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Optimal Data Transfer Strategies for the Hierarchical Storage Management within a Server System

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Abstract: Under the technique of Hierarchical Storage Management (HSM), this paper discusses optimal times of data transfers for enormous data within a server system. First of all, we propose three classifications in storage, *i.e.*, Solid State Drive (SSD), Serial Attached SCSI (SAS) HDD, and Serial ATA (SATA) HDD, which are used for frequent accessed, inactive, and long-term preserved data blocks. To save the total time for data scans and data transfers, we secondly formulate two models in which the times when data transfers should be made: 1) Number N of data transfers from SSD to SAS; 2) Time T of data transfers from SAS to SATA. We suppose that data scans occur at non-homogeneous and homogeneous Poisson processes, and optimize respective models in number N and time T. Finally, two cases of numerical examples are given to illustrate the proposed models.

Keywords: *Stochastic model, database management, big data, data transfer, reliability*

1. Introduction

In recent years, the topic of huge amounts of data is discussed flourishingly. One of the challenges to utilize the enormous data for an enterprise is to store data in several hundreds of terabytes within a server system effectively, which is also an important problem for engineers to manage server systems well nowadays [1].

Although the capability of computer processing is unimaginable, forecasting the data growth has become impossible now. In this case, the Database Management System (DMBS) cannot store and manage such an enormous data in traditional ways. Therefore, several techniques of the Hierarchical Storage Management (HSM) are developed into server systems [2-6], and it is recognized that the hybrid of Solid State Drive (SSD) and Hard Disk Drive (HDD) in HSM has been widely used [5, 6]. However, we may give a new hierarchy for HDD in HSM in an effective way, that is, it is possible to divide all storages into three levels rather than two as applied before: The first level of storage apparatus is for the frequent accessed data in the semiconductor memory, which does not have the drive for high-speed I/O access; the second level of apparatus is Performance Storage Hierarchy with high reliability that is called Serial Attached SCSI (SAS) HDD; and the third apparatus is a Mass storage with high capacity and cost saving. The Mass storage are commonly used Serial ATA (SATA) HDD.

Using such classifications in storage, the first apparatus is a Solid State Drive (SSD) with cache memory for high-speed I/O access, but it has limited storage capacity and high cost. To save access frequencies of SSD, inactive data blocks whose access frequencies

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decrease to a low lever or even to 0 should be moved to SAS. Using the same data management notion, the fairly inactive data blocks, *i.e.*, the long-term preserved and low accessed data, should be moved from SAS to Mass or SATA. Under the above discussions of the automatic hierarchical storage for enormous data within a server system, we formulate and optimize models to save the total time for data scans and data transfers, by using the techniques in reliability and maintainability models [7, 8].

The remainder of this paper is organized as follows: Section 2 describes actual data transfer schemes and formulates the models in which the number N of data scans and data transfers from SSD to SAS could be optimized. Section 3 gives two cases of numerical examples, *i.e.*, when data scans occur at Non-homogeneous and Homogeneous Poisson processes. Section 4 optimizes data transfer time T from SAS to SATA and two cases of numerical examples are given in Section 5. Finally, conclusions of the paper are provided in Section 6.

2. Model and Optimization

2.1. Data Transfer Schemes

We observe the following actual data transfer schemes:

1) New data is accessed from Solid State Drive (SSD). When the access time of data blocks is more than one predefined threshold, Database Management System (DBMS) moves its inactive data blocks from SSD to the Performance Storage Hierarchy, *i.e.*, SAS.
2) Data blocks in SAS accumulate over time due to data transfer. When the access time of data blocks in SAS is more than another threshold, DBMS moves its fairly inactive data blocks to Archive Storage Drive, *i.e.*, SATA.
3) The system will stop when the capacity of free space of High-Speed Cash Hierarchy is reduced to less than one minimum value determined by the system.

In this paper, we consider the repeated 1) until 2) occurs as one renewal cycle, as the system will be maintained after data transfer in 2). We suppose transfer parameters that are counted by time or cost, model expected cost rates, and obtain their optimal solutions to save the total data transfer time for a long run. For this, we give the following assumptions:

1) The newly accessed data, including the existing data is stored in SSD, and it is accumulated over time. When the total amount of data reaches to a threshold level K, DMBS scans all access control tables. Here, we use K as a threshold level as the system response time depends on the free space in SSD.
2) After every scanning, DBMS moves the inactive data blocks $\alpha_1 K$ from SSD to SAS. When the accumulated data blocks at SSD reaches level K again, the second scan starts and an amount of $\alpha_2 K$ will be moved from SSD to SAS. Here, $\alpha_j (j = 1,2,3,\cdots; 0 = \alpha_0 < \alpha_1 < \alpha_2 < \cdots < 1)$ denotes the ratio of the inactive data to the stored data at the j-th scan. The scans and data transfers repeat until 3) occurs.
3) The whole system will be maintained after DBMS carries out N $(N = 1,2,\cdots)$ scans of access control tables, that is, more time-consuming data transfers for fairly inactive data from SAS to SATA will occur after N data transfers from SSD to SAS. At the same time, we maintain SSD, SAS, and SATA to prepare the next data transfer cycle.

2.2. Model and Optimization

Suppose that scans of access control tables and data transfers occur at a non-homogeneous Poisson process with density function $\lambda(t)$ and mean $R(t) \equiv \int_0^t \lambda(u)du$. Then, the probability that j times of scans occur in $(0,t]$ is

$$H_j(t) \equiv \frac{[R(t)]^j}{j!} e^{-R(t)} \qquad (j = 0,1,2,\cdots). \tag{1}$$

We consider the time when data transfers from SAS to SATA as one renewal point for the whole system. The reason is that when data has been saved at SATA, it becomes fairly inactive, and the remaining job for managers is to keep SATA in safety. This renewal point is triggered by number N of data transfers from SSD to SAS. So that the mean time until the whole system maintenance, *i.e.*, the mean time when data transfer from SAS to SATA occurs after N data transfers from SSD to SAS is

$$\int_0^\infty t\, H_{N-1}(t)\lambda(t)dt = \sum_{j=0}^{N-1} \int_0^\infty H_j(t)dt. \tag{2}$$

We suppose the following consumed times for data transfers denoted by costs: $c_1 + c_2 x$ is the scanning cost for access control tables, where c_1 constantly determined for scanning and c_2 is unit scanning cost that considers the size of table x, and $c_3 (c_3 > c_1)$ is transfer cost of data blocks moving from SAS to SATA. Then, the expected cost of the j-th scanning of access control tables in SSD is

$$C_j \equiv c_1 + c_2 \alpha_j K \quad (j = 1,2,\cdots). \tag{3}$$

Therefore, the expected cost rate is

$$C(N) = \frac{\sum_{j=1}^{N-1} C_j + c_3}{\sum_{j=0}^{N-1} \int_0^\infty H_j(t)dt} \quad (N = 1,2,\cdots). \tag{4}$$

We find a minimum N^* which minimizes $C(N)$, that is, we obtain optimal scanning numbers to save the total time for data transfers. From $C(N+1) - C(N) \geq 0$,

$$\frac{C_N \sum_{j=0}^{N-1} \int_0^\infty H_j(t)dt}{\int_0^\infty H_N(t)dt} - \sum_{j=1}^{N-1} C_j \geq c_3. \tag{5}$$

Denote the left-hand side of (5) by $L(N)$,

$$L(N+1) - L(N) = \sum_{j=0}^{N} \int_0^\infty H_j(t)dt \left(\frac{C_{N+1}}{\int_0^\infty H_{N+1}(t)dt} - \frac{C_N}{\int_0^\infty H_N(t)dt} \right).$$

When $\lambda(t)$ increases with t, $\int_0^\infty H_j(t)dt$ decreases with j to $1/\lambda(\infty)$ [3, p.98]. Therefore, if C_j increases strictly with j and $\lambda(t)$ increases, or C_j increases and $\lambda(t)$ increases strictly, and $L(\infty) > c_3$, then there exists a finite and unique minimum $N^* (1 \leq N^* < \infty)$ which satisfies (5).

In particular, when $\alpha_j \equiv \alpha$, the expected cost rate in (4) is

$$C(N) = \frac{(c_1 + c_2 K\alpha)(N-1) + c_3}{\sum_{j=0}^{N-1} \int_0^\infty H_j(t)dt}, \tag{6}$$

and (5) is

$$\tilde{L}(N) \equiv \frac{\sum_{j=0}^{N-1} \int_0^\infty H_j(t)dt}{\int_0^\infty H_N(t)dt} - (N-1) \geq \frac{c_3}{c_1 + c_2 \alpha K}. \tag{7}$$

Thus, if $\lambda(t)$ increases strictly and $\tilde{L}(\infty) > c_3/(c_1 + c_2 \alpha K)$, then there exists a finite and unique minimum $N^* (1 \leq N^* < \infty)$ which satisfies (7).

3. Numerical Example 1

3. 1 Poisson Process

Suppose that scans and data transfers occur at a fixed frequency such that a Poisson process with rate $\lambda(t)=\lambda$, *i.e.*,

$$H_j(t)=\frac{(\lambda t)^j}{j!}e^{-\lambda t} \quad (j=0,1,2,\cdots).$$

Then, (5) is

$$\sum_{j=0}^{N-1}(C_N-C_j)\geq c_3, \qquad i.e., \quad \sum_{j=0}^{N-1}(\alpha_N-\alpha_j)\geq\frac{c_3}{c_2K}, \tag{8}$$

whose left-hand side increases strictly with N from α_1 to $\sum_{j=0}^{\infty}(\alpha_\infty-\alpha_j)$. Therefore, if α_j increases strictly to α_∞ and $\sum_{j=0}^{\infty}(\alpha_\infty-\alpha_j)>c_3/c_2K)$, then there exists a finite and unique $N^*(1\leq N^*<\infty)$ which satisfies (8).

We next consider the following two numerical cases: When $\alpha_i=\alpha(1-q^i)$ $(i=0,1,2,\cdots)$, (8) is

$$\sum_{j=0}^{N-1}(q^j-q^N)\geq\frac{c_3}{c_2\alpha K}, \tag{9}$$

whose left-hand side increases strictly with N from $1-q$ to $1/(1-q)$. Therefore, if $1/(1-q)>c_3/(c_2\alpha K)$, then there exists a finite and unique $N^*(1\leq N^*<\infty)$ which satisfies (9).

When $\alpha_i=\alpha[1-1/(i+1)]$ $(i=0,1,2,\cdots)$, (8) is

$$\sum_{j=0}^{N-1}\left(\frac{1}{j+1}-\frac{1}{N+1}\right)\geq\frac{c_3}{c_2\alpha K}, \tag{10}$$

whose left-hand side increases strictly with N from $1/2$ to ∞. Therefore, there exists a finite and unique $N^*(1\leq N^*<\infty)$ which satisfies (10).

3.2 Non-homogeneous Poisson Process

Suppose that scans and data transfers occur at an increasing frequency such that a non-homogeneous Poisson process with $R(t)=(\lambda t)^m$ for $m>1$. Then,

$$\int_0^\infty\frac{[R(t)]^N}{N!}e^{-R(t)}dt=\frac{1}{m\lambda}\frac{\Gamma(N+1/m)}{\Gamma(N+1)}, \tag{11}$$

$$\sum_{j=0}^{N-1}\int_0^\infty\frac{[R(t)]^j}{j!}e^{-R(t)}dt=\frac{1}{\lambda}\frac{\Gamma(N+1/m)}{\Gamma(N)}, \tag{12}$$

where $\Gamma(j+1)=\int_0^\infty x^j e^{-x}dx$ $(j\geq 0)$. In this case, (5) is

$$\sum_{j=0}^{N-1}(mC_N-C_j)\geq c_3, \tag{13}$$

which agrees with (8) when $m=1$.

When $\alpha_i=\alpha(1-q^i)$, (13) is

$$(m-1)(c_1+c_2\alpha K)N+c_2\alpha K\sum_{j=0}^{N-1}(q^j-mq^N)\geq c_3. \tag{14}$$

whose left-hand side increases strictly with N to ∞. Therefore, there exists a finite and unique minimum $N^*(1 \le N^* < \infty)$ which satiffies (14). If $(m-1)c_1 + mc_2\alpha K(1-q) \ge c_3$ then $N^* = 1$.

When $\alpha_i = \alpha[1 - 1/(i+1)]$, (13) is

$$(m-1)(c_1 + c_2\alpha K)N + c_2\alpha K \sum_{j=0}^{N-1}\left(\frac{1}{j+1} - \frac{m}{N+1}\right) \ge c_3, \tag{15}$$

whose left-hand side increases strictly with N to ∞. Therefore, there exists a finite and unique minimum $N^*(1 \le N^* < \infty)$ which satisfies (15), If $(m-1)c_1 + mc_2\alpha K/2 \ge c_3$ then $N^* = 1$.

Table 1 presents optimal number $\boldsymbol{N}^*$ of data transfers in model (4), that is, the DBMS performs $\boldsymbol{N}^* - \mathbf{1}$ times of data transfers from SSD to SAS and transfers data at the $\boldsymbol{N}^*$ scan from SAS to SATA. It shows that $\boldsymbol{N}^*$ decreases with $(\boldsymbol{c_2\alpha K})/\boldsymbol{c_1}$ and m, and increases with $\boldsymbol{c_3}/\boldsymbol{c_1}$.

Table 1: Optimal N^* for the case when $\alpha_i = \alpha[1 - 1/(i+1)]$.

$\frac{c_2\alpha K}{c_1}$	*m*=2			*m*=3			*m*=4		
	$\frac{c_3}{c_1} = 10$	$\frac{c_3}{c_1} = 30$	$\frac{c_3}{c_1} = 45$	$\frac{c_3}{c_1} = 10$	$\frac{c_3}{c_1} = 30$	$\frac{c_3}{c_1} = 45$	$\frac{c_3}{c_1} = 10$	$\frac{c_3}{c_1} = 30$	$\frac{c_3}{c_1} = 45$
0.1	9	28	41	5	14	21	4	10	14
0.5	7	20	30	4	10	15	3	7	11
1.0	5	15	22	3	8	12	2	6	8
1.5	4	12	18	3	7	9	2	5	6
2.0	4	10	15	2	6	8	2	4	6
2.5	3	8	12	2	5	7	2	4	5
3.0	3	7	11	2	4	6	2	3	5

4. Periodic Transfer

Suppose that DBMS carries out data transfers from SAS to SATA at periodic times jT $(j = 1,2,\cdots)$ $(0 < T \le \infty)$. That is, for every jT, all fairly inactive data should be transferred to SATA and the system undergoes maintenance. In other words, times jT can be considered as renewal points for the system.

Under the same assumptions in Section 2, the expected cost rate is

$$C(T) = \frac{\sum_{j=1}^{\infty} H_j(T)\sum_{i=1}^{j} C_i + c_3}{T}. \tag{16}$$

We find optimal T^* $(0 < T^* \le \infty)$ which minimizes (16). Differentiating $C(T)$ with respect to T and setting it equal to zero,

$$T\lambda(T)\sum_{j=0}^{\infty} H_j(T)C_{j+1} - \sum_{j=1}^{\infty} H_j(T)\sum_{i=1}^{j} C_i = c_3. \tag{17}$$

Denoting the left-hand side of (17) by $L(T)$,

$$L'(T) = \lambda'(T)\sum_{j=0}^{\infty} H_j(T)C_{j+1} + \lambda(T)\sum_{j=0}^{\infty} H_j(T)(C_{j+1} - C_j).$$

When $\lambda(t)$ increases with t and C_j increases strictly, or $\lambda(t)$ increases strictly and C_j increases, and $L(\infty) > c_3$, then there exists a finite and unique T^* $(0 < T^* < \infty)$ which satisfies (17).

In particular, when $\alpha_i \equiv \alpha$, (16) is

$$C_2(T) = \frac{(c_1 + c_2\alpha K)R(t) + c_3}{T}, \tag{18}$$

and (15) is

$$T\lambda(T) - R(T) = \frac{c_3}{c_1 + c_2\alpha K}. \tag{19}$$

Thus, if $\lambda(t)$ increases strictly and $\int_0^\infty td\lambda(t) > c_3/(c_1 + c_2\alpha K)$, then there exists a finite and unique $T^*(0 < T^* < \infty)$ which satisfies (19).

5. Numerical Example 2

5.1 Poisson Process

Suppose that scans and data transfers occur at a Poisson process with rate $\lambda(t) = \lambda$. Then, (17) is

$$\sum_{j=1}^{\infty} H_j(T) \sum_{i=1}^{j} (C_j - C_i) = c_3, \qquad i.e., \qquad \sum_{j=1}^{\infty} H_j(T) \sum_{i=1}^{j} (\alpha_j - \alpha_i) = \frac{c_3}{c_2 K}. \tag{20}$$

Therefore, if α_j increases strictly to α_∞ and $\sum_{j=1}^{\infty}(\alpha_\infty - \alpha_j) > c_3/(c_2K)$ then there exists a finite and unique $T^*(0 < T^* < \infty)$ which satisfies (20).

When $\alpha_i = \alpha(1 - q^i)$, (20) is

$$\sum_{j=1}^{\infty} H_j(T) \sum_{i=1}^{j} (q^i - q^j) = \frac{c_3}{c_2\alpha K}, \tag{21}$$

whose left-hand increases strictly with T from 0 to $q/(1-q)$. Therefore, if $q/(1-q) > c_3/(c_2\alpha K)$, then there exists a finite and unique T^* $(0 < T^* < \infty)$ which satisfies (21).

When $\alpha_i = \alpha[1 - 1/(i+1)]$, (20) is

$$\sum_{j=1}^{\infty} H_j(T) \sum_{i=1}^{j} \left(\frac{1}{i+1} - \frac{1}{j+1}\right) = \frac{c_3}{c_2\alpha K}, \tag{22}$$

whose left-hand side increases strictly with T from 0 to ∞. Therefore, there exists a finite and unique T^* $(0 < T^* < \infty)$ which satisfies (22).

5.2 Non-homogeneous Poisson Process

Suppose that scans and data transfers occur at a non-homogeneous Poisson process with $R(t) = (\lambda t)^m$ $(m > 1)$. Then, (17) is

$$\sum_{j=1}^{\infty} H_j(T) \sum_{i=1}^{j} \left(mC_j - C_i\right) = c_3, \tag{23}$$

which agrees with (20) when $m = 1$.

When $\alpha_i = \alpha(1 - q^i)$, (23) is

$$(m-1)(c_1 + c_2\alpha K)\left((\lambda T)^m + c_2\alpha K \sum_{j=1}^{\infty} H_j(T) \sum_{i=1}^{j} (q^i - mq^j\right) = c_3, \tag{24}$$

whose left-hand increases strictly with T from 0 to ∞. Therefore, there exists a finite and unique T^* $(0 < T^* < \infty)$ which satisfies (24).

When $\alpha_i = \alpha[1 - 1/(i+1)$. Then, (23) is

$$(m-1)(c_1+c_2\alpha K)(\lambda T)^m + c_2\alpha K\sum_{j=1}^{\infty} H_j(T)\sum_{i=1}^{j}\left(\frac{1}{i+1}-\frac{m}{j+1}\right) = c_3, \qquad (25)$$

whose left-hand side increases strictly with T from 0 to ∞. Therefore, there exists a finite and unique T^* $(0 < T^* < \infty)$ which satisfies (25).

Table 2 presents optimal number $\boldsymbol{T}^*$ of data transfers in model (16), that is, the DBMS performs time interval $\boldsymbol{T}^*$ of data transfers from SSD to SAS and transfers data at the $\boldsymbol{T}^*$ from SAS to SATA. It shows that $\boldsymbol{T}^*$ decreases with $(\boldsymbol{c_2\alpha K})/\boldsymbol{c_1}$ and *m*, and increases with $\boldsymbol{c_3/c_1}$.

Table 2: Optimal T^* for the case when $\alpha_i = \alpha[1-1/(i+1)]$.

$\frac{c_2\alpha K}{c_1}$	*m*=2			*m*=3			*m*=4		
	$\frac{c_3}{c_1}=10$	$\frac{c_3}{c_1}=30$	$\frac{c_3}{c_1}=45$	$\frac{c_3}{c_1}=10$	$\frac{c_3}{c_1}=30$	$\frac{c_3}{c_1}=45$	$\frac{c_3}{c_1}=10$	$\frac{c_3}{c_1}=30$	$\frac{c_3}{c_1}=45$
0.1	3.013	5.214	6.386	1.662	2.391	2.735	1.325	1.739	1.923
0.5	2.587	4.445	5.445	1.520	2.163	2.470	1.245	1.619	1.786
1.0	2.259	3.842	4.701	1.402	1.976	2.251	1.176	1.517	1.671
1.5	2.042	3.438	4.199	1.320	1.845	2.098	1.126	1.445	1.588
2.0	1.885	3.144	3.832	1.256	1.747	1.982	1.087	1.390	1.525
2.5	1.764	2.919	3.551	1.206	1.670	1.891	1.054	1.345	1.474
3.0	1.667	2.740	3.326	1.163	1.606	1.816	1.027	1.308	1.432

6. Conclusions

Using the technique of Hierarchical Storage Management (HSM) for enormous data within a server system, we could consider two levels of optimizations to save the total data transfers for a long run, that is, 1) optimal time when data transfer should be made from SSD to SAS, and 2) optimal time when we should transfer data from SAS to SATA. For 1), it is nature we are not sure the exact time when scans should be made, which may follow some stochastic processes. So that we have supposed in this paper that scans and data transfers occur at non-homogeneous and homogeneous Poisson processes. For 2), two stochastic models have been formulated in optimizing a) Number *N* of data transfers from SSD to SAS, and b) Time *T* of data transfers from SAS to SATA. We have obtained the expected cost rate models, and obtained optimal solutions analytically and numerically. It has been shown that optimal policies of data transfer times will be depended on selected parameters discussed in models. This topic of data transfer strategies would provide engineers with new thinking of data management.

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