

# Collisions for Hash Functions

## MD4, MD5, HAVAL-128 and RIPEMD

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revised on August 17, 2004

### 1 Collisions for MD5

MD5 is the hash function designed by Ron Rivest [9] as a strengthened version of MD4 [8]. In 1993 Bert den Boer and Antoon Bosselaers [1] found pseudo-collision for MD5 which is made of the same message with two different sets of initial value. H. Dobbertin[3] found a free-start collision which consists of two different 512-bit messages with a chosen initial value  $IV'_0$ .

$$IV'_0 : A'_0 = 0x12AC2375, B'_0 = 0x3B341042, C'_0 = 0x5F62B97C, D'_0 = 0x4BA763ED$$

Our attack can find many real collisions which are composed of two 1024-bit messages with the original initial value  $IV_0$  of MD5:

$$IV_0 : A_0 = 0x67452301, B_0 = 0xefcdab89, C_0 = 0x98badcfe, D_0 = 0x10325476$$

$$M' = M + \Delta C_1, \Delta C_1 = (0,0,0,0,2^{31}, \dots, 2^{15}, \dots, 2^{31}, 0)$$

$$N'_i = N_i + \Delta C_2, \Delta C_2 = (0,0,0,0,2^{31}, \dots, -2^{15}, \dots, 2^{31}, 0)$$

(non-zeros at position 4,11 and 14)

such that

$$MD5(M, N_i) = MD5(M', N'_i).$$

On IBM P690, it takes about one hour to find such  $M$  and  $M'$ , after that, it takes only 15 seconds to 5 minutes to find  $N_i$  and  $N'_i$ , so that  $(M, N_i)$  and  $(M', N'_i)$  will produce the same hash same value. Moreover, our attack works for any given initial value.

The following are two pairs of 1024-bit messages producing collisions, the two examples have the same 1-st half 512 bits.

X <sub>1</sub>	M	2dd31d1 c4eee6c5 69a3d69 5cf9af98 <u>87b5ca2f</u> ab7e4612 3e580440 897ffbb8 634ad55 2b3f409 8388e483 <u>5a417125</u> e8255108 9fc9cdf7 <u>f2bd1dd9</u> 5b3c3780
	N <sub>1</sub>	d11d0b96 9c7b41dc f497d8e4 d555655a c79a7335 cfdeb0 66f12930 8fb109d1 797f2775 eb5cd530 baade822 5c15cc79 ddc74ed 6dd3c55f d80a9bb1 e3a7cc35
X <sub>1</sub>	M <sup>0</sup>	2dd31d1 c4eee6c5 69a3d69 5cf9af98 <u>7b5ca2f</u> ab7e4612 3e580440 897ffbb8 634ad55 2b3f409 8388e483 <u>5a41f125</u> e8255108 9fc9cdf7 <u>72bd1dd9</u> 5b3c3780
	N <sub>1</sub>	d11d0b96 9c7b41dc f497d8e4 d555655a 479a7335 cfdeb0 66f12930 8fb109d1 797f2775 eb5cd530 baade822 5c154c79 ddc74ed 6dd3c55f 580a9bb1 e3a7cc35
H		9603161f f41fc7ef 9f65ffbc a30f9dbf
X <sub>2</sub>	M	2dd31d1 c4eee6c5 69a3d69 5cf9af98 87b5ca2f ab7e4612 3e580440 897ffbb8 634ad55 2b3f409 8388e483 5a417125 e8255108 9fc9cdf7 f2bd1dd9 5b3c3780
	N <sub>2</sub>	313e82d8 5b8f3456 d4ac6dae c619c936 b4e253dd fd03da87 6633902 a0cd48d2 42339fe9 e87e570f 70b654ce 1e0da880 bc2198c6 9383a8b6 2b65f996 702af76f
X <sub>2</sub>	M <sup>0</sup>	2dd31d1 c4eee6c5 69a3d69 5cf9af98 7b5ca2f ab7e4612 3e580440 897ffbb8 634ad55 2b3f409 8388e483 5a41f125 e8255108 9fc9cdf7 72bd1dd9 5b3c3780
	N <sub>2</sub>	313e82d8 5b8f3456 d4ac6dae c619c936 34e253dd fd03da87 6633902 a0cd48d2 42339fe9 e87e570f 70b654ce 1e0d2880 bc2198c6 9383a8b6 ab65f996 702af76f
H		8d5e7019 6324c015 715d6b58 61804e08

Table 1 Two pairs of collisions for MD5

## 2 Collisions for HAVAL-128

HAVAL is proposed in [10]. HAVAL is a hashing algorithm that can compress messages of any length in 3,4 or 5 passes and produce a fingerprint of length 128, 160, 192 or 224 bits.

Attack on a reduced version for HAVAL was given by P. R. Kasselmann and W T Penzhorn [7], which consists of last rounds for HAVAL-128. We break the full HAVAL-128 with only about the  $2^6$  HAVAL computations. Here we give two examples of collisions of HAVAL-128, where

$$M' = M + \Delta C, \Delta C = (2^{i-1}, 0, 0, 0, 2^{i-12}, \dots, 2^{i-8}, 0, \dots, 0)$$

with non-zeros at position 0,11,18, and  $i = 0,1,2, \dots, 31$ , such that  $HAVAL(M) = HAVAL(M')$ .

M <sub>1</sub>	6377448b d9e59f18 f2aa3cbb d6cb92ba ee544a44 879fa576 1ca34633 76ca5d4f
	a67a8a42 8d3adc8b b6e3d814 5630998d 86ea5dcd a739ae7b 54fd8e32 acbb2b36
	38183c9a b67a9289 c47299b2 27039ee5 dd555e14 839018d8 aabb9c9 d78fc632
	fff4b3a7 40000096 7f466aac ffffbc0 5f4016d2 5f4016d0 12e2b0 f4307f87

M <sub>1</sub>	6377488b a67a8a42 38183c9a fff4b3a7	d9e59f18 8d3adc8b b67a9289 40000096	f2aa3cbb b6e3d814 c47299ba 7f466aac	d6cb92ba d630998d 27039ee5 ffffbc0	ee544a44 86ea5dcd dd555e14 5f4016d2	879fa576 a739ae7b 839018d8 5f4016d0	1ca34633 54fd8e32 aabb9c9 12e2b0	76ca5d4f acbb2b36 d78fc632 f4307f87
H	95b5621c	ca62817a	a48dacd8	6d2b54bf				
M <sub>2</sub>	6377448b a67a8a42 38183c9a fff4b3a7	d9e59f18 8d3adc8b b67a9289 40000096	f2aa3cbb b6e3d814 c47299b2 7f466aac	d6cb92ba 5630998d 27039ee5 ffffbc0	ee544a44 86ea5dcd dd555e14 5f4016d2	879fa576 a739ae7b 839018d8 5f4016d0	1ca34633 54fd8e32 aabb9c9 12e2b0	76ca5d4f acbb2b36 d78fc632 f5b16963
M <sub>2</sub>	6377488b a67a8a42 38183c9a fff4b3a7	d9e59f18 8d3adc8b b67a9289 40000096	f2aa3cbb b6e3d814 c47299ba 7f466aac	d6cb92ba d630998d 27039ee5 ffffbc0	ee544a44 86ea5dcd dd555e14 5f4016d2	879fa576 a739ae7b 839018d8 5f4016d0	1ca34633 54fd8e32 aabb9c9 12e2b0	76ca5d4f acbb2b36 d78fc632 f5b16963
H	b0e99492	d64eb647	5149ef30	4293733c				

Table 2 Two pairs of collision, where  $i=11$  and these two examples differ only at the last word

### 3 Collisions for MD4

MD4 is designed by R. L. Rivest[8]. Attack of H. Dobbertin in Eurocrypt'96[2] can find collision with probability  $1/2^{22}$ . Our attack can find collision with hand calculation, such that

$$M' = M + \Delta C, \Delta C = (0, 2^{31}, -2^{28} + 2^{31}, 0, 0, 0, 0, 0, 0, 0, -2^{16}, 0, 0, 0)$$

$$\text{and } MD4(M) = MD4(M').$$

M <sub>1</sub>	4d7a9c83 c69d71b3	56cb927a f9e99198	b9d5a578 d79f805e	57a7a5ee a63bb2e8	de748a3c 45dd8e31	dcc366b3 97e31fe5	b683a020 2794bf08	3b2a5d9f b9e8c3e9
M <sub>1</sub>	4d7a9c83 c69d71b3	d6cb927a f9e99198	29d5a578 d79f805e	57a7a5ee a63bb2e8	de748a3c 45dc8e31	dcc366b3 97e31fe5	b683a020 2794bf08	3b2a5d9f b9e8c3e9
H	5f5c1a0d	71b36046	1b5435da	9b0d807a				
M <sub>2</sub>	4d7a9c83 c69d71b3	56cb927a f9e99198	b9d5a578 d79f805e	57a7a5ee a63bb2e8	de748a3c 45dd8e31	dcc366b3 97e31fe5	b683a020 f713c240	3b2a5d9f a7b8cf69
M <sub>2</sub>	4d7a9c83 c69d71b3	d6cb927a f9e99198	29d5a578 d79f805e	57a7a5ee a63bb2e8	de748a3c 45dc8e31	dcc366b3 97e31fe5	b683a020 f713c240	3b2a5d9f a7b8cf69
H	e0f76122	c429c56c	ebb5e256	b809793				

Table 3 Two pairs of collisions for MD4

### 4 Collisions for RIPEMD

RIPEMD was developed for the RIPE project (RACE Integrity Primitives Evaluation, 1988-1992). In 1995, H. Dobbertin proved that the reduced version RIPEMD with two rounds is not collision-free[4]. We show

that the full RIPEMD also isn't collision-free. The following are two pairs of collisions for RIPEMD:

$$M'_i = M_i + \Delta C, \Delta C = (0,0,0,2^{20},0,0,0,0,0,0,2^{18} + 2^{31},0,0,0,0,2^{31})$$

M <sub>1</sub>	579faf8e	9ecf579	574a6aba	78413511	a2b410a4	ad2f6c9f	b56202c	4d757911
	bdeaae7	78bc91f2	47bc6d7d	9abdd1b1	a45d2015	817104ff	264758a8	61064ea5
M <sub>1</sub>	579faf8e	9ecf579	574a6aba	78513511	a2b410a4	ad2f6c9f	b56202c	4d757911
	bdeaae7	78bc91f2	c7c06d7d	9abdd1b1	a45d2015	817104ff	264758a8	e1064ea5
H	1fab152	1654a31b	7a33776a	9e968ba7				
M <sub>2</sub>	579faf8e	9ecf579	574a6aba	78413511	a2b410a4	ad2f6c9f	b56202c	4d757911
	bdeaae7	78bc91f2	47bc6d7d	9abdd1b1	a45d2015	a0a504ff	b18d58a8	e70c66b6
M <sub>2</sub>	579faf8e	9ecf579	574a6aba	78513511	a2b410a4	ad2f6c9f	b56202c	4d757911
	bdeaae7	78bc91f2	c7c06d7d	9abdd1b1	a45d2015	a0a504ff	b18d58a8	670c66b6
H	1f2c159f	569b31a6	dfcaa51a	25665d24				

Table 4 The collisions for RIPEMD

## 5 Remark

Besides the above hash functions we break, there are some other hash functions not having ideal security. For example, collision of SHA-0 [6] can be found with about  $2^{40}$  computations of SHA-0 algorithms, and a collision for HAVAL-160 can be found with probability  $1/2^{32}$ .

Note that the messages and all other values in this paper are composed of 32-bit words, in each 32-bit word the most left byte is the most significant byte.

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