ECAL Data Compression Study

Ph. Busson, A. Karar, G.B. Kim

(LPNHE, Palaiseau, France)

O Schedule of our Study in 1998

Our study \ Month		1	2	3	4	5	6	7	. . .	12
Time domain	Signal Modeling	→								
	Data compression		→	→	→	→	→	→	→	→
	DSP card				→	→	→	→	→	→
Space domain	Simulation the CMSIM							→	→	→

* We started studying data compression in space domain by using the CMSIM with D.W. Kim, S.C. Lee .

(Kangnung National University, South Korea)

1. Introduction

① The problem of the ECAL data volume in CMS:

- The full ECAL event size :

80,000 crystals × 10 pulse samples × 2bytes = 1.6 Mbytes

FPU+ADC system

80,000 crystals × 10 pulse samples × 3bytes = 2.4 Mbytes

in ULR

- CMS DAQ is ~1 Mbytes in total.

② How to reduce this volume ?

- Select "interesting" crystals :
  "Selective Readout" ⇒ ~100 kbytes/triggered event
  Preliminary studies (CMS Note 97/059 : C.Tully)

- But the extra reduction is needed
  ○ We propose to study data compression methods

  ♠ Time domain : Ph. Busson, A. Karar, G.B Kim
  (LPNHE, Palaiseau, France)
  ♠ Space domain : D.W Kim, S.C Lee, K.S Kang
  (Kangnung National University, South Korea)

2. The lossless compression in the time domain

Compression

Lossless

Lossy

What is needed in CMS ?

Lossless

● Lossless compression allows to reconstruct the original frame. ⇒
This reconstruction allows to process the time frame with sophisticated offline methods(jitter correction, pile-up study)

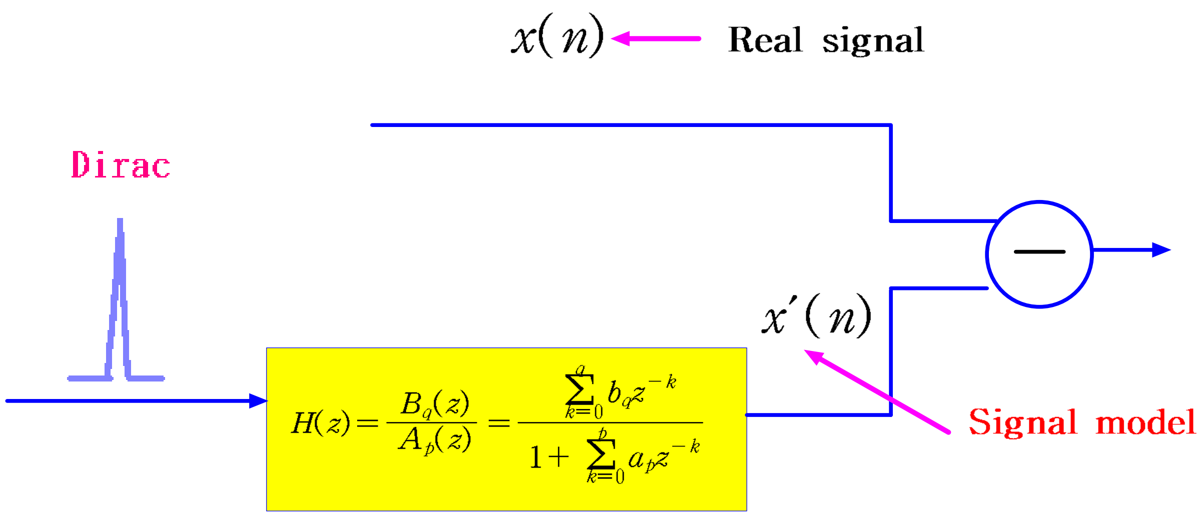
♠ Signal Modeling
♠ Data compression

♠ The DSP
(Digital Signal processor)

3. The signal modeling using the MATLAB

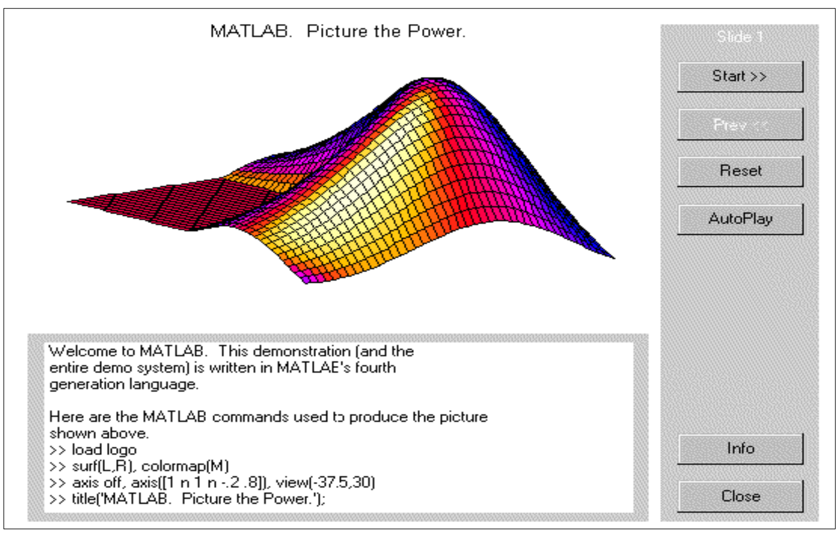
①The signal modeling

● What is main idea of signal modeling ?

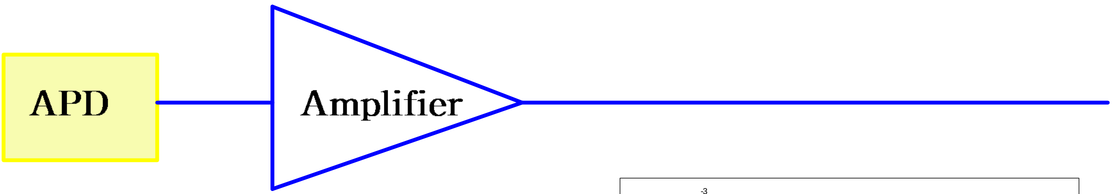


※ find the filter H(z) that make $x'(n)$ as close as possible to $x(n)$.

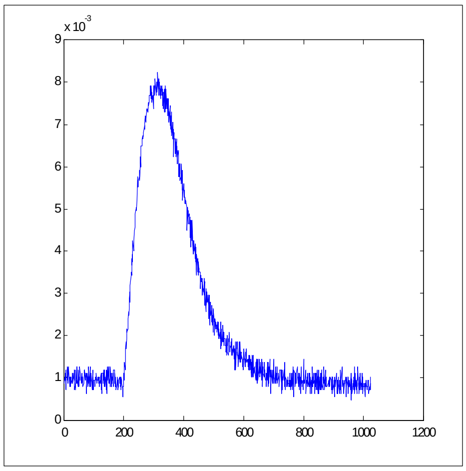
※ The calculation of coefficients a_p and b_q is very easy in the program MatLab(Matrix Laboratory) using the toolboxes.



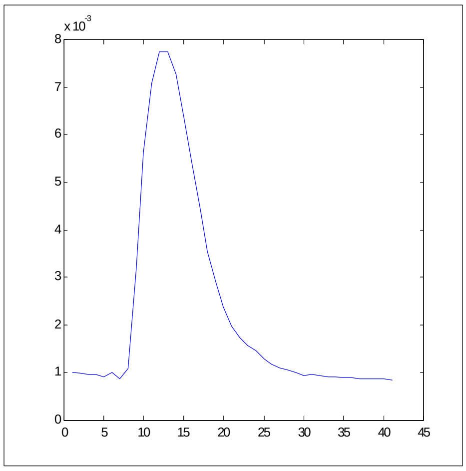
● What is the signal ?



1 G samples/s
(1 ns)

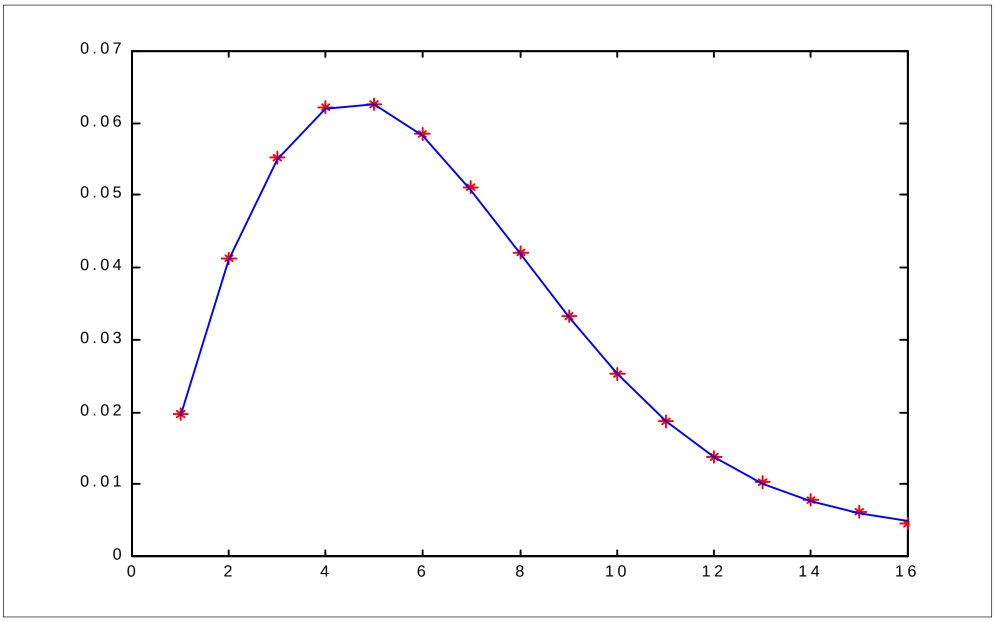


40 Msamples/s
(25ns)

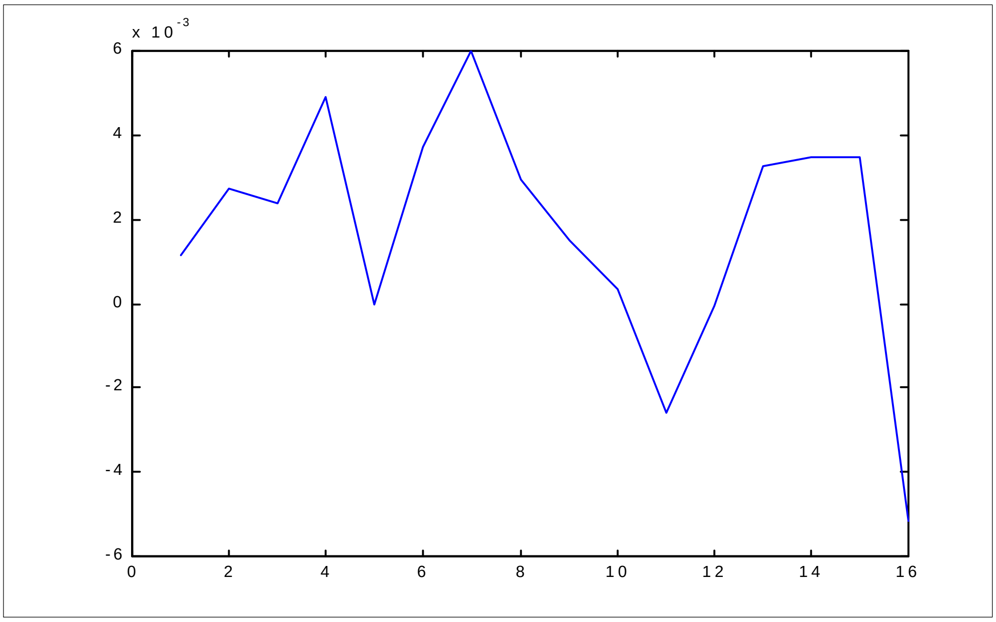


◆ The result

1. The signal model (line) and data signal(red *)



2. The difference $d(n) = x(n) - x(n)'$



Conclusion : We can make good signal model

4. The different methods of data compression

- The methods we have studies can be diveded into:

The differents method of data compression	
Differential coding	DPCM (Differential Pulse Code Modulation) PDPCM (Predictive Differential Pulse Code Modulation)
Entropy coding	Huffuman coding
Transformation coding	Wavelet coding DCT(Discrete Cosine Transforme) coding

- We propose two methods :

♠Dynamic coding
♠Residual parametric coding

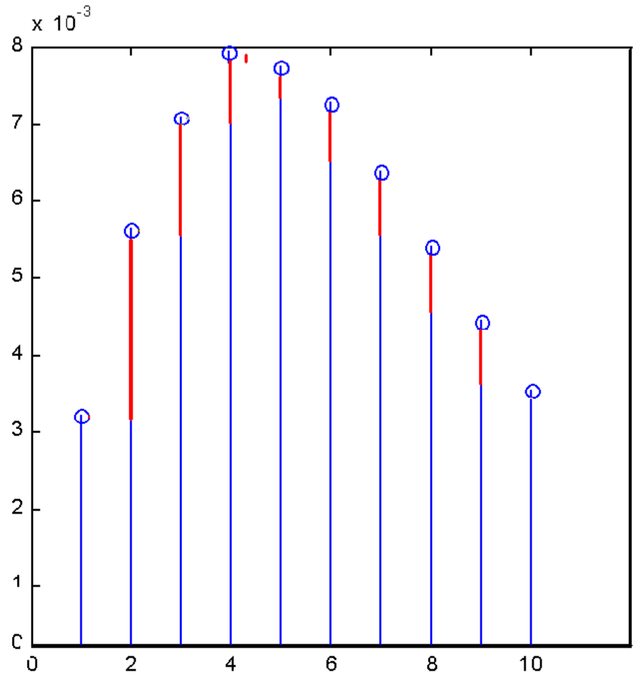
1. Data compression from the differential coding.

* DPCM (Differential Pulse Code Modulation)

* PDCPM (Predictive Differential Pulse Code Modulation)

1.1 DPCM (Differential Pulse Code Modulation)

The main idea : code the difference between neighbouring samples.



But we found that this method does not allow to reduce the code length significantly because our signal increases fast.

So we changed the method :

1.1.1 Improvement of the differential coding

O Method of sorting of the samples

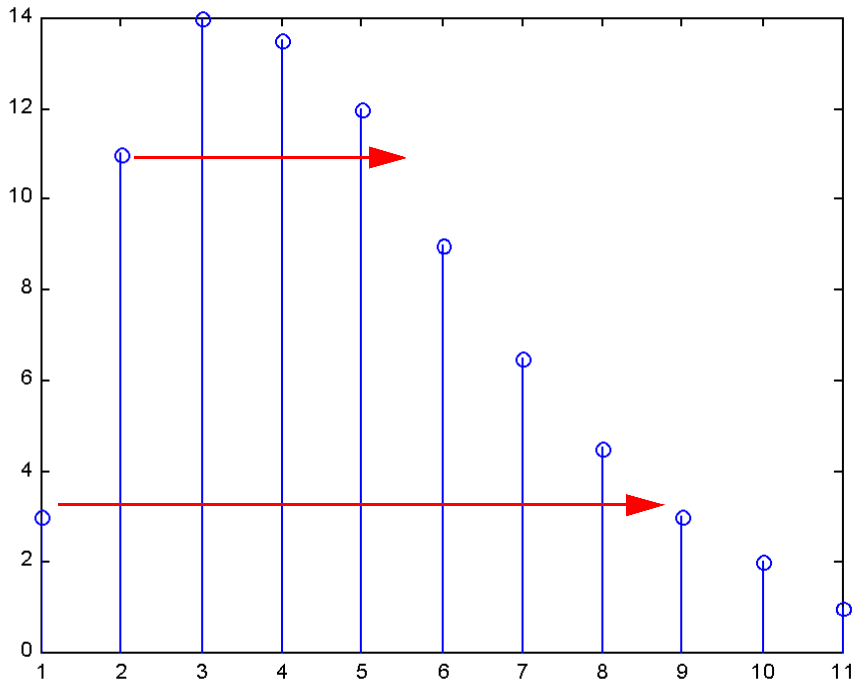
The main idea : we can reduce the difference values between two samples by sorting of the samples.

For example,

1. we change the order of samples :

1, 2, 3, 4, 5, 6, 7, 8, 9, 10

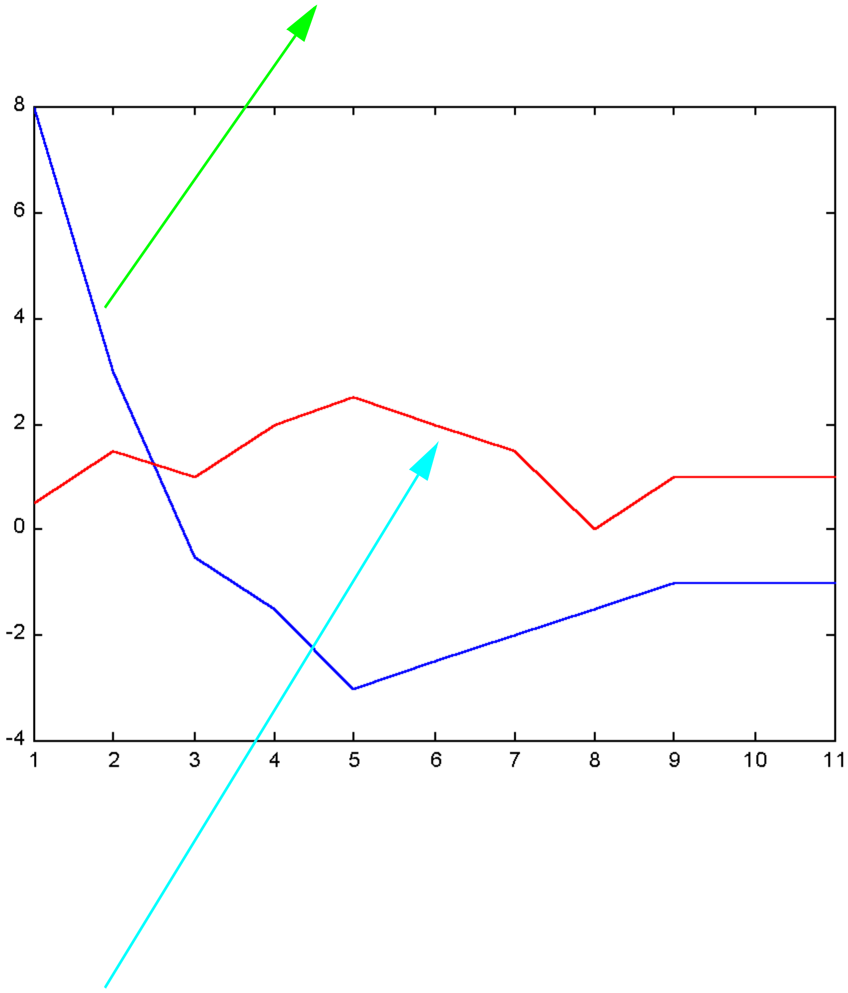
→ 3, 4, 5, 2, 6, 7, 8,1, 9, 10



2. we compute the difference values between the samples

O The Result

The difference values between the samples with the original order.

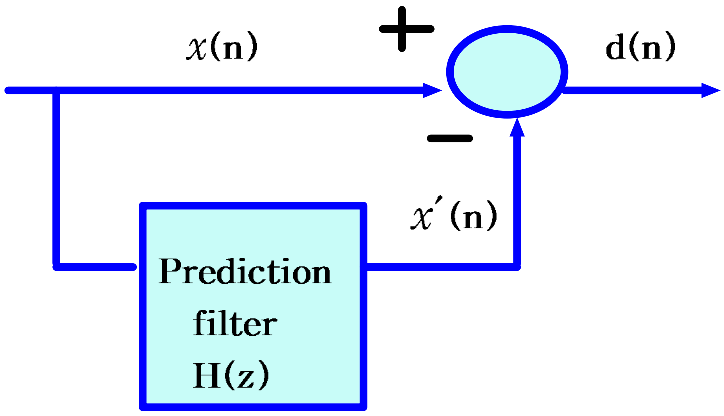


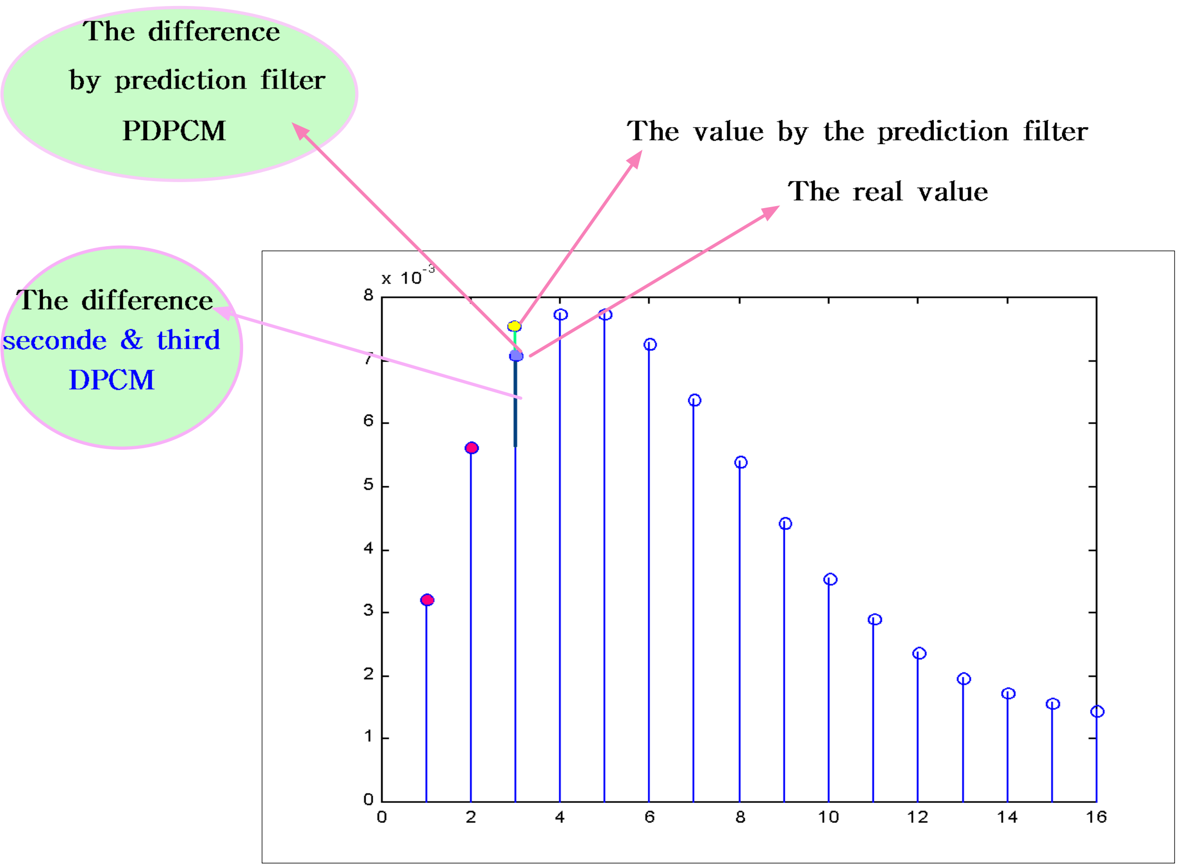
The difference values between the samples with the sorted order.

We think that this new method may allow to increase the rate of the compression.

● PDPCM (Predictive Differential Pulse Code Modulation)

The main idea of PDPCM is the try to predict one sample from the previous samples to improve the differential coding





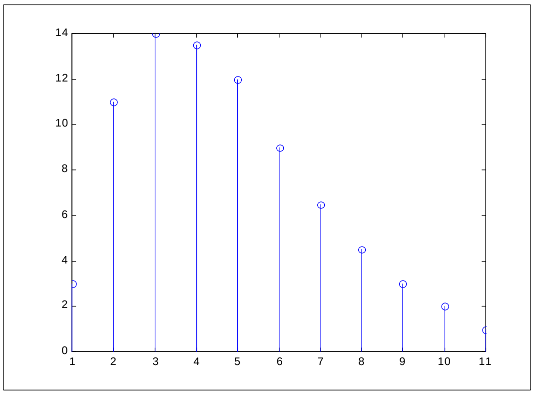
The compression from PDPCM is more effective than DPCM.

But this method also not allows to reduce very much code length because that we have only one sample to prodict the 2nd sample.

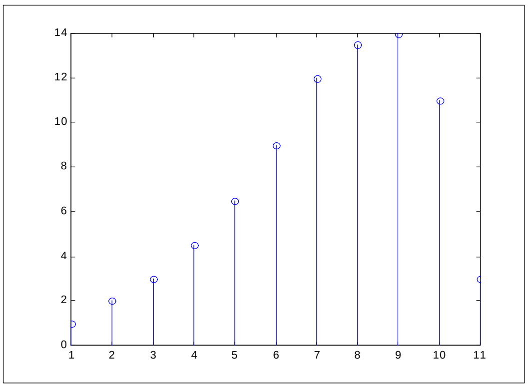
★ Improvement of predictive coding

The main idea : to invert the order of samples

♠The order of original samples : 1, 2, 3, 4, 5, 6, 7, 8, 9, 10



♠The order of inverted samples : 10, 9, 8, 7, 6, 5, 4, 3, 2, 1



To predict 1st sample, we have the 9 samples.

⇒ It may allow to product the significant predictive value for the 1st sample.

⇒ This new method may allow to increse the rate of the compression.

② The data compression from entropy coding

♠ The main idea of entropy coding is

※signal with larger probability ⇒ code with smaller code length
※signal with smaller probability ⇒ code with longer code length

♠ The example of Huffman coding for natural image

Value	Probability	Huffman code	Huffman code length	P × length
0 (4bit)	0.450	1	1	0.450
1 (4bit)	0.313	00	2	0.625
2 (4bit)	0.114	011	3	0.342
3 (4bit)	0.046	01000	5	0.23
4 (4bit)	0.026	01010	5	0.13
5 (4bit)	0.015	010010	6	0.09
6 (4bit)	0.012	010110	6	0.072
7 (4bit)	0.0069	0100110	7	0.0483
8 (4bit)	0.0060	0101110	7	0.042
9 (4bit)	0.0032	01001110	8	0.0256
10 (4bit)	0.0032	01001111	8	0.0256
11 (4bit)	0.0017	01011111	8	0.0136
12 (4bit)	0.0013	010111101	9	0.0117
13 (4bit)	0.0009	0101111000	10	0.009
14 (4bit)	0.0004	01011110010	11	0.0044
15(4bit)	0.0004	01011110011	11	0.0044
average 4 bit				1.8239

① The average of Huffman code length = 1.8239 bit
② The average of code length= 4 bit

⇒ Efficiency of compression = $\frac{4}{1.823} = 2.2$

③ The data compression from the transformation coding

● Main idea:

Original values (The correlation form) $\xrightarrow{\text{Transform}}$ Transformed values (No correlation)

Smaller number of bits

● The example of wavelet compression of images

4 values (1, 2, 3, 4)

first step

Compute 2 averages

$$\frac{1+2}{2}=\frac{3}{2},\ \frac{3+4}{2}=\frac{7}{2}$$

Compute 2 differences

$$\frac{1-2}{2}=\frac{-1}{2},\ \frac{3-4}{2}=\frac{-1}{2}$$

second step

Compute 1 average

$$\frac{1}{2}\times\frac{3+7}{2}=\frac{10}{4}$$

Compute 1 difference

$$\frac{1}{2}\times\frac{3-7}{2}=\frac{-4}{4}$$

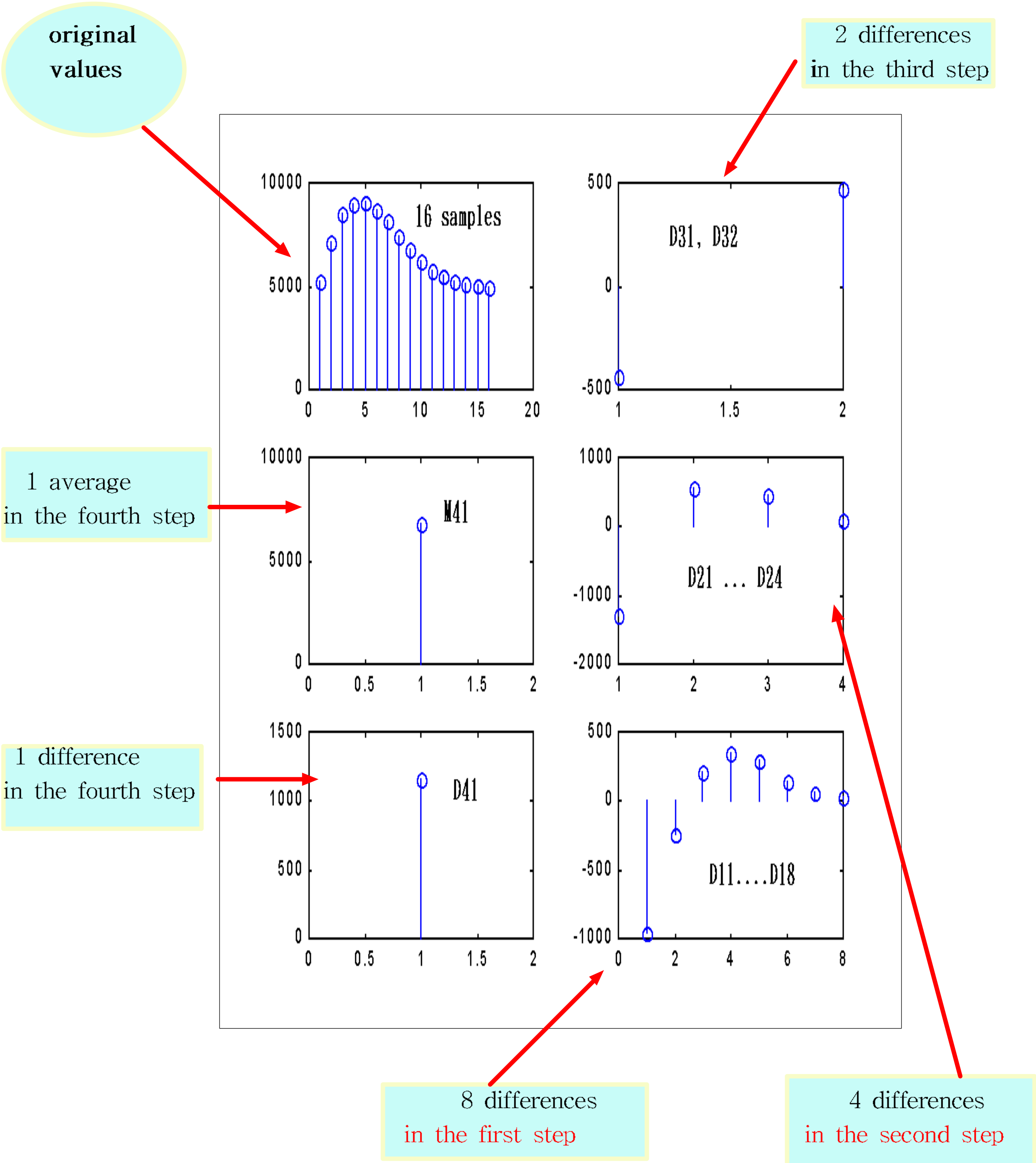
Wavelet values

$$\frac{-1}{2},\ \frac{-1}{2},\ \frac{-4}{4},\ \frac{10}{4}$$

Using the differences, the wavelet transform has numbers smaller than the original value

◆ The result

In case of 16 samples of our signal



● The original values were compressed significantly by this method.

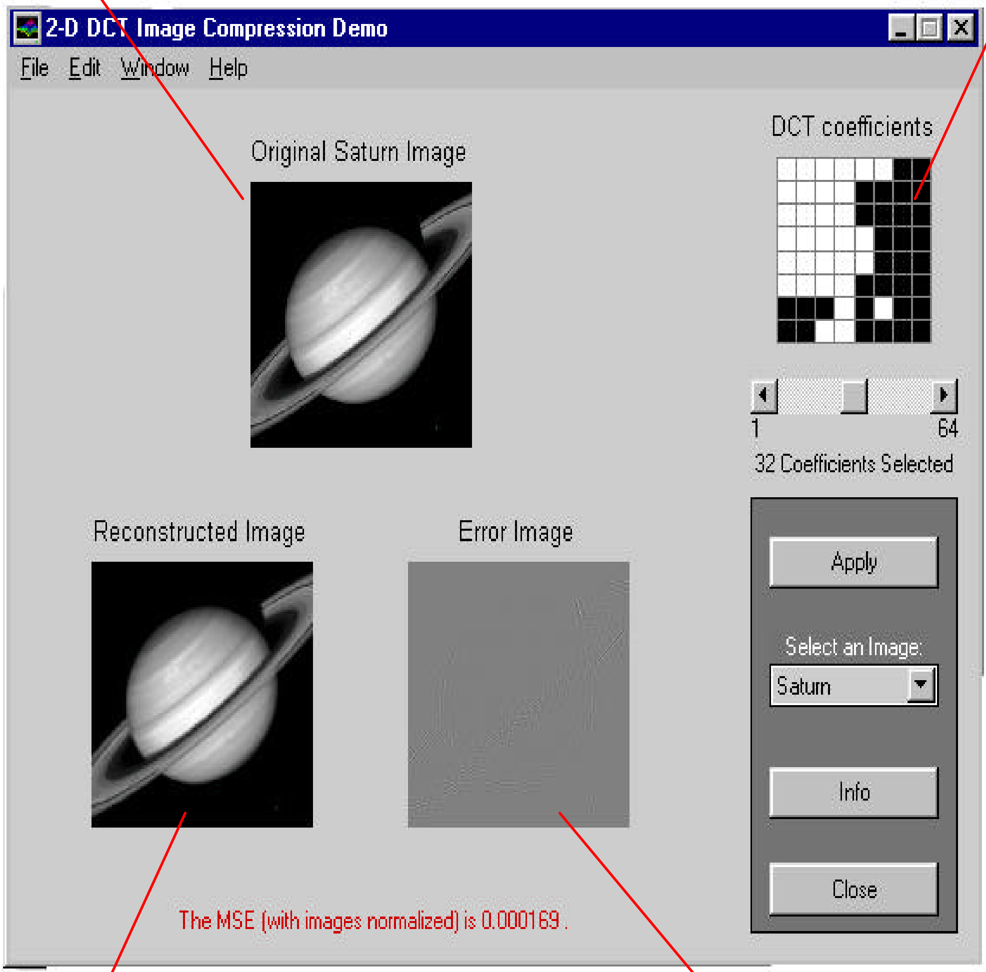
● If we change the differences to zero ⇒ Lossy compression

♠ Lossy compression from DCT(Discrete Cosine Transform)

◆ Lossy compression with 32 zero values/ 64 values

Original image

zero values



Reconstructed image

Error image

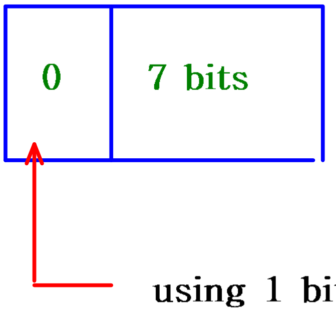
S. Mallat : We want to work with specialist for the lossy compression of image and telecommunication

④ The data compression from the "dynamic" coding

● The main idea :

Code the samples with 1, 2, 3, bytes according to their amplitude

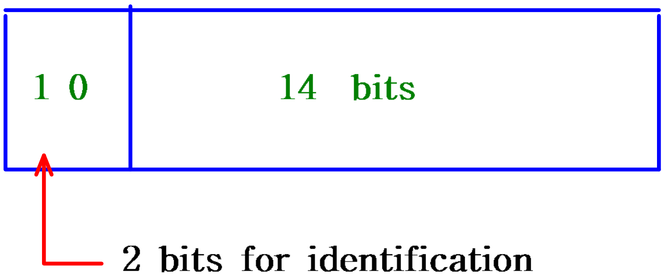
♠ If amplitude of sample $<$ 128 $\Rightarrow$ Code with 8 bits



: Code 1 byte

using 1 bit for identification

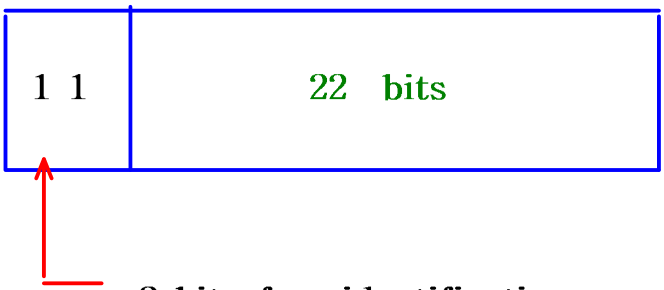
♠ If 128 $<$ amplitude $<$ 16384 $\Rightarrow$ Code with 16 bits



: Code 2 bytes

2 bits for identification

♠ If 16384 $<$ amplitude $<$ 4194304 $\Rightarrow$ Code with 24 bits



: Code 3 bytes

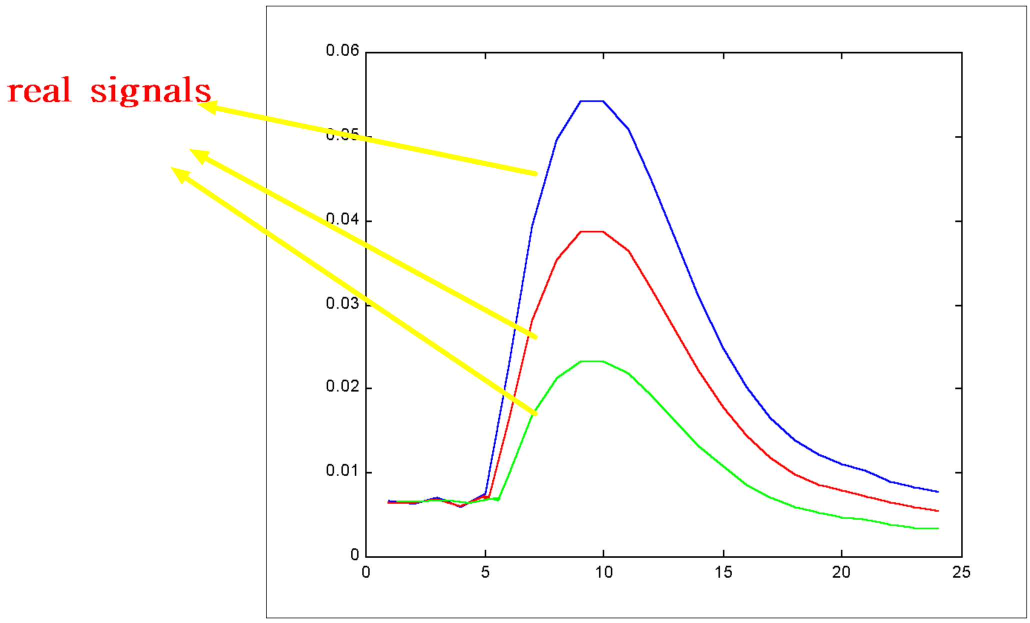
2 bits for identification

We suppose that this method is simple.

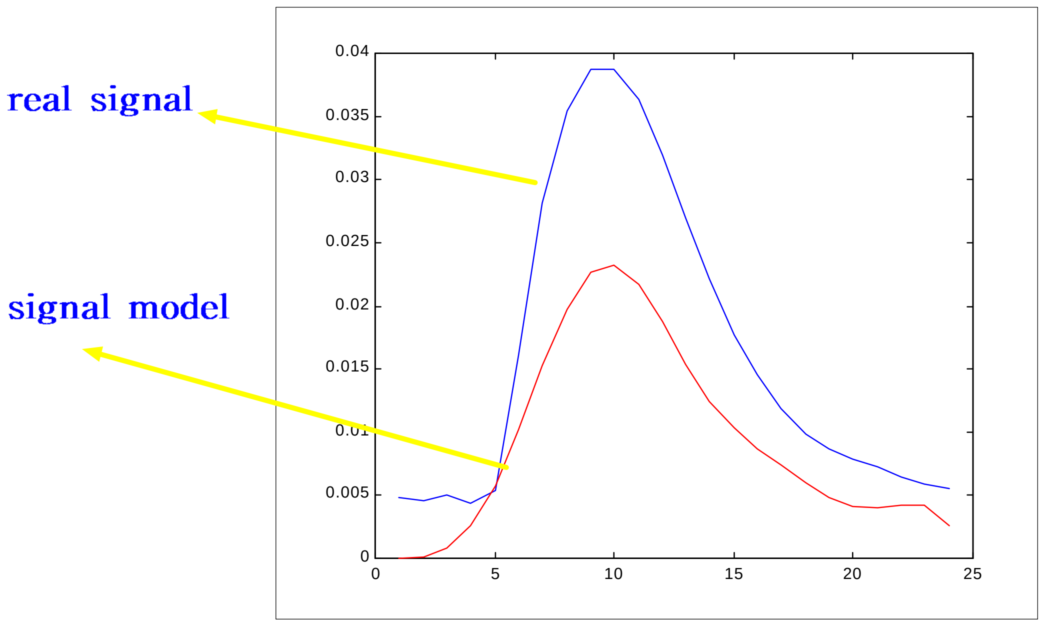
⑤ The data compression from the Residual parametric coding

● The main idea :

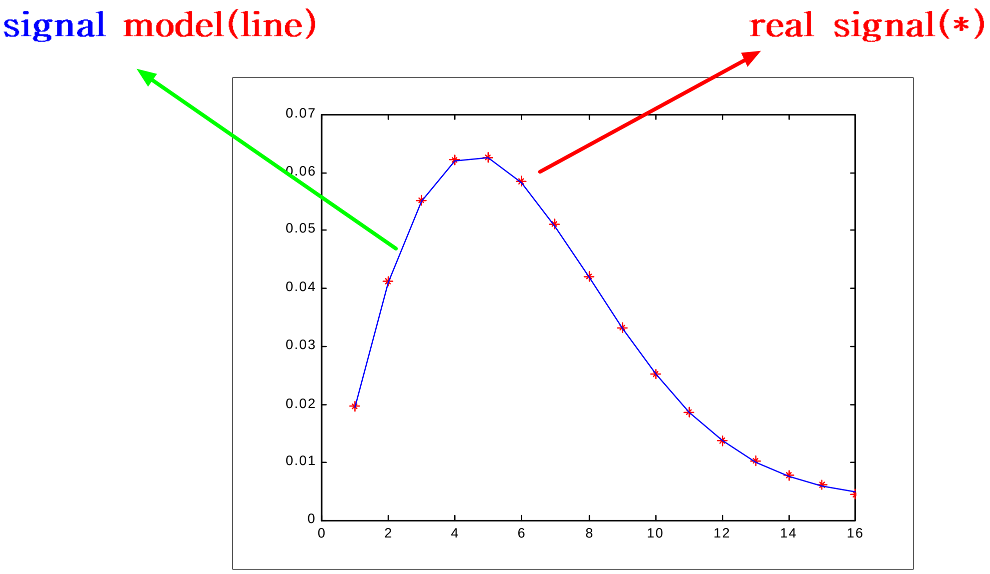
① If time jitter of the CMS signals is small.



② Generation of the signal model.



③ Normalize the signal model to the maximum value of the real signal.



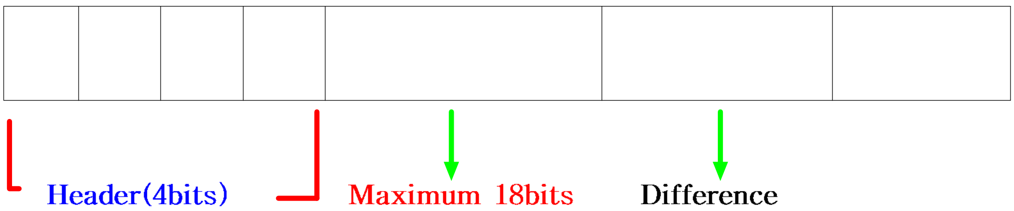
④ The calculation:

① The maximum value.

② The difference between the real signal and our signal model normalized to the maximum value of the real signal.

⑤ The coding :

◆ We make the frame



★Header depends on the bit length of the difference values. It has 16 possibilities, for example :

0000 : Does not code the diffrence values (case : pile-up)
Code the origianl values

0001 : The bit length of the difference value is 3 bit.

0010 : The bit length of the difference value is 4 bit.

⋮

● How much the number of bits is reduced ?

If we can take 10 smples and code each sample by 18 bits

⇒ the total number of bits in case of no data compression is 180 bits.

⇒ If bit length of the difference is 3, the total number of bit in case of data compression from redidual parametric coding is

$$4+18+9\times 3 = 49 \text{ bits.}$$

In this example, we have the compression of $4 \approx \frac{180}{49}$ factors .

♠ Calculation of compression factor

bit length (difference)	Total number of bits (with compression)	Total number of bits (without compression)		
		180	160	140
3	49	3.6	3.2	2.8
4	58	3.1	2.7	2.4
5	67	2.6	2.3	2.0
6	76	2.3	2.1	1.8
7	85	2.1	1.8	1.6
8	94	1.9	1.7	1.4

compression factor

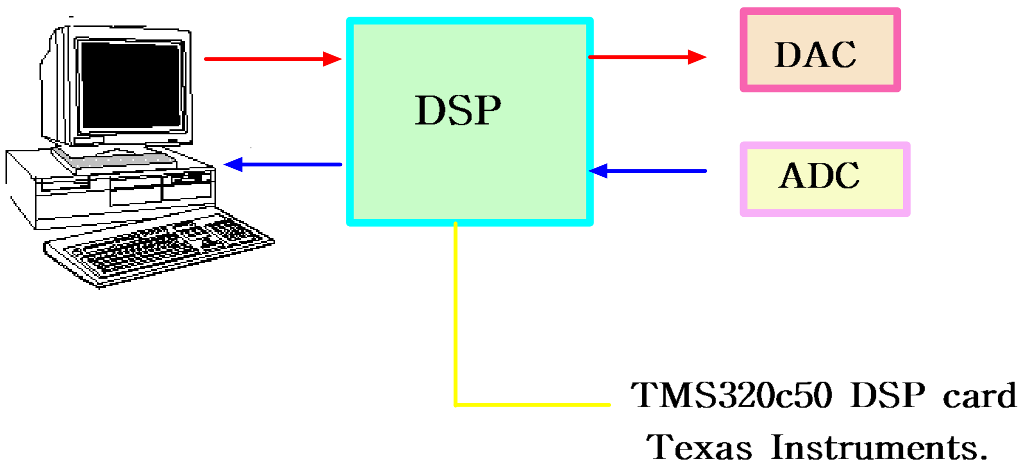
Different methods of data compression		Status	Our opinion (for CMS)
Differntial coding	DPCM ADPCM	(not efficient) Being continue	Not efficient
Entropy coding	Huffuman	Being continue	Complicate
Transformation coding	Wavelet DCT	Being continue with S. Mallat	Complicate

- We propose two methods :
  - ♠Dynamic coding
  - ♠Residual parametric coding

5. Study of the DSP (Digital Signal Processor)

① About the DSP card

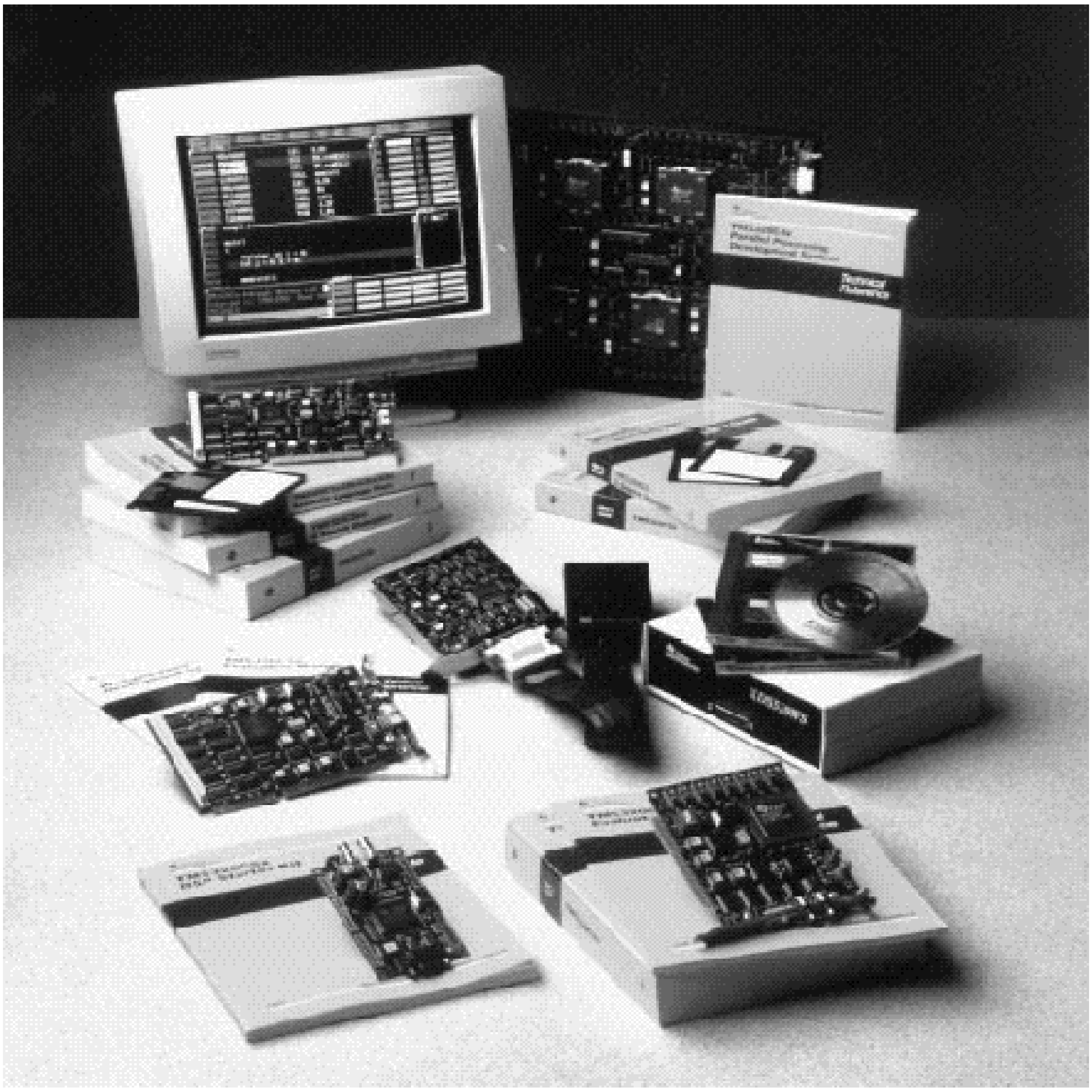
♠ Why do we need the DSP card : faster processing



♠Characteristics of the TMS320c5x DSP Processors

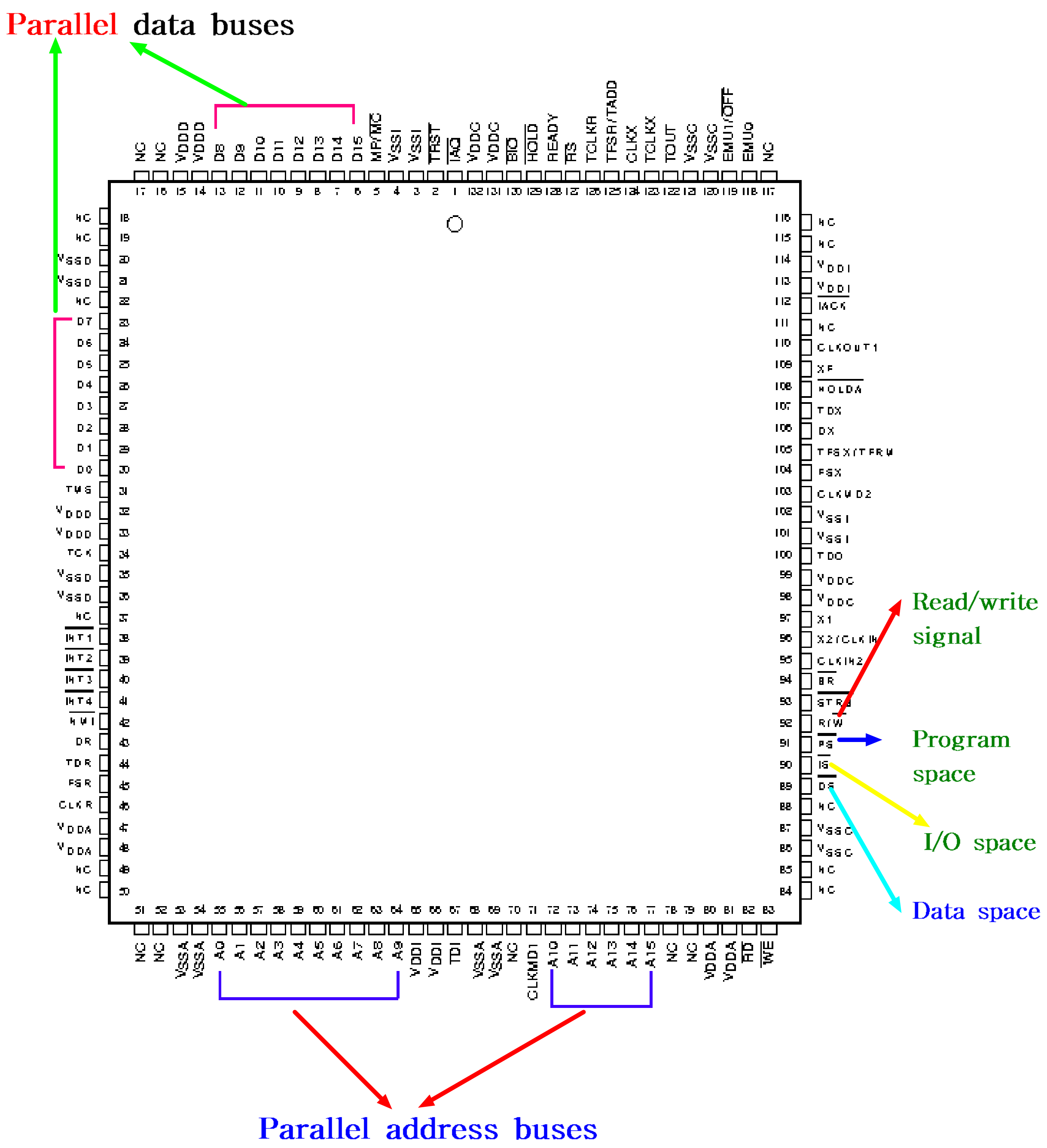
TMS320 Device	On-chip Memory			I/O Ports		Cycle Time (ns)	Package Type
	RAM		ROM	Serial	Parallel		
	Data	Data-Prog	Prog				
TMS320c50	1K	9K	2K	2	64K	50/35	132pin ceramic
TMS320c51	1K	1K	8K	2	64K	50/35	132pin plastic
TMS320c53	1K	3K	16K	2	64K	50/35	132pin plastic

The TMS320c5x family



② About the Hardware

● The signal assignments for TMS320c50 132-pin

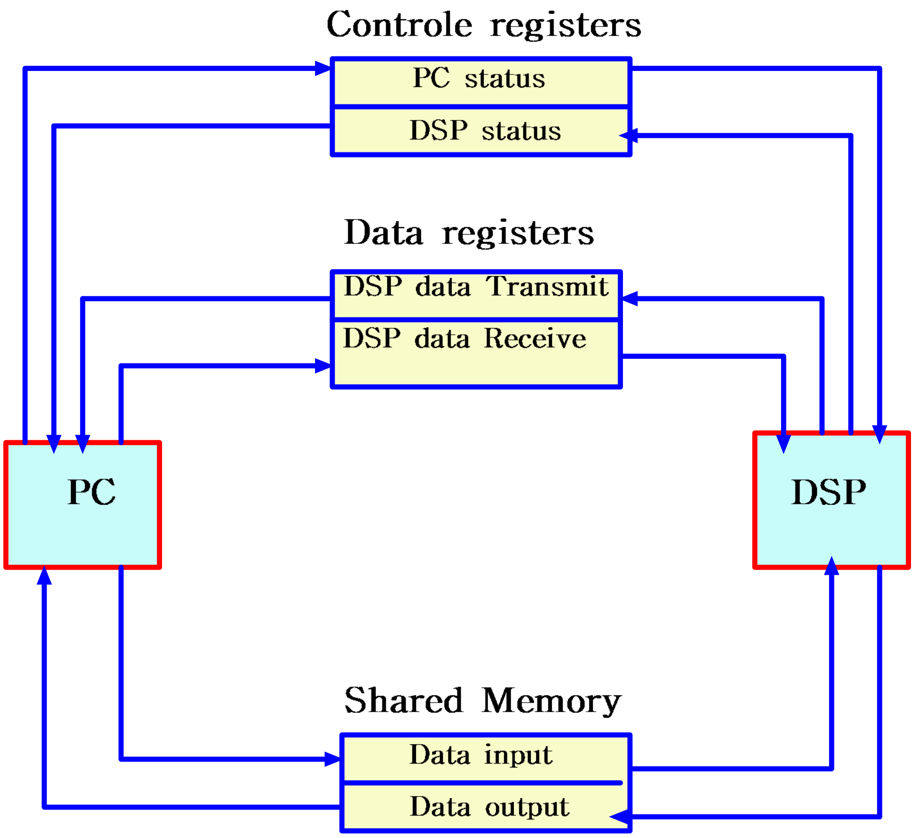


● The communication between DSP and Host (Pc)

♠ The Pc communicates with DSP through 16-bit data, status, and control registers.

♠ The diagram of the communication

① The Pc and DSP communicated by the Control registers and Data registers.



② About the Software

The DSP is well supported by :

♠ C Language : No standard C

♠ Assembler

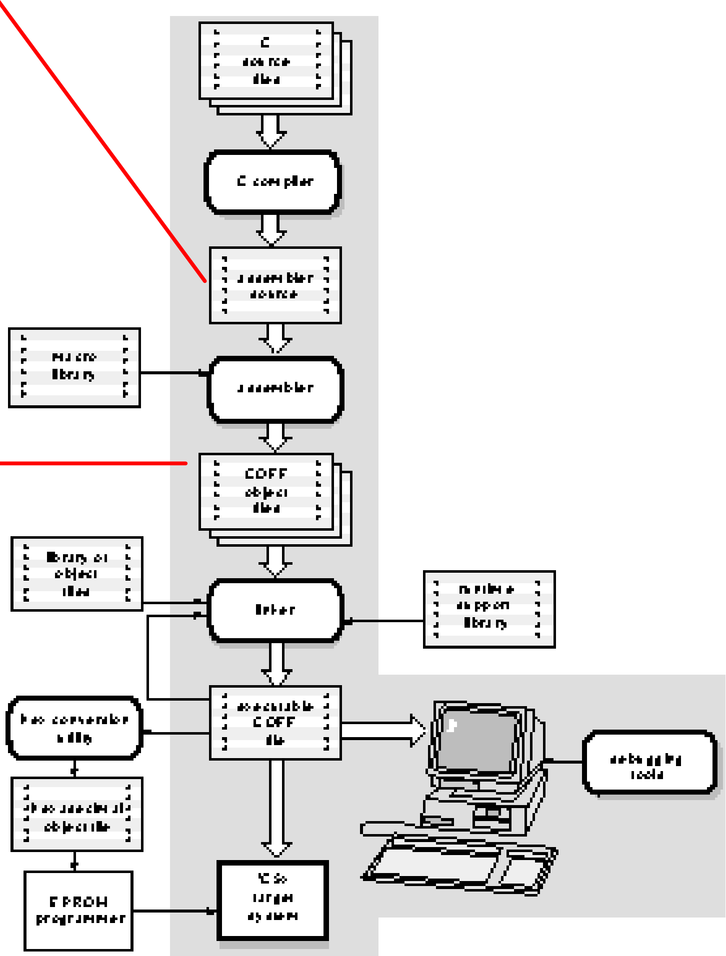
★ They are different.

The PC is well supportes by :

♠ C Language : Standard C

The DSP compiler generates assembly language source

COFF
Common Objet
File Format

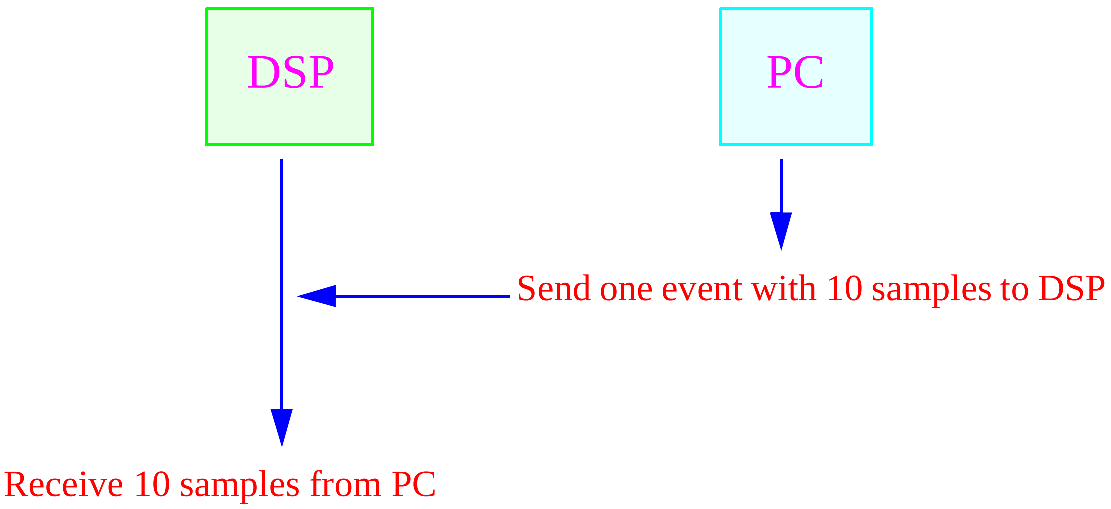


Study of the DSP Card

1. Computation of the execution time

1.1. The method of DPCM coding

1.1.1. Principle of Programming



Compute 9 difference values between the neighbouring samples

Send 9 difference values to PC

1.1.2. Computation of the execution time

* To compute 9 difference values between the neighbouring samples

Execution time = 13 μs

1.2. The method of Residual parametric coding

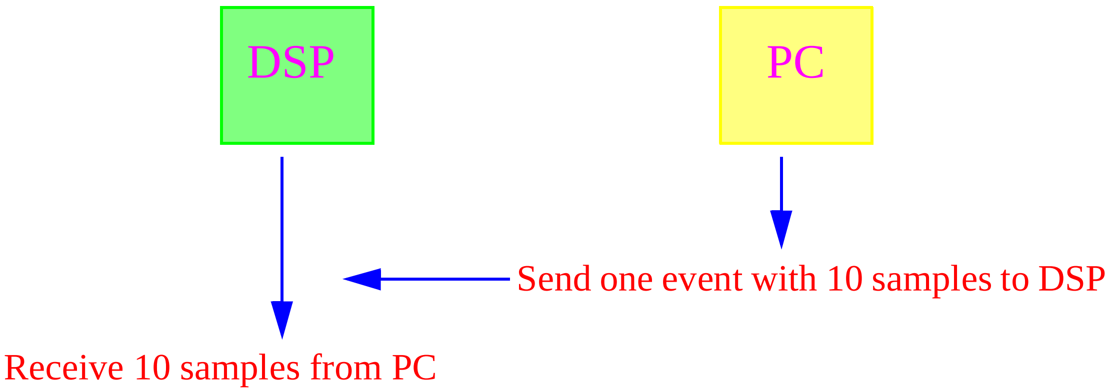
∗ The Main idea

If the time jitter of the CMS signals is small,

we can reduce the data volume by coding one maximum value and

the difference values between the signal and model

1.2.1 Principle of Programming.



Generate the maximum value in 10 samples

Compute the normalization factor using the maximum value

Normalize the samples of signal using the normalization factor

Compute 9 difference values between the signal and our model

Send one maximum value and 9 difference values to PC

1.2.2. Computation of the execution time

* To generate the maximum value

  Execution time = 4.3 μs

* To compute the normalization factor

  Execution time = 0.4 μs

* To normalize the model values

  Execution time = 7 μs

* To compute 9 difference values

  Execution time = 13 μs

Total execution time = 4.3 + 0.4 +7 +13

= 24.7 μs

Conclusion

Future of our study

- Test our methods with the data of beam test and of simulation using the CMSIM
- Continue to study the DSP
- try to study the FPGA