
**Information technology — Security
techniques — Hash-functions —**

**Part 3:
Dedicated hash-functions**

*Technologies de l'information — Techniques de sécurité — Fonctions de
brouillage —*

Partie 3: Fonctions de hachage dédiées

Foreword

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International Standard ISO/IEC 10118-3 was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Sub-Committee SC27, *IT Security techniques*.

ISO/IEC 10118 consists of the following parts, under the general title *Information technology — Security techniques — Hash-functions*:

- *Part 1: General*
- *Part 2: Hash-functions using an n -bit block cipher algorithm*
- *Part 3: Dedicated hash-functions*
- *Part 4: Hash-functions using modular arithmetic*

Further parts may follow.

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Information technology — Security techniques — Hash-functions — Part 3: Dedicated hash-functions

1 Scope

This part of ISO/IEC 10118 specifies dedicated hash-functions, i.e. specially designed hash-functions. The hash-functions in this part of ISO/IEC 10118 are based on the iterative use of a round-function. Three distinct round-functions are specified, giving rise to distinct dedicated hash-functions. The first and third provide hash-codes of lengths up to 160 bits, and the second provides hash-codes of lengths up to 128 bits.

2 Normative reference

The following standard contains provisions which, through reference in the text, constitute provisions of this part of ISO/IEC 10118. At the time of publication, the edition indicated was valid. All standards are subject to revision and parties to agreements based on this part of ISO/IEC 10118 are encouraged to investigate the possibility of applying the most recent edition of the standard indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO/IEC 10118-1: 1994, *Information technology — Security techniques — Hash-functions — Part 1: General*.

3 Definitions

For the purposes of this part of ISO/IEC 10118, the definitions given in ISO/IEC 10118-1 and the following definitions apply.

3.1 block: A bit-string of length L_1 , i.e. the length

of the first input to the round-function.

3.2 hash-function identifier: A byte identifying a specific hash-function.

3.3 round-function: A function $\phi(.,.)$ that transforms two binary strings of lengths L_1 and L_2 to a binary string of length L_2 . It is used iteratively as part of a hash-function, where it combines a data string of length L_1 with the previous output of length L_2 .

3.4 word: A string of 32 bits.

4 Symbols and notation

This part of ISO/IEC 10118 makes use of the following symbols and notation defined in ISO/IEC 10118-1.

D A data string to be input to the hash-function.

H Hash-code.

IV Initializing value.

L_X Length (in bits) of a bit-string X .

$X \oplus Y$ Exclusive-or of bit-strings X and Y .

For the purpose of this Part of ISO/IEC 10118, the following symbols and notation apply:

a_i, a'_i Sequences of indices used in specifying a round-function.

B_i A byte.

C_i, C'_i Constant words used in the round-functions.

D_i A block derived from the data-string after the padding process.

f_i, g_i Functions taking three words as input and producing a single word as output, used in specifying round-functions.

H_i A string of L_2 bits which is used in the hashing operation to store an intermediate result.

L_1 The length (in bits) of the first of the two input strings to the round-function ϕ .

L_2 The length (in bits) of the second of the two input strings to the round-function ϕ , of the output string from the round-function ϕ , and of IV .

q The number of blocks in the data string after the padding and splitting processes.

$S^n()$ The operation of 'circular left shift' by n bit positions, i.e. if A is a word and n is a non-negative integer then $S^n(A)$ denotes the word obtained by left-shifting the contents of A by n places in a cyclic fashion.

t_i, t'_i Shift-values used in specifying a round-function.

W, X_i, X'_i, Y_i, Z_i Words used to store the results of intermediate computations.

ϕ A round-function, i.e. if X, Y are bit-strings of lengths L_1 and L_2 respectively, then $\phi(X, Y)$ is the string obtained by applying ϕ to X and Y .

\wedge The bit-wise logical AND operation on bit-strings, i.e. if A, B are words then $A \wedge B$ is the word equal to the bit-wise logical AND of A and B .

\vee The bit-wise logical OR operation on bit-strings, i.e. if A, B are words then $A \vee B$ is the word equal to the bit-wise logical OR of A and B .

\neg The bit-wise logical NOT operation on a bit-string, i.e. if A is a word then $\neg A$ is the word equal to the bit-wise logical NOT of A .

\oplus The modulo 2^{32} addition operation, i.e. if A, B are words then $A \oplus B$ is the word obtained by treating A and B as the binary representations of integers and computing their sum modulo 2^{32} , where the result is constrained to lie between 0 and $2^{32} - 1$ inclusive.

$:=$ A symbol denoting the 'set equal to' operation used in procedural specifications of round-functions, where it indicates that the word on the left side of the symbol shall be made equal to the value of the expression on the right side of the symbol.

5 Requirements

Users who wish to employ a hash-function from this part of ISO/IEC 10118 shall select:

- one of the dedicated hash-functions specified below; and
- the length L_H of the hash-code H .

NOTE 1 — The first and second dedicated hash-functions are defined so as to facilitate software implementations for 'little-endian' computers, i.e. where the lowest-addressed byte in a word is interpreted as the least significant; conversely, the third round-function is defined so as to facilitate software implementations for 'big-endian' computers, i.e. where the lowest-addressed byte in a word is interpreted as the most significant. However, by adjusting the definition appropriately, any of the round-functions can be implemented on a 'big-endian' or a 'little-endian' computer. All the hash-functions defined in this part of ISO/IEC 10118 take a bit-string as input and give a bit-string as output; this is independent of the internal byte-ordering convention used within each hash-function.

NOTE 2 — The choice of L_H affects the security of the hash-function. All of the hash-functions specified in this part of ISO/IEC 10118 are believed to be collision-resistant hash-functions in environments where performing $2^{L_H/2}$ hash-code computations is deemed to be computationally infeasible.

6 Model for dedicated hash-functions

6.1 General

The hash-functions specified in this standard require the use of a round-function ϕ . In subsequent clauses of this part of ISO/IEC 10118, three alternatives for the function ϕ are specified.

The hash-functions which are specified in this standard provide hash-codes of length L_H , where L_H is less than or equal to the value of L_2 for the round-function ϕ being used.

In the specifications of the hash-functions in this part of ISO/IEC 10118, it is assumed that the padded data-string input to the hash-function is in the form of a sequence of bytes. If the padded data-string is in the form of a sequence of $8n$ bits, $x_0, x_1, \dots, x_{8n-1}$, then it shall be interpreted as a sequence of n bytes, B_0, B_1, \dots, B_{n-1} , in the following way. Each group of eight consecutive bits is considered as a byte, the first bit of a group being the most significant bit of that byte. Hence

$$B_i = 2^7 x_{8i} + 2^6 x_{8i+1} + \dots + x_{8i+7}$$

for every i ($0 \leq i < n$).

Identifiers are defined for each of the three dedicated hash-functions specified in this standard. The hash-function identifiers for the dedicated hash-functions specified in clauses 7, 8 and 9 are equal to 31, 32, and 33 (hexadecimal) respectively. The range of values from 34 to 3F (hexadecimal) are reserved for future use as hash-function identifiers by this part of ISO/IEC 10118.

6.2 Hashing operation

Let ϕ be a round-function and IV be an initializing value of length L_2 . For the hash-functions specified in this part of ISO/IEC 10118, the value of the IV shall be fixed for a given round-function ϕ .

The hash-code H of the data D shall be calculated in four steps.

6.2.1 Step 1 (padding)

The data string D is padded in order to ensure that its length is a multiple of L_1 . Specific instances of padding methods are specified in subsequent clauses of this part of ISO/IEC 10118.

6.2.2 Step 2 (splitting)

The padded version of the data string D is split into L_1 -bit blocks D_1, D_2, \dots, D_q , where D_1 represents

the first L_1 bits of the padded version of D , D_2 represents the next L_1 bits, and so on. The Padding and Splitting Processes are illustrated in Figure 1.

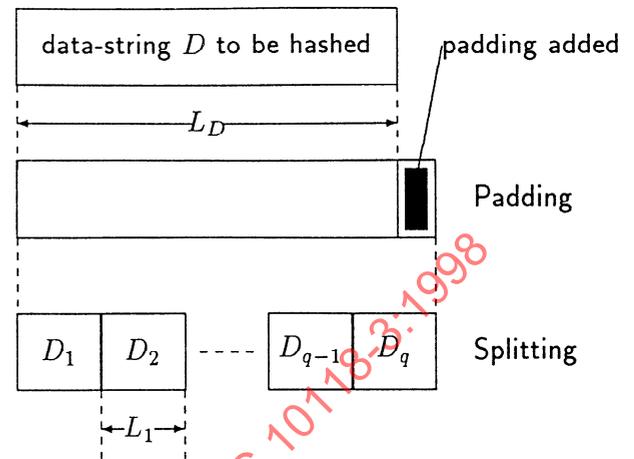


Figure 1: Padding & splitting processes

6.2.3 Step 3 (iteration)

Let D_1, D_2, \dots, D_q be the L_1 -bit blocks of the data after padding and splitting. Let H_0 be a bit-string equal to IV . The L_2 -bit strings H_1, H_2, \dots, H_q are calculated iteratively in the following way.

for i from 1 to q :

$$H_i = \phi(D_i, H_{i-1});$$

The Iteration Process is illustrated in Figure 2.

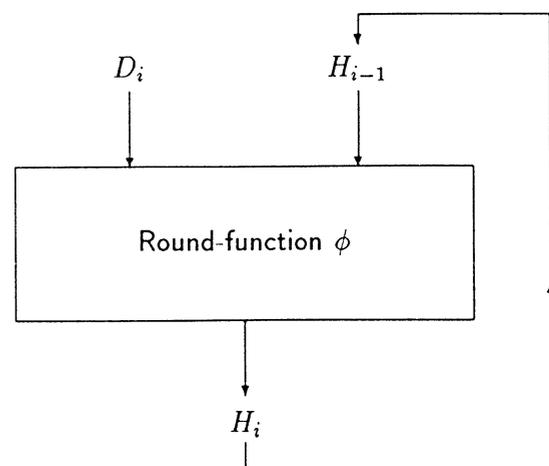


Figure 2: The Iteration Process

6.2.4 Step 4 (truncation)

The hash-code H is derived by taking the leftmost L_H bits of the final L_2 -bit output string H_q .

7 Dedicated Hash-Function 1

NOTE — This clause contains a description of the round-function, initializing value and padding method for RIPEMD-160, [3].

7.1 General

In this clause we specify a padding method, an initializing value, and a round-function for use in the general model described in this part of ISO/IEC 10118. The padding method, initializing value and round-function specified here, when used in the above general model, together define Dedicated Hash-Function 1. This dedicated hash-function can be applied to all data strings D containing at most $2^{64} - 1$ bits.

The ISO/IEC hash-function identifier for Dedicated Hash-Function 1 is equal to 31 (hexadecimal).

7.2 Parameters, functions and constants

7.2.1 Parameters

For this hash-function $L_1 = 512$ and $L_2 = 160$.

7.2.2 Byte ordering convention

In the specification of the round-function of clause 7 it is assumed that the block input to the round-function is in the form of a sequence of words, each 512-bit block being made up of 16 such words. A sequence of 64 bytes, B_0, B_1, \dots, B_{63} , shall be interpreted as a sequence of 16 words, Z_0, Z_1, \dots, Z_{15} , in the following way. Each group of four consecutive bytes is considered as a word, the first byte of a word being the least significant byte of that word. Hence

$$Z_i = 2^{24} B_{4i+3} + 2^{16} B_{4i+2} + 2^8 B_{4i+1} + B_{4i}, \quad (0 \leq i \leq 15).$$

To convert the hash-code from a sequence of words to a byte-sequence, the inverse process shall be followed.

NOTE — The byte-ordering specified here is different from that of subclause 9.2.2.

7.2.3 Functions

To facilitate software implementation, the round-function ϕ is described in terms of operations on words. A sequence of functions g_0, g_1, \dots, g_{79} is

used in this round-function, where each function g_i , $0 \leq i \leq 79$, takes three words X_0, X_1 and X_2 as input and produces a single word as output.

The functions g_i are defined as follows:

$$g_i(X_0, X_1, X_2) = X_0 \oplus X_1 \oplus X_2, \quad (0 \leq i \leq 15),$$

$$g_i(X_0, X_1, X_2) = (X_0 \wedge X_1) \vee (\neg X_0 \wedge X_2), \quad (16 \leq i \leq 31),$$

$$g_i(X_0, X_1, X_2) = (X_0 \vee \neg X_1) \oplus X_2, \quad (32 \leq i \leq 47),$$

$$g_i(X_0, X_1, X_2) = (X_0 \wedge X_2) \vee (X_1 \wedge \neg X_2), \quad (48 \leq i \leq 63),$$

$$g_i(X_0, X_1, X_2) = X_0 \oplus (X_1 \vee \neg X_2), \quad (64 \leq i \leq 79).$$

7.2.4 Constants

Two sequences of constant words C_0, C_1, \dots, C_{79} and $C'_0, C'_1, \dots, C'_{79}$ are used in this round-function. In a hexadecimal representation (where the most significant bit corresponds to the left-most bit) these are defined as follows:

$$C_i = 00000000, \quad (0 \leq i \leq 15),$$

$$C_i = 5A827999, \quad (16 \leq i \leq 31),$$

$$C_i = 6ED9EBA1, \quad (32 \leq i \leq 47),$$

$$C_i = 8F1BBCDC, \quad (48 \leq i \leq 63),$$

$$C_i = A953FD4E, \quad (64 \leq i \leq 79),$$

$$C'_i = 50A28BE6, \quad (0 \leq i \leq 15),$$

$$C'_i = 5C4DD124, \quad (16 \leq i \leq 31),$$

$$C'_i = 6D703EF3, \quad (32 \leq i \leq 47),$$

$$C'_i = 7A6D76E9, \quad (48 \leq i \leq 63),$$

$$C'_i = 00000000, \quad (64 \leq i \leq 79).$$

Two sequences of 80 shift-values are used in this round-function, where each shift-value is between 5 and 15. We denote these sequences by $(t_0, t_1, \dots, t_{79})$ and $(t'_0, t'_1, \dots, t'_{79})$. A further two sequences of 80 indices are used in this round-function, where each value in the sequence is between 0 and 15. We denote these sequences as $(a_0, a_1, \dots, a_{79})$, and $(a'_0, a'_1, \dots, a'_{79})$. All four sequences are defined in the following table.

i	0	1	2	3	4	5	6	7
t_i	11	14	15	12	5	8	7	9
t'_i	8	9	9	11	13	15	15	5
a_i	0	1	2	3	4	5	6	7
a'_i	5	14	7	0	9	2	11	4
i	8	9	10	11	12	13	14	15
t_i	11	13	14	15	6	7	9	8
t'_i	7	7	8	11	14	14	12	6
a_i	8	9	10	11	12	13	14	15
a'_i	13	6	15	8	1	10	3	12
i	16	17	18	19	20	21	22	23
t_i	7	6	8	13	11	9	7	15
t'_i	9	13	15	7	12	8	9	11
a_i	7	4	13	1	10	6	15	3
a'_i	6	11	3	7	0	13	5	10
i	24	25	26	27	28	29	30	31
t_i	7	12	15	9	11	7	13	12
t'_i	7	7	12	7	6	15	13	11
a_i	12	0	9	5	2	14	11	8
a'_i	14	15	8	12	4	9	1	2
i	32	33	34	35	36	37	38	39
t_i	11	13	6	7	14	9	13	15
t'_i	9	7	15	11	8	6	6	14
a_i	3	10	14	4	9	15	8	1
a'_i	15	5	1	3	7	14	6	9
i	40	41	42	43	44	45	46	47
t_i	14	8	13	6	5	12	7	5
t'_i	12	13	5	14	13	13	7	5
a_i	2	7	0	6	13	11	5	12
a'_i	11	8	12	2	10	0	4	13
i	48	49	50	51	52	53	54	55
t_i	11	12	14	15	14	15	9	8
t'_i	15	5	8	11	14	14	6	14
a_i	1	9	11	10	0	8	12	4
a'_i	8	6	4	1	3	11	15	0
i	56	57	58	59	60	61	62	63
t_i	9	14	5	6	8	6	5	12
t'_i	6	9	12	9	12	5	15	8
a_i	13	3	7	15	14	5	6	2
a'_i	5	12	2	13	9	7	10	14
i	64	65	66	67	68	69	70	71
t_i	9	15	5	11	6	8	13	12
t'_i	8	5	12	9	12	5	14	6
a_i	4	0	5	9	7	12	2	10
a'_i	12	15	10	4	1	5	8	7

i	72	73	74	75	76	77	78	79
t_i	5	12	13	14	11	8	5	6
t'_i	8	13	6	5	15	13	11	11
a_i	14	1	3	8	11	6	15	13
a'_i	6	2	13	14	0	3	9	11

7.2.5 Initializing Value

For this round-function the initializing value, IV , shall always be the following 160-bit string, represented here as a sequence of five words Y_0, Y_1, Y_2, Y_3, Y_4 in a hexadecimal representation, where Y_0 represents the left-most 32 of the 160 bits:

$$Y_0 = 67452301,$$

$$Y_1 = \text{EFCDAB89},$$

$$Y_2 = 98BADCFE,$$

$$Y_3 = 10325476,$$

$$Y_4 = \text{C3D2E1F0}.$$

7.3 Padding method

The data string D needs to be padded to make it contain a number of bits which is an integer multiple of 512. The padding procedure operates as follows:

1. D is concatenated with a single '1' bit.
2. The result of the previous step is concatenated with between zero and 511 '0' bits such that the length (in bits) of the resultant string is congruent to 448 modulo 512. More explicitly, if the original length of D is L_D , and letting r be the remainder when L_D is divided by 512, then the number of concatenated zeros is equal to either $447 - r$ (if $r \leq 447$) or $959 - r$ (if $r > 447$). The result will be a bit string whose length will be 64 bits short of an integer multiple of 512 bits.
3. Divide the 64-bit binary representation of L_D into two 32-bit strings, one representing the 'most significant half' of L_D and the other the 'least significant half'. Now concatenate the string resulting from the previous step with these two 32-bit strings, with the 'least significant half' preceding the 'most significant half'.

In the description of the round-function which follows, each 512-bit data block D_i , $1 \leq i \leq q$, is treated as a sequence of 16 words, Z_0, Z_1, \dots, Z_{15} , where Z_0 corresponds to the left-most 32 bits of D_i .

7.4 Description of the round-function

The round-function ϕ operates as follows. Note that, in this description, we use the symbols $W, X_0, X_1, X_2, X_3, X_4, X'_0, X'_1, X'_2, X'_3, X'_4$ to denote eleven distinct words which contain values required in the computations.

1. Suppose the 512-bit (first) input to ϕ is contained in Z_0, Z_1, \dots, Z_{15} , where Z_0 contains the left-most 32 of the 512 bits. Suppose also that the 160-bit (second) input to ϕ is contained in five words, Y_0, Y_1, Y_2, Y_3, Y_4 .
2. Let $X_0 := Y_0, X_1 := Y_1, X_2 := Y_2, X_3 := Y_3$ and $X_4 := Y_4$.
3. Let $X'_0 := Y_0, X'_1 := Y_1, X'_2 := Y_2, X'_3 := Y_3$ and $X'_4 := Y_4$.
4. For $i := 0$ to 79 do the following four steps in the order specified:

- (a) $W := S^{t_i}(X_0 \oplus g_i(X_1, X_2, X_3) \oplus Z_{a_i} \oplus C_i) \oplus X_4$;
- (b) $X_0 := X_4; X_4 := X_3; X_3 := S^{10}(X_2); X_2 := X_1; X_1 := W$;
- (c) $W := S^{t'_i}(X'_0 \oplus g_{79-i}(X'_1, X'_2, X'_3) \oplus Z_{a'_i} \oplus C'_i) \oplus X'_4$;
- (d) $X'_0 := X'_4; X'_4 := X'_3; X'_3 := S^{10}(X'_2); X'_2 := X'_1; X'_1 := W$;

5. Let

$$\begin{aligned} W &:= Y_0, \\ Y_0 &:= Y_1 \oplus X_2 \oplus X'_3, \\ Y_1 &:= Y_2 \oplus X_3 \oplus X'_4, \\ Y_2 &:= Y_3 \oplus X_4 \oplus X'_0, \\ Y_3 &:= Y_4 \oplus X_0 \oplus X'_1, \\ Y_4 &:= W \oplus X_1 \oplus X'_2. \end{aligned}$$

6. The five words Y_0, Y_1, Y_2, Y_3, Y_4 represent the output of the round-function ϕ . After the final iteration of the round-function, the five words Y_0, Y_1, Y_2, Y_3, Y_4 shall be converted to a sequence of 20 bytes using the inverse of the procedure specified in 7.2.2, and where Y_0 shall yield the first four bytes, Y_1 the next four bytes, and so on. Thus the first (left-most) byte will correspond to the least significant byte of Y_0 , and

the 20th (right-most) byte will correspond to the most significant byte of Y_4 . The 20 bytes shall be converted to a string of 160 bits using the inverse of the procedure specified in 6.1, i.e. the first (left-most) bit will correspond to the most significant bit of the first (left-most) byte, and the 160th (right-most) bit will correspond to the least significant bit of the 20th (right-most) byte.

8 Dedicated Hash-Function 2

NOTE — This clause contains a description of the round-function, initializing value and padding method for RIPEMD-128, [3].

This hash-function should only be used in applications where a hash-code containing 128 bits or less is considered adequately secure.

8.1 General

In this clause we specify a padding method, an initializing value, and a round-function for use in the general model described in this part of ISO/IEC 10118. The padding method, initializing value and round-function specified here, when used in the above general model, together define Dedicated Hash-Function 2. This dedicated hash-function can be applied to all data strings D containing at most $2^{64} - 1$ bits.

The ISO/IEC hash-function identifier for Dedicated Hash-Function 2 is equal to 32 (hexadecimal).

8.2 Parameters, functions and constants

8.2.1 Parameters

For this hash-function $L_1 = 512$ and $L_2 = 128$.

8.2.2 Byte ordering convention

The byte ordering convention for this hash-function is the same as that for the hash-function of clause 7.

8.2.3 Functions

To facilitate software implementation, the round-function ϕ is described in terms of operations on words. A sequence of functions g_0, g_1, \dots, g_{63} is used in this round-function, where each function g_i , $0 \leq i \leq 63$, takes three words X_0, X_1 and X_2 as input and produces a single word as output.

The functions g_i are defined to be the same as the first 64 of the functions defined in subclause 7.2.3.

8.2.4 Constants

Two sequences of constant words C_0, C_1, \dots, C_{63} and $C'_0, C'_1, \dots, C'_{63}$ are used in this round-function. In a hexadecimal representation (where the most significant bit corresponds to the left-most bit) these are defined as follows:

$$\begin{aligned} C_i &= 00000000, & (0 \leq i \leq 15), \\ C_i &= 5A827999, & (16 \leq i \leq 31), \\ C_i &= 6ED9EBA1, & (32 \leq i \leq 47), \\ C_i &= 8F1BBCDC, & (48 \leq i \leq 63), \end{aligned}$$

$$\begin{aligned} C'_i &= 50A28BE6, & (0 \leq i \leq 15), \\ C'_i &= 5C4DD124, & (16 \leq i \leq 31), \\ C'_i &= 6D703EF3, & (32 \leq i \leq 47), \\ C'_i &= 00000000, & (48 \leq i \leq 63). \end{aligned}$$

Two sequences of 64 shift-values are also used in this round-function, where each shift-value is between 5 and 15. We denote these sequences by $(t_0, t_1, \dots, t_{63})$ and $(t'_0, t'_1, \dots, t'_{63})$, and they are defined to be equal to the first 64 values of the corresponding sequences defined in subclause 7.2.4.

Finally, two further sequences of 64 indices are used in this round-function, where each value in the sequence is between 0 and 15. We denote these sequences by $(a_0, a_1, \dots, a_{63})$, and $(a'_0, a'_1, \dots, a'_{63})$, and they are defined to be equal to the first 64 values of the corresponding sequences defined in subclause 7.2.4.

8.2.5 Initializing Value

For this hash-function the initializing value, IV , shall always be the following 128-bit string, represented here as a sequence of four words Y_0, Y_1, Y_2, Y_3 in a hexadecimal representation, where Y_0 represents the left-most 32 of the 128 bits:

$$\begin{aligned} Y_0 &= 67452301, \\ Y_1 &= EFCDA889, \\ Y_2 &= 98BADCFE, \\ Y_3 &= 10325476. \end{aligned}$$

8.3 Padding method

The padding method to be used with this hash-function shall be the same as the padding method defined in subclause 7.3.

8.4 Description of the round-function

The round-function ϕ operates as follows. Note that, in this description, we use the symbols $W, X_0, X_1, X_2, X_3, X'_0, X'_1, X'_2, X'_3$ to denote nine distinct words which contain values required in the computations.

1. Suppose the 512-bit (first) input to ϕ is contained in Z_0, Z_1, \dots, Z_{15} , where Z_0 contains the left-most 32 of the 512 bits. Suppose also that the 128-bit (second) input to ϕ is contained in four words, Y_0, Y_1, Y_2, Y_3 .
2. Let $X_0 := Y_0$, $X_1 := Y_1$, $X_2 := Y_2$ and $X_3 := Y_3$.
3. Let $X'_0 := Y_0$, $X'_1 := Y_1$, $X'_2 := Y_2$ and $X'_3 := Y_3$.
4. For $i := 0$ to 63 do the following four steps in the order specified:

$$(a) W := S^{t_i}(X_0 \oplus g_i(X_1, X_2, X_3) \oplus Z_{a_i} \oplus C_i);$$

$$(b) X_0 := X_3; X_3 := X_2; X_2 := X_1; X_1 := W;$$

$$(c) W := S^{t'_i}(X'_0 \oplus g_{63-i}(X'_1, X'_2, X'_3) \oplus Z_{a'_i} \oplus C'_i);$$

$$(d) X'_0 := X'_3; X'_3 := X'_2; X'_2 := X'_1; X'_1 := W;$$

5. Let

$$W := Y_0,$$

$$Y_0 := Y_1 \oplus X_2 \oplus X'_3,$$

$$Y_1 := Y_2 \oplus X_3 \oplus X'_0,$$

$$Y_2 := Y_3 \oplus X_0 \oplus X'_1,$$

$$Y_3 := W \oplus X_1 \oplus X'_2.$$

6. The four words Y_0, Y_1, Y_2, Y_3 represent the output of the round-function ϕ . After the final iteration of the round-function, the four words Y_0, Y_1, Y_2, Y_3 shall be converted to a sequence of 16 bytes using the inverse of the procedure specified in 7.2.2, and where Y_0 shall yield the first four bytes, Y_1 the next four bytes, and so on. Thus the first (left-most) byte will correspond to the least significant byte of Y_0 , and the 16th (right-most) byte will correspond to the most significant byte of Y_3 . The 16 bytes shall be converted to a string of 128 bits using the inverse of the procedure specified in 6.1, i.e. the

first (left-most) bit will correspond to the most significant bit of the first (left-most) byte, and the 128th (right-most) bit will correspond to the least significant bit of the 16th (right-most) byte.

9 Dedicated Hash-Function 3

NOTE — This clause contains a description of the round-function, initializing value and padding method for SHA-1 (the US NIST 'Secure Hash Algorithm'), [2].

9.1 General

In this clause we specify a padding method, an initializing value, and a round-function for use in the general model described in this part of ISO/IEC 10118. The padding method, initializing value and round-function specified here, when used in the above general model, together define Dedicated Hash-Function 3. This dedicated hash-function can be applied to all data strings D containing at most $2^{64} - 1$ bits.

The ISO/IEC hash-function identifier for Dedicated Hash-Function 3 is equal to 33 (hexadecimal).

9.2 Parameters, functions and constants

9.2.1 Parameters

For this hash-function $L_1 = 512$ and $L_2 = 160$.

9.2.2 Byte ordering convention

In the specification of the round-function of clause 9 it is assumed that the block input to the round-function is in the form of a sequence of words, each 512-bit block being made up of 16 such words. A sequence of 64 bytes, B_0, B_1, \dots, B_{63} , shall be interpreted as a sequence of 16 words, Z_0, Z_1, \dots, Z_{15} , in the following way. Each group of four consecutive bytes is considered as a word, the first byte of a word being the most significant byte of that word. Hence

$$Z_i = 2^{24}B_{4i} + 2^{16}B_{4i+1} + 2^8B_{4i+2} + B_{4i+3}, \quad (0 \leq i \leq 15).$$

To convert the hash-code from a sequence of words to a sequence of bytes, the inverse process shall be followed.

NOTE — The byte-ordering specified here is different from that of subclause 7.2.2.

9.2.3 Functions

To facilitate software implementation, the round-function ϕ is described in terms of operations on words. A sequence of functions f_0, f_1, \dots, f_{79} is used in this round-function, where each function f_i , $0 \leq i \leq 79$, takes three words X_0, X_1 and X_2 as input and produces a single word as output.

The functions f_i are defined as follows:

$$f_i(X_0, X_1, X_2) = (X_0 \wedge X_1) \vee (\neg X_0 \wedge X_2), \quad (0 \leq i \leq 19),$$

$$f_i(X_0, X_1, X_2) = X_0 \oplus X_1 \oplus X_2, \quad (20 \leq i \leq 39),$$

$$f_i(X_0, X_1, X_2) = (X_0 \wedge X_1) \vee (X_0 \wedge X_2) \vee (X_1 \wedge X_2), \quad (40 \leq i \leq 59),$$

$$f_i(X_0, X_1, X_2) = X_0 \oplus X_1 \oplus X_2, \quad (60 \leq i \leq 79).$$

9.2.4 Constants

A sequence of constant words C_0, C_1, \dots, C_{79} is used in this round-function. In a hexadecimal representation (where the most significant bit corresponds to the left-most bit) these are defined as follows:

$$C_i = 5A827999, \quad (0 \leq i \leq 19),$$

$$C_i = 6ED9EBA1, \quad (20 \leq i \leq 39),$$

$$C_i = 8F1BBCDC, \quad (40 \leq i \leq 59),$$

$$C_i = CA62C1D6, \quad (60 \leq i \leq 79).$$

9.2.5 Initializing Value

For this round-function the initializing value, IV , shall always be the following 160-bit string, represented here as a sequence of five words Y_0, Y_1, Y_2, Y_3, Y_4 in a hexadecimal representation, where Y_0 represents the left-most 32 of the 160 bits:

$$Y_0 = 67452301,$$

$$Y_1 = EFCDB89,$$

$$Y_2 = 98BADCFE,$$

$$Y_3 = 10325476,$$

$$Y_4 = C3D2E1F0.$$

9.3 Padding method

The data string D needs to be padded to make it contain a number of bits which is an integer multiple of 512. The padding procedure operates as follows:

1. D is concatenated with a single '1' bit.

2. The result of the previous step is concatenated with between zero and 511 '0' bits such that the length (in bits) of the resultant string is congruent to 448 modulo 512. More explicitly, if the original length of D is L_D , and letting r be the remainder when L_D is divided by 512, then the number of concatenated zeros is equal to either $447 - r$ (if $r \leq 447$) or $959 - r$ (if $r > 447$). The result will be a bit string whose length will be 64 bits short of an integer multiple of 512 bits.
3. Concatenate the string resulting from the previous step with the 64-bit binary representation of L_D , most significant bit first.

In the description of the round-function which follows, each 512-bit data block D_i , $1 \leq i \leq q$, is treated as a sequence of 16 words, Z_0, Z_1, \dots, Z_{15} , where Z_0 corresponds to the left-most 32 bits of D_i .

9.4 Description of the round-function

The round-function ϕ operates as follows. Note that, in this description, we use the symbols $W, X_0, X_1, X_2, X_3, X_4, Z_0, Z_1, \dots, Z_{79}$ to denote 86 distinct words which contain values required in the computations.

1. Suppose the 512-bit (first) input to ϕ is contained in Z_0, Z_1, \dots, Z_{15} , where Z_0 contains the left-most 32 of the 512 bits. Suppose also that the 160-bit (second) input to ϕ is contained in five words, Y_0, Y_1, Y_2, Y_3, Y_4 .
2. For $i = 16$ to 79 let

$$Z_i := S^1(Z_{i-3} \oplus Z_{i-8} \oplus Z_{i-14} \oplus Z_{i-16}).$$
3. Let $X_0 := Y_0$, $X_1 := Y_1$, $X_2 := Y_2$, $X_3 := Y_3$ and $X_4 := Y_4$.
4. For $i = 0$ to 79 do the following two steps
 - (a) $W := S^5(X_0) \uplus f_i(X_1, X_2, X_3) \uplus X_4 \uplus Z_i \uplus C_i$;
 - (b) $X_4 := X_3$; $X_3 := X_2$; $X_2 := S^{30}(X_1)$;
 $X_1 := X_0$; $X_0 := W$.
5. Let $Y_0 := Y_0 \uplus X_0$, $Y_1 := Y_1 \uplus X_1$, $Y_2 := Y_2 \uplus X_2$, $Y_3 := Y_3 \uplus X_3$ and $Y_4 := Y_4 \uplus X_4$.
6. The five words Y_0, Y_1, Y_2, Y_3, Y_4 represent the output of the round-function ϕ . After the final iteration of the round-function, the five words

Y_0, Y_1, Y_2, Y_3, Y_4 shall be converted to a sequence of 20 bytes using the inverse of the procedure specified in 9.2.2, and where Y_0 shall yield the first four bytes, Y_1 the next four bytes, and so on. Thus the first (left-most) byte will correspond to the most significant byte of Y_0 , and the 20th (right-most) byte will correspond to the least significant byte of Y_4 . The 20 bytes shall be converted to a string of 160 bits using the inverse of the procedure specified in 6.1, i.e. the first (left-most) bit will correspond to the most significant bit of the first (left-most) byte, and the 160th (right-most) bit will correspond to the least significant bit of the 20th (right-most) byte.

Annex A (informative)

Examples

A.1 General

This annex gives examples for the computation of Dedicated Hash-Functions 1, 2 and 3. Nine examples of hash-code calculation are given for each of the hash-functions. For each of the hash-functions, intermediate values derived during the hash-function's operation are given for examples numbers 3 and 8.

A.2 Dedicated Hash-Function 1

Throughout this annex we refer to ASCII coding of data strings; this is equivalent to coding using ISO 646.

NOTE — Reference [3] contains a pseudocode description of Dedicated Hash-Function 1.

A.2.1 Example 1

In this example the data-string is the empty string, i.e. the string of length zero.

The hash-code is the following 160-bit string.

9C 11 85 A5 C5 E9 FC 54 61 28 08 97 7E E8 F5 48 B2 25 8D 31

A.2.2 Example 2

In this example the data-string consists of a single byte, namely the ASCII-coded version of the letter 'a'.

The hash-code is the following 160-bit string.

0B DC 9D 2D 25 6B 3E E9 DA AE 34 7B E6 F4 DC 83 5A 46 7F FE

A.2.3 Example 3

In this example the data-string is the three-byte string consisting of the ASCII-coded version of 'abc'. This is equivalent to the bit-string: '01100001 01100010 01100011'.

After the padding process, the single 16-word block derived from the data-string is as follows.

80636261	00000000	00000000	00000000	00000000	00000000	00000000	00000000
00000000	00000000	00000000	00000000	00000000	00000000	00000018	00000000

The following are (hexadecimal representations of) the successive values of the variables $X_0, X_1, X_2, X_3, X_4, X'_0, X'_1, X'_2, X'_3, X'_4$.

67452301, EFCDAB89, 98BADCFE, 10325476, C3D2E1F0, 67452301, EFCDAB89, 98BADCFE, 10325476, C3D2E1F0
 C3D2E1F0, 3115FC67, EFCDAB89, EB73FA62, 10325476, C3D2E1F0, DDD63FB8, EFCDAB89, EB73FA62, 10325476
 10325476, B41192D5, 3115FC67, 36AE27BF, EB73FA62, 10325476, 322E7AE3, DDD63FB8, 36AE27BF, EB73FA62
 EB73FA62, 3A35DC50, B41192D5, 57F19CC4, 36AE27BF, EB73FA62, 883EE903, 322E7AE3, 58FEE377, 36AE27BF

36AE27BF, D3786413, 3A35DC50, 464B56D0, 57F19CC4, 36AE27BF, 92B2B79B, 883EE903, B9EB8CC8, 58FEE377
 57F19CC4, 0E946720, D3786413, D77140E8, 464B56D0, 58FEE377, F9091FF2, 92B2B79B, FBA40E20, B9EB8CC8
 464B56D0, D52BF632, 0E946720, E1904F4D, D77140E8, B9EB8CC8, E5B09992, F9091FF2, CADE6E4A, FBA40E20
 D77140E8, 150BD8A8, D52BF632, 519C803A, E1904F4D, FBA40E20, 8B2D9FB3, E5B09992, 247FCBE4, CADE6E4A
 E1904F4D, 3D6F601F, 150BD8A8, AFD8CB54, 519C803A, CADE6E4A, E755F422, 8B2D9FB3, C2664B96, 247FCBE4
 519C803A, B7B60384, 3D6F601F, 2F62A054, AFD8CB54, 247FCBE4, 5922D09E, E755F422, B67ECE2C, C2664B96
 AFD8CB54, B85A0A3F, B7B60384, BD807CF5, 2F62A054, C2664B96, CF24E72C, 5922D09E, 57D08B9D, B67ECE2C
 2F62A054, 7F8B38E5, B85A0A3F, D80E12DE, BD807CF5, B67ECE2C, CA6A1C75, CF24E72C, 8B427964, 57D08B9D
 BD807CF5, 9DAC4A95, 7F8B38E5, 6828FEE1, D80E12DE, 57D08B9D, 227F6D84, CA6A1C75, 939CB33C, 8B427964
 D80E12DE, BC05F46F, 9DAC4A95, 2CE395FE, 6828FEE1, 8B427964, 5D801685, 227F6D84, A871D729, 939CB33C
 6828FEE1, 1494F053, BC05F46F, B2925676, 2CE395FE, 939CB33C, B3C3F4D5, 5D801685, FDB61089, A871D729
 2CE395FE, 85861D02, 1494F053, 17D1BEF0, B2925676, A871D729, 3D16242D, B3C3F4D5, 005A1576, FDB61089
 B2925676, 597BF629, 85861D02, 53C14C52, 17D1BEF0, FDB61089, FF459078, 3D16242D, OFD356CF, 005A1576
 17D1BEF0, 6347EF78, 597BF629, 18740A16, 53C14C52, 005A1576, 927E40A8, FF459078, 5890B4F4, OFD356CF
 53C14C52, 45C8FA44, 6347EF78, EFD8A565, 18740A16, OFD356CF, ACBB994E, 927E40A8, 1641E3FD, 5890B4F4
 18740A16, AD2956AF, 45C8FA44, 1FBDE18D, EFD8A565, 5890B4F4, AD30AD24, ACBB994E, F902A249, 1641E3FD
 EFD8A565, 5EAF16B7, AD2956AF, 23E91117, 1FBDE18D, 1641E3FD, 6261732E, AD30AD24, EE653AB2, F902A249
 1FBDE18D, 41730D4B, 5EAF16B7, A55ABEB4, 23E91117, F902A249, 45ED27AF, 6261732E, C2B492B4, EE653AB2
 23E91117, FC0CCBD3, 41730D4B, BC5ADD7A, A55ABEB4, EE653AB2, 243C5668, 45ED27AF, 85CCB989, C2B492B4
 A55ABEB4, 042ECC93, FC0CCBD3, CC352D05, BC5ADD7A, C2B492B4, 82F89BD1, 243C5668, B49EBD17, 85CCB989
 BC5ADD7A, 4D4D4377, 042ECC93, 332F4FF0, CC352D05, 85CCB989, 5FC74686, 82F89BD1, F159A090, B49EBD17
 CC352D05, 5207002B, 4D4D4377, BB324C10, 332F4FF0, B49EBD17, B2720031, 5FC74686, E26F460B, F159A090
 332F4FF0, 388278F5, 5207002B, 350DDD35, BB324C10, F159A090, 58A100F8, B2720031, 1D1A197F, E26F460B
 BB324C10, 62879D70, 388278F5, 1C00AD48, 350DDD35, E26F460B, 5992068B, 58A100F8, C800C6C9, 1D1A197F
 350DDD35, A30A1FD9, 62879D70, 09E3D4E2, 1C00AD48, 1D1A197F, CC290DCA, 5992068B, 8403E162, C800C6C9
 1C00AD48, BDA2B31B, A30A1FD9, 1E75C18A, 09E3D4E2, C800C6C9, 863D625E, CC290DCA, 481A2D66, 8403E162
 09E3D4E2, F7211DEE, BDA2B31B, 287F668C, 1E75C18A, 8403E162, 6061B5A5, 863D625E, A4372B30, 481A2D66
 1E75C18A, B6A665C6, F7211DEE, 8ACC6EF6, 287F668C, 481A2D66, AA98ADB5, 6061B5A5, F5897A18, A4372B30
 287F668C, 2D30FA02, B6A665C6, 8477BBDC, 8ACC6EF6, A4372B30, 2999255A, AA98ADB5, 86D69581, F5897A18
 8ACC6EF6, C76D12F9, 2D30FA02, 99971ADA, 8477BBDC, F5897A18, 98237631, 2999255A, 62B6D6AA, 86D69581
 8477BBDC, 516F84DF, C76D12F9, C3E808B4, 99971ADA, 86D69581, 6C472A90, 98237631, 649568A6, 62B6D6AA
 99971ADA, F3FA5B05, 516F84DF, B44BE71D, C3E808B4, 62B6D6AA, 2EAD5672, 6C472A90, 8DD8C660, 649568A6
 C3E808B4, D539625E, F3FA5B05, BE137D45, B44BE71D, 649568A6, 2EAD5672, 1CAA41B1, 8DD8C660
 B44BE71D, D8500C99, D539625E, E96C17CF, BE137D45, 8DD8C660, 05286DFB, C5CB48BA, B559C8BA, 1CAA41B1
 BE137D45, 7ECDE5B2, D8500C99, E5897B54, E96C17CF, 1CAA41B1, 88396DD2, 05286DFB, 2D22EB17, B559C8BA
 E96C17CF, 681D30B9, 7ECDE5B2, 40326761, E5897B54, B559C8BA, 333F2212, 88396DD2, A1B7EC14, 2D22EB17
 E5897B54, 960F7BFD, 681D30B9, 3796C9FB, 40326761, 2D22EB17, C699295B, 333F2212, E5B74A20, A1B7EC14
 40326761, 6770E498, 960F7BFD, 74C2E5A0, 3796C9FB, A1B7EC14, BFD68874, C699295B, FC8848CC, E5B74A20
 3796C9FB, 75EB06C5, 6770E498, 3DEFF658, 74C2E5A0, E5B74A20, BDDF3474, BFD68874, 64A56F1A, FC8848CC
 74C2E5A0, 14FA827A, 75EB06C5, C392619D, 3DEFF658, FC8848CC, 8CBC87E9, BDDF3474, 5A21D2FF, 64A56F1A
 3DEFF658, 804B0068, 14FA827A, AC1B15D7, C392619D, 64A56F1A, CDDA6EBF, 8CBC87E9, 7CD1D2F7, 5A21D2FF
 C392619D, 475BA81B, 804B0068, EA09E853, AC1B15D7, 5A21D2F7, 656C7DA3, CDDA6EBF, F21FA632, 7CD1D2F7
 AC1B15D7, D26BC25D, 475BA81B, 2C01A201, EA09E853, 7CD1D2F7, 76D66CA3, 656C7DA3, 69BAFF37, F21FA632
 EA09E853, DBC5A2CB, D26BC25D, 6EA06D1D, 2C01A201, F21FA632, C9B17F72, 76D66CA3, B1F68D95, 69BAFF37
 2C01A201, 77367F5E, DBC5A2CB, AF097749, 6EA06D1D, 69BAFF37, 65A60151, C9B17F72, 59B28DDB, B1F68D95
 6EA06D1D, 8155A6B4, 77367F5E, 168B2F6F, AF097749, B1F68D95, 33F3AC81, 65A60151, C5FDCB26, 59B28DDB
 AF097749, 090C4D38, 8155A6B4, D9FD79DC, 168B2F6F, 59B28DDB, 9BFB827D, 33F3AC81, 98054596, C5FDCB26
 168B2F6F, 9762713B, C90C4D38, 569AD205, D9FD79DC, C5FDCB26, DDC8130E, 9BFB827D, CEB204CF, 98054596
 D9FD79DC, 7EBF9C32, 9762713B, 3134E324, 569AD205, 98054596, C24C2C79, DDC8130E, EE09F66F, CEB204CF
 569AD205, 20EFFA01, 7EBF9C32, 89C4EE5D, 3134E324, CEB204CF, F255847E, C24C2C79, 204C3B77, EE09F66F
 3134E324, 75B7117F, 20EFFA01, FE70C9FA, 89C4EE5D, EE09F66F, DCD63949, F255847E, 30B1E709, 204C3B77
 89C4EE5D, A96BE4C7, 75B7117F, BFE80483, FE70C9FA, 204C3B77, 5B99238D, DCD63949, 5611FBC9, 30B1E709
 FE70C9FA, 5E3201FC, A96BE4C7, DC45FDD6, BFE80483, 30B1E709, B43484F4, 5B99238D, 58E52773, 5611FBC9
 BFE80483, 2CF95A98, 5E3201FC, AF931EA5, DC45FDD6, 5611FBC9, 52325A09, B43484F4, 648E356E, 58E52773
 DC45FDD6, 1393F0C3, 2CF95A98, C807F178, AF931EA5, 58E52773, D015577D, 52325A09, D213D2D0, 648E356E
 AF931EA5, BB49CCF7, 1393F0C3, E56A60B3, C807F178, 648E356E, BB9C87C4, D015577D, C9682548, D213D2D0
 C807F178, 6A330EB4, BB49CCF7, 4FC30C4E, E56A60B3, D213D2D0, B1BB1A2E, BB9C87C4, 555DF740, C9682548
 E56A60B3, 14E58204, 6A330EB4, 2733DEED, 4FC30C4E, C9682548, AC77F96D, B1BB1A2E, 721F12EE, 555DF740
 4FC30C4E, 79AAF53E, 14E58204, CC3AD1A8, 2733DEED, 555DF740, 1774D326, AC77F96D, EC68BAC6, 721F12EE
 2733DEED, 210769B3, 79AAF53E, 96081053, CC3AD1A8, 721F12EE, A625F112, 1774D326, DFE5B6B1, EC68BAC6
 CC3AD1A8, F44B53A7, 210769B3, ABD4F9E6, 96081053, EC68BAC6, 5DCA4D12, A625F112, D34C985D, DFE5B6B1

96081053, 7C1E3640, F44B53A7, 1DA6CC84, ABD4F9E6, DFE5B6B1, EBC4D9C6, 5DCA4D12, 97C44A98, D34C985D
 ABD4F9E6, 06B59EE8, 7C1E3640, 2D4E9FD1, 1DA6CC84, D34C985D, 095F37FD, EBC4D9C6, 29344977, 97C44A98
 1DA6CC84, C422C3CD, 06B59EE8, 78D901F0, 2D4E9FD1, 97C44A98, 5BBEE487, 095F37FD, 13671BAF, 29344977
 2D4E9FD1, AD864025, C422C3CD, D67BA01A, 78D901F0, 29344977, BF5B2529, 5BBEE487, 7CDDFF425, 13671BAF
 78D901F0, 29A83BB5, AD864025, 8B0F3710, D67BA01A, 13671BAF, FB5747C5, BF5B2529, FB921D6E, 7CDDFF425
 D67BA01A, 626E3910, 29A83BB5, 190096B6, 8B0F3710, 7CDDFF425, DD935A5F, FB5747C5, 6C94A6FD, FB921D6E
 8B0F3710, A719D8BC, 626E3910, A0EED4A6, 190096B6, FB921D6E, 27754F3A, DD935A5F, 5D1F17ED, 6C94A6FD
 190096B6, BA84C782, A719D8BC, B8E44189, A0EED4A6, 6C94A6FD, 4F5CA4A5, 27754F3A, 4D697F76, 5D1F17ED
 A0EED4A6, 9F6887A9, BA84C782, 6762F29C, B8E44189, 5D1F17ED, 325AFE7E, 4F5CA4A5, D53CE89D, 4D697F76
 B8E44189, 3A88288C, 9F6887A9, 131E0AEA, 6762F29C, 4D697F76, 86AFE021, 325AFE7E, 7292953D, D53CE89D
 6762F29C, AB23F78F, 3A88288C, A21EA67D, 131E0AEA, D53CE89D, C97F9EA1, 86AFE021, 6BF9F8C9, 7292953D
 131E0AEA, 7299044A, AB23F78F, 20A230EA, A21EA67D, 7292953D, 9F60751C, C97F9EA1, BF80861A, 6BF9F8C9
 A21EA67D, 6A3F10CF, 7299044A, 8FDE3EAC, 20A230EA, 6BF9F8C9, 1E9CE713, 9F60751C, FE7A8725, BF80861A
 20A230EA, 1A1B904D, 6A3F10CF, 641129CA, 8FDE3EAC, BF80861A, C13F038A, 1E9CE713, 81D4727D, FE7A8725
 8FDE3EAC, 0B2CDC01, 1A1B904D, FC433DA8, 641129CA, FE7A8725, BF627814, C13F038A, 739C4C7A, 81D4727D
 641129CA, D563BFDC, 0B2CDC01, 6E413468, FC433DA8, 81D4727D, 5FCCBADE, BF627814, FC0E2B04, 739C4C7A

The hash-code is the following 160-bit string.

8E B2 08 F7 E0 5D 98 7A 9B 04 4A 8E 98 C6 B0 87 F1 5A 0B FC

A.2.4 Example 4

In this example the data-string is the 14-byte string consisting of the ASCII-coded version of

‘message digest’

The hash-code is the following 160-bit string.

5D 06 89 EF 49 D2 FA E5 72 B8 81 B1 23 A8 5F FA 21 59 5F 36

A.2.5 Example 5

In this example the data-string is the 26-byte string consisting of the ASCII-coded version of

‘abcdefghijklmnopqrstuvwxy’

The hash-code is the following 160-bit string.

F7 1C 27 10 9C 69 2C 1B 56 BB DC EB 5B 9D 28 65 B3 70 8D BC

A.2.6 Example 6

In this example the data-string is the 62-byte string consisting of the ASCII-coded version of

‘ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxy0123456789’

The hash-code is the following 160-bit string.

B0 E2 0B 6E 31 16 64 02 86 ED 3A 87 A5 71 30 79 B2 1F 51 89

A.2.7 Example 7

In this example the data-string is the 80-byte string consisting of the ASCII-coded version of eight repetitions of

'1234567890'

The hash-code is the following 160-bit string.

9B 75 2E 45 57 3D 4B 39 F4 DB D3 32 3C AB 82 BF 63 32 6B FB

A.2.8 Example 8

In this example the data-string is the 56-byte string consisting of the ASCII-coded version of

'abcdcbcdcedfdefgefghfghighijhijkjklklmklmnlmnomnopnopq'

After the padding process, the two 16-word blocks derived from the data-string are as follows.

64636261	65646362	66656463	67666564	68676665	69686766	6A696867	6B6A6968
6C6B6A69	6D6C6B6A	6E6D6C6B	6F6E6D6C	706F6E6D	71706F6E	00000080	00000000
00000000	00000000	00000000	00000000	00000000	00000000	00000000	00000000
00000000	00000000	00000000	00000000	00000000	00000000	000001C0	00000000

The following are (hexadecimal representations of) the successive values of the variables $X_0, X_1, X_2, X_3, X_4, X'_0, X'_1, X'_2, X'_3, X'_4$, obtained during the processing of the first block.

67452301, EFCDAB89, 98BADCFE, 10325476, C3D2E1F0, 67452301, EFCDAB89, 98BADCFE, 10325476, C3D2E1F0
 C3D2E1F0, 3115FB87, EFCDAB89, EB73FA62, 10325476, C3D2E1F0, 463DA521, EFCDAB89, EB73FA62, 10325476
 10325476, CC21EC2E, 3115FB87, 36AE27BF, EB73FA62, 10325476, DB247A12, 463DA521, 36AE27BF, EB73FA62
 EB73FA62, DFE9B7A, CC21EC2E, 57EE1CC4, 36AE27BF, EB73FA62, 1D166A23, DB247A12, F6948518, 36AE27BF
 36AE27BF, 2363912E, DFE9B7A, 87B0BB30, 57EE1CC4, 36AE27BF, CE7A12F6, 1D166A23, 91E84B6C, F6948518
 57EE1CC4, A1B60DC7, 2363912E, AE6DEB7F, 87B0BB30, F6948518, 57FF19DD, CE7A12F6, 59A88C74, 91E84B6C
 87B0BB30, 96AC7C1E, A1B60DC7, 8E44B88D, AE6DEB7F, 91E84B6C, 01A9FEFA, 57FF19DD, E84BDB39, 59A88C74
 AE6DEB7F, 6AE46154, 96AC7C1E, D8371E86, 8E44B88D, 59A88C74, 5D9A609C, 01A9FEFA, FC67755F, E84BDB39
 8E44B88D, 3CF61F09, 6AE46154, B1F07A5A, D8371E86, E84BDB39, 030F7FE7, 5D9A609C, A7FBE806, FC67755F
 D8371E86, 696F0D9A, 3CF61F09, 918551AB, B1F07A5A, FC67755F, 7456C8E3, 030F7FE7, 69827176, A7FBE806
 B1F07A5A, AB957B91, 696F0D9A, D87C24F3, 918551AB, A7FBE806, F64C4453, 7456C8E3, 3DFF9C0C, 69827176
 918551AB, 9FF4A064, AB957B91, BC3669A5, D87C24F3, 69827176, 22A5FE6E, F64C4453, 5B238DD1, 3DFF9C0C
 D87C24F3, 912FE998, 9FF4A064, 55EE46AE, BC3669A5, 3DFF9C0C, 8D7E53E4, 22A5FE6E, 31114FD9, 5B238DD1
 BC3669A5, C45F164E, 912FE998, D281927F, 55EE46AE, 5B238DD1, 695B23B7, 8D7E53E4, 97F9B88A, 31114FD9
 55EE46AE, 2211A508, C45F164E, BFA66244, D281927F, 31114FD9, 6FAA776F, 695B23B7, F94F9235, 97F9B88A
 D281927F, 80B1F3DE, 2211A508, 7C593B11, BFA66244, 97F9B88A, 4D94F720, 6FAA776F, 6C8EDDA5, F94F9235
 BFA66244, 3AA6A8F5, 80B1F3DE, 46942088, 7C593B11, F94F9235, D81C6137, 4D94F720, A9DDBDBE, 6C8EDDA5
 7C593B11, 9E4C4BF6, 3AA6A8F5, C7CF7A02, 46942088, 6C8EDDA5, B2ECCABD, D81C6137, 53DC8136, A9DDBDBE
 46942088, F929216E, 9E4C4BF6, 9AA3D4EA, C7CF7A02, A9DDBDBE, A96B1820, B2ECCABD, 7184DF60, 53DC8136
 C7CF7A02, D9AEEFAF, F929216E, 312FDA79, 9AA3D4EA, 53DC8136, 5A5E09B3, A96B1820, B32AF6CB, 7184DF60
 9AA3D4EA, 8BB34505, D9AEEFAF, A485BBE4, 312FDA79, 7184DF60, 616711FA, 5A5E09B3, AC6082A5, B32AF6CB
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 A485BBE4, 51997747, 07067302, CD14162E, BBEBF66, AC6082A5, FAE97297, F4F47116, 9C47E985, 7826CD69
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 F1736D67, 0B3B88C1, 65BBCCCC, 2BAFB53D, 8C3EFA2B, 09EAB91A, 54B06FBD, EC65CB85, 3CE3F3A4, 5EA41E9D
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 556E3B3E, 2FF847D6, F336AA45, 0F110DE5, DADFA20E, 386EF6FB, 40CBA97D, 91704BDB, A9E7D76F, F3FBB365
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 0F110DE5, 78378FE9, 33FE64C9, E11F58BF, DAA917CC, A9E7D76F, CA09D415, B0BD2456, 2EA5F503, C12F6E45

The following are (hexadecimal representations of) the successive values of the variables $X_0, X_1, X_2, X_3, X_4, X'_0, X'_1, X'_2, X'_3, X'_4$, obtained during the processing of the second block.

52720555, 3B09A402, 94C343B1, 9CEDC3EA, 9039D740, 52720555, 3B09A402, 94C343B1, 9CEDC3EA, 9039D740

9039D740, 59874B6C, 3B09A402, 0D0EC653, 9CEDC3EA, 9039D740, 7FA6C9AF, 3B09A402, 0D0EC653, 9CEDC3EA
 9CEDC3EA, 1D0D43D8, 59874B6C, 269008EC, 0D0EC653, 9CEDC3EA, 149F92B4, 7FA6C9AF, 269008EC, 0D0EC653
 0D0EC653, EF3045D6, 1D0D43D8, 1D2DB166, 269008EC, 0D0EC653, 0E887E05, 149F92B4, 9B26BDFE, 269008EC
 269008EC, 1E6BC8AD, EF3045D6, 350F6074, 1D2DB166, 269008EC, 6E8757AC, 0E887E05, 7E4AD052, 9B26BDFE
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 350F6074, 13A4B937, 79CC70E3, AF22B479, C1175BBC, 7E4AD052, 8EB02C5A, 32C1290B, 1D5EB1BA, 21F8143A
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 19B2E7B8, 0FDE892D, 50EEC8A1, 89E90E27, 2BFE4E82, 7AE765C6, 4456D048, A6AACEE1, 7A828D1F, 6E2A68F5
 2BFE4E82, 47B046C8, 0FDE892D, BB228543, 89E90E27, 6E2A68F5, 072D166E, 4456D048, AB3B869A, 7A828D1F
 89E90E27, 5C8F582E, 47B046C8, 7A24B43F, BB228543, 7A828D1F, B37A11D1, 072D166E, 5B412111, AB3B869A
 BB228543, 3D7F05B8, 5C8F582E, C11B211E, 7A24B43F, AB3B869A, 654CBE94, B37A11D1, B459B81C, 5B412111
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 DBAF23FC, 2256AF69, FE05BEE3, AFED7654, 04314D68, 4727C006, B44977A5, C9EABB3E, E5924DF9, EEACD883
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 AFED7654, 1DFB856C, 5285B0D3, 5ABDA489, 16FB8FF8, E5924DF9, 1E1DBD16, 287580C6, 25DE96D1, AAECFB27
 16FB8FF8, 32974404, 1DFB856C, 16C34D4A, 5ABDA489, AAECFB27, FBEB21BA, 1E1DBD16, D60318A1, 25DE96D1
 5ABDA489, 90AC71CE, 32974404, EE15B077, 16C34D4A, 25DE96D1, B74BF3E2, FBEB21BA, 76F45878, D60318A1
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 EE15B077, 340CBE92, 849CCC12, B1C73A42, 5D1010CA, 76F45878, 3CD099C6, 755BEDDF, 2FCF8ADD, AC86EBEF
 5D1010CA, F531E5F5, 340CBE92, 73304A12, B1C73A42, AC86EBEF, A19BBA2, 3CD099C6, 6FB77DD5, 2FCF8ADD
 B1C73A42, 27528557, F531E5F5, 3AFA48D0, 73304A12, 2FCF8ADD, EFC554F1, A19BBA2, 426718F3, 6FB77DD5
 73304A12, E4AFA69F, 27528557, C797D7D4, 3AFA48D0, 6FB77DD5, F56F1485, EFC554F1, 6EEA8A86, 426718F3
 3AFA48D0, E3462C93, E4AFA69F, 4A155C9D, C797D7D4, 426718F3, E0A1480A, F56F1485, 1553C7BF, 6EEA8A86
 C797D7D4, 3CF5CD85, E3462C93, BE9A7F92, 4A155C9D, 6EEA8A86, 9F80007D, E0A1480A, BC5217D5, 1553C7BF
 4A155C9D, B6C756F9, 3CF5CD85, 18B24F8D, BE9A7F92, 1553C7BF, 090898BE, 9F80007D, 85202B82, BC5217D5
 BE9A7F92, CC2AB627, B6C756F9, D73614F3, 18B24F8D, BC5217D5, A0CD75A2, 090898BE, 0001F67E, 85202B82
 18B24F8D, E5471921, CC2AB627, 1D5BE6DB, D73614F3, 85202B82, 95FE46E6, A0CD75A2, 2262F824, 0001F67E
 D73614F3, E8FEFBC6, E5471921, AAD89F30, 1D5BE6DB, 0001F67E, 4B55D832, 95FE46E6, 35D68A83, 2262F824
 1D5BE6DB, 788FFBE7, E8FEFBC6, 1C648795, AAD89F30, 2262F824, 681302D4, 4B55D832, F91B9A57, 35D68A83
 AAD89F30, FA97F1BB, 788FFBE7, FBEB1BA3, 1C648795, 35D68A83, 860F8E32, 681302D4, 5760C92D, F91B9A57
 1C648795, 2FE154B4, FA97F1BB, 3FEF9DE2, FBEB1BA3, F91B9A57, CA3DDAC0, 860F8E32, 4C0B51A0, 5760C92D
 FBEB1BA3, D884695B, 2FE154B4, 5FC6EFEA, 3FEF9DE2, 5760C92D, 7E790793, CA3DDAC0, 3E38CA18, 4C0B51A0
 3FEF9DE2, A09357E9, D884695B, 8552D0BF, 5FC6EFEA, 4C0B51A0, 4E0DF927, 7E790793, F76B0328, 3E38CA18
 5FC6EFEA, 019B9791, A09357E9, 11A56F62, 8552D0BF, 3E38CA18, 311DFB90, 4E0DF927, E41E4DF9, F76B0328
 8552D0BF, 70DB6FDF, 019B9791, 4D5FA682, 11A56F62, F76B0328, 24FA9DC7, 311DFB90, 37E49D38, E41E4DF9
 11A56F62, 82F104B4, 70DB6FDF, 6E5E4406, 4D5FA682, E41E4DF9, CE45E142, 24FA9DC7, 77EE40C4, 37E49D38
 4D5FA682, BFAB29F8, 82F104B4, 6DBF7DC3, 6E5E4406, 37E49D38, 9C4F267F, CE45E142, EA771C93, 77EE40C4
 6E5E4406, 880198A9, BFAB29F8, C412D20B, 6DBF7DC3, 77EE40C4, 06880805, 9C4F267F, 17850B39, EA771C93
 6DBF7DC3, 917C197C, 880198A9, ACA7E2FE, C412D20B, EA771C93, 7625BD09, 06880805, 3C99FE71, 17850B39

C412D20B, 03E7992A, 917C197C, 0662A620, ACA7E2FE, 17850B39, 8720C8E7, 7625BD09, 2020141A, 3C99FE71
 ACA7E2FE, 824CEF7A, 03E7992A, F065F245, 0662A620, 3C99FE71, CBB7DA7A, 8720C8E7, 96F425D8, 2020141A
 0662A620, AF16F218, 824CEF7A, 9E64A80F, F065F245, 2020141A, 88851068, CBB7DA7A, 83239E1C, 96F425D8
 F065F245, EFC8943D, AF16F218, 33BDEA09, 9E64A80F, 96F425D8, C85C4EB8, 88851068, DF69EB2E, 83239E1C
 9E64A80F, C80FF53B, EFC8943D, 5BC862BC, 33BDEA09, 83239E1C, 57BF18E2, C85C4EB8, 1441A222, DF69EB2E
 33BDEA09, 28DF9E36, C80FF53B, 2250F7BF, 5BC862BC, DF69EB2E, 48932C1A, 57BF18E2, 713AE321, 1441A222
 5BC862BC, 6E1D8950, 28DF9E36, 3FD4EF20, 2250F7BF, 1441A222, 15C7B0BD, 48932C1A, FC63895E, 713AE321
 2250F7BF, 21EEE621, 6E1D8950, 7E78D8A3, 3FD4EF20, 713AE321, FCBC9E78, 15C7B0BD, 4CB06922, FC63895E
 3FD4EF20, 561379BA, 21EEE621, 762541B8, 7E78D8A3, FC63895E, DD28EA60, FCBC9E78, 1EC2F457, 4CB06922
 7E78D8A3, 4D0255C5, 561379BA, BB988487, 762541B8, 4CB06922, CF1BB810, DD28EA60, F279E3F2, 1EC2F457
 762541B8, 966845EC, 4D0255C5, 4DE6E958, BB988487, 1EC2F457, 5D899D62, CF1BB810, A3A98374, F279E3F2
 BB988487, D922DEB8, 966845EC, 09571534, 4DE6E958, F279E3F2, F1144141, 5D899D62, 6EE0433C, A3A98374
 4DE6E958, B919B2A3, D922DEB8, A117B259, 09571534, A3A98374, 940BBA12, F1144141, 26758976, 6EE0433C
 09571534, D3CF80F9, B919B2A3, 8B7AE364, A117B259, 6EE0433C, 33DDA9B5, 940BBA12, 510507C4, 26758976
 A117B259, F548EA98, D3CF80F9, 66CA8EE4, 8B7AE364, 26758976, DCE0B562, 33DDA9B5, 2EE84A50, 510507C4
 8B7AE364, A1D3372D, F548EA98, 3E03E74F, 66CA8EE4, 510507C4, C103FBE9, DCE0B562, 76A6D4CF, 2EE84A50
 66CA8EE4, 6578D66C, A1D3372D, 23AA63D5, 3E03E74F, 2EE84A50, 832961D9, C103FBE9, 82D58B73, 76A6D4CF
 3E03E74F, 57C29604, 6578D66C, 4DCB687, 23AA63D5, 76A6D4CF, B183744E, 832961D9, 0FEFA704, 82D58B73
 23AA63D5, 27F5E937, 57C29604, E359B195, 4DCB687, 82D58B73, E710A112, B183744E, A587660C, 0FEFA704

The hash-code is the following 160-bit string.

12 A0 53 38 4A 9C 0C 88 E4 05 A0 6C 27 DC F4 9A DA 62 EB 2B

A.2.9 Example 9

In this example the data-string is the 1000000-byte string consisting of the ASCII-coded version of 'a' repeated 10^6 times.

The hash-code is the following 160-bit string.

52 78 32 43 C1 69 7B DB E1 6D 37 F9 7F 68 F0 83 25 DC 15 28

A.3 Dedicated Hash-Function 2

Hash-Function 1.

A.3.1 Example 1

In this example the data-string is the empty string, i.e. the string of length zero.

The hash-code is the following 128-bit string.

CD F2 62 13 A1 50 DC 3E CB 61 0F 18 F6 B3 8B 46

A.3.2 Example 2

In this example the data-string consists of a single byte, namely the ASCII-coded version of the letter 'a'.

The hash-code is the following 128-bit string.

86 BE 7A FA 33 9D 0F C7 CF C7 85 E7 2F 57 8D 33

A.3.3 Example 3

In this example the data-string is the three-byte string consisting of the ASCII-coded version of 'abc'. This is equivalent to the bit-string: '01100001 01100010 01100011'.

After the padding process, the single 16-word block derived from the data-string is as follows.

```
80636261 00000000 00000000 00000000 00000000 00000000 00000000 00000000
00000000 00000000 00000000 00000000 00000000 00000000 00000018 00000000
```

The following are (hexadecimal representations of) the successive values of the variables $X_0, X_1, X_2, X_3, X'_0, X'_1, X'_2, X'_3$.

```
67452301, EFCDAB89, 98BADCFE, 10325476, 67452301, EFCDAB89, 98BADCFE, 10325476
10325476, 6D431A77, EFCDAB89, 98BADCFE, 10325476, 70376F40, EFCDAB89, 98BADCFE
98BADCFE, B05D8A99, 6D431A77, EFCDAB89, 98BADCFE, 989F6BB0, 70376F40, EFCDAB89
EFCDAB89, 0C32E5C7, B05D8A99, 6D431A77, EFCDAB89, 39B14904, 989F6BB0, 70376F40
6D431A77, A20B2C0F, 0C32E5C7, B05D8A99, 70376F40, 671C03CC, 39B14904, 989F6BB0
B05D8A99, 74EBB911, A20B2C0F, 0C32E5C7, 989F6BB0, BFD55C42, 671C03CC, 39B14904
0C32E5C7, 2FFB728B, 74EBB911, A20B2C0F, 39B14904, A12F346F, BFD55C42, 671C03CC
A20B2C0F, A766AE02, 2FFB728B, 74EBB911, 671C03CC, 989C2210, A12F346F, BFD55C42
74EBB911, 03234F3D, A766AE02, 2FFB728B, BFD55C42, 0F95FBEA, 989C2210, A12F346F
2FFB728B, 52662805, 03234F3D, A766AE02, A12F346F, 068D5115, 0F95FBEA, 989C2210
A766AE02, E778A4C3, 52662805, 03234F3D, 989C2210, AFCD27FC, 068D5115, 0F95FBEA
03234F3D, 1C7F5769, E778A4C3, 52662805, 0F95FBEA, CBD1F3F8, AFCD27FC, 068D5115
52662805, 95765642, 1C7F5769, E778A4C3, 068D5115, CFFE405F, CBD1F3F8, AFCD27FC
E778A4C3, 35F37B70, 95765642, 1C7F5769, AFCD27FC, 2B55C9C3, CFFE405F, CBD1F3F8
1C7F5769, 398F8F52, 35F37B70, 95765642, CBD1F3F8, DD6A43FB, 2B55C9C3, CFFE405F
95765642, 13F3C36B, 398F8F52, 35F37B70, CFFE405F, 049B909E, DD6A43FB, 2B55C9C3
35F37B70, 058D8BB5, 13F3C36B, 398F8F52, 2B55C9C3, 3713BFFD, 049B909E, DD6A43FB
398F8F52, FCBE3664, 058D8BB5, 13F3C36B, DD6A43FB, 82ADB53, 3713BFFD, 049B909E
13F3C36B, F7F306A6, FCBE3664, 058D8BB5, 049B909E, CC1D8105, 82ADB53, 3713BFFD
058D8BB5, 34CC3963, F7F306A6, FCBE3664, 3713BFFD, BE09159A, CC1D8105, 82ADB53
FCBE3664, 416E8BA0, 34CC3963, F7F306A6, 82ADB53, 541AE568, BE09159A, CC1D8105
F7F306A6, EDE91870, 416E8BA0, 34CC3963, CC1D8105, 27D40F94, 541AE568, BE09159A
34CC3963, C352C547, EDE91870, 416E8BA0, BE09159A, 675C363A, 27D40F94, 541AE568
416E8BA0, 5D5EEE28, C352C547, EDE91870, 541AE568, 77F3A38B, 675C363A, 27D40F94
EDE91870, 6CC4BEF2, 5D5EEE28, C352C547, 27D40F94, 84D73C44, 77F3A38B, 675C363A
C352C547, E140970B, 6CC4BEF2, 5D5EEE28, 675C363A, D2958F37, 84D73C44, 77F3A38B
5D5EEE28, 79F631A9, E140970B, 6CC4BEF2, 77F3A38B, FC39C927, D2958F37, 84D73C44
6CC4BEF2, 038E0E91, 79F631A9, E140970B, 84D73C44, E3A5A4DE, FC39C927, D2958F37
E140970B, 1B942D52, 038E0E91, 79F631A9, D2958F37, 4BA3A889, E3A5A4DE, FC39C927
79F631A9, 496AECFD, 1B942D52, 038E0E91, FC39C927, A964BA74, 4BA3A889, E3A5A4DE
038E0E91, FE6CD56F, 496AECFD, 1B942D52, E3A5A4DE, 7AF9DBB0, A964BA74, 4BA3A889
1B942D52, 2E94F501, FE6CD56F, 496AECFD, 4BA3A889, 7DA68EA9, 7AF9DBB0, A964BA74
496AECFD, 584E8E58, 2E94F501, FE6CD56F, A964BA74, 9C7247E5, 7DA68EA9, 7AF9DBB0
FE6CD56F, 41A17EFA, 584E8E58, 2E94F501, 7AF9DBB0, 0130312B, 9C7247E5, 7DA68EA9
2E94F501, 8981C6CD, 41A17EFA, 584E8E58, 7DA68EA9, 90552232, 0130312B, 9C7247E5
584E8E58, 400A93E1, 8981C6CD, 41A17EFA, 9C7247E5, 99C1FBA4, 90552232, 0130312B
41A17EFA, 841F817F, 400A93E1, 8981C6CD, 0130312B, 9D481CD2, 99C1FBA4, 90552232
8981C6CD, 659379BE, 841F817F, 400A93E1, 90552232, F5AABE07, 9D481CD2, 99C1FBA4
400A93E1, AB3D9A70, 659379BE, 841F817F, 99C1FBA4, C3AFB7E6, F5AABE07, 9D481CD2
841F817F, D3D21DC8, AB3D9A70, 659379BE, 9D481CD2, 473E2B79, C3AFB7E6, F5AABE07
659379BE, 38C8D29D, D3D21DC8, AB3D9A70, F5AABE07, C4CAFF99, 473E2B79, C3AFB7E6
AB3D9A70, 738B9B0F, 38C8D29D, D3D21DC8, C3AFB7E6, A2879AA4, C4CAFF99, 473E2B79
D3D21DC8, 8528B83E, 738B9B0F, 38C8D29D, 473E2B79, 56565EDB, A2879AA4, C4CAFF99
38C8D29D, 7345AF18, 8528B83E, 738B9B0F, C4CAFF99, E7A4BD86, 56565EDB, A2879AA4
738B9B0F, FFCC52B, 7345AF18, 8528B83E, A2879AA4, 974B9E10, E7A4BD86, 56565EDB
8528B83E, A77E902B, FFCC52B, 7345AF18, 56565EDB, 96CC5AE1, 974B9E10, E7A4BD86
```

7345AF18, CB9C6C83, A77E902B, FFCC52B, E7A4BD86, 57E6A772, 96CC5AE1, 974B9E10
 FFCC52B, 38A2DA83, CB9C6C83, A77E902B, 974B9E10, F10B6CF5, 57E6A772, 96CC5AE1
 A77E902B, 487F9401, 38A2DA83, CB9C6C83, 96CC5AE1, 90426E6B, F10B6CF5, 57E6A772
 CB9C6C83, C7184576, 487F9401, 38A2DA83, 57E6A772, 0066E6BE, 90426E6B, F10B6CF5
 38A2DA83, 56D619B1, C7184576, 487F9401, F10B6CF5, 22D17257, 0066E6BE, 90426E6B
 487F9401, 3A35A3C5, 56D619B1, C7184576, 90426E6B, 016777A4, 22D17257, 0066E6BE
 C7184576, B5517538, 3A35A3C5, 56D619B1, 0066E6BE, 9A8DC5A0, 016777A4, 22D17257
 56D619B1, 4609C4C2, B5517538, 3A35A3C5, 22D17257, A9C46E68, 9A8DC5A0, 016777A4
 3A35A3C5, D5C2B699, 4609C4C2, B5517538, 016777A4, 13B0D540, A9C46E68, 9A8DC5A0
 B5517538, 342AF741, D5C2B699, 4609C4C2, 9A8DC5A0, 983D8B08, 13B0D540, A9C46E68
 4609C4C2, 38286DDA, 342AF741, D5C2B699, A9C46E68, 96084F4E, 983D8B08, 13B0D540
 D5C2B699, 9BCEEC0A, 38286DDA, 342AF741, 13B0D540, D25FDBB1, 96084F4E, 983D8B08
 342AF741, 5803DF3A, 9BCEEC0A, 38286DDA, 983D8B08, 35EA6FE0, D25FDBB1, 96084F4E
 38286DDA, E1B026EB, 5803DF3A, 9BCEEC0A, 96084F4E, B862709F, 35EA6FE0, D25FDBB1
 9BCEEC0A, 31587C22, E1B026EB, 5803DF3A, D25FDBB1, C02839EB, B862709F, 35EA6FE0
 5803DF3A, 9B25E1DC, 31587C22, E1B026EB, 35EA6FE0, 00245200, C02839EB, B862709F
 E1B026EB, 2205379E, 9B25E1DC, 31587C22, B862709F, CB116A95, 00245200, C02839EB
 31587C22, 5E3334A3, 2205379E, 9B25E1DC, C02839EB, B90EE1BF, CB116A95, 00245200
 9B25E1DC, 56F80FA9, 5E3334A3, 2205379E, 00245200, 64132D32, B90EE1BF, CB116A95

The hash-code is the following 128-bit string.

C1 4A 12 19 9C 66 E4 BA 84 63 6B 0F 69 14 4C 77

A.3.4 Example 4

In this example the data-string is the 14-byte string consisting of the ASCII-coded version of

'message digest'

The hash-code is the following 128-bit string.

9E 32 7B 3D 8E 52 30 62 AF C1 13 2D 7D F9 D1 B8

A.3.5 Example 5

In this example the data-string is the 26-byte string consisting of the ASCII-coded version of

'abcdefghijklmnopqrstuvwxy'

The hash-code is the following 128-bit string.

FD 2A A6 07 F7 1D C8 F5 10 71 49 22 B3 71 83 4E

A.3.6 Example 6

In this example the data-string is the 62-byte string consisting of the ASCII-coded version of

'ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxy0123456789'

The hash-code is the following 128-bit string.

D1 E9 59 EB 17 9C 91 1F AE A4 62 4C 60 C5 C7 02

A.3.7 Example 7

In this example the data-string is the 80-byte string consisting of the ASCII-coded version of eight repetitions of

'1234567890'

The hash-code is the following 128-bit string.

3F 45 EF 19 47 32 C2 DB B2 C4 A2 C7 69 79 5F A3

A.3.8 Example 8

In this example the data-string is the 56-byte string consisting of the ASCII-coded version of

'abcdbcdecdefdefgefghfghighijhijkijklklmklmnlmnomnopnopq'

After the padding process, the two 16-word blocks derived from the data-string are as follows.

64636261	65646362	66656463	67666564	68676665	69686766	6A696867	6B6A6968
6C6B6A69	6D6C6B6A	6E6D6C6B	6F6E6D6C	706F6E6D	71706F6E	00000080	00000000
00000000	00000000	00000000	00000000	00000000	00000000	00000000	00000000
00000000	00000000	00000000	00000000	00000000	00000000	000001C0	00000000

The following are (hexadecimal representations of) the successive values of the variables $X_0, X_1, X_2, X_3, X'_0, X'_1, X'_2, X'_3$, obtained during the processing of the first block.

67452301, EFCDAB89, 98BADCFE, 10325476, 67452301, EFCDAB89, 98BADCFE, 10325476
 10325476, 6D431997, EFCDAB89, 98BADCFE, 10325476, D89ED5A9, EFCDAB89, 98BADCFE
 98BADCFE, C9AE23F2, 6D431997, EFCDAB89, 98BADCFE, 69B10AC1, D89ED5A9, EFCDAB89
 EFCDAB89, 69A6A520, C9AE23F2, 6D431997, EFCDAB89, B661DB9C, 69B10AC1, D89ED5A9
 6D431997, FB032247, 69A6A520, C9AE23F2, D89ED5A9, ABACC2AF, B661DB9C, 69B10AC1
 C9AE23F2, 16C49226, FB032247, 69A6A520, 69B10AC1, D412CAD1, ABACC2AF, B661DB9C
 69A6A520, 77A099B7, 16C49226, FB032247, B661DB9C, E2DEF22, D412CAD1, ABACC2AF
 FB032247, 3B9BAEB7, 77A099B7, 16C49226, ABACC2AF, CFB03688, E2DEF22, D412CAD1
 16C49226, DA61AB82, 3B9BAEB7, 77A099B7, D412CAD1, 72599389, CFB03688, E2DEF22
 77A099B7, 54C888CC, DA61AB82, 3B9BAEB7, E2DEF22, CF3CD682, 72599389, CFB03688
 3B9BAEB7, F2635347, 54C888CC, DA61AB82, CFB03688, B235784E, CF3CD682, 72599389
 DA61AB82, E2CAC9B4, F2635347, 54C888CC, 72599389, 881678DF, B235784E, CF3CD682
 54C888CC, 9596C718, E2CAC9B4, F2635347, CF3CD682, E815373B, 881678DF, B235784E
 F2635347, 9DD54912, 9596C718, E2CAC9B4, B235784E, BD994B56, E815373B, 881678DF
 E2CAC9B4, 2E8539A7, 9DD54912, 9596C718, 881678DF, B0055655, BD994B56, E815373B
 9596C718, 2303C213, 2E8539A7, 9DD54912, E815373B, CC87EF5A, B0055655, BD994B56
 9DD54912, EA79BE25, 2303C213, 2E8539A7, BD994B56, 6B24384D, CC87EF5A, B0055655
 2E8539A7, 23D7CB45, EA79BE25, 2303C213, B0055655, 93E7329F, 6B24384D, CC87EF5A
 2303C213, F028EF04, 23D7CB45, EA79BE25, CC87EF5A, 35B95AE7, 93E7329F, 6B24384D
 EA79BE25, 48863F19, F028EF04, 23D7CB45, 6B24384D, 06C6536D, 35B95AE7, 93E7329F
 23D7CB45, 514C81B6, 48863F19, F028EF04, 93E7329F, FF1C5DC7, 06C6536D, 35B95AE7
 F028EF04, 6102CE67, 514C81B6, 48863F19, 35B95AE7, D0D541F1, FF1C5DC7, 06C6536D
 48863F19, 330485FD, 6102CE67, 514C81B6, 06C6536D, A94C0DD9, D0D541F1, FF1C5DC7

514C81B6, 289E8C82, 330485FD, 6102CE67, FF1C5DC7, DEDC1E39, A94C0DD9, D0D541F1
 6102CE67, 13CC3A1D, 289E8C82, 330485FD, D0D541F1, 12D926C0, DEDC1E39, A94C0DD9
 330485FD, 40A226A6, 13CC3A1D, 289E8C82, A94C0DD9, ED7EDA63, 12D926C0, DEDC1E39
 289E8C82, 70BFB1A8, 40A226A6, 13CC3A1D, DEDC1E39, 9F52219C, ED7EDA63, 12D926C0
 13CC3A1D, CE1D1A37, 70BFB1A8, 40A226A6, 12D926C0, F5D22339, 9E52219C, ED7EDA63
 40A226A6, EC9F7830, CE1D1A37, 70BFB1A8, ED7EDA63, 0BC5B4FC, F5D22339, 9E52219C
 70BFB1A8, 3CF2D6EE, EC9F7830, CE1D1A37, 9E52219C, FCFBD391, 0BC5B4FC, F5D22339
 CE1D1A37, F0C1F95C, 3CF2D6EE, EC9F7830, F5D22339, 2B6A389B, FCFBD391, 0BC5B4FC
 EC9F7830, 9A351A9D, F0C1F95C, 3CF2D6EE, 0BC5B4FC, FBF85B05, 2B6A389B, FCFBD391
 3CF2D6EE, 138B0685, 9A351A9D, F0C1F95C, FCFBD391, F7BBBE8B, FBF85B05, 2B6A389B
 F0C1F95C, EA3574D1, 138B0685, 9A351A9D, 2B6A389B, C8592ACC, F7BBBE8B, FBF85B05
 9A351A9D, 4719C849, EA3574D1, 138B0685, FBF85B05, FE2D3EFA, C8592ACC, F7BBBE8B
 138B0685, 57F52A13, 4719C849, EA3574D1, F7BBBE8B, 5411CC34, FE2D3EFA, C8592ACC
 EA3574D1, 4751F880, 57F52A13, 4719C849, C8592ACC, DC8ED546, 5411CC34, FE2D3EFA
 4719C849, 80605BAF, 4751F880, 57F52A13, FE2D3EFA, 55C1E317, DC8ED546, 5411CC34
 57F52A13, 1E53AD4A, 80605BAF, 4751F880, 5411CC34, 0B92E4F0, 55C1E317, DC8ED546
 4751F880, 1ABEED79, 1E53AD4A, 80605BAF, DC8ED546, 5E192900, 0B92E4F0, 55C1E317
 80605BAF, 75EACBB7, 1ABEED79, 1E53AD4A, 55C1E317, 186EB0CF, 5E192900, 0B92E4F0
 1E53AD4A, 08AC1056, 75EACBB7, 1ABEED79, 0B92E4F0, 8F3A64E3, 186EB0CF, 5E192900
 1ABEED79, 9BDB7A88, 08AC1056, 75EACBB7, 5E192900, 3701E7B3, 8F3A64E3, 186EB0CF
 75EACBB7, ADF32F05, 9BDB7A88, 08AC1056, 186EB0CF, 6CE969E9, 3701E7B3, 8F3A64E3
 08AC1056, 2277B80D, ADF32F05, 9BDB7A88, 8F3A64E3, EE7224D5, 6CE969E9, 3701E7B3
 9BDB7A88, 535DBB9A, 2277B80D, ADF32F05, 3701E7B3, 3E849D0F, EE7224D5, 6CE969E9
 ADF32F05, 2A494EC5, 535DBB9A, 2277B80D, 6CE969E9, DDBD8EE7, 3E849D0F, EE7224D5
 2277B80D, 693C7A09, 2A494EC5, 535DBB9A, EE7224D5, C3DDAC40, DDBD8EE7, 3E849D0F
 535DBB9A, 148A5796, 693C7A09, 2A494EC5, 3E849D0F, 5E0E10B9, C3DDAC40, DDBD8EE7
 2A494EC5, D2932448, 148A5796, 693C7A09, DDBD8EE7, 1CCB75AF, 5E0E10B9, C3DDAC40
 693C7A09, 39CA97B6, D2932448, 148A5796, C3DDAC40, 27F81499, 1CCB75AF, 5E0E10B9
 148A5796, 770BCE98, 39CA97B6, D2932448, 5E0E10B9, 82843491, 27F81499, 1CCB75AF
 D2932448, 8C4DC6AF, 770BCE98, 39CA97B6, 1CCB75AF, 4E4E13E9, 82843491, 27F81499
 39CA97B6, 048CC517, 8C4DC6AF, 770BCE98, 27F81499, 03BD1BD9, 4E4E13E9, 82843491
 770BCE98, 419960CF, 048CC517, 8C4DC6AF, 82843491, 6FA999B7, 03BD1BD9, 4E4E13E9
 8C4DC6AF, 407700EE, 419960CF, 048CC517, 4E4E13E9, 37B18629, 6FA999B7, 03BD1BD9
 048CC517, E60ABEC4, 407700EE, 419960CF, 03BD1BD9, 9EA44395, 37B18629, 6FA999B7
 419960CF, 0E248A8B, E60ABEC4, 407700EE, 6FA999B7, F877D28C, 9EA44395, 37B18629
 407700EE, 10667792, 0E248A8B, E60ABEC4, 37B18629, F63EA862, F877D28C, 9EA44395
 E60ABEC4, 646BB7A8, 10667792, 0E248A8B, 9EA44395, 424072F0, F63EA862, F877D28C
 0E248A8B, 625CCE22, 646BB7A8, 10667792, F877D28C, 3B7642B8, 424072F0, F63EA862
 10667792, 8E0E1101, 625CCE22, 646BB7A8, F63EA862, CD620F4E, 3B7642B8, 424072F0
 646BB7A8, C23D3583, 8E0E1101, 625CCE22, 424072F0, BFAA1A02, CD620F4E, 3B7642B8
 625CCE22, 81DE3DC5, C23D3583, 8E0E1101, 3B7642B8, 1BA7FD36, BFAA1A02, CD620F4E
 8E0E1101, D24E4181, 81DE3DC5, C23D3583, CD620F4E, E62BB2A4, 1BA7FD36, BFAA1A02

The following are (hexadecimal representations of) the successive values of the variables $X_0, X_1, X_2, X_3, X'_0, X'_1, X'_2, X'_3$, obtained during the processing of the second block.

31560350, 285A21CF, 846C181B, 553B61B8, 31560350, 285A21CF, 846C181B, 553B61B8
 553B61B8, 1ADDE153, 285A21CF, 846C181B, 553B61B8, 56C8C102, 285A21CF, 846C181B
 846C181B, CE8FC309, 1ADDE153, 285A21CF, 846C181B, 702249A4, 56C8C102, 285A21CF
 285A21CF, ODD8403A, CE8FC309, 1ADDE153, 285A21CF, 22CBOA97, 702249A4, 56C8C102
 1ADDE153, 4842F01E, ODD8403A, CE8FC309, 56C8C102, 35B2DCDF, 22CBOA97, 702249A4
 CE8FC309, BE6A9014, 4842F01E, ODD8403A, 702249A4, D2EFFB4A, 35B2DCDF, 22CBOA97
 ODD8403A, 7FE339CA, BE6A9014, 4842F01E, 22CBOA97, 59EA6C60, D2EFFB4A, 35B2DCDF
 4842F01E, D1CCFD4B, 7FE339CA, BE6A9014, 35B2DCDF, 82DEA3AE, 59EA6C60, D2EFFB4A
 BE6A9014, 108966B1, D1CCFD4B, 7FE339CA, D2EFFB4A, 4481FDE2, 82DEA3AE, 59EA6C60
 7FE339CA, 899223E8, 108966B1, D1CCFD4B, 59EA6C60, 13BB8F73, 4481FDE2, 82DEA3AE
 D1CCFD4B, 5E3B9917, 899223E8, 108966B1, 82DEA3AE, 946BD478, 13BB8F73, 4481FDE2
 108966B1, 7666663B, 5E3B9917, 899223E8, 4481FDE2, BD0605EA, 946BD478, 13BB8F73
 899223E8, A1BAD92C, 7666663B, 5E3B9917, 13BB8F73, 36F99153, BD0605EA, 946BD478
 5E3B9917, DE527A04, A1BAD92C, 7666663B, 946BD478, EB4AE872, 36F99153, BD0605EA

766663B, E52F1533, DE527A04, A1BAD92C, BD0605EA, 7C346442, EB4AE872, 36F99153
 A1BAD92C, 5C3C2C22, E52F1533, DE527A04, 36F99153, AFA320AD, 7C346442, EB4AE872
 DE527A04, FC1C4108, 5C3C2C22, E52F1533, EB4AE872, B4905651, AFA320AD, 7C346442
 E52F1533, 0A03E84B, FC1C4108, 5C3C2C22, 7C346442, 02E94FA1, B4905651, AFA320AD
 5C3C2C22, FB74BD26, 0A03E84B, FC1C4108, AFA320AD, E08D1799, 02E94FA1, B4905651
 FC1C4108, C78DC5C4, FB74BD26, 0A03E84B, B4905651, 69AFAA80, E08D1799, 02E94FA1
 0A03E84B, ACF60434, C78DC5C4, FB74BD26, 02E94FA1, FA665E46, 69AFAA80, E08D1799
 FB74BD26, 58F751E0, ACF60434, C78DC5C4, E08D1799, 269AB7E3, FA665E46, 69AFAA80
 C78DC5C4, EB75C7CB, 58F751E0, ACF60434, 69AFAA80, 0F06388B, 269AB7E3, FA665E46
 ACF60434, 83C0A8B7, EB75C7CB, 58F751E0, FA665E46, FD44FBD5, 0F06388B, 269AB7E3
 58F751E0, 27C87178, 83C0A8B7, EB75C7CB, 269AB7E3, DBBC0190, FD44FBD5, 0F06388B
 EB75C7CB, B7B9163F, 27C87178, 83C0A8B7, 0F06388B, DOE3FC2B, DBBC0190, FD44FBD5
 83C0A8B7, OFA1C6DC, B7B9163F, 27C87178, FD44FBD5, 7D87B4BA, DOE3FC2B, DBBC0190
 27C87178, 2CC60316, OFA1C6DC, B7B9163F, DBBC0190, 68367FDB, 7D87B4BA, DOE3FC2B
 B7B9163F, 08029C44, 2CC60316, OFA1C6DC, DOE3FC2B, 53AB5439, 68367FDB, 7D87B4BA
 OFA1C6DC, F693A10E, 08029C44, 2CC60316, 7D87B4BA, E78B75B5, 53AB5439, 68367FDB
 2CC60316, 356224B9, F693A10E, 08029C44, 68367FDB, 830530DF, E78B75B5, 53AB5439
 08029C44, 669F7869, 356224B9, F693A10E, 53AB5439, 67FCB1AC, 830530DF, E78B75B5
 F693A10E, 7B70C168, 669F7869, 356224B9, E78B75B5, 757BB243, 67FCB1AC, 830530DF
 356224B9, 037FB19C, 7B70C168, 669F7869, 830530DF, FOCA8878, 757BB243, 67FCB1AC
 669F7869, 9B0A10B3, 037FB19C, 7B70C168, 67FCB1AC, FA10CB33, FOCA8878, 757BB243
 7B70C168, 9D015956, 9B0A10B3, 037FB19C, 757BB243, 5487E56C, FA10CB33, FOCA8878
 037FB19C, 6A7DE5F4, 9D015956, 9B0A10B3, FOCA8878, A5D33699, 5487E56C, FA10CB33
 9B0A10B3, E522D913, 6A7DE5F4, 9D015956, FA10CB33, BEB495BC, A5D33699, 5487E56C
 9D015956, OEFD42E5, E522D913, 6A7DE5F4, 5487E56C, 05202F93, BEB495BC, A5D33699
 6A7DE5F4, 7902100B, OEFD42E5, E522D913, A5D33699, BACE7DD9, 05202F93, BEB495BC
 E522D913, 1ACEFABC, 7902100B, OEFD42E5, BEB495BC, 08D045DD, BACE7DD9, 05202F93
 OEFD42E5, E07378FF, 1ACEFABC, 7902100B, 05202F93, 5448A3A0, 08D045DD, BACE7DD9
 7902100B, 489C7A1A, E07378FF, 1ACEFABC, BACE7DD9, D98BE3AA, 5448A3A0, 08D045DD
 1ACEFABC, C02A45A5, 489C7A1A, E07378FF, 08D045DD, 12EC982F, D98BE3AA, 5448A3A0
 E07378FF, 3068DDE8, C02A45A5, 489C7A1A, 5448A3A0, 4A1EB2B2, 12EC982F, D98BE3AA
 489C7A1A, D5DD5018, 3068DDE8, C02A45A5, D98BE3AA, D677AAA8, 4A1EB2B2, 12EC982F
 C02A45A5, B9D75D76, D5DD5018, 3068DDE8, 12EC982F, 5AA89133, D677AAA8, 4A1EB2B2
 3068DDE8, 51A9B2DD, B9D75D76, D5DD5018, 4A1EB2B2, 49BCE169, 5AA89133, D677AAA8
 D5DD5018, 36F589C4, 51A9B2DD, B9D75D76, D677AAA8, CF4FA8D2, 49BCE169, 5AA89133
 B9D75D76, B5C60EAF, 36F589C4, 51A9B2DD, 5AA89133, C1985969, CF4FA8D2, 49BCE169
 51A9B2DD, 725DF80C, B5C60EAF, 36F589C4, 49BCE169, 427440B4, C1985969, CF4FA8D2
 36F589C4, 3F7A2507, 725DF80C, B5C60EAF, CF4FA8D2, 60927896, 427440B4, C1985969
 B5C60EAF, 9D539EB6, 3F7A2507, 725DF80C, C1985969, 7050ED96, 60927896, 427440B4
 725DF80C, 5A249895, 9D539EB6, 3F7A2507, 427440B4, CBC74513, 7050ED96, 60927896
 3F7A2507, A7CECDCD, 5A249895, 9D539EB6, 60927896, 8431C75E, CBC74513, 7050ED96
 9D539EB6, F8DCD12B, A7CECDCD, 5A249895, 7050ED96, 0E3A1C68, 8431C75E, CBC74513
 5A249895, 3E30DB2A, F8DCD12B, A7CECDCD, CBC74513, 62EEEC87, 0E3A1C68, 8431C75E
 A7CECDCD, A25D36CE, 3E30DB2A, F8DCD12B, 8431C75E, 2B1F312D, 62EEEC87, 0E3A1C68
 F8DCD12B, A92CF759, A25D36CE, 3E30DB2A, 0E3A1C68, FB124197, 2B1F312D, 62EEEC87
 3E30DB2A, OCD0BA66, A92CF759, A25D36CE, 62EEEC87, DB8A5C11, FB124197, 2B1F312D
 A25D36CE, AF62D775, OCD0BA66, A92CF759, 2B1F312D, EC3264DC, DB8A5C11, FB124197
 A92CF759, 69D4E1DF, AF62D775, OCD0BA66, FB124197, 9AA87F7C, EC3264DC, DB8A5C11
 OCD0BA66, OEE66339, 69D4E1DF, AF62D775, DB8A5C11, 04512915, 9AA87F7C, EC3264DC
 AF62D775, 5C5B5FBD, OEE66339, 69D4E1DF, EC3264DC, C763272A, 04512915, 9AA87F7C
 69D4E1DF, 0D80E8CF, 5C5B5FBD, OEE66339, 9AA87F7C, CCD7DF45, C763272A, 04512915

The hash-code is the following 128-bit string.

A1 AA 06 89 D0 FA FA 2D DC 22 E8 8B 49 13 3A 06

A.3.9 Example 9

In this example the data-string is the 1000000-byte string consisting of the ASCII-coded version of 'a' repeated 10⁶ times.

The hash-code is the following 128-bit string.

4A 7F 57 23 F9 54 EB A1 21 6C 9D 8F 63 20 43 1F

A.4 Dedicated Hash-Function 3

Hash-Function 3.

A.4.1 Example 1

In this example the data-string is the empty string, i.e. the string of length zero.

The hash-code is the following 160-bit string.

DA 39 A3 EE 5E 6B 4B 0D 32 55 BF EF 95 60 18 90 AF D8 07 09

A.4.2 Example 2

In this example the data-string consists of a single byte, namely the ASCII-coded version of the letter 'a'.

The hash-code is the following 160-bit string.

86 F7 E4 37 FA A5 A7 FC E1 5D 1D DC B9 EA EA EA 37 76 67 B8

A.4.3 Example 3

In this example the data-string is the three-byte string consisting of the ASCII-coded version of 'abc'. This is equivalent to the bit-string: '01100001 01100010 01100011'.

After the padding process, the single 16-word block derived from the data-string is as follows.

61626380	00000000	00000000	00000000	00000000	00000000	00000000	00000000
00000000	00000000	00000000	00000000	00000000	00000000	00000000	00000018

The following are (hexadecimal representations of) the successive values of the variables X_0, X_1, X_2, X_3, X_4 .

0116FC33, 67452301, 7BF36AE2, 98BADCFE, 10325476
 8990536D, 0116FC33, 59D148C0, 7BF36AE2, 98BADCFE
 A1390F08, 8990536D, C045BF0C, 59D148C0, 7BF36AE2
 CDD8E11B, A1390F08, 626414DB, C045BF0C, 59D148C0
 CFD499DE, CDD8E11B, 284E43C2, 626414DB, C045BF0C
 3FC7CA40, CFD499DE, F3763846, 284E43C2, 626414DB
 993E30C1, 3FC7CA40, B3F52677, F3763846, 284E43C2
 9E8C07D4, 993E30C1, 0FF1F290, B3F52677, F3763846
 4B6AE328, 9E8C07D4, 664F8C30, 0FF1F290, B3F52677
 8351F929, 4B6AE328, 27A301F5, 664F8C30, 0FF1F290

FBDA9E89, 8351F929, 12DAB8CA, 27A301F5, 664F8C30
63188FE4, FBDA9E89, 60D47E4A, 12DAB8CA, 27A301F5
4607B664, 63188FE4, 7EF6A7A2, 60D47E4A, 12DAB8CA
9128F695, 4607B664, 18C623F9, 7EF6A7A2, 60D47E4A
196BEE77, 9128F695, 1181ED99, 18C623F9, 7EF6A7A2
20BDD62F, 196BEE77, 644A3DA5, 1181ED99, 18C623F9
4E925823, 20BDD62F, C65AFB9D, 644A3DA5, 1181ED99
82AA6728, 4E925823, C82F758B, C65AFB9D, 644A3DA5
DC64901D, 82AA6728, D3A49608, C82F758B, C65AFB9D
FD9E1D7D, DC64901D, 20AA99CA, D3A49608, C82F758B
1A37BOCA, FD9E1D7D, 77192407, 20AA99CA, D3A49608
33A23BFC, 1A37BOCA, 7F67875F, 77192407, 20AA99CA
21283486, 33A23BFC, 868DEC32, 7F67875F, 77192407
D541F12D, 21283486, 0CE88EFF, 868DEC32, 7F67875F
C7567DC6, D541F12D, 884A0D21, 0CE88EFF, 868DEC32
48413BA4, C7567DC6, 75507C4B, 884A0D21, 0CE88EFF
BE35FBD5, 48413BA4, B1D59F71, 75507C4B, 884A0D21
4AA84D97, BE35FBD5, 12104EE9, B1D59F71, 75507C4B
8370B52E, 4AA84D97, 6F8D7EF5, 12104EE9, B1D59F71
C5FBAF5D, 8370B52E, D2AA1365, 6F8D7EF5, 12104EE9
1267B407, C5FBAF5D, A0DC2D4B, D2AA1365, 6F8D7EF5
3B845D33, 1267B407, 717EEBD7, A0DC2D4B, D2AA1365
046FAA0A, 3B845D33, C499ED01, 717EEBD7, A0DC2D4B
2C0EBC11, 046FAA0A, CEE1174C, C499ED01, 717EEBD7
21796AD4, 2C0EBC11, 811BEA82, CEE1174C, C499ED01
DCBBBOCB, 21796AD4, 4B03AF04, 811BEA82, CEE1174C
0F511FD8, DCBBBOCB, 085E5AB5, 4B03AF04, 811BEA82
DC63973F, 0F511FD8, F72EEC32, 085E5AB5, 4B03AF04
4C986405, DC63973F, 03D447F6, F72EEC32, 085E5AB5
32DE1CBA, 4C986405, F718E5CF, 03D447F6, F72EEC32
FC87DEDF, 32DE1CBA, 53261901, F718E5CF, 03D447F6
970A0D5C, FC87DEDF, 8CB7872E, 53261901, F718E5CF
7F193DC5, 970A0D5C, FF21F7B7, 8CB7872E, 53261901
EE1B1AAF, 7F193DC5, 25C28357, FF21F7B7, 8CB7872E
40F28E09, EE1B1AAF, 5FC64F71, 25C28357, FF21F7B7
1C51E1F2, 40F28E09, FB86C6AB, 5FC64F71, 25C28357
A01B846C, 1C51E1F2, 503CA382, FB86C6AB, 5FC64F71
BEAD02CA, A01B846C, 8714787C, 503CA382, FB86C6AB
BAF39337, BEAD02CA, 2806E11B, 8714787C, 503CA382
120731C5, BAF39337, AFAB40B2, 2806E11B, 8714787C
641DB2CE, 120731C5, EEBCE4CD, AFAB40B2, 2806E11B
3847AD66, 641DB2CE, 4481CC71, EEBCE4CD, AFAB40B2
E490436D, 3847AD66, 99076CB3, 4481CC71, EEBCE4CD
27E9F1D8, E490436D, 8E11EB59, 99076CB3, 4481CC71
7B71F76D, 27E9F1D8, 792410DB, 8E11EB59, 99076CB3
5E6456AF, 7B71F76D, 09FA7C76, 792410DB, 8E11EB59
C846093F, 5E6456AF, 5EDC7DDB, 09FA7C76, 792410DB
D262FF50, C846093F, D79915AB, 5EDC7DDB, 09FA7C76
09D785FD, D262FF50, F211824F, D79915AB, 5EDC7DDB
3F52DE5A, 09D785FD, 3498BFD4, F211824F, D79915AB
D756C147, 3F52DE5A, 4275E17F, 3498BFD4, F211824F
548C9CB2, D756C147, 8FD4B796, 4275E17F, 3498BFD4
B66C020B, 548C9CB2, F5D5B051, 8FD4B796, 4275E17F
6B61C9E1, B66C020B, 9523272C, F5D5B051, 8FD4B796
19DFA7AC, 6B61C9E1, ED9B0082, 9523272C, F5D5B051
101655F9, 19DFA7AC, 5AD87278, ED9B0082, 9523272C
0C3DF2B4, 101655F9, 0677E9EB, 5AD87278, ED9B0082
78DD4D2B, 0C3DF2B4, 4405957E, 0677E9EB, 5AD87278
497093C0, 78DD4D2B, 030F7CAD, 4405957E, 0677E9EB
3F2588C2, 497093C0, DE37534A, 030F7CAD, 4405957E
C199F8C7, 3F2588C2, 125C24F0, DE37534A, 030F7CAD

39859DE7, C199F8C7, 8FC96230, 125C24F0, DE37534A
 EDB42DE4, 39859DE7, F0667E31, 8FC96230, 125C24F0
 11793F6F, EDB42DE4, CE616779, F0667E31, 8FC96230
 5EE76897, 11793F6F, 3B6D0B79, CE616779, F0667E31
 63F7DAB7, 5EE76897, C45E4FDB, 3B6D0B79, CE616779
 A079B7D9, 63F7DAB7, D7B9DA25, C45E4FDB, 3B6D0B79
 860D21CC, A079B7D9, D8FDF6AD, D7B9DA25, C45E4FDB
 5738D5E1, 860D21CC, 681E6DF6, D8FDF6AD, D7B9DA25
 42541B35, 5738D5E1, 21834873, 681E6DF6, D8FDF6AD

The hash-code is the following 160-bit string.

A9 99 3E 36 47 06 81 6A BA 3E 25 71 78 50 C2 6C 9C D0 D8 9D

A.4.4 Example 4

In this example the data-string is the 14-byte string consisting of the ASCII-coded version of

'message digest'

The hash-code is the following 160-bit string.

C1 22 52 CE DA 8B E8 99 4D 5F A0 29 0A 47 23 1C 1D 16 AA E3

A.4.5 Example 5

In this example the data-string is the 26-byte string consisting of the ASCII-coded version of

'abcdefghijklmnopqrstuvwxy'

The hash-code is the following 160-bit string.

32 D1 0C 7B 8C F9 65 70 CA 04 CE 37 F2 A1 9D 84 24 0D 3A 89

A.4.6 Example 6

In this example the data-string is the 62-byte string consisting of the ASCII-coded version of

'ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxy0123456789'

The hash-code is the following 160-bit string.

76 1C 45 7B F7 3B 14 D2 7E 9E 92 65 C4 6F 4B 4D DA 11 F9 40

A.4.7 Example 7

In this example the data-string is the 80-byte string consisting of the ASCII-coded version of eight repetitions of

'1234567890'

The hash-code is the following 160-bit string.

50 AB F5 70 6A 15 09 90 A0 8B 2C 5E A4 0F A0 E5 85 55 47 32

A.4.8 Example 8

In this example the data-string is the 56-byte string consisting of the ASCII-coded version of

'abcdbcdecdefdefgefghfghighijhijkijklklmklmnlmnomnopnpq'

After the padding process, the two 16-word blocks derived from the data-string are as follows.

61626364	62636465	63646566	64656667	65666768	66676869	6768696A	68696A6B
696A6B6C	6A6B6C6D	6B6C6D6E	6C6D6E6F	6D6E6F70	6E6F7071	80000000	00000000
00000000	00000000	00000000	00000000	00000000	00000000	00000000	00000000
00000000	00000000	00000000	00000000	00000000	00000000	00000000	000001C0

The following are (hexadecimal representations of) the successive values of the variables X_0 , X_1 , X_2 , X_3 , X_4 , obtained during the processing of the first block.

0116FC17, 67452301, 7BF36AE2, 98BADCFE, 10325476
 EBF3B452, 0116FC17, 59D148C0, 7BF36AE2, 98BADCFE
 5109913A, EBF3B452, C045BF05, 59D148C0, 7BF36AE2
 2C4F6EAC, 5109913A, BAFCE1D4, C045BF05, 59D148C0
 33F4AE5B, 2C4F6EAC, 9442644E, BAFCE1D4, C045BF05
 96B85189, 33F4AE5B, 0B13DBAB, 9442644E, BAFCE1D4
 DB04CB58, 96B85189, CCFD2B96, 0B13DBAB, 9442644E
 45833F0F, DB04CB58, 65AE1462, CCFD2B96, 0B13DBAB
 C565C35E, 45833F0F, 36C132D6, 65AE1462, CCFD2B96
 6350AFDA, C565C35E, D160CFC3, 36C132D6, 65AE1462
 8993EA77, 6350AFDA, B15970D7, D160CFC3, 36C132D6
 E19ECAA2, 8993EA77, 98D42BF6, B15970D7, D160CFC3
 8603481E, E19ECAA2, E264FA9D, 98D42BF6, B15970D7
 32F94A85, 8603481E, B867B2A8, E264FA9D, 98D42BF6
 B2E7A8BE, 32F94A85, A180D207, B867B2A8, E264FA9D
 42637E39, B2E7A8BE, 4CBE52A1, A180D207, B867B2A8
 6B068048, 42637E39, ACB9EA2F, 4CBE52A1, A180D207
 426B9C35, 6B068048, 5098DF8E, ACB9EA2F, 4CBE52A1
 944B1BD1, 426B9C35, 1AC1A012, 5098DF8E, ACB9EA2F
 6C445652, 944B1BD1, 509AE70D, 1AC1A012, 5098DF8E
 95836DA5, 6C445652, 6512C6F4, 509AE70D, 1AC1A012
 09511177, 95836DA5, 9B111594, 6512C6F4, 509AE70D
 E2B92DC4, 09511177, 6560DB69, 9B111594, 6512C6F4
 FD224575, E2B92DC4, C254445D, 6560DB69, 9B111594
 EEB82D9A, FD224575, 38AE4B71, C254445D, 6560DB69
 5A142C1A, EEB82D9A, 7F48915D, 38AE4B71, C254445D
 2972F7C7, 5A142C1A, BBAE0B66, 7F48915D, 38AE4B71
 D526A644, 2972F7C7, 96850B06, BBAE0B66, 7F48915D
 E1122421, D526A644, CA5CBDF1, 96850B06, BBAE0B66
 05B457B2, E1122421, 3549A991, CA5CBDF1, 96850B06
 A9C84BEC, 05B457B2, 78448908, 3549A991, CA5CBDF1
 52E31F60, A9C84BEC, 816D15EC, 78448908, 3549A991

5AF3242C, 52E31F60, 2A7212FB, 816D15EC, 78448908
 31C756A9, 5AF3242C, 14B8C7D8, 2A7212FB, 816D15EC
 E9AC987C, 31C756A9, 16BCC90B, 14B8C7D8, 2A7212FB
 AB7C32EE, E9AC987C, 4C71D5AA, 16BCC90B, 14B8C7D8
 5933FC99, AB7C32EE, 3A6B261F, 4C71D5AA, 16BCC90B
 43F87AE9, 5933FC99, AADF0CBB, 3A6B261F, 4C71D5AA
 24957F22, 43F87AE9, 564CFF26, AADF0CBB, 3A6B261F
 ADEB7478, 24957F22, 50FE1EBA, 564CFF26, AADF0CBB
 D70E5010, ADEB7478, 89255FC8, 50FE1EBA, 564CFF26
 79BCFB08, D70E5010, 2B7ADD1E, 89255FC8, 50FE1EBA
 F9BCB8DE, 79BCFB08, 35C39404, 2B7ADD1E, 89255FC8
 633E9561, F9BCB8DE, 1E6F3EC2, 35C39404, 2B7ADD1E
 98C1EA64, 633E9561, BE6F2E37, 1E6F3EC2, 35C39404
 C6EA241E, 98C1EA64, 58CFA558, BE6F2E37, 1E6F3EC2
 A2AD4F02, C6EA241E, 26307A99, 58CFA558, BE6F2E37
 C8A69090, A2AD4F02, B1BA8907, 26307A99, 58CFA558
 88341600, C8A69090, A8AB53C0, B1BA8907, 26307A99
 7EB46F58, 88341600, 3229A424, A8AB53C0, B1BA8907
 86E358BA, 7EB46F58, 220D0580, 3229A424, A8AB53C0
 8D2E76C8, 86E358BA, 1FA11BD6, 220D0580, 3229A424
 CE892E10, 8D2E76C8, A1B8D62E, 1FA11BD6, 220D0580
 EDEA95B1, CE892E10, 234B9DB2, A1B8D62E, 1FA11BD6
 36D1230A, EDEA95B1, 33A24B84, 234B9DB2, A1B8D62E
 776C3910, 36D1230A, 7B7AA56C, 33A24B84, 234B9DB2
 A681B723, 776C3910, 8DB448C2, 7B7AA56C, 33A24B84
 ACOA794F, A681B723, 1DDB0E44, 8DB448C2, 7B7AA56C
 F03D3782, ACOA794F, E9A06DC8, 1DDB0E44, 8DB448C2
 9EF775C3, F03D3782, EB029E53, E9A06DC8, 1DDB0E44
 36254B13, 9EF775C3, BCOF4DE0, EB029E53, E9A06DC8
 4080D4DC, 36254B13, E7BDD70, BCOF4DE0, EB029E53
 2BFAF7A8, 4080D4DC, CD8952C4, E7BDD70, BCOF4DE0
 513F9CA0, 2BFAF7A8, 10203537, CD8952C4, E7BDD70
 E5895C81, 513F9CA0, 0AFEBDEA, 10203537, CD8952C4
 1037D2D5, E5895C81, 144FE728, 0AFEBDEA, 10203537
 14A82DA9, 1037D2D5, 79625720, 144FE728, 0AFEBDEA
 6D17C9FD, 14A82DA9, 440DF4B5, 79625720, 144FE728
 2C7B07BD, 6D17C9FD, 452A0B6A, 440DF4B5, 79625720
 FDF6EFFF, 2C7B07BD, 5B45F27F, 452A0B6A, 440DF4B5
 112B96E3, FDF6EFFF, 4B1EC1EF, 5B45F27F, 452A0B6A
 84065712, 112B96E3, FF7DBBFF, 4B1EC1EF, 5B45F27F
 AB89FB71, 84065712, C44AE5B8, FF7DBBFF, 4B1EC1EF
 C5210E35, AB89FB71, A10195C4, C44AE5B8, FF7DBBFF
 352D9F4B, C5210E35, 6AE27EDC, A10195C4, C44AE5B8
 1A0E0E0A, 352D9F4B, 7148438D, 6AE27EDC, A10195C4
 D0D47349, 1A0E0E0A, CD4B67D2, 7148438D, 6AE27EDC
 AD38620D, D0D47349, 86838382, CD4B67D2, 7148438D
 D3AD7C25, AD38620D, 74351CD2, 86838382, CD4B67D2
 8CE34517, D3AD7C25, 6B4E1883, 74351CD2, 86838382

The following are (hexadecimal representations of) the successive values of the variables X_0 , X_1 , X_2 , X_3 , X_4 , obtained during the processing of the second block.

2DF257E9, F4286818, B0DEC9EB, 0408F581, 84677148
 4D3DC58F, 2DF257E9, 3D0A1A06, B0DEC9EB, 0408F581
 C352BB05, 4D3DC58F, 4B7C95FA, 3D0A1A06, B0DEC9EB
 EEF743C6, C352BB05, D34F7163, 4B7C95FA, 3D0A1A06
 41E34277, EEF743C6, 70D4AEC1, D34F7163, 4B7C95FA
 5443915C, 41E34277, BBBDD0F1, 70D4AEC1, D34F7163
 E7FA0377, 5443915C, D078D09D, BBBDD0F1, 70D4AEC1
 C6946813, E7FA0377, 1510E457, D078D09D, BBBDD0F1

FDDE1DE1, C6946813, F9FE80DD, 1510E457, D078D09D
 B8538ACA, FDDE1DE1, F1A51A04, F9FE80DD, 1510E457
 6BA94F63, B8538ACA, 7F778778, F1A51A04, F9FE80DD
 43A2792F, 6BA94F63, AE14E2B2, 7F778778, F1A51A04
 FECD7BBF, 43A2792F, DAEA53D8, AE14E2B2, 7F778778
 A2604CA8, FECD7BBF, D0E89E4B, DAEA53D8, AE14E2B2
 258B0BAA, A2604CA8, FFB35EEF, D0E89E4B, DAEA53D8
 D9772360, 258B0BAA, 2898132A, FFB35EEF, D0E89E4B
 5507DB6E, D9772360, 8962C2EA, 2898132A, FFB35EEF
 A51B58BC, 5507DB6E, 365DC8D8, 8962C2EA, 2898132A
 C2EB709F, A51B58BC, 9541F6DB, 365DC8D8, 8962C2EA
 D8992153, C2EB709F, 2946D62F, 9541F6DB, 365DC8D8
 37482F5F, D8992153, F0BADC27, 2946D62F, 9541F6DB
 EE8700BD, 37482F5F, F6264854, F0BADC27, 2946D62F
 9AD594B9, EE8700BD, CDD20BD7, F6264854, F0BADC27
 8FBAA5B9, 9AD594B9, 7BA1C02F, CDD20BD7, F6264854
 88FB5867, 8FBAA5B9, 66B5652E, 7BA1C02F, CDD20BD7
 EEC50521, 88FB5867, 63EEA96E, 66B5652E, 7BA1C02F
 50BCE434, EEC50521, E23ED619, 63EEA96E, 66B5652E
 5C416DAF, 50BCE434, 7BB14148, E23ED619, 63EEA96E
 2429BE5F, 5C416DAF, 142F390D, 7BB14148, E23ED619
 0A2FB108, 2429BE5F, D7105B6B, 142F390D, 7BB14148
 17986223, 0A2FB108, C90A6F97, D7105B6B, 142F390D
 8A4AF384, 17986223, 028BEC42, C90A6F97, D7105B6B
 6B629993, 8A4AF384, C5E61888, 028BEC42, C90A6F97
 F15F04F3, 6B629993, 2292BCE1, C5E61888, 028BEC42
 295CC25B, F15F04F3, DAD8A664, 2292BCE1, C5E61888
 696DA404, 295CC25B, FC57C13C, DAD8A664, 2292BCE1
 CEF5AE12, 696DA404, CA573096, FC57C13C, DAD8A664
 87D5B80C, CEF5AE12, 1A5B6901, CA573096, FC57C13C
 84E2A5F2, 87D5B80C, B3BD6B84, 1A5B6901, CA573096
 03BB6310, 84E2A5F2, 21F56E03, B3BD6B84, 1A5B6901
 C2D8F75F, 03BB6310, A138A97C, 21F56E03, B3BD6B84
 BFB25768, C2D8F75F, 00EED8C4, A138A97C, 21F56E03
 28589152, BFB25768, F0B63DD7, 00EED8C4, A138A97C
 EC1D3D61, 28589152, 2FEC95DA, F0B63DD7, 00EED8C4
 3CAED7AF, EC1D3D61, 8A162454, 2FEC95DA, F0B63DD7
 C3D033EA, 3CAED7AF, 7B074F58, 8A162454, 2FEC95DA
 7316056A, C3D033EA, CF2BB5EB, 7B074F58, 8A162454
 46F93B68, 7316056A, B0F40CFA, CF2BB5EB, 7B074F58
 DC8E7F26, 46F93B68, 9CC5815A, B0F40CFA, CF2BB5EB
 850D411C, DC8E7F26, 11BE4EDA, 9CC5815A, B0F40CFA
 7E4672C0, 850D411C, B7239FC9, 11BE4EDA, 9CC5815A
 89FBD41D, 7E4672C0, 21435047, B7239FC9, 11BE4EDA
 1797E228, 89FBD41D, 1F919CB0, 21435047, B7239FC9
 431D65BC, 1797E228, 627EF507, 1F919CB0, 21435047
 2BDBB8CB, 431D65BC, 05E5F88A, 627EF507, 1F919CB0
 6DA72E7F, 2BDBB8CB, 10C7596F, 05E5F88A, 627EF507
 A8495A9B, 6DA72E7F, CAF6EE32, 10C7596F, 05E5F88A
 E785655A, A8495A9B, DB69CB9F, CAF6EE32, 10C7596F
 5B086C42, E785655A, EA1256A6, DB69CB9F, CAF6EE32
 A65818F7, 5B086C42, B9E15956, EA1256A6, DB69CB9F
 7AAB101B, A65818F7, 96C21B10, B9E15956, EA1256A6
 93614C9C, 7AAB101B, E996063D, 96C21B10, B9E15956
 F66D9BF4, 93614C9C, DEAAC406, E996063D, 96C21B10
 D504902B, F66D9BF4, 24D85327, DEAAC406, E996063D
 60A9DA62, D504902B, 3D9B66FD, 24D85327, DEAAC406
 8B687819, 60A9DA62, F541240A, 3D9B66FD, 24D85327
 083E90C3, 8B687819, 982A7698, F541240A, 3D9B66FD
 F6226BBF, 083E90C3, 62DA1E06, 982A7698, F541240A
 76C0563B, F6226BBF, C20FA430, 62DA1E06, 982A7698

989DD165, 76C0563B, FD889AEF, C20FA430, 62DA1E06
 8B2C7573, 989DD165, DDB0158E, FD889AEF, C20FA430
 AE1B8E7B, 8B2C7573, 66277459, DDB0158E, FD889AEF
 CA1840DE, AE1B8E7B, E2CB1D5C, 66277459, DDB0158E
 16F3BABB, CA1840DE, EB86E39E, E2CB1D5C, 66277459
 D28D83AD, 16F3BABB, B2861037, EB86E39E, E2CB1D5C
 6BC02DFE, D28D83AD, C5BCEEAE, B2861037, EB86E39E
 D3A6E275, 6BC02DFE, 74A360EB, C5BCEEAE, B2861037
 DA955482, D3A6E275, 9AF00B7F, 74A360EB, C5BCEEAE
 58C0AAC0, DA955482, 74E9B89D, 9AF00B7F, 74A360EB
 906FD62C, 58C0AAC0, B6A55520, 74E9B89D, 9AF00B7F

The hash-code is the following 160-bit string.

84 98 3E 44 1C 3B D2 6E BA AE 4A A1 F9 51 29 E5 E5 46 70 F1

A.4.9 Example 9

In this example the data-string is the 1000000-byte string consisting of the ASCII-coded version of 'a' repeated 10^6 times.

The hash-code is the following 160-bit string.

34 AA 97 3C D4 C4 DA A4 F6 1E EB 2B DB AD 27 31 65 34 01 6F

Annex B

(Informative)

Formal specifications

B.0 Introduction

In the following sections are complete specifications of the Dedicated Hash-Functions 1, 2 and 3 in the specification language called Z. The notation for Z is that as described in [1].

The Z retains much of the naming, structure, etc. used in the main body of this standard.

The Z is written purely in Z, including the comments. The comments point to sections of the main text of the standard from which the Z is derived.

The Z models a message as a sequence of natural numbers 0 and 1 (*String*).

B.1 Specification of Dedicated Hash-Function 1

#3 Definitions

#3.2 round-function

$Bit == \{0, 1\}$

$String == \text{seq } Bit$

$$\left| \begin{array}{l} L_1 : \mathbb{N} \\ L_2 : \mathbb{N}_1 \end{array} \right.$$

$String_L_1 == \{s : String \mid \#s = L_1\}$

$String_L_2 == \{s : String \mid \#s \in L_2\}$

$\left| \phi : String_L_1 \times String_L_2 \rightarrow String_L_2 \right.$

#3.3 word

$Word == \{w : String \mid \#w = 32\}$

$Word_capacity == 2 \uparrow 32$

$Word_capacity_m_1 == (2 \uparrow 32) - 1$

$IWord == 0 .. Word_capacity_m_1$

#4 Symbols and notation

$S^n()$ It is only necessary to define S as S^n (relation iteration) is defined in Z.

$$\left| \begin{array}{l} S : Word \rightarrow Word \\ \forall A : Word \bullet \\ \quad (\text{let } I == W_to_I(A) \bullet \\ \quad (\text{let } Shift_I == (I * 2 + (I \text{ div } (2 \uparrow 31))) \text{ mod } (2 \uparrow 32) \bullet \\ \quad \quad S(A) = I_to_W(Shift_I))) \end{array} \right.$$

$\wedge \vee \oplus$ These are defined for words only as that is all that is required.

$$BO == Bit \times Bit \rightarrow Bit$$

$LO : Word \times Word \times BO \rightarrow Word$ $\forall p, q : Word; bo : BO \bullet$ $LO(p, q, bo) = \{ n : 1.. \#p \bullet n \mapsto bo(p(n), q(n)) \}$

$_xor _, _or _, _and _ : BO$

$$0 \text{ xor } 1 = 1$$

$$0 \text{ xor } 0 = 0$$

$$1 \text{ xor } 0 = 1$$

$$1 \text{ xor } 1 = 0$$

$$0 \text{ or } 1 = 1$$

$$0 \text{ or } 0 = 0$$

$$1 \text{ or } 0 = 1$$

$$1 \text{ or } 1 = 1$$

$$0 \text{ and } 1 = 0$$

$$0 \text{ and } 0 = 0$$

$$1 \text{ and } 0 = 0$$

$$1 \text{ and } 1 = 1$$

$_XOR _, _OR _, _AND _ : Word \times Word \rightarrow Word$

$$\forall A, B : Word \bullet$$

$$A \text{ XOR } B = LO(A, B, (_xor _)) \wedge$$

$$A \text{ OR } B = LO(A, B, (_or _)) \wedge$$

$$A \text{ AND } B = LO(A, B, (_and _))$$

¬

$NOT : Word \rightarrow Word$

$$\forall A : Word \bullet$$

$$NOT A = A \text{ XOR } \{ n : 1.. \#A \bullet n \mapsto 1 \}$$

⊕

$_⊕ _ : Word \times Word \rightarrow Word$
--

$$\forall A, B : Word \bullet$$

$$A \oplus B = I_to_W((W_to_I(A) + W_to_I(B)) \bmod Word_capacity)$$

#5 Requirements

#6 Model for dedicated hash-functions

#6.1 General

$$\frac{L_H : \mathbb{N}_1}{L_H \leq L_2}$$

Byte == { *b* : *String* | #*b* = 8 }

Byte == 0 .. 255

$$\frac{B_to_I : \textit{Byte} \longrightarrow \textit{Byte}}{\forall x : \textit{Byte} \bullet B_to_I(x) = x(1) * 2 \uparrow 7 + x(2) * 2 \uparrow 6 + x(3) * 2 \uparrow 5 + x(4) * 2 \uparrow 4 + x(5) * 2 \uparrow 3 + x(6) * 2 \uparrow 2 + x(7) * 2 + x(8)}$$

#6.2 Hashing operation

| *IV* : *String*_{*L*2}

| *Maximum_Length_of_String* : \mathbb{N}

$$\frac{hash : \textit{String} \twoheadrightarrow \textit{String}_{L_H}}{\forall D : \textit{String} \mid \#D \leq \textit{Maximum_Length_of_String} \bullet hash(D) = (\textit{let } PD == \textit{pad}(D) \bullet (\textit{let } SD == \textit{split}(PD) \bullet (\textit{let } H_q \twoheadrightarrow \textit{iterate}(SD, IV) \bullet \textit{truncate}(H_q))))}$$

#6.2.1 Step 1 (padding)

*StringMultiple*_{*L*1} == { *s* : *String* | #*s* mod *L*₁ = 0 }

| *pad* : *String* → *StringMultiple*_{*L*1}

#6.2.2 Step 2 (splitting)

StringBlocks == seq *String*_{*L*1}

$$\frac{split : \textit{StringMultiple}_{L_1} \longrightarrow \textit{StringBlocks}}{split = \{ sml1 : \textit{StringMultiple}_{L_1}; sb : \textit{StringBlocks} \mid sml1 = \wedge / sb \bullet sml1 \mapsto sb \}}$$

#6.2.3 Step 3 (iteration)

$$\frac{iterate : \textit{StringBlocks} \times \textit{String}_{L_2} \twoheadrightarrow \textit{String}_{L_2}}{\forall sb : \textit{StringBlocks}; H_{i-1} : \textit{String}_{L_2} \mid \#sb \geq 1 \bullet iterate(sb, H_{i-1}) = (\textit{let } D_i == sb(1) \bullet (\textit{let } H_i == \phi(D_i, H_{i-1}) \bullet \textit{if } \#sb = 1 \textit{ then } H_i \textit{ else } iterate(\textit{tail } sb, H_i)))}$$

#6.2.4 Step 4 (truncation)

$$\text{String_}L_H == \{ s : \text{String} \mid \#s = L_H \}$$

$\text{truncate} : \text{String_}L_2 \rightarrow \text{String_}L_H$	
$\forall sy : \text{String_}L_2 \bullet$	$\text{truncate}(sy) = (1..L_H) \mid sy$

#7 Dedicated Hash-Function 1**#7.1 General**

$$\text{Maximum_Length_of_String} = (2 \uparrow 64) - 1$$
#7.2 Parameters, functions and constants**#7.2.1 Parameters**

$$L_1 = 512$$

$$L_2 = 160$$

$$L_H = 160$$
#7.2.2 Byte ordering convention

$W_to_I : \text{Word} \rightarrow \text{IWord}$	
$\forall w : \text{Word} \bullet$	$W_to_I(w) =$
	$(\text{let } B_0 == B_to_I((1..8) \mid w) \bullet$
	$(\text{let } B_1 == B_to_I((9..16) \mid w) \bullet$
	$(\text{let } B_2 == B_to_I((17..24) \mid w) \bullet$
	$(\text{let } B_3 == B_to_I((25..32) \mid w) \bullet$
	$B_3 * 2 \uparrow 24 + B_2 * 2 \uparrow 16 + B_1 * 2 \uparrow 8 + B_0))$

$I_to_W : \text{IWord} \rightarrow \text{Word}$	
$I_to_W = W_to_I \sim$	

#7.2.3 Functions

$$\text{Indexed_g} == \{ g : \text{seq}(\text{Word} \times \text{Word} \times \text{Word} \rightarrow \text{Word}) \mid \#g = 80 \}$$

$g : \text{Indexed_g}$ $\forall X_0, X_1, X_2 : \text{Word} \bullet$ $(\forall i : 1..16 \bullet$ $g(i)(X_0, X_1, X_2) = X_0 \text{ XOR } X_1 \text{ XOR } X_2) \wedge$ $(\forall i : 17..32 \bullet$ $g(i)(X_0, X_1, X_2) = (X_0 \text{ AND } X_1) \text{ OR } (\text{NOT } X_0 \text{ AND } X_2)) \wedge$ $(\forall i : 33..48 \bullet$ $g(i)(X_0, X_1, X_2) = (X_0 \text{ OR } \text{NOT } X_1) \text{ XOR } X_2) \wedge$ $(\forall i : 49..64 \bullet$ $g(i)(X_0, X_1, X_2) = (X_0 \text{ AND } X_2) \text{ OR } (X_1 \text{ AND } \text{NOT } X_2)) \wedge$ $(\forall i : 65..80 \bullet$ $g(i)(X_0, X_1, X_2) = X_0 \text{ XOR } (X_1 \text{ OR } \text{NOT } X_2))$
--

#7.2.4 Constants

$x00000000 == 0$
 $x5A827999 == 1518500249$
 $x6ED9EBA1 == 1859775393$
 $x8F1BBCDC == 2400959708$
 $xA953FD4E == 2840853838$

$x50A28BE6 == 1352829926$
 $x5C4DD124 == 1548603684$
 $x6D703EF3 == 1836072691$
 $x7A6D76E9 == 2053994217$

$\text{Constants} == \{ c : \text{StringWord} \mid \#c = 80 \}$

<p><i>C, C' : Constants</i></p> <p>($\forall i : 1..16 \bullet$ $C(i) = I_to_W(x00000000)) \wedge$</p> <p>($\forall i : 17..32 \bullet$ $C(i) = I_to_W(x5A827999)) \wedge$</p> <p>($\forall i : 33..48 \bullet$ $C(i) = I_to_W(x6ED9EBA1)) \wedge$</p> <p>($\forall i : 49..64 \bullet$ $C(i) = I_to_W(x8F1BBCDC)) \wedge$</p> <p>($\forall i : 65..80 \bullet$ $C(i) = I_to_W(xA953FD4E)) \wedge$</p> <p>($\forall i : 1..16 \bullet$ $C'(i) = I_to_W(x50A28BE6)) \wedge$</p> <p>($\forall i : 17..32 \bullet$ $C'(i) = I_to_W(x5C4DD124)) \wedge$</p> <p>($\forall i : 33..48 \bullet$ $C'(i) = I_to_W(x6D703EF3)) \wedge$</p> <p>($\forall i : 49..64 \bullet$ $C'(i) = I_to_W(x7A6D76E9)) \wedge$</p> <p>($\forall i : 65..80 \bullet$ $C'(i) = I_to_W(x00000000))$</p>
--

$t ==$
 {11, 14, 15, 12, 5, 8, 7, 9, 11, 13, 14, 15, 6, 7, 9, 8,
 7, 6, 8, 13, 11, 9, 7, 15, 7, 12, 15, 9, 11, 7, 13, 12,
 11, 13, 6, 7, 14, 9, 13, 15, 14, 8, 13, 6, 5, 12, 7, 5,
 11, 12, 14, 15, 14, 15, 9, 8, 9, 14, 5, 6, 8, 6, 5, 12,
 9, 15, 5, 11, 6, 8, 13, 12, 5, 12, 13, 14, 11, 8, 5, 6}

$t' ==$
 {8, 9, 9, 11, 13, 15, 15, 5, 7, 7, 8, 11, 14, 14, 12, 6,
 9, 13, 15, 7, 12, 8, 9, 11, 7, 7, 12, 7, 6, 15, 13, 11,
 9, 7, 15, 11, 8, 6, 6, 14, 12, 13, 5, 14, 13, 13, 7, 5,
 15, 5, 8, 11, 14, 14, 6, 14, 6, 9, 12, 9, 12, 5, 15, 8,
 8, 5, 12, 9, 12, 5, 14, 6, 8, 13, 6, 5, 15, 13, 11, 11}

Note values for a and a' are one greater than the normative text as sequences in Z start at 1.

$a ==$
 {1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16,
 8, 5, 14, 2, 11, 7, 16, 4, 13, 1, 10, 6, 3, 15, 12, 9,
 4, 11, 15, 5, 10, 16, 9, 2, 3, 8, 1, 7, 14, 12, 6, 13,
 2, 10, 12, 11, 1, 9, 13, 5, 14, 4, 8, 16, 15, 6, 7, 3,
 5, 1, 6, 10, 8, 13, 3, 11, 15, 2, 4, 9, 12, 7, 16, 14}

$a' ==$
 (6, 15, 8, 1, 10, 3, 12, 5, 14, 7, 16, 9, 2, 11, 4, 13,
 7, 12, 4, 8, 1, 14, 6, 11, 15, 16, 9, 13, 5, 10, 2, 3,
 16, 6, 2, 4, 8, 15, 7, 10, 12, 9, 13, 3, 11, 1, 5, 14,
 9, 7, 5, 2, 4, 12, 16, 1, 6, 13, 3, 14, 10, 8, 11, 15,
 13, 16, 11, 5, 2, 6, 9, 8, 7, 3, 14, 15, 1, 4, 10, 12)

#7.2.5 Initializing Value

$x67452301 == 1732584193$
 $Y_0 == I_to_W(x67452301)$
 $xEFCDA89 == 4023233417$
 $Y_1 == I_to_W(xEFCDA89)$
 $x98BADCFE == 2562383102$
 $Y_2 == I_to_W(x98BADCFE)$
 $x10325476 == 271733878$
 $Y_3 == I_to_W(x10325476)$
 $xC3D2E1F0 == 3285377520$
 $Y_4 == I_to_W(xC3D2E1F0)$

$IV = Y_0 \wedge Y_1 \wedge Y_2 \wedge Y_3 \wedge Y_4$

#7.3 Padding method

$\forall D : String \bullet$
 $pad(D) =$
 (let $L_D == \#D \bullet$
 (let $Zeros == \{ n : 1..((447 - L_D) \bmod 512) \bullet n \mapsto 0 \} \bullet$
 (let $Length_D_LSH == I_to_W(L_D \bmod (2 \uparrow 32)) \bullet$
 (let $Length_D_MSH == I_to_W(L_D \text{ div } (2 \uparrow 32)) \bullet$
 $D \wedge \{1\} \wedge Zeros \wedge Length_D_LSH \wedge Length_D_MSH))))$

#7.4 Description of the round-function

$StringWord == seq\ Word$

$Split_String_to_StringWord : String \rightarrow StringWord$
$Split_String_to_StringWord =$ $\{ s : String; sw : StringWord \mid s = \wedge / sw \bullet s \mapsto sw \}$

$$\begin{array}{l} L80 : StringWord \times StringWord \times \\ Indexed_g \times seq \mathbb{N} \times seq \mathbb{N} \times \\ Constants \times 1 \dots 80 \longrightarrow StringWord \end{array}$$

$$\forall Z, X : StringWord; g : Indexed_g; t, a : seq \mathbb{N}; \\ C : Constants; i : 1 \dots 80 \mid \#Z = 16 \wedge \#X = 5 \bullet$$

$$\begin{array}{l} L80(Z, X, g, t, a, C, i) = \\ \quad (\text{let } X0 == X(1); X1 == X(2); X2 == X(3); X3 == X(4); X4 == X(5) \bullet \\ \quad (\text{let } W == S^{t(i)}(X0 \boxplus g(i)(X1, X2, X3) \boxplus Z(a(i)) \boxplus C(i)) \boxplus X4 \bullet \\ \quad (\text{let } Y == \langle X4, W, X1, S^{10}(X2), X3 \rangle \bullet \\ \quad \quad \text{if } (i = 80) \\ \quad \quad \text{then } Y \\ \quad \quad \text{else } L80(Z, Y, g, t, a, C, i + 1))) \end{array}$$

$$\forall sx : String_L_1; sy : String_L_2 \bullet$$

$$\begin{array}{l} \phi(sx, sy) = \\ \quad (\text{let } Z == Split_String_to_StringWord(sx) \bullet \\ \quad (\text{let } Y == Split_String_to_StringWord(sy) \bullet \\ \quad (\text{let } X == L80(Z, Y, g, t, a, C, 1) \bullet \\ \quad (\text{let } X' == L80(Z, Y, rev\ g, t', a', C', 1) \bullet \\ \quad (\text{let } Y0 == Y(2) \boxplus X(3) \boxplus X'(4) \bullet \\ \quad (\text{let } Y1 == Y(3) \boxplus X(4) \boxplus X'(5) \bullet \\ \quad (\text{let } Y2 == Y(4) \boxplus X(5) \boxplus X'(1) \bullet \\ \quad (\text{let } Y3 == Y(5) \boxplus X(1) \boxplus X'(2) \bullet \\ \quad (\text{let } Y4 == Y(1) \boxplus X(2) \boxplus X'(3) \bullet \\ \quad \quad Y0 \cap Y1 \cap Y2 \cap Y3 \cap Y4)))))) \end{array}$$

B.1.1 Auxiliary functions

$$\frac{}{- \uparrow - : \mathbb{N} \times \mathbb{N} \longrightarrow \mathbb{N}}$$

$$\forall p : \mathbb{N} \bullet$$

$$p \uparrow 0 = 1 \wedge$$

$$(\forall n : \mathbb{N}_1 \bullet p \uparrow n = p * (p \uparrow (n - 1)))$$