

# Uporaba diskretne kosinusne transformacije pri kompresiji slik v formatu JPEG

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Zagovor diplomske naloge  
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- Diskretna kosinusna transformacija
- Kodiranje bloka v JPEG
- Primeri slik v JPEG

2023-09-13

## Uporaba DCT v formatu JPEG

## └ Uvod

- Diskretna kosinusna transformacija
- Kodiranje bloka v JPEG
- Primeri slik v JPEG

# Diskretna kosinusna transformacija (DCT)

- enodimenzionalna DCT

$$C(u) = \alpha(u) \sum_{x=0}^{N-1} f(x) \cos \left[ \frac{\pi(2x+1)u}{2N} \right], u = 0, 1, 2, \dots, N-1$$

$$\alpha(u) = \begin{cases} \sqrt{\frac{1}{N}}, & u = 0 \\ \sqrt{\frac{2}{N}}, & u \neq 0 \end{cases}$$

- dvodimenzionalna DCT

$$C(u, v) = \alpha(u)\alpha(v) \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} f(x, y) \cos \left[ \frac{\pi(2x+1)u}{2N} \right] \cos \left[ \frac{\pi(2y+1)v}{2N} \right],$$

$$u, v = 0, 1, 2, \dots, N-1$$

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### └ Diskretna kosinusna transformacija (DCT)

1. Definicija enodimenzionalne DCT
2. Definicija dvodimenzionalne DCT

Diskretna kosinusna transformacija (DCT)

• enodimenzionalna DCT

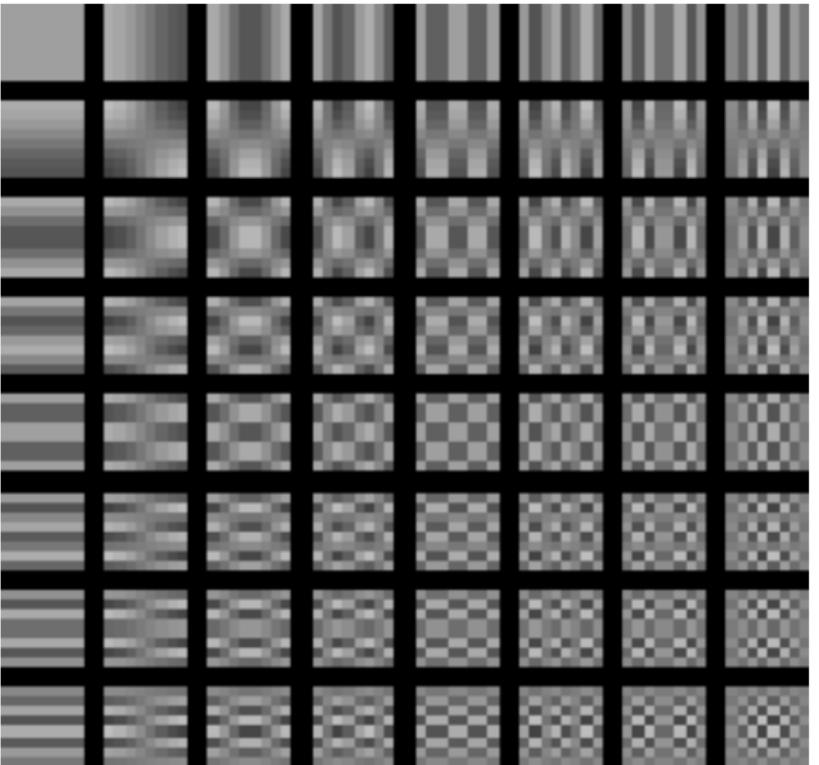
$$C(u) = \alpha(u) \sum_{x=0}^{N-1} f(x) \cos \left[ \frac{\pi(2x+1)u}{2N} \right], u = 0, 1, 2, \dots, N-1$$
$$\alpha(u) = \begin{cases} \sqrt{\frac{1}{N}}, & u = 0 \\ \sqrt{\frac{2}{N}}, & u \neq 0 \end{cases}$$

• dvodimenzionalna DCT

$$C(u, v) = \alpha(u)\alpha(v) \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} f(x, y) \cos \left[ \frac{\pi(2x+1)u}{2N} \right] \cos \left[ \frac{\pi(2y+1)v}{2N} \right],$$
$$u, v = 0, 1, 2, \dots, N-1$$

# Kosinusne bazne funkcije DCT

- koeficient DC
- koeficienti AC



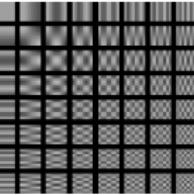
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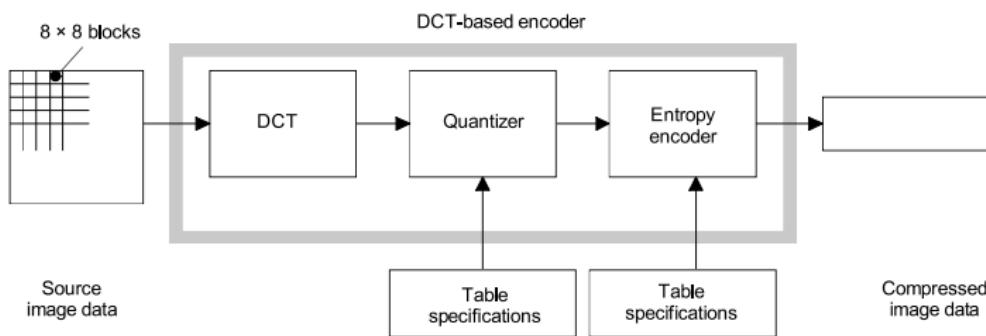
### └ Kosinusne bazne funkcije DCT

Kosinusne bazne funkcije DCT

- koeficient DC
- koeficienti AC



# Shema kodiranja JPEG

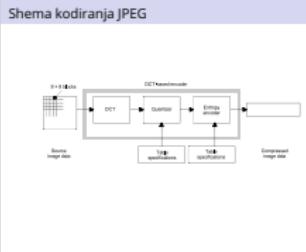


## Uporaba DCT v formatu JPEG

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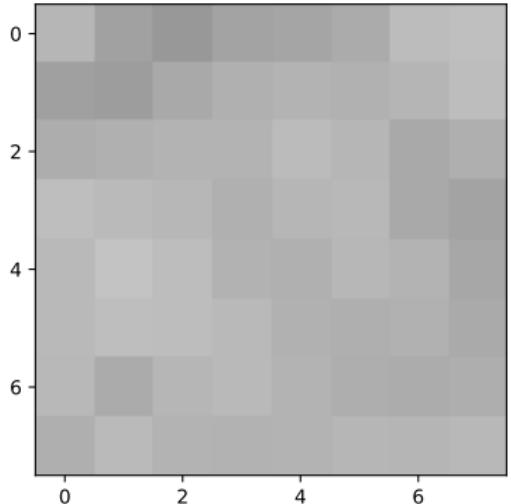
### Shema kodiranja JPEG

1. Slika ... blok
2. DCT
3. Kvantizacija s preddoločenimi kvantizacijskimi tabelami
4. Entropijsko kodiranje s Huffmanovim kodiranjem
5. Bitni niz



# Blok slike

$I = \begin{bmatrix} 182 & 161 & 152 & 164 & 165 & 171 & 188 & 191 \\ 160 & 157 & 169 & 176 & 179 & 177 & 181 & 189 \\ 173 & 176 & 179 & 180 & 187 & 182 & 169 & 175 \\ 190 & 186 & 183 & 176 & 182 & 184 & 169 & 164 \\ 185 & 195 & 189 & 178 & 176 & 183 & 180 & 167 \\ 185 & 190 & 189 & 185 & 177 & 175 & 177 & 170 \\ 184 & 171 & 182 & 185 & 180 & 174 & 172 & 174 \\ 175 & 186 & 179 & 178 & 180 & 182 & 181 & 184 \end{bmatrix}$

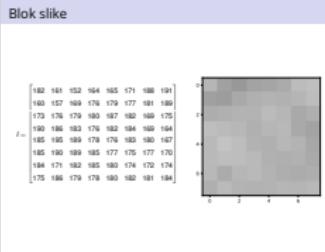


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## Uporaba DCT v formatu JPEG

### └ Blok slike

1. Primer bloka, ki ga bomo kodirali v format JPEG
2. Ta blok zamaknemo za 128, da bo povprečna intenziteta enaka 0



# Zamaknjen blok

$$I' = I - 128 = \begin{bmatrix} 54 & 33 & 24 & 36 & 37 & 43 & 60 & 63 \\ 32 & 29 & 41 & 48 & 51 & 49 & 53 & 61 \\ 45 & 48 & 51 & 52 & 59 & 54 & 41 & 47 \\ 62 & 58 & 55 & 48 & 54 & 56 & 41 & 36 \\ 57 & 67 & 61 & 50 & 48 & 55 & 52 & 39 \\ 57 & 62 & 61 & 57 & 49 & 47 & 49 & 42 \\ 56 & 43 & 54 & 57 & 52 & 46 & 44 & 46 \\ 47 & 58 & 51 & 50 & 52 & 54 & 53 & 56 \end{bmatrix}$$

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### └ Zamaknjen blok

1. Ta blok zamaknemo za 128, da bo povprečna intenziteta enaka 0

Zamaknjen blok
$I' = I - 128 =$ 

$$C(u, v) = \alpha(u)\alpha(v) \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} f(x, y) \cos\left[\frac{\pi(2x+1)u}{2N}\right] \cos\left[\frac{\pi(2y+1)v}{2N}\right]$$

399,1	3,5	-0,7	4,2	0,9	0,3	1,8	0
-20,6	-27,3	9,3	6,1	9,8	2,3	1,1	1
-15,1	-35	15,4	-4,2	14,7	5,6	-3,1	-0,5
-2,7	3,8	15,3	-0,6	-0,9	12	-5,2	0,3
3,4	4,7	16,6	10	-8,9	-1,9	-4	-2,8
-4,8	10,9	3,4	9,1	10,1	4,1	4,1	1,1
5	5,7	3,9	0,3	-3,3	-4,4	-4,6	-2,5
0,2	-0,4	0	0,3	-0,2	0	0	-0,3

$$C(f) =$$

# Izračun DCT bloka

$$C(u, v) = \alpha(u)\alpha(v) \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} f(x, y) \cos\left[\frac{\pi(2x+1)u}{2N}\right] \cos\left[\frac{\pi(2y+1)v}{2N}\right]$$

$$C(I') = \begin{bmatrix} 399,1 & 3,5 & -0,7 & 4,2 & 0,9 & 0,3 & 1,8 & 0 \\ -20,6 & -27,3 & 9,3 & 6,1 & 9,8 & 2,3 & 1,1 & 1 \\ -15,1 & -35 & 15,4 & -4,2 & 14,7 & 5,6 & -3,1 & -0,5 \\ -2,7 & 3,8 & 15,3 & -0,6 & -0,9 & 12 & -5,2 & 0,3 \\ 3,4 & 4,7 & 16,6 & 10 & -8,9 & -1,9 & -4 & -2,8 \\ -4,8 & 10,9 & 3,4 & 9,1 & 10,1 & 4,1 & 4,1 & 1,1 \\ 5 & 5,7 & 3,9 & 0,3 & -3,3 & -4,4 & -4,6 & -2,5 \\ 0,2 & -0,4 & 0 & 0,3 & -0,2 & 0 & 0 & -0,3 \end{bmatrix}$$

# Uporaba DCT v formatu JPEG

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## Izračun DCT bloka

- Levo zgoraj visoka števila

# Pomen DCT

399,1	3,5	-0,7	4,2	0,9	0,3	1,8	0
-20,6	-27,3	9,3	6,1	9,8	2,3	1,1	1
-15,1	-35	15,4	-4,2	14,7	5,6	-3,1	-0,5
-2,7	3,8	15,3	-0,6	-0,9	12	-5,2	0,3
3,4	4,7	16,6	10	-8,9	-1,9	-4	-2,8
-4,8	10,9	3,4	9,1	10,1	4,1	4,1	1,1
5	5,7	3,9	0,3	-3,3	-4,4	-4,6	-2,5
0,2	-0,4	0	0,3	-0,2	0	0	-0,3

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└ Pomen DCT



# Kvantizacija

- Kompresija z izgubo

$$C^Q(u, v) = \text{Integer round} \left( \frac{C(u, v)}{Q(u, v)} \right)$$

399,1	3,5	-0,7	4,2	0,9	0,3	1,8	0
-20,6	-27,3	9,3	6,1	9,8	2,3	1,1	1
-15,1	-35	15,4	-4,2	14,7	5,6	-3,1	-0,5
-2,7	3,8	15,3	-0,6	-0,9	12	-5,2	0,3
3,4	4,7	16,6	10	-8,9	-1,9	-4	-2,8
-4,8	10,9	3,4	9,1	10,1	4,1	4,1	1,1
5	5,7	3,9	0,3	-3,3	-4,4	-4,6	-2,5
0,2	-0,4	0	0,3	-0,2	0	0	-0,3

$C(u, v)$

16	11	10	16	24	40	51	61
12	12	14	19	26	58	60	55
14	13	16	24	40	57	69	56
14	17	22	29	51	87	80	12
18	22	37	56	68	109	103	77
24	35	55	64	81	104	113	92
49	64	78	87	103	121	120	101
72	92	95	98	112	100	103	99

$Q(u, v)$

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### └ Kvantizacija

Kvantizacija

• Kompresija z izgubo

$C^Q(u, v) = \text{Integer round} \left( \frac{C(u, v)}{Q(u, v)} \right)$

$C(u, v)$	$Q(u, v)$
208,1	2,8
-20,6	-27,3
-15,1	-35
-2,7	3,8
3,4	4,7
-4,8	10,9
5	5,7
0,2	-0,4
16	11
12	12
14	14
19	19
26	26
58	58
60	60
55	55
69	69
56	56
12	12
13	13
16	16
24	24
40	40
51	51
61	61
22	22
37	37
56	56
68	68
109	109
103	103
77	77
35	35
55	55
64	64
81	81
104	104
113	113
92	92
64	64
78	78
87	87
103	103
121	121
120	120
101	101
92	92
95	95
98	98
112	112
100	100
103	103
99	99

# Zapis v vrstici

$$C^Q(I') = \begin{bmatrix} 25 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -2 & -2 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & -3 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

## Uporaba DCT v formatu JPEG

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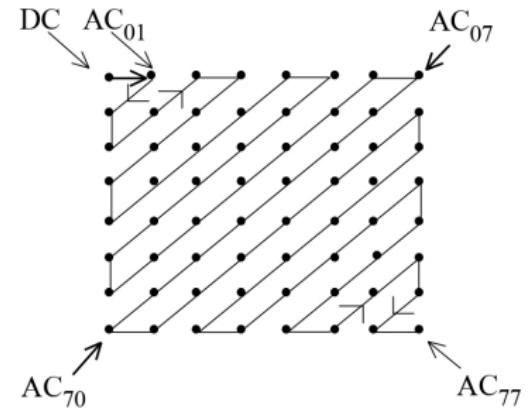
└ Zapis v vrstici

Zapis v vrstici

$$C^Q(I) = \begin{bmatrix} 25 & -2 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ -2 & 1 & -3 & 1 & 0 & 0 & 0 & 0 & 0 \\ -1 & -3 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

# Zapis v vrstici

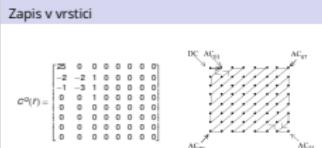
$$C^Q(I') = \begin{bmatrix} 25 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -2 & -2 & 1 & 0 & 0 & 0 & 0 & 0 \\ -1 & -3 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$



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## Uporaba DCT v formatu JPEG

└ Zapis v vrstici

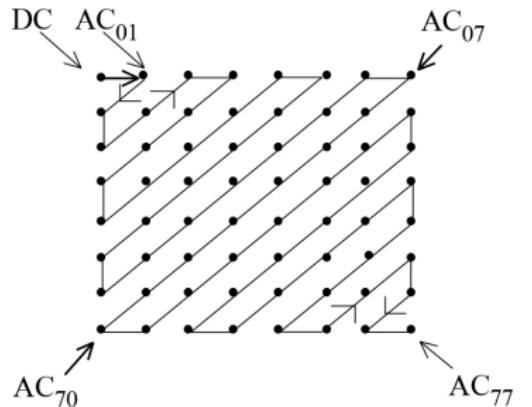


# Zapis v vrstici

$$C^Q(I') = \begin{bmatrix} 25 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -2 & -2 & 1 & 0 & 0 & 0 & 0 & 0 \\ -1 & -3 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

DC = 25

$$AC = \begin{bmatrix} 0, & -2, & -1, & -2, & 0, & 0, & 1, & -3, & 0, & 0, & 0, & 1, & 0, & 0, & 0, & 0, & 0, \\ 0, & 1, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, \\ 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, \\ 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0 \end{bmatrix}$$



## Uporaba DCT v formátu JPEG

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### └ Zapis v vrstici

Zapis v vrstici	
$C^Q(I) =$ $\begin{bmatrix} 25 & -2 & -1 & -2 & 0 & 0 & 1 & -3 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$	DC = 25 AC = $\begin{bmatrix} 0, & -2, & -1, & -2, & 0, & 0, & 1, & -3, & 0, & 0, & 0, & 1, & 0, & 0, & 0, & 0, & 0 \\ 0, & 1, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0 \\ 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0 \\ 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0 \end{bmatrix}$

DC = 25 —→ (5)(25)

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└ Vmesna predstavitev

## Vmesna predstavitev

$$DC = 25 \rightarrow (5)(25)$$

$$(1, 2)(-2)$$

### 3 Uporaba DCT v formátu JPEG

## └ Vmesna predstavitev

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$$DC = 25 \rightarrow (5)(25)$$

## Vmesna predstavitev

$$DC = 25 \rightarrow (5)(25)$$

$$(1,2)(-2), (0,1)(-1)$$

### 3 Uporaba DCT v formátu JPEG

└ Vmesna predstavitev

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$$DC = 25 \rightarrow (5)(25)$$

$$A_2 = \begin{pmatrix} 0, & -2, & -1, & -2, & 0, & 0, & 1, & -3, & 0, & 0, & 0, & 1, & 0, & 0, & 0, & 0 \\ 0, & 1, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0 \\ 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0 \\ 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0 \end{pmatrix} =$$

(1,2)(-2), (0,1)(-1)

## Vmesna predstavitev

$$DC = 25 \rightarrow (5)(25)$$

$$(1, 2)(-2), (0, 1)(-1), (0, 2)(-2), (2, 1)(1),$$

$$(0, 2)(-3), (3, 1)(1), \quad (5, 1)(1),$$

### 3 Uporaba DCT v formátu JPEG

## └ Vmesna predstavitev

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$$DC = 25 \rightarrow (5)(25)$$

$$(1,2)(-2), (0,1)(-1), (0,2)(-2), (2,1)(1), \\ (0,2)(-3), (3,1)(1), (5,1)(1),$$

## Vmesna predstavitev

$$DC = 25 \rightarrow (5)(25)$$

$$(1, 2)(-2), (0, 1)(-1), (0, 2)(-2), (2, 1)(1), \\ (0, 2)(-3), (3, 1)(1), (5, 1)(1), (0, 0)$$

### 3 Uporaba DCT v formátu JPEG

└ Vmesna predstavitev

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### Vmesna predstavitev

$$DC = 25 \rightarrow (5)(25)$$

$$\begin{aligned} \mathbf{AC} = & \begin{bmatrix} 0, & -2, & -1, & -2, & 0, & 0, & 1, & -3, & 0, & 0, & 0, & 1, & 0, & 0, & 0, \\ 0, & 1, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, \\ 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, \\ 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0, & 0 \end{bmatrix} \\ & \begin{pmatrix} (1, 2)(-2), & (0, 1)(-1), & (0, 2)(-2), & (2, 1)(1), \\ (0, 2)(-3), & (3, 1)(1), & (5, 1)(1), & (0, 0) \end{pmatrix} \end{aligned}$$

# Kodiranje

Huffmanova kodirna tabela koeficientov DC

$S$	Kodna beseda
0	00
1	010
2	011
3	100
4	101
5	110
6	1110
7	11110
8	111110
9	1111110
10	11111110
11	111111110

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## Uporaba DCT v formatu JPEG

### └ Kodiranje

Kodiranje

Huffmanova kodirna tabela koeficientov DC

(5)	$S$	Kodna beseda
0	0	00
1	1	010
2	2	011
3	3	100
4	4	101
5	5	110
6	6	1110
7	7	11110
8	8	111110
9	9	1111110
10	10	11111110
11	11	111111110

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Uporaba DCT v formatu JPEG

# Kodiranje

(5) 110

Huffmanova kodirna tabela koeficientov DC

$S$	Kodna beseda
0	00
1	010
2	011
3	100
4	101
5	110
6	1110
7	11110
8	111110
9	1111110
10	11111110
11	111111110

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## Uporaba DCT v formatu JPEG

### └ Kodiranje

Kodiranje

Huffmanova kodirna tabela koeficientov DC

$S$	Kodna beseda
0	00
1	010
2	011
3	100
4	101
5	110
6	1110
7	11110
8	111110
9	1111110
10	11111110
11	111111110

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# Kodiranje

Variable-length integer(VLI)

(5)(25) 110

Huffmanova kodirna tabela koeficientov DC

$S$	Kodna beseda
0	00
1	010
2	011
3	100
4	101
5	110
6	1110
7	11110
8	111110
9	1111110
10	11111110
11	111111110

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└ Kodiranje

Kodiranje

Huffmanova kodirna tabela koeficientov DC

$S$	Kodna beseda
0	00
1	010
2	011
3	100
4	101
5	110
6	1110
7	11110
8	111110
9	1111110
10	11111110
11	111111110

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# Kodiranje

Variable-length integer(VLI)

(5)(25) 110 11001

Huffmanova kodirna tabela  
koeficientov DC

<i>S</i>	Kodna beseda
0	00
1	010
2	011
3	100
4	101
5	110
6	1110
7	11110
8	111110
9	1111110
10	11111110
11	111111110

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# Uporaba DCT v formatu JPEG

└ Kodiranje

Kodiranje	
Huffmanova kodirna tabela koeficientov DC	
Variable-length integer(VLI)	
(5)(25)	110 11001
0	00
1	010
2	011
3	100
4	101
5	110
6	1110
7	11110
8	111110
9	1111110
10	11111110
11	111111110

# Kodiranje

## Variable-length integer(VLI)

(5)(25)	110 11001
(1, 2)	
(0, 1)	
(0, 2)	
(2, 1)	
(0, 2)	
(3, 1)	
(5, 1)	
(0, 0)	

Huffmanova kodirna tabela  
koeficientov DC

<i>S</i>	Kodna beseda
0	00
1	010
2	011
3	100
4	101
5	110
6	1110
7	11110
8	111110
9	1111110
10	11111110
11	111111110

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## Uporaba DCT v formatu JPEG

### └ Kodiranje

Kodiranje	
Huffmanova kodirna tabela koeficientov DC	
Variable-length integer(VLI)	
(5)(25)	110 11001
(1, 2)	
(0, 1)	
(0, 2)	
(2, 1)	
(0, 2)	
(3, 1)	
(5, 1)	
(0, 0)	

Huffmanova kodirna tabela koeficientov DC	
<i>S</i>	Kodna beseda
0	00
1	010
2	011
3	100
4	101
5	110
6	1110
7	11110
8	111110
9	1111110
10	11111110
11	111111110

# Kodiranje

## Variable-length integer(VLI)

(5)(25)	110 11001
(1, 2)	11011
(0, 1)	00
(0, 2)	01
(2, 1)	11100
(0, 2)	01
(3, 1)	111010
(5, 1)	1111010
(0, 0)	1010

## Huffmanova kodirna tabela koeficientov DC

<i>S</i>	Kodna beseda
0	00
1	010
2	011
3	100
4	101
5	110
6	1110
7	11110
8	111110
9	1111110
10	11111110
11	111111110

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## Uporaba DCT v formatu JPEG

### └ Kodiranje

Kodiranje	
Huffmanova kodirna tabela koeficientov DC	
Variable-length integer(VLI)	
(5)(25)	110 11001
(1, 2)	11011
(0, 1)	00
(0, 2)	01
(2, 1)	11100
(0, 2)	01
(3, 1)	111010
(5, 1)	1111010
(0, 0)	1010
0	00
1	010
2	011
3	100
4	101
5	110
6	1110
7	11110
8	111110
9	1111110
10	11111110
11	111111110

# Kodiranje

## Variable-length integer(VLI)

(5)(25)	110 11001
(1, 2)(-2)	11011
(0, 1)(-1)	00
(0, 2)(-2)	01
(2, 1)(1)	11100
(0, 2)(-3)	01
(3, 1)(1)	111010
(5, 1)(1)	1111010
(0, 0)	1010

## Huffmanova kodirna tabela koeficientov DC

<i>S</i>	Kodna beseda
0	00
1	010
2	011
3	100
4	101
5	110
6	1110
7	11110
8	111110
9	1111110
10	11111110
11	111111110

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## Uporaba DCT v formatu JPEG

### └ Kodiranje

Kodiranje	
Huffmanova kodirna tabela koeficientov DC	
Variable-length integer(VLI)	
(5)(25)	110 11001
(1, 2)(-2)	11011
(0, 1)(-1)	00
(0, 2)(-2)	01
(2, 1)(1)	11100
(0, 2)(-3)	01
(3, 1)(1)	111010
(5, 1)(1)	1111010
(0, 0)	1010
0	00
1	010
2	011
3	100
4	101
5	110
6	1110
7	11110
8	111110
9	1111110
10	11111110
11	111111110

# Kodiranje

## Variable-length integer(VLI)

(5)(25)	110 11001
(1, 2)(-2)	11011 01
(0, 1)(-1)	00 0
(0, 2)(-2)	01 01
(2, 1)(1)	11100 1
(0, 2)(-3)	01 00
(3, 1)(1)	111010 1
(5, 1)(1)	1111010 1
(0, 0)	1010

## Huffmanova kodirna tabela koeficientov DC

S	Kodna beseda
0	00
1	010
2	011
3	100
4	101
5	110
6	1110
7	11110
8	111110
9	1111110
10	11111110
11	111111110

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## Uporaba DCT v formatu JPEG

### └ Kodiranje

Kodiranje	
Huffmanova kodirna tabela koeficientov DC	
Variable-length integer(VLI)	
(5)(25)	110 11001
(1, 2)(-2)	11011 01
(0, 1)(-1)	00 0
(0, 2)(-2)	01 01
(2, 1)(1)	11100 1
(0, 2)(-3)	01 00
(3, 1)(1)	111010 1
(5, 1)(1)	1111010 1
(0, 0)	1010
0	00
1	010
2	011
3	100
4	101
5	110
6	1110
7	11110
8	111110
9	1111110
10	11111110
11	111111110

# Kodiranje

## Variable-length integer(VLI)

(5)(25)	110 11001
(1, 2)(-2)	11011 01
(0, 1)(-1)	00 0
(0, 2)(-2)	01 01
(2, 1)(1)	11100 1
(0, 2)(-3)	01 00
(3, 1)(1)	111010 1
(5, 1)(1)	1111010 1
(0, 0)	1010

11011001 11011010 00010111 10010100 11101011 11101011 010

## Huffmanova kodirna tabela koeficientov DC

S	Kodna beseda
0	00
1	010
2	011
3	100
4	101
5	1100 1
6	1110
7	11110
8	111110
9	1111110
10	11111110
11	111111110

## Uporaba DCT v formatu JPEG

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### └ Kodiranje

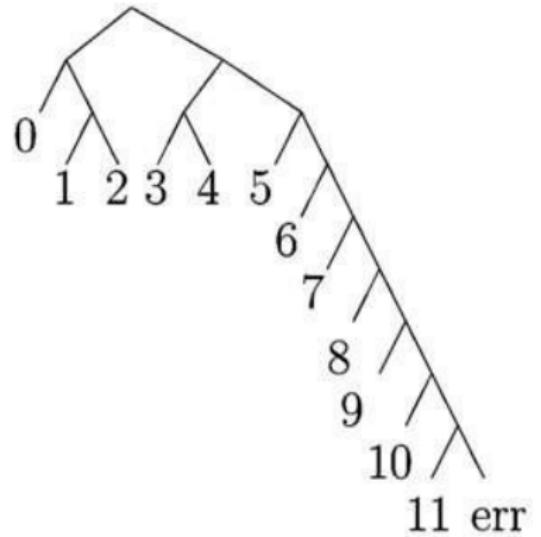
Huffmanova kodirna tabela koeficientov DC	
Variable-length integer(VLI)	Kodiranje
(5)(25)	110 11001
(1, 2)(-2)	11011 01
(0, 1)(-1)	00 0
(0, 2)(-2)	01 01
(2, 1)(1)	11100 1
(0, 2)(-3)	01 00
(3, 1)(1)	111010 1
(5, 1)(1)	1111010 1
(0, 0)	1010

S	Kodna beseda
0	00
1	010
2	011
3	100
4	101
5	110
6	1110
7	11110
8	111110
9	1111110
10	11111110
11	111111110

11011001 11011010 00010111 10010100 11101011 11101011 010

# Dekodiranje

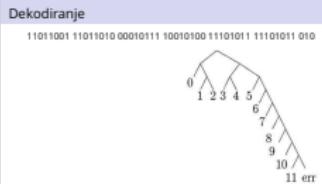
11011001 11011010 00010111 10010100 11101011 11101011 010



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## Uporaba DCT v formatu JPEG

└ Dekodiranje

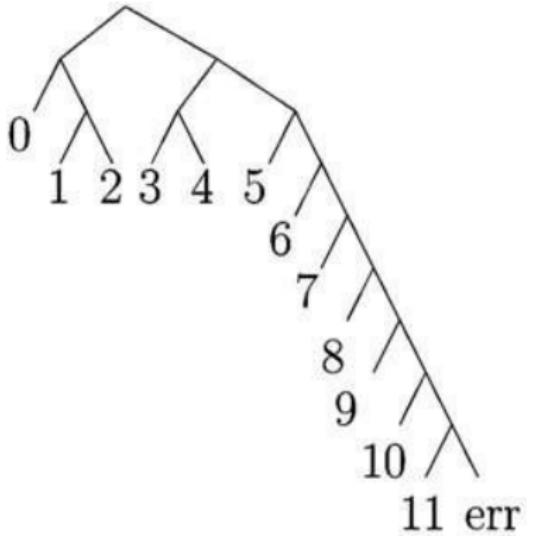


# Dekodiranje

11011001 11011010 00010111 10010100 11101011 11101011 010

(5)

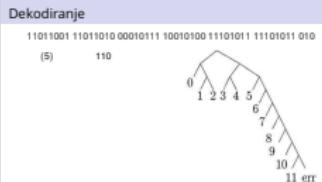
110



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## Uporaba DCT v formatu JPEG

└ Dekodiranje

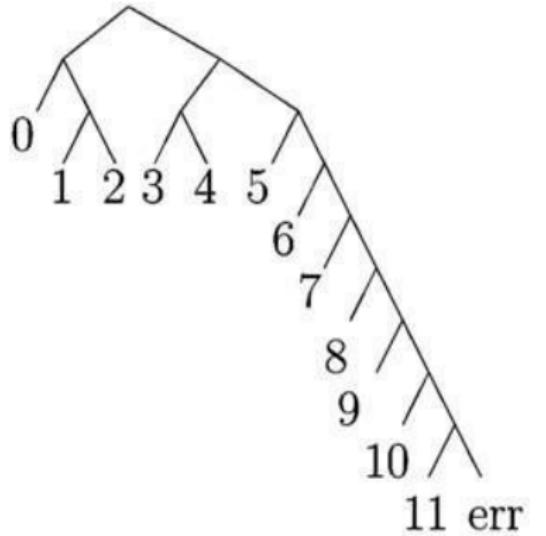


# Dekodiranje

11011001 11011010 00010111 10010100 11101011 11101011 010

(5)

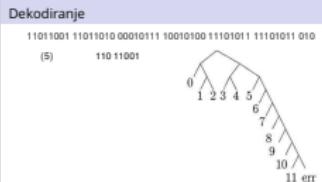
110 11001



## Uporaba DCT v formatu JPEG

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### └ Dekodiranje

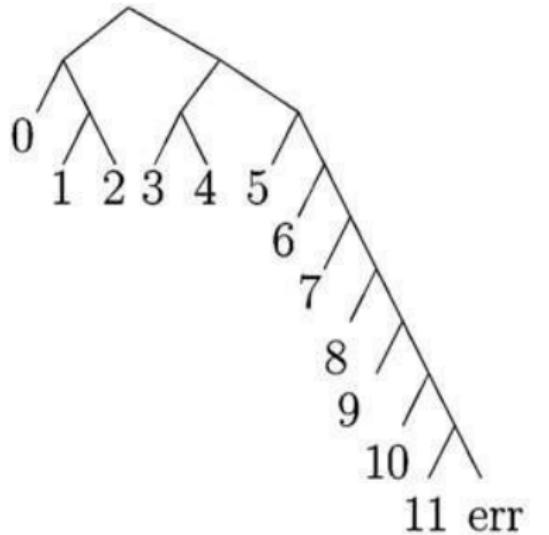


# Dekodiranje

11011001 11011010 00010111 10010100 11101011 11101011 010

(5)(25)

110 11001

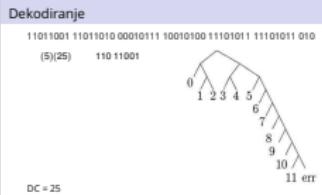


DC = 25

## Uporaba DCT v formatu JPEG

2023-09-13

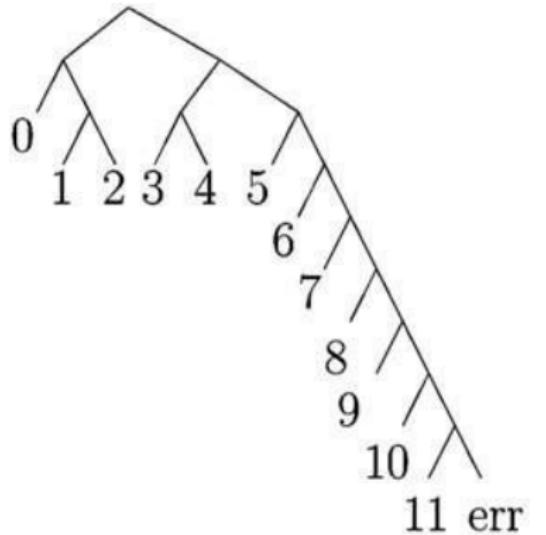
### └ Dekodiranje



# Dekodiranje

11011001 11011010 00010111 10010100 11101011 11101011 010

(5)(25)      110 11001  
                11011

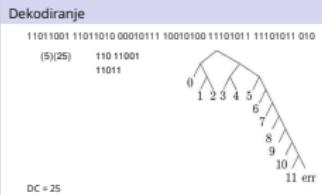


DC = 25

## Uporaba DCT v formatu JPEG

2023-09-13

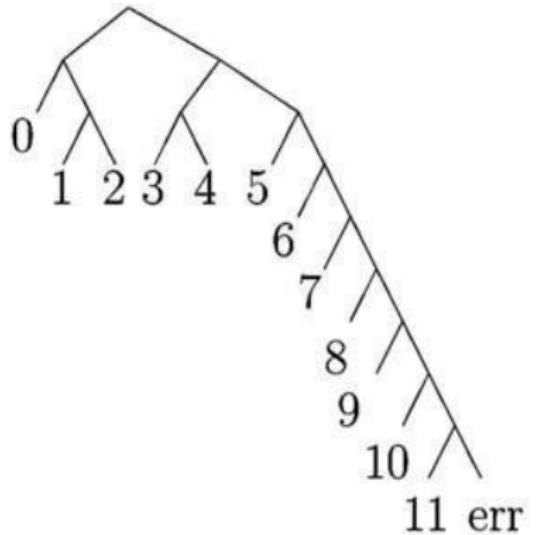
### └ Dekodiranje



# Dekodiranje

11011001 11011010 00010111 10010100 11101011 11101011 010

(5)(25)      110 11001  
(1,2)        11011

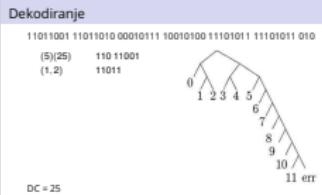


DC = 25

## Uporaba DCT v formatu JPEG

2023-09-13

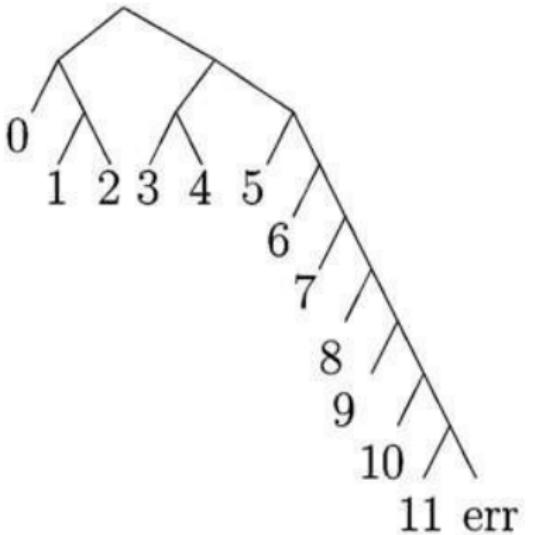
### └ Dekodiranje



# Dekodiranje

11011001 11011010 00010111 10010100 11101011 11101011 010

(5)(25) 110 11001  
(1,2) 11011 01



DC = 25

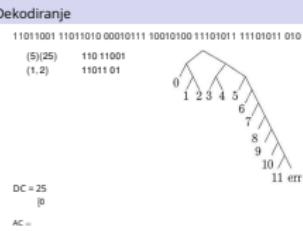
[0]

AC =

## Uporaba DCT v formatu JPEG

2023-09-13

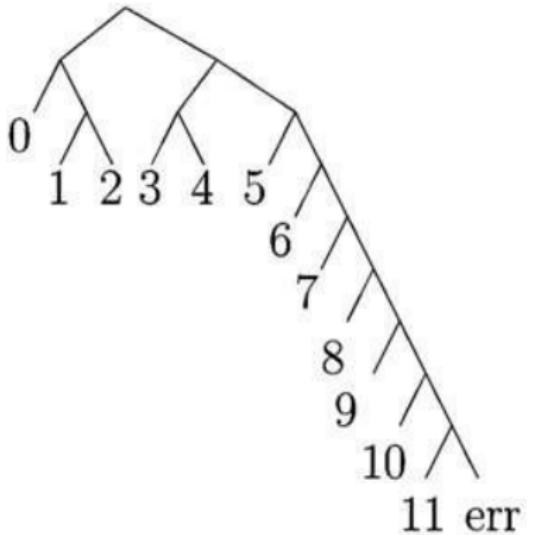
### └ Dekodiranje



# Dekodiranje

11011001 11011010 00010111 10010100 11101011 11101011 010

(5)(25) 110 11001  
(1,2)(-2) 11011 01



DC = 25

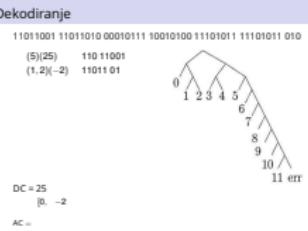
[0, -2]

AC =

## Uporaba DCT v formatu JPEG

2023-09-13

### └ Dekodiranje



# Dekodiranje

11011001 11011010 00010111 10010100 11101011 11101011 010

(5)(25) 110 11001

(1,2)(-2) 11011 01

(0,1)(-1) 00 0

(0,2)(-2) 01 01

(2,1)(1) 11100 1

(0,2)(-3) 01 00

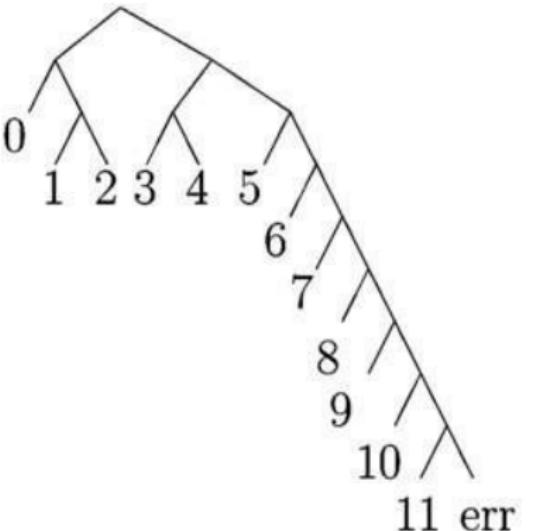
(3,1)(1) 111010 1

(5,1)(1) 1111010 1

DC = 25

[0, -2, -1, -2, 0, 0, 1, -3, 0, 0, 0, 1, 0, 0, 0, 0,  
0, 1,

AC =



2023-09-13

## Uporaba DCT v formatu JPEG

### └ Dekodiranje

Dekodiranje

11011001 11011010 00010111 10010100 11101011 11101011 010  
(5)(25) 110 11001  
(1,2)(-2) 11011 01  
(0,1)(-1) 00 0  
(0,2)(-2) 01 01  
(2,1)(1) 11100 1  
(0,2)(-3) 01 00  
(3,1)(1) 111010 1  
(5,1)(1) 1111010 1  
  
DC = 25  
[0, -2, -1, -2, 0, 0, 1, -3, 0, 0, 0, 1, 0, 0, 0, 0,  
0, 1,  
AC =

# Dekodiranje

11011001 11011010 00010111 10010100 11101011 11101011 010

(5)(25) 110 11001

(1, 2)(-2) 11011 01

(0, 1)(-1) 00 0

(0, 2)(-2) 01 01

(2, 1)(1) 11100 1

(0, 2)(-3) 01 00

(3, 1)(1) 111010 1

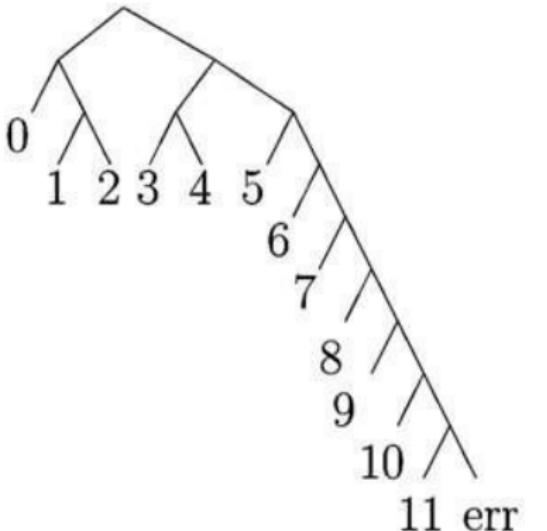
(5, 1)(1) 1111010 1

(0, 0) 1010

DC = 25

[0, -2, -1, -2, 0, 0, 1, -3, 0, 0, 0, 1, 0, 0, 0, 0,  
0, 1,

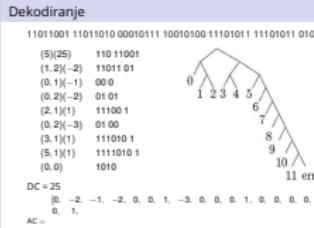
AC =



## Uporaba DCT v formatu JPEG

2023-09-13

### └ Dekodiranje



# Dekodiranje

11011001 11011010 00010111 10010100 11101011 11101011 010

(5)(25) 110 11001

(1,2)(-2) 11011 01

(0,1)(-1) 00 0

(0,2)(-2) 01 01

(2,1)(1) 11100 1

(0,2)(-3) 01 00

(3,1)(1) 111010 1

(5,1)(1) 1111010 1

(0,0) 1010

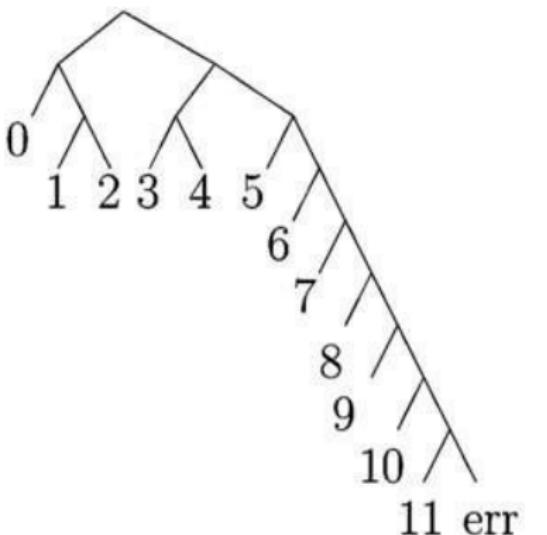
DC = 25

[0, -2, -1, -2, 0, 0, 1, -3, 0, 0, 0, 1, 0, 0, 0, 0,

0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,

AC = 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,

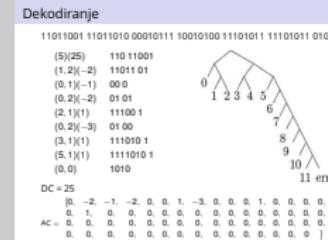
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0 ]



# Uporaba DCT v formatu JPEG

2023-09-13

## └ Dekodiranje



# Dekvantizacija

$$C^Q(\tilde{I}) = \begin{bmatrix} 25 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -2 & -2 & 1 & 0 & 0 & 0 & 0 & 0 \\ -1 & -3 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

## Uporaba DCT v formatu JPEG

2023-09-13

### └ Dekvantizacija

$$C^Q(\tilde{I}) = \begin{bmatrix} 25 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -2 & -2 & 1 & 0 & 0 & 0 & 0 & 0 \\ -1 & -3 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

# Dekvantizacija

## Uporaba DCT v formatu JPEG

2023-09-13

### └ Dekvantizacija

$$C(u, v) = C^Q(u, v) \cdot Q(u, v)$$

$$C^Q(\tilde{I}') = \begin{bmatrix} 25 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -2 & -2 & 1 & 0 & 0 & 0 & 0 & 0 \\ -1 & -3 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$C(\tilde{I}') = \begin{bmatrix} 400 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -24 & -24 & 14 & 0 & 0 & 0 & 0 & 0 \\ -14 & -39 & 16 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 22 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Dekvantizacija

$$C(u, v) = C^Q(u, v) \cdot Q(u, v)$$
$$C^Q(\tilde{I}') = \begin{bmatrix} 25 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -2 & -2 & 1 & 0 & 0 & 0 & 0 & 0 \\ -1 & -3 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$
$$C(\tilde{I}') = \begin{bmatrix} 400 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -24 & -24 & 14 & 0 & 0 & 0 & 0 & 0 \\ -14 & -39 & 16 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 22 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$f(x, y) = \sum_{u=0}^{N-1} \sum_{v=0}^{N-1} \alpha(u)\alpha(v)C(u, v) \cos\left[\frac{\pi(2x+1)u}{2N}\right] \cos\left[\frac{\pi(2y+1)v}{2N}\right],$$

$x, y = 0, 1, 2, \dots, N-1$

$$C(\tilde{I}') = \begin{bmatrix} 400 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -24 & -24 & 14 & 0 & 0 & 0 & 0 & 0 & 0 \\ -14 & -39 & 16 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 22 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$\tilde{I}' = \begin{bmatrix} 40 & 36 & 31 & 30 & 36 & 47 & 60 & 69 \\ 40 & 40 & 39 & 41 & 44 & 49 & 54 & 57 \\ 44 & 47 & 51 & 53 & 53 & 50 & 46 & 44 \\ 54 & 56 & 58 & 59 & 56 & 49 & 43 & 38 \\ 62 & 61 & 59 & 56 & 52 & 48 & 44 & 42 \\ 62 & 60 & 56 & 53 & 50 & 49 & 48 & 48 \\ 54 & 54 & 53 & 53 & 53 & 52 & 51 & 51 \\ 45 & 48 & 52 & 55 & 56 & 55 & 53 & 51 \end{bmatrix}$$

# Inverzni DCT

$$f(x, y) = \sum_{u=0}^{N-1} \sum_{v=0}^{N-1} \alpha(u)\alpha(v)C(u, v) \cos\left[\frac{\pi(2x+1)u}{2N}\right] \cos\left[\frac{\pi(2y+1)v}{2N}\right],$$

$$x, y = 0, 1, 2, \dots, N-1$$

## Uporaba DCT v formatu JPEG

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### └ Inverzni DCT

$$C(\tilde{I}') = \begin{bmatrix} 400 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -24 & -24 & 14 & 0 & 0 & 0 & 0 & 0 & 0 \\ -14 & -39 & 16 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 22 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

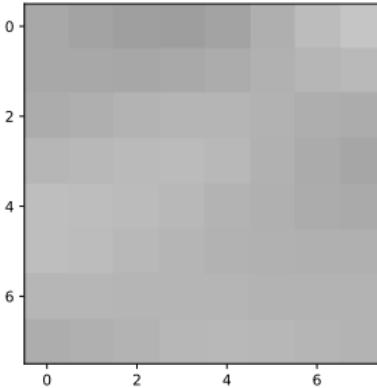
$$\tilde{I}' = \begin{bmatrix} 40 & 36 & 31 & 30 & 36 & 47 & 60 & 69 \\ 40 & 40 & 39 & 41 & 44 & 49 & 54 & 57 \\ 44 & 47 & 51 & 53 & 53 & 50 & 46 & 44 \\ 54 & 56 & 58 & 59 & 56 & 49 & 43 & 38 \\ 62 & 61 & 59 & 56 & 52 & 48 & 44 & 42 \\ 62 & 60 & 56 & 53 & 50 & 49 & 48 & 48 \\ 54 & 54 & 53 & 53 & 53 & 52 & 51 & 51 \\ 45 & 48 & 52 & 55 & 56 & 55 & 53 & 51 \end{bmatrix}$$

$$F = \begin{bmatrix} 40 & 36 & 31 & 30 & 36 & 47 & 60 & 69 \\ 40 & 40 & 39 & 41 & 44 & 49 & 54 & 57 \\ 44 & 47 & 51 & 53 & 53 & 50 & 46 & 44 \\ 54 & 56 & 58 & 59 & 56 & 49 & 43 & 38 \\ 62 & 61 & 59 & 56 & 52 & 48 & 44 & 42 \\ 62 & 60 & 56 & 53 & 50 & 49 & 48 & 48 \\ 54 & 54 & 53 & 53 & 53 & 52 & 51 & 51 \\ 45 & 48 & 52 & 55 & 56 & 55 & 53 & 51 \end{bmatrix}$$

# Primerjava blokov

## Približek originalnemu bloku

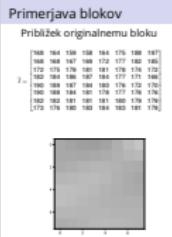
$\tilde{I} = \begin{bmatrix} 168 & 164 & 159 & 158 & 164 & 175 & 188 & 197 \\ 168 & 168 & 167 & 169 & 172 & 177 & 182 & 185 \\ 172 & 175 & 179 & 181 & 181 & 178 & 174 & 172 \\ 182 & 184 & 186 & 187 & 184 & 177 & 171 & 166 \\ 190 & 189 & 187 & 184 & 180 & 176 & 172 & 170 \\ 190 & 188 & 184 & 181 & 178 & 177 & 176 & 176 \\ 182 & 182 & 181 & 181 & 181 & 180 & 179 & 179 \\ 173 & 176 & 180 & 183 & 184 & 183 & 181 & 179 \end{bmatrix}$



## Uporaba DCT v formatu JPEG

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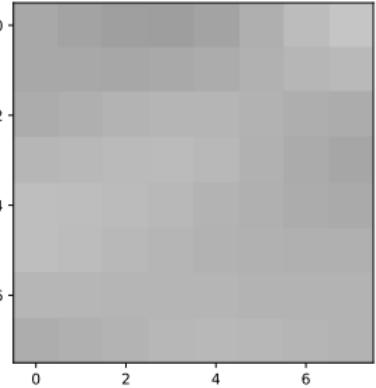
### └ Primerjava blokov



# Primerjava blokov

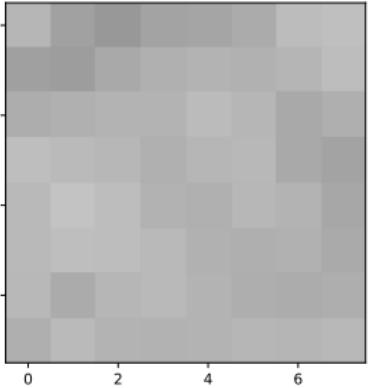
## Približek originalnemu bloku

$$\tilde{I} = \begin{bmatrix} 168 & 164 & 159 & 158 & 164 & 175 & 188 & 197 \\ 168 & 168 & 167 & 169 & 172 & 177 & 182 & 185 \\ 172 & 175 & 179 & 181 & 181 & 178 & 174 & 172 \\ 182 & 184 & 186 & 187 & 184 & 177 & 171 & 166 \\ 190 & 189 & 187 & 184 & 180 & 176 & 172 & 170 \\ 190 & 188 & 184 & 181 & 178 & 177 & 176 & 176 \\ 182 & 182 & 181 & 181 & 181 & 180 & 179 & 179 \\ 173 & 176 & 180 & 183 & 184 & 185 & 186 & 187 \end{bmatrix}$$



## Originalen blok

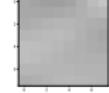
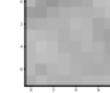
$$I = \begin{bmatrix} 182 & 161 & 152 & 164 & 165 & 171 & 188 & 191 \\ 160 & 157 & 169 & 176 & 179 & 177 & 181 & 189 \\ 173 & 176 & 179 & 180 & 187 & 182 & 169 & 175 \\ 190 & 186 & 183 & 176 & 182 & 184 & 169 & 164 \\ 185 & 195 & 189 & 178 & 176 & 183 & 180 & 167 \\ 185 & 190 & 189 & 185 & 177 & 175 & 177 & 170 \\ 184 & 171 & 182 & 185 & 180 & 174 & 172 & 174 \\ 175 & 186 & 179 & 178 & 180 & 182 & 181 & 184 \end{bmatrix}$$



## Uporaba DCT v formatu JPEG

2023-09-13

### └ Primerjava blokov

Primerjava blokov	
Približek originalnemu bloku	Originalen blok
	

# Primer slike v JPEG



peppers



peppers 5



peppers 25



peppers 50



peppers 75



peppers 95

Ime slike	velikost
peppers	769 kB
peppers 5	8 kB
peppers 25	17 kB
peppers 50	26 kB
peppers 75	41 kB
peppers 95	122 kB

2023-09-13

## Uporaba DCT v formatu JPEG

### └ Primer slike v JPEG

Primer slike v JPEG



## Problematičen primer

A large grid of 100 small, identical images, each labeled "JPEG" in black text on a white background. The images are arranged in a 10x10 pattern.

text

text 5

text 25

A large grid of 100 small, identical images arranged in a 10x10 pattern. Each individual image is a small thumbnail of a document page, showing a table with several columns and rows of text. The word "JPEG" is printed in the top-left corner of each thumbnail.

text 50

### Text 75

text 95

ime slike	velikost
text	18 kB
text 5	22 kB
text 25	44 kB
text 50	63 kB
text 75	85 kB
text 95	151 kB

2023-09-13

poraba DCT v formátu JPEG

– Problematičen primer



# Problematičen primer

JPEG      JPEG      JPEG

text      text 5      text 25

JPEG      JPEG      JPEG

text 50    text 75    text 95

Uporaba DCT v formatu JPEG

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└ Problematičen primer

Problematičen primer

JPEG      JPEG      JPEG

text      text 5      text 25

JPEG      JPEG      JPEG

text 50    text 75    text 95

Gregor Šraj

Uporaba DCT v formatu JPEG

Hvala za vašo pozornost