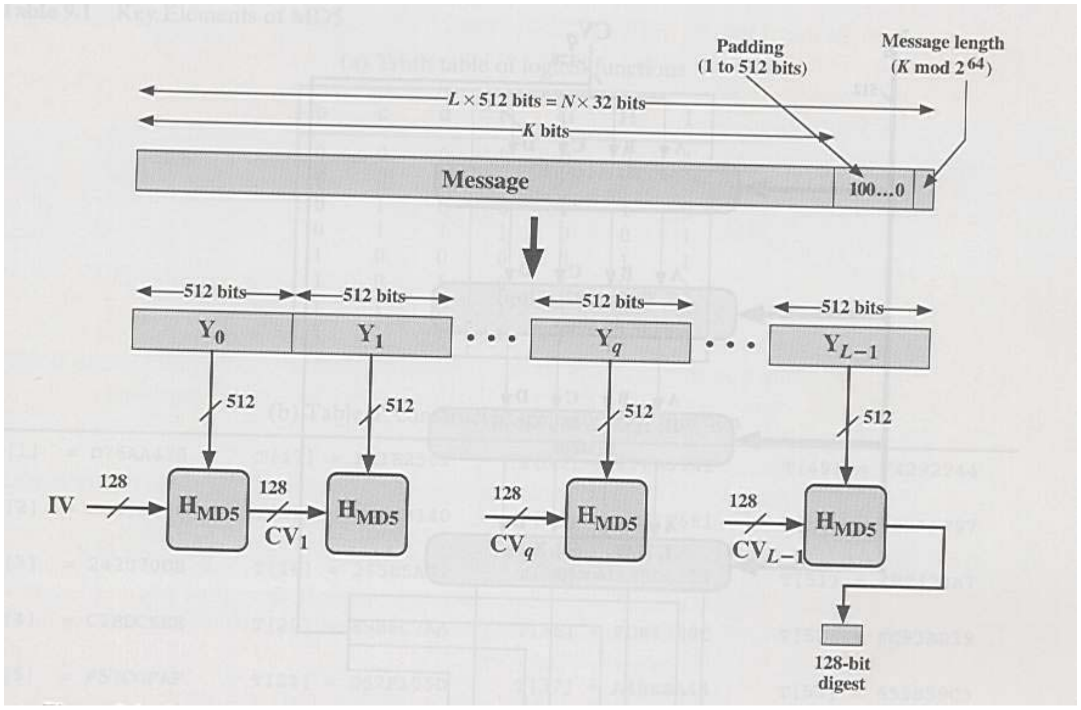
Week 14

MD5 message digest algorithm

The MD5 message-digest algorithm was developed by Ron Rivest at MIT. Until the last few years, when both brute-force and cryptanalytic concerns have arisen, MD5 was the most widely used secure hash algorithm.

MD5 logic. The algorithm takes as input a message of arbitrary length and produces as output a 128-bit message digest. The input is processed in 512-bit blocks. The processing consists of the following steps:

- **Step 1: Appending padding bits.** The massage is padded so that its length in bits is congruent to 448 modulo 512 (length ≡ 448 mod 512). That is, the length of the padded message is 64 bits less than an integer multiple of 512 bits. Padding is always is added, even if the message is already of the desired length. For example, if the message is 448 bits long, it is padded by 512 bits to a length of 960 bits. Thus, the number of padding bits is in the range of 1 to 512. The padding consists of a single 1-bit followed by the necessary number of 0-bits.



Message digest generation using MD5

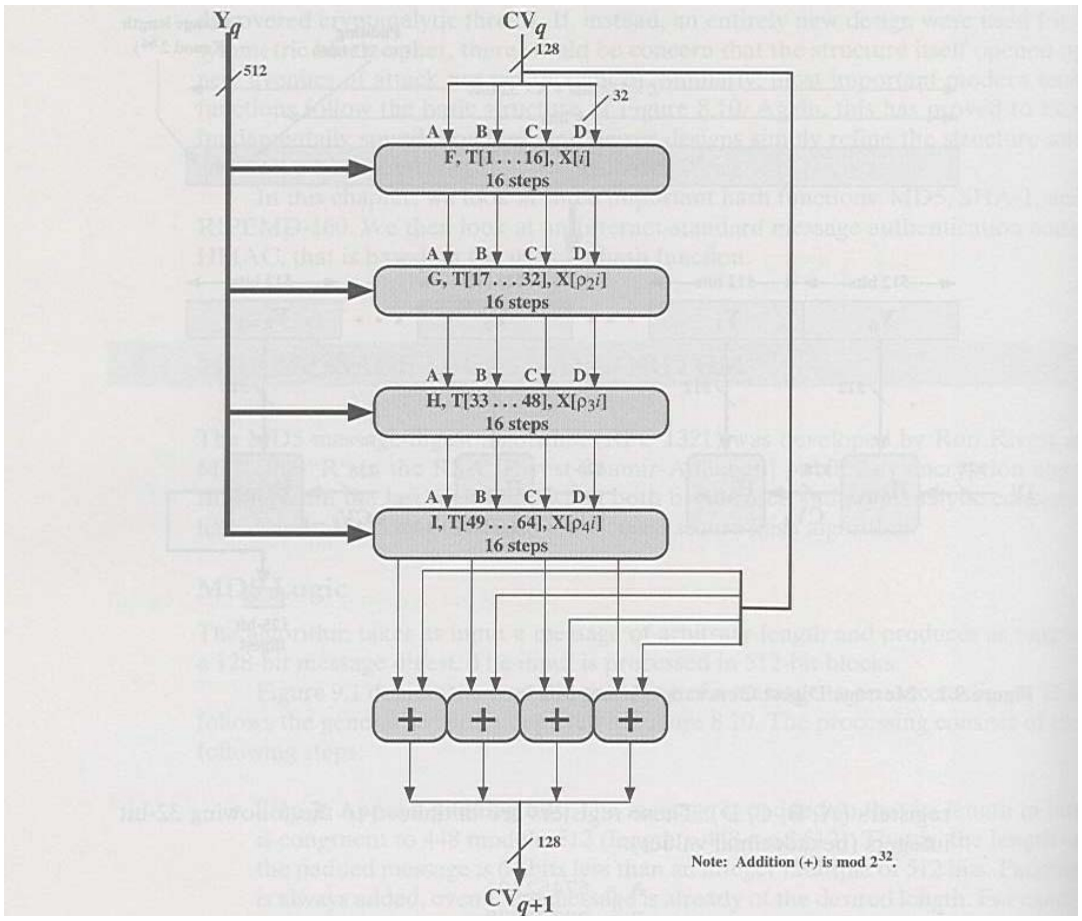
- **Step 2: Append length.** A 64-bit representation of the length in bits of the original message (before the padding) is appended to the result of step 1 (least significant byte first). If the original length is greater than 2^{64}, then only the low-order 64 bits of the length are used. Thus, field contains the length of the original message, modulo 2^{64}.

  The outcome of the first two steps yields a message that is an integer multiple of 512 bits in length. In figure below, expended message is represented as the sequence of 512-bit blocks $Y_0, Y_1, \ldots, Y_{L-1}$, so that the total length of the expanded message is $L \times 512$ bits. Equivalently, the result is a multiple of 16 32-bit words. Let $M[0 \ldots N-1]$ denote the words of the resulting message, with N an integer multiple of 16. Thus, $N = L \times 16$.
- **Step 3: Initialize MD buffer.** A 128-bit buffer is used to hold intermediate and final results of the hash function. The buffer can be represented as four 32-bit registers (A, B, C, D). These registers are initialized to the following 32-bit integers (hexadecimal values):

  A = 67452301
  B = EFCDAB89
  C = 98BADCFE
  D = 10325476

  These values are stored in little-endian format, which is the least significant byte of a word in the low-address byte position. As 32-bit strings, the initialization values (in hexadecimal) appears as follows:

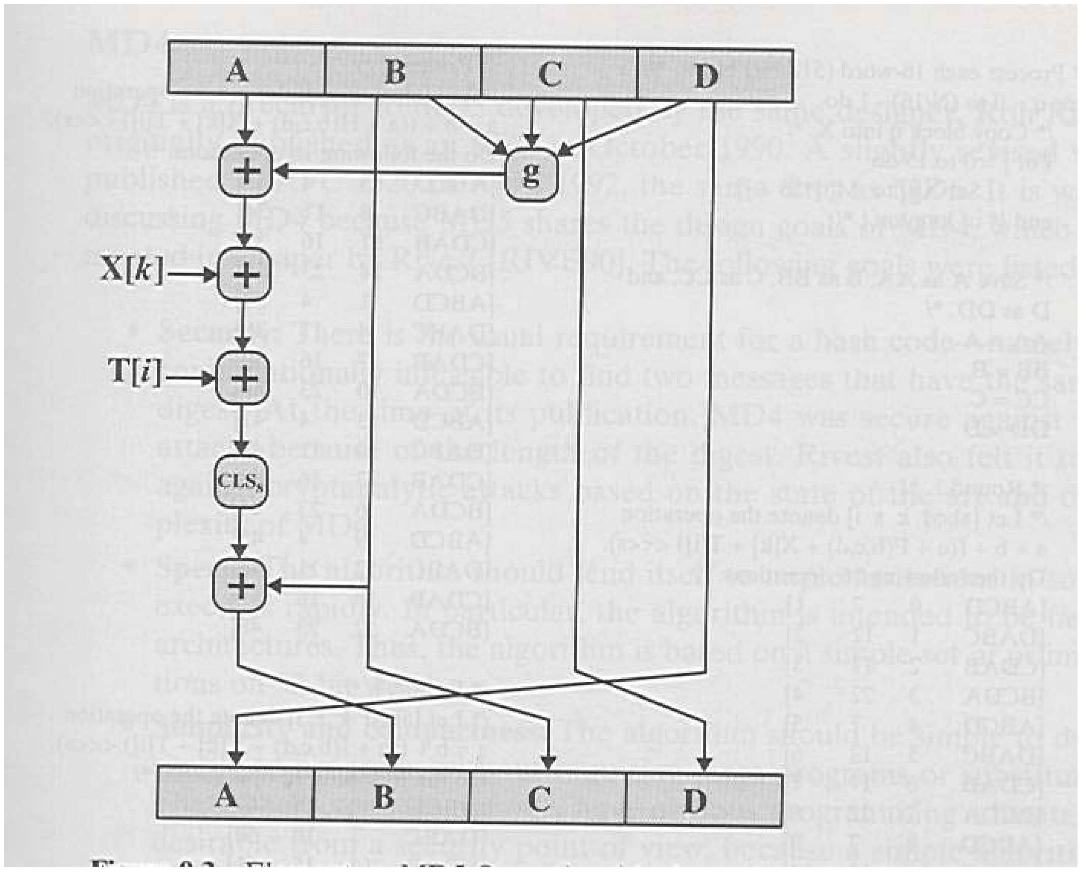
Word A:	01	23	45	67
Word B:	89	AB	CD	EF
Word C:	FE	DC	BA	98
Word D:	76	54	32	10



Y_q
CV_q
128
512
32
A B C D
F, T[1 . . . 16], X[i]
16 steps
G, T[17 . . . 32], X[$\rho_2 i$]
16 steps
H, T[33 . . . 48], X[$\rho_3 i$]
16 steps
I, T[49 . . . 64], X[$\rho_4 i$]
16 steps
+
128
Note: Addition (+) is mod 2^{32}.
CV_{q+1}

MD5 processing of a single 512-bit block (MD5 compression function)

- **Step 4: Process message in 512-bit (16-word) blocks.** The heart of the algorithm is a compression algorithm that consists of four "rounds" of processing; this module is labeled H_{MD5}. The four rounds have the similar structure, but each uses a different primitive logical function, referred to as *F*, *G*, *H*, and *I* in the specification.
  Each round takes as input the current 512-bit block being processed (Y_q) and the 28-bit buffer value ABCD and updates the contents of the buffer. Each round also makes use of one-fourth of a 64-element table $T[1...64]$, constructed from the sine function. The *i*th element of *T*, denoted *T*[*i*], has the value equal to the integer part of $2^{32} \times abs(\sin(i))$, where I is in radians.
- **Step 5: Output.** After all *L* 512-bit blocks have been processed, the output from the *L*th stage is the 160-bit message digest.



Elementary MD5 operation

We can summarize the behavior of MD5 as follows:

$$
\begin{aligned}
CV_0 &= IV \\
CV_{q+1} &= SUM_{32}(CV_q, RF_I[Y_q, RF_H[Y_q, RF_G[Y_q, RF_F[Y_q, CV_q]]]]) \\
MD &= CV_L
\end{aligned}
$$

where

IV - initial value of the ABCD buffer, defined in step 3

Y_q - the *q*th 512-bit block of the message

L - the number of blocks in the message (including padding and length fields)

CV_q - chaining variable processed with the *q*th block of the message

RF_x - round function using primitive logical function *x*

MD - final message digest value

SUM_{32} - addition modulo 2^{32} performed separately on each word of the pair of inputs

References

1. William Stallings. Cryptography and Networks Security. Prentice Hall.
2. Douglas E. Comer. Computer Networks and Internet. Prentice Hall.