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1 Karnaugh maps



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KMap technique

- Aim is to have an optimal 2-level SOP (or POS) form



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- Algebraic operation used repeatedly on FPs pz and $p\bar{z}$ where p is



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- $pz + p\bar{z} = p(z + \bar{z}) = p$



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- Algebraic operation used repeatedly on FPs pz and $p\bar{z}$ where p is contained in FPs pz and $p\bar{z}$
- $pz + p\bar{z} = p(z + \bar{z}) = p$
- FPs pz and $p\bar{z}$ are *adjacent*



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- $pz + p\bar{z} = p(z + \bar{z}) = p$
- FPs pz and $p\bar{z}$ are *adjacent*
- By absorption [$p = p + p$], FPs are not exclusive

f

c, d

a, b

	00	01	11	10
00	0	1	3	2
01	4	5	7	6
11	12	13	15	14
10	8	9	11	10

$$\underbrace{\bar{a}\bar{b}\bar{c}\bar{d}}_{0000 \leftrightarrow 0} + \underbrace{\bar{a}bcd}_{0111 \leftrightarrow 7} + \underbrace{a\bar{b}\bar{c}d}_{1001 \leftrightarrow 9} +$$

$$\underbrace{a\bar{b}\bar{c}d}_{1100 \leftrightarrow 12} + \underbrace{abcd}_{1111 \leftrightarrow 15}$$

$$f = \sum_m(0, 7, 9, 12, 15)$$



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- For convenience minterms are placed on a Karnaugh map where adjacent minterms get placed in adjacent cells

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- Algebraic operation used repeatedly on FPs pz and $p\bar{z}$ where p is contained in FPs pz and $p\bar{z}$
- $pz + p\bar{z} = p(z + \bar{z}) = p$
- FPs pz and $p\bar{z}$ are *adjacent*
- By absorption [$p = p + p$], FPs are not exclusive
- For convenience minterms are placed on a Karnaugh map where adjacent minterms get placed in adjacent cells
- Enables easier identification of adjacent FPs for simplification

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	00	01	11	10
00	0	1	3	2
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$$f = \sum_m(0, 7, 9, 12, 15)$$



$$f = \underbrace{\bar{a}\bar{b}\bar{c}\bar{d}}_{0000 \leftrightarrow 0} + \underbrace{\bar{a}bcd}_{0111 \leftrightarrow 7} + \underbrace{a\bar{b}\bar{c}d}_{1001 \leftrightarrow 9} + \underbrace{ab\bar{c}\bar{d}}_{1100 \leftrightarrow 12} + \underbrace{abcd}_{1111 \leftrightarrow 15}$$

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a, b

	00	01	11	10
00	0	1	3	2
01	4	5	7	6
11	12	13	15	14
10	8	9	11	10

$$f = \underline{\hspace{1cm}} + \underline{\hspace{1cm}} + \underline{\hspace{1cm}} + \underline{\hspace{1cm}}$$



$$f = \underbrace{\bar{a}\bar{b}\bar{c}\bar{d}}_{0000 \leftrightarrow 0} + \underbrace{\bar{a}bcd}_{0111 \leftrightarrow 7} + \underbrace{a\bar{b}\bar{c}d}_{1001 \leftrightarrow 9} + \underbrace{ab\bar{c}\bar{d}}_{1100 \leftrightarrow 12} + \underbrace{abcd}_{1111 \leftrightarrow 15}$$

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	00	01	11	10
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$$f = \underline{bcd} + \underline{\hspace{1cm}} + \underline{\hspace{1cm}} + \underline{\hspace{1cm}}$$



$$f = \underbrace{\bar{a}\bar{b}\bar{c}\bar{d}}_{0000 \leftrightarrow 0} + \underbrace{\bar{a}bcd}_{0111 \leftrightarrow 7} + \underbrace{a\bar{b}\bar{c}d}_{1001 \leftrightarrow 9} + \underbrace{ab\bar{c}\bar{d}}_{1100 \leftrightarrow 12} + \underbrace{abcd}_{1111 \leftrightarrow 15}$$

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01	4	5	7	6
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$$f = \underline{bcd} + \underline{ab\bar{c}\bar{d}} + \underline{\hspace{1cm}} + \underline{\hspace{1cm}}$$



$$f = \underbrace{\bar{a}\bar{b}\bar{c}\bar{d}}_{0000 \leftrightarrow 0} + \underbrace{\bar{a}bcd}_{0111 \leftrightarrow 7} + \underbrace{a\bar{b}\bar{c}d}_{1001 \leftrightarrow 9} + \underbrace{ab\bar{c}\bar{d}}_{1100 \leftrightarrow 12} + \underbrace{abcd}_{1111 \leftrightarrow 15}$$

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c, d

a, b

	00	01	11	10
00	0	1	3	2
01	4	5	7	6
11	12	13	15	14
10	8	9	11	10

$$f = \underline{bcd} + \underline{ab\bar{c}\bar{d}} + \underline{a\bar{b}\bar{c}d} + \underline{\hspace{2cm}}$$



$$f = \underbrace{\bar{a}\bar{b}\bar{c}\bar{d}}_{0000 \leftrightarrow 0} + \underbrace{\bar{a}bcd}_{0111 \leftrightarrow 7} + \underbrace{a\bar{b}\bar{c}d}_{1001 \leftrightarrow 9} + \underbrace{ab\bar{c}\bar{d}}_{1100 \leftrightarrow 12} + \underbrace{abcd}_{1111 \leftrightarrow 15}$$

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c, d

a, b

	00	01	11	10
00	0	1	3	2
01	4	5	7	6
11	12	13	15	14
10	8	9	11	10

$$f = \underbrace{bcd}_{\text{blue}} + \underbrace{a\bar{b}\bar{c}\bar{d}}_{\text{red}} + \underbrace{a\bar{b}\bar{c}d}_{\text{orange}} + \underbrace{\bar{a}\bar{b}\bar{c}\bar{d}}_{\text{teal}}$$



$$f(a, b, c, d) = \sum_m (0, 1, 2, 4, 5, 6, 8, 9, 12, 13, 14)$$

f

a, b

c, d

00	0	1	3	2
01	4	5	7	6
11	12	13	15	14
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f

a, b

c, d

	00	01	11	10
00	0	1	3	2
01	4	5	7	6
11	12	13	15	14
10	8	9	11	10



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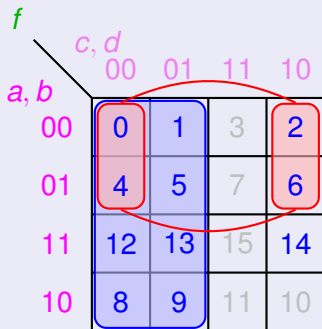
f

a, b

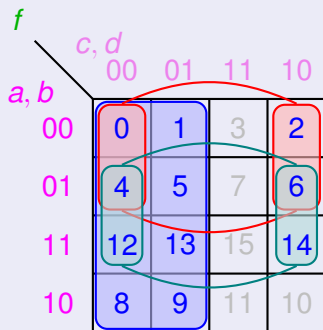
c, d

	00	01	11	10
00	0	1	3	2
01	4	5	7	6
11	12	13	15	14
10	8	9	11	10

$$f(a, b, c, d) = \sum_m (0, 1, 2, 4, 5, 6, 8, 9, 12, 13, 14)$$



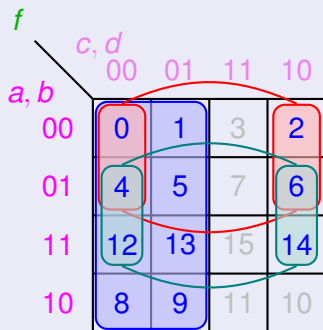
$$f(a, b, c, d) = \sum_m (0, 1, 2, 4, 5, 6, 8, 9, 12, 13, 14)$$



$$f = \underline{\quad} + \underline{\quad} + \underline{\quad}$$



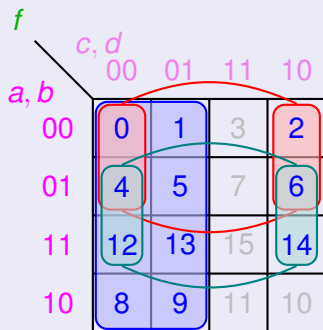
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$$f = \bar{c} + \text{---} + \text{---}$$



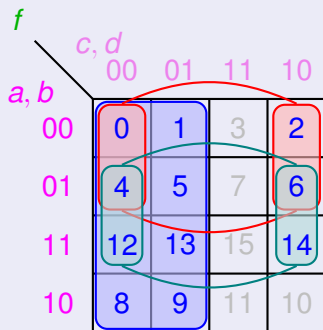
$$f(a, b, c, d) = \sum_m (0, 1, 2, 4, 5, 6, 8, 9, 12, 13, 14)$$



$$f = \underline{\bar{c}} + \underline{\bar{a}\bar{d}} + \underline{\quad}$$



$$f(a, b, c, d) = \sum_m (0, 1, 2, 4, 5, 6, 8, 9, 12, 13, 14)$$



$$f = \bar{c} + \bar{a}\bar{d} + b\bar{d}$$



$$f(a, b, c, d) = \sum_m (0, 5, 7, 8, 11, 13, 14, 15)$$

f

a, b

c, d

	00	01	11	10
00	0	1	3	2
01	4	5	7	6
11	12	13	15	14
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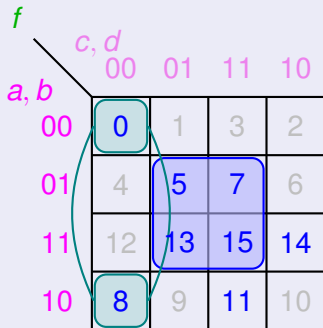
f

a, b

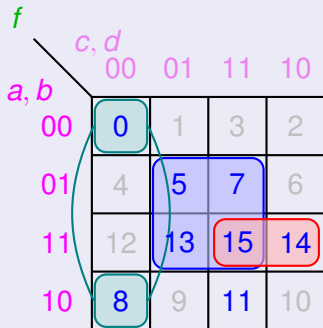
c, d

00	0	1	3	2
01	4	5	7	6
11	12	13	15	14
10	8	9	11	10

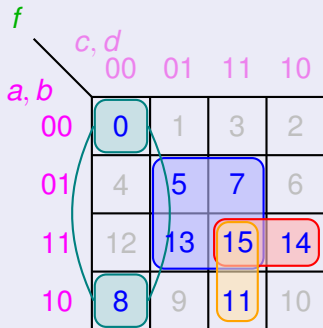
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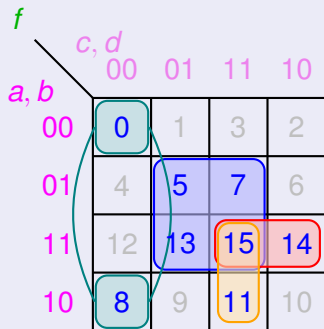
$$f(a, b, c, d) = \sum_m (0, 5, 7, 8, 11, 13, 14, 15)$$



$$f = \text{blue} + \text{red} + \text{yellow} + \text{green}$$



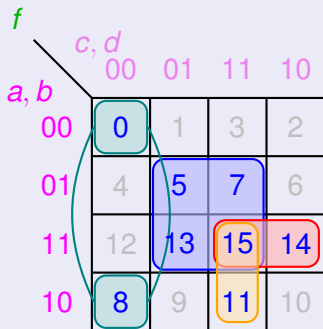
$$f(a, b, c, d) = \sum_m (0, 5, 7, 8, 11, 13, 14, 15)$$



$$f = \underline{bd} + \underline{\quad} + \underline{\quad} + \underline{\quad}$$



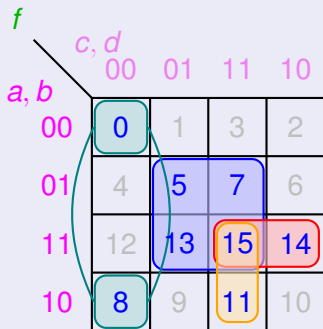
$$f(a, b, c, d) = \sum_m (0, 5, 7, 8, 11, 13, 14, 15)$$



$$f = \underline{bd} + \underline{abc} + \underline{\quad} + \underline{\quad}$$



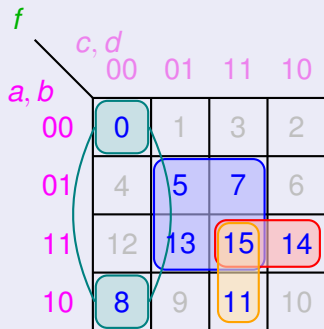
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$$f = \underline{bd} + \underline{abc} + \underline{acd} + \underline{\quad}$$



$$f(a, b, c, d) = \sum_m (0, 5, 7, 8, 11, 13, 14, 15)$$



$$f = \underline{bd} + \underline{abc} + \underline{acd} + \underline{\bar{b}\bar{c}\bar{d}}$$



$$f(a, b, c, d, e) = \sum_m (0, 1, 2, 7, 8, 9, 10, 15, 16, 17, 18, 24, 25, 26, 28, 30)$$

f

c, d, e

a, b

	000	001	011	010	110	111	101	100
00								
01								
11								
10								

$$f(a, b, c, d, e) = \sum_m (0, 1, 2, 7, 8, 9, 10, 15, 16, 17, 18, 24, 25, 26, 28, 30)$$

f

c, d, e

a, b

	000	001	011	010	110	111	101	100
00	0	1	3	2	6	7	5	4
01	8	9	11	10	14	15	13	12
11	24	25	27	26	30	31	29	28
10	16	17	19	18	22	23	21	20

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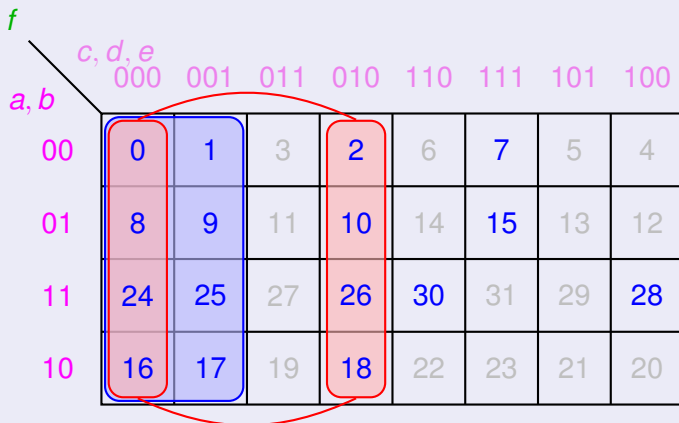
f

c, d, e

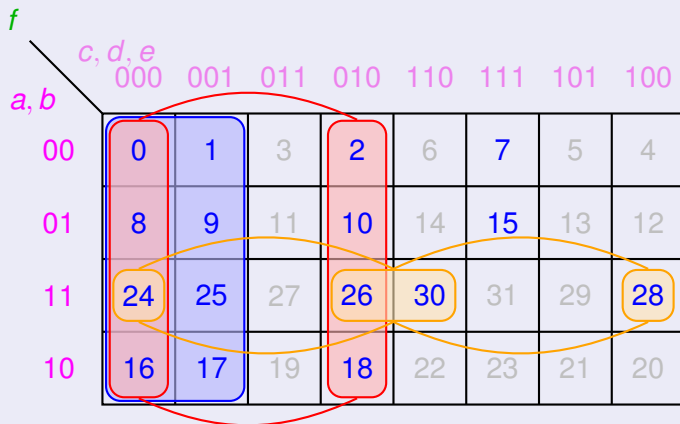
a, b

	000	001	011	010	110	111	101	100
00	0	1	3	2	6	7	5	4
01	8	9	11	10	14	15	13	12
11	24	25	27	26	30	31	29	28
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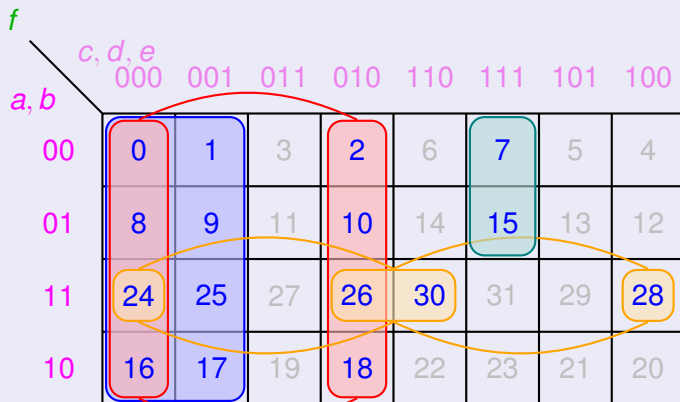
$$f(a, b, c, d, e) = \sum_m (0, 1, 2, 7, 8, 9, 10, 15, 16, 17, 18, 24, 25, 26, 28, 30)$$



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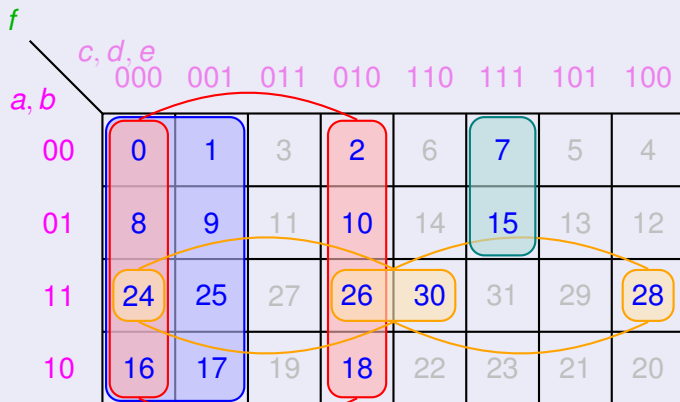
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$f = \text{---} + \text{---} + \text{---} + \text{---}$



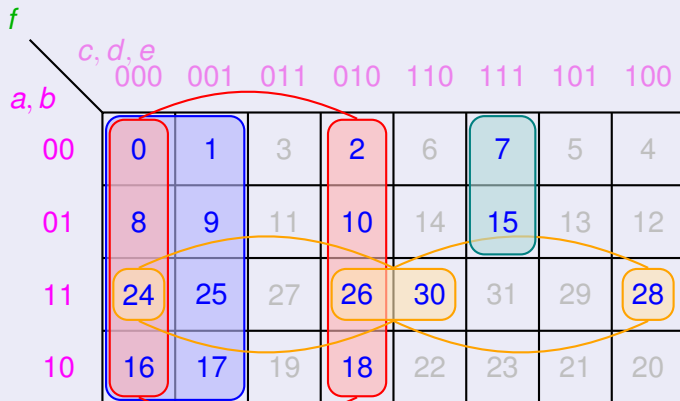
$$f(a, b, c, d, e) = \sum_m (0, 1, 2, 7, 8, 9, 10, 15, 16, 17, 18, 24, 25, 26, 28, 30)$$



$$f = \bar{c}\bar{d} + \text{---} + \text{---} + \text{---}$$



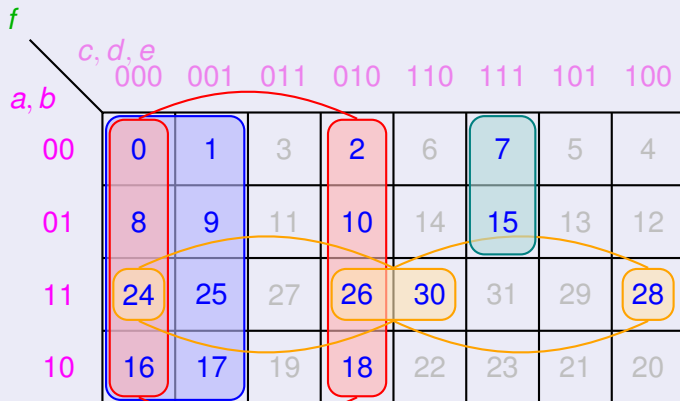
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$$f = \bar{c}\bar{d} + \bar{e}\bar{c} + \text{_____} + \text{_____}$$



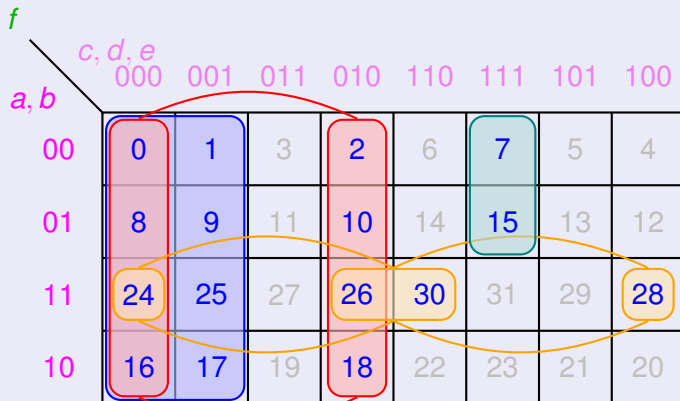
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$$f = \bar{c}\bar{d} + \bar{e}\bar{c} + ab\bar{e} + \underline{\hspace{1cm}}$$



$$f(a, b, c, d, e) = \sum_m (0, 1, 2, 7, 8, 9, 10, 15, 16, 17, 18, 24, 25, 26, 28, 30)$$



$$f = \bar{c}\bar{d} + \bar{e}\bar{c} + ab\bar{e} + \bar{a}cde$$



$$f(a, b, c, d, e) = \sum_m (3, 6, 7, 8, 10, 12, 14, 17, 20, 21, 24, 25, 27, 28) + \sum_d (0, 1, 18, 19, 31)$$

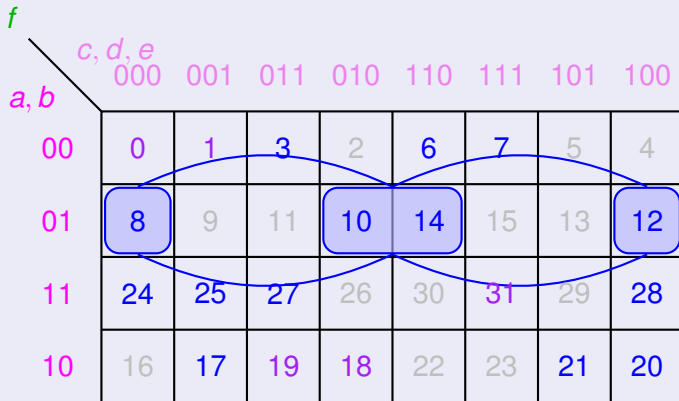
f

c, d, e

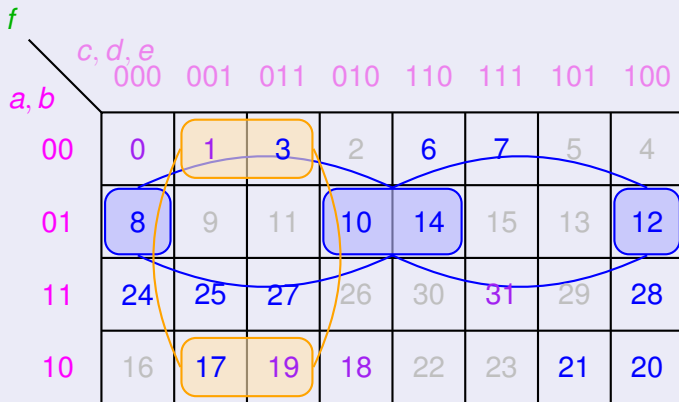
a, b

	000	001	011	010	110	111	101	100
00	0	1	3	2	6	7	5	4
01	8	9	11	10	14	15	13	12
11	24	25	27	26	30	31	29	28
10	16	17	19	18	22	23	21	20

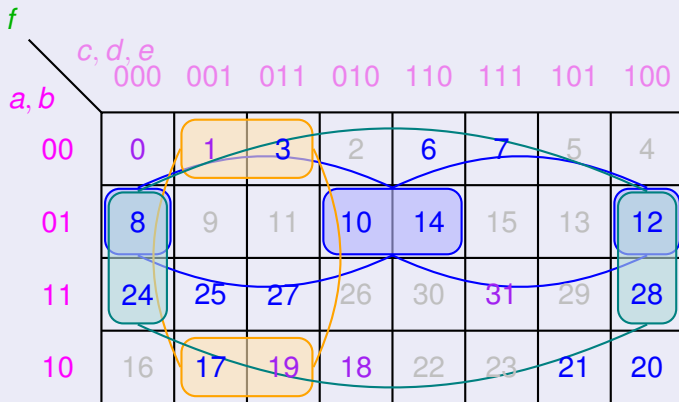
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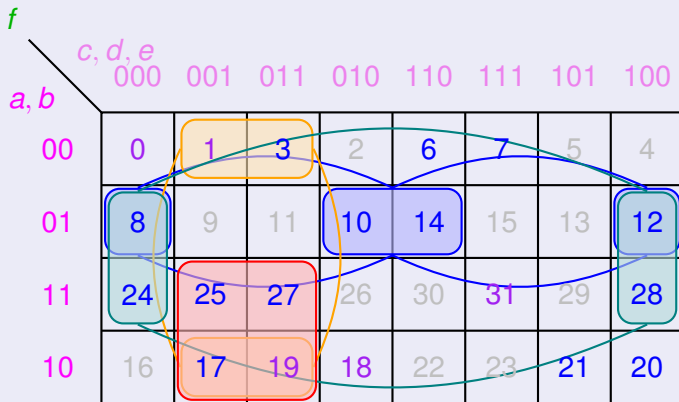
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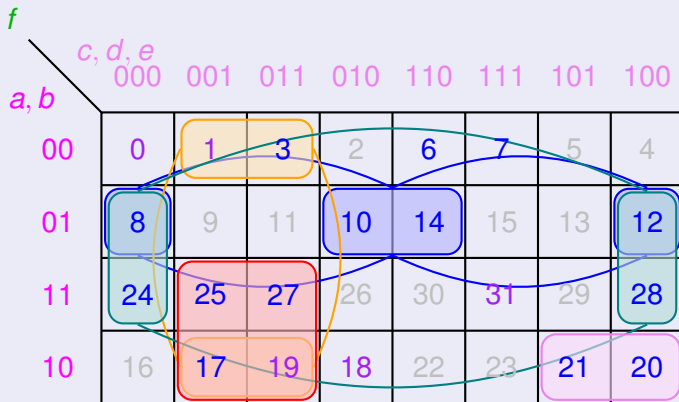
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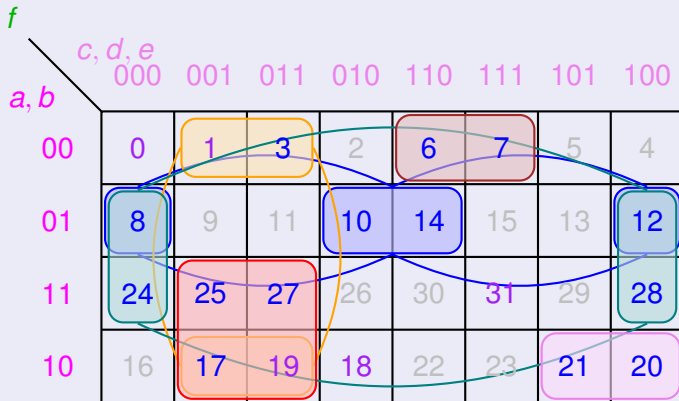
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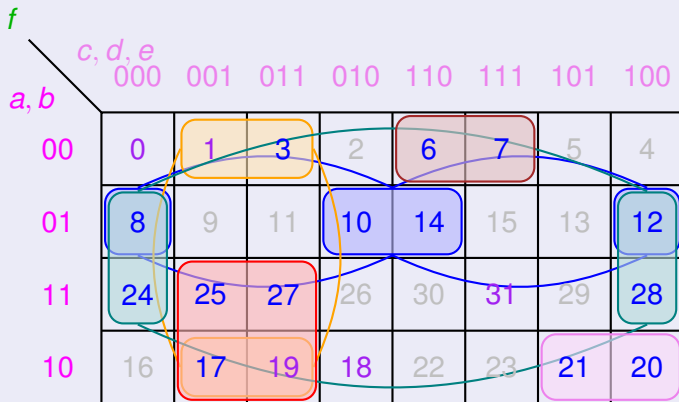


$$f(a, b, c, d, e) = \sum_m (3, 6, 7, 8, 10, 12, 14, 17, 20, 21, 24, 25, 27, 28) + \sum_d (0, 1, 18, 19, 31)$$



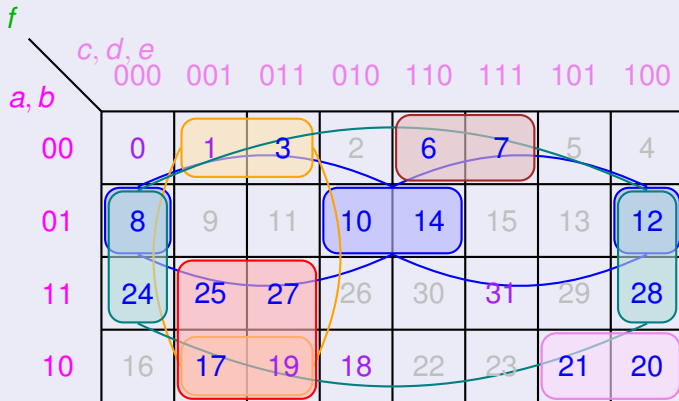
$$f = \text{---} + \text{---} + \text{---} + \text{---} + \text{---} + \text{---}$$

$$f(a, b, c, d, e) = \sum_m (3, 6, 7, 8, 10, 12, 14, 17, 20, 21, 24, 25, 27, 28) + \sum_d (0, 1, 18, 19, 31)$$



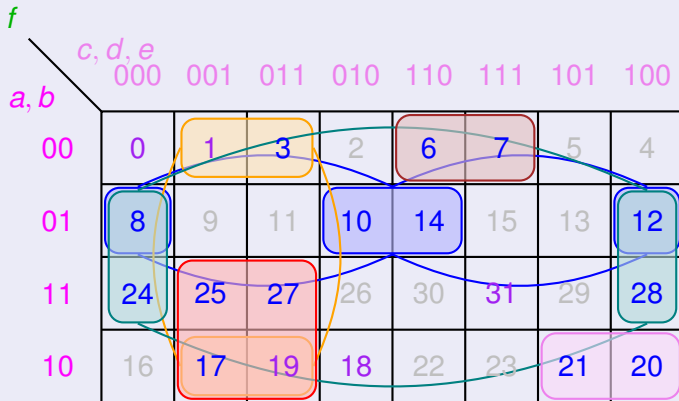
$$f = \underline{\bar{a}b\bar{e}} + \text{orange} + \text{yellow} + \text{teal} + \text{blue} + \text{pink}$$

$$f(a, b, c, d, e) = \sum_m (3, 6, 7, 8, 10, 12, 14, 17, 20, 21, 24, 25, 27, 28) + \sum_d (0, 1, 18, 19, 31)$$



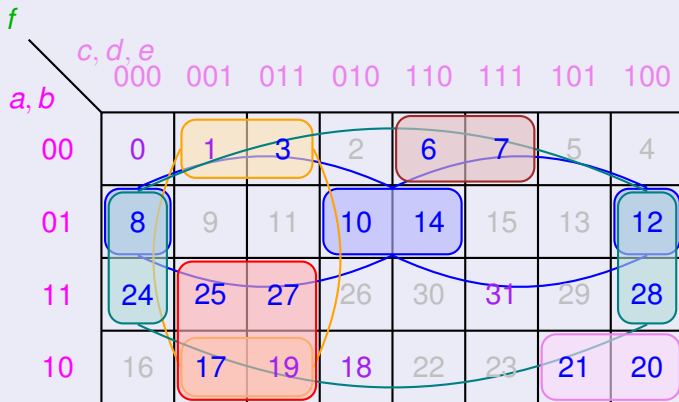
$$f = \underline{\bar{a}b\bar{e}} + \underline{a\bar{c}e} + \underline{\quad} + \underline{\quad} + \underline{\quad} + \underline{\quad}$$

$$f(a, b, c, d, e) = \sum_m (3, 6, 7, 8, 10, 12, 14, 17, 20, 21, 24, 25, 27, 28) + \sum_d (0, 1, 18, 19, 31)$$



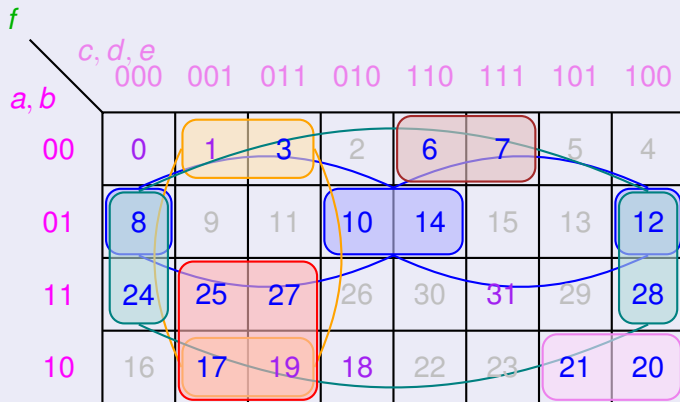
$$f = \underline{\bar{a}}\underline{\bar{b}}\underline{\bar{e}} + \underline{a}\underline{\bar{c}}\underline{e} + \underline{\bar{b}}\underline{\bar{c}}\underline{e} + \underline{\hspace{1cm}} + \underline{\hspace{1cm}} + \underline{\hspace{1cm}}$$

$$f(a, b, c, d, e) = \sum_m (3, 6, 7, 8, 10, 12, 14, 17, 20, 21, 24, 25, 27, 28) + \sum_d (0, 1, 18, 19, 31)$$



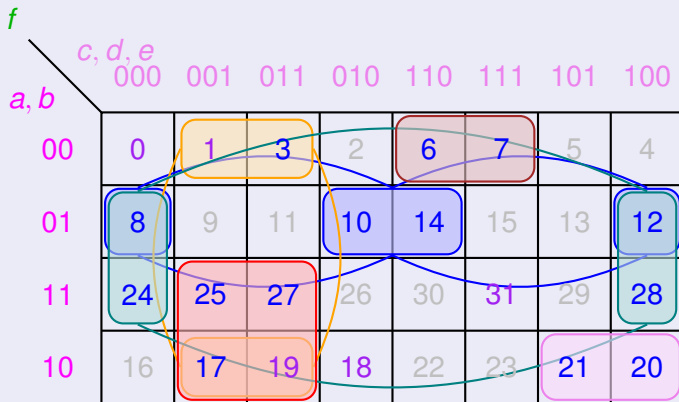
$$f = \underline{\bar{a}}\underline{\bar{b}}\underline{\bar{e}} + \underline{a}\underline{\bar{c}}\underline{e} + \underline{\bar{b}}\underline{\bar{c}}\underline{e} + \underline{b}\underline{\bar{d}}\underline{\bar{e}} + \underline{\quad} + \underline{\quad}$$

$$f(a, b, c, d, e) = \sum_m (3, 6, 7, 8, 10, 12, 14, 17, 20, 21, 24, 25, 27, 28) + \sum_d (0, 1, 18, 19, 31)$$



$$f = \underline{\bar{a}b\bar{e}} + \underline{a\bar{c}e} + \underline{\bar{b}\bar{c}e} + \underline{b\bar{d}\bar{e}} + \underline{a\bar{b}c\bar{d}} + \underline{\hspace{1cm}}$$

$$f(a, b, c, d, e) = \sum_m (3, 6, 7, 8, 10, 12, 14, 17, 20, 21, 24, 25, 27, 28) + \sum_d (0, 1, 18, 19, 31)$$



$$f = \underline{\bar{a}b\bar{e}} + \underline{a\bar{c}e} + \underline{\bar{b}\bar{c}e} + \underline{b\bar{d}\bar{e}} + \underline{a\bar{b}c\bar{d}} + \underline{\bar{a}\bar{b}cd}$$

$$f(a, b, c, d, e) = \sum_m (0, 2, 3, 4, 5, 6, 7, 11, 15, 16, 18, 19, 23, 27, 31) + \sum_d (1, 9, 24, 30)$$

f

c, d, e

a, b

	000	001	011	010	110	111	101	100
00	0	1	3	2	6	7	5	4
01	8	9	11	10	14	15	13	12
11	24	25	27	26	30	31	29	28
10	16	17	19	18	22	23	21	20

$$f(a, b, c, d, e) = \sum_m (0, 2, 3, 4, 5, 6, 7, 11, 15, 16, 18, 19, 23, 27, 31) + \sum_d (1, 9, 24, 30)$$

f

c, d, e

a, b

	000	001	011	010	110	111	101	100
00	0	1	3	2	6	7	5	4
01	8	9	11	10	14	15	13	12
11	24	25	27	26	30	31	29	28
10	16	17	19	18	22	23	21	20

$$f(a, b, c, d, e) = \sum_m (0, 2, 3, 4, 5, 6, 7, 11, 15, 16, 18, 19, 23, 27, 31) + \sum_d (1, 9, 24, 30)$$

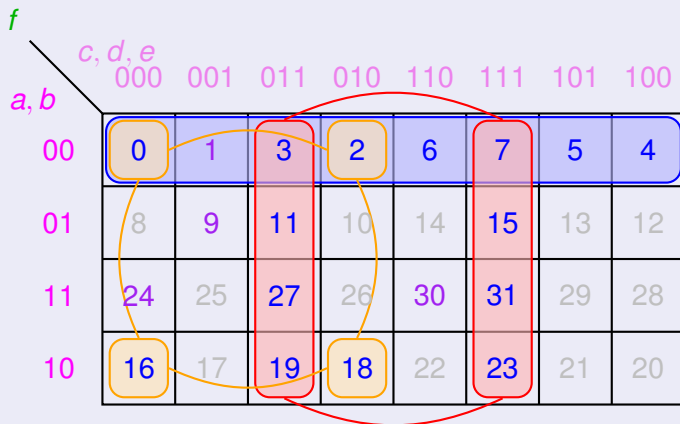
f

c, d, e

a, b

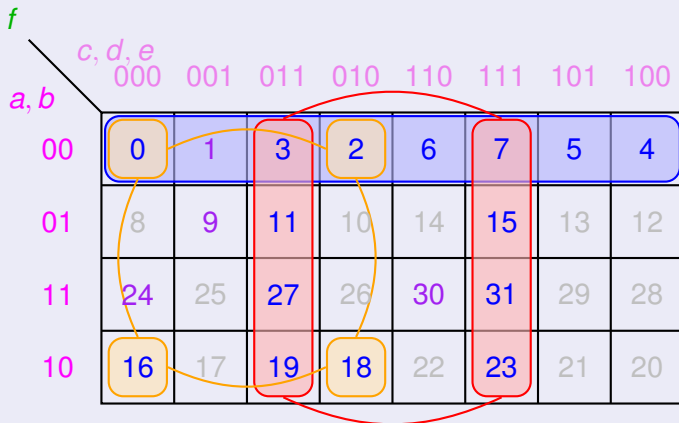
	000	001	011	010	110	111	101	100
00	0	1	3	2	6	7	5	4
01	8	9	11	10	14	15	13	12
11	24	25	27	26	30	31	29	28
10	16	17	19	18	22	23	21	20

$$f(a, b, c, d, e) = \sum_m (0, 2, 3, 4, 5, 6, 7, 11, 15, 16, 18, 19, 23, 27, 31) + \sum_d (1, 9, 24, 30)$$



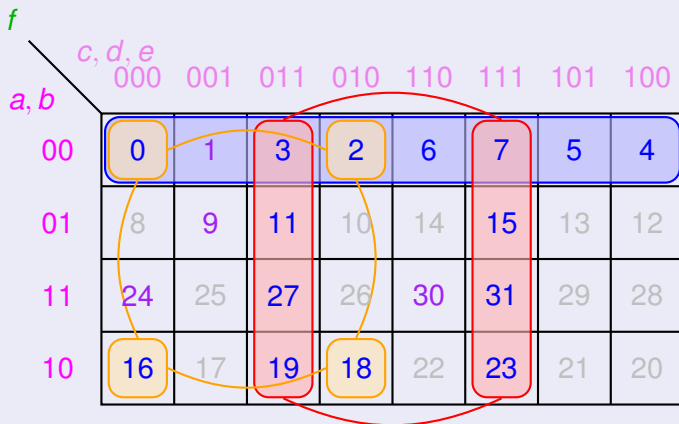
f = + +

$$f(a, b, c, d, e) = \sum_m (0, 2, 3, 4, 5, 6, 7, 11, 15, 16, 18, 19, 23, 27, 31) + \sum_d (1, 9, 24, 30)$$



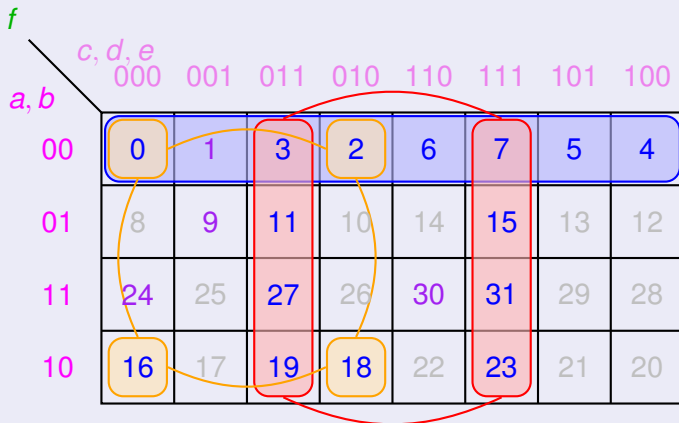
$$f = \bar{a}\bar{b} + \quad +$$

$$f(a, b, c, d, e) = \sum_m (0, 2, 3, 4, 5, 6, 7, 11, 15, 16, 18, 19, 23, 27, 31) + \sum_d (1, 9, 24, 30)$$



$$f = \underline{\bar{a}\bar{b}} + \underline{de} +$$

$$f(a, b, c, d, e) = \sum_m (0, 2, 3, 4, 5, 6, 7, 11, 15, 16, 18, 19, 23, 27, 31) + \sum_d (1, 9, 24, 30)$$



$$f = \bar{a}\bar{b} + \underline{de} + \underline{\bar{b}\bar{c}\bar{e}}$$

$$f(a, b, c, d, e, f) =$$

$$\sum_m \left(\begin{array}{l} 0, 2, 4, 8, 10, 13, 15, 16, 18, 20, 23, 24, 26, 32, 34, 40, 41, 42, 45, 47, 48, \\ 50, 56, 57, 58, 60, 61 \end{array} \right)$$

g

d, e, f

a, b, c

000	0	1	3	2	6	7	5	4
001	8	9	11	10	14	15	13	12
011	24	25	27	26	30	31	29	28
010	16	17	19	18	22	23	21	20
110	48	49	51	50	54	55	53	52
111	56	57	59	58	62	63	61	60
101	40	41	43	42	46	47	45	44
100	32	33	35	34	38	39	37	36

$$g = \text{---} + \text{---} + \text{---} + \text{---} + \text{---} + \text{---}$$

$$f(a, b, c, d, e, f) =$$

$$\sum_m \left(\begin{array}{l} 0, 2, 4, 8, 10, 13, 15, 16, 18, 20, 23, 24, 26, 32, 34, 40, 41, 42, 45, 47, 48, \\ 50, 56, 57, 58, 60, 61 \end{array} \right)$$

g

d, e, f

a, b, c

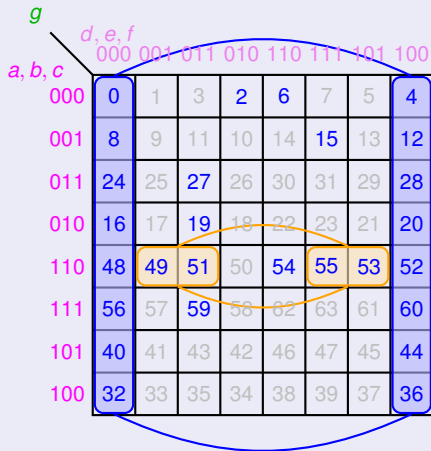
000	0	1	3	2	6	7	5	4
001	8	9	11	10	14	15	13	12
011	24	25	27	26	30	31	29	28
010	16	17	19	18	22	23	21	20
110	48	49	51	50	54	55	53	52
111	56	57	59	58	62	63	61	60
101	40	41	43	42	46	47	45	44
100	32	33	35	34	38	39	37	36

Diagram showing a Karnaugh map for function $f(a, b, c, d, e, f)$. The map is a 8x8 grid with rows labeled a, b, c (000 to 100) and columns labeled d, e, f (000 to 100). The cells contain values from 0 to 63. A blue circle highlights the cells 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44, 46, 48, 50, 52, 54, 56, 58, 60, 62, which are the minterms where d, e, f are all 0 or all 1. A blue line connects the top-left corner (000) to the bottom-right corner (100), indicating a wrap-around.

$$g = \bar{e}\bar{f} + \text{---} + \text{---} + \text{---} + \text{---} + \text{---}$$

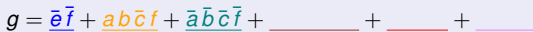
$$f(a, b, c, d, e, f) =$$

$$\sum_m \left(\begin{array}{l} 0, 2, 4, 8, 10, 13, 15, 16, 18, 20, 23, 24, 26, 32, 34, 40, 41, 42, 45, 47, 48, \\ 50, 56, 57, 58, 60, 61 \end{array} \right)$$



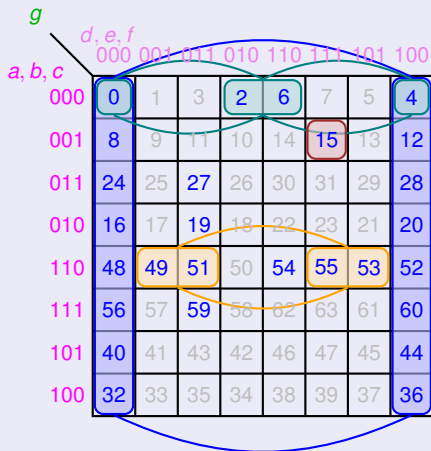
$$g = \bar{e}\bar{f} + ab\bar{c}f + \text{_____} + \text{_____} + \text{_____} + \text{_____}$$

$$\sum_m \binom{0, 2, 4, 8, 10, 13, 15, 16, 18, 20, 23, 24, 26, 32, 34, 40, 41, 42, 45, 47, 48, 50, 56, 57, 58, 60, 61}{m}$$



$$f(a, b, c, d, e, f) =$$

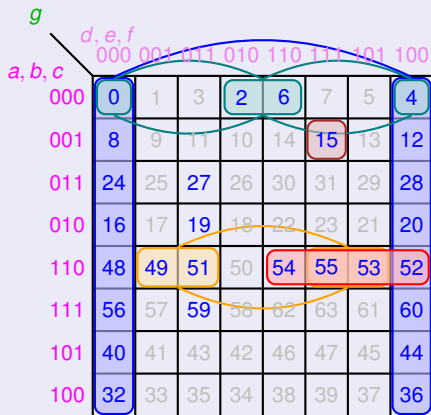
$$\sum_m \left(\begin{array}{l} 0, 2, 4, 8, 10, 13, 15, 16, 18, 20, 23, 24, 26, 32, 34, 40, 41, 42, 45, 47, 48, \\ 50, 56, 57, 58, 60, 61 \end{array} \right)$$



$$g = \bar{e}\bar{f} + ab\bar{c}f + \bar{a}\bar{b}\bar{c}\bar{f} + \bar{a}\bar{b}cdef + \underline{\hspace{1cm}} + \underline{\hspace{1cm}}$$

$$f(a, b, c, d, e, f) =$$

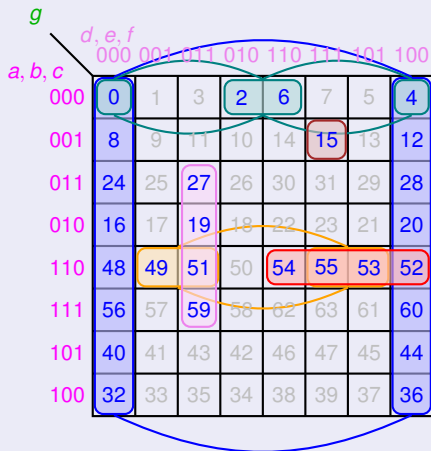
$$\sum_m \left(\begin{array}{l} 0, 2, 4, 8, 10, 13, 15, 16, 18, 20, 23, 24, 26, 32, 34, 40, 41, 42, 45, 47, 48, \\ 50, 56, 57, 58, 60, 61 \end{array} \right)$$



$$g = \bar{e}\bar{f} + ab\bar{c}f + \bar{a}\bar{b}\bar{c}\bar{f} + \bar{a}\bar{b}cdef + ab\bar{c}d + \underline{\hspace{2cm}}$$

$$f(a, b, c, d, e, f) =$$

$$\sum_m \left(\begin{array}{l} 0, 2, 4, 8, 10, 13, 15, 16, 18, 20, 23, 24, 26, 32, 34, 40, 41, 42, 45, 47, 48, \\ 50, 56, 57, 58, 60, 61 \end{array} \right)$$



$$f = \left\{ \begin{array}{c} \underbrace{(a+b+\bar{c}+\bar{d})}_{0011 \leftrightarrow 3} \cdot \underbrace{(a+\bar{b}+c+d)}_{0100 \leftrightarrow 4} \cdot \underbrace{(a+\bar{b}+\bar{c}+d)}_{0110 \leftrightarrow 6} \cdot \underbrace{(a+\bar{b}+\bar{c}+\bar{d})}_{0111 \leftrightarrow 7} \cdot \underbrace{(\bar{a}+b+\bar{c}+\bar{d})}_{1011 \leftrightarrow 11} \\ \underbrace{(\bar{a}+\bar{b}+c+d)}_{1100 \leftrightarrow 12} \cdot \underbrace{(\bar{a}+\bar{b}+c+\bar{d})}_{1101 \leftrightarrow 13} \cdot \underbrace{(\bar{a}+\bar{b}+\bar{c}+d)}_{1110 \leftrightarrow 14} \cdot \underbrace{(\bar{a}+\bar{b}+\bar{c}+\bar{d})}_{1111 \leftrightarrow 15} \end{array} \right.$$

- Direct minimisation: $(s+x)(s+\bar{x}) = s$

NB Literals in a minterm and the corresponding maxterm are complemented

f

	<i>c, d</i>	00	01	11	10
<i>a, b</i>	00	0	1	3	2
	01	4	5	7	6
	11	12	13	15	14
	10	8	9	11	10

$$f = \left\{ \begin{array}{c} \underbrace{(a+b+\bar{c}+\bar{d})}_{0011 \leftrightarrow 3} \cdot \underbrace{(a+\bar{b}+c+d)}_{0100 \leftrightarrow 4} \cdot \underbrace{(a+\bar{b}+\bar{c}+d)}_{0110 \leftrightarrow 6} \cdot \underbrace{(a+\bar{b}+\bar{c}+\bar{d})}_{0111 \leftrightarrow 7} \cdot \underbrace{(\bar{a}+b+\bar{c}+\bar{d})}_{1011 \leftrightarrow 11} \\ \underbrace{(\bar{a}+\bar{b}+c+d)}_{1100 \leftrightarrow 12} \cdot \underbrace{(\bar{a}+\bar{b}+c+\bar{d})}_{1101 \leftrightarrow 13} \cdot \underbrace{(\bar{a}+\bar{b}+\bar{c}+d)}_{1110 \leftrightarrow 14} \cdot \underbrace{(\bar{a}+\bar{b}+\bar{c}+\bar{d})}_{1111 \leftrightarrow 15} \end{array} \right.$$

- Direct minimisation: $(s+x)(s+\bar{x}) = s$
- Minimising via \bar{f}

NB Literals in a minterm and the corresponding maxterm are complemented

f

	<i>c, d</i>	00	01	11	10
<i>a, b</i>	00	0	1	3	2
	01	4	5	7	6
	11	12	13	15	14
	10	8	9	11	10

$$f = \left\{ \begin{array}{c} \underbrace{(a+b+\bar{c}+\bar{d})}_{0011 \leftrightarrow 3} \cdot \underbrace{(a+\bar{b}+c+d)_{0100 \leftrightarrow 4}} \cdot \underbrace{(a+\bar{b}+\bar{c}+d)_{0110 \leftrightarrow 6}} \cdot \underbrace{(a+\bar{b}+\bar{c}+\bar{d})_{0111 \leftrightarrow 7}} \cdot \underbrace{(\bar{a}+b+\bar{c}+\bar{d})_{1011 \leftrightarrow 11}} \\ \underbrace{(\bar{a}+\bar{b}+c+d)_{1100 \leftrightarrow 12}} \cdot \underbrace{(\bar{a}+\bar{b}+c+\bar{d})_{1101 \leftrightarrow 13}} \cdot \underbrace{(\bar{a}+\bar{b}+\bar{c}+d)_{1110 \leftrightarrow 14}} \cdot \underbrace{(\bar{a}+\bar{b}+\bar{c}+\bar{d})_{1111 \leftrightarrow 15}} \end{array} \right.$$

- Direct minimisation: $(s+x)(s+\bar{x}) = s$
- Minimising via \bar{f}
- Cover is obtained where f is false

NB Literals in a minterm and the corresponding maxterm are complemented

f

	<i>c, d</i>	00	01	11	10
<i>a, b</i>	00	0	1	3	2
	01	4	5	7	6
	11	12	13	15	14
	10	8	9	11	10

$$f = \left\{ \begin{array}{c} \underbrace{(a+b+\bar{c}+\bar{d})}_{0011 \leftrightarrow 3} \cdot \underbrace{(a+\bar{b}+c+d)_{0100 \leftrightarrow 4}} \cdot \underbrace{(a+\bar{b}+\bar{c}+d)_{0110 \leftrightarrow 6}} \cdot \underbrace{(a+\bar{b}+\bar{c}+\bar{d})_{0111 \leftrightarrow 7}} \cdot \underbrace{(\bar{a}+b+\bar{c}+\bar{d})_{1011 \leftrightarrow 11}} \\ \underbrace{(\bar{a}+\bar{b}+c+d)_{1100 \leftrightarrow 12}} \cdot \underbrace{(\bar{a}+\bar{b}+c+\bar{d})_{1101 \leftrightarrow 13}} \cdot \underbrace{(\bar{a}+\bar{b}+\bar{c}+d)_{1110 \leftrightarrow 14}} \cdot \underbrace{(\bar{a}+\bar{b}+\bar{c}+\bar{d})_{1111 \leftrightarrow 15}} \end{array} \right.$$

- Direct minimisation: $(s + x)(s + \bar{x}) = s$
- Minimising via \bar{f}
- Cover is obtained where f is false
- $f = m_0 + m_1 + m_2 + m_5 + m_8 + m_9 + m_{10}$

NB Literals in a minterm and the corresponding maxterm are complemented

f

	c, d	00	01	11	10
a, b	00	0	1	3	2
	01	4	5	7	6
	11	12	13	15	14
	10	8	9	11	10

$$f = \left\{ \begin{array}{c} \underbrace{(a+b+\bar{c}+\bar{d})}_{0011 \leftrightarrow 3} \cdot \underbrace{(a+\bar{b}+c+d)}_{0100 \leftrightarrow 4} \cdot \underbrace{(a+\bar{b}+\bar{c}+d)}_{0110 \leftrightarrow 6} \cdot \underbrace{(a+\bar{b}+\bar{c}+\bar{d})}_{0111 \leftrightarrow 7} \cdot \underbrace{(\bar{a}+b+\bar{c}+\bar{d})}_{1011 \leftrightarrow 11} \\ \underbrace{(\bar{a}+\bar{b}+c+d)}_{1100 \leftrightarrow 12} \cdot \underbrace{(\bar{a}+\bar{b}+c+\bar{d})}_{1101 \leftrightarrow 13} \cdot \underbrace{(\bar{a}+\bar{b}+\bar{c}+d)}_{1110 \leftrightarrow 14} \cdot \underbrace{(\bar{a}+\bar{b}+\bar{c}+\bar{d})}_{1111 \leftrightarrow 15} \end{array} \right.$$

- Direct minimisation: $(s + x)(s + \bar{x}) = s$
- Minimising via \bar{f}
- Cover is obtained where f is false
- $f = m_0 + m_1 + m_2 + m_5 + m_8 + m_9 + m_{10}$
- $\bar{f} = \left\{ \begin{array}{l} m_3 + m_4 + m_6 + m_7 + m_{11} + \\ m_{12} + m_{13} + m_{14} + m_{15} \end{array} \right.$

NB Literals in a minterm and the corresponding maxterm are complemented

f

	<i>c, d</i>	00	01	11	10
<i>a, b</i>	00	0	1	3	2
	01	4	5	7	6
	11	12	13	15	14
	10	8	9	11	10

$$f = \left\{ \begin{array}{c} \underbrace{(a+b+\bar{c}+\bar{d})}_{0011 \leftrightarrow 3} \cdot \underbrace{(a+\bar{b}+c+d)}_{0100 \leftrightarrow 4} \cdot \underbrace{(a+\bar{b}+\bar{c}+d)}_{0110 \leftrightarrow 6} \cdot \underbrace{(a+\bar{b}+\bar{c}+\bar{d})}_{0111 \leftrightarrow 7} \cdot \underbrace{(\bar{a}+b+\bar{c}+\bar{d})}_{1011 \leftrightarrow 11} \\ \underbrace{(\bar{a}+\bar{b}+c+d)}_{1100 \leftrightarrow 12} \cdot \underbrace{(\bar{a}+\bar{b}+c+\bar{d})}_{1101 \leftrightarrow 13} \cdot \underbrace{(\bar{a}+\bar{b}+\bar{c}+d)}_{1110 \leftrightarrow 14} \cdot \underbrace{(\bar{a}+\bar{b}+\bar{c}+\bar{d})}_{1111 \leftrightarrow 15} \end{array} \right.$$

- Direct minimisation: $(s + x)(s + \bar{x}) = s$
- Minimising via \bar{f}
- Cover is obtained where f is false
- $f = m_0 + m_1 + m_2 + m_5 + m_8 + m_9 + m_{10}$
- $\bar{f} = \begin{cases} m_3 + m_4 + m_6 + m_7 + m_{11} + \\ m_{12} + m_{13} + m_{14} + m_{15} \end{cases}$
- $\bar{f} = \begin{cases} \bar{M}_3 + \bar{M}_4 + \bar{M}_6 + \bar{M}_7 + \bar{M}_{11} + \\ \bar{M}_{12} + \bar{M}_{13} + \bar{M}_{14} + \bar{M}_{15} \end{cases}$

NB Literals in a minterm and the corresponding maxterm are complemented

f

	<i>c, d</i>	00	01	11	10
<i>a, b</i>	00	0	1	3	2
	01	4	5	7	6
	11	12	13	15	14
	10	8	9	11	10

$$f = \left\{ \begin{array}{c} \underbrace{(a+b+\bar{c}+\bar{d})}_{0011 \leftrightarrow 3} \cdot \underbrace{(a+\bar{b}+c+d)}_{0100 \leftrightarrow 4} \cdot \underbrace{(a+\bar{b}+\bar{c}+d)}_{0110 \leftrightarrow 6} \cdot \underbrace{(a+\bar{b}+\bar{c}+\bar{d})}_{0111 \leftrightarrow 7} \cdot \underbrace{(\bar{a}+b+\bar{c}+\bar{d})}_{1011 \leftrightarrow 11} \\ \underbrace{(\bar{a}+\bar{b}+c+d)}_{1100 \leftrightarrow 12} \cdot \underbrace{(\bar{a}+\bar{b}+c+\bar{d})}_{1101 \leftrightarrow 13} \cdot \underbrace{(\bar{a}+\bar{b}+\bar{c}+d)}_{1110 \leftrightarrow 14} \cdot \underbrace{(\bar{a}+\bar{b}+\bar{c}+\bar{d})}_{1111 \leftrightarrow 15} \end{array} \right.$$

- Direct minimisation: $(s+x)(s+\bar{x}) = s$
- Minimising via \bar{f}
- Cover is obtained where f is false
- $f = m_0 + m_1 + m_2 + m_5 + m_8 + m_9 + m_{10}$

$$\bar{f} = \left\{ \begin{array}{l} m_3 + m_4 + m_6 + m_7 + m_{11} + \\ m_{12} + m_{13} + m_{14} + m_{15} \end{array} \right.$$

$$\bar{f} = \left\{ \begin{array}{l} \bar{M}_3 + \bar{M}_4 + \bar{M}_6 + \bar{M}_7 + \bar{M}_{11} + \\ \bar{M}_{12} + \bar{M}_{13} + \bar{M}_{14} + \bar{M}_{15} \end{array} \right.$$

$$f = \left\{ \begin{array}{l} M_3 \cdot M_4 \cdot M_6 \cdot M_7 \cdot M_{11} \cdot \\ M_{12} \cdot M_{13} \cdot M_{14} \cdot M_{15} \end{array} \right.$$

NB Literals in a minterm and the corresponding maxterm are complemented

f

	c, d	00	01	11	10
a, b	00	0	1	3	2
	01	4	5	7	6
	11	12	13	15	14
	10	8	9	11	10

$$f = \left\{ \begin{array}{c} \underbrace{(a+b+\bar{c}+\bar{d})}_{0011 \leftrightarrow 3} \cdot \underbrace{(a+\bar{b}+c+d)}_{0100 \leftrightarrow 4} \cdot \underbrace{(a+\bar{b}+\bar{c}+d)}_{0110 \leftrightarrow 6} \cdot \underbrace{(a+\bar{b}+\bar{c}+\bar{d})}_{0111 \leftrightarrow 7} \cdot \underbrace{(\bar{a}+b+\bar{c}+\bar{d})}_{1011 \leftrightarrow 11} \\ \underbrace{(\bar{a}+\bar{b}+c+d)}_{1100 \leftrightarrow 12} \cdot \underbrace{(\bar{a}+\bar{b}+c+\bar{d})}_{1101 \leftrightarrow 13} \cdot \underbrace{(\bar{a}+\bar{b}+\bar{c}+d)}_{1110 \leftrightarrow 14} \cdot \underbrace{(\bar{a}+\bar{b}+\bar{c}+\bar{d})}_{1111 \leftrightarrow 15} \end{array} \right.$$

- Direct minimisation: $(s+x)(s+\bar{x}) = s$
- Minimising via \bar{f}
- Cover is obtained where f is false
- $f = m_0 + m_1 + m_2 + m_5 + m_8 + m_9 + m_{10}$

$$\bar{f} = \left\{ \begin{array}{l} m_3 + m_4 + m_6 + m_7 + m_{11} + \\ m_{12} + m_{13} + m_{14} + m_{15} \end{array} \right.$$

$$\bar{f} = \left\{ \begin{array}{l} \bar{M}_3 + \bar{M}_4 + \bar{M}_6 + \bar{M}_7 + \bar{M}_{11} + \\ \bar{M}_{12} + \bar{M}_{13} + \bar{M}_{14} + \bar{M}_{15} \end{array} \right.$$

$$f = \left\{ \begin{array}{l} M_3 \cdot M_4 \cdot M_6 \cdot M_7 \cdot M_{11} \cdot \\ M_{12} \cdot M_{13} \cdot M_{14} \cdot M_{15} \end{array} \right.$$

- Minterm accepts iff maxterm rejects

NB Literals in a minterm and the corresponding maxterm are complemented

f

	c, d	00	01	11	10
a, b	00	0	1	3	2
	01	4	5	7	6
	11	12	13	15	14
	10	8	9	11	10

$$f = \left\{ \begin{array}{c} \underbrace{(a+b+\bar{c}+\bar{d})}_{0011 \leftrightarrow 3} \cdot \underbrace{(a+\bar{b}+c+d)}_{0100 \leftrightarrow 4} \cdot \underbrace{(a+\bar{b}+\bar{c}+d)}_{0110 \leftrightarrow 6} \cdot \underbrace{(a+\bar{b}+\bar{c}+\bar{d})}_{0111 \leftrightarrow 7} \cdot \underbrace{(\bar{a}+b+\bar{c}+\bar{d})}_{1011 \leftrightarrow 11} \\ \underbrace{(\bar{a}+\bar{b}+c+d)}_{1100 \leftrightarrow 12} \cdot \underbrace{(\bar{a}+\bar{b}+c+\bar{d})}_{1101 \leftrightarrow 13} \cdot \underbrace{(\bar{a}+\bar{b}+\bar{c}+d)}_{1110 \leftrightarrow 14} \cdot \underbrace{(\bar{a}+\bar{b}+\bar{c}+\bar{d})}_{1111 \leftrightarrow 15} \end{array} \right.$$

- Direct minimisation: $(s+x)(s+\bar{x}) = s$
- Minimising via \bar{f}
- Cover is obtained where f is false
- $f = m_0 + m_1 + m_2 + m_5 + m_8 + m_9 + m_{10}$
- $\bar{f} = \left\{ \begin{array}{l} m_3 + m_4 + m_6 + m_7 + m_{11} + \\ m_{12} + m_{13} + m_{14} + m_{15} \end{array} \right.$
- $\bar{f} = \left\{ \begin{array}{l} \bar{M}_3 + \bar{M}_4 + \bar{M}_6 + \bar{M}_7 + \bar{M}_{11} + \\ \bar{M}_{12} + \bar{M}_{13} + \bar{M}_{14} + \bar{M}_{15} \end{array} \right.$
- $f = \left\{ \begin{array}{l} M_3 \cdot M_4 \cdot M_6 \cdot M_7 \cdot M_{11} \cdot \\ M_{12} \cdot M_{13} \cdot M_{14} \cdot M_{15} \end{array} \right.$
- Minterm accepts iff maxterm rejects

NB Literals in a minterm and the corresponding maxterm are complemented

f

	c, d	00	01	11	10
a, b	00	0	1	3	2
	01	4	5	7	6
	11	12	13	15	14
	10	8	9	11	10

$$f = \left\{ \begin{array}{c} \underbrace{(a+b+\bar{c}+\bar{d})}_{0011 \leftrightarrow 3} \cdot \underbrace{(a+\bar{b}+c+d)}_{0100 \leftrightarrow 4} \cdot \underbrace{(a+\bar{b}+\bar{c}+d)}_{0110 \leftrightarrow 6} \cdot \underbrace{(a+\bar{b}+\bar{c}+\bar{d})}_{0111 \leftrightarrow 7} \cdot \underbrace{(\bar{a}+b+\bar{c}+\bar{d})}_{1011 \leftrightarrow 11} \\ \underbrace{(\bar{a}+\bar{b}+c+d)}_{1100 \leftrightarrow 12} \cdot \underbrace{(\bar{a}+\bar{b}+c+\bar{d})}_{1101 \leftrightarrow 13} \cdot \underbrace{(\bar{a}+\bar{b}+\bar{c}+d)}_{1110 \leftrightarrow 14} \cdot \underbrace{(\bar{a}+\bar{b}+\bar{c}+\bar{d})}_{1111 \leftrightarrow 15} \end{array} \right.$$

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- $f = m_0 + m_1 + m_2 + m_5 + m_8 + m_9 + m_{10}$

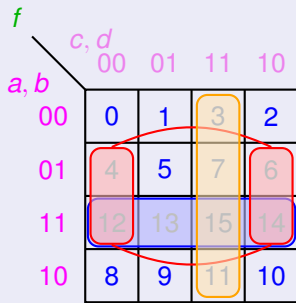
$$\bar{f} = \left\{ \begin{array}{l} m_3 + m_4 + m_6 + m_7 + m_{11} + \\ m_{12} + m_{13} + m_{14} + m_{15} \end{array} \right.$$

$$\bar{f} = \left\{ \begin{array}{l} \bar{M}_3 + \bar{M}_4 + \bar{M}_6 + \bar{M}_7 + \bar{M}_{11} + \\ \bar{M}_{12} + \bar{M}_{13} + \bar{M}_{14} + \bar{M}_{15} \end{array} \right.$$

$$f = \left\{ \begin{array}{l} M_3 \cdot M_4 \cdot M_6 \cdot M_7 \cdot M_{11} \cdot \\ M_{12} \cdot M_{13} \cdot M_{14} \cdot M_{15} \end{array} \right.$$

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NB Literals in a minterm and the corresponding maxterm are complemented



$$f = \left\{ \begin{array}{l} \underbrace{(a+b+\bar{c}+\bar{d})}_{0011 \leftrightarrow 3} \cdot \underbrace{(a+\bar{b}+c+d)}_{0100 \leftrightarrow 4} \cdot \underbrace{(a+\bar{b}+\bar{c}+d)}_{0110 \leftrightarrow 6} \cdot \underbrace{(a+\bar{b}+\bar{c}+\bar{d})}_{0111 \leftrightarrow 7} \cdot \underbrace{(\bar{a}+b+\bar{c}+\bar{d})}_{1011 \leftrightarrow 11} \\ \underbrace{(\bar{a}+\bar{b}+c+d)}_{1100 \leftrightarrow 12} \cdot \underbrace{(\bar{a}+\bar{b}+c+\bar{d})}_{1101 \leftrightarrow 13} \cdot \underbrace{(\bar{a}+\bar{b}+\bar{c}+d)}_{1110 \leftrightarrow 14} \cdot \underbrace{(\bar{a}+\bar{b}+\bar{c}+\bar{d})}_{1111 \leftrightarrow 15} \end{array} \right.$$

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- $f = m_0 + m_1 + m_2 + m_5 + m_8 + m_9 + m_{10}$

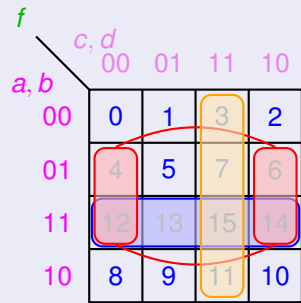
$$\bar{f} = \left\{ \begin{array}{l} m_3 + m_4 + m_6 + m_7 + m_{11} + \\ m_{12} + m_{13} + m_{14} + m_{15} \end{array} \right.$$

$$\bar{f} = \left\{ \begin{array}{l} \bar{M}_3 + \bar{M}_4 + \bar{M}_6 + \bar{M}_7 + \bar{M}_{11} + \\ \bar{M}_{12} + \bar{M}_{13} + \bar{M}_{14} + \bar{M}_{15} \end{array} \right.$$

$$f = \left\{ \begin{array}{l} M_3 \cdot M_4 \cdot M_6 \cdot M_7 \cdot M_{11} \cdot \\ M_{12} \cdot M_{13} \cdot M_{14} \cdot M_{15} \end{array} \right.$$

- Minterm accepts iff maxterm rejects

NB Literals in a minterm and the corresponding maxterm are complemented

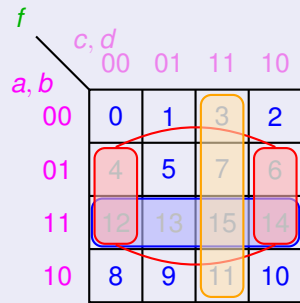


$$f = (\quad) (\quad) (\quad) (\quad)$$

$$f = \left\{ \begin{array}{c} \underbrace{(a+b+\bar{c}+\bar{d})}_{0011 \leftrightarrow 3} \cdot \underbrace{(a+\bar{b}+c+d)}_{0100 \leftrightarrow 4} \cdot \underbrace{(a+\bar{b}+\bar{c}+d)}_{0110 \leftrightarrow 6} \cdot \underbrace{(a+\bar{b}+\bar{c}+\bar{d})}_{0111 \leftrightarrow 7} \cdot \underbrace{(\bar{a}+b+\bar{c}+\bar{d})}_{1011 \leftrightarrow 11} \\ \underbrace{(\bar{a}+\bar{b}+c+d)}_{1100 \leftrightarrow 12} \cdot \underbrace{(\bar{a}+\bar{b}+c+\bar{d})}_{1101 \leftrightarrow 13} \cdot \underbrace{(\bar{a}+\bar{b}+\bar{c}+d)}_{1110 \leftrightarrow 14} \cdot \underbrace{(\bar{a}+\bar{b}+\bar{c}+\bar{d})}_{1111 \leftrightarrow 15} \end{array} \right.$$

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- $\bar{f} = \left\{ \begin{array}{l} \bar{M}_3 + \bar{M}_4 + \bar{M}_6 + \bar{M}_7 + \bar{M}_{11} + \\ \bar{M}_{12} + \bar{M}_{13} + \bar{M}_{14} + \bar{M}_{15} \end{array} \right.$
- $f = \left\{ \begin{array}{l} M_3 \cdot M_4 \cdot M_6 \cdot M_7 \cdot M_{11} \cdot \\ M_{12} \cdot M_{13} \cdot M_{14} \cdot M_{15} \end{array} \right.$
- Minterm accepts iff maxterm rejects

NB Literals in a minterm and the corresponding maxterm are complemented



$$f = (\bar{a} + \bar{b}) (\quad) (\quad) (\quad)$$

$$f = \left\{ \begin{array}{c} \underbrace{(a+b+\bar{c}+\bar{d})}_{0011 \leftrightarrow 3} \cdot \underbrace{(a+\bar{b}+c+d)}_{0100 \leftrightarrow 4} \cdot \underbrace{(a+\bar{b}+\bar{c}+d)}_{0110 \leftrightarrow 6} \cdot \underbrace{(a+\bar{b}+\bar{c}+\bar{d})}_{0111 \leftrightarrow 7} \cdot \underbrace{(\bar{a}+b+\bar{c}+\bar{d})}_{1011 \leftrightarrow 11} \\ \underbrace{(\bar{a}+\bar{b}+c+d)}_{1100 \leftrightarrow 12} \cdot \underbrace{(\bar{a}+\bar{b}+c+\bar{d})}_{1101 \leftrightarrow 13} \cdot \underbrace{(\bar{a}+\bar{b}+\bar{c}+d)}_{1110 \leftrightarrow 14} \cdot \underbrace{(\bar{a}+\bar{b}+\bar{c}+\bar{d})}_{1111 \leftrightarrow 15} \end{array} \right.$$

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- Minimising via \bar{f}
- Cover is obtained where f is false
- $f = m_0 + m_1 + m_2 + m_5 + m_8 + m_9 + m_{10}$

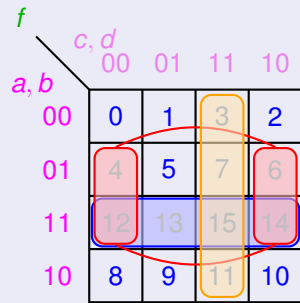
$$\bar{f} = \left\{ \begin{array}{l} m_3 + m_4 + m_6 + m_7 + m_{11} + \\ m_{12} + m_{13} + m_{14} + m_{15} \end{array} \right.$$

$$\bar{f} = \left\{ \begin{array}{l} \bar{M}_3 + \bar{M}_4 + \bar{M}_6 + \bar{M}_7 + \bar{M}_{11} + \\ \bar{M}_{12} + \bar{M}_{13} + \bar{M}_{14} + \bar{M}_{15} \end{array} \right.$$

$$f = \left\{ \begin{array}{l} M_3 \cdot M_4 \cdot M_6 \cdot M_7 \cdot M_{11} \cdot \\ M_{12} \cdot M_{13} \cdot M_{14} \cdot M_{15} \end{array} \right.$$

- Minterm accepts iff maxterm rejects

NB Literals in a minterm and the corresponding maxterm are complemented

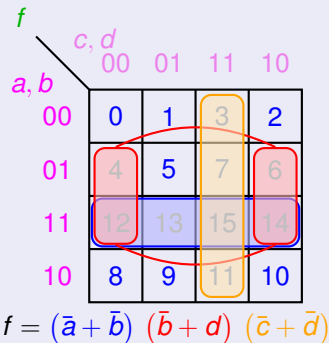


$$f = (\bar{a} + \bar{b}) (\bar{b} + d) (\quad)$$

$$f = \left\{ \begin{array}{c} \underbrace{(a+b+\bar{c}+\bar{d})}_{0011 \leftrightarrow 3} \cdot \underbrace{(a+\bar{b}+c+d)}_{0100 \leftrightarrow 4} \cdot \underbrace{(a+\bar{b}+\bar{c}+d)}_{0110 \leftrightarrow 6} \cdot \underbrace{(a+\bar{b}+\bar{c}+\bar{d})}_{0111 \leftrightarrow 7} \cdot \underbrace{(\bar{a}+b+\bar{c}+\bar{d})}_{1011 \leftrightarrow 11} \\ \underbrace{(\bar{a}+\bar{b}+c+d)}_{1100 \leftrightarrow 12} \cdot \underbrace{(\bar{a}+\bar{b}+c+\bar{d})}_{1101 \leftrightarrow 13} \cdot \underbrace{(\bar{a}+\bar{b}+\bar{c}+d)}_{1110 \leftrightarrow 14} \cdot \underbrace{(\bar{a}+\bar{b}+\bar{c}+\bar{d})}_{1111 \leftrightarrow 15} \end{array} \right.$$

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- $f = m_0 + m_1 + m_2 + m_5 + m_8 + m_9 + m_{10}$
- $\bar{f} = \begin{cases} m_3 + m_4 + m_6 + m_7 + m_{11} + \\ m_{12} + m_{13} + m_{14} + m_{15} \end{cases}$
- $\bar{f} = \begin{cases} \bar{M}_3 + \bar{M}_4 + \bar{M}_6 + \bar{M}_7 + \bar{M}_{11} + \\ \bar{M}_{12} + \bar{M}_{13} + \bar{M}_{14} + \bar{M}_{15} \end{cases}$
- $f = \begin{cases} M_3 \cdot M_4 \cdot M_6 \cdot M_7 \cdot M_{11} \cdot \\ M_{12} \cdot M_{13} \cdot M_{14} \cdot M_{15} \end{cases}$
- Minterm accepts iff maxterm rejects

NB Literals in a minterm and the corresponding maxterm are complemented



$$f(a, b, c, d) = \prod_M (3, 5, 7, 8, 10, 11, 12, 13)$$

f

c, d

a, b

	00	01	11	10
00	0	1	3	2
01	4	5	7	6
11	12	13	15	14
10	8	9	11	10

$$f(a, b, c, d) = \prod_M (3, 5, 7, 8, 10, 11, 12, 13)$$

f

c, d

a, b

	00	01	11	10
00	0	1	3	2
01	4	5	7	6
11	12	13	15	14
10	8	9	11	10

$$f(a, b, c, d) = \prod_M (3, 5, 7, 8, 10, 11, 12, 13)$$

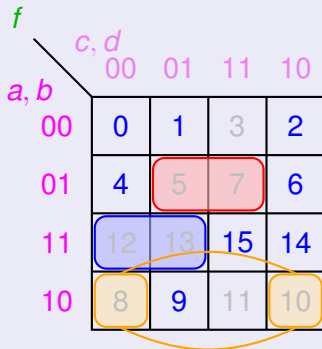
f

a, b

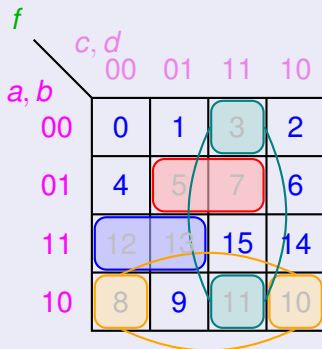
c, d

00	0	1	3	2
01	4	5	7	6
11	12	13	15	14
10	8	9	11	10

$$f(a, b, c, d) = \prod_M (3, 5, 7, 8, 10, 11, 12, 13)$$



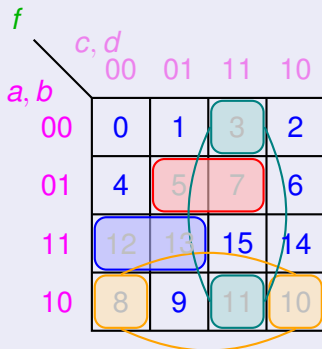
$$f(a, b, c, d) = \prod_M (3, 5, 7, 8, 10, 11, 12, 13)$$



$$f = (\quad) (\quad) (\quad) (\quad)$$



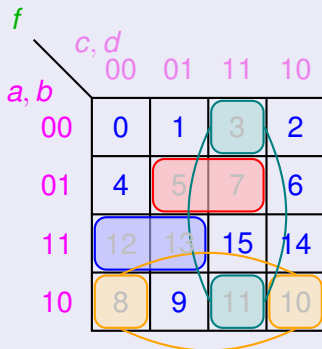
$$f(a, b, c, d) = \prod_M (3, 5, 7, 8, 10, 11, 12, 13)$$



$$f = (\bar{a} + \bar{b} + c) (\quad) (\quad) (\quad)$$



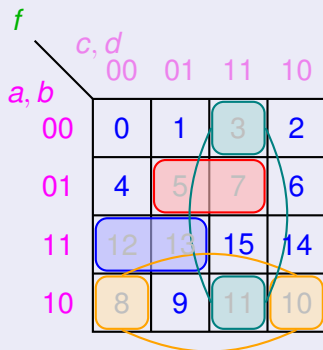
$$f(a, b, c, d) = \prod_M (3, 5, 7, 8, 10, 11, 12, 13)$$



$$f = (\bar{a} + \bar{b} + c) (a + \bar{b} + \bar{d}) (\quad) (\quad)$$



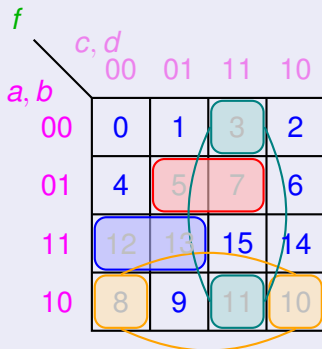
$$f(a, b, c, d) = \prod_M (3, 5, 7, 8, 10, 11, 12, 13)$$



$$f = (\bar{a} + \bar{b} + c) (a + \bar{b} + \bar{d}) (\bar{a} + b + d) (\quad)$$



$$f(a, b, c, d) = \prod_M (3, 5, 7, 8, 10, 11, 12, 13)$$



$$f = (\bar{a} + \bar{b} + c) (a + \bar{b} + \bar{d}) (\bar{a} + b + d) (b + \bar{c} + \bar{d})$$

