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Title: **CE6-related: Fast DST-7/DCT-8 with dual implementation support**

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Source: Tencent

Abstract

This contribution presents a fast DST-7/DCT-8 method which supports identical results between matrix multiplication and fast method, i.e., dual implementations. Theoretically, compared to matrix multiplication, the number of multiplication operation is reportedly reduced by 50%, 39% and 46% for 16-, 32- and 64-point DST-7/DCT-8, respectively. On top of VTM, when Adaptive Multiple Transform (AMT) is enabled, it is reportedly shown that an average of 7%, 5% and 6% overall decoding time saving and 3%, 6% and 8% overall encoding time saving is achieved for AI, RA and LDB, respectively, with almost no coding efficiency change.

1 Introduction

In AMT of BMS-1.1, DCT-5/8 and DST-1/7 are used as primary separable transform for coding residual blocks. However, these four additional transform types are implemented as matrix multiplication, which is costly in terms of arithmetic operation counts. In this contribution, an alternative implementation of DST-7 and DCT-8 is proposed, which reduced the arithmetic operations with little impact on coding performance. Moreover, the methods support dual implementation, i.e., DST-7/DCT-8 can be implemented by either fast method or matrix multiplication, and both ways lead to identical results.

2 Proposed method

In an N-point DST-7/DCT-8 transform core, there are only N distinct numbers without considering sign changes, or additional zeros. Three features on the transform cores have been exploited to implement the fast method.

Feature #1: In some basis vectors which contain N distinct numbers without considering the sign changes, it is observed that the sum of several (2 or 3) numbers equals to the sum of another several (1 or 2) numbers.

Feature #2: Replicate patterns with symmetric or anti-symmetric characteristics can be observed in some basis vectors.

Feature #3: There is another one or two basis vector(s) which only contain(s) very few (1 or 2) distinct number(s) without considering the sign changes.

To explain the fast methods utilizing these features, an example from 16-point DST-7 transform using each of the three features is discussed. Denote the input vector for a 16-point transform as **x**={`x0, x1, x2, …, x15`}, and the output transform coefficient vector as **y**={`y0, y1, y2, …, y15`}. The transform core in the forward transform is shown as below:

```
{ a  b  c  d  e  f  g  h  i  j  k  l  m  n  o  p }
{ c  f  i  l  o  o  l  i  f  c  0 -c -f -i -l -o }
{ e  j  o  m  h  c -b -g -l -p -k -f -a  d  i  n }
{ g  n  l  e -b -i -p -j -c  d  k  o  h  a -f -m }
{ i  o  f -c -l -l -c  f  o  i  0 -i -o -f  c  l }
{ k  k  0 -k -k  0  k  k  0 -k -k  0  k  k  0 -k }
{ m  g -f -n -a  l  h -e -o -b  k  i -d -p -c  j }
{ o  c -l -f  i  i -f -l  c  o  0 -o -c  l  f -i }
{ p -a -o  b  n -c -m  d  l -e -k  f  j -g -i  h }
{ n -e -i  j  d -o  a  m -f -h  k  c -p  b  l -g }
{ l -i -c  o -f -f  o -c -i  l  0 -l  i  c -o  f }
{ j -m  c  g -p  f  d -n  i  a -k  l -b -h  o -e }
{ h -p  i -a -g  o -j  b  f -n  k -c -e  m -l  d }
{ f -l  o -i  c  c -i  o -l  f  0 -f  l -o  i -c }
{ d -h  l -p  m -i  e -a -c  g -k  o -n  j -f  b }
{ b -d  f -h  j -l  n -p  o -m  k -i  g -e  c -a }
```

where {a,b,c,d,e,f,g,h,i,j,k,l,m,n,o,p} are the N unique numbers which are specified by the formulation of DST-7.

Example of Feature #1:

It is noted that the element values have the following characteristics.

a + j = l

b + i = m

c + h = n

d + g = o

e + f = p

Therefore, to calculate y0, instead of doing the following vector-by-vector multiplication:

y0 = a·x0 + b·x1 + … + p·x15

which requires 16 multiplications. The following alternative implementation can be done to derive the same results:

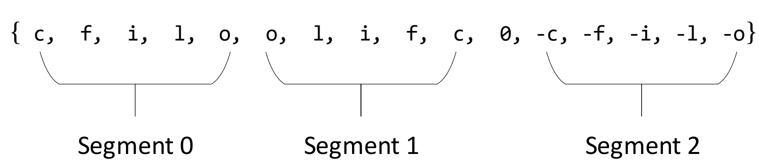
y0 = a·(x0+x11) + b·(x1+x12) + … + j·(x9+x11) + k·x10

which requires 10 multiplications. It is observed that the number of multiplications is reduced.

In addition, while calculating y2, y3, y6, y8, y9, y11, y12, y14, y15, similar implementation can be done, and the intermediate results (x0+x11), (x1+x12), (x2+x13), (x3+x14), (x4+x15), (x5+x15), (x6+x14), (x7+x13), (x8+x12), (x9+x11) and k·x10 can be re-used. It is observed that the number of additions is reduced.

Example of Feature #2:

The second basis vector is



which can be divided into three segments, and they are replicate with sign changes, or flipped version of each other. Based on Feature #2, when calculating y1, instead of doing the following vector-by-vector multiplication

y1 = c·x0 + f·x1 + … - o·x15

which requires 16 multiplications. The following alternative implementation can be used to derive the same results.

```
y1 = c·(x0+x9-x11) + f·(x1+x8-x12) + i·(x2+x7-x13) + l·(x3+x6-x14) + o·(x4+x5-x15)
```

which only requires 5 multiplications. It is reported the number of multiplications is reduced.

In addition, when calculating `y1, y4, y7, y10, y13`, the implementation can be done in similar way, therefore, the intermediate results of `(x0+x9-x11), (x1+x8-x12, (x2+x7-x13), (x3+x6-x14)` and `(x4+x5-x15)` can be re-used. It is observed the number of additions is reduced.

Example of Feature #3:

It is observed that the 6th basis vector only contains 1 distinct number without considering the sign changes as shown below.

```
{k, k, 0, -k, -k, 0, k, k, 0, -k, -k, 0, k, k, 0, -k}
```

Instead of taking the vector-by-vector multiplication of

```
y5 = k·x0 + k·x1 + … - k·x15
```

which requires 11 multiplications, `y5` can also be achieved by the following operations:

```
y5 = k·(x0 + x1 - … - x15)
```

which only requires 1 multiplication.

The abovementioned three features apply to 16-, 32- and 64-point DST-7/DCT-8 forward transform matrices. It is understood that the inverse transform is the transpose of corresponding forward transform, thus similar fast methods can be implemented using the three features.

Due to the rounding error, the integer DST-7/DCT-8 cores in BMS-1.1 do not fully comply with these features. Therefore, the integer DST-7/DCT-8 transform cores are further tuned by ±1 in order to make it fully compatible with the three features. The proposed 8-bit and 10-bit DST-7 transform cores for 16-, 32- and 64-point transforms are shown in Appendix A.

3 Results

Two experiments are conducted to evaluate the proposed methods, namely Test #1 and Test #2. Test #1 reports the coding performance using VTM configuration, with AMT enabled, and Test #2 reports the coding performance using BMS configuration. Transform cores are represented by 10-bit integers which is aligned with BMS-1.1. Common test condition (CTC) is used for simulations, with the following parameter setting to enable AMT when VTM configuration is used:

- VTM: --EMT=3 --EMTFast=3

Table 1: The experiment settings of two tests.

		VTM/BMS	Adjusted DST7/DCT8 cores	Matrix Multiplication	Fast
Test #1	anchor1	VTM1.1+AMT	N	N	N
	anchor2	VTM1.1+AMT	Y	Y	N
	test	VTM1.1+AMT	Y	Y	Y
Test #2	anchor1	BMS1.1	N	N	N
	anchor2	BMS1.1	Y	Y	N
	test	BMS1.1	Y	Y	Y

Table 2 and **Table 3** show the coding performance of Test #1 and Test #2, respectively. As can be seen from **Table 2**, an average of 7%, 5% and 6% decoding time has been saved for AI, RA and LDB, respectively, and an average of 3%, %6 and 8% encoding time has been saved for AI, RA and LDB, respectively. Table 3 reports the coding performance of Test #2 and it has been observed that an average of 6%, 3% and 4% decoding time is saved for AI, RA and LDB, respectively, and an average of 3%, 4% and 4% decoding time is saved for AI, RA and LDB, respectively. In addition, no obvious coding performance changes have been observed with the abovementioned time savings.

Table 2: Coding performance of Test #1.

	All Intra Main10									
	Over Anchor 1					Over Anchor2				
	Y	U	V	EncT	DecT	Y	U	V	EncT	DecT
Class A1	0.00%	-0.05%	0.04%	97%	89%	0.00%	0.00%	0.00%	98%	89%
Class A2	0.00%	0.01%	0.00%	98%	92%	0.00%	0.00%	0.00%	98%	92%
Class B	0.00%	0.00%	0.00%	98%	94%	0.00%	0.00%	0.00%	97%	92%
Class C	0.00%	0.00%	0.00%	98%	100%	0.00%	0.00%	0.00%	94%	93%
Class E	0.02%	-0.03%	-0.07%	96%	89%	0.00%	0.00%	0.00%	98%	91%
Overall	0.00%	-0.01%	-0.01%	97%	93%	0.00%	0.00%	0.00%	97%	92%
Class D	0.01%	-0.02%	0.11%	96%	93%	0.00%	0.00%	0.00%	104%	97%
Class F	-0.02%	0.00%	-0.05%	98%	98%	0.00%	0.00%	0.00%	98%	100%

	Random Access Main 10									
	Over Anchor 1					Over Anchor2				
	Y	U	V	EncT	DecT	Y	U	V	EncT	DecT
Class A1	-0.01%	0.00%	-0.11%	93%	91%	0.00%	0.00%	0.00%	93%	91%
Class A2	0.01%	0.11%	-0.07%	94%	96%	0.00%	0.00%	0.00%	93%	95%
Class B	-0.03%	0.03%	0.16%	94%	95%	0.00%	0.00%	0.00%	95%	95%
Class C	0.04%	-0.02%	0.18%	95%	96%	0.00%	0.00%	0.00%	94%	95%
Class E										
Overall	0.00%	0.03%	0.06%	94%	95%	0.00%	0.00%	0.00%	94%	95%
Class D	0.03%	-0.25%	0.04%	96%	96%	0.00%	0.00%	0.00%	95%	96%
Class F	0.00%	0.28%	0.27%	94%	98%	0.00%	0.00%	0.00%	94%	98%

	Low delay B Main10									
	Over Anchor 1					Over Anchor2				
	Y	U	V	EncT	DecT	Y	U	V	EncT	DecT
Class A1										
Class A2										
Class B	-0.01%	-0.13%	0.48%	91%	92%	0.00%	0.00%	0.00%	92%	90%
Class C	0.02%	-0.06%	-0.09%	93%	95%	0.00%	0.00%	0.00%	91%	95%
Class E	0.03%	-0.68%	-0.46%	92%	96%	0.00%	0.00%	0.00%	93%	96%
Overall	0.01%	-0.24%	0.05%	92%	94%	0.00%	0.00%	0.00%	92%	93%
Class D	0.06%	-0.06%	-0.43%	96%	95%	0.00%	0.00%	0.00%	97%	96%
Class F	-0.07%	-0.19%	0.06%	90%	92%	0.00%	0.00%	0.00%	93%	94%

Table 3: Coding performance of Test #2.

	All Intra Main10									
	Over Anchor 1					Over Anchor2				
	Y	U	V	EncT	DecT	Y	U	V	EncT	DecT
Class A1	0.00%	0.03%	-0.05%	97%	93%	0.00%	0.00%	0.00%	99%	93%
Class A2	0.00%	0.02%	0.02%	94%	90%	0.00%	0.00%	0.00%	97%	94%
Class B	-0.01%	0.02%	-0.01%	98%	94%	0.00%	0.00%	0.00%	98%	96%
Class C	0.00%	0.01%	0.05%	98%	93%	0.00%	0.00%	0.00%	99%	96%
Class E	-0.01%	0.03%	-0.05%	99%	99%	0.00%	0.00%	0.00%	99%	98%
Overall	0.00%	0.02%	0.00%	97%	94%	0.00%	0.00%	0.00%	98%	96%
Class D	-0.02%	0.05%	0.04%	100%	101%	0.00%	0.00%	0.00%	97%	95%
Class F	-0.03%	0.01%	-0.08%	103%	102%	0.00%	0.00%	0.00%	103%	98%

	Random Access Main 10									
	Over Anchor 1					Over Anchor2				
	Y	U	V	EncT	DecT	Y	U	V	EncT	DecT
Class A1	0.01%	0.11%	0.06%	96%	96%	0.00%	0.00%	0.00%	96%	97%
Class A2	0.01%	0.11%	0.10%	96%	97%	0.00%	0.00%	0.00%	95%	97%
Class B	-0.01%	0.04%	-0.05%	96%	98%	0.00%	0.00%	0.00%	95%	97%
Class C	0.03%	0.13%	-0.15%	96%	97%	0.00%	0.00%	0.00%	97%	99%
Class E										
Overall	0.01%	0.09%	-0.02%	96%	97%	0.00%	0.00%	0.00%	96%	98%
Class D	0.01%	-0.04%	-0.04%	99%	103%	0.00%	0.00%	0.00%	98%	101%
Class F	-0.02%	0.24%	0.09%	96%	97%	0.00%	0.00%	0.00%	96%	98%

	Low delay B Main10									
	Over Anchor 1					Over Anchor2				
	Y	U	V	EncT	DecT	Y	U	V	EncT	DecT
Class A1										
Class A2										
Class B	-0.02%	0.02%	0.04%	95%	97%	0.00%	0.00%	0.00%	96%	96%
Class C	-0.04%	0.02%	-0.14%	97%	95%	0.00%	0.00%	0.00%	97%	94%
Class E	-0.18%	0.98%	-0.01%	97%	96%	0.00%	0.00%	0.00%	97%	97%
Overall	-0.07%	0.26%	-0.03%	96%	96%	0.00%	0.00%	0.00%	96%	96%
Class D	0.01%	-0.37%	0.10%	103%	100%	0.00%	0.00%	0.00%	102%	97%
Class F	-0.08%	0.24%	-0.13%	100%	98%	0.00%	0.00%	0.00%	99%	98%

4 Complexity analysis

4.1 Arithmetic operations

The numbers of arithmetic operations required for a 1D N-point transform of matrix multiplication and the proposed fast method are tabulated in Table I. Theoretically, 50.4%, 39.5% and 46.1% total number of multiplications have been saved for 16-point, 32-point and 64-point transform respectively, and 35.4%, 27.6% and 42.2% add/subs have been saved for 16-point, 32-point and 64-point transform respectively.

Table 4: The number of arithmetic operations for a 1D transform

	Matrix multiplication			Proposed fast DST-7/DCT-8		
Transform size	Mult	Add/Sub	Shift	Mult	Add/Sub	Shift

16	256	240	16	127	155	16
32	1024	992	32	620	718	32
64	4096	4032	64	2207	2331	64

4.2 Software execution speed

4.2.1 Run-time consumption within codec

The actual forward/inverse transform execution time is measured in seconds for all the test sequences under AI and RA configurations. The fast methods are enabled step by step in each block level. In the following Figure 1, the decoding transform time is reported. The horizontal axis and vertical axis represent the transform time of anchor and proposed fast method, respectively.

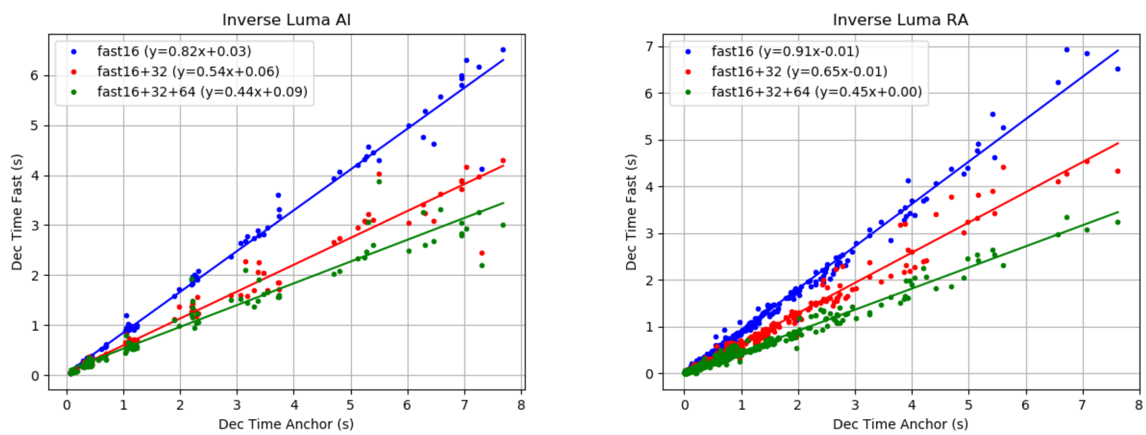


Figure 1: Comparisons of run-time consumption (seconds) of transform function during decoding.

It should be noted that this is the run-time consumption by only the inverse transform, not the whole decoding time. The straight line is the linear regression result with L2 norm constraints. As can be seen from the figures, an average of 56% and 55% decoding transform time has been saved for AI and RA, respectively.

4.2.2 Run-time consumption of individual transform function

In this test, a standalone test program is used to measure the run-time (in seconds) of individual transform functions by repeating a large amount of times. The test program is written in C, and auto-vectorization is disabled (`#pragma loop(no_vector)`) for compiling to provide fair comparisons.

Table 5: Comparisons on software execution speed (seconds)

		Matrix multiplication		Proposed fast method	
Transform size	No. of iterations	Forward	Inverse	Forward	Inverse
16-point DCT-8	2^23	11.3	15.2	4.8	4.9
32-point DCT-8	2^20	11.1	14.8	5.7	5.5
64-point DCT-8	2^17	11.0	14.2	5.2	5.1

5 Conclusions

This proposal provides a fast DST-7/DCT-8 method which supports dual implementations (identical output between matrix multiplication and fast method). With the proposed fast method, it is reported that the number of multiplication operations is reduced by 50%, 40% and 46% for 16-point, 32-point and 64-point DST-7/DCT-8, respectively. The experimental results show reduced encoding and decoding time, with almost no change on BD-Rate. It is recommended to adopt this proposed scheme into VTM.

6 Patent rights declarations(s)

Tencent may have current or pending patent rights relating to the technology described in this contribution and, conditioned on reciprocity, is prepared to grant licenses under reasonable and non-discriminatory terms as necessary for implementation of the resulting ITU-T Recommendation | ISO/IEC International Standard (per box 2 of the ITU-T/ITU-R/ISO/IEC patent statement and licensing declaration form).

Appendix A

8-bit 16x16 DST-7

```
{ 9 17 25 33 41 49 56 62 66 72 77 81 83 87 89 90}
{25 49 66 81 89 89 81 66 49 25  0-25-49-66-81-89}
{41 72 89 83 62 25-17-56-81-90-77-49 -9 33 66 87}
{56 87 81 41-17-66-90-72-25 33 77 89 62  9-49-83}
{66 89 49-25-81-81-25 49 89 66  0-66-89-49 25 81}
{77 77  0-77-77  0 77 77  0-77-77  0 77 77  0-77}
{83 56-49-87 -9 81 62-41-89-17 77 66-33-90-25 72}
{89 25-81-49 66 66-49-81 25 89  0-89-25 81 49-66}
{90 -9-89 17 87-25-83 33 81-41-77 49 72-56-66 62}
{87-41-66 72 33-89  9 83-49-62 77 25-90 17 81-56}
{81-66-25 89-49-49 89-25-66 81  0-81 66 25-89 49}
{72-83 25 56-90 49 33-87 66  9-77 81-17-62 89-41}
{62-90 66 -9-56 89-72 17 49-87 77-25-41 83-81 33}
{49-81 89-66 25 25-66 89-81 49  0-49 81-89 66-25}
{33-62 81-90 83-66 41 -9-25 56-77 89-87 72-49 17}
{17-33 49-62 72-81 87-90 89-83 77-66 56-41 25 -9}
```

8-bit 32x32 DST-7

```
{ 4  9 13 17 21 26 30 34 38 42 45 50 53 56 60 63 66 68 72 74 77 78 80 82 84 85 86 88 88 89 90 90}
{13 26 38 50 60 68 77 82 86 89 90 88 85 80 74 66 56 45 34 21  9 -4-17-30-42-53-63-72-78-84-88-90}
{21 42 60 74 84 89 89 84 74 60 42 21  0-21-42-60-74-84-89-89-84-74-60-42-21  0 21 42 60 74 84 89}
{30 56 77 88 89 80 63 38  9-21-50-72-85-90-84-68-45-17 13 42 66 82 90 86 74 53 26 -4-34-60-78-88}
{38 68 86 88 74 45  9-30-63-84-90-78-53-17 21 56 80 90 82 60 26-13-50-77-89-85-66-34  4 42 72 88}
{45 78 90 77 42 -4-50-80-90-74-38  9 53 82 89 72 34-13-56-84-88-68-30 17 60 85 88 66 26-21-63-86}
{53 85 85 53  0-53-85-85-53  0 53 85 85 53  0-53-85-85-53  0 53 85 85 53  0-53-85-85-53  0 53 85}
{60 89 74 21-42-84-84-42 21 74 89 60  0-60-89-74-21 42 84 84 42-21-74-89-60  0 60 89 74 21-42-84}
{66 90 56-13-74-88-45 26 80 84 34-38-85-78-21 50 88 72  9-60-90-63  4 68 89 53-17-77-86-42 30 82}
{72 86 34-45-89-63 13 78 82 21-56-90-53 26 84 77  9-66-88-42 38 88 68 -4-74-85-30 50 90 60-17-80}
{77 80  9-72-84-17 66 86 26-60-88-34 53 90 42-45-90-50 38 89 56-30-88-63 21 85 68-13-82-74  4 78}
{80 72-17-86-60 34 90 45-50-89-30 63 85 13-74-78  4 82 68-21-88-56 38 90 42-53-88-26 66 84  9-77}
{84 60-42-89-21 74 74-21-89-42 60 84  0-84-60 42 89 21-74-74 21 89 42-60-84  0 84 60-42-89-21 74}
{86 45-63-78 21 90 26-77-66 42 88  4-85-50 60 80-17-90-30 74 68-38-88 -9 84 53-56-82 13 89 34-72}
{88 30-78-56 60 77-34-88  4 89 26-80-53 63 74-38-86  9 90 21-82-50 66 72-42-85 13 90 17-84-45 68}
{90 13-88-26 84 38-78-50 72 60-63-68 53 77-42-82 30 86-17-89  4 90  9-88-21 85 34-80-45 74 56-66}
{90 -4-90  9 89-13-88 17 88-21-86 26 85-30-84 34 82-38-80 42 78-45-77 50 74-53-72 56 68-60-66 63}
{89-21-84 42 74-60-60 74 42-84-21 89  0-89 21 84-42-74 60 60-74-42 84 21-89  0 89-21-84 42 74-60}
{88-38-72 68 42-86 -4 88-34-74 66 45-85 -9 89-30-77 63 50-84-13 90-26-78 60 53-82-17 90-21-80 56}
{85-53-53 85  0-85 53 53-85  0 85-53-53 85  0-85 53 53-85  0 85-53-53 85  0-85 53 53-85  0 85-53}
{82-66-30 90-42-56 86-13-77 74 17-88 53 45-89 26 68-80 -4 84-63-34 90-38-60 85 -9-78 72 21-88 50}
{78-77 -4 80-74 -9 82-72-13 84-68-17 85-66-21 86-63-26 88-60-30 88-56-34 89-53-38 90-50-42 90-45}
{74-84 21 60-89 42 42-89 60 21-84 74  0-74 84-21-60 89-42-42 89-60-21 84-74  0 74-84 21 60-89 42}
{68-88 45 30-84 78-17-56 90-60-13 77-85 34 42-88 72 -4-66 89-50-26 82-80 21 53-90 63  9-74 86-38}
{63-90 66 -4-60 90-68  9 56-89 72-13-53 88-74 17 50-88 77-21-45 86-78 26 42-85 80-30-38 84-82 34}
{56-88 80-38-21 72-90 68-17-42 82-86 53  4-60 88-78 34 26-74 90-66 13 45-84 85-50 -9 63-89 77-30}
{50-82 88-66 21 30-72 90-78 42  9-56 85-86 60-13-38 77-90 74-34-17 63-88 84-53  4 45-80 89-68 26}
{42-74 89-84 60-21-21 60-84 89-74 42  0-42 74-89 84-60 21 21-60 84-89 74-42  0 42-74 89-84 60-21}
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