시간을 줄일 수 있는 새로운 확장형 이타적 잠금기법인 전후진방식의 신형 확장 기법인 2DL(two-way donation locking)을 제안하였다. 기법의 적용 광범위성을 위해 분산 계산 환경에서도 작동될 수 있게끔 설계하였다. 모의실험에 의한 성능평가 결과 장기거래의 길이가 5이상, 9이하인 상황에서 2DL은 2PL보다 작업 처리율과 거래의 평균 대기시간 면에서 우수한 결과를 나타내었다.

Two-Way Donation Locking for Transaction Management in Distributed Database Systems

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ABSTRACT

Database correctness is guaranteed by standard transaction scheduling schemes like two-phase locking for the context of concurrent execution environment in which short-lived ones are normally mixed with long-lived ones. Traditional syntax-oriented serializability notions are considered to be not enough to handle in particular various types of transaction in terms of duration of execution. To deal with this situation, altruistic locking has attempted to reduce delay effect associated with lock release moment by use of the idea of donation. An improved form of altruism has also been deployed in extended altruistic locking in a way that scope of data to be early released is enlarged to include even data initially not intended to be donated. In this paper, we first of all investigated limitations inherent in both altruistic schemes from the perspective of alleviating starvation occasions for transactions in particular of short-lived nature. The idea of two-way donation locking(2DL) has then been experimented to see the effect of more than single donation in distributed database systems. Simulation experiments shows that 2DL outperforms the conventional two-phase locking in terms of the degree of concurrency and average transaction waiting time under the circumstances that the size of long-transaction is in between 5 and 9.

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1. Introduction

In case database correctness is guaranteed by standard transaction scheduling schemes like *two-phase locking*(2PL)[1] for the context of concurrent execution environment in which short-lived ones are normally mixed with long-lived ones, degree of concurrency might be hampered by selfishness associated with lock retention. This sort of reluctance for early release of locks is essentially due to their discipline. Lazy release in turn could aggravate fate of misfortune for long-lived ones in that they are more vulnerable to get involved in deadlock situations. This could the other way around aggravate the fate of short-lived ones as well in a way that they suffer from starvation or livelock affected by long-lived ones.

As long as long transactions and short transactions live together, we could have to live up with this kind of dilemma. To reduce the degree of livelock, the idea of altruism has been suggested in the literature. *Altruistic locking*[2], *AL* for short, is basically an extension to 2PL in the sense that several transactions may hold locks on an object simultaneously under certain conditions. Such conditions are signaled by an operation *donate*. Like yet another primitive *unlock*, donate is used to inform the scheduler that further access to a certain data item is no longer required by a transaction entity of that donation. The basic philosophy behind *AL* is to allow long lived transactions to release their locks early, once it has determined a set of data to which the locks protect will no longer be accessed. In this respect, effect of donate is actually to increase the degree. In order to allow more freedom, an entity of donation is let continue to acquire new locks. This implies that donate and lock operations need not be strictly two-phase.

The idea of donating could further be exploited to pursue an enhanced degree of concurrency. *Extended altruistic locking*[2], *XAL* for short, attempted to expand the scope of donation in a way that data to be early disengaged is augmented by extra data originally not conceived to be rendered.

2. Related Work

2.1 Altruistic Locking

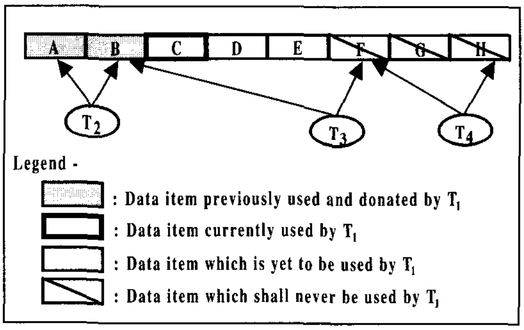
The basic idea of *AL* is to allow long transactions to release their locks early, once it is determined that the data which the locks protect will no longer be accessed. Unlike other early-released protocols, the *AL* guarantees serializable executions and places no restrictions on the way data must be accessed. Unlike other early-release approaches, the *AL* strategy guarantees serializable executions and places no restrictions on the way data must be accessed.

AL is like *2PL* except for the concept of wakes. If transactions do not make use of the Donate operation, altruistic scheduling reduces to *2PL* since no transactions will create wakes. However, when donations are made and transactions create wakes, an altruistic scheduler can allow a transaction to run within a wake, provided it remains completely within the wake.

2.2 Extended Altruistic Locking

While the donation of wake is rigid in *AL* in terms of fixedness of it size, a dynamic way of forming a wake could be devised given that serializability is never violated. This was realized in *XAL* by simply letting data originally not intended to bestowed to be dynamically included in a wake predefined. The rule is that wake expansion comes true only after a short transaction has already accessed data in its predefined wake list. So, the presumption made for *XAL* is that a short transaction still restlessly wishes to access data of its wake-dependent long transaction even after it has done with data in its wake list. The assumption could be called data-in-wake-list-first/other-data-later access fashion. *XAL* therefore performs inevitably badly if others-first wake-later access paradigm is in fact to be observed. Example 1 shows this.

Example 1(Delay Effect Caused by Donation Extension) : Suppose that T_1 attempts to access data items, *A*, *B*, *C* and *D*, in an orderly manner. Note that data items, *E*, *F*, *G*, and *H* shall never be accessed by T_1 at all. Presume that T_1 has already locked and successfully donated *A*, *B* and *C*. T_1 now is supposed in the stage of accessing D. Suppose also that there are three more transactions concurrently in execution along with T_1: T_2 wishing for *B* and *E*, T_3 wishing for *E* and *F*, and T_4 wishing for *F* and *H*(Figure 1).



(Figure 1) Four Transactions, T1 through T4, Competing for Same Data Donated

If we apply *XAL* for this situation, T_2 could in some circumstances fortunately be allowed to access both *B* and *E* without experiencing any delay.

In case T_2 initially requests *B* first rather than *E*, T_2 is able to access not only *B* but *E* as well, since T_2 is fully in the wake of T_1. T_2 therefore succeeds to commit. T_3 then could acquire *E* released by T_2. T_4 could thereafter acquire *F* released by T_3.

In case, however, T_2 initially requests *E* first rather than *B*, T_2 can certainly acquire *E* but it fails for *B* because wake relationship cannot honor *E* as a member of the wake list. Once this sort of wake dependency is detected, T_2 can be allowed to access *B* only after it is finally released by T_1. T_2 in this case is therefore blocked. T_3 must then be blocked for *E* to be released by T_2. T_4 as well must be blocked for *F* to be released by T_3, forging a chain of blockage.

End of Example 1.

To resolve this sort of chained delay, others-first wake-later approach could be made viable in a way of including others, not honored before, to a wake list. This enhancement is one of substances, made in our proposed scheme, which could be considered as *backward donation*, compared to *XAL*, which is based on *forward donation*. *XAL* can be viewed as *uni-donation* scheme in that it deals with donation principle involving only one single long transaction. One other major substance of our proposed scheme is to let more than one long transaction donate while serializability is preserved. The notion of *multiple serializability* is thus developed in our scheme. Our solution, *multiple-donation* scheme, allows donation from more than one long transaction but for the sake of presentation simplicity, degree of donation is limited to two in this paper.

3. Transaction Processing Model

To describe wake expansion rule in detail, simplifications were made mainly with regard to transaction management principle.

1(***Donation Privilege***) : Only long-lived transactions are privileged to use donate operation.

2(***Commit Policy***) : A long-lived transaction eventually commits.

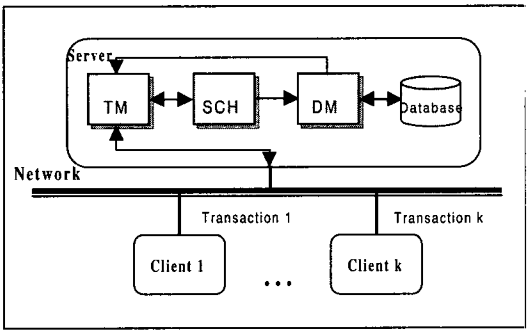
3(***Deadlock Handling***) : If a transaction happens to fall into deadlock situation, that transaction will be eliminated by using a certain deadlock timeout scheme.

In this paper, the multiplicity is rendered to the case of two to measure the effect of donation variety. Two-way donation altruistic locking protocol, *2DL* for short, can be pseudo-coded as follows(Algorithm

Wake Expansion).

3.1 Transaction Processing Model

TM receives transactions from clients and passes them SCH queue(Figure 2). TM could receive a message informing abortion from SCH or an acknowledgement informing completion of a requested operation from DM. DM analyzes an operation from SCH to determine which data item the operation is intended to access, and then sends the operation to the disk where the requested data item is stored. The server in each disk executes operations in its own FIFO queue one at a time. Whenever an operation is completed at the server, it sends to TM the message informing that the requested operation has been completed successfully.

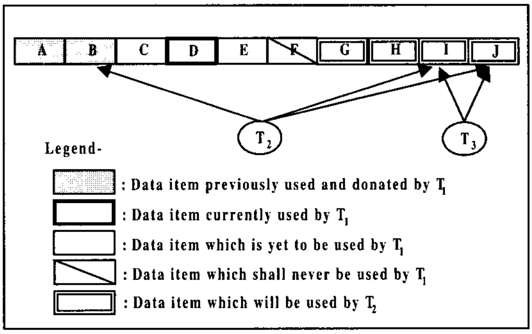


(Figure 2) Transaction Processing Model

3.2 Operation Instance of 2DL

In case donated data items are used under *XAL*, it is allowed to request data items which are donated by only one transaction. Under *2DL*, in contrast, short-lived transactions are treated to be given more freedom in accessing donated data items by eliminating the single-donation constraint. Short-lived transactions can access data items donated by two different long lived transactions. In Example 2 shows this.

Example 2(Allowing Proceeding for Short-Lived Transaction with Multiple Concurrent Long-Lived Ones) : Suppose that T_1, a long transaction, attempts to access data items *A*, *B*, *C*, *D* and *E* in an orderly manner. Note that data items *F*, *G*, *H*, *I* and *J* shall never be accessed by T_1 at all. Presume that T_1 has already locked and thereafter donated *A* and *B*. T_1 now is supposed in the stage of accessing *C*. Suppose also that there are two more transactions concurrently in execution along with T_1: T_2 wishing for *J*, *I* and *B*, and T_3 wishing for *J* and *I* in an orderly manner(Figure 3).



(Figure 3) Execution of T1 with Two More Concurrent Transactions

If we apply *XAL* for these transactions, lock request for *B* by T_2 would be rejected due to donation extension. T_2 unfortunately cannot be included in the wake of T_1. While T_2 experiences delay, T_3 would not be permitted to access *J* and *I* because they were still locked by T_2.

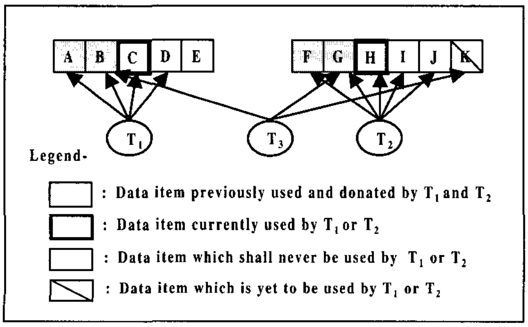
In case *2DL* is adopted rather than *XAL*, T_2 could fortunately be allowed to access *B* without any delay. The scheduler checks whether T_1 will later access *J* and I. The scheduler then includes *J* and I into the wake of T_1, since we presumed that T_1 will not request those data items. When T_3 attempts to request *J* and *I*, T_3 is as well allowed to continue to acquire locks without delay because data item *J* and *I* have already been donated by T_2. All of data items that accessed by T_3 could in turn be included into

the wake of T_1. If there are many transactions like T_3, the scheduler has a burden to maintain enlarged wakes. This sort of deficiency would fortunately not incur a substantial burden to the system because the access time of short transactions usually do not take too long.

End of Example 2.

2DL also permits short-lived transactions request data items which have been donated by two different long-lived transactions. A way to conduct a two-way donation is shown, in Example 3, with two separate long transactions and a single short transaction.

Example 3(Allowing Proceeding of Short Transaction with Two Concurrent Long Ones) : Suppose that T_1, a long transaction, attempts to access data items, *A*, *B*, *C*, *D* and *E*, in an orderly manner. Presume that T_1 has already locked and successfully donated *A* and *B*. T_1 now is supposed in the stage of accessing *C*. Suppose also that there are two more concurrent transactions in execution along with T_1: T_2, long, wishing for data items, *F*, *G*, *H*, *I* and *J*, in an orderly manner and T_3, short, wishing for *B*, *G* and *K* similarly. Presume that T_2 has already locked and successfully donated *F* and *G*. T_2 now is supposed in the stage of accessing *H*(Figure 4).



(Figure 4) Execution of T3 with Two Concurrent Long-Lived Transactions

If we apply *XAL* for these transactions, a lock request for *B* by T_3 would be allowed to be granted but a lock request *G* would not because *G* has already been donated by another long-lived transaction. Only after T_2 commits, *G* can be tossed to T_3.

In case *2DL* is adopted rather than *XAL*, T_3 could fortunately be allowed to access without any delay. This is made possible by simply including the wake of T_2 into the wake of T_1.

End of Example 3.

4. Two-Way Donation Locking

Short-lived transactions are treated to be given more freedom in accessing donated data items by eliminating the single-donation constraint under *2DL*. *2DL* permits short-lived transactions request data items which have been donated by two different long-lived transactions.

```
Algorithm(Wake Expansion Rule of 2DL)
Input: LT1; LT2; ST
 /* ST:short trans;
    LT1, LT2:long trans */
BEGIN
 FOREACH LockRequest
   IF(LockRequest.ST.data = Lock)
   THEN
 /* Locks being requested by ST already granted to long trans other than LT1 and LT2 */
   Reply:=ScheduleWait(LockRequest);
   ELSE IF(LockRequest.ST.data = Donated)
THEN
 /* Locks being requested by ST donated by long trans other than LT1 and LT2 */
    FOREACH∈LT1 OR LT2)
       IF(ST.wake = LT1) THEN
 /* Donation conducted by LT1? */
         IF(ST.data ∈ LT1.marking-set) THEN
 /* Data being requested by ST to be later accessed by LT1 ? */
           Reply:=ScheduleWait(LockRequest)
         ELSE
           Reply:=ScheduleDonated(LockRequest)
         ENDIF
        ELSE
        IF(ST.data ∈ LT2.marking-set) THEN
 /* Data being requested by ST to be later accessed by
```

```
LT2 ? */
          Reply := ScheduleWait(LockRequest)
       ELSE
          Reply:=ScheduleDonated(LockRequest)
       ENDIF
     ENDIF
   ENDFOR
 ELSE
          Reply := ScheduleLock(LockRequest)
 ENDIF
 IF(Reply = Abort) THEN
 /* Lock request of ST aborted */
   Abort Transaction(Transactionid);
   Send(Abort);
   Return();
   ENDIF
 ENDFOR
END
```

5. Performance Evaluation

In this section, we experimented the performance behavior of *2DL*. Performance comparison is made against *2PL* under various workloads. Major metrics chosen are transaction throughput and average transaction waiting time. A simulation model has first of all been established.

5.1 Simulation Model

To cultivate the model in detail, a number of assumptions have been brought in.

1(***Reliable System Resources***) : Client machines as well as the server are perfect in the sense that they are always operable.

2(***Read-Once Policy***) : A transaction does not read a data item again after a transaction has already read or written the same data item.

3(***Fake Restart***) : Whenever a transaction experiences a restart, it is replaced by a new, independent transaction.

4(***Number of Long Transactions***) : At most one long lived transaction may be active at any time.

5(***Commit Policy***) : Long-lived transactions always commit.

6(***Resource Service Policy***) : There are two resource type in our model. One is CPU and the other is input/output devices(I/O).

5.2 Simulation Parameters

The simulation input parameters used, as follows, are classified into two categories : those of which values are fixed throughout simulation and those of which values vary<Table 1>.

- Number of data items in database(*db_size*)
- Number of CPUs(*num_cpus*)
- Number of disks(*num_disks*)
- Mean size of short transactions(*short_tran_size*)
- Mean size of long transactions(*long_tran_size*)
- Mean time for creating a transaction (*tran_creation_time*)
- Mean time for deadlock time out(*timeout*)
- Simulation length(*sim_leng*)

〈Table 1〉 Parameters Setting for Simulation

Parameters	Values
db_size	100
num_cpus	2
num_disks	4
short_tran_size	2, 3, 4, 5
long_tran_size	4, 5, 6, 7, 8, 9, 10
tran_creation_time	5 units
timeout	30, 50
sim_leng	100, 300, ..., 1500

Values for parameters were chosen by reflecting real world computing practices. Database size matters if it affects the degree of conflict. If *db_size* is much larger than *short_tran_size* and *long_tran_size*, conflicts rarely occur. To see performance tradeoff between *2DL* and *2PL*, average transaction length represented by number of operation in transaction were treated to vary. The shortest one is assumed to access 2 percent of the entire database, while it is 80 percent for the longest one.

In case a transaction is exposed to a substantial delay, even exceeding a certain timeout, once it has been blocked, it is judged to be involved in deadlock situations. Deadlock resolution shall then be followed.

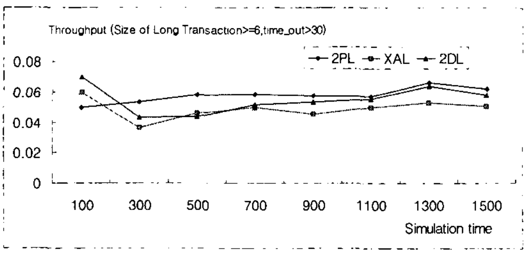
5.3 Simulation Results and Their Interpretations

Our simulation experiments were focused on the effects of sensitive parameters in the performance indices to measure their performance behaviors. We now discuss the results of simulation experiments performed for the three different replication control schemes : *2PL*, *XAL*, and *2DL*. Overall behaviors have been revealed that as the simulation length gets longer, in terms of throughput *2PL* and *2DL* perform similarly.

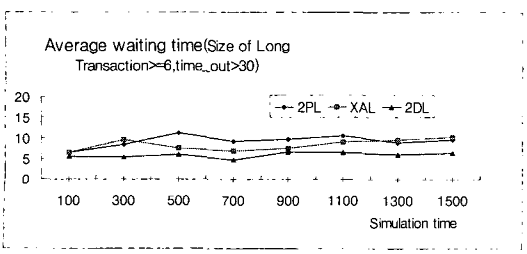
5.3.1 Effect of Multiprogramming Level

The major force behind prevailness of *2DL* mainly comes from capitalizing advantage from maintaining two different transaction wakes. Performance gain of *2DL* against *2PL* is about 155 per cent in terms of average waiting time(Figure 6). *2PL* however outperforms *XAL* and *2DL* with 105 per cent of performance at transaction throughput(Figure 5). This is because both *XAL* and *2DL* have a certain overheads to reserve data objects to be accessed.

We can observe that the waiting time curve of *2DL* tends to be flat as the simulation length is getting longer. *2DL* performs best in terms of average waiting time owing to two-way donation which contributes to give transactions more chance to use the objects than one-way donation.



(Figure 5) Throughput



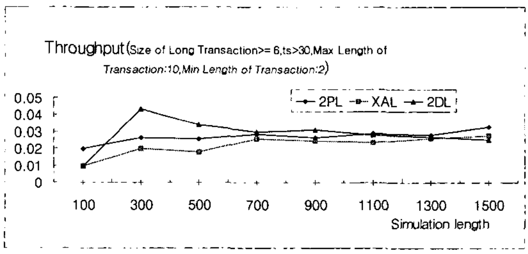
(Figure 6) Average Waiting Time

2DL and *2PL* eventually perform similarly in terms of throughput, at simulation time 1500. It seems that the performance between two schemes appear to be about the same, however the average waiting time of *2DL* exhibits slightly better behavior than *2PL*. *2DL* outperforms the other schemes due mainly to enhanced degree of freedom given to *2DL* in accessing donated data by extending to multiple donation.

5.3.2 Effect of Transaction Size

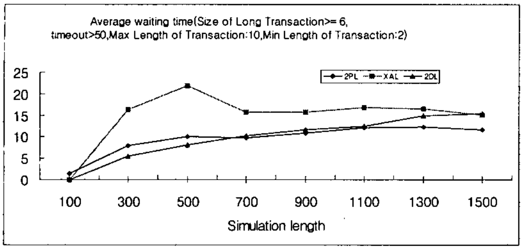
This experiment is used to investigate the effect of the size of transaction on the performance of concurrency control schemes, as the degree of donations varies.

Overall simulation result shows that *2DL* performs best in terms of throughput and its average waiting time since as the size of transaction gets longer, two-way donation which contributes to give transactions more chance to use the objects than one-way donation. We can observe that the throughput curves of *2DL* inclines rapidly down from simulation time 300(Figure 7). The throughput curve of *2DL* tends to be flat as the simulation length is getting longer.



(Figure 7) Throughput with Larger Transactions

2DL and *2PL* eventually perform similarly in terms of average waiting time, at simulation time 700(Figure 8). It seems that the performance between two schemes appear to be about the same, however the average waiting time of *2PL* exhibits slightly better behavior than *2DL*. As the transaction size gets longer, *2DL* outperforms the other schemes due mainly to enhanced degree of freedom given to *2DL* in accessing donated data by extending to multiple donation.



(Figure 8) Average Waiting Time with Larger Transactions

6. Conclusions

The performances of *2DL*, *XAL*, and *2PL* have been evaluated through simulation approach under various workloads in order to probe their performance tradeoffs. The simulation results indicate that *2DL* is capable of providing a moderate performance across a wide range of workloads. *2DL* leads to its superior performance in the property of average waiting time in most cases. We have also observed that *XAL* exhibits the worst performance among the three with respect to an average waiting time, due to wake expansion overhead.

2DL is considered to be a practical solution to take in real world environments where long-lived transactions naturally coexist with short-lived ones. Although liveness duration might not be a serious issue in the arena of standard on-line transaction processing, in which transactions are normally expected to finish shortly, it certainly matters in circumstances where a number of long-lived ones are supposed to access a substantial number of data. In traditional standard transaction scheduling schemes, such as two-phase locking, the degree of concurrency might be hampered by selfishness associated with lock retention in which short-lived ones are normally mixed with long-lived ones. Lazy release in turn could aggravate the fate of long-lived ones in that they are more vulnerable to get involved in deadlock situations. This could the other way around contribute to exacerbate the fate of short-lived ones as well in a way that they suffer from starvation or livelock affected by long-lived ones.

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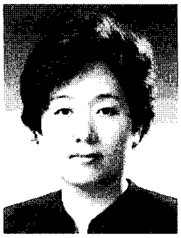

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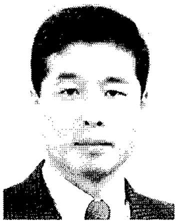

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