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DYNAMIC CODING DESIGN FOR STATE-TRANSITION-TABLE-DRIVEN ARITHMETIC CODER: STT-CODER

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ABSTRACT

We have proposed STT-coder, a simple binary arithmetic coder, in which encoding and decoding procedures can be executed by referring a state transition table. We found that STT-coder having a 6-bit interval register with 8 probability states achieves satisfactory performance in static coding. In this paper, as the next step, we studied the dynamic coding performance based on a probability state transition type rule. In the study, we introduced a new concept of "transit LPS (Less Probable Symbol) ratio" to improve the coding efficiency. It was shown that the improvement would be around 4% compared to the conventional probability state transition rule. The proposed method introduces additional 8 probability states with little increase of complexity. Compared with a conventional arithmetic coder MQ-coder covering the same range of MPS (More Probable Symbol) probability, it was found that STT-coder outperforms by 1.5% in coding efficiency on average.

1. INTRODUCTION

We have proposed a simple binary arithmetic coder STT-coder [1,2,3], in which encoding and decoding procedures can be executed by referring a state transition table as shown in Fig.1. In order to satisfy the condition of state-transition-table-based coding, the accumulation of bottom address is omitted and the several offset values of the bottom address are introduced by allowing the increase of ROM size, to cope with the inefficiency caused by the limitation of the combination of interval subdivision values. We found that the static coding efficiency of STT-coder having a 6-bit register with 8 probability states for the MPS probability range less than 0.987 is only 0.5% lower than the coding efficiency of theoretical arithmetic coder.

In arithmetic coding, MPS (or LPS) interval is calculated by multiplying the current interval and the predefined value of MPS (or LPS) probability. As it is practical to limit the possible values of MPS probability, we define the number of the values of MPS probability, and each context is considered to correspond to one of the values of MPS probability, which is called the probability state hereafter.

We will study the dynamic coding design for STT-coder by an adaptive probability estimation scheme based on a probability state transition rule for unknown information sources. This type of estimation is adopted in various arithmetic coders such as Q-Coder[4] and MQ-coder[5], because of its simplicity. The dynamic coding performance of STT-coder for 3-bit register is already studied[1], but to examine the performance for 6-bit register needs more theoretical approach. So, we analyze the probability state transition method and introduce the new probability estimation method to achieve highly efficient dynamic coding performance.

2. DYNAMIC CODING BY PROBABILITY STATE TRANSITION RULE

In STT-coder, the probability state directly defines the coding method though some limitation of the combination of MPS and LPS interval sizes are

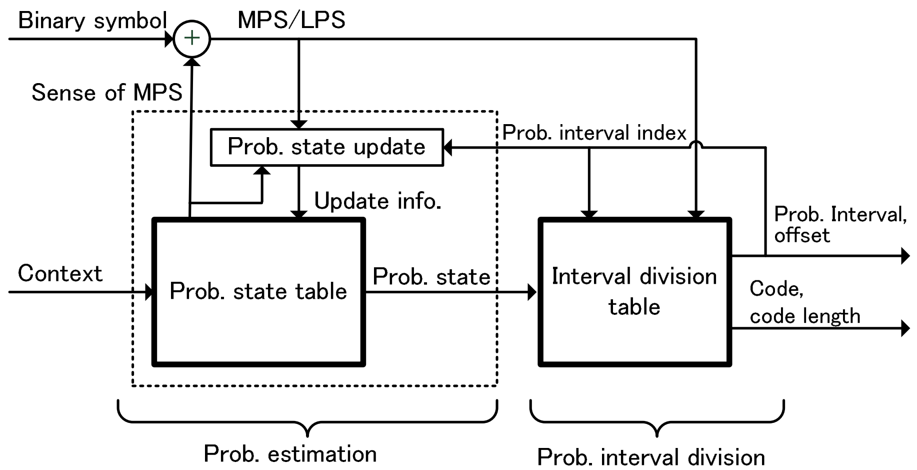

Fig. 1 STT-coder block diagram

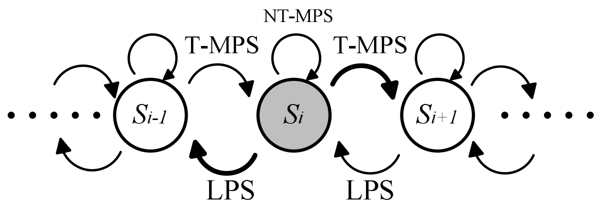

Fig.2 State transition diagram of conventional probability estimation

introduced. So, the minimum coding efficiency will be given when the actual MPS probability is just the middle of two consecutive probability states. In the set of MPS probability values given in Table 1, the minimum efficiency is set to 99%, and the highest MPS probability being covered is given from the number of register bits, which is 0.987, and the number of probability states is 8 in 6-bit case.

In the probability state transition type dynamic coding, the transition will be triggered by the occurrence of MPS or LPS, and the probability state indicated by the context is updated by the state transition. Conventional state transition type probability estimation is executed as shown in Fig.2. If an LPS happens, the probability state for the context will be updated from S_i to S_{i-1}, that is, the MPS probability estimate will be decreased. On the other hand, if an MPS happens, the state will not always be updated. It will be updated once per a certain number of MPSs from S_i to S_{i+1}. We call the MPS which triggers the update as "T-MPS (transit MPS)", and other MPS as "NT-MPS (non-transit MPS)".

To balance the transition, the following equation has to be satisfied, where an MPS probability p_i gives the highest coding efficiency at the probability state S_i, and B_i is the ratio of the number of T-MPSs in the total MPSs.

$$1-p_i = B_i \cdot p_i$$

This equation means the probabilities of transition to the upper state and the lower state should be equal at the probability state S_i.

In our study of dynamic coding, we at first employ 8

Table 1 T-MPS ratio and T-LPS ratio for eight probability states

Probability state S_i	Optimum MPS p_i	T-MPS ratio B_i	B_{i+1}/B_i	Proposed ratios of T-LPS and T-MPS	
				T-LPS ratio r_i	T-MPS Ratio r_iB_i
S_0	0.559	0.789	0.620	0.328	0.259
S_1	0.671	0.490	0.614	0.410	0.201
S_2	0.769	0.301	0.603	0.512	0.154
S_3	0.847	0.181	0.589	0.640	0.116
S_4	0.904	0.107	0.573	0.800	0.085
S_5	0.942	0.061	0.555	1.000	0.061
S_6	0.967	0.034	0.535	1.000	0.034
S_7	0.982	0.018	-	1.000	0.018

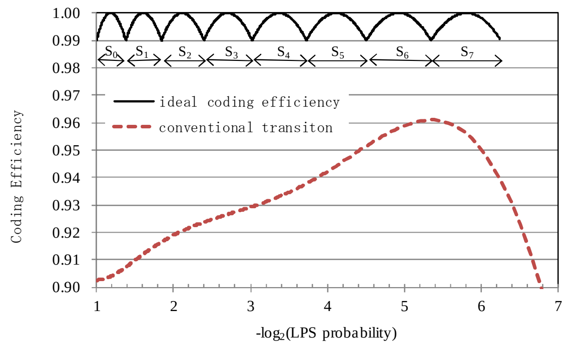

Fig.3 Coding efficiency of the conventional probability estimation

probability states introduced in static coding, S_0 to S_7 as in Table 1, which cover the MPS probability from 0.5 to 0.987. In Table 1, the optimum MPS probability Pi and the ratio of T-MPS Bi for each probability state are also shown. The coding efficiency by the conventional state transition probability estimation for STT-coder with 6-bit register is shown in Fig. 3. As you can see, the coding efficiency is relatively low at low MPS probabilities, which is similar to other arithmetic coders such as MQ-coder. In Fig. 3 we also show the statistic coding efficiency for each probability state with the predetermined minimum coding efficiency of 0.99.

3. ADOPTION OF TRANSIT LPS RATIO

3.1 Transit LPS ratio

The phenomenon of showing low dynamic coding efficiency when MPS probability is around 0.5 can be found in Fig.3. This tendency is considered to be caused by the fact that information sources having lower MPS probabilities do not stay longer at the appropriate probability states than those having higher MPS probability. In order to obtain a stable and flat coding efficiency over the whole range, it is necessary to stay at appropriate probability states long enough regardless of the MPS probability of information sources. However, in the conventional state transition rule shown in Fig. 2, the state is updated to a lower MPS probability state whenever an LPS happens. As the probability staying at the current state is $2p_i$-1 (p_i is the optimum MPS probability for the state) it would not lead to flat staying probabilities, if we adopt the probability states introduced in the study of the static coding. Therefore, we introduce a way to restrict LPS transition by a given probability according to the probability states. We call the LPS that triggers the state transition as "T-LPS (transit LPS)", and other LPS as "NT-LPS (non-transit LPS)".

In Fig. 4, state transition using T-LPS ratio is depicted. Note that in this case, the ratio causing MPS transit is derived by multiplying the conventional MPS transit ratio by T-LPS.

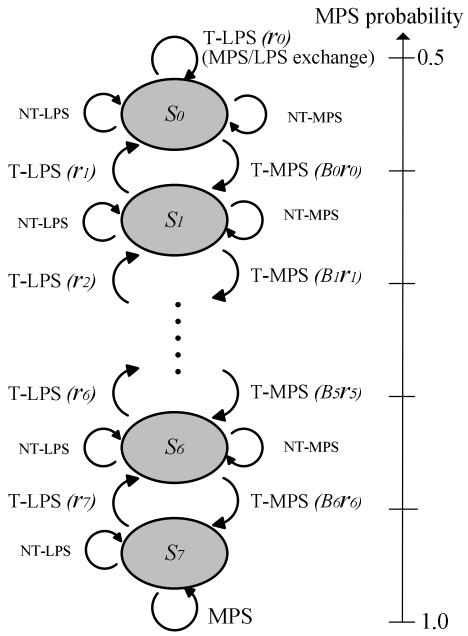

Fig. 4 State transition diagram using T-LPS

3.2 Design of state transition using T-LPS ratio

For information source which gives the highest coding efficiency at the probability state S_i, we analyzed the condition of the T-LPS ratio so that the probability staying at S_i would be higher than any other states. As a result, we found the following condition should be satisfied:

$$\frac{B_{i+1}}{B_i} < \frac{r_i}{r_{i+1}} < 1 \qquad (i = 0,\ldots,6)$$

We compared the cases where the reduction rate $g = r_{i+1}/r_i$ to be 0.7, 0.8, 0.9 as shown by the curves indicated as 8 states in Fig. 5. Among those three, we found that the performance of g=0.8 is the highest, since it provides relatively stable performance at lower MPS probabilities and its worst efficiency is higher than other two.

Furthermore, we examined a design to modify the reduction rate so that the reduction rate is set to be 1.0 at some upper probability states with lower MPS probability, while g=0.8 at other probability states. We found that restriction at upper three probability states outperforms the other candidates. The coding efficiency is shown by the curves indicated as g=0.8, r_5-r_7=1, in Fig. 6, and the values of T-LPS ratio and T-MPS ratio are shown in Table 1.

4. EXTENSION TO 16 PROBABILITY STATES

4.1 Extension to 16-state transition

In the previous section, we designed a coder with 8 probability states having stable coding efficiency, where the coding efficiency is around 92 – 95 %. Since the

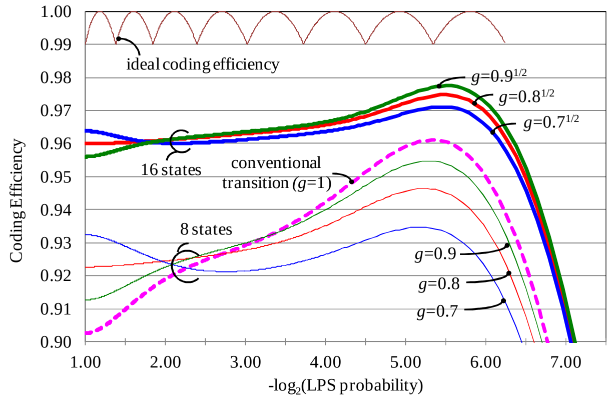

Fig. 5 Coding performance for various unified *g* values

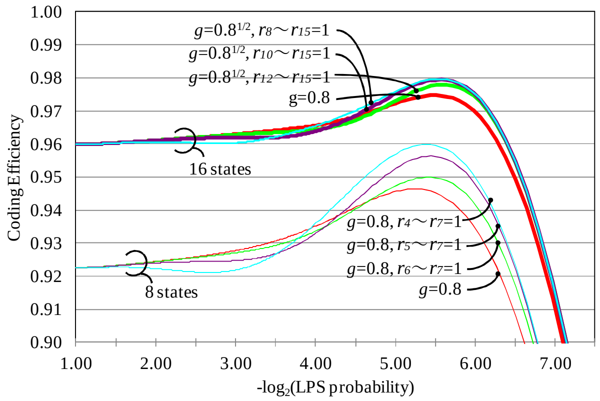

Fig. 6 Coding performance for different *g* values depending states

number of probability states is smaller than conventional arithmetic coders such as Q-coder, we studied the extension of probability states to 16 states.

To extend to 16 states, we divided each of 8 probability states into 2 states, where at the probabilities corresponding to 1/4 and 3/4 in each of the original probability states, the coding efficiency reaches the maximum. The reduction rates of the T-LPS ratio were set to $\sqrt{0.7}, \sqrt{0.8}, \sqrt{0.9}$, so that the rate decreases proportionally, and we examined the coding efficiency of these three candidates.

By comparing these three values in 16-state model, we found that $\sqrt{0.8}$ provides the most flat performance as shown in Fig. 5. The restriction of reduction rates at upper states is found to be effective and the number of upper restricted states should be 6 in 16-state model as shown in Fig.6.

4.2 Simplified extension without coding parameter change

For further modification of state transition, we examine a simplified 16-state transition, in which each of 8 states is subdivided into two states having common

Table 2. T-LPS ratio and T-MPS ratio for simplified 16 states

probability state	optimum MPS p_i	T-LPS Ratio r_i	T-MPS Ratio r_i B_i
S_{00}	0.559	0.328	0.259
S_{01}	0.559	0.328	0.259
S_{10}	0.671	0.410	0.201
S_{11}	0.671	0.410	0.201
S_{20}	0.769	0.512	0.154
S_{21}	0.769	0.512	0.154
S_{30}	0.847	0.640	0.116
S_{31}	0.847	0.640	0.116
S_{40}	0.904	0.800	0.085
S_{41}	0.904	0.800	0.085
S_{50}	0.942	1.000	0.061
S_{51}	0.942	1.000	0.061
S_{60}	0.967	1.000	0.034
S_{61}	0.967	1.000	0.034
S_{70}	0.982	1.000	0.018
S_{71}	0.982	1.000	0.018

coding parameters, such as an optimum MPS probability p_i , T-LPS ratio and T-MPS ratio. This simplification will keep the coding parameters in the 8-state STT-coder, and the size of the interval division table would become a half of the table for ordinary 16-state transition. We call this method simplified 16-state transition. In Table 2, optimal MPS probabilities, T-LPS ratio, and T-MPS ratio for the simplified 16-state transition are shown. It can be seen that the degradation of the coding efficiency of simplified 16-state transition is only 0.2% compared with the ordinary 16-state transition as shown in Fig. 7.

We compared the coding performance with two modifications of MQ-coder. The one is MQ-coder having the same number of probability states, i.e., 16 states, denoted as 16-state MQ-coder in Fig. 7. The other is 22-state MQ-coder covering the same probability range as STT-coder by 22 probability states, in Fig. 7. It can be observed that even simplified STT-coder outperforms MQ-coder with 22 probability states on average.

5. CONCLUSION

We studied state transition type probability estimation for STT-coder and introduced probability estimation using T-LPS ratio to solve the low coding efficiency at low MPS probability. Analysis of dynamic coding performance of probability estimation based on 8-state ideal coding efficiency revealed that T-LPS ratio improves the coding efficiency by about 2% for 8-state transition. For 16-state simplified state transition, about 4% improvement of coding efficiency was achieved. By

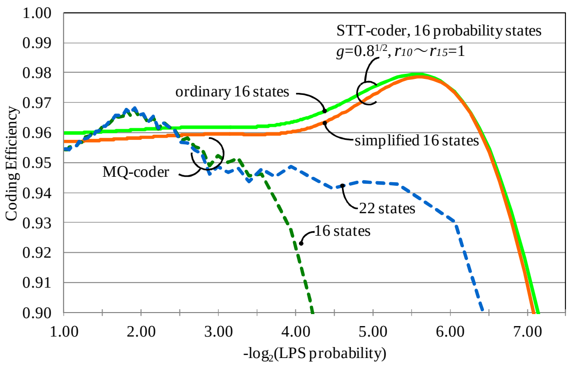

Fig. 7 Coding performance of 6-bit STT-coder compared with other coders

comparing with MQ-coder modified to cover the same probability range as STT-coder, it was found that STT-coder provides better coding efficiency by 1.5% on average.

6. REFERENCES

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