كلية الحاسبات و المعلومات

Introduction to Multimedia Data Compression

Prof. Khaled Mostafa El- Sayed
khaledms@fci-cu.edu.eg
Khaledms@gmail.com
Faculty of Computers and Information
Cairo University
Feb 2015

Course Reference

"Introduction to Data Compression"

By Khalid Sayood

Fourth Edition , 2012

(The Morgan Kaufmann Series in Multimedia Information and Systems)

Why Compress?

- To reduce the **volume of data to be transmitted** (text, fax, images)
- To reduce **storage requirements** (speech, audio, video)
- To reduce the **bandwidth required for transmission**

كلية الحاسبات و المعلومات
جامعة القاهرة

Image Data Size

Gray Image (one Byte / Pixel)

- For 1024*768 Pixel Gray Image
- Original Size = 1024*768 * 1 Byte = 768 K bytes

Color Image (Three Bytes / Pixel {Red, Green, Blue})

- For 1024*768 Pixel Color Image
- Original Size = 1024*768 * 3 Bytes = 2304 K bytes

Video Data Size

Video (25 Frame / Second)

For 1 Minute 1024*768 Pixel Video clip

- Original Size (for 1 Sec) = 1024*768 * 3 Bytes * 25 Frames = 57600 K bytes
- Original Size (for 1 Min) = 1024*768 * 3 Bytes * 25 Frames / Sec * 60 Sec/Min = 57600 * 60 = 3456000 K bytes = 3.456 GB
- What About 2 Hours Movie ?? (3.456 * 120 Min = !!!!)
- What of using NTSC system (30 Frame / Sec) !!!

How is compression possible?

[1] **Redundancy** in digital audio, image, and video data

[2] Properties of **human perception**

Digital audio is a series of sample values;

Image is a rectangular array of pixel values;

Video is a sequence of images played out at a certain rate

Neighboring sample values are correlated

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

Redundancy

Adjacent **audio samples** are similar (predictive encoding); samples corresponding to silence (silence removal)

In **digital image**, neighboring samples on a scanning line are normally similar (spatial redundancy)

In **digital video**, in addition to spatial redundancy, neighboring images in a video sequence may be similar (temporal redundancy)

Human Perception Factors

Compressed version of digital **audio**, **image**, **video** need not represent the original information exactly

Perception sensitivities are different for different signal patterns

Human eye is less sensitive to the higher spatial frequency components than the lower frequencies

Classification of Compression Techniques

[1] Lossless compression

lossless compression for legal and medical documents, computer programs

exploit only data redundancy

[2] Lossy compression

digital audio, image, video where some errors or loss can be tolerated

exploit both data redundancy and human perception properties

[3] Near Lossless Compression

- It is a lossy compression with a predefined max accepted error

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

Classification of Compression Techniques

[4] Hybrid Techniques

A compression algorithm that utilizes many lossy/lossless techniques to achieve high compression ratio with best quality. (.e.g. JPEG, MPEG, H264,..)

***Constant* bit rate versus *variable* bit rate coding ??**

Image Quality Measure

Subjective

- Evaluated by human observers
- Do not require the original copy as a reference
- Reliable, accurate yet impractical

Objective

- Easy to operate (automatic)
- Often requires the original copy as the reference (measures fidelity rather than quality)
- Works better if taking HVS model into account

Image Quality

Gray Image 400 * 500 Pixels

Image Size = 400 * 500 * 1 byte/pixel
=200,000 byte =~ 200 Kbyte

What will be the degradation in Quality if this image is compressed using lossy compression ?

- Degradation in <u>smoothness</u> ?
- Degradation in <u>Eye details</u> ?
- Degradation in <u>Sharpness</u> of finger edges?

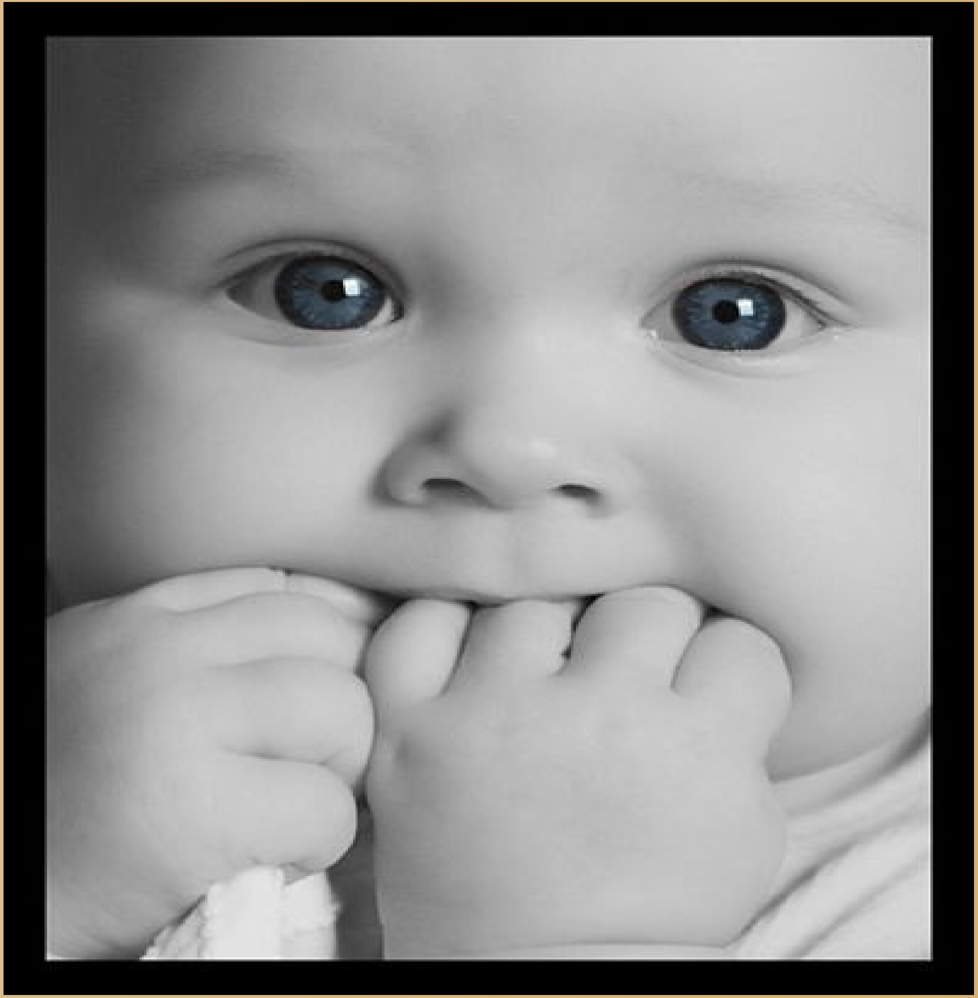
Image Quality

Gray Image 400 * 500 Pixels

Image Size = 400 * 500 * 1 byte/pixel
=200,000 byte =~ 200 Kbyte

What will be the degradation in Quality if this image is compressed using lossy compression ?

- Degradation in smoothness ?
- Degradation in Eye details ?
- Degradation in Sharpness of finger edges?



Sorry, this is the compressed version with size 38Kbyte Only
Is this quality accepted for you ??
The compressed size is about 1/5 of the original size

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

كلية الحاسبات و المعلومات

All These Images are Lossy Compressed images

All These Images are Lossy Compressed images

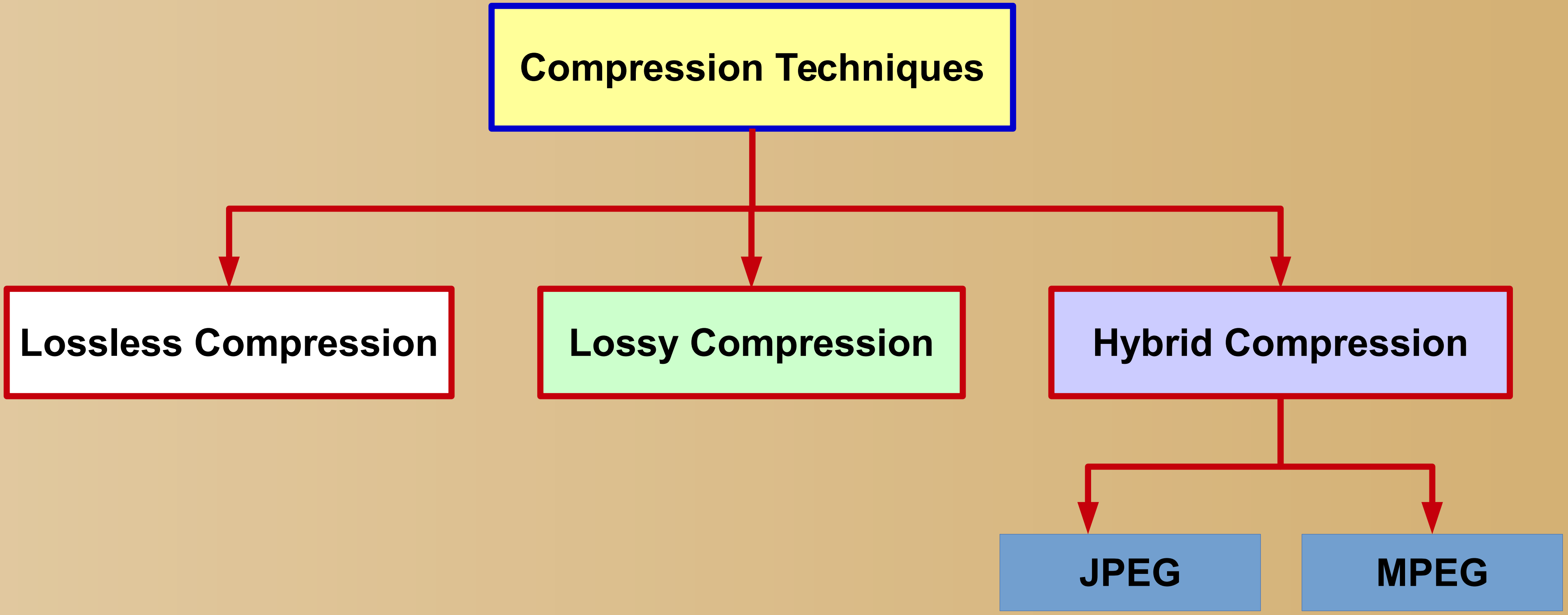
670 * 527 Pixes
Original 353K
Compressed 91K

400 * 400 pixels
Original 160K
Compressed 80K

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

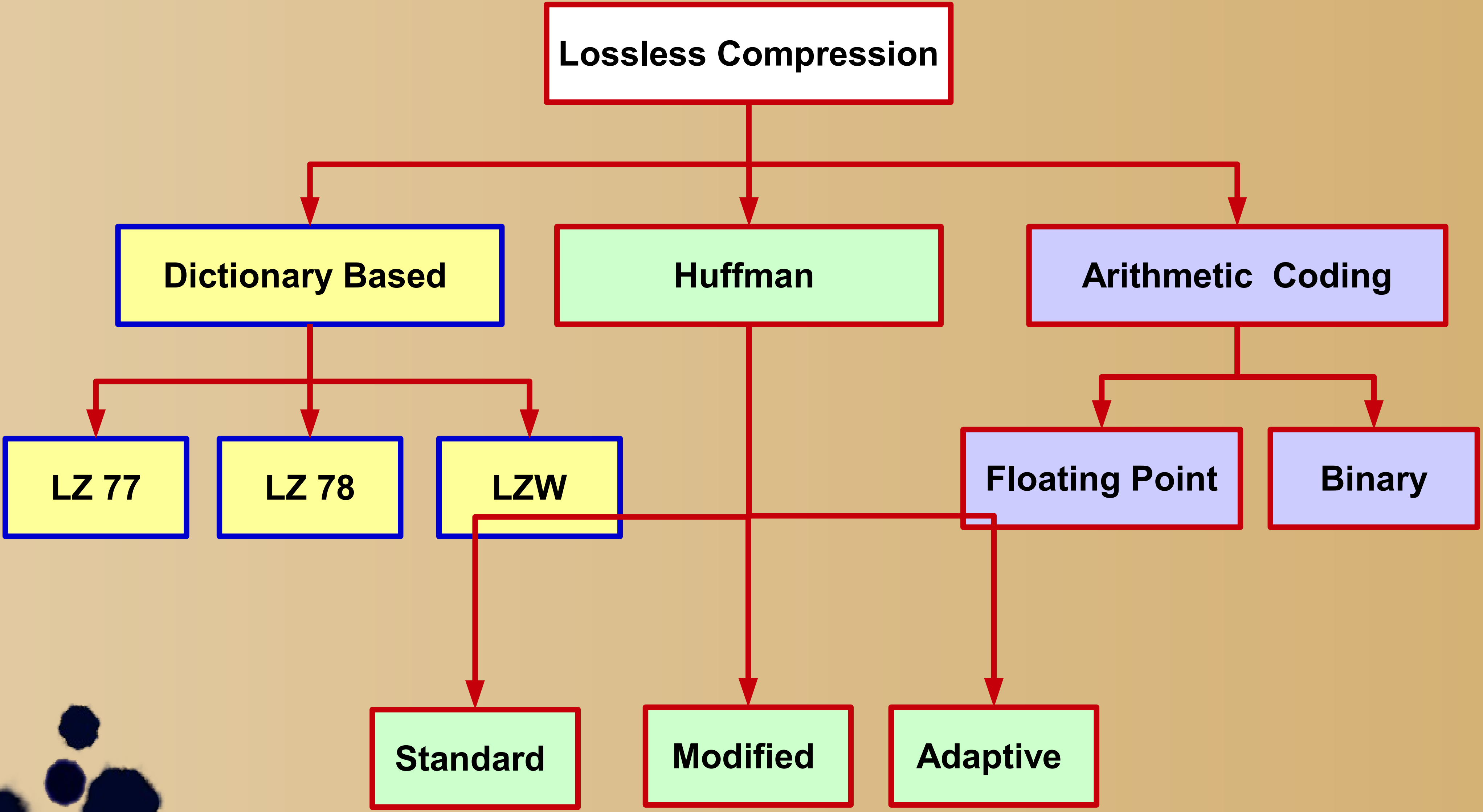
Covered Compression Techniques
for our course

كلية الحاسبات و المعلومات

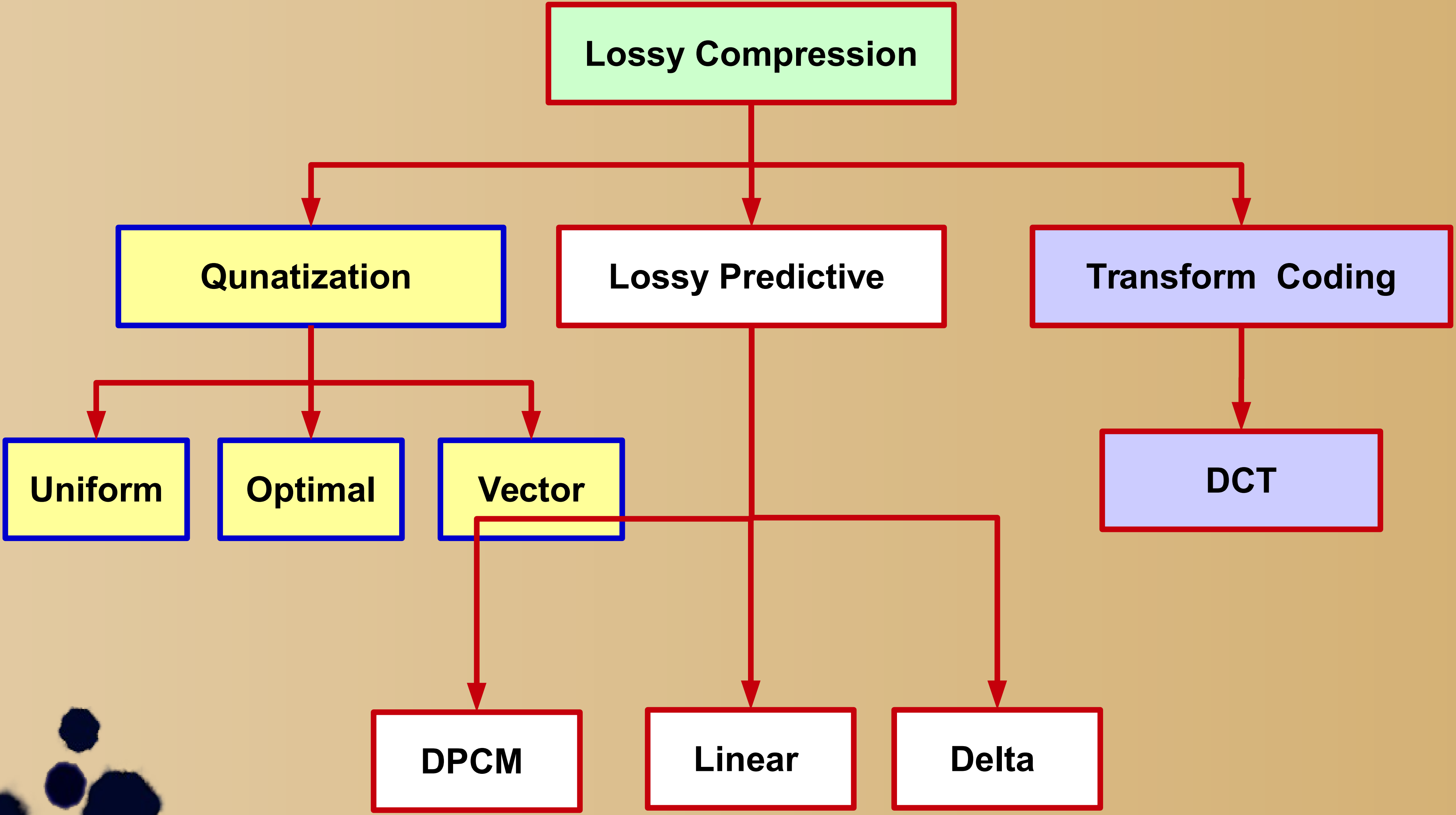


Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

Covered Compression Techniques for our course



Covered Compression Techniques for our course



Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

كلية الحاسبات و المعلومات

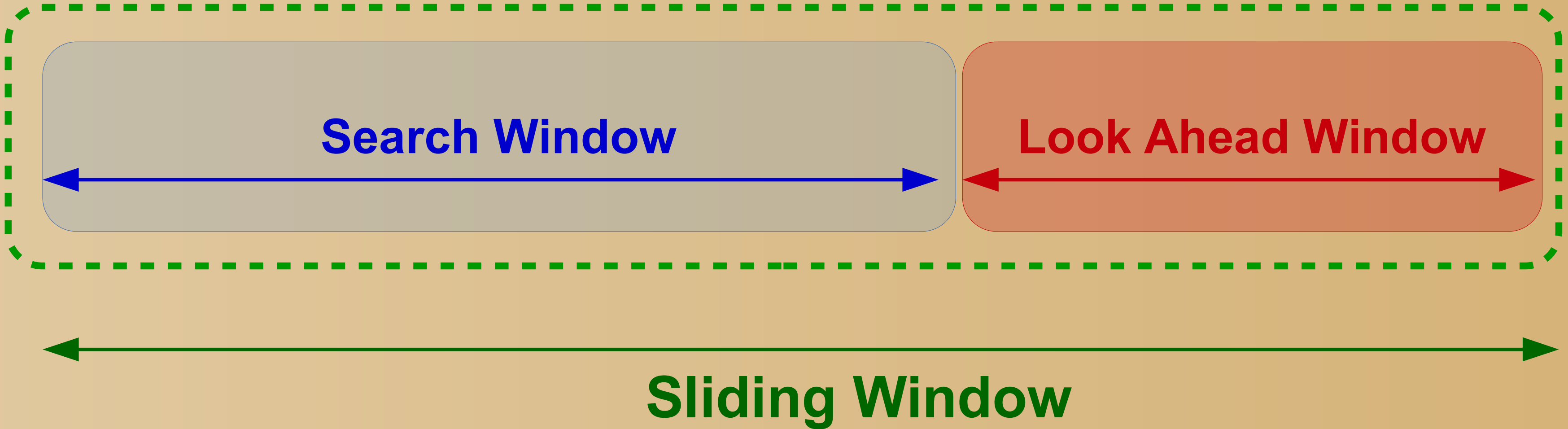
Dictionary Based Compression

LZ 77

LZ78

LZW

Lempel Ziv 77 Algorithm



A	B	A	A	B	A	B	A	A	B	B	B	B	B	B	B	B	B	B	B	B	A

TAG ⇒ <Position , Length , Next Symbol >

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

Lempel Ziv 77 Algorithm

Search Buffer: It contains a portion of the recently encoded sequence.

Look-Ahead Buffer: It contains the next portion of the sequence to be encoded.

Once the longest match has been found, the encoder encodes it with a triple ***<Position , Length , Next Symbol >***

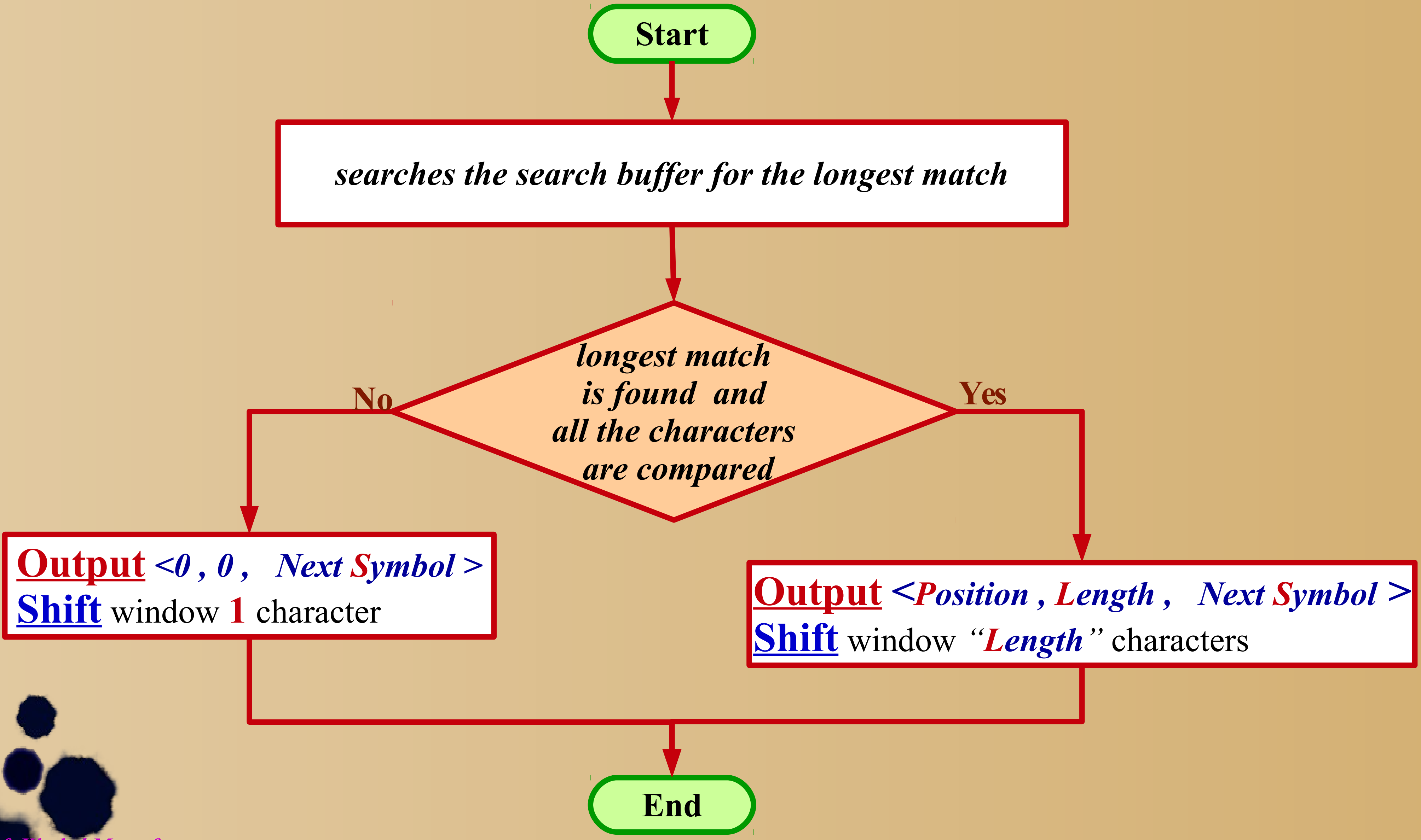
Position :the offset or position of the longest match from the lookahead buffer

Length :the length of the longest matching string

Next Symbol :the codeword corresponding to the symbol in the look-ahead buffer that follows the match

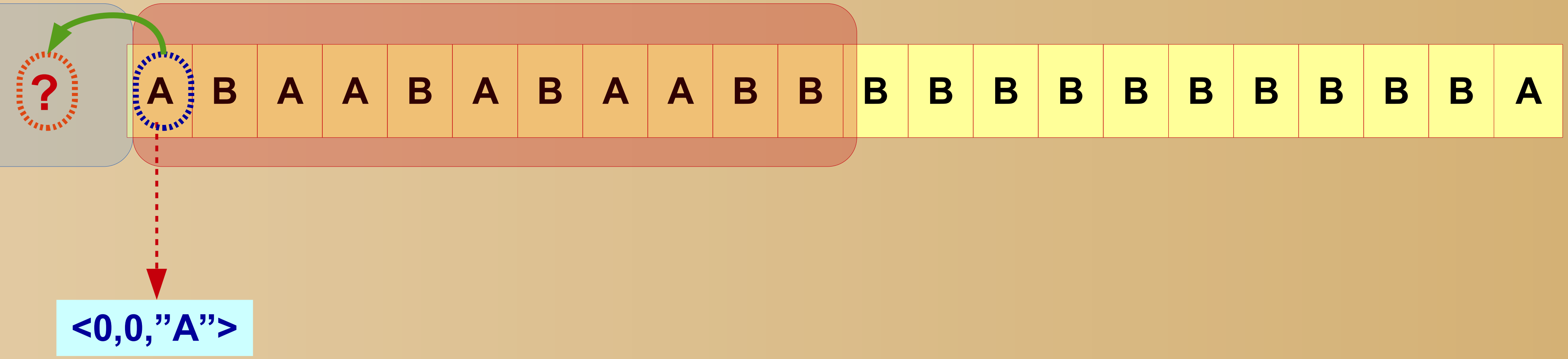
Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

Lempel Ziv 77 Algorithm


Start
searches the search buffer for the longest match
longest match is found and all the characters are compared
No
Yes
Output <0 , 0 , Next Symbol >
Shift window 1 character
Output <Position , Length , Next Symbol >
Shift window "Length" characters
End

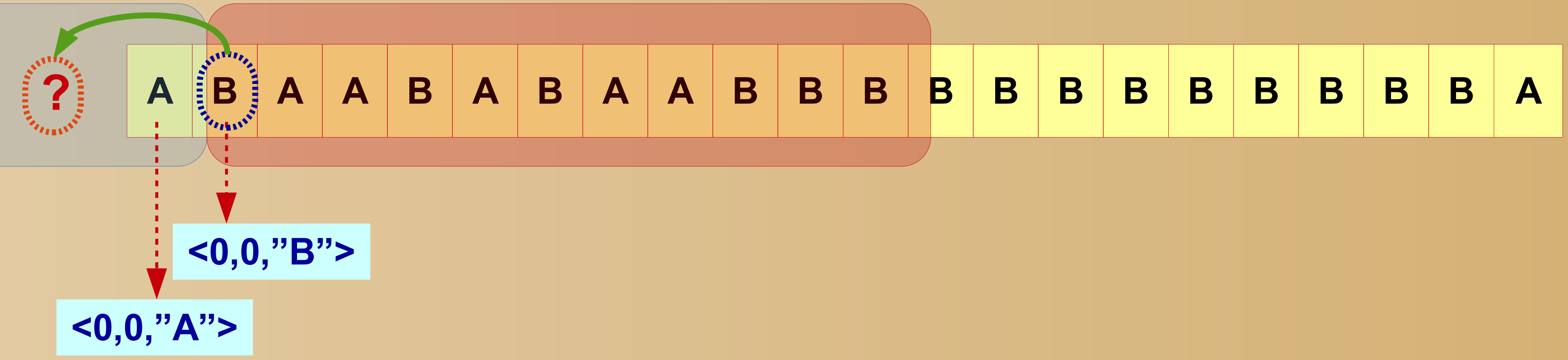
Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZ 77 (Compression)



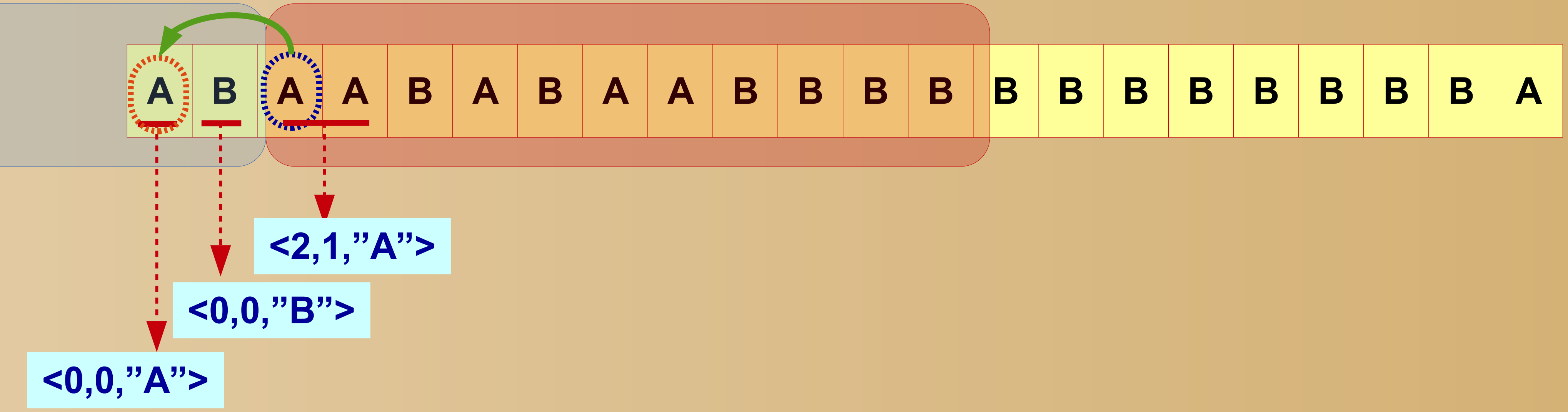
There is no "A" in search buffer
Position=0, Length =0, next Symbol="A"

LZ 77 (Compression)



*There is no "**B**" in search buffer*
Position=0, Length =0, next Symbol="B"

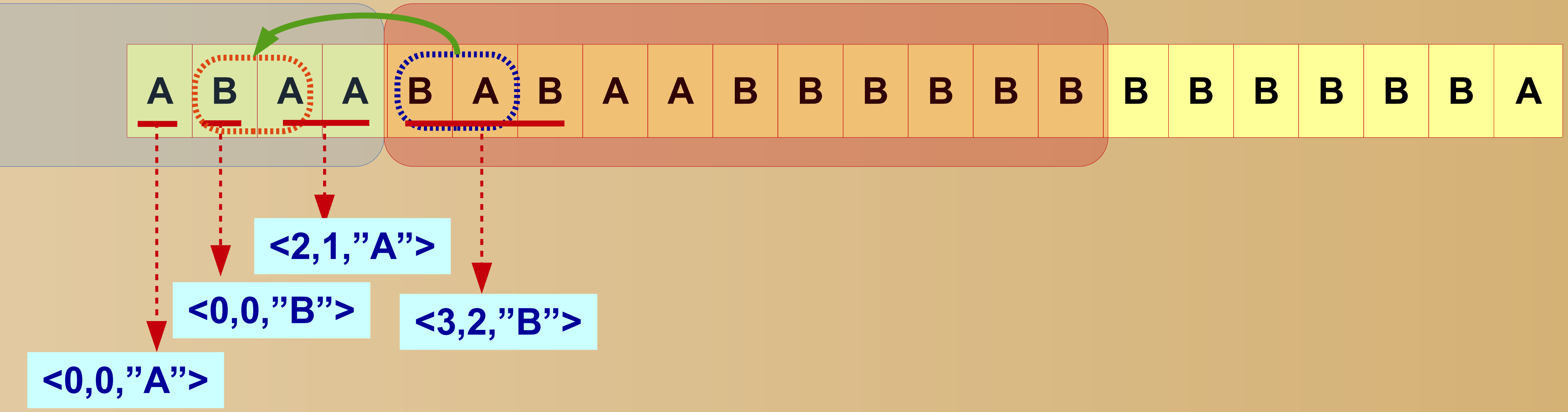
LZ 77 (Compression)



Only "A" exists in search buffer
Go Back <u>two Steps</u>, Pick <u>One Symbol</u>
Position=2, Length =1, next Symbol="A"

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZ 77 (Compression)



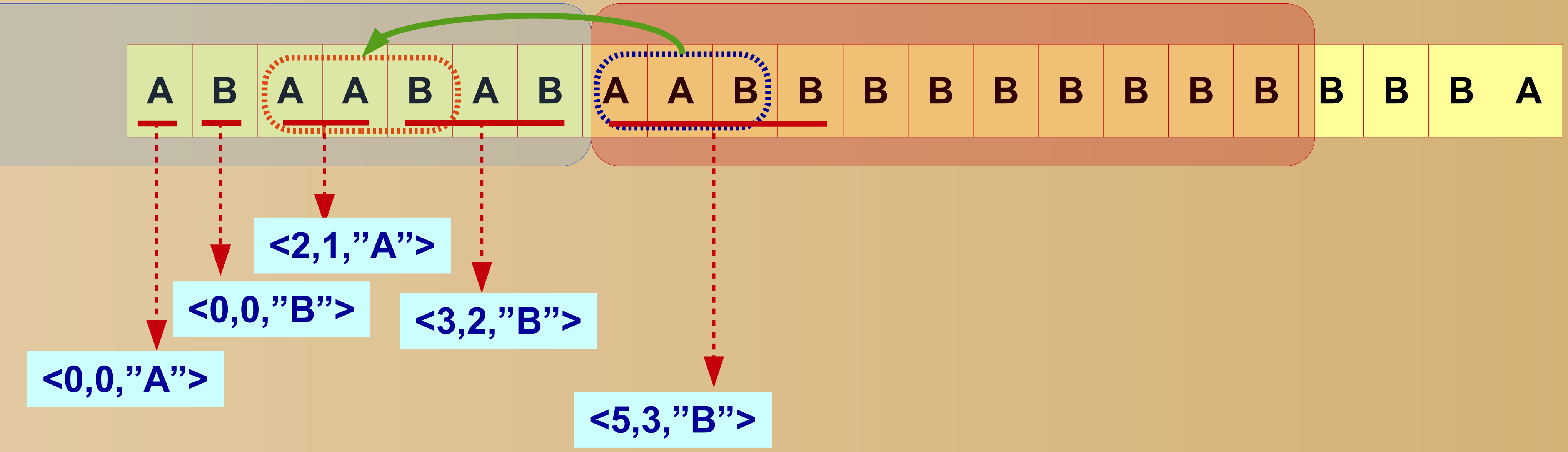
"**BA**" exists in search buffer

Go Back three Steps, Pick Two Symbol

Position=3, Length =2, next Symbol="B"

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZ 77 (Compression)



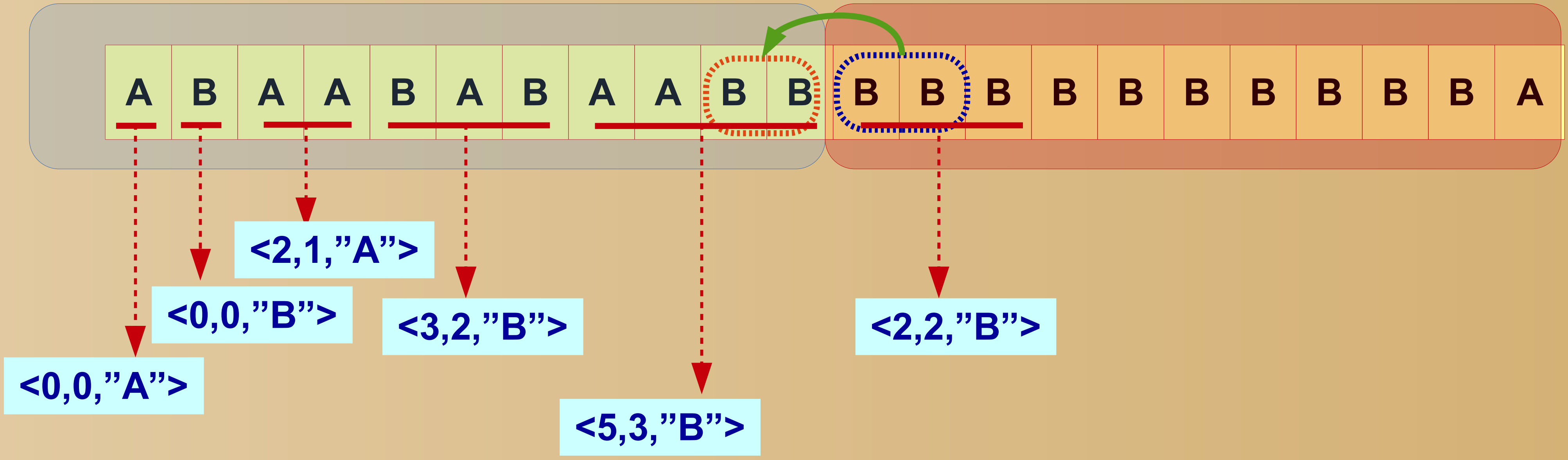
"*AAB*" *exists in search buffer*

Go Back five Steps, Pick Three Symbol

Position=5, Length =3, next Symbol="B"

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZ 77 (Compression)

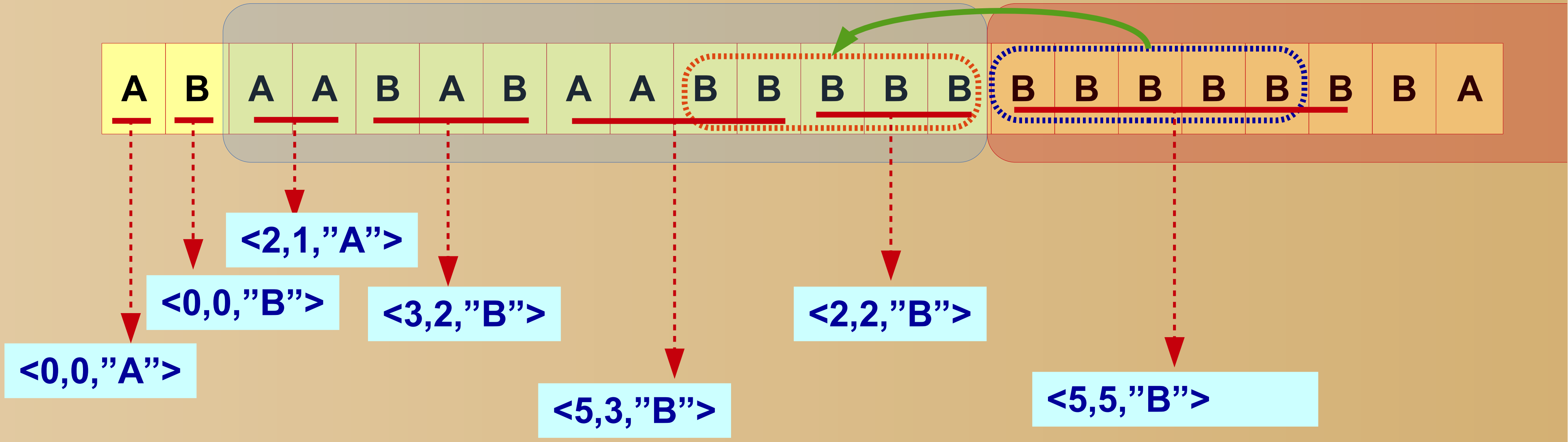


"BB" exists in search buffer

Go Back two Steps, Pick two Symbol

Position=2, Length =2, next Symbol="B"

LZ 77 (Compression)



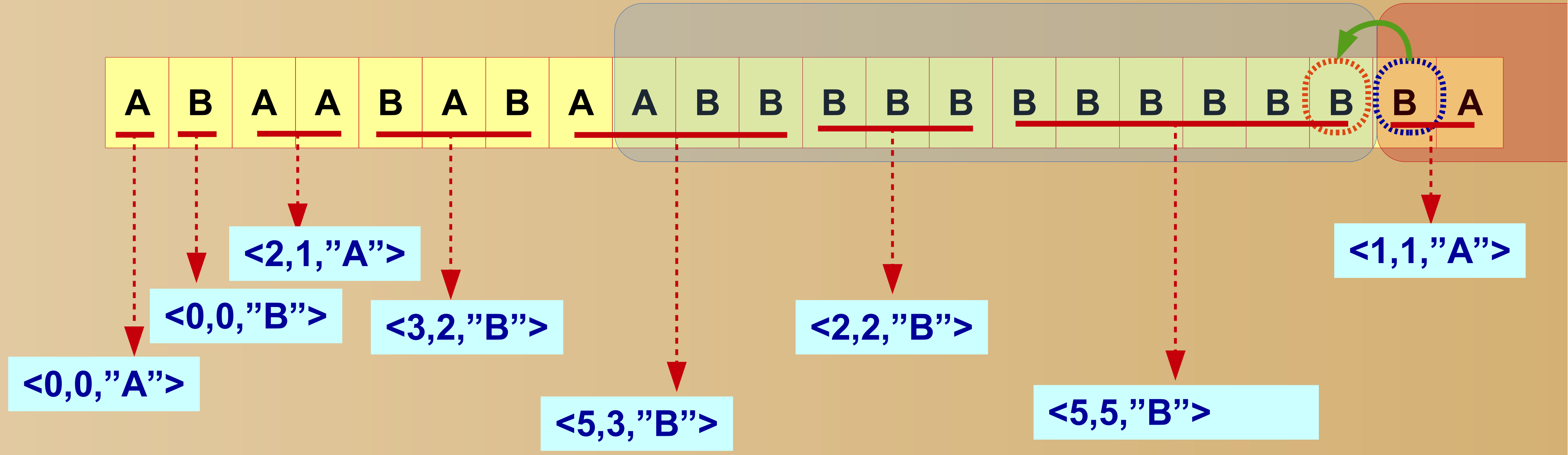
*"**BBBBB**" exists in search buffer*

Go Back five Steps, Pick five Symbol

Position=5, Length =5, next Symbol="B"

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZ 77 (Compression)



"B" exists in search buffer

Go Back One Steps, Pick One Symbol

Position=1, Length =1, next Symbol="A"

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZ77 (Compression Ratio)

Remember

1 Bit	can represent	2 Values (0,1) [0-1]
2 Bits	can represent	4 values (00,01,10,11) [0-3]
3 Bits	can represent	8 Values (000,001,010,011,100,101,110,111) [0-7]

In General

N Bits can be used to represent 2^N Values [1 - 2^N-1]

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

كلية الحاسبات و المعلومات

LZ77 (Compression Ratio)

Tag = < Position, Length ,Next Symbol Code>

<0,0,"A">	<0,0,"B">	<2,1,"A">	<3,2,"B">	<5,3,"B">	<2,2,"B">	<5,5,"B">	<1,1,"A">

Original Size = Number of Symbols * Bits used to Store one Symbol
= 22 Symbols * 8 Bits / Symbol = 176 bits
(Store "Symbol" ASCII Code in 8 Bits)

Max "Position" Value = 5	Store "Position" Value in 3 Bits
Max "Length" Value=5	Store "Length" Value in 3 Bits
Max Symbols = 256 Symbol	Store "Symbol" ASCII Code in 8 Bits

Tag size = 3 + 3 + 8 =14 Bits

Number of Tags = 8 Tags
Compressed Size=8*14=112 bits

كلية الحاسبات و المعـلومات

LZ77 (Compression Ratio)

Tag = < Position, Length ,Next Symbol Code>

Effect of Increasing length of Search Window

Higher Probability to find matched strings (Decrease Number of Tags) 👍

Increase Number of Bits used to Store "Position" values 👎

Effect of Increasing length of Look Ahead Buffer

Higher Probability to match longer strings(Decrease Number of Tags) 👍

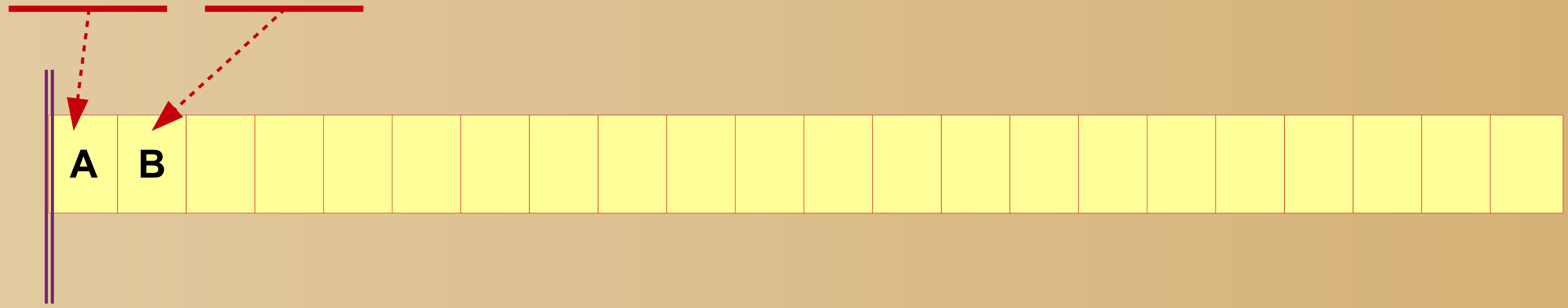
Increase Number of Bits used to Store "Length" values 👎

LZ 77 (Decompression)

Original Data

A	B	A	A	B	A	B	A	A	B	B	B	B	B	B	B	B	B	B	B	B	A

<0,0,”A”> <0,0,”B”> <2,1,”A”> <3,2,”B”> <5,3,”B”> <2,2,”B”> <5,5,”B”> <1,1,”A”>



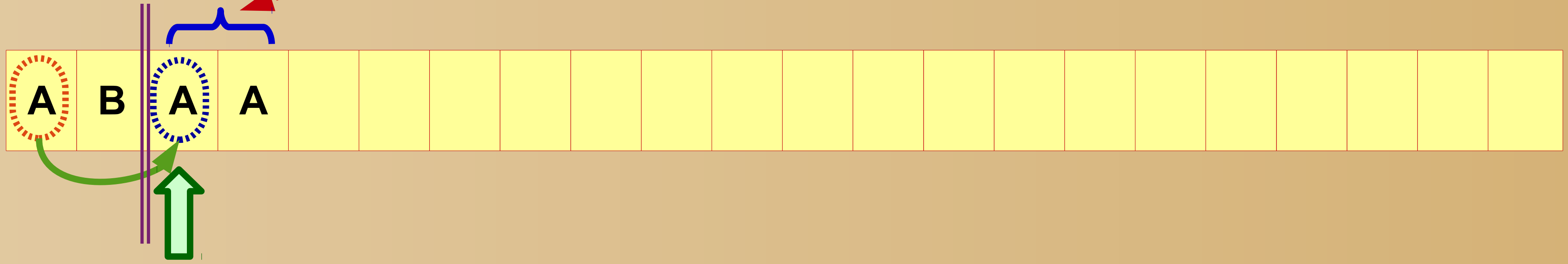
Don't pick any symbol from Search Window
Add Symbol=”A”
Add Symbol=”B”

LZ 77 (Decompression)

Original Data

A	B	A	A	B	A	B	A	A	B	B	B	B	B	B	B	B	B	B	B	B	A

<0,0,"A"> <0,0,"B"> <2,1,"A"> <3,2,"B"> <5,3,"B"> <2,2,"B"> <5,5,"B"> <1,1,"A">



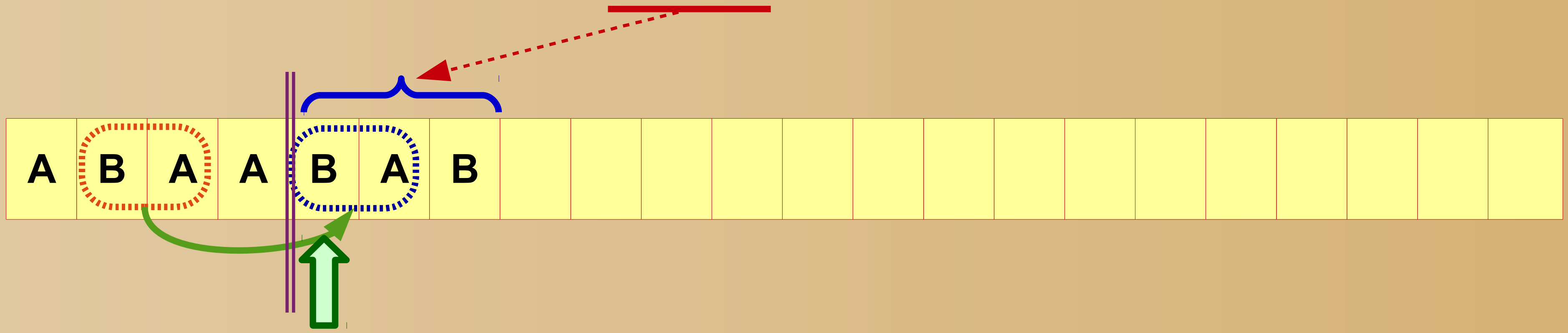
Go back Two Positions in search window
pick One symbol from Search Window
Add Symbol="A"

LZ 77 (Decompression)

Original Data

A	B	A	A	B	A	B	A	A	B	B	B	B	B	B	B	B	B	B	B	B	A

<0,0,"A"> <0,0,"B"> <2,1,"A"> <3,2,"B"> <5,3,"B"> <2,2,"B"> <5,5,"B"> <1,1,"A">



Go back Three Positions in search window
pick Two symbols from Search Window
Add Symbol="B"

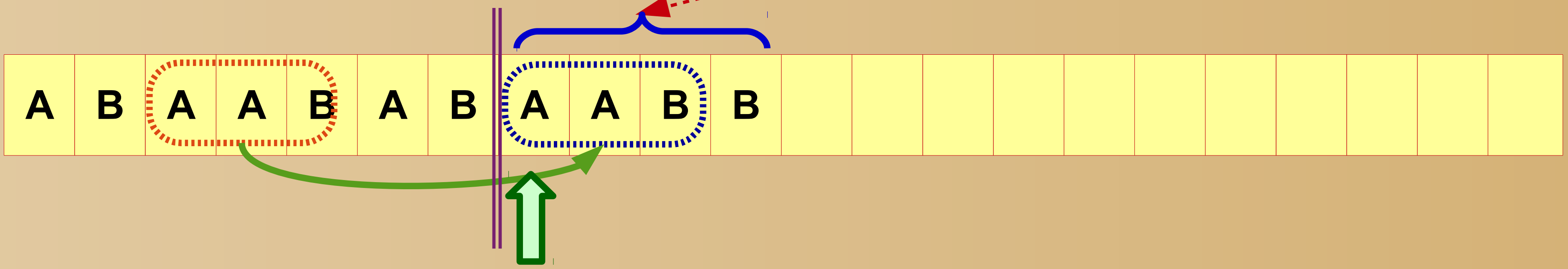
LZ 77 (Decompression)

كلية الحاسبات و المعلومات
جامعة القاهرة

Original Data

A	B	A	A	B	A	B	A	A	B	B	B	B	B	B	B	B	B	B	B	B	A

<0,0,"A"> <0,0,"B"> <2,1,"A"> <3,2,"B"> <5,3,"B"> <2,2,"B"> <5,5,"B"> <1,1,"A">



Go back Five Positions in search window
pick Three symbols from Search Window
Add Symbol="B"

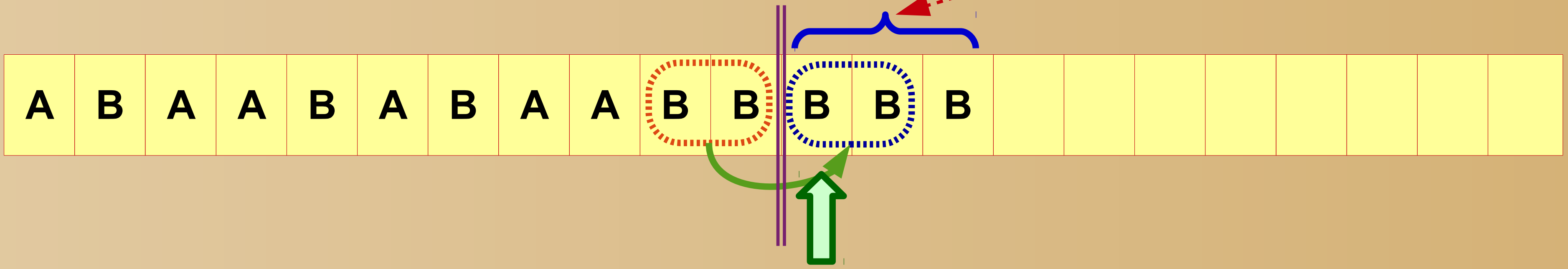
Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZ 77 (Decompression)

Original Data

A	B	A	A	B	A	B	A	A	B	B	B	B	B	B	B	B	B	B	B	B	A

<0,0,"A"> <0,0,"B"> <2,1,"A"> <3,2,"B"> <5,3,"B"> <2,2,"B"> <5,5,"B"> <1,1,"A">



A	B	A	A	B	A	B	A	A	B	B	B	B	B								

*Go back **Two P**ositions in search window*
*pick **Two** symbols from Search Window*
*Add **S**ymbol="**B**"*

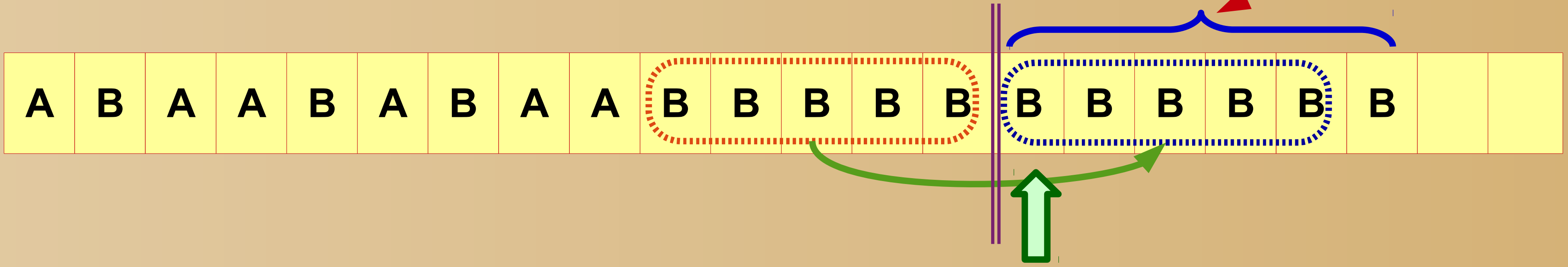
Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZ 77 (Decompression)

Original Data

A	B	A	A	B	A	B	A	A	B	B	B	B	B	B	B	B	B	B	B	B	A

<0,0,"A"> <0,0,"B"> <2,1,"A"> <3,2,"B"> <5,3,"B"> <2,2,"B"> <5,5,"B"> <1,1,"A">



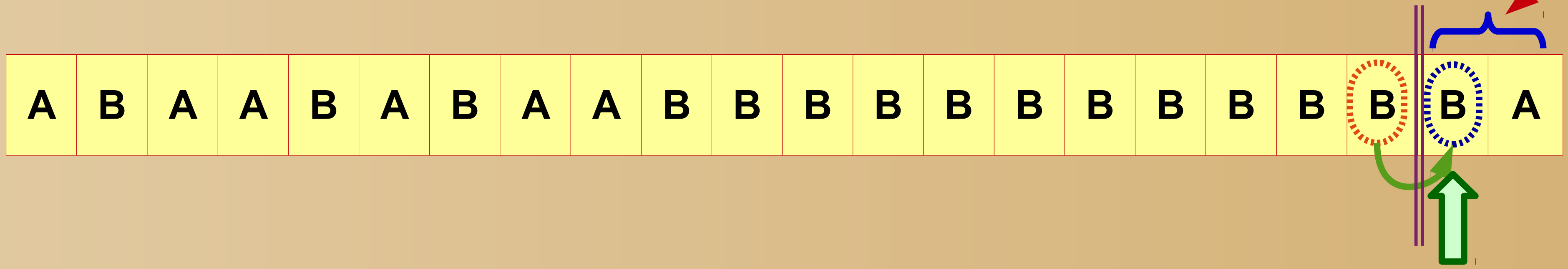
Go back Five Positions in search window
pick Five symbols from Search Window
Add Symbol="B"

LZ 77 (Decompression)

Original Data

A	B	A	A	B	A	B	A	A	B	B	B	B	B	B	B	B	B	B	B	B	A

<0,0,"A"> <0,0,"B"> <2,1,"A"> <3,2,"B"> <5,3,"B"> <2,2,"B"> <5,5,"B"> <1,1,"A">



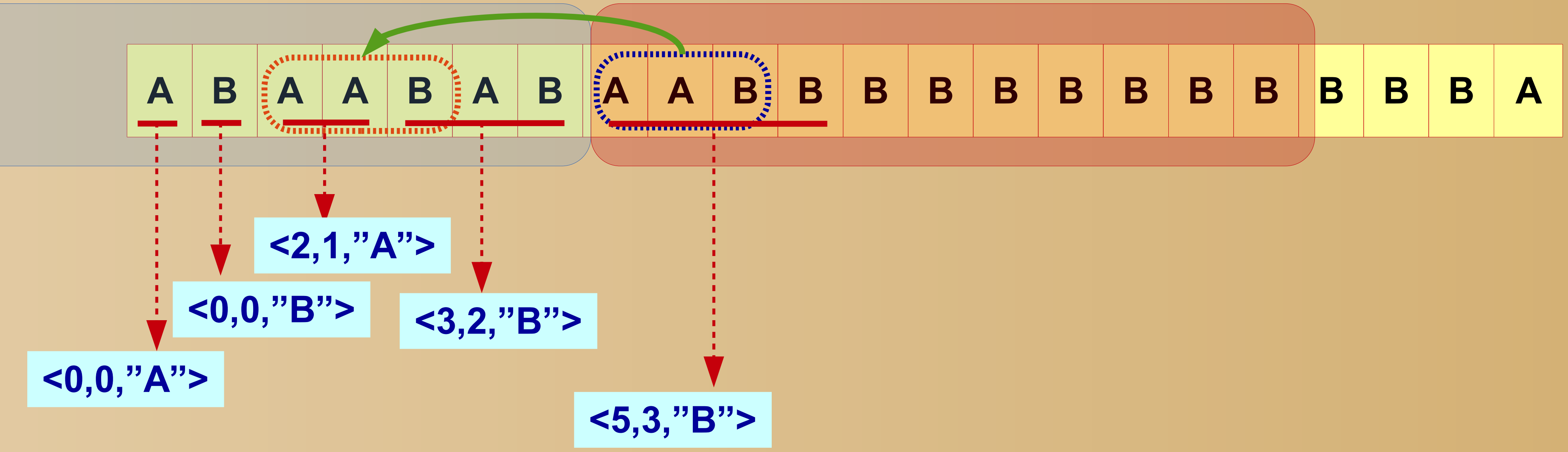
Go back One Positions in search window
pick One symbol from Search Window
Add Symbol="B"

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZ 77 (Compression) (Handling Repetitive Sequence)

Back to Previous Example

Can We manipulate Consecutive "B"s more efficient ?



"AAB" exists in search buffer

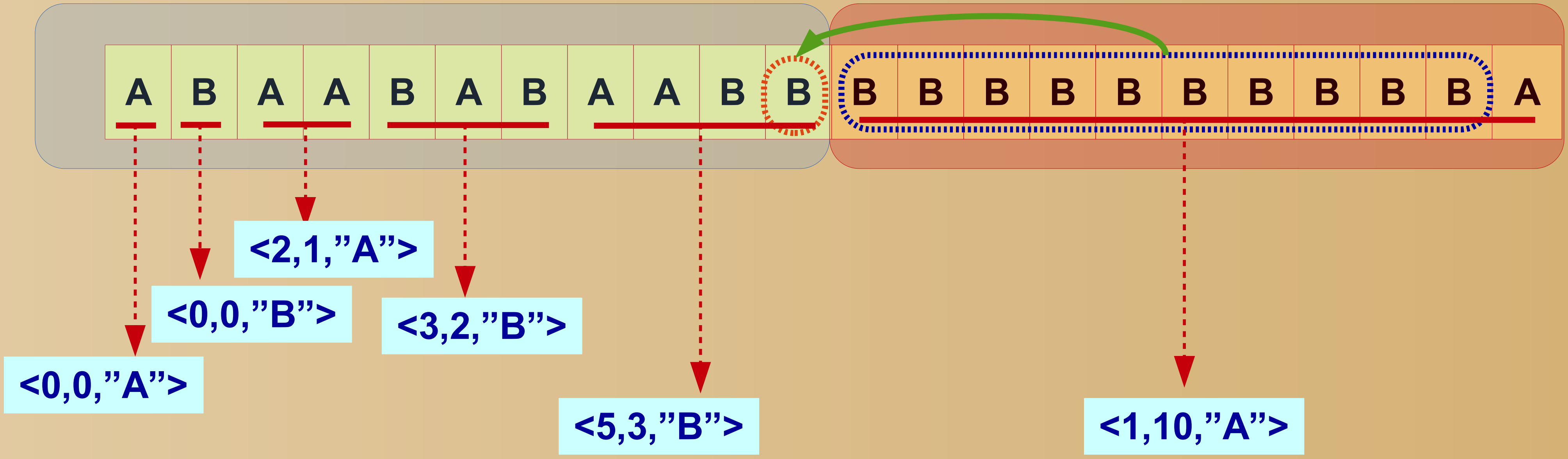
Go Back five Steps, Pick Three Symbol

Position=5, Length =3, next Symbol="B"

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZ 77 (Compression)
(Handling Repetitive Sequence)

YES, We Can



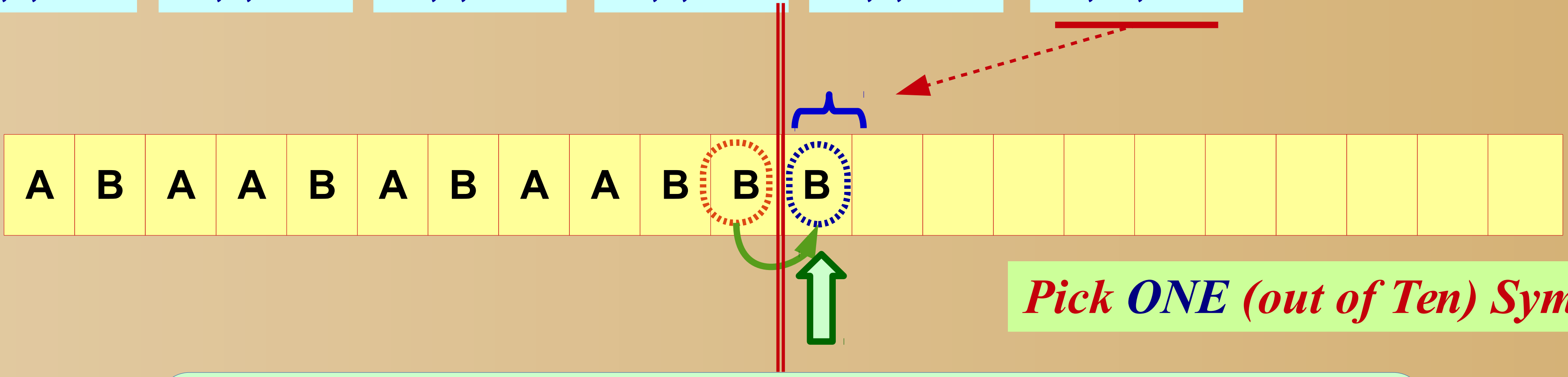
There are Ten Consecutive "B" in Look Ahead Buffer
"B" exists in search buffer One position Backward
Go Back One Steps, Pick Ten Symbols
Position=1, Length =10, next Symbol="A"

LZ 77 (Decompression) (Handling Repetitive Sequence)

Original Data

A	B	A	A	B	A	B	A	A	B	B	B	B	B	B	B	B	B	B	B	B	A

<0,0,"A"> <0,0,"B"> <2,1,"A"> <3,2,"B"> <5,3,"B"> <1,10,"A">



Pick ONE (out of Ten) Symbol

Go back One Position in search window
pick Ten symbols from Search Window (in 10 Steps)
Add Symbol="A"

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

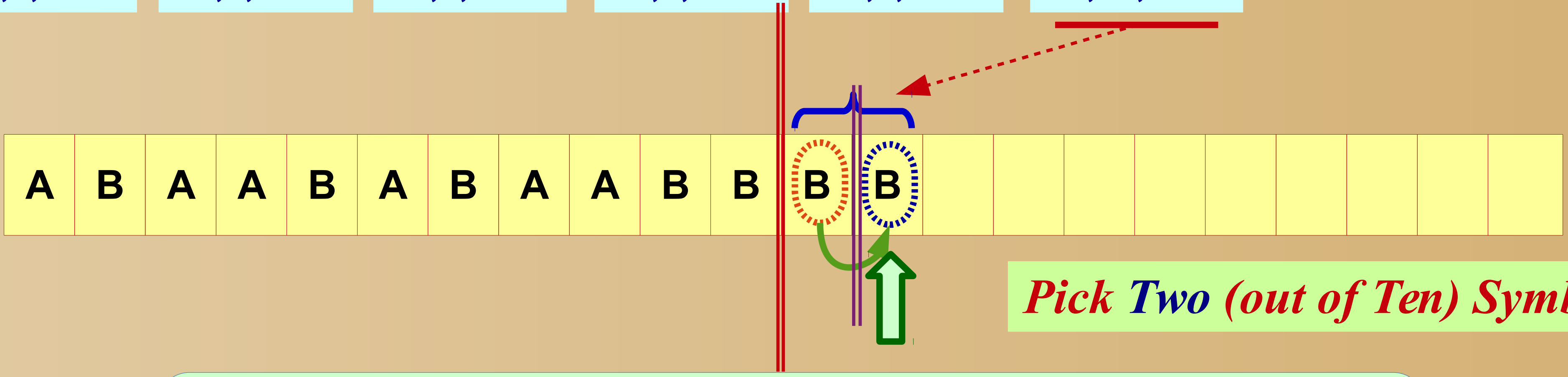
LZ 77 (Decompression)
(Handling Repetitive Sequence)

كلية الحاسبات و المعلومات

Original Data

A	B	A	A	B	A	B	A	A	B	B	B	B	B	B	B	B	B	B	B	B	A

<0,0,"A"> <0,0,"B"> <2,1,"A"> <3,2,"B"> <5,3,"B"> <1,10,"A">



A	B	A	A	B	A	B	A	A	B	B	B	B									

Pick Two (out of Ten) Symbol

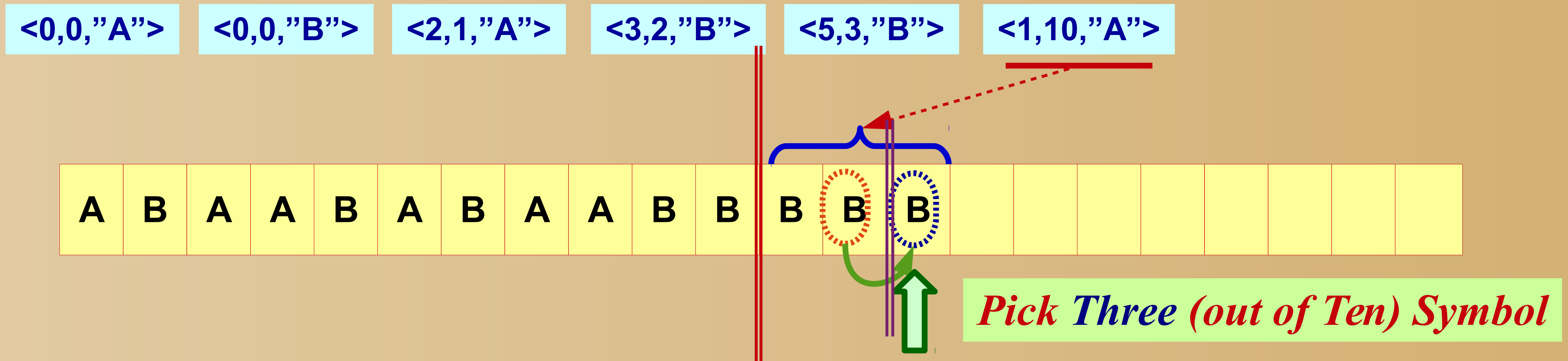
Go back One Position in search window
pick Ten symbols from Search Window (in 10 Steps)
Add Symbol="A"

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZ 77 (Decompression) (Handling Repetitive Sequence)

Original Data

A	B	A	A	B	A	B	A	A	B	B	B	B	B	B	B	B	B	B	B	B	A



Go back One Position in search window
pick Ten symbols from Search Window (in 10 Steps)
Add Symbol="A"

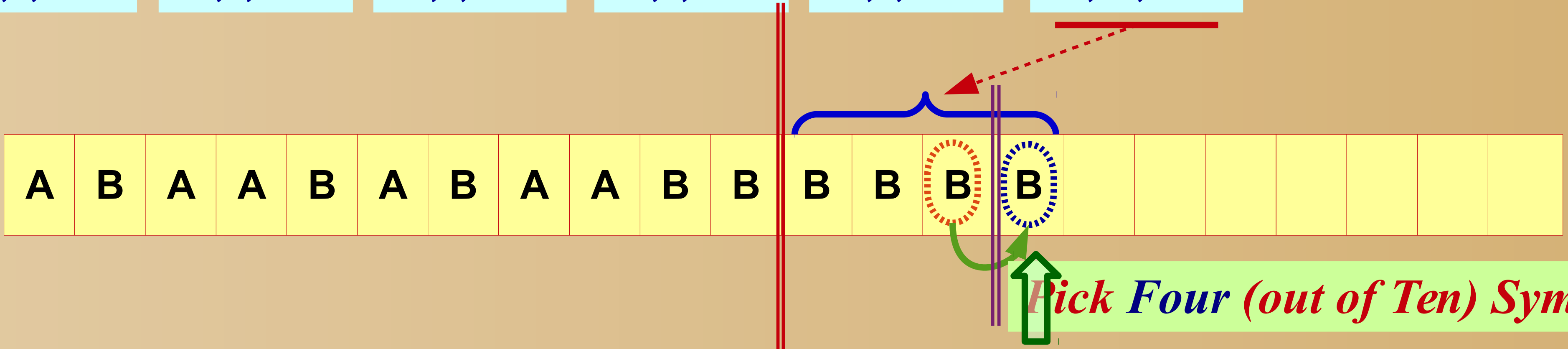
Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZ 77 (Decompression) (Handling Repetitive Sequence)

Original Data

A	B	A	A	B	A	B	A	A	B	B	B	B	B	B	B	B	B	B	B	B	A

<0,0,"A"> <0,0,"B"> <2,1,"A"> <3,2,"B"> <5,3,"B"> <1,10,"A">



A	B	A	A	B	A	B	A	A	B	B	B	B	B	B							

Pick Four (out of Ten) Symbol

Repeat , Five, Six, Seven, Eight, Nine, and Ten

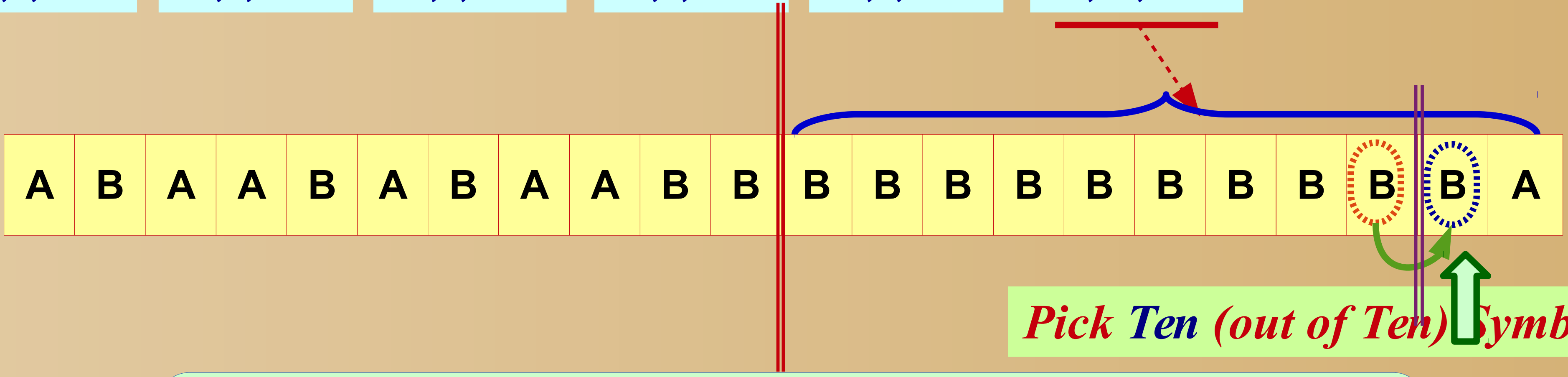
Go back One Position in search window
pick Ten symbols from Search Window (in 10 Steps)
Add Symbol="A"

LZ 77 (Decompression) (Handling Repetitive Sequence)

Original Data

A	B	A	A	B	A	B	A	A	B	B	B	B	B	B	B	B	B	B	B	B	A

<0,0,"A"> <0,0,"B"> <2,1,"A"> <3,2,"B"> <5,3,"B"> <1,10,"A">



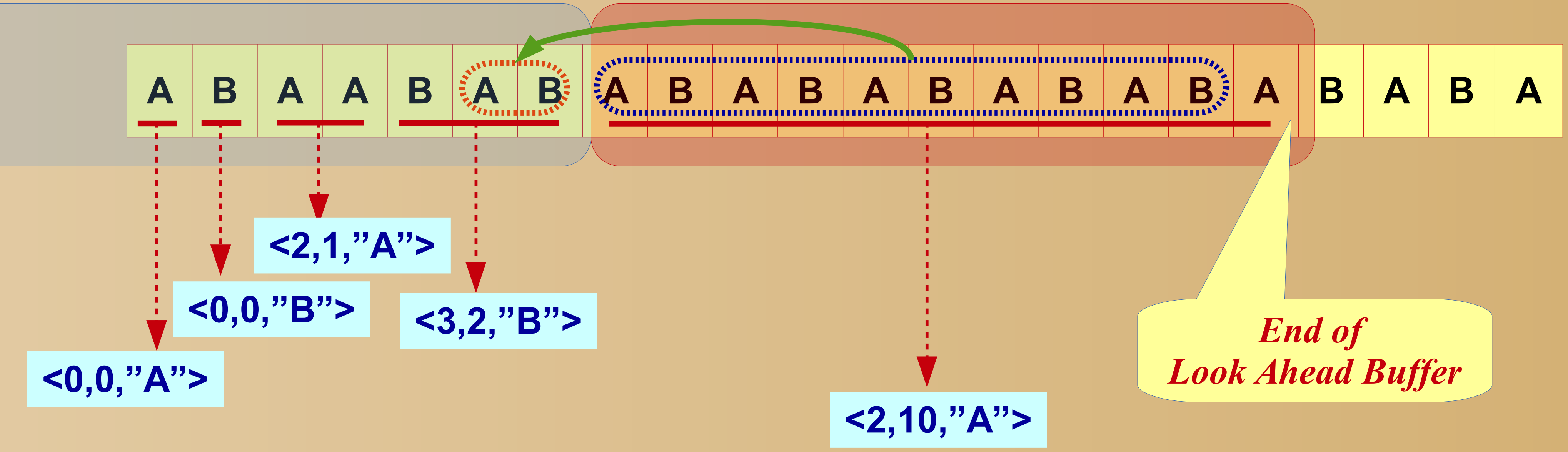
A	B	A	A	B	A	B	A	A	B	B	B	B	B	B	B	B	B	B	B	B	A

Pick Ten (out of Ten) Symbol

Go back One Position in search window
pick Ten symbols from Search Window (in 10 Steps)
Add Symbol="A"

LZ 77 (Compression) (Handling Repetitive Sequence)

Can We Apply the same Technique on Consecutive "Two Symbols" ?



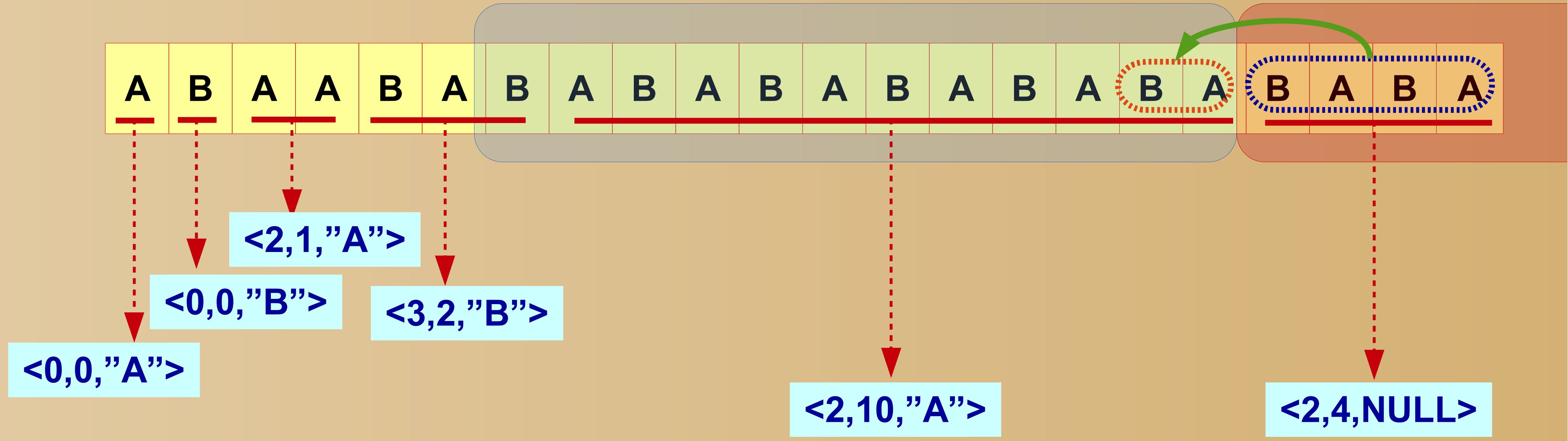
There are Ten Consecutive Symbols "AB" in Look Ahead Buffer

"AB" exists in search buffer Adjacent to Look Ahead Buffer

Go Back Two Steps, Pick Ten Symbols

Position=2, Length =10, next Symbol="A"

LZ 77 (Compression)
(Handling Repetitive Sequence)



There are Four Consecutive Symbols "BA" in Look Ahead Buffer

"BA" exists in search buffer Adjacent to Look Ahead Buffer

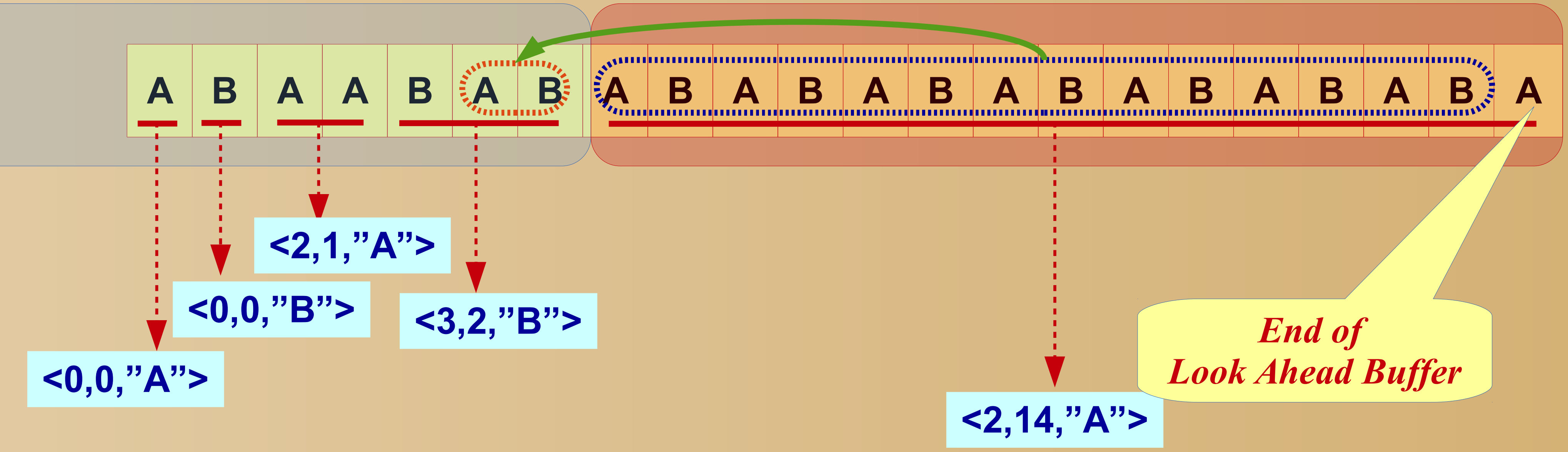
Go Back Two Steps, Pick Four Symbols

Position=2, Length =4, next Symbol=NULL

جامعة القاهرة
كلية الحاسبات و المعلومات

LZ 77

*What if we use **BIGGER** look Ahead Buffer ?*



There are 14 Consecutive Symbols "AB" in Look Ahead Buffer

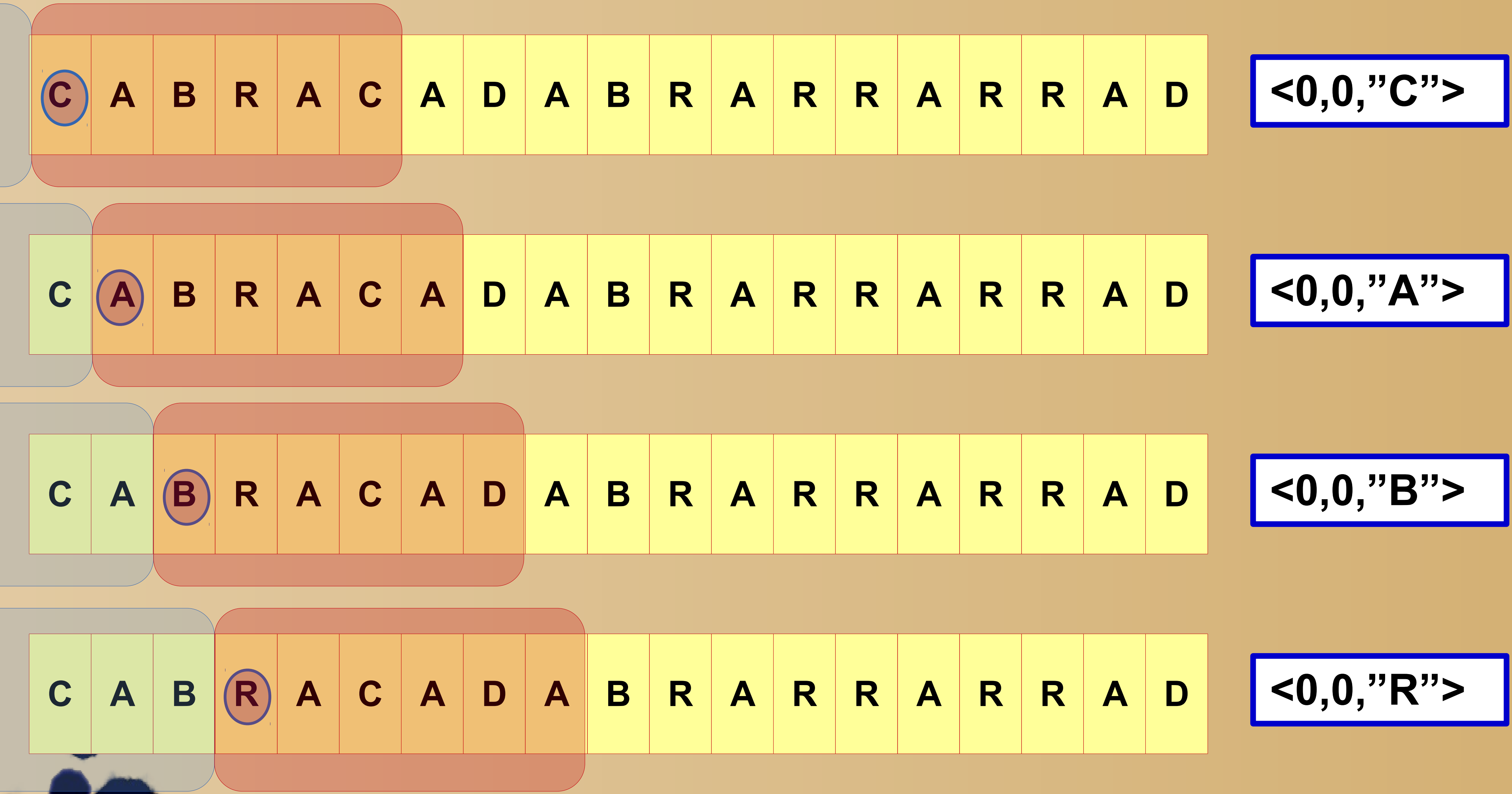
"AB" exists in search buffer Adjacent to Look Ahead Buffer

Go Back Two Steps, Pick Ten Symbols

Position=2, Length =14, next Symbol="A"

LZ 77 (Compression)

(Handling Repetitive Overlapped Sequence)

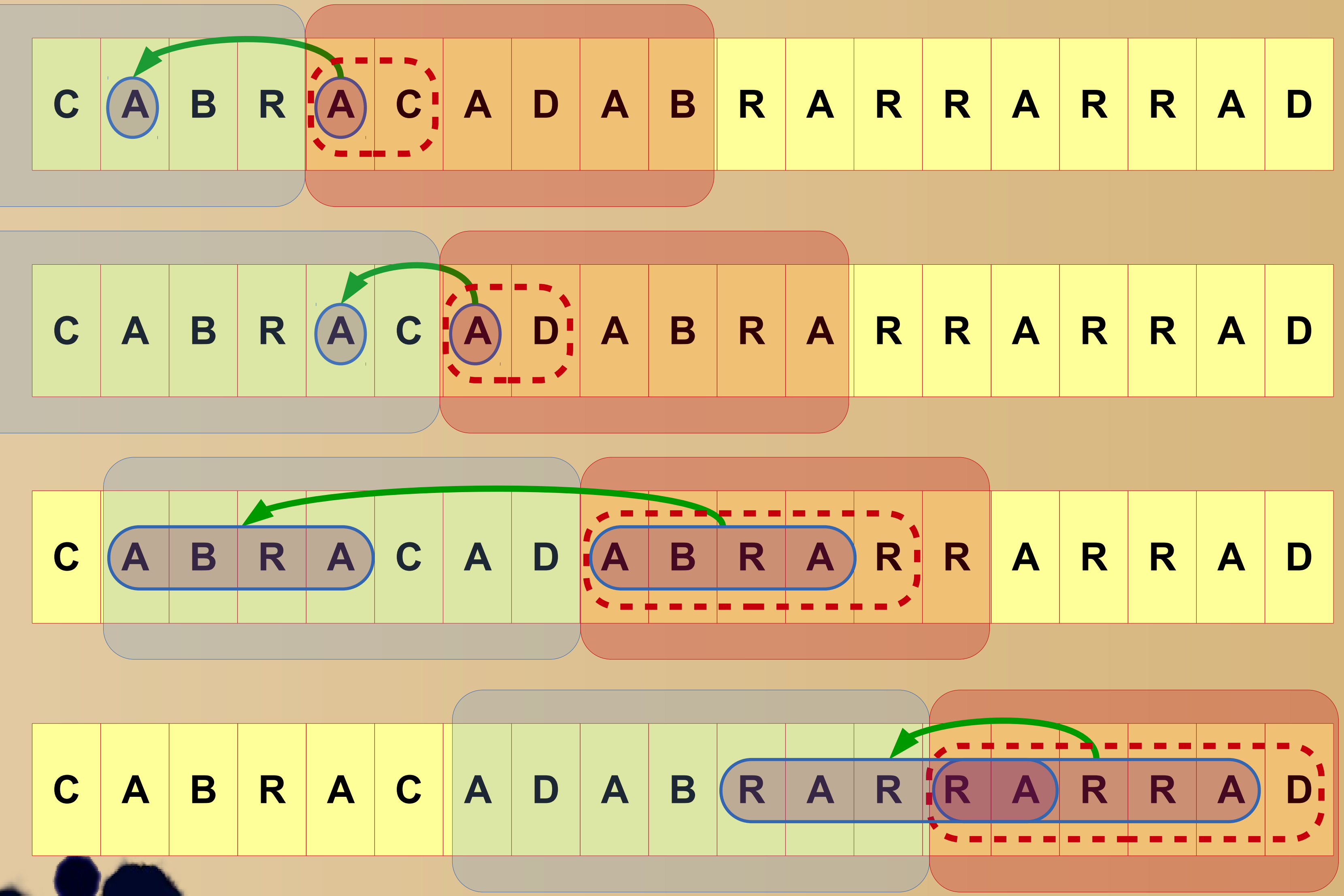

C A B R A C A D A B R A R R A R R A D
<0,0,"C">
C A B R A C A D A B R A R R A R R A D
<0,0,"A">
C A B R A C A D A B R A R R A R R A D
<0,0,"B">
C A B R A C A D A B R A R R A R R A D
<0,0,"R">

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZ 77 (Compression)

(Handling Repetitive Overlapped Sequence)

كلية الحاسبات و المعلومات
جامعة القاهرة


C A B R A C A D A B R A R R A R R A D
C A B R A C A D A B R A R R A R R A D
C A B R A C A D A B R A R R A R R A D
C A B R A C A D A B R A R R A R R A D

<3,1,"C">

<2,1,"D">

<7,4,"R">

<3,5,"D">

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

Compression Ratio

<0,0,"C"> <0,0,"A"> <0,0,"B"> <0,0,"R"> <3,1,"C"> <2,1,"D"> <7,4,"R"> <3,5,"D">

Original Size = Number of Symbols * Bits used to Store one Symbol
= 19 Symbols * 8 Bits / Symbol = 152 bits
(Store "Symbol" ASCII Code in 8 Bits)

Max "Position" Value = 7	Store "Position" Value in 3 Bits
Max "Length" Value=5	Store "Length" Value in 3 Bits
Max Symbols = 256 Symbol	Store "Symbol" ASCII Code in 8 Bits

Tag size = 3 + 3 + 8 =14 Bits

Number of Tags = 8 Tags
Compressed Size=8*14=112 bits

Advantages and Disadvantage of LZ77

كلية الحاسبات و المعـلومات

Advantages of LZ77

- Probabilities of symbols is not required to be known a priori. (suitable for Real time Compression).
- That is, the longer the size of the sliding window, the better the performance of data compression
- No coding table Required for Decompression.

Disadvantage of LZ77

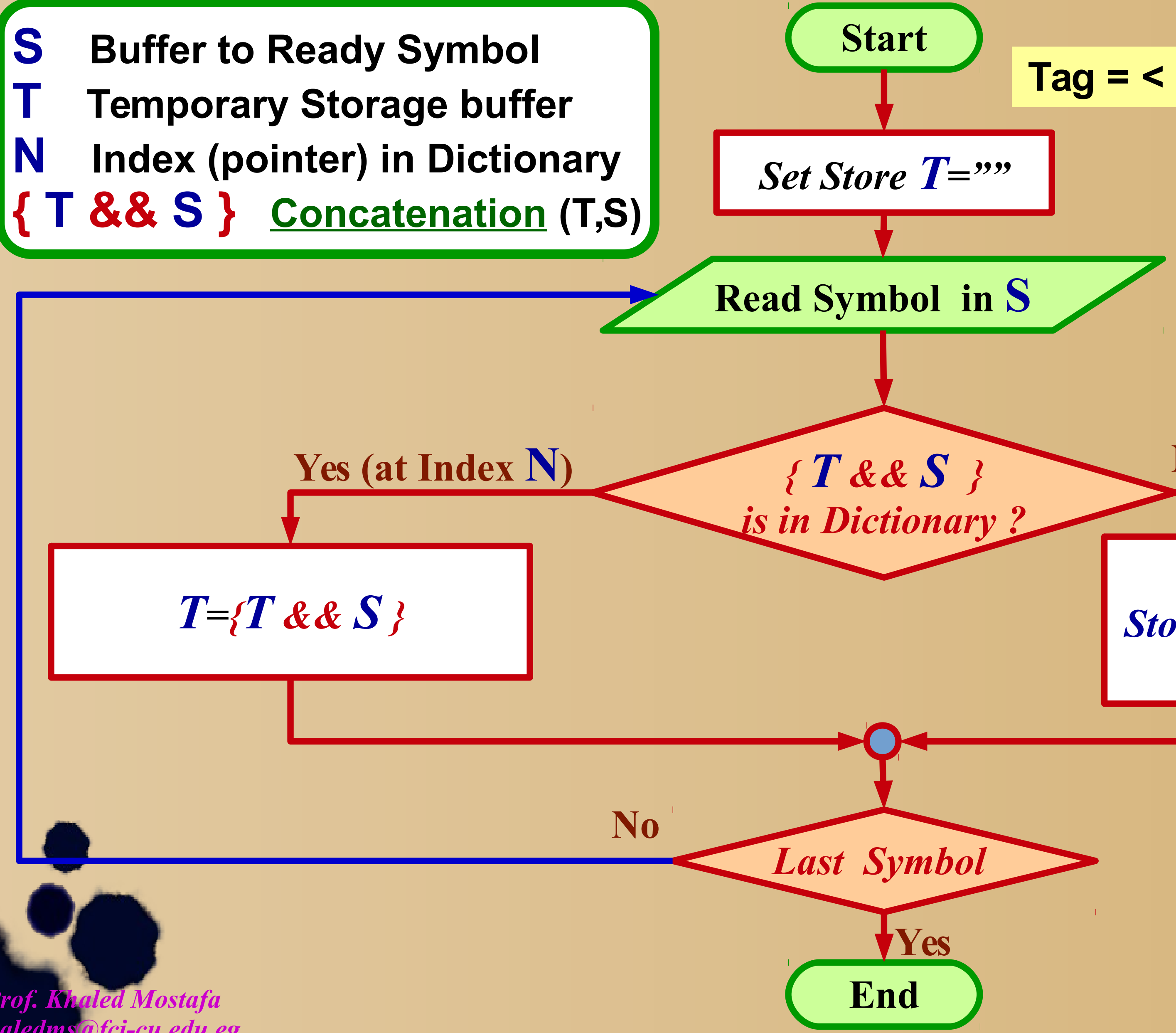
A straightforward implementation would require up to [Look Ahead Buffer Size] * [Search Window Size] Symbol comparisons per Tag produced. Complexity of comparison is very large

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZ 78 (Compression)

S	Buffer to Ready Symbol
T	Temporary Storage buffer
N	Index (pointer) in Dictionary
{ T && S }	Concatenation (T,S)

Tag = < iNdex in Dict , Next Symbol>



Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZ 78 (Compression)

A	B	A	A	B	A	B	A	A	B	A	B	B	B	B	B	B	B	B	B	B	A

Compress the Following Text
(22 Characters)

Custom Dictionary
(first Word is reserved as Empty)

0	------
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	

TAG ⇒ <Index in dictionary , Next Symbol >

LZ 78 (Compression)

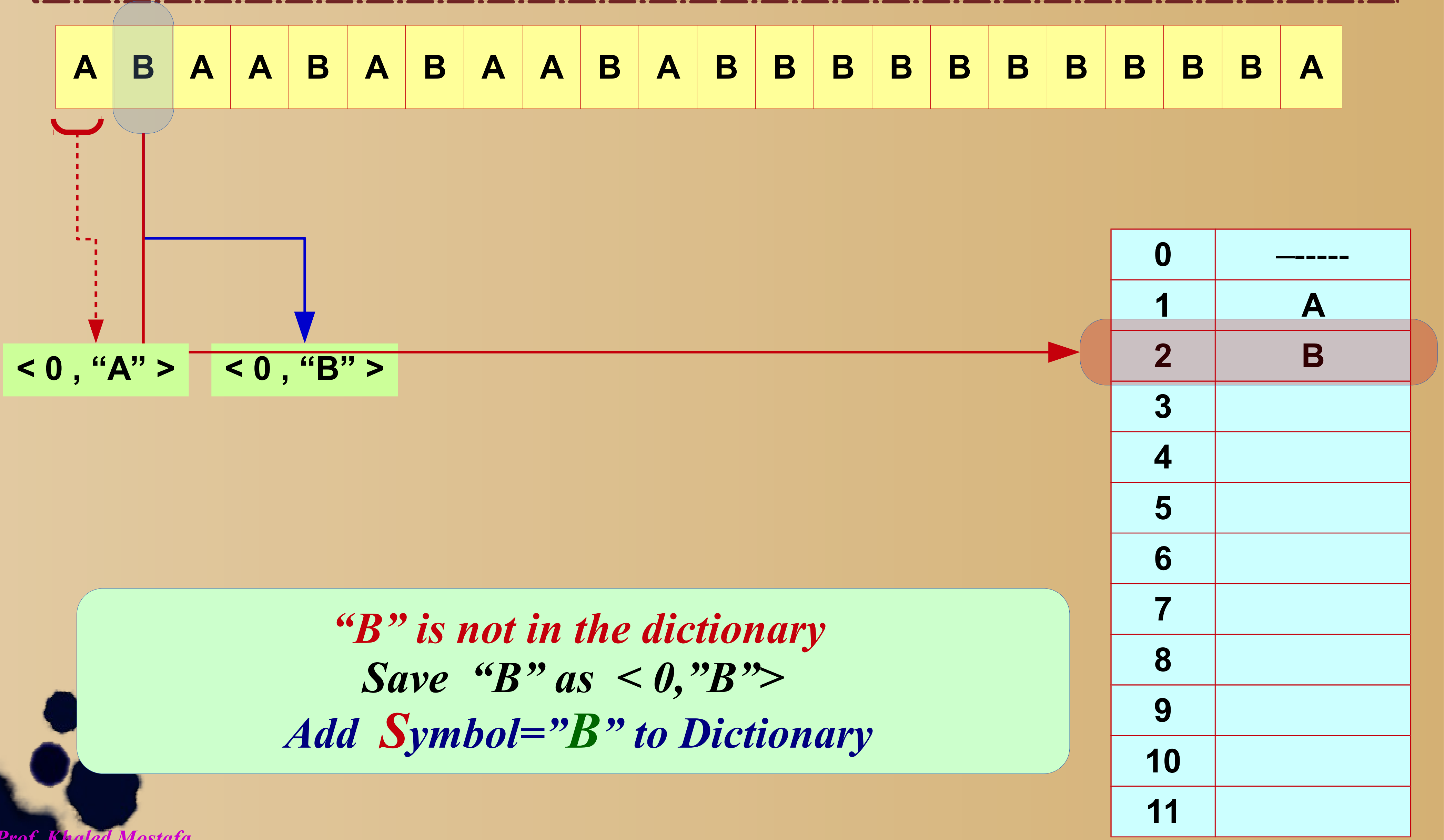
A	B	A	A	B	A	B	A	A	B	A	B	B	B	B	B	B	B	B	B	B	A

< 0 , "A" >

0	-------
1	A
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	

"A" is not in the dictionary
Save "A" as < 0,"A">
Add Symbol="A" to Dictionary

LZ 78 (Compression)

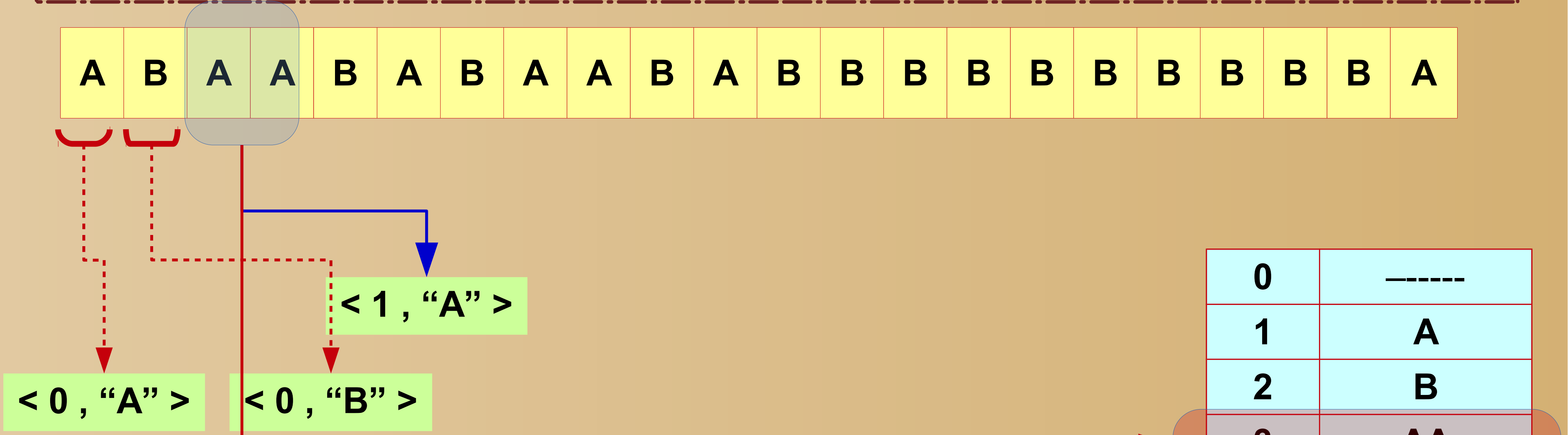


0	------
1	A
2	B
3	
4	
5	
6	
7	
8	
9	
10	
11	

"B" is not in the dictionary
Save "B" as < 0,"B">
Add Symbol="B" to Dictionary

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZ 78 (Compression)

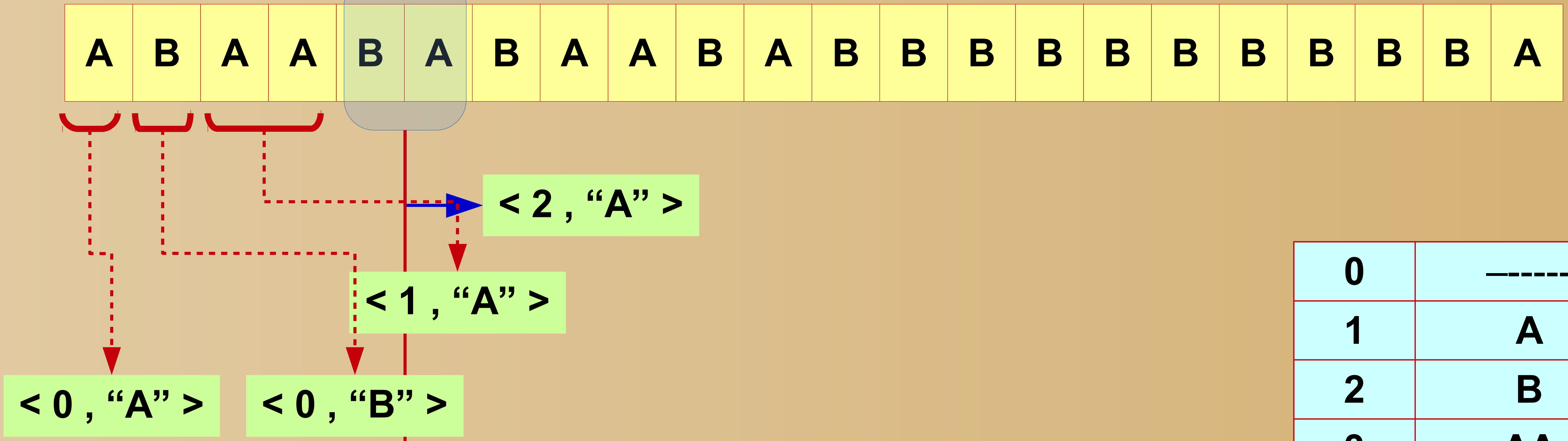


0	------
1	A
2	B
3	AA
4	
5	
6	
7	
8	
9	
10	
11	

"A" is in the dictionary BUT "AA" is NOT
Save "AA" as < 1,"A">
Add Symbols="AA" to Dictionary

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZ 78 (Compression)

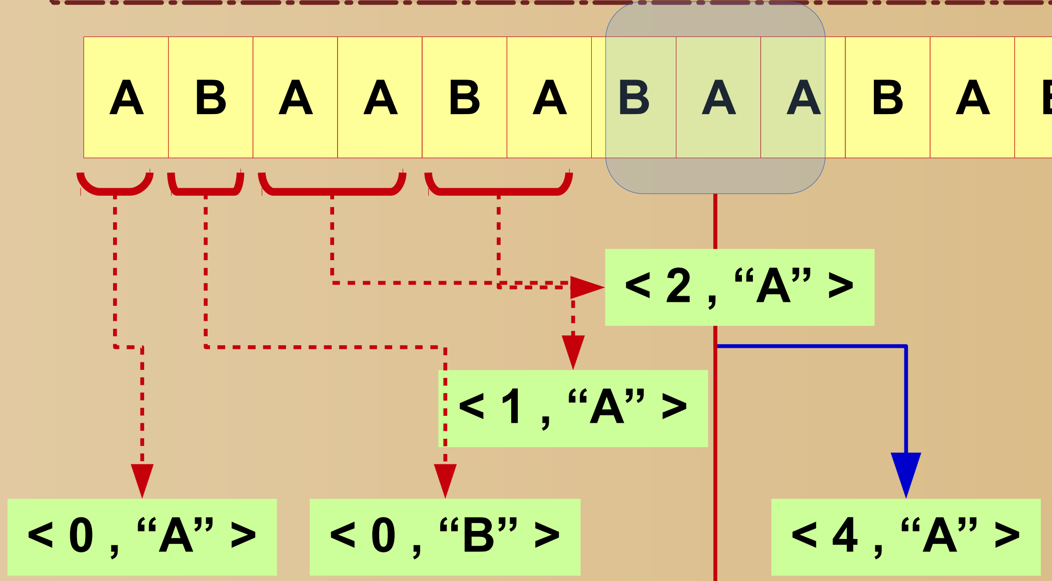


0	------
1	A
2	B
3	AA
4	BA
5	
6	
7	
8	
9	
10	
11	

"B" is in the dictionary BUT "BA" is NOT
Save "BA" as < 2,"A">
Add Symbols="BA" to Dictionary

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZ 78 (Compression)

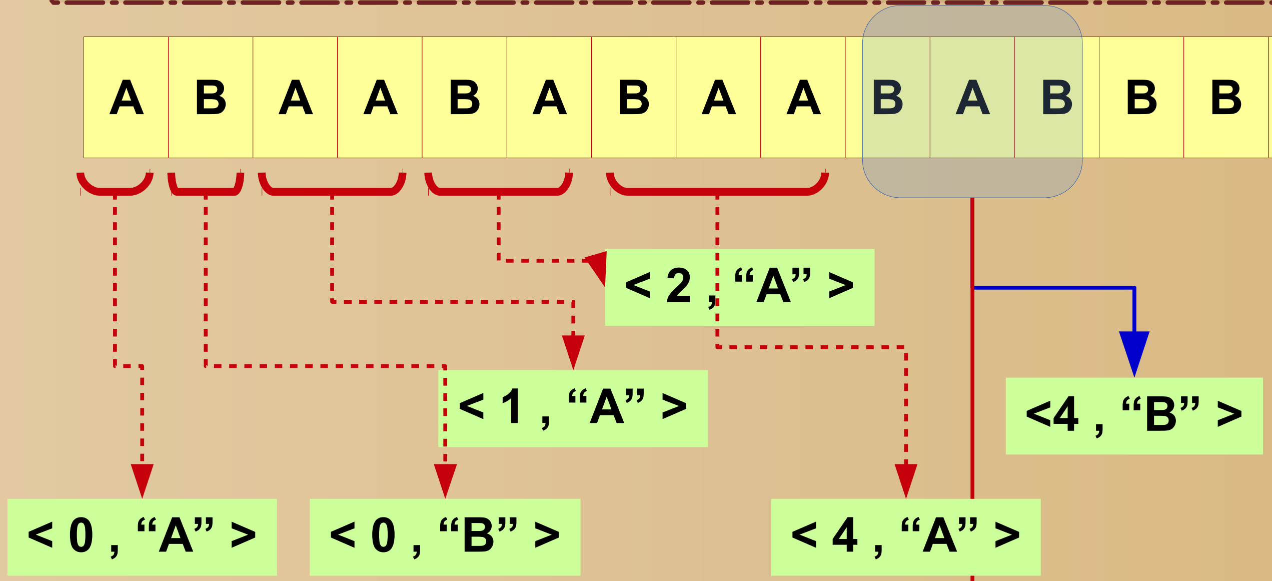


0	------
1	A
2	B
3	AA
4	BA
5	BAA
6	
7	
8	
9	
10	
11	

"BA" is in the dictionary BUT "BAA" is NOT
Save "BAA" as < 4,"A">
Add Symbols="BAA" to Dictionary

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

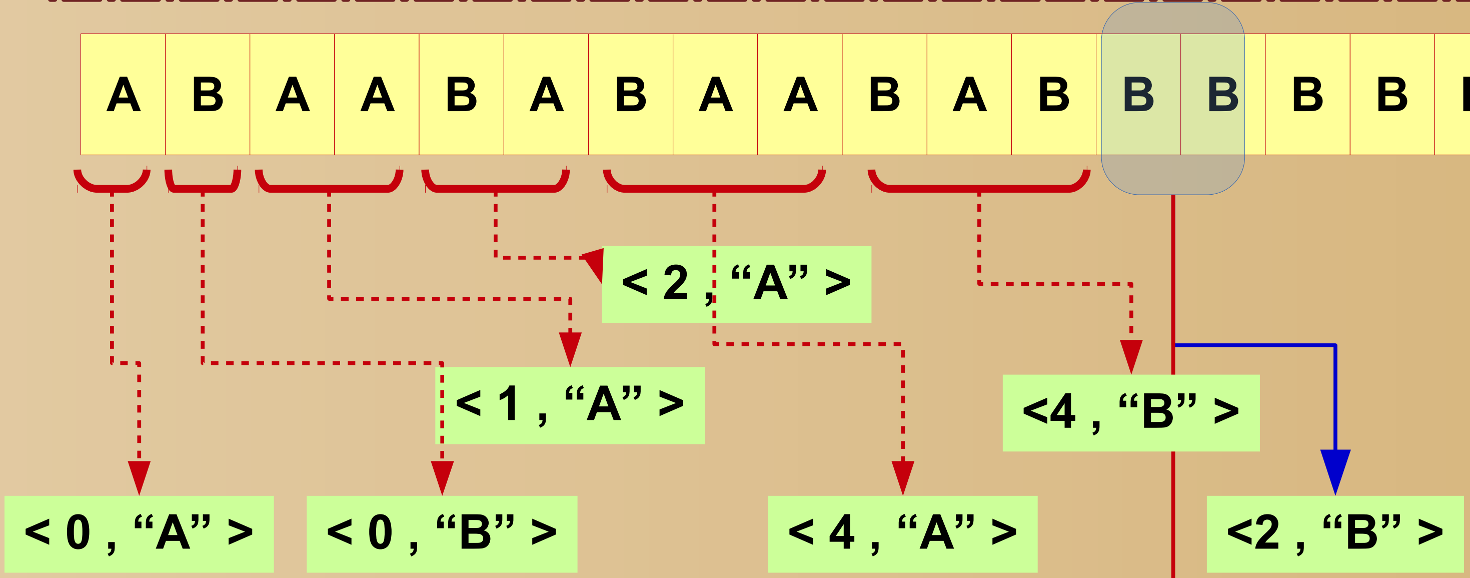
LZ 78 (Compression)



0	------
1	A
2	B
3	AA
4	BA
5	BAA
6	BAB
7	
8	
9	
10	
11	

"BA" is in the dictionary BUT "BAB" is NOT
Save "BAA" as < 4,"B">
Add Symbols="BAB" to Dictionary

LZ 78 (Compression)

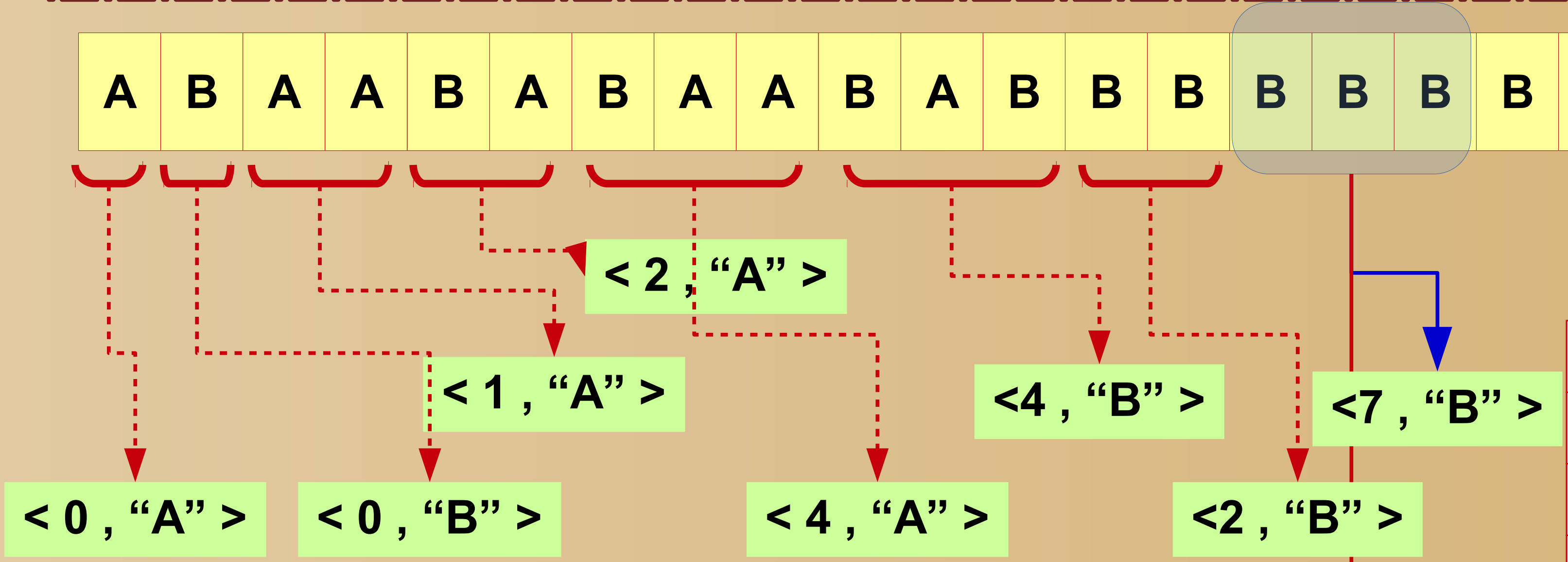


0	------
1	A
2	B
3	AA
4	BA
5	BAA
6	BAB
7	BB
8	
9	
10	
11	

"B" is in the dictionary BUT "BB" is NOT
Save "BB" as < 2,"B">
Add Symbols="BB" to Dictionary

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZ 78 (Compression)

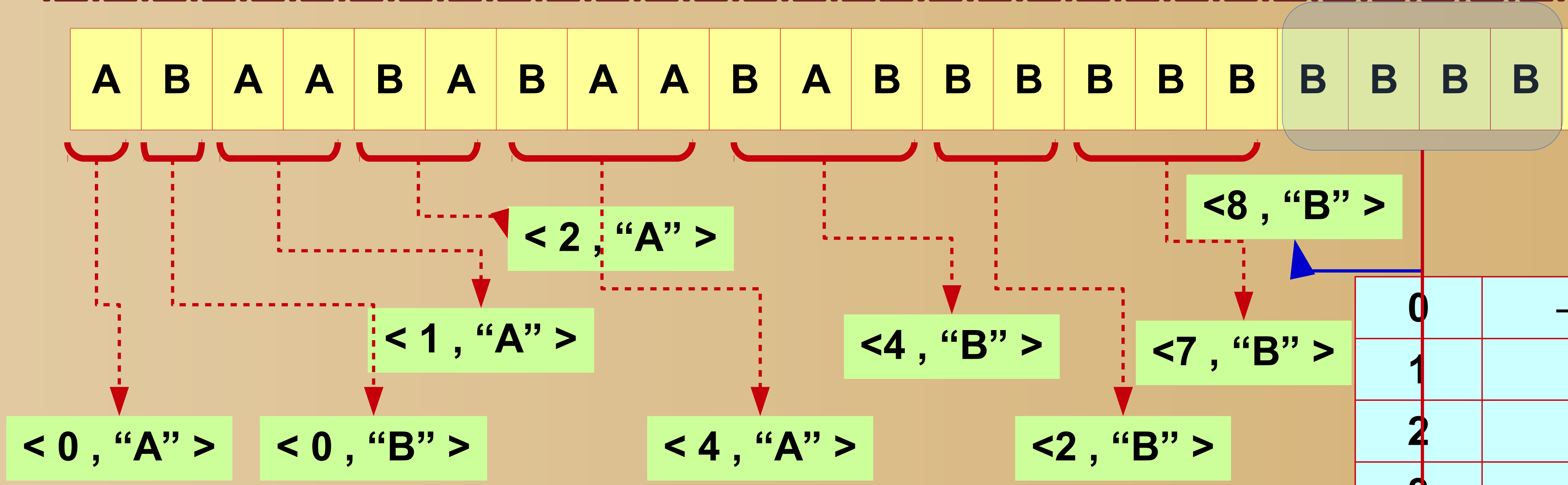


0	------
1	A
2	B
3	AA
4	BA
5	BAA
6	BAB
7	BB
8	BBB
9	
10	
11	

"BB" is in the dictionary BUT "BBB" is NOT
Save "BBB" as < 7,"B">
Add Symbols="BBB" to Dictionary

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

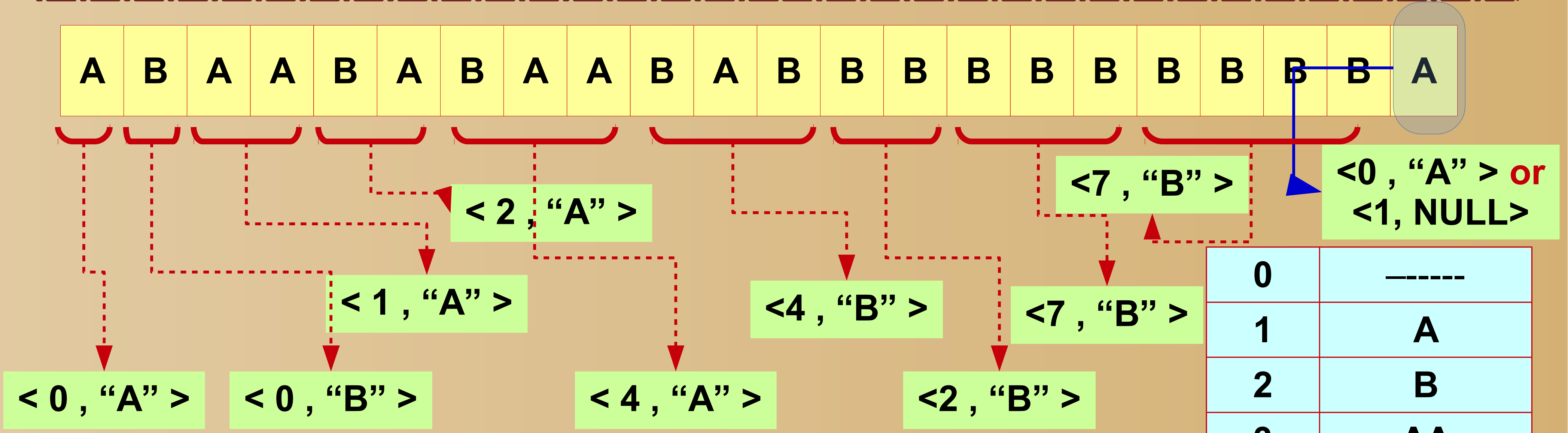
LZ 78 (Compression)



0	-------
1	A
2	B
3	AA
4	BA
5	BAA
6	BAB
7	BB
8	BBB
9	BBBB
10	
11	

"BBB" is in the dictionary BUT "BBBB" is NOT
Save "BBBB" as < 8,"B">
Add Symbols="BBBB" to Dictionary

LZ 78 (Compression)



0	------
1	A
2	B
3	AA
4	BA
5	BAA
6	BAB
7	BB
8	BBB
9	BBBB
10	
11	

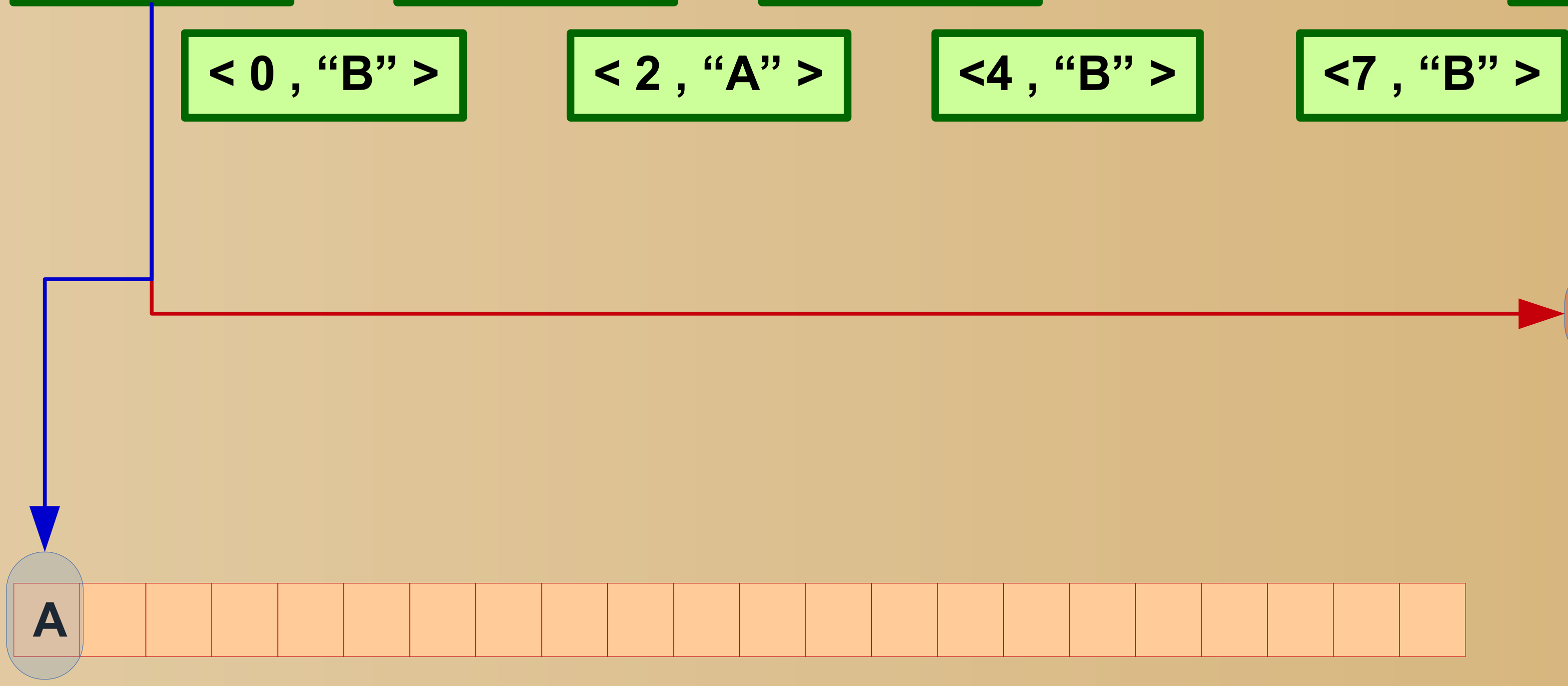
"A" is in the dictionary
Save "A" as <1 ,NULL> or < 0,"A">
Add NOTHING to Dictionary

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZ 78 (De-Compression)

كلية الحاسبات و المعلومات

< 0 , "A" > < 0 , "B" > < 1 , "A" > < 2 , "A" > < 4 , "A" > <4 , "B" > <2 , "B" > <7 , "B" > <8 , "B" > <0 , "A" > or <1, NULL>



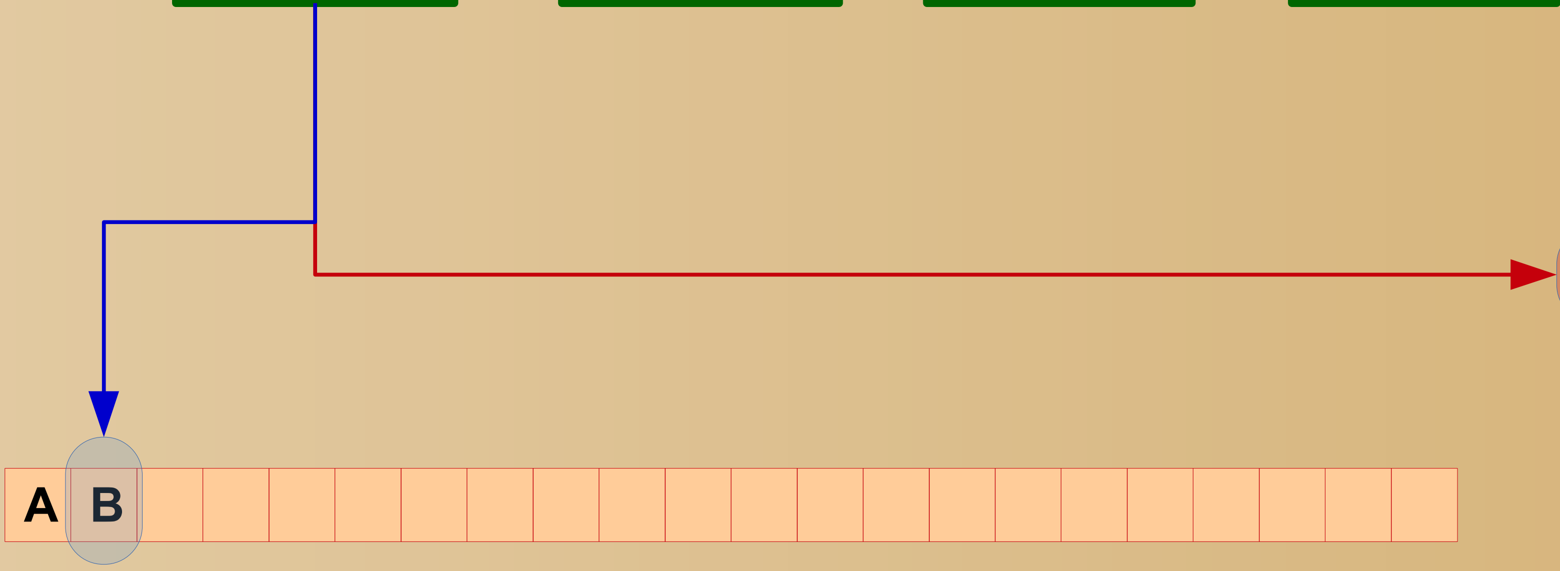
0	-------
1	A
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	

Get symbol at Index [0] in Dictionary {""}
Concatenate Symbol "A" , Obtain {"A"}
Add {"A"} to Dictionary

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZ 78 (De-Compression)

< 0 , “A” > < 0 , “B” > < 1 , “A” > < 2 , “A” > < 4 , “A” > <4 , “B” > <2 , “B” > <7 , “B” > <8 , “B” > <0 , “A” > or <1, NULL>



0	------
1	A
2	B
3	
4	
5	
6	
7	
8	
9	
10	
11	

Get symbol at Index [0] in Dictionary {“”}
Concatenate Symbol “B” , Obtain {“B”}
Add {“B”} to Dictionary

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

جامعة القاهرة
كلية الحاسبات
و المعلومات

LZ 78 (De-Compression)

< 0 , "A" >   < 0 , "B" >   < 1 , "A" >   < 2 , "A" >   < 4 , "A" >   <4 , "B" >   <2 , "B" >   <7 , "B" >   <8 , "B" >   <0 , "A" > or <1, NULL>

A	B	A	A																		

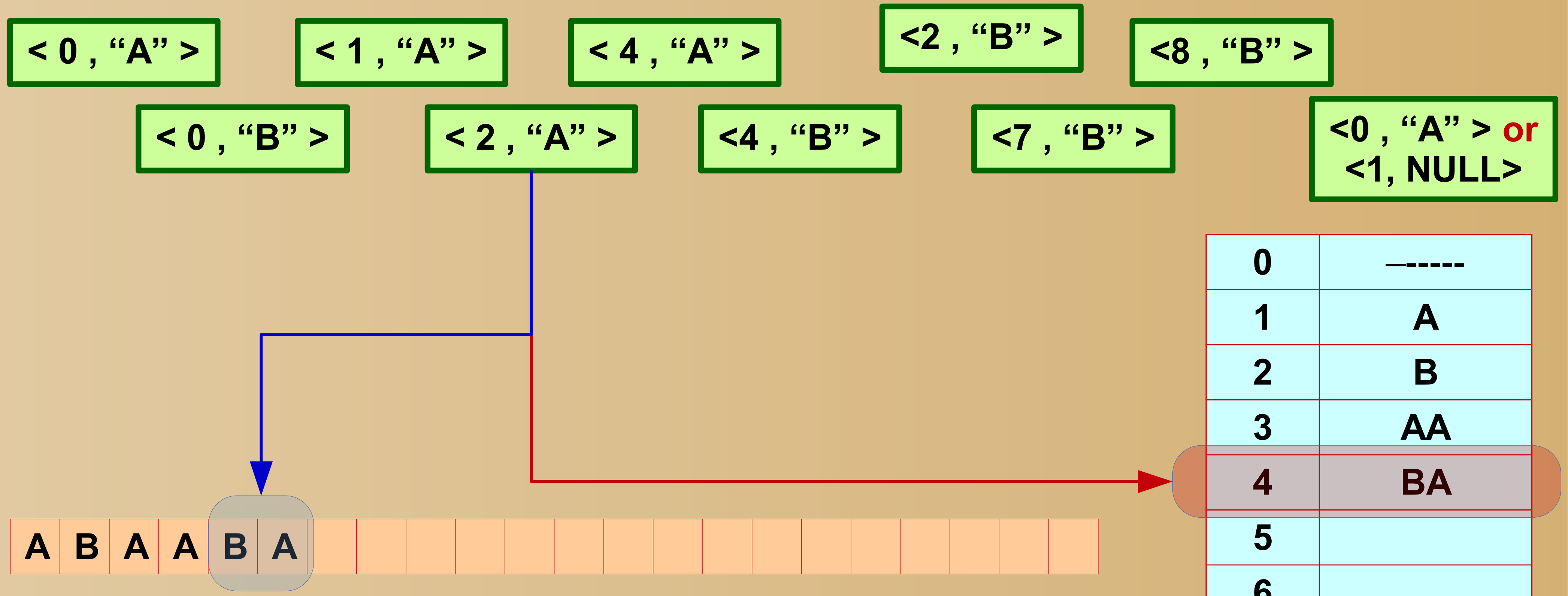
0	------
1	A
2	B
3	AA
4	
5	
6	
7	
8	
9	
10	
11	

Get symbol at Index [1] in Dictionary {"A"}
Concatenate Symbol "B" , Obtain {"AA"}
Add {"AA"} to Dictionary

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

جامعة القاهرة
كلية الحاسبات
و المعلـومات

LZ 78 (De-Compression)



< 0 , “A” > < 0 , “B” > < 1 , “A” > < 2 , “A” > < 4 , “A” > <4 , “B” > <2 , “B” > <7 , “B” > <8 , “B” > <0 , “A” > or <1, NULL>

A	B	A	A	B	A																

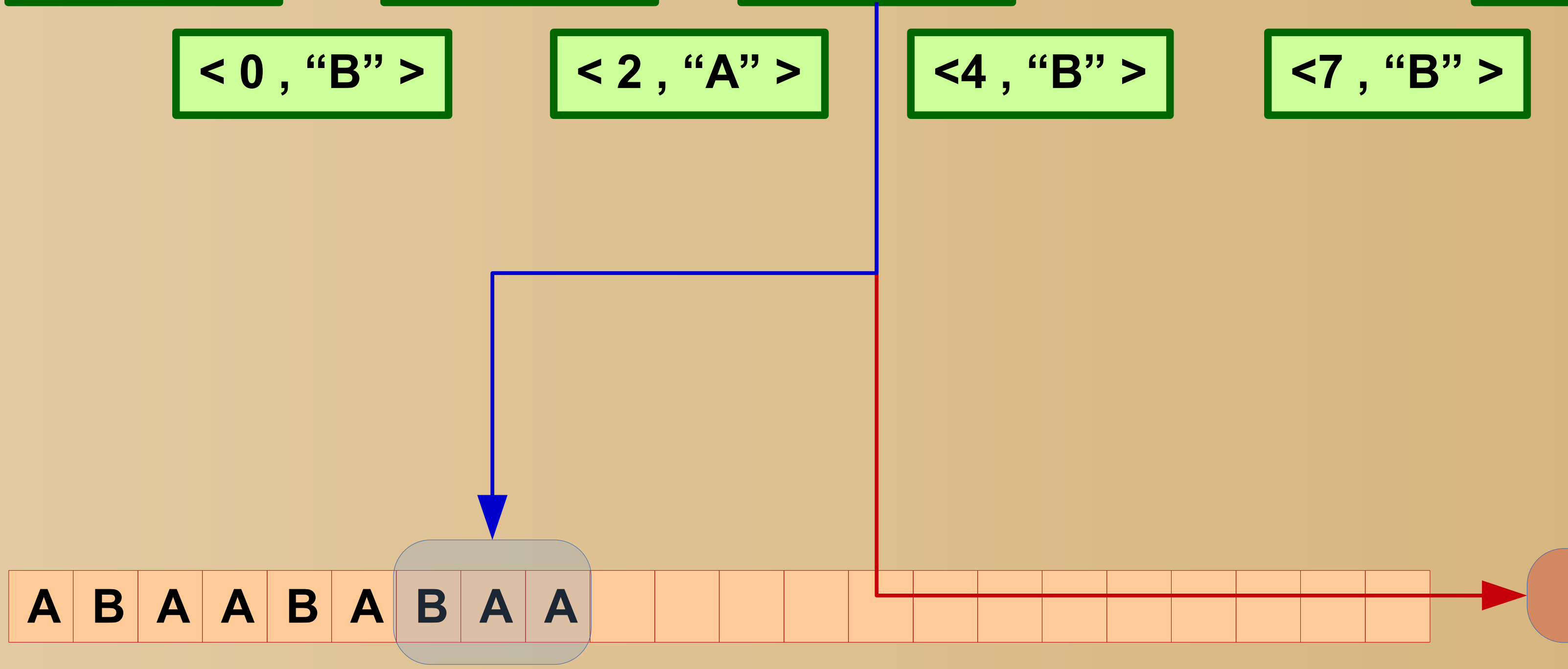
0	------
1	A
2	B
3	AA
4	BA
5	
6	
7	
8	
9	
10	
11	

Get symbol at Index [2] in Dictionary {“B”}
Concatenate Symbol “A” , Obtain {“BA”}
Add {“BA”} to Dictionary

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZ 78 (De-Compression)

< 0 , "A" > < 0 , "B" > < 1 , "A" > < 2 , "A" > < 4 , "A" > <4 , "B" > <2 , "B" > <7 , "B" > <8 , "B" > <0 , "A" > or <1, NULL>



A	B	A	A	B	A	B	A	A													

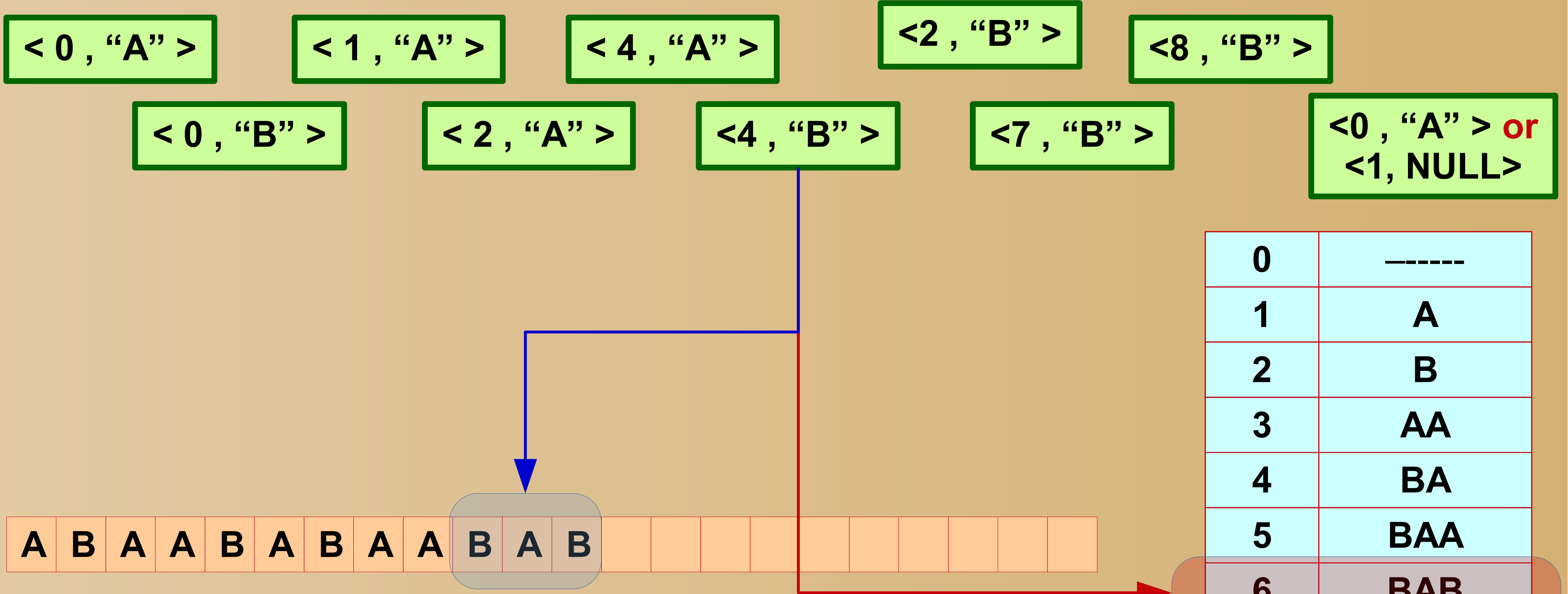
0	------
1	A
2	B
3	AA
4	BA
5	BAA
6	
7	
8	
9	
10	
11	

Get symbol at Index [4] in Dictionary {"BA"}
Concatenate Symbol "A" , Obtain {"BAA"}
Add {"BAA"} to Dictionary

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZ 78 (De-Compression)

كلية الحاسبات و المعلومات



0	------
1	A
2	B
3	AA
4	BA
5	BAA
6	BAB
7	
8	
9	
10	
11	

Get symbol at Index [4] in Dictionary {"BA"}
Concatenate Symbol "B" , Obtain {"BAB"}
Add {"BAB"} to Dictionary

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZ 78 (De-Compression)

< 0 , "A" > < 0 , "B" > < 1 , "A" > < 2 , "A" > < 4 , "A" > <4 , "B" > <2 , "B" > <7 , "B" > <8 , "B" > <0 , "A" > or <1, NULL>

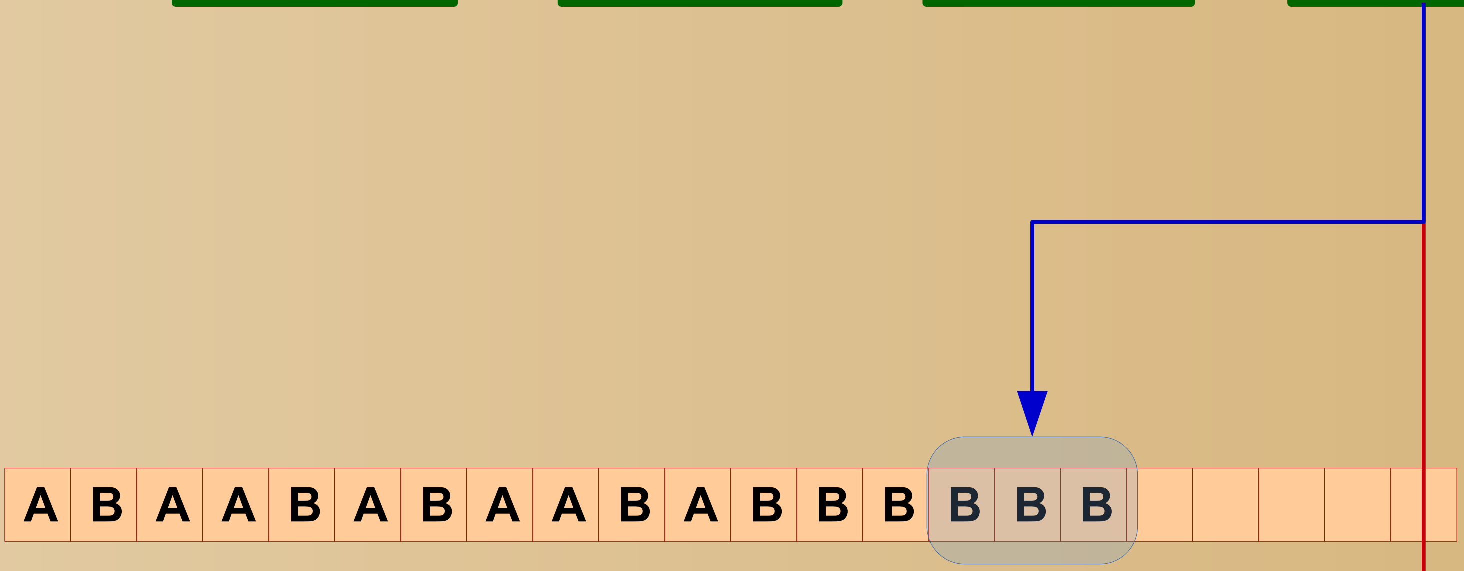
A	B	A	A	B	A	B	A	A	B	A	B	B	B								

0	------
1	A
2	B
3	AA
4	BA
5	BAA
6	BAB
7	BB
8	
9	
10	
11	

Get symbol at Index [2] in Dictionary {"B"}
Concatenate Symbol "B" , Obtain {"BB"}
Add {"BB"} to Dictionary

LZ 78 (De-Compression)

< 0 , "A" > < 0 , "B" > < 1 , "A" > < 2 , "A" > < 4 , "A" > <4 , "B" > <2 , "B" > <7 , "B" > <8 , "B" > <0 , "A" > or <1, NULL>



0	------
1	A
2	B
3	AA
4	BA
5	BAA
6	BAB
7	BB
8	BBB
9	
10	
11	

Get symbol at Index [7] in Dictionary {"BB"}
Concatenate Symbol "B" , Obtain {"BBB"}
Add {"BBB"} to Dictionary

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZ 78 (De-Compression)

< 0 , "A" > < 0 , "B" > < 1 , "A" > < 2 , "A" > < 4 , "A" > <4 , "B" > <2 , "B" > <7 , "B" > <8 , "B" > <0 , "A" > or <1, NULL>

A	B	A	A	B	A	B	A	A	B	A	B	B	B	B	B	B	B	B	B	B

0	------
1	A
2	B
3	AA
4	BA
5	BAA
6	BAB
7	BB
8	BBB
9	BBBB
10	
11	

Get symbol at Index [8] in Dictionary {"BBB"}
Concatenate Symbol "B" , Obtain {"BBBB"}
Add {"BBBB"} to Dictionary

كلية الحاسبات و المعلومات

LZ 78 (De-Compression)

< 0 , "A" > < 0 , "B" > < 1 , "A" > < 2 , "A" > < 4 , "A" > <4 , "B" > <2 , "B" > <7 , "B" > <8 , "B" > <0 , "A" > or <1, NULL>

0	-------
1	A
2	B
3	AA
4	BA
5	BAA
6	BAB
7	BB
8	BBB
9	BBBB
10	
11	

A	B	A	A	B	A	B	A	A	B	A	B	B	B	B	B	B	B	B	B	B	A

Get symbol at Index [1] in Dictionary {"A"}
Concatenate Symbol "NULL" , Obtain {"A"}
Add NOTHING to Dictionary

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZ 78 Compression Ratio

كلية الحاسبات و المعلومات

< 0 , "A" > < 1 , "A" > < 4 , "A" > <2 , "B" > <8 , "B" >

< 0 , "B" > < 2 , "A" > <4 , "B" > <7 , "B" > <0 , "A" > or <1, NULL>

Original Size = Number of Symbols * Bits used to Store one Symbol
= 22 Symbols * 8 Bits / Symbol = 176 bits
(Store "Symbol" ASCII Code in 8 Bits)

Max "Index" Value = 8 — Store "Index" Value in 4 Bits
Max Symbols = 256 Symbol — Store "Symbol" ASCII Code in 8 Bits
Tag size = 4 + 8 =12 Bits

Number of Tags = 10 Tags
Compressed Size=10*12=120 bits

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

كلية الحاسبات و المعلومات

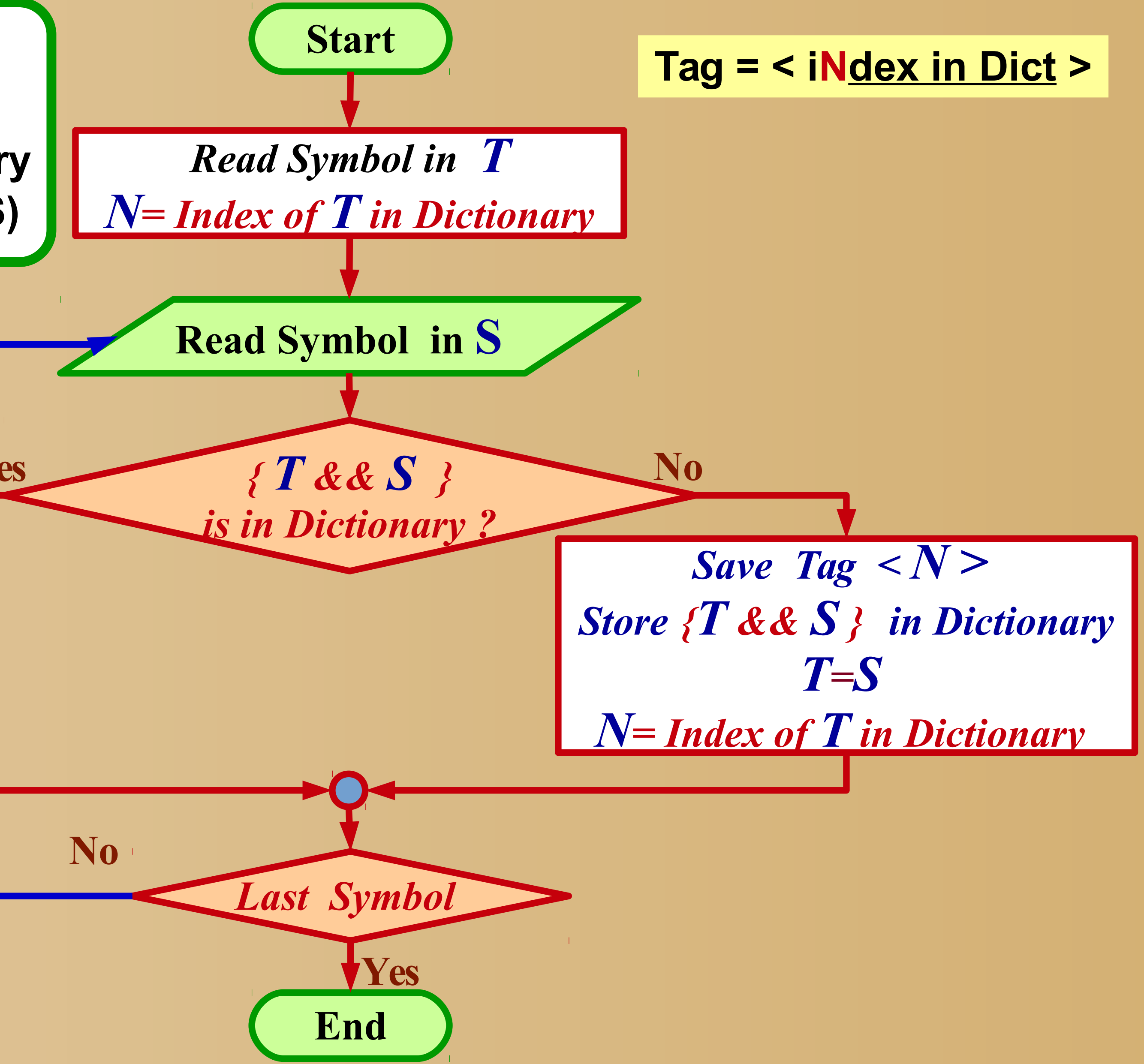
LZ 78: Main Features

- No use of the sliding window.
- Instead of the triples used in the LZ77, only pairs are used in the LZ78. Specifically, only the **Position** (index in the list) of the matched string and the **Next Symbol** following the matched string need to be encoded (in the Tag).
- Use encoded text as a dictionary which, potentially, does not have a fixed size.
- Each time a Tag is issued, the encoded string is included in the dictionary.
- Once a preset limit to the dictionary size has been reached, it is reset to zero, i.e., it must be restarted.
-

LZW (Compression)

S Buffer to Ready Symbol
T Temporary Storage buffer
N Index (pointer) in Dictionary
{ T && S } Concatenation (T,S)

Tag = < iNdex in Dict >



Start
Read Symbol in T
N= Index of T in Dictionary
Read Symbol in S
{ T && S } is in Dictionary ?
Yes
No
T={T && S }
N= Index in Dictionary
Save Tag < N >
Store {T && S } in Dictionary
T=S
N= Index of T in Dictionary
No
Last Symbol
Yes
End

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZW Compression

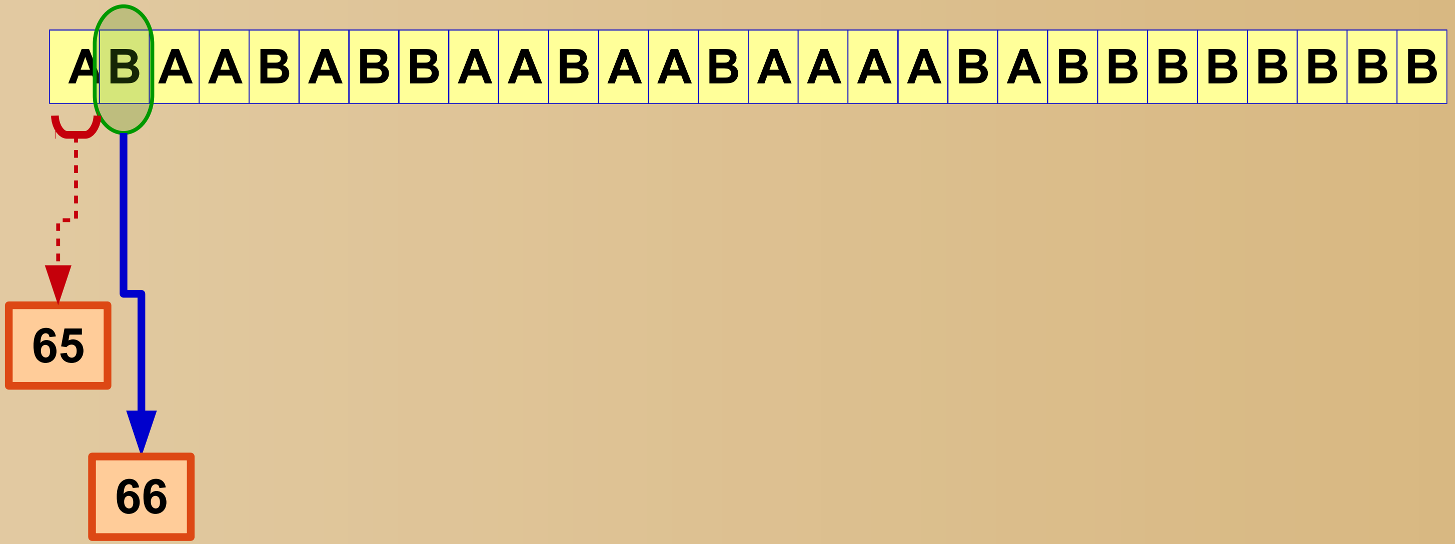
A	B	A	A	B	A	B	B	A	A	B	A	A	B	A	A	A	A	B	A	B	B	B	B	B	B	B	B

65

…	…
65	A
66	B
…	…
…	…
128	AB
129	
130	
131	
132	
133	
134	
135	
136	
137	
138	
139	
140	
141	
142	

"A" exists in the table at index [97]
"AB" does NOT exist in the table
Save Symbol "A" as [97]
Add "AB" to Dictionary

LZW Compression

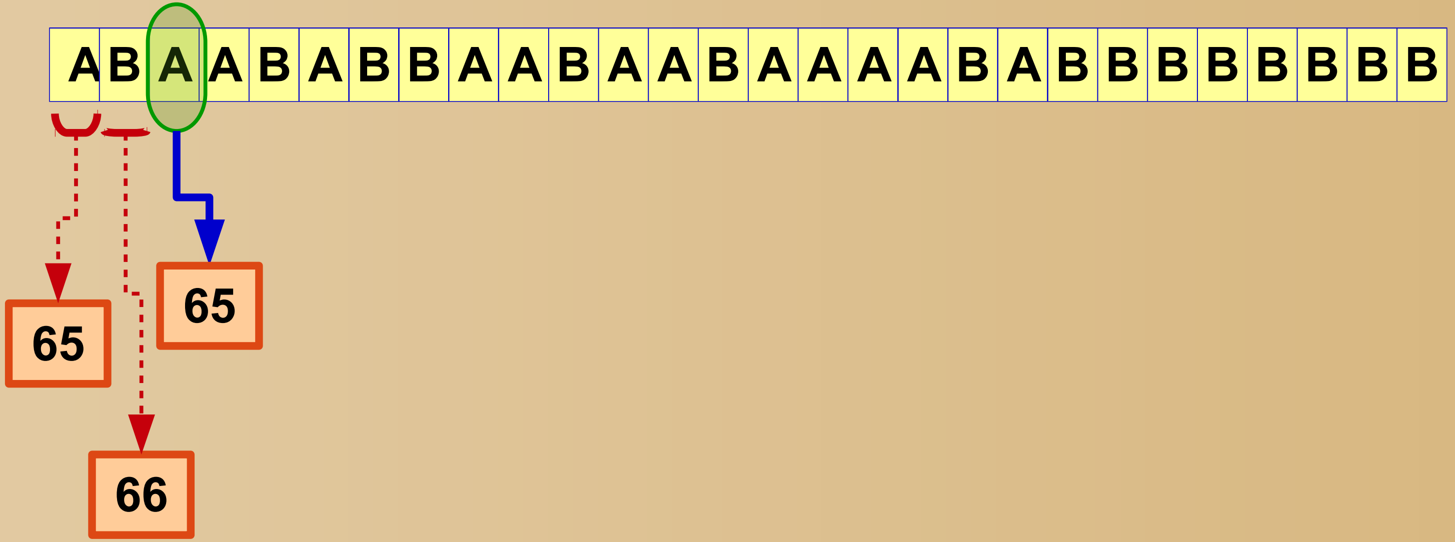


...	...
65	A
66	B
...	...
...	...
128	AB
129	BA
130	
131	
132	
133	
134	
135	
136	
137	
138	
139	
140	
141	
142	

"B" exists in the table at index [98]
"BA" does NOT exist in the table
Save Symbol "B" as [98]
Add "BA" to Dictionary

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZW Compression

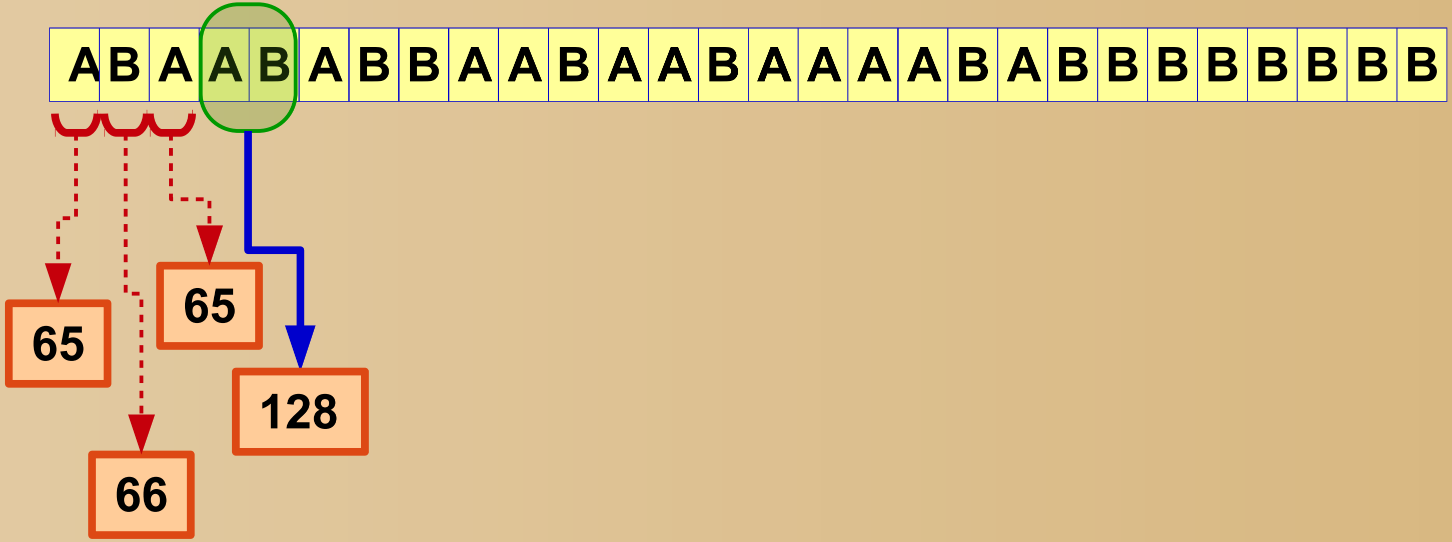


…	…
65	A
66	B
…	…
…	…
128	AB
129	BA
130	AA
131	
132	
133	
134	
135	
136	
137	
138	
139	
140	
141	
142	

"A" exists in the table at index [97]
"AA" does NOT exist in the table
Save Symbol "A" as [97]
Add "AA" to Dictionary

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZW Compression

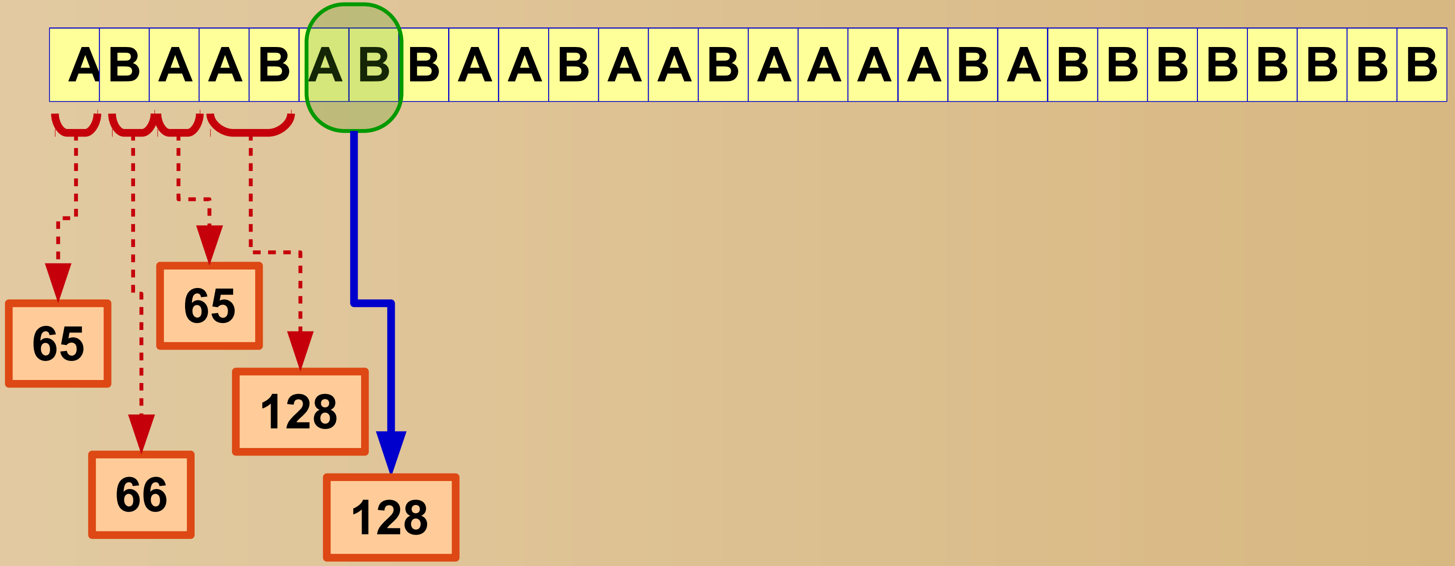


...	...
65	A
66	B
...	...
...	...
128	AB
129	BA
130	AA
131	ABA
132	
133	
134	
135	
136	
137	
138	
139	
140	
141	
142	

"AB" exists in the table at index [128]
"ABA" does NOT exist in the table
Save Symbol "AB" as [128]
Add "ABA" to Dictionary

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZW Compression

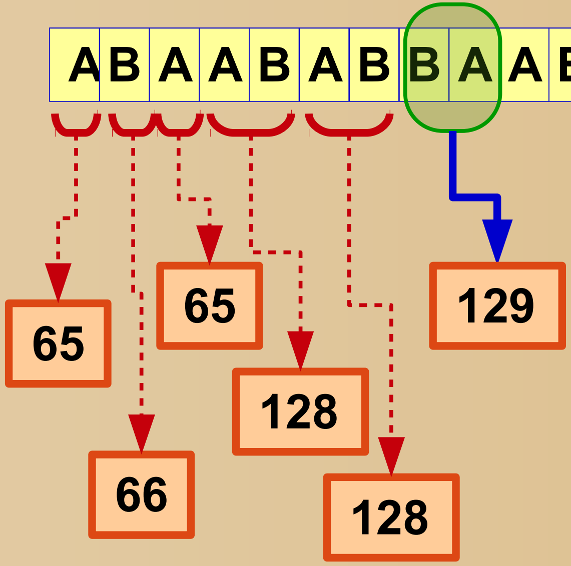


...	...
65	A
66	B
...	...
...	...
128	AB
129	BA
130	AA
131	ABA
132	ABB
133	
134	
135	
136	
137	
138	
139	
140	
141	
142	

"AB" exists in the table at index [128]
"ABB" does NOT exist in the table
Save Symbol "AB" as [128]
Add "ABB" to Dictionary

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZW Compression

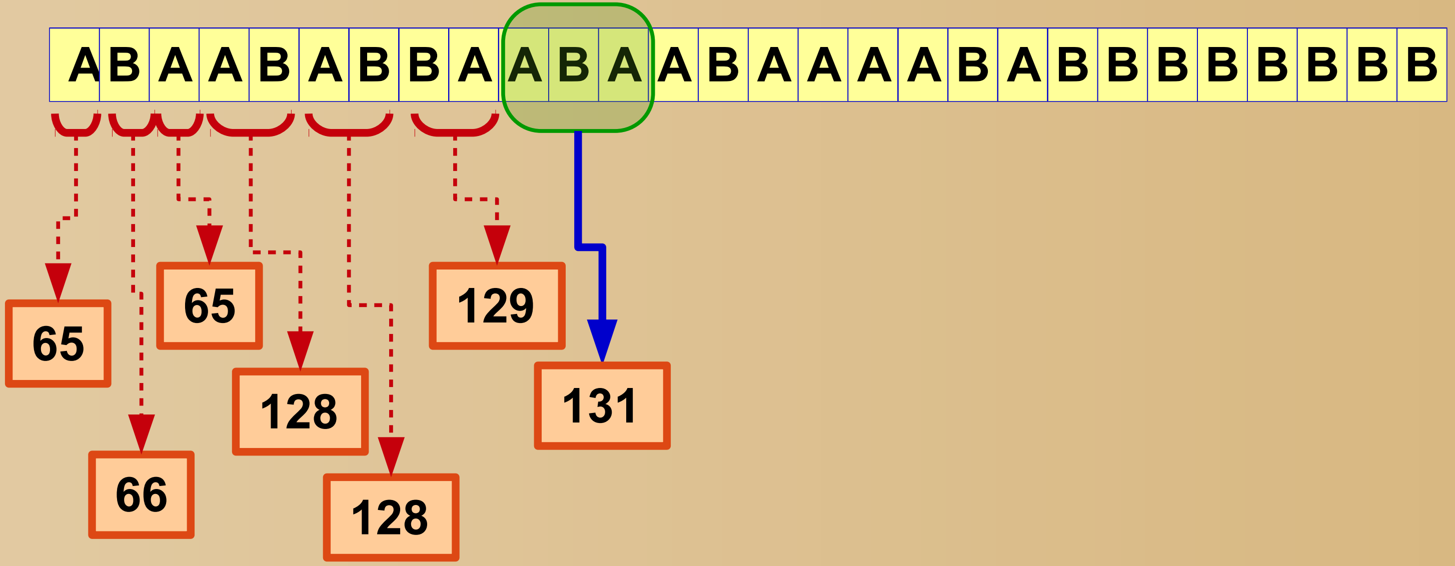


…	…
65	A
66	B
…	…
…	…
128	AB
129	BA
130	AA
131	ABA
132	ABB
133	BAA
134	
135	
136	
137	
138	
139	
140	
141	
142	

"BA" exists in the table at index [129]
"BAA" does NOT exist in the table
Save Symbol "BA" as [129]
Add "BAA" to Dictionary

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZW Compression

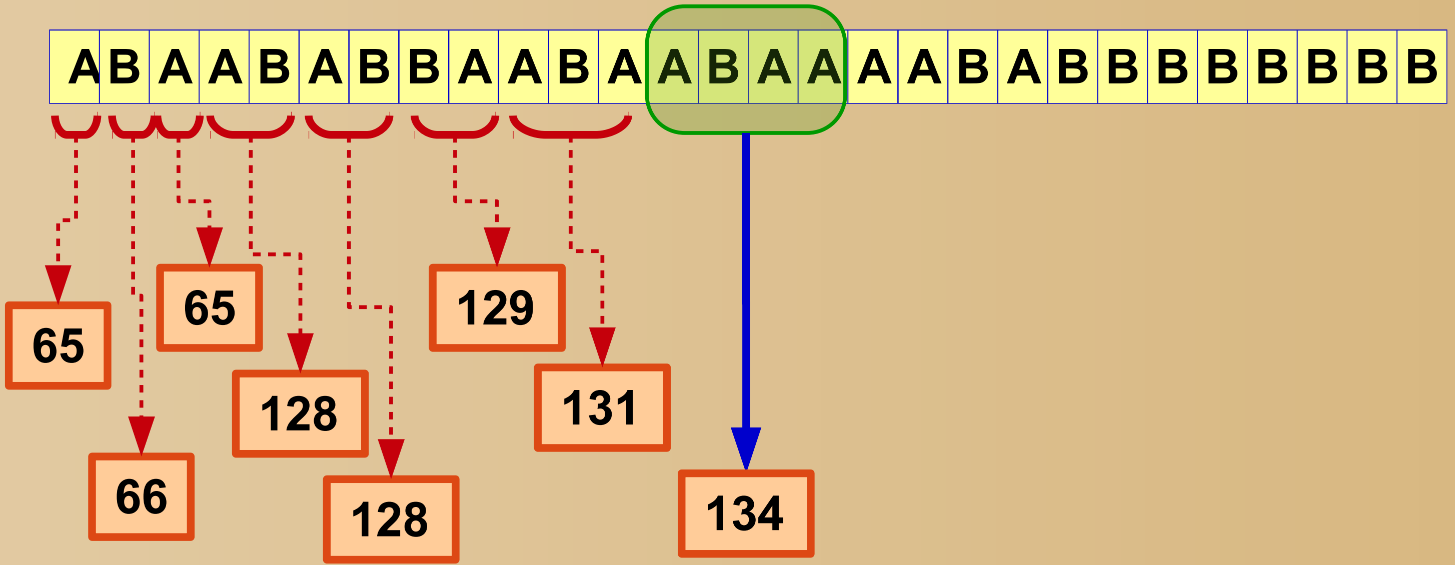


...	...
65	A
66	B
...	...
...	...
128	AB
129	BA
130	AA
131	ABA
132	ABB
133	BAA
134	ABAA
135	
136	
137	
138	
139	
140	
141	
142	

"ABA" exists in the table at index [131]
"ABAA" does NOT exist in the table
Save Symbol "ABA" as [131]
Add "ABAA" to Dictionary

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

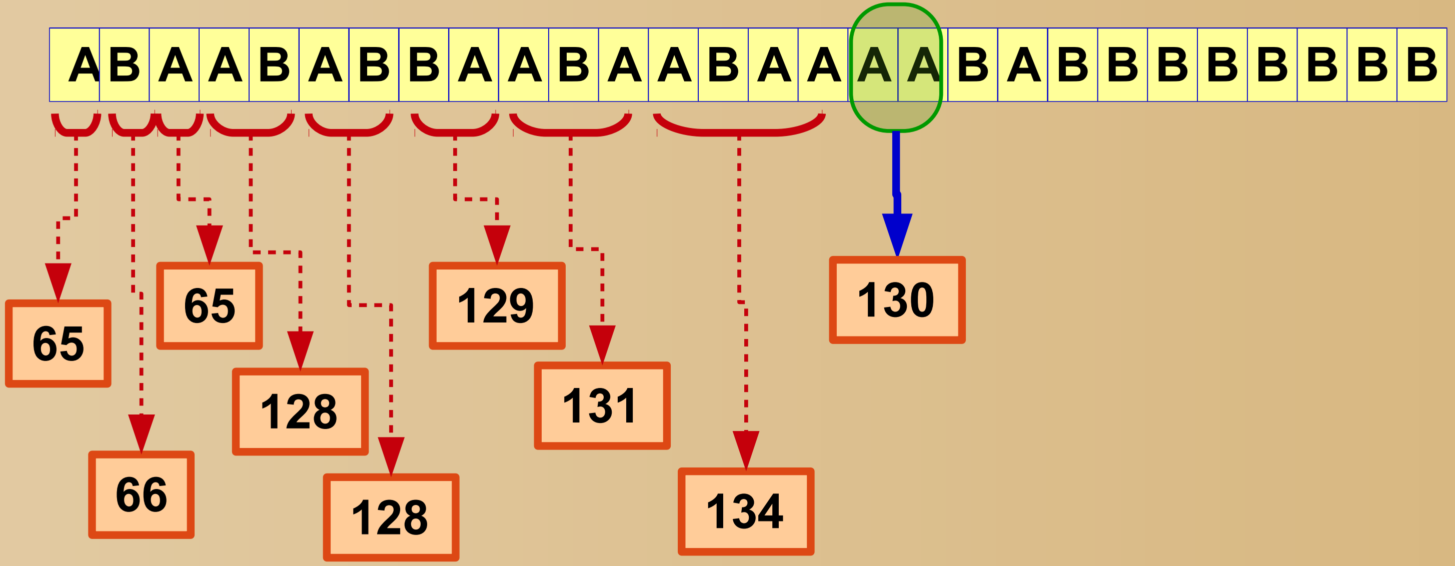
LZW Compression



...	...
65	A
66	B
...	...
...	...
128	AB
129	BA
130	AA
131	ABA
132	ABB
133	BAA
134	ABAA
135	ABAAA
136	
137	
138	
139	
140	
141	
142	

"ABAA" exists in the table at index [134]
"ABAAA" does NOT exist in the table
Save Symbol "ABAA" as [134]
Add "ABAAA" to Dictionary

LZW Compression

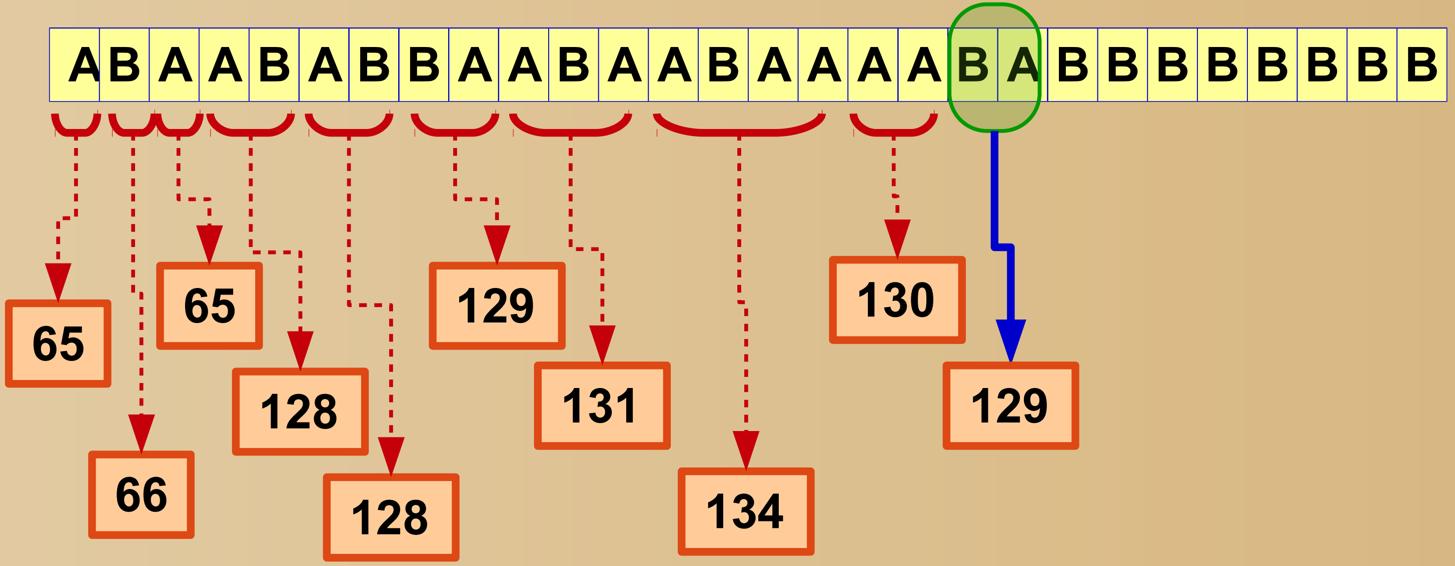


...	...
65	A
66	B
...	...
...	...
128	AB
129	BA
130	AA
131	ABA
132	ABB
133	BAA
134	ABAA
135	ABAAA
136	AAB
137	
138	
139	
140	
141	
142	

"AA" exists in the table at index [130]
"AAB" does NOT exist in the table
Save Symbol "AA" as [130]
Add "AAB" to Dictionary

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

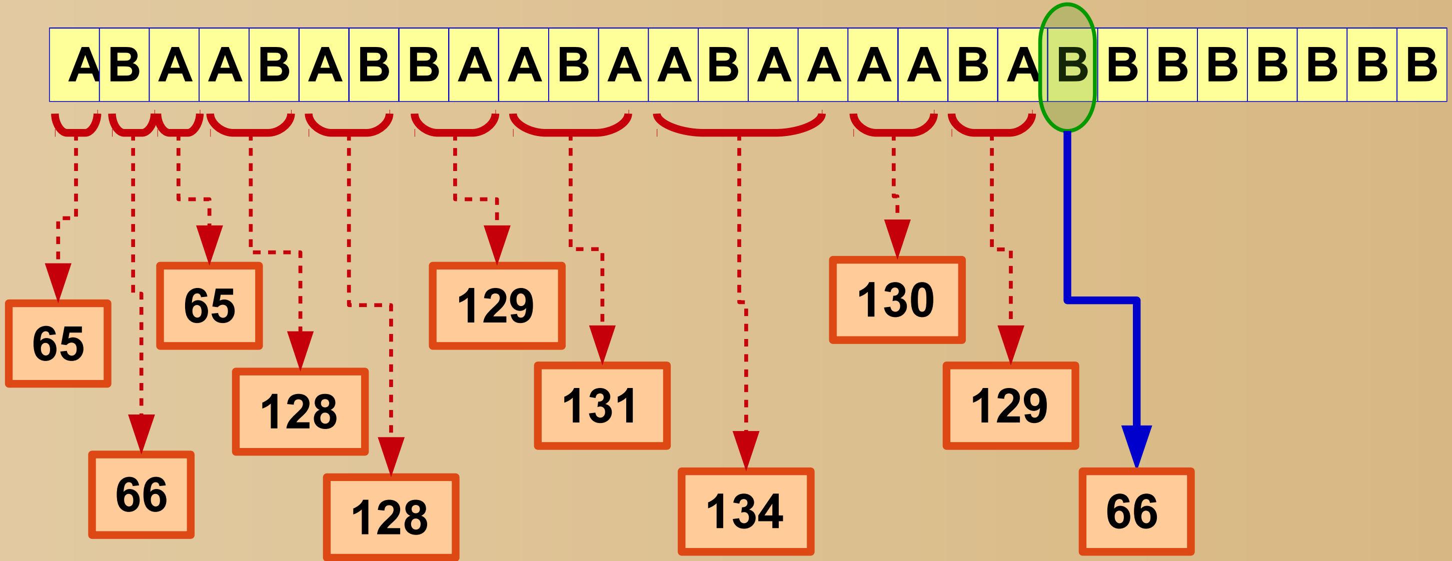
LZW Compression



...	...
65	A
66	B
...	...
...	...
128	AB
129	BA
130	AA
131	ABA
132	ABB
133	BAA
134	ABAA
135	ABAAA
136	AAB
137	BAB
138	
139	
140	
141	
142	

"BA" exists in the table at index [129]
"BAB" does NOT exist in the table
Save Symbol "BA" as [129]
Add "BAB" to Dictionary

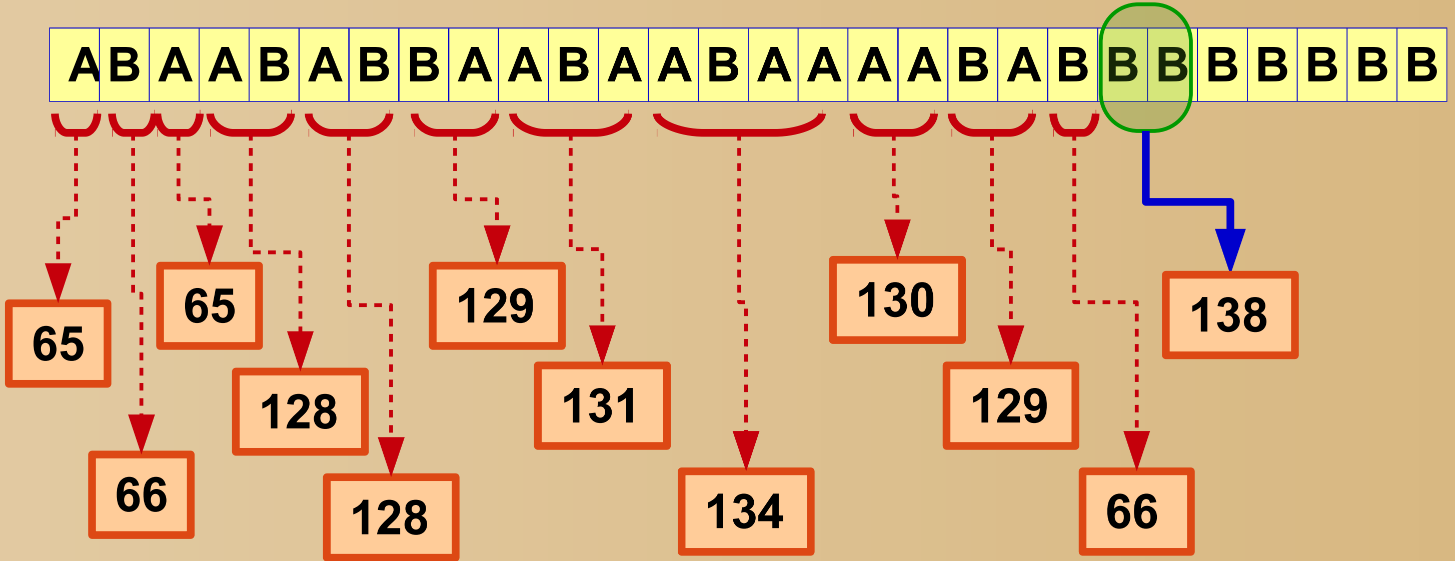
LZW Compression



...	...
65	A
66	B
...	...
...	...
128	AB
129	BA
130	AA
131	ABA
132	ABB
133	BAA
134	ABAA
135	ABAAA
136	AAB
137	BAB
138	BB
139	
140	
141	
142	

"B" exists in the table at index [98]
"BB" does NOT exist in the table
Save Symbol "B" as [98]
Add "BB" to Dictionary

LZW Compression

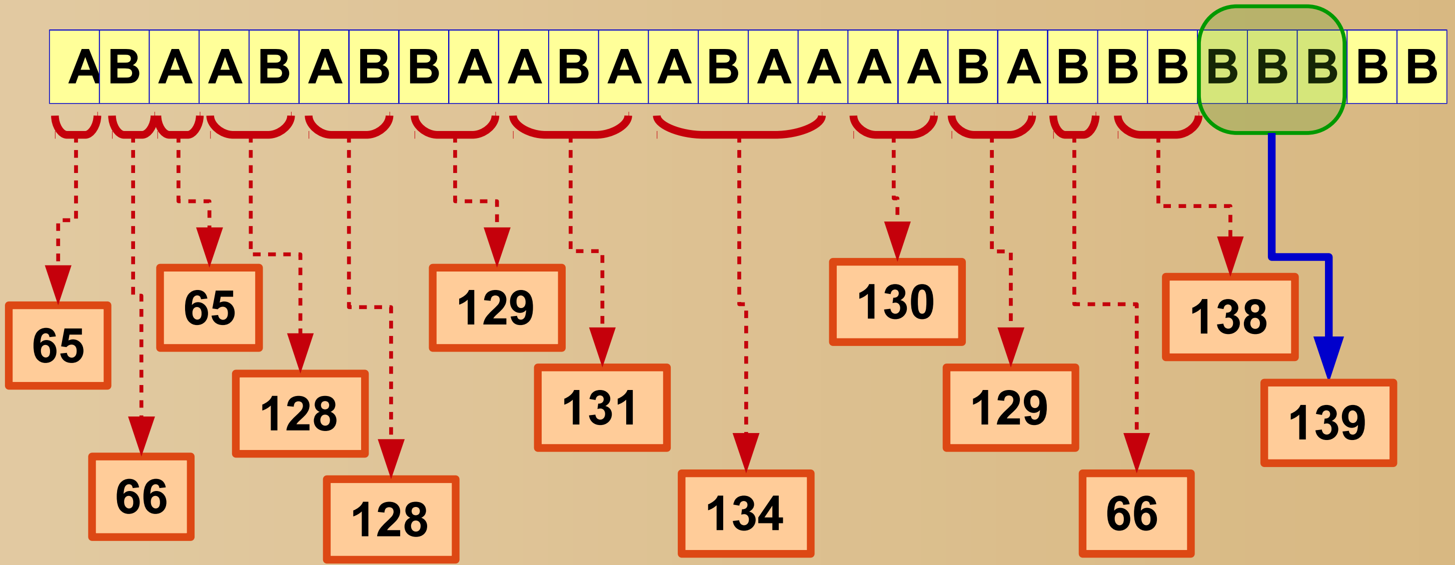


...	...
65	A
66	B
...	...
...	...
128	AB
129	BA
130	AA
131	ABA
132	ABB
133	BAA
134	ABAA
135	ABAAA
136	AAB
137	BAB
138	BB
139	BBB
140	
141	
142	

"BB" exists in the table at index [138]
"BBB" does NOT exist in the table
Save Symbol "BB" as [138]
Add "BBB" to Dictionary

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZW Compression

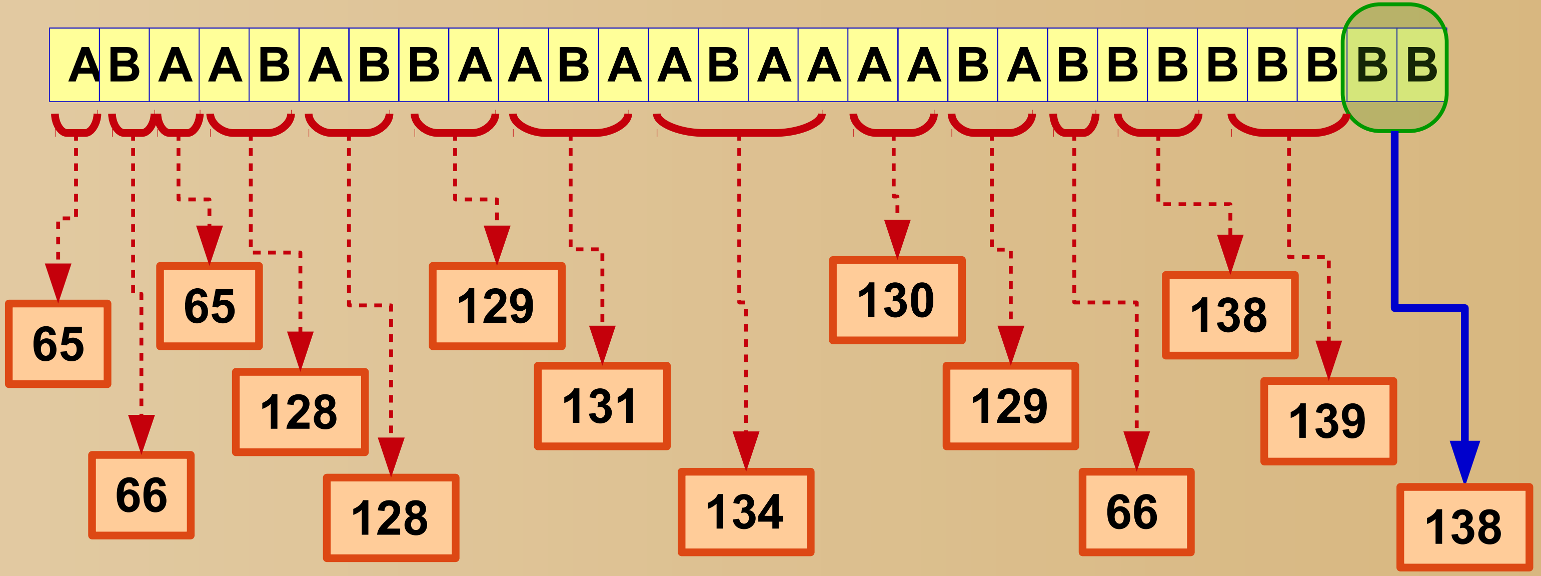


...	...
65	A
66	B
...	...
...	...
128	AB
129	BA
130	AA
131	ABA
132	ABB
133	BAA
134	ABAA
135	ABAAA
136	AAB
137	BAB
138	BB
139	BBB
140	BBBB
141	
142	

"BBB" exists in the table at index [139]
"BBBB" does NOT exist in the table
Save Symbol "BBB" as [139]
Add <u>"BBBB"</u> to Dictionary

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZW Compression

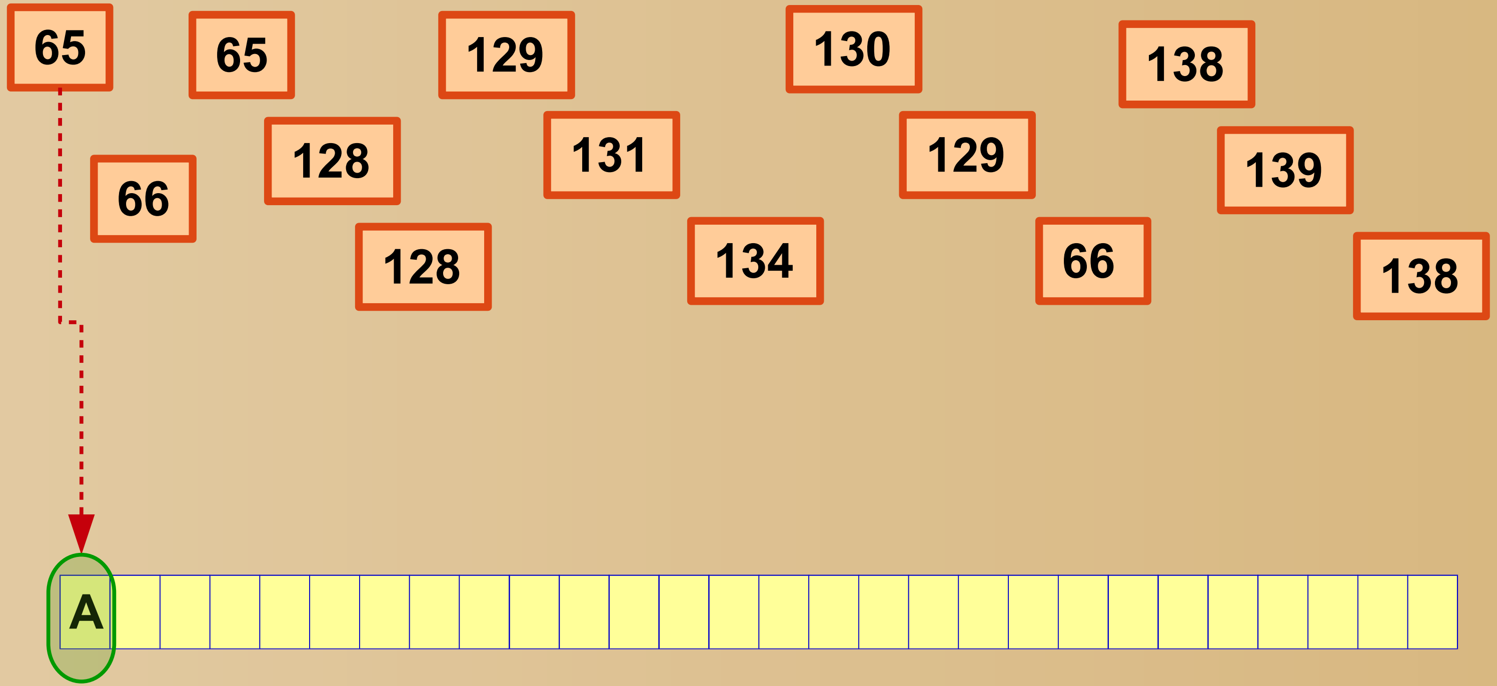


...	...
65	A
66	B
...	...
...	...
128	AB
129	BA
130	AA
131	ABA
132	ABB
133	BAA
134	ABAA
135	ABAAA
136	AAB
137	BAB
138	BB
139	BBB
140	BBBB
141	
142	

"BB" exists in the table at index [138]
Save Symbol "BB" as [138]
Add NOTHING to Dictionary

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZW De-Compression

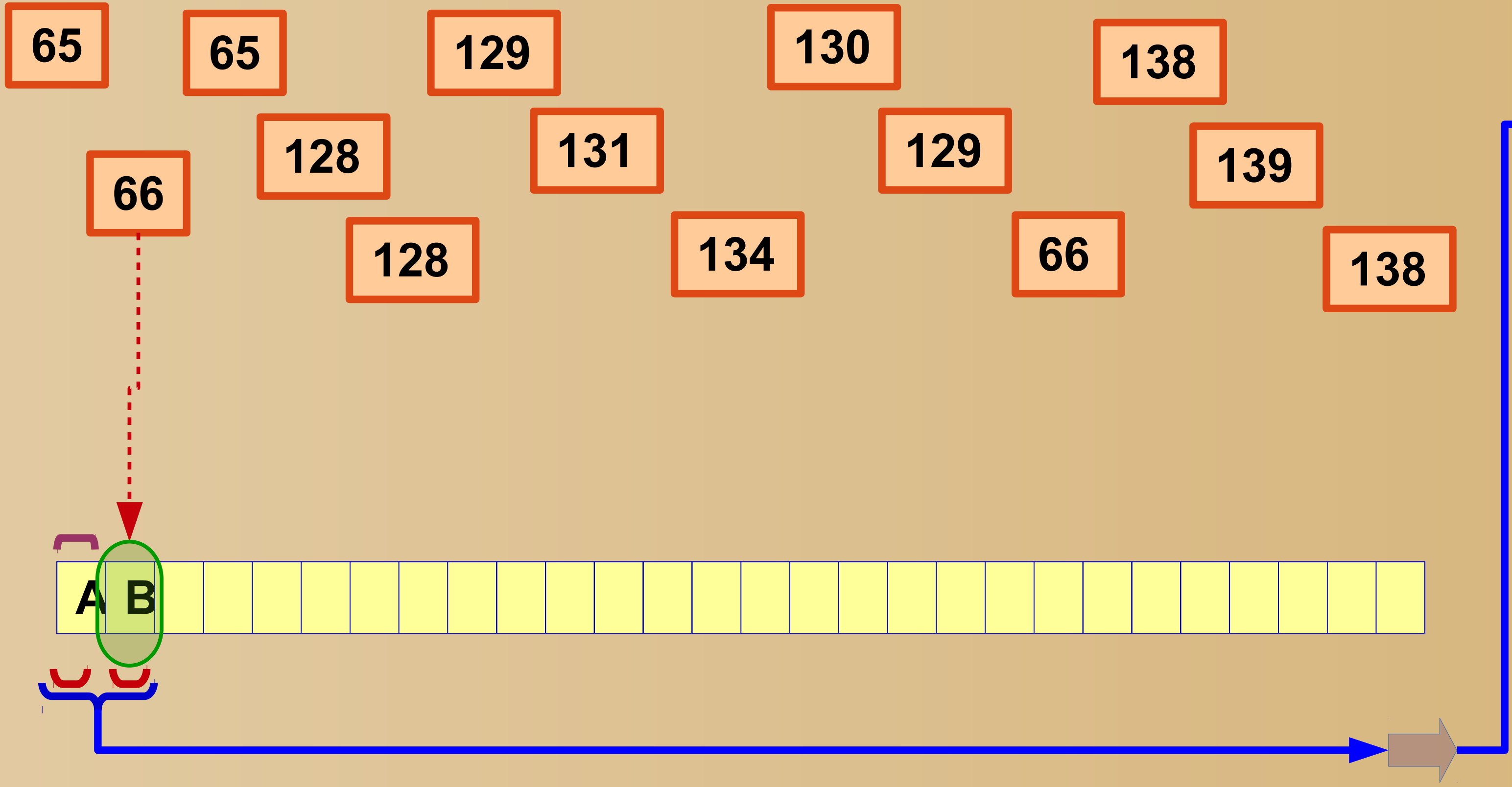


...	...
65	A
66	B
...	...
...	...
128	
129	
130	
131	
132	
133	
134	
135	
136	
137	
138	
139	
140	
141	
142	

Pick symbol at Index [97] from the Dictionary; "A"
Add NOTHING to Dictionary
(as this is the first symbol)

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZW De-Compression

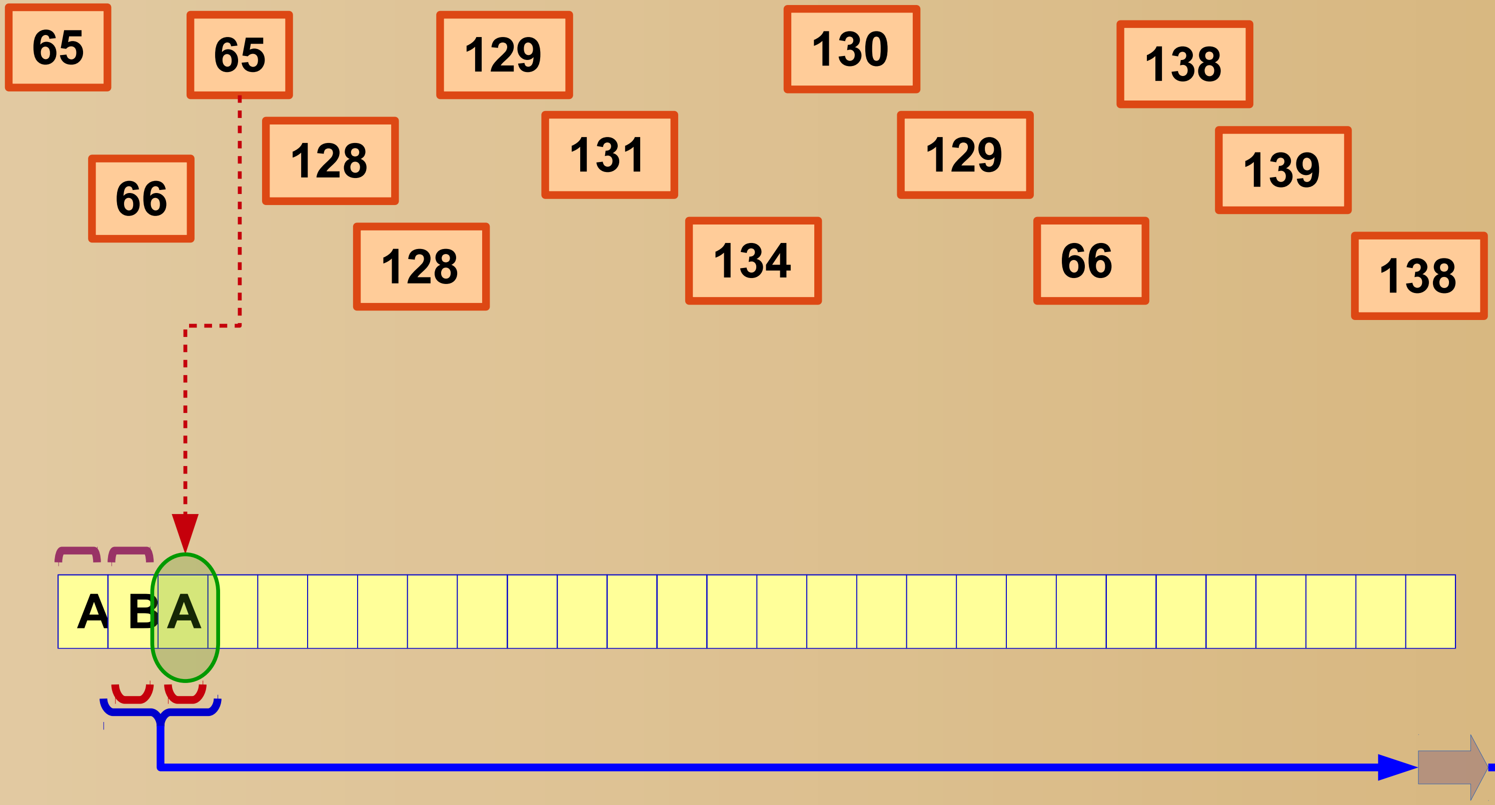


...	...
65	A
66	B
...	...
...	...
128	AB
129	
130	
131	
132	
133	
134	
135	
136	
137	
138	
139	
140	
141	
142	

Pick symbols at Index [98] from the Dictionary; "B"
Concatenate ALL Symbols picked from Previous step
and first Symbol picked from current step
(Add concatenated Symbols to Dictionary)

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZW De-Compression

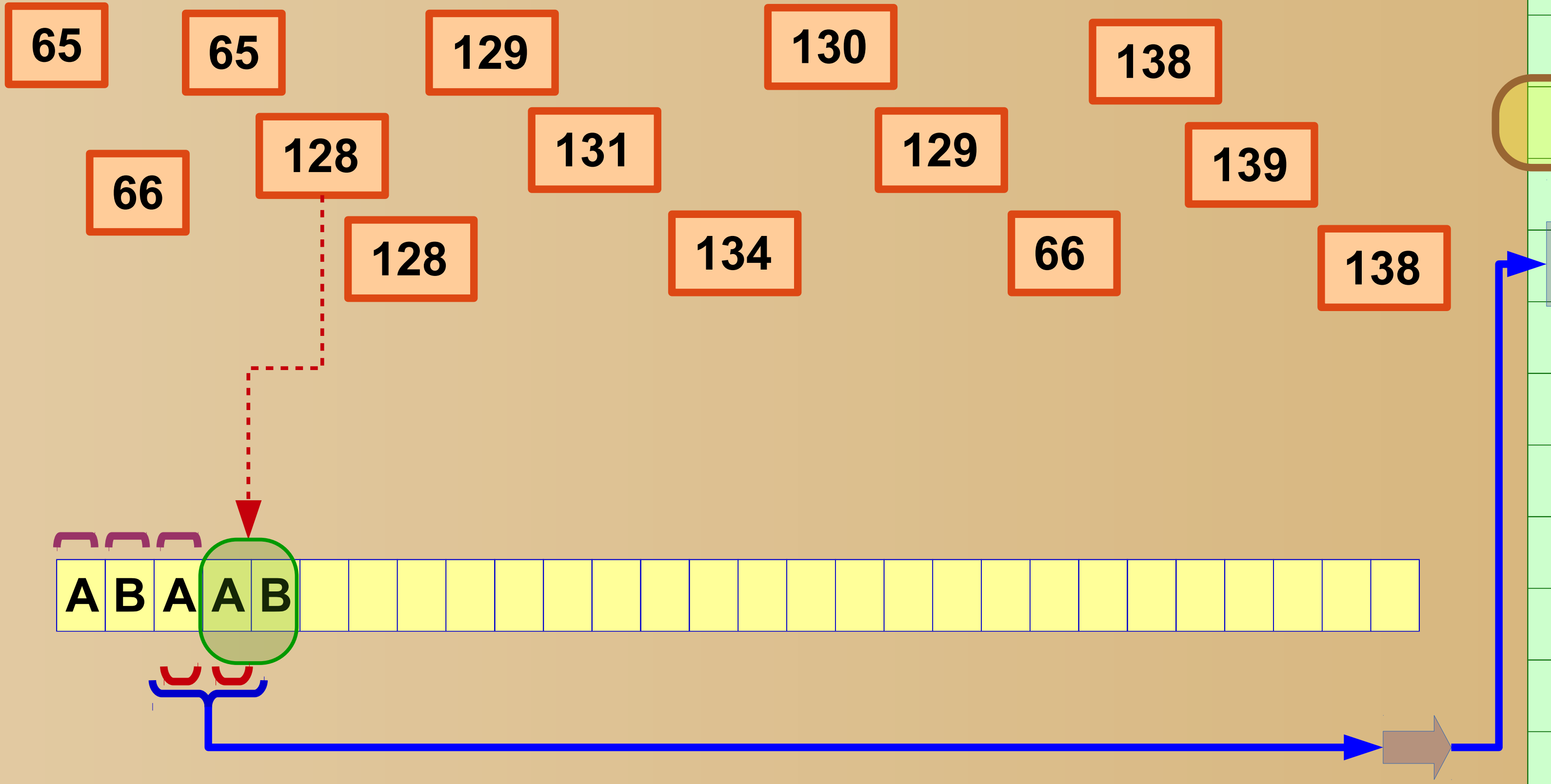


...	...
65	A
66	B
...	...
...	...
128	AB
129	BA
130	
131	
132	
133	
134	
135	
136	
137	
138	
139	
140	
141	
142	

Pick symbols at Index [97] from the Dictionary; "A"
Concatenate ALL Symbols picked from Previous step
and first Symbol picked from current step
(Add concatenated Symbols to Dictionary)

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZW De-Compression

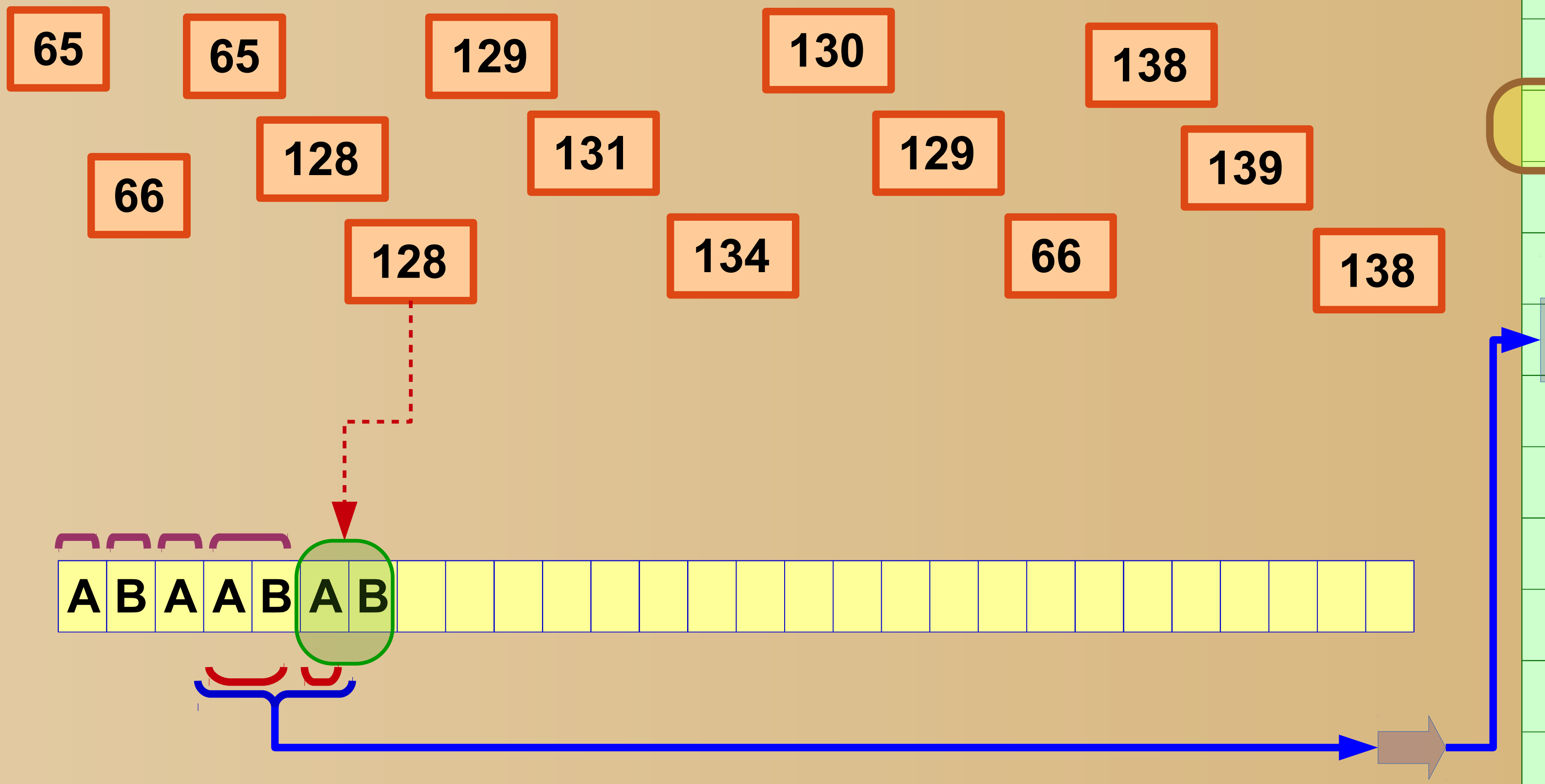


...	...
65	A
66	B
...	...
...	...
128	AB
129	BA
130	AA
131	
132	
133	
134	
135	
136	
137	
138	
139	
140	
141	
142	

Pick symbols at Index [128] from the Dictionary; "AB"
Concatenate ALL Symbols picked from Previous step
and first Symbol picked from current step
(Add concatenated Symbols to Dictionary)

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZW De-Compression

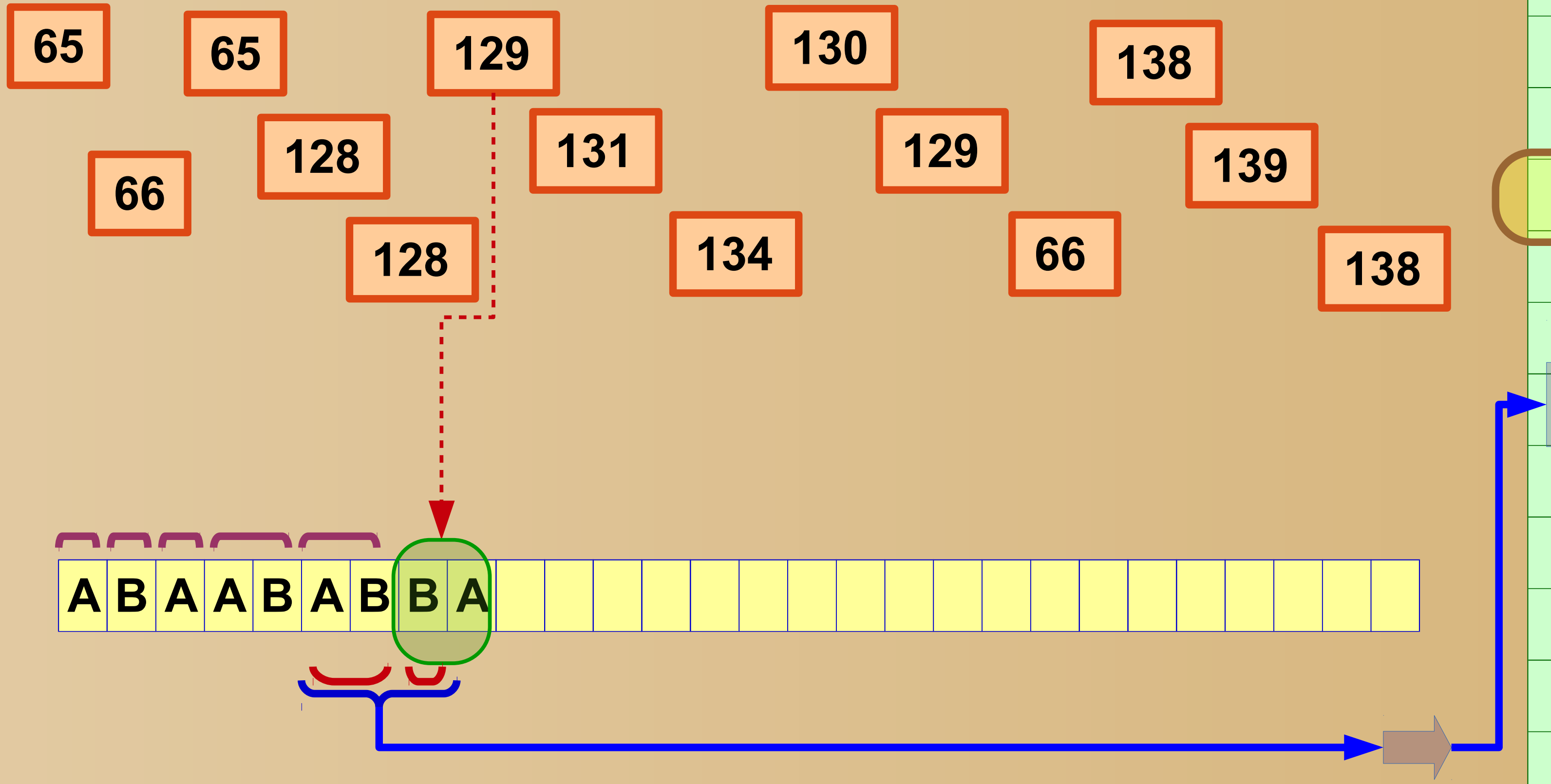


...	...
65	A
66	B
...	...
...	...
128	AB
129	BA
130	AA
131	ABA
132	
133	
134	
135	
136	
137	
138	
139	
140	
141	
142	

Pick symbols at Index [128] from the Dictionary; "AB"
Concatenate ALL Symbols picked from Previous step
and first Symbol picked from current step
(Add concatenated Symbols to Dictionary)

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZW De-Compression

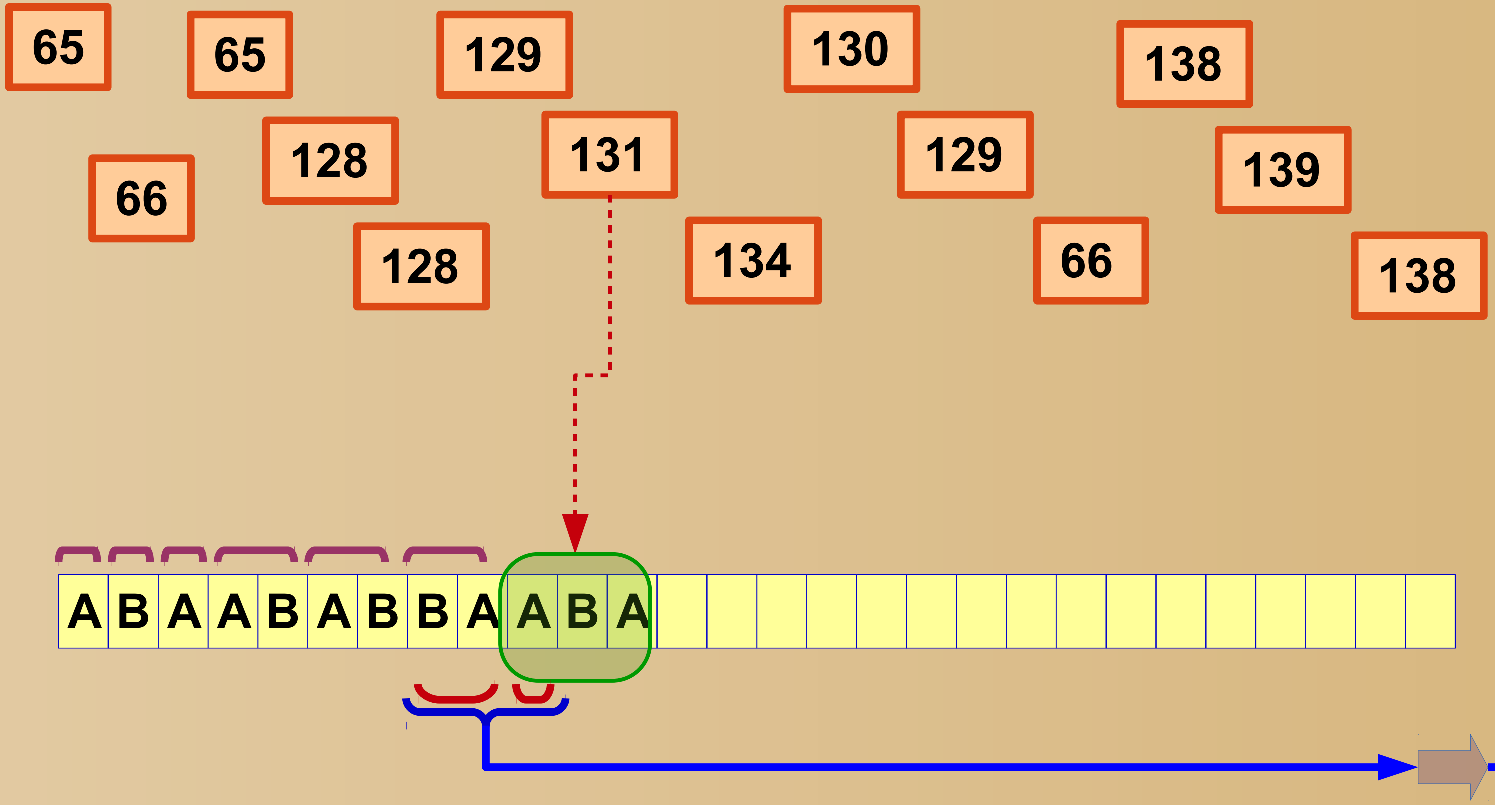


...	...
65	A
66	B
...	...
...	...
128	AB
129	BA
130	AA
131	ABA
132	ABB
133	
134	
135	
136	
137	
138	
139	
140	
141	
142	

Pick symbols at Index [129] from the Dictionary; "BA"
Concatenate ALL Symbols picked from Previous step
and first Symbol picked from current step
(Add concatenated Symbols to Dictionary)

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

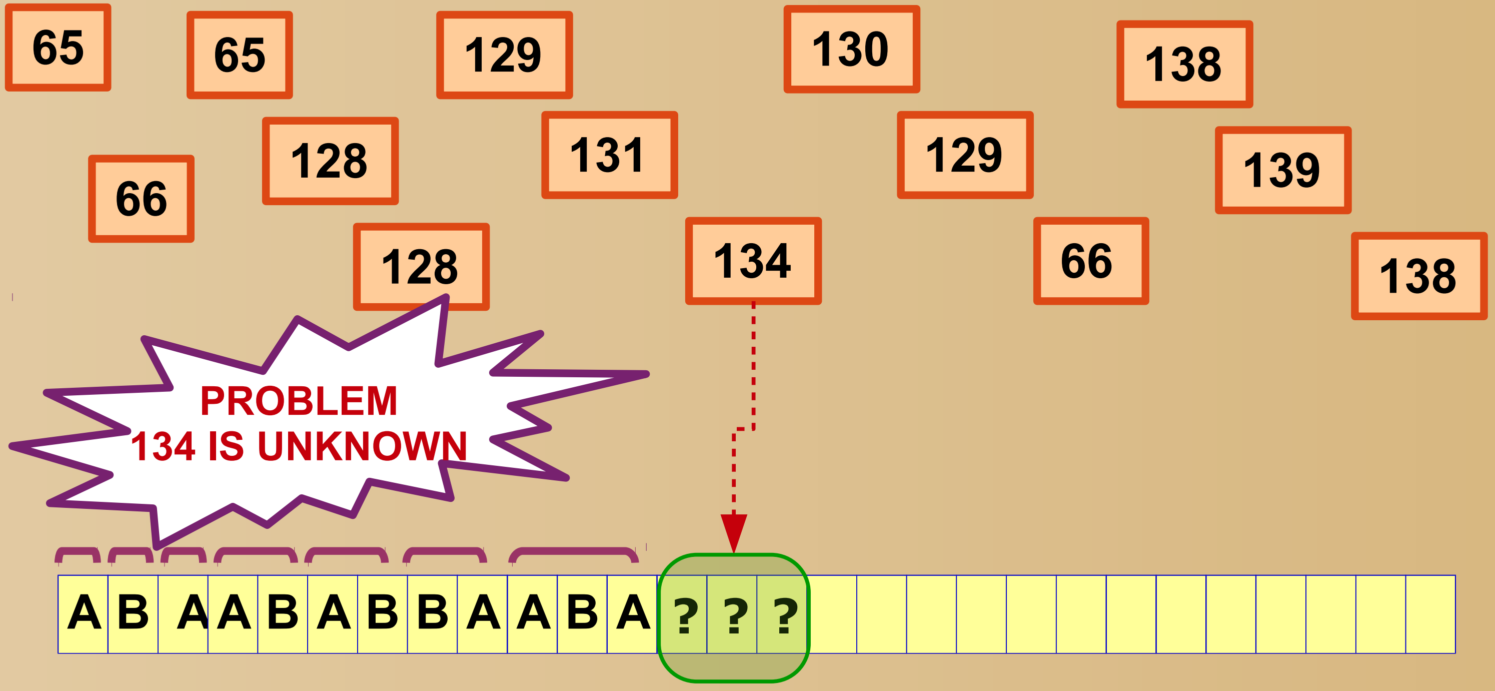
LZW De-Compression



...	...
65	A
66	B
...	...
...	...
128	AB
129	BA
130	AA
131	ABA
132	ABB
133	BAA
134	
135	
136	
137	
138	
139	
140	
141	
142	

Pick symbols at Index [131] from the Dictionary; "ABA"
Concatenate <u>ALL</u> Symbols picked from <u>Previous step</u>
and <u>first</u> Symbol picked from <u>current step</u>
(Add concatenated <u>Symbols</u> to Dictionary)

LZW De-Compression



...	...
65	A
66	B
...	...
...	...
128	AB
129	BA
130	AA
131	ABA
132	ABB
133	BAA
134	???
135	
136	
137	
138	
139	
140	
141	
142	

Pick symbols at Index [134] from the Dictionary

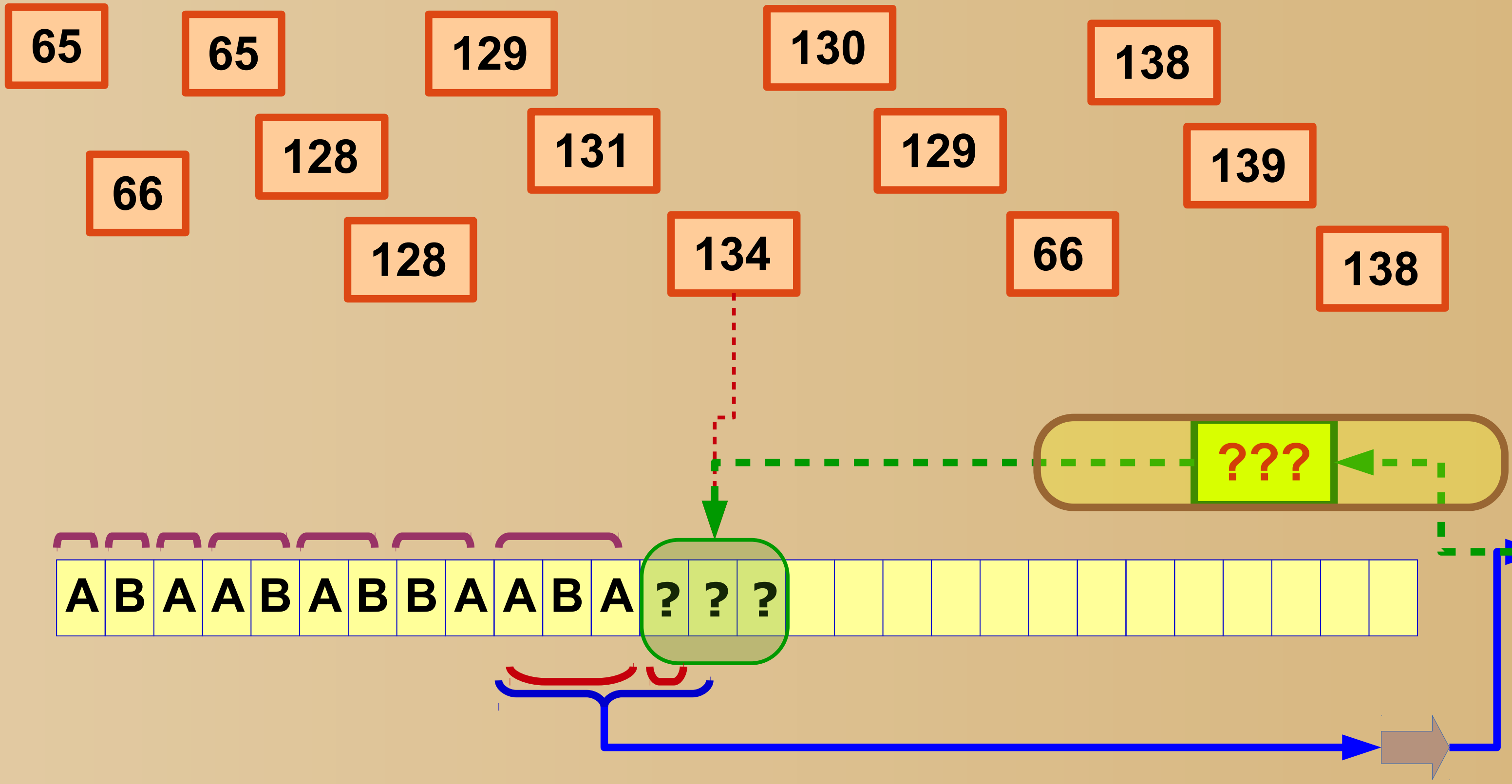
Symbols at Index [134] are not constructed yet

Assume they are "???" for the time being

Continue the algorithm

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZW De-Compression

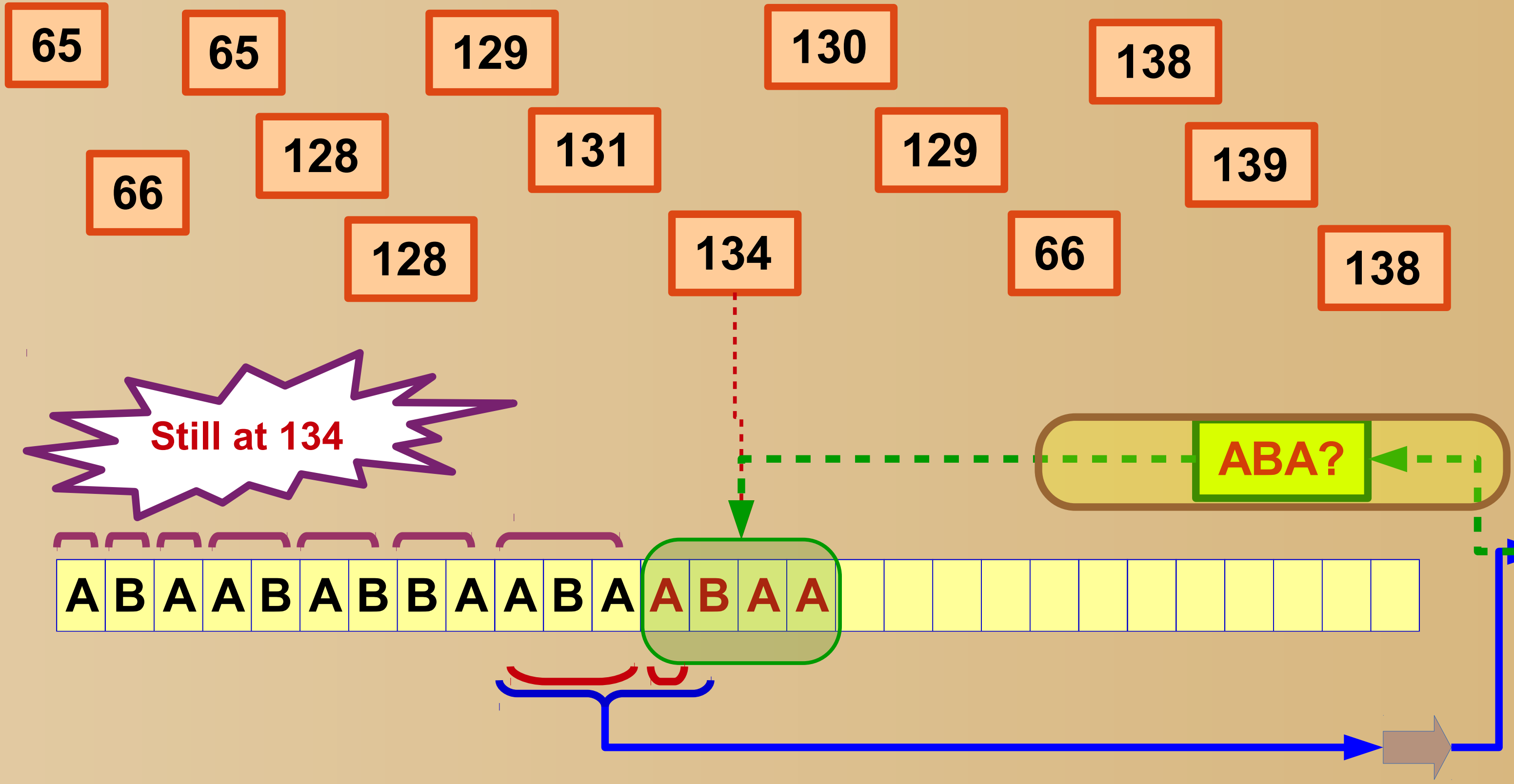


...	...
65	A
66	B
...	...
...	...
128	AB
129	BA
130	AA
131	ABA
132	ABB
133	BAA
134	ABA?
135	
136	
137	
138	
139	
140	
141	
142	

Pick symbols at Index [134] from the Dictionary; "???"
Concatenate ALL Symbols picked from Previous step
and first Symbol picked from current step
(Add concatenated Symbols to Dictionary)

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZW De-Compression

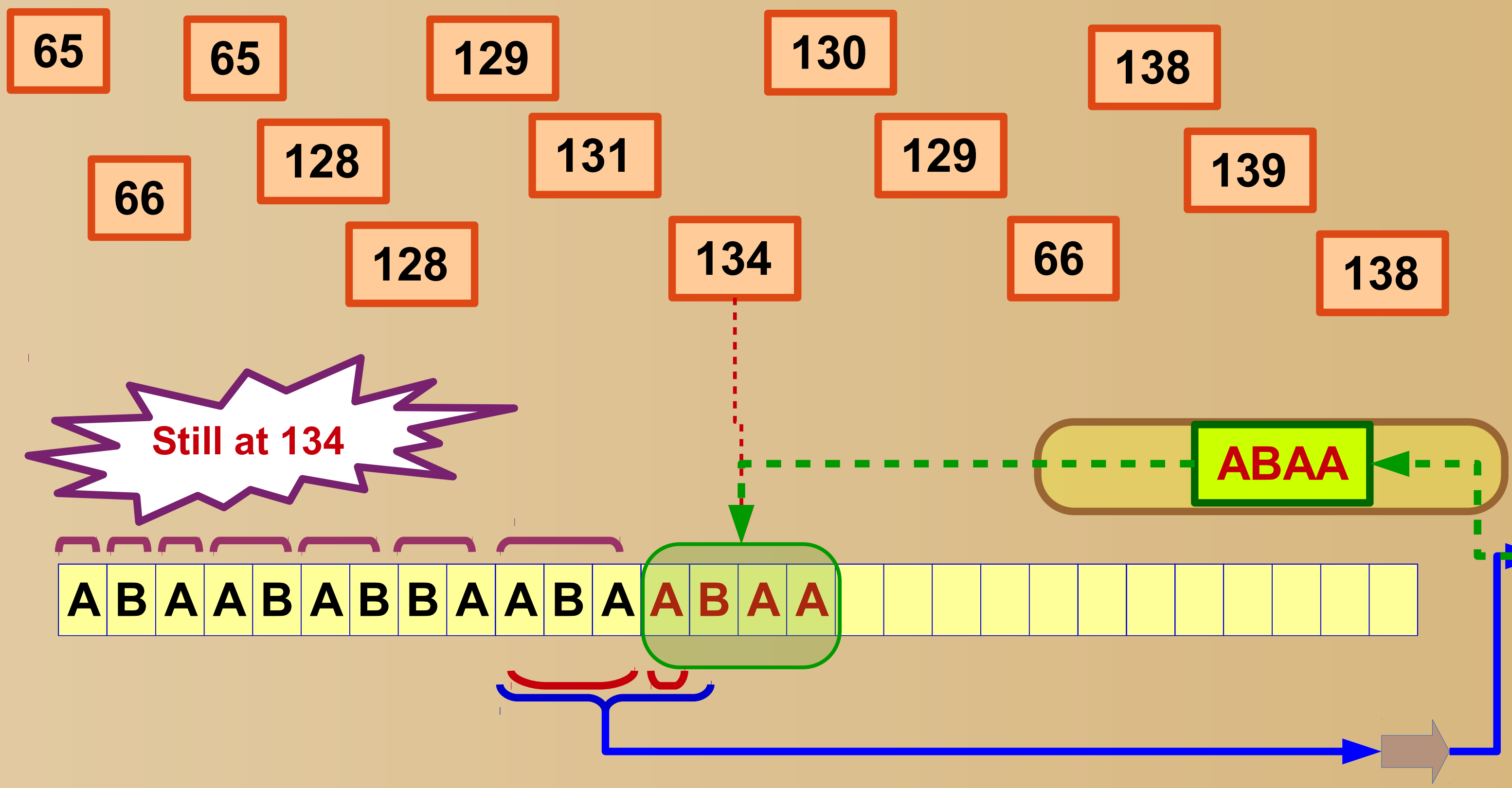


...	...
65	A
66	B
...	...
...	...
128	AB
129	BA
130	AA
131	ABA
132	ABB
133	BAA
134	ABAA
135	
136	
137	
138	
139	
140	
141	
142	

Pick symbols at Index [134] from the Dictionary; "ABA?"
Concatenate <u>ALL</u> Symbols picked from <u>Previous step</u>
and <u>first</u> Symbol picked from <u>current step</u>
(Add concatenated <u>Symbols</u> to Dictionary)

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZW De-Compression



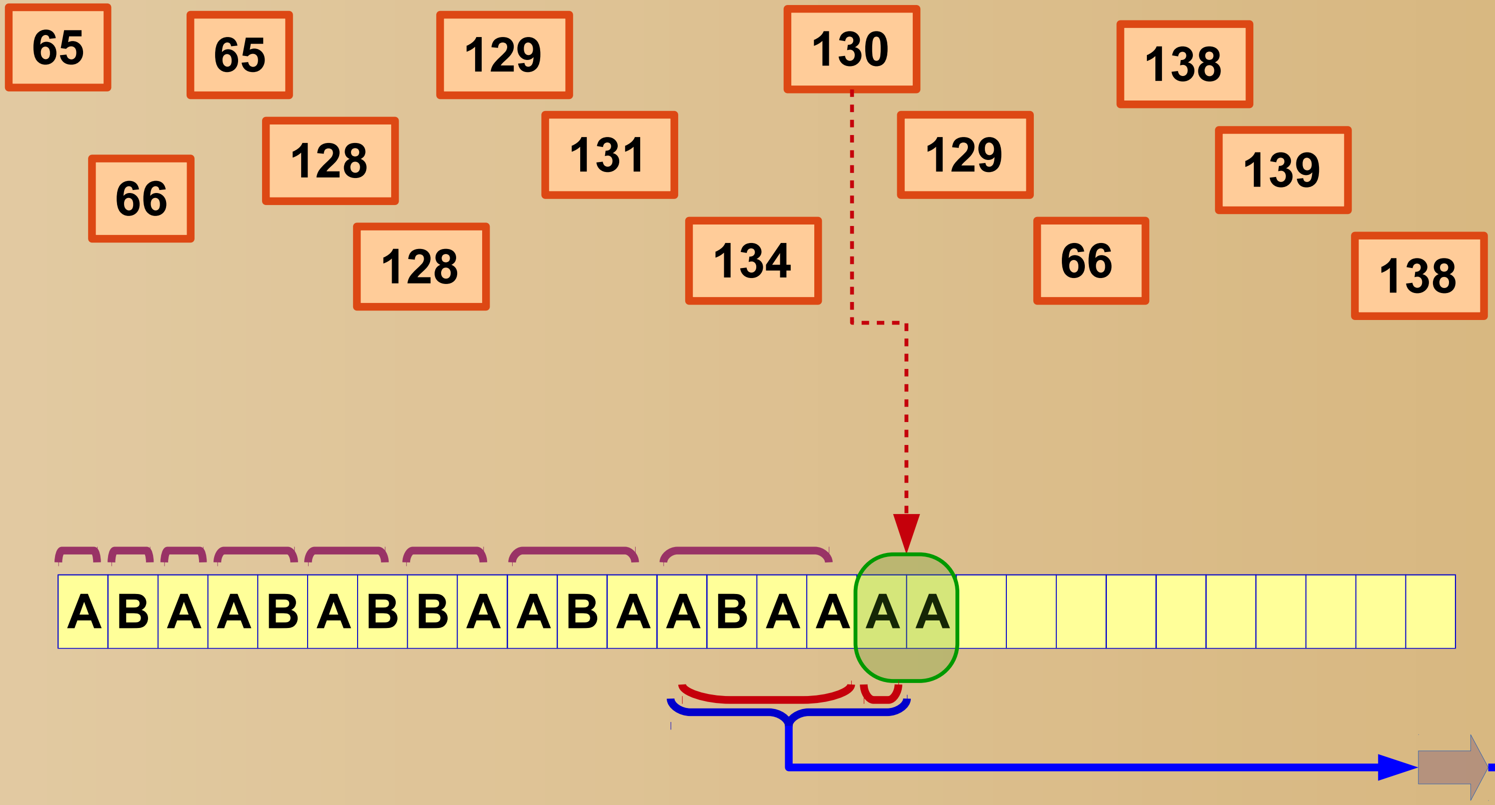
...	...
65	A
66	B
...	...
...	...
128	AB
129	BA
130	AA
131	ABA
132	ABB
133	BAA
134	ABAA
135	
136	
137	
138	
139	
140	
141	
142	

Pick symbols at Index [134] from the Dictionary; "ABAA"

Construct Unknown Symbols by Concatenating
Symbols in Previous Step "ABA"
and First Symbol in Previous Step "A"

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZW De-Compression

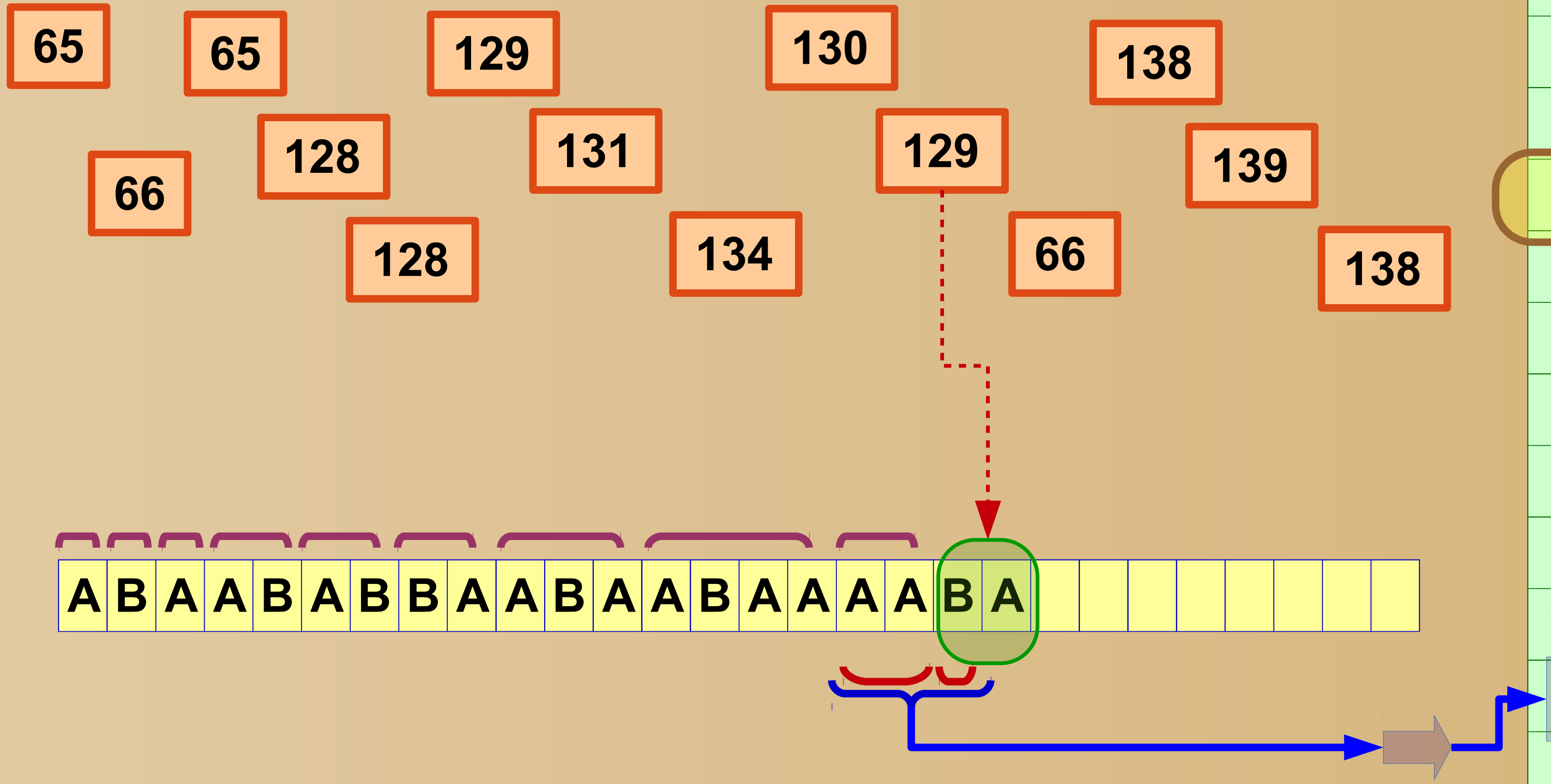


...	...
65	A
66	B
...	...
...	...
128	AB
129	BA
130	AA
131	ABA
132	ABB
133	BAA
134	ABAA
135	ABAAA
136	
137	
138	
139	
140	
141	
142	

Pick symbols at Index [130] from the Dictionary; "AA"
Concatenate <u>ALL</u> Symbols picked from <u>Previous step</u>
and <u>first</u> Symbol picked from <u>current step</u>
(Add concatenated <u>Symbols</u> to Dictionary)

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZW De-Compression

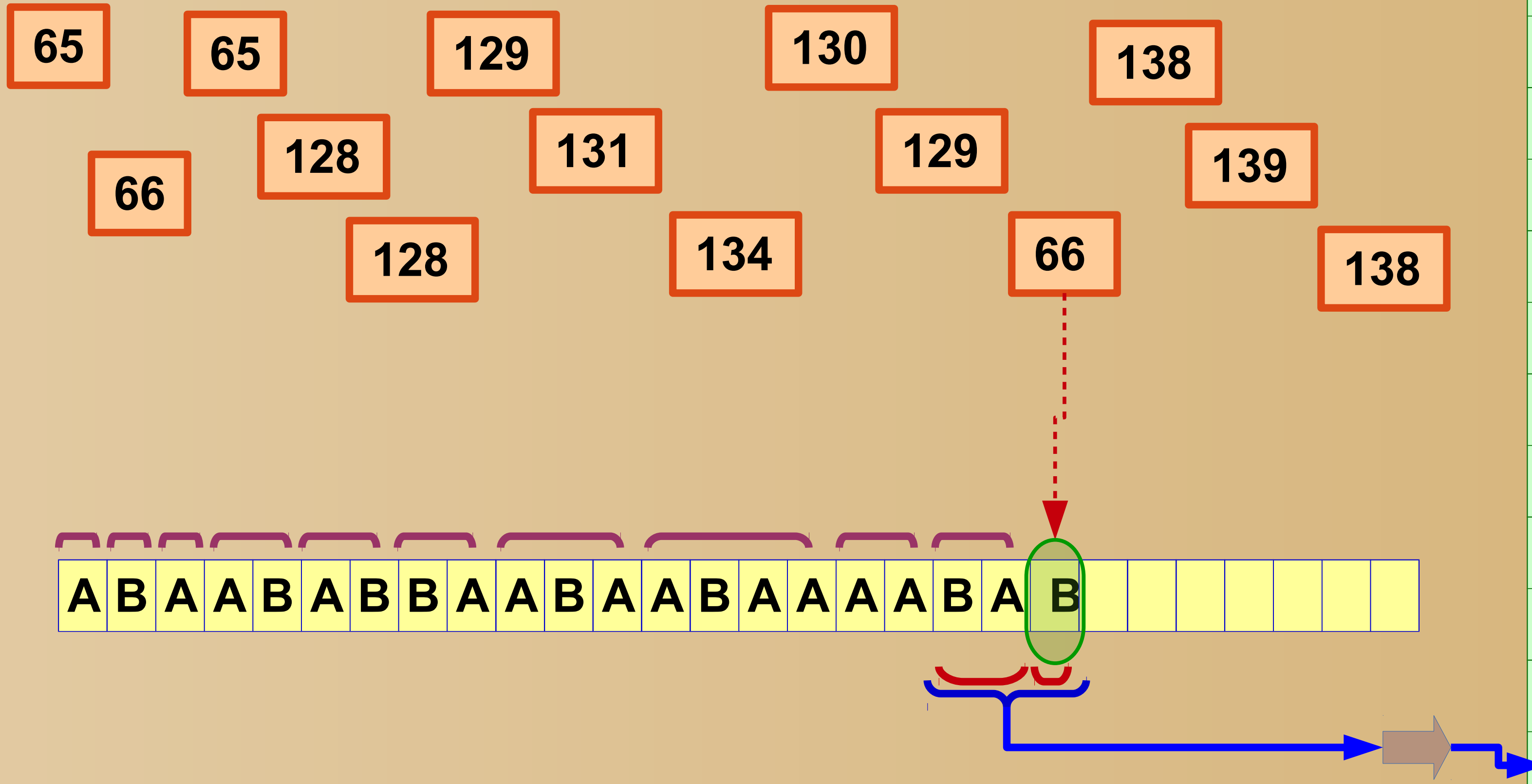


...	...
65	A
66	B
...	...
...	...
128	AB
129	BA
130	AA
131	ABA
132	ABB
133	BAA
134	ABAA
135	ABAAA
136	AAB
137	
138	
139	
140	
141	
142	

Pick symbols at Index [129] from the Dictionary; "BA"
Concatenate ALL Symbols picked from Previous step
and first Symbol picked from current step
(Add concatenated Symbols to Dictionary)

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZW De-Compression

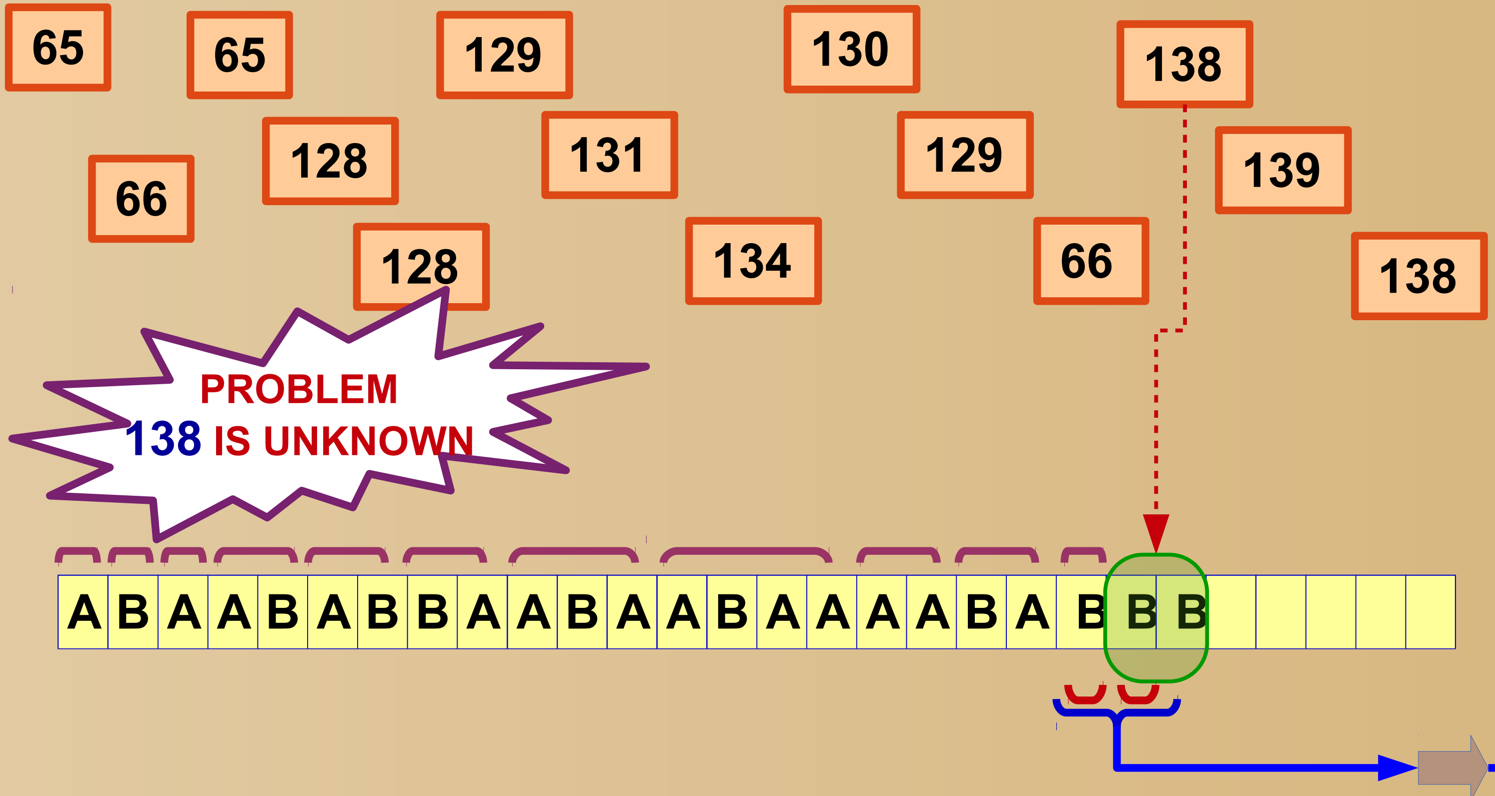


...	...
65	A
66	B
...	...
...	...
128	AB
129	BA
130	AA
131	ABA
132	ABB
133	BAA
134	ABAA
135	ABAAA
136	AAB
137	BAB
138	
139	
140	
141	
142	

Pick symbols at Index [98] from the Dictionary; "B"
Concatenate <u>ALL</u> Symbols picked from <u>Previous step</u>
and <u>first</u> Symbol picked from <u>current step</u>
(Add concatenated <u>Symbols</u> to Dictionary)

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

LZW De-Compression



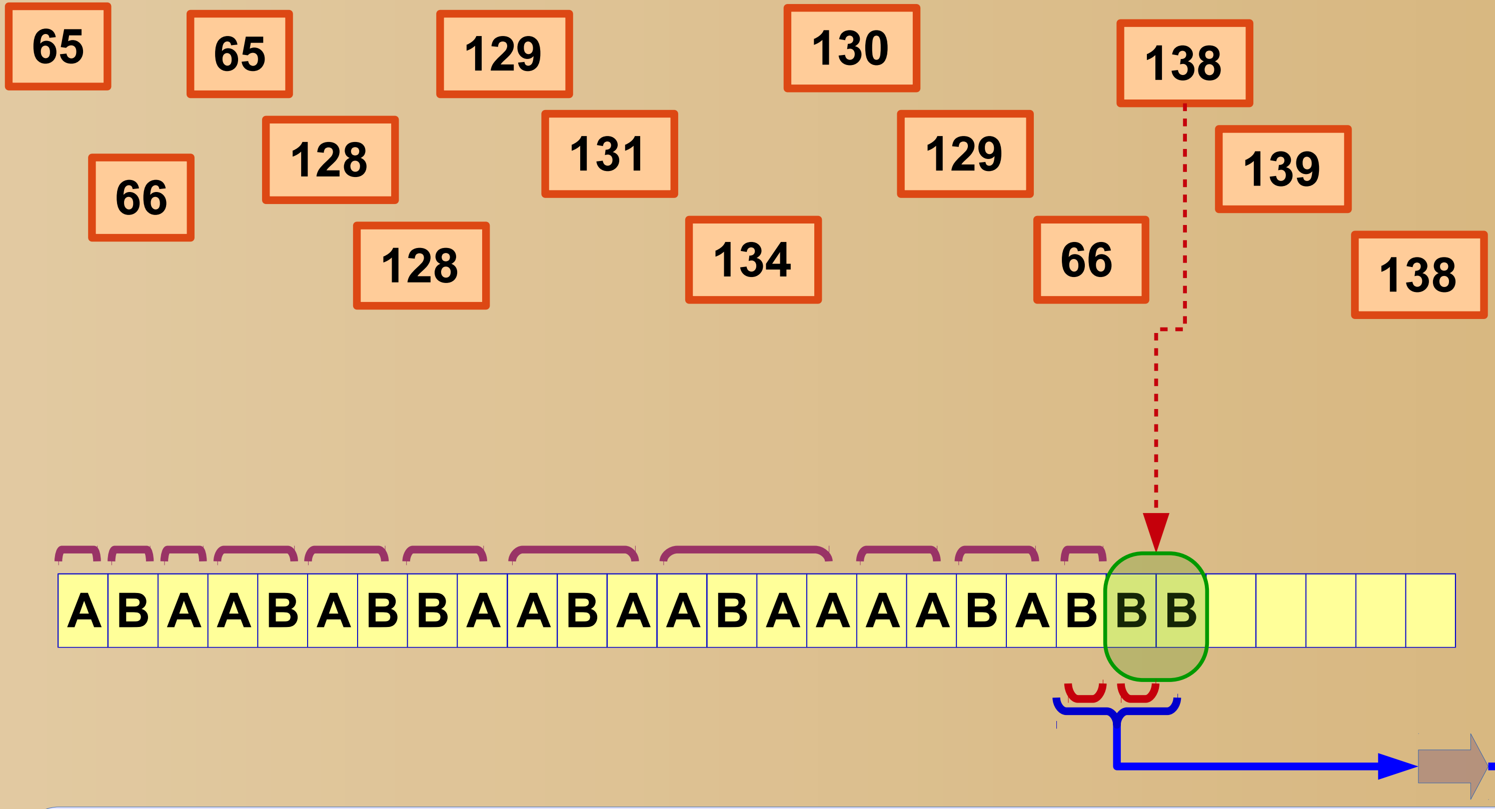
...	...
65	A
66	B
...	...
...	...
128	AB
129	BA
130	AA
131	ABA
132	ABB
133	BAA
134	ABAA
135	ABAAA
136	AAB
137	BAB
138	???
139	
140	
141	
142	

Pick symbols at Index [138] from the Dictionary; "???"

Construct Unknown Symbols by Concatenating Symbols in Previous Step "B" and First Symbol in Previous Step "B"

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

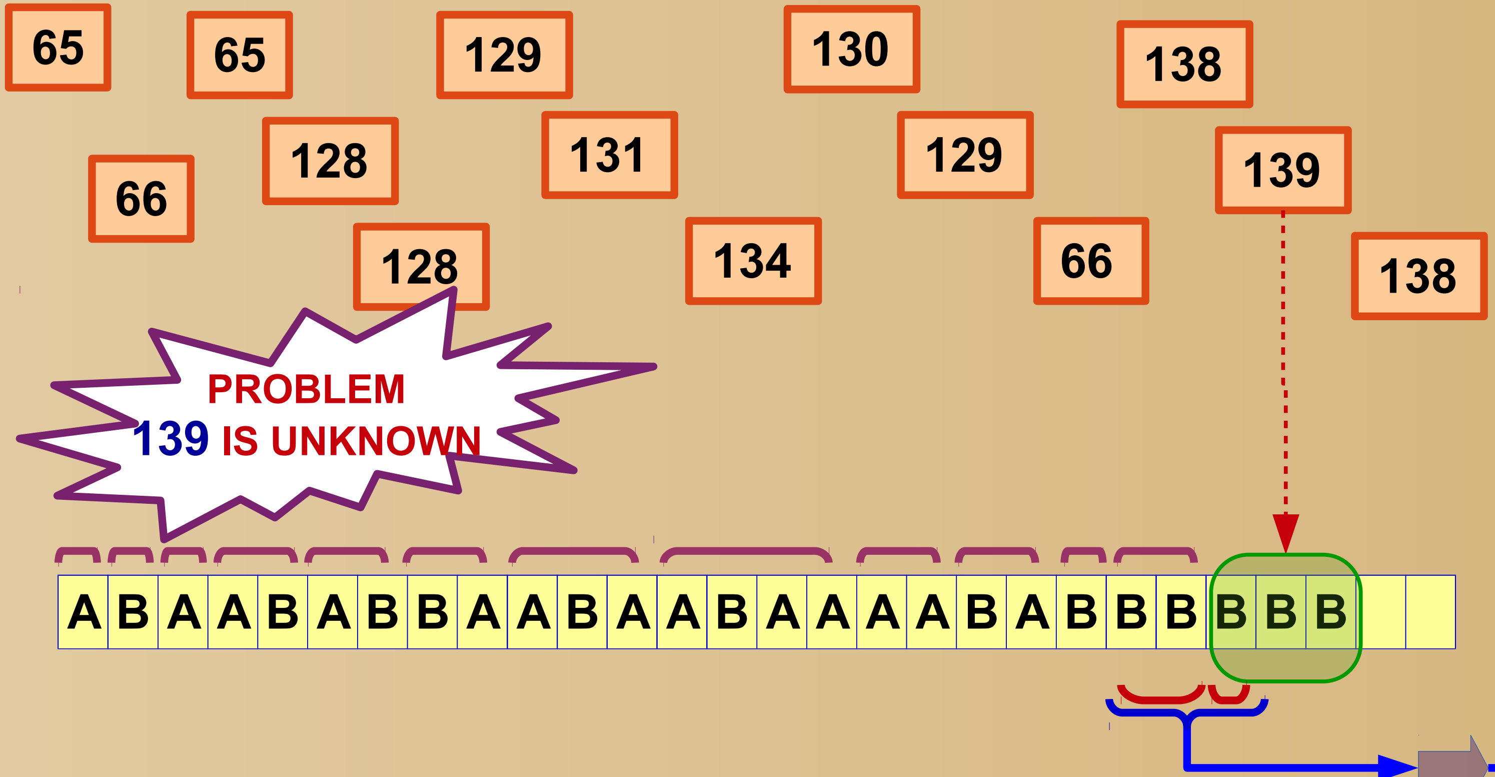
LZW De-Compression



...	...
65	A
66	B
...	...
...	...
128	AB
129	BA
130	AA
131	ABA
132	ABB
133	BAA
134	ABAA
135	ABAAA
136	AAB
137	BAB
138	BB
139	
140	
141	
142	

Concatenate ALL Symbols picked from Previous step and first Symbol picked from current step (Add concatenated Symbols to Dictionary)

LZW De-Compression



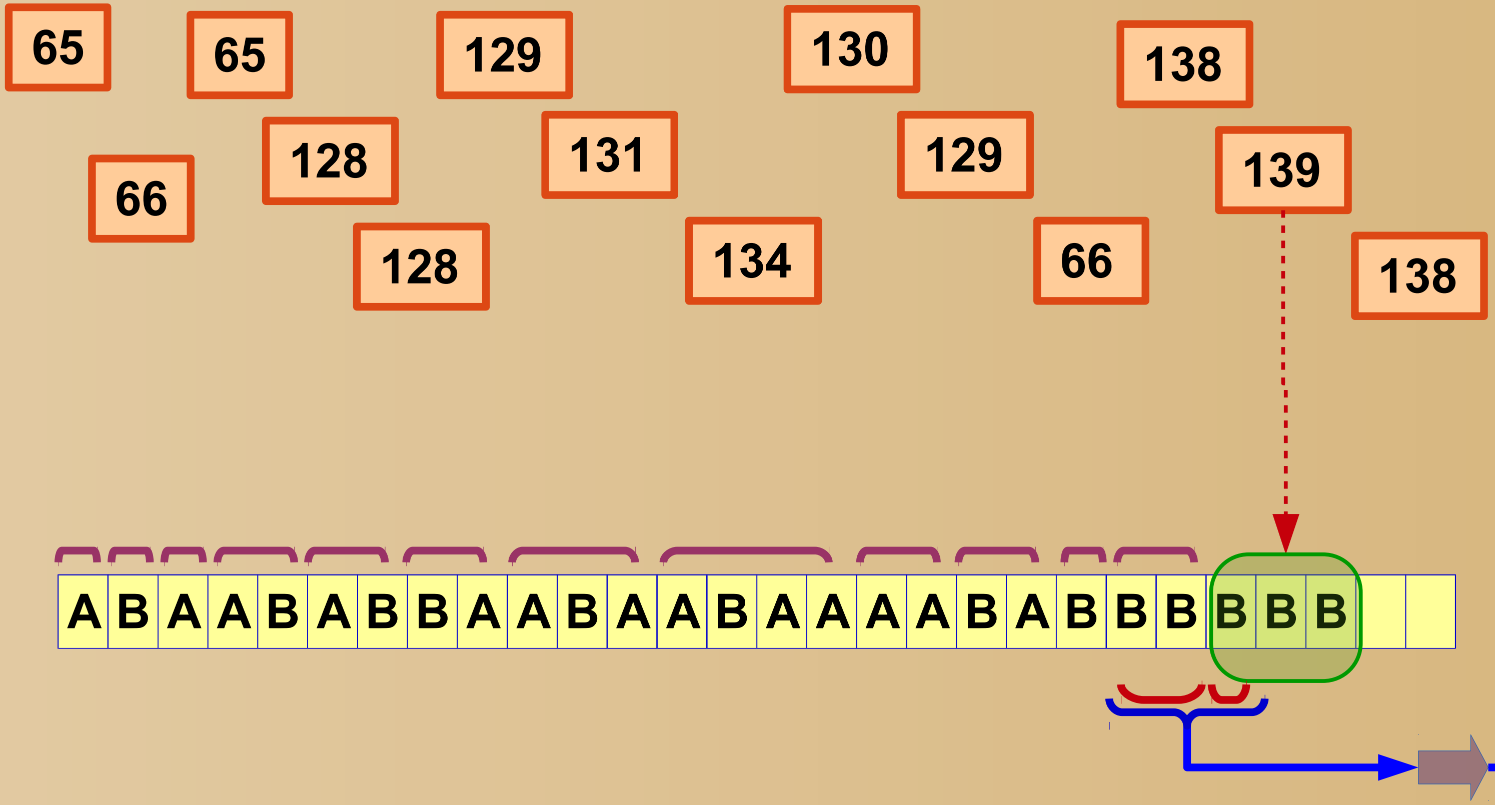
...	...
65	A
66	B
...	...
...	...
128	AB
129	BA
130	AA
131	ABA
132	ABB
133	BAA
134	ABAA
135	ABAAA
136	AAB
137	BAB
138	BB
139	???
140	
141	
142	

Pick symbols at Index [139] from the Dictionary; "???"

Construct Unknown Symbols by Concatenating
Symbols in Previous Step "BB"
and First Symbol in Previous Step "B"

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg

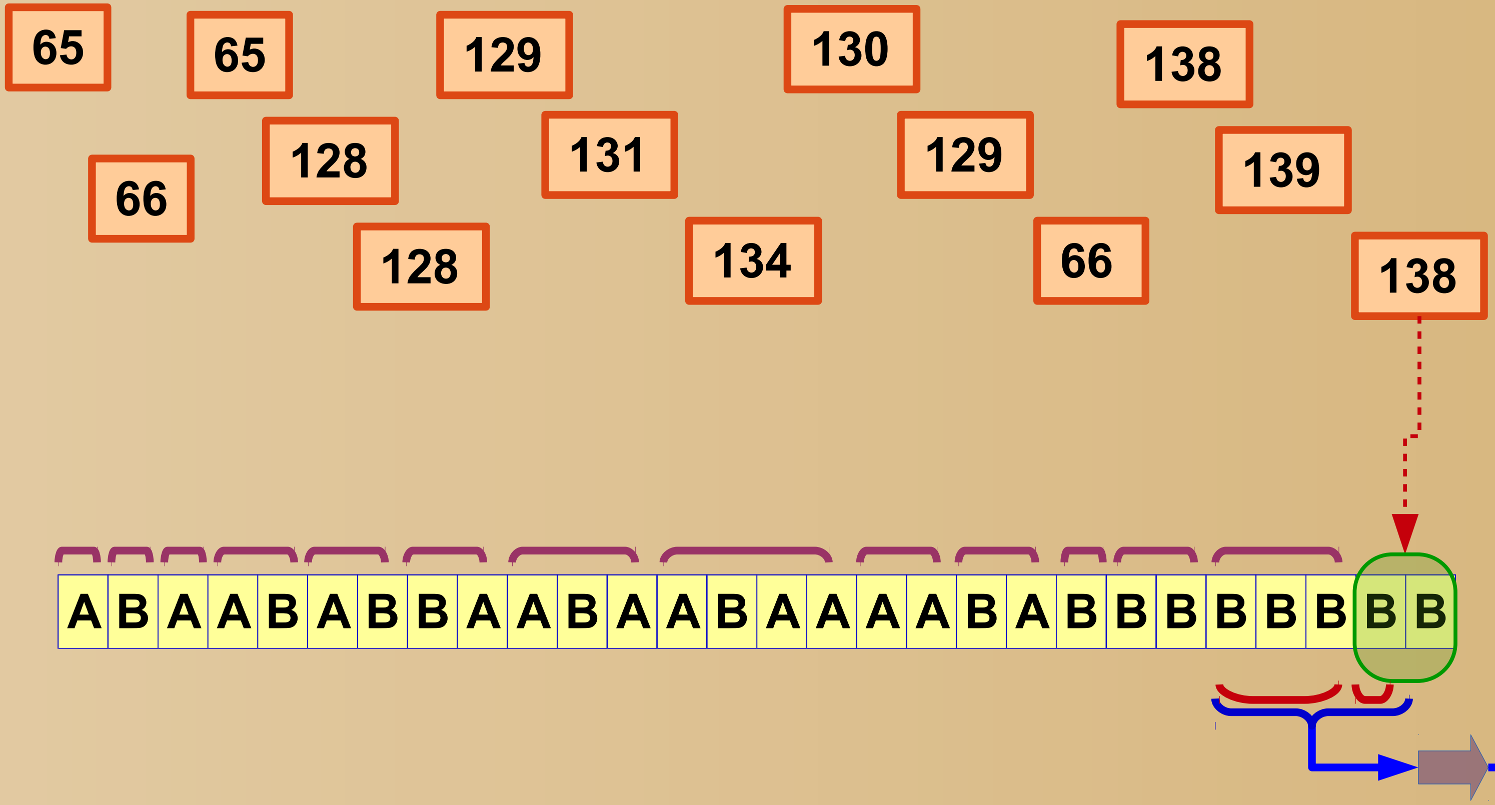
LZW De-Compression



...	...
65	A
66	B
...	...
...	...
128	AB
129	BA
130	AA
131	ABA
132	ABB
133	BAA
134	ABAA
135	ABAAA
136	AAB
137	BAB
138	BB
139	BBB
140	
141	
142	

Concatenate ALL Symbols picked from Previous step and first Symbol picked from current step (Add concatenated Symbols to Dictionary)

LZW De-Compression



...	...
65	A
66	B
...	...
...	...
128	AB
129	BA
130	AA
131	ABA
132	ABB
133	BAA
134	ABAA
135	ABAAA
136	AAB
137	BAB
138	BB
139	BBB
140	BBBB
141	
142	

Pick symbols at Index [138] from the Dictionary; "BB"
Concatenate ALL Symbols picked from Previous step
and first Symbol picked from current step
(Add concatenated Symbols to Dictionary)

LZW Compression Ratio

65 66 65 128 128 129 131 134 130 129 66 138 139 138

Original Size = Number of Symbols * Bits used to Store one Symbol
= 28 Symbols * 8 Bits / Symbol = 224 bits
(Store "Symbol" ASCII Code in 8 Bits)

Max "Index" Value = 139 Store "Index" Value in 8 Bits

Tag size = 8 Bits

Number of Tags = 14 Tags

Compressed Size=14*8=112 bits

Prof. Khaled Mostafa
khaledms@fci-cu.edu.eg