

Exercise 1

The following equivalences hold for 2-valued logic. In the context of database systems we have to deal with 3-valued logic (NULL values). Which of these equivalences holds for 3-valued logic? For the ones that don't hold, find a counter example. For the ones that hold, prove the equivalence by evaluating the truth table. Note that you only have to evaluate the cases where *unknown* occurs since you can assume that they hold for 2-valued logic.

Solution

AND	t	u	f
t	t	u	f
u	u	u	f
f	f	f	f

OR	t	u	f
t	t	t	t
u	t	u	u
f	t	u	f

NOT	
t	f
u	u
f	t

Exercise 1 a)

$$x \wedge \neg x = \text{false}$$

and

$$x \vee \neg x = \text{true}$$

Solution

\Rightarrow Don't hold. Consider $x = \text{unknown}$:

$$\text{unknown} \wedge \neg \text{unknown} = \text{unknown} = \text{unknown} \vee \neg \text{unknown}$$

Exercise 1 b)

$$(x \wedge y) \wedge z = x \wedge (y \wedge z)$$

and

$$(x \vee y) \vee z = x \vee (y \vee z)$$

Solution

The equivalences hold.

There are $3^3 = 27$ combinations in total. If we subtract the ones where only *true* and *false* occurs, i.e., $2^3 = 8$ we are left with 19. The following shows a sample of the full truth table.

x	y	z	$(x \wedge y) \wedge z$	$x \wedge (y \wedge z)$	$(x \vee y) \vee z$	$x \vee (y \vee z)$
T	T	U	U	U	T	T
T	U	T	U	U	T	T
U	T	T	U	U	T	T
T	U	U	U	U	T	T
U	T	U	U	U	T	T
U	U	T	U	U	T	T
F	F	U	F	F	U	U
F	U	F	F	F	U	U
U	F	F	F	F	U	U
F	U	U	F	F	U	U
U	F	U	F	F	U	U
U	U	F	F	F	U	U
U	U	U	U	U	U	U

Exercise 2

Greedy algorithms are applied to solve optimization problems. The solution obtained is not necessarily globally optimal. Greedy algorithms construct a solution step-by-step where each step is locally optimal. Steps taken cannot be undone in subsequent steps. Greedy algorithms terminate once a complete solution is found.

Exercise 2 a)

Using your favorite book on algorithms or Wikipedia, read about the greedy algorithm technique.

Exercise 2 b)

Implement either `GreedyJoinOrdering-1` or `GreedyJoinOrdering-2` from Chapter 3.2.1 Heuristics in the script.

Solution

See code.

Exercise 2 c)

What types of query graphs can GreedyJoinOrdering-1 and GreedyJoinOrder-2 handle? What type of join trees do they generate?

Solution

All types of query graphs. They generate left-deep trees.

Exercise 3

You are given the cardinalities for relations $R_i, i \in \{1, \dots, 4\}$ together with their join selectivities:

$$|R_1| = 10, |R_2| = 100, |R_3| = 1000, |R_4| = 25$$

$$f_{1,2} = 0, 1, f_{2,3} = 0, 2, f_{1,3} = 0, 4, f_{3,4} = 0, 1$$

We already know that there is a large number of possible join trees (120, bushy and cross-products considered).

To see how costs vary from one join tree to another, compute the cost for some of the join trees for the cost functions C_{out} , C_{nlj} , C_{hj} and C_{smj} . You will find their definitions in the script.

Note that the cost of a cross product $e_1 \times e_2$ is given by $|e_1| * |e_2|$.

Solution

Join	Card	C_{out}	C_{nlj}	C_{hj}	C_{smj}
$R_1 \bowtie R_2$	100	100	1000	12	697.60
$R_2 \bowtie R_1$	100	100	1000	120	697.60
$R_1 \bowtie R_3$	4000	4000	10000	12	9999.00
$R_3 \bowtie R_1$	4000	4000	10000	1200	9999.00
$R_1 \times R_4$	250	250	250	250	250.00
$R_4 \times R_1$	250	250	250	250	250.00
$R_2 \bowtie R_3$	20000	20000	100000	120	10630.17
$R_3 \bowtie R_2$	20000	20000	100000	1200	10630.17
$R_2 \times R_4$	2500	2500	2500	2500	2500.00
$R_4 \times R_2$	2500	2500	2500	2500	2500.00
$R_3 \bowtie R_4$	2500	2500	25000	1200	10081.88
$R_4 \bowtie R_3$	2500	2500	25000	30	10081.88
$R_1 \bowtie (R_2 \bowtie R_3)$	8000	28000	300000	132	296417.64
$(R_1 \bowtie R_2) \bowtie R_3$	8000	8100	101000	132	11327.77
$R_1 \bowtie (R_3 \bowtie R_2)$	8000	28000	300000	1212	296417.64
$(R_1 \bowtie R_3) \bowtie R_2$	8000	12000	410000	4812	58526.53
$R_2 \bowtie (R_1 \bowtie R_3)$	8000	12000	410000	132	58526.53
$(R_2 \bowtie R_1) \bowtie R_3$	8000	8100	101000	240	11327.77
$R_2 \bowtie (R_3 \bowtie R_1)$	8000	12000	410000	1320	58526.53
$(R_2 \bowtie R_3) \bowtie R_1$	8000	28000	300000	24120	296417.64

$R_3 \bowtie (R_1 \bowtie R_2)$	8000	8100	101000	1212	11327.77
$(R_3 \bowtie R_1) \bowtie R_2$	8000	12000	410000	6000	58526.53
$R_3 \bowtie (R_2 \bowtie R_1)$	8000	8100	101000	1320	11327.77
$(R_3 \bowtie R_2) \bowtie R_1$	8000	28000	300000	25200	296417.64
$R_1 \bowtie (R_2 \times R_4)$	2500	5000	27500	2512	30752.50
$(R_1 \bowtie R_2) \times R_4$	2500	2600	3500	2512	3197.60
$R_1 \bowtie (R_4 \times R_2)$	2500	5000	27500	2512	30752.50
$(R_1 \times R_4) \bowtie R_2$	2500	2750	25250	550	2905.83
$R_2 \bowtie (R_1 \times R_4)$	2500	2750	25250	370	2905.83
$(R_2 \bowtie R_1) \times R_4$	2500	2600	3500	2620	3197.60
$R_2 \bowtie (R_4 \times R_1)$	2500	2750	25250	370	2905.83
$(R_2 \times R_4) \bowtie R_1$	2500	5000	27500	5500	30752.50
$R_4 \times (R_1 \bowtie R_2)$	2500	2600	3500	2512	3197.60
$(R_4 \times R_1) \bowtie R_2$	2500	2750	25250	550	2905.83
$R_4 \times (R_2 \bowtie R_1)$	2500	2600	3500	2620	3197.60
$(R_4 \times R_2) \bowtie R_1$	2500	5000	27500	5500	30752.50
$R_1 \bowtie (R_3 \bowtie R_4)$	10000	12500	50000	1212	38334.38
$(R_1 \bowtie R_3) \bowtie R_4$	10000	14000	110000	4812	57978.24
$R_1 \bowtie (R_4 \bowtie R_3)$	10000	12500	50000	42	38334.38
$(R_1 \times R_4) \bowtie R_3$	10000	10250	250250	550	12207.23
$R_3 \bowtie (R_1 \times R_4)$	10000	10250	250250	1450	12207.23
$(R_3 \bowtie R_1) \bowtie R_4$	10000	14000	110000	6000	57978.24
$R_3 \bowtie (R_4 \times R_1)$	10000	10250	250250	1450	12207.23
$(R_3 \bowtie R_4) \bowtie R_1$	10000	12500	50000	4200	38334.38
$R_4 \bowtie (R_1 \bowtie R_3)$	10000	14000	110000	42	57978.24
$(R_4 \times R_1) \bowtie R_3$	10000	10250	250250	550	12207.23
$R_4 \bowtie (R_3 \bowtie R_1)$	10000	14000	110000	1230	57978.24
$(R_4 \bowtie R_3) \bowtie R_1$	10000	12500	50000	3030	38334.38
$R_2 \bowtie (R_3 \bowtie R_4)$	50000	52500	275000	1320	38965.55
$(R_2 \bowtie R_3) \bowtie R_4$	50000	70000	600000	24120	296500.51
$R_2 \bowtie (R_4 \bowtie R_3)$	50000	52500	275000	150	38965.55
$(R_2 \times R_4) \bowtie R_3$	50000	52500	2502500	5500	40685.07
$R_3 \bowtie (R_2 \times R_4)$	50000	52500	2502500	3700	40685.07
$(R_3 \bowtie R_2) \bowtie R_4$	50000	70000	600000	25200	296500.51
$R_3 \bowtie (R_4 \times R_2)$	50000	52500	2502500	3700	40685.07
$(R_3 \bowtie R_4) \bowtie R_2$	50000	52500	275000	4200	38965.55
$R_4 \bowtie (R_2 \bowtie R_3)$	50000	70000	600000	150	296500.51
$(R_4 \times R_2) \bowtie R_3$	50000	52500	2502500	5500	40685.07
$R_4 \bowtie (R_3 \bowtie R_2)$	50000	70000	600000	1230	296500.51
$(R_4 \bowtie R_3) \bowtie R_2$	50000	52500	275000	3030	38965.55
$R_1 \bowtie ((R_2 \bowtie R_3) \bowtie R_4)$	20000	90000	1100000	24132	1077015.76
$R_1 \bowtie ((R_2 \bowtie R_3) \bowtie R_4)$	20000	90000	1100000	24132	1077015.76
$(R_1 \bowtie R_2) \bowtie (R_3 \bowtie R_4)$	20000	22600	276000	1332	39663.15
$((R_1 \bowtie R_2) \bowtie R_3) \bowtie R_4$	20000	28100	301000	9732	115170.15
$((R_1 \bowtie R_2) \bowtie R_3) \bowtie R_4$	20000	28100	301000	9732	115170.15
$R_1 \bowtie ((R_2 \times R_4) \bowtie R_3)$	20000	72500	3002500	5512	821200.31

$R_1 \bowtie ((R_2 \times R_4) \bowtie R_3)$	20000	72500	3002500	5512	821200.31
$(R_1 \bowtie R_2) \bowtie (R_4 \bowtie R_3)$	20000	22600	276000	162	39663.15
$((R_1 \bowtie R_2) \times R_4) \bowtie R_3$	20000	22600	2503500	5512	41382.67
$((R_1 \bowtie R_2) \times R_4) \bowtie R_3$	20000	22600	2503500	5512	41382.67
$R_1 \bowtie ((R_3 \bowtie R_2) \bowtie R_4)$	20000	90000	1100000	25212	1077015.76
$R_1 \bowtie ((R_3 \bowtie R_2) \bowtie R_4)$	20000	90000	1100000	25212	1077015.76
$(R_1 \bowtie R_3) \bowtie (R_2 \times R_4)$	20000	26500	10012500	7312	88581.42
$((R_1 \bowtie R_3) \bowtie R_2) \bowtie R_4$	20000	32000	610000	14412	162368.90
$((R_1 \bowtie R_3) \bowtie R_2) \bowtie R_4$	20000	32000	610000	14412	162368.90
$R_1 \bowtie ((R_3 \bowtie R_4) \bowtie R_2)$	20000	72500	775000	4212	819480.79
$R_1 \bowtie ((R_3 \bowtie R_4) \bowtie R_2)$	20000	72500	775000	4212	819480.79
$(R_1 \bowtie R_3) \bowtie (R_4 \times R_2)$	20000	26500	10012500	7312	88581.42
$((R_1 \bowtie R_3) \bowtie R_4) \bowtie R_2$	20000	34000	1110000	16812	191519.75
$((R_1 \bowtie R_3) \bowtie R_4) \bowtie R_2$	20000	34000	1110000	16812	191519.75
$R_1 \bowtie ((R_4 \times R_2) \bowtie R_3)$	20000	72500	3002500	5512	821200.31
$R_1 \bowtie ((R_4 \times R_2) \bowtie R_3)$	20000	72500	3002500	5512	821200.31
$(R_1 \times R_4) \bowtie (R_2 \bowtie R_3)$	20000	40250	5100250	670	298625.86
$((R_1 \times R_4) \bowtie R_2) \bowtie R_3$	20000	22750	2525250	3550	41090.90
$((R_1 \times R_4) \bowtie R_2) \bowtie R_3$	20000	22750	2525250	3550	41090.90
$R_1 \bowtie ((R_4 \bowtie R_3) \bowtie R_2)$	20000	72500	775000	3042	819480.79
$R_1 \bowtie ((R_4 \bowtie R_3) \bowtie R_2)$	20000	72500	775000	3042	819480.79
$(R_1 \times R_4) \bowtie (R_3 \bowtie R_2)$	20000	40250	5100250	1750	298625.86
$((R_1 \times R_4) \bowtie R_3) \bowtie R_2$	20000	30250	1250250	12550	145748.74
$((R_1 \times R_4) \bowtie R_3) \bowtie R_2$	20000	30250	1250250	12550	145748.74
$R_2 \bowtie ((R_1 \bowtie R_3) \bowtie R_4)$	20000	34000	1110000	4932	191519.75
$R_2 \bowtie ((R_1 \bowtie R_3) \bowtie R_4)$	20000	34000	1110000	4932	191519.75
$(R_2 \bowtie R_1) \bowtie (R_3 \bowtie R_4)$	20000	22600	276000	1440	39663.15
$((R_2 \bowtie R_1) \bowtie R_3) \bowtie R_4$	20000	28100	301000	9840	115170.15
$((R_2 \bowtie R_1) \bowtie R_3) \bowtie R_4$	20000	28100	301000	9840	115170.15
$R_2 \bowtie ((R_1 \times R_4) \bowtie R_3)$	20000	30250	1250250	670	145748.74
$R_2 \bowtie ((R_1 \times R_4) \bowtie R_3)$	20000	30250	1250250	670	145748.74
$(R_2 \bowtie R_1) \bowtie (R_4 \bowtie R_3)$	20000	22600	276000	270	39663.15
$((R_2 \bowtie R_1) \times R_4) \bowtie R_3$	20000	22600	2503500	5620	41382.67
$((R_2 \bowtie R_1) \times R_4) \bowtie R_3$	20000	22600	2503500	5620	41382.67
$R_2 \bowtie ((R_3 \bowtie R_1) \bowtie R_4)$	20000	34000	1110000	6120	191519.75
$R_2 \bowtie ((R_3 \bowtie R_1) \bowtie R_4)$	20000	34000	1110000	6120	191519.75
$(R_2 \bowtie R_3) \bowtie (R_1 \times R_4)$	20000	40250	5100250	24370	298625.86
$((R_2 \bowtie R_3) \bowtie R_1) \bowtie R_4$	20000	48000	500000	33720	400260.01
$((R_2 \bowtie R_3) \bowtie R_1) \bowtie R_4$	20000	48000	500000	33720	400260.01
$R_2 \bowtie ((R_3 \bowtie R_4) \bowtie R_1)$	20000	32500	1050000	4320	171875.89
$R_2 \bowtie ((R_3 \bowtie R_4) \bowtie R_1)$	20000	32500	1050000	4320	171875.89
$(R_2 \bowtie R_3) \bowtie (R_4 \times R_1)$	20000	40250	5100250	24370	298625.86
$((R_2 \bowtie R_3) \bowtie R_4) \bowtie R_1$	20000	90000	1100000	84120	1077015.76
$((R_2 \bowtie R_3) \bowtie R_4) \bowtie R_1$	20000	90000	1100000	84120	1077015.76
$R_2 \bowtie ((R_4 \times R_1) \bowtie R_3)$	20000	30250	1250250	670	145748.74
$R_2 \bowtie ((R_4 \times R_1) \bowtie R_3)$	20000	30250	1250250	670	145748.74

$(R_2 \times R_4) \bowtie (R_1 \bowtie R_3)$	20000	26500	10012500	5512	88581.42
$((R_2 \times R_4) \bowtie R_1) \bowtie R_3$	20000	25000	2527500	8500	68937.57
$((R_2 \times R_4) \bowtie R_1) \bowtie R_3$	20000	25000	2527500	8500	68937.57
$R_2 \bowtie ((R_4 \bowtie R_3) \bowtie R_1)$	20000	32500	1050000	3150	171875.89
$R_2 \bowtie ((R_4 \bowtie R_3) \bowtie R_1)$	20000	32500	1050000	3150	171875.89
$(R_2 \times R_4) \bowtie (R_3 \bowtie R_1)$	20000	26500	10012500	6700	88581.42
$((R_2 \times R_4) \bowtie R_3) \bowtie R_1$	20000	72500	3002500	65500	821200.31
$((R_2 \times R_4) \bowtie R_3) \bowtie R_1$	20000	72500	3002500	65500	821200.31
$R_3 \bowtie ((R_1 \bowtie R_2) \times R_4)$	20000	22600	2503500	3712	41382.67
$R_3 \bowtie ((R_1 \bowtie R_2) \times R_4)$	20000	22600	2503500	3712	41382.67
$(R_3 \bowtie R_1) \bowtie (R_2 \times R_4)$	20000	26500	10012500	8500	88581.42
$((R_3 \bowtie R_1) \bowtie R_2) \bowtie R_4$	20000	32000	610000	15600	162368.90
$((R_3 \bowtie R_1) \bowtie R_2) \bowtie R_4$	20000	32000	610000	15600	162368.90
$R_3 \bowtie ((R_1 \times R_4) \bowtie R_2)$	20000	22750	2525250	1750	41090.90
$R_3 \bowtie ((R_1 \times R_4) \bowtie R_2)$	20000	22750	2525250	1750	41090.90
$(R_3 \bowtie R_1) \bowtie (R_4 \times R_2)$	20000	26500	10012500	8500	88581.42
$((R_3 \bowtie R_1) \bowtie R_4) \bowtie R_2$	20000	34000	1110000	18000	191519.75
$((R_3 \bowtie R_1) \bowtie R_4) \bowtie R_2$	20000	34000	1110000	18000	191519.75
$R_3 \bowtie ((R_2 \bowtie R_1) \times R_4)$	20000	22600	2503500	3820	41382.67
$R_3 \bowtie ((R_2 \bowtie R_1) \times R_4)$	20000	22600	2503500	3820	41382.67
$(R_3 \bowtie R_2) \bowtie (R_1 \times R_4)$	20000	40250	5100250	25450	298625.86
$((R_3 \bowtie R_2) \bowtie R_1) \bowtie R_4$	20000	48000	500000	34800	400260.01
$((R_3 \bowtie R_2) \bowtie R_1) \bowtie R_4$	20000	48000	500000	34800	400260.01
$R_3 \bowtie ((R_2 \times R_4) \bowtie R_1)$	20000	25000	2527500	6700	68937.57
$R_3 \bowtie ((R_2 \times R_4) \bowtie R_1)$	20000	25000	2527500	6700	68937.57
$(R_3 \bowtie R_2) \bowtie (R_4 \times R_1)$	20000	40250	5100250	25450	298625.86
$((R_3 \bowtie R_2) \bowtie R_4) \bowtie R_1$	20000	90000	1100000	85200	1077015.76
$((R_3 \bowtie R_2) \bowtie R_4) \bowtie R_1$	20000	90000	1100000	85200	1077015.76
$R_3 \bowtie ((R_4 \times R_1) \bowtie R_2)$	20000	22750	2525250	1750	41090.90
$R_3 \bowtie ((R_4 \times R_1) \bowtie R_2)$	20000	22750	2525250	1750	41090.90
$(R_3 \bowtie R_4) \bowtie (R_1 \bowtie R_2)$	20000	22600	276000	4212	39663.15
$((R_3 \bowtie R_4) \bowtie R_1) \bowtie R_2$	20000	32500	1050000	16200	171875.89
$((R_3 \bowtie R_4) \bowtie R_1) \bowtie R_2$	20000	32500	1050000	16200	171875.89
$R_3 \bowtie ((R_4 \times R_2) \bowtie R_1)$	20000	25000	2527500	6700	68937.57
$R_3 \bowtie ((R_4 \times R_2) \bowtie R_1)$	20000	25000	2527500	6700	68937.57
$(R_3 \bowtie R_4) \bowtie (R_2 \bowtie R_1)$	20000	22600	276000	4320	39663.15
$((R_3 \bowtie R_4) \bowtie R_2) \bowtie R_1$	20000	72500	775000	64200	819480.79
$((R_3 \bowtie R_4) \bowtie R_2) \bowtie R_1$	20000	72500	775000	64200	819480.79
$R_4 \bowtie ((R_1 \bowtie R_2) \bowtie R_3)$	20000	28100	301000	162	115170.15
$R_4 \bowtie ((R_1 \bowtie R_2) \bowtie R_3)$	20000	28100	301000	162	115170.15
$(R_4 \times R_1) \bowtie (R_2 \bowtie R_3)$	20000	40250	5100250	670	298625.86
$((R_4 \times R_1) \bowtie R_2) \bowtie R_3$	20000	22750	2525250	3550	41090.90
$((R_4 \times R_1) \bowtie R_2) \bowtie R_3$	20000	22750	2525250	3550	41090.90
$R_4 \bowtie ((R_1 \bowtie R_3) \bowtie R_2)$	20000	32000	610000	4842	162368.90
$R_4 \bowtie ((R_1 \bowtie R_3) \bowtie R_2)$	20000	32000	610000	4842	162368.90
$(R_4 \times R_1) \bowtie (R_3 \bowtie R_2)$	20000	40250	5100250	1750	298625.86

$((R_4 \times R_1) \bowtie R_3) \bowtie R_2$	20000	30250	1250250	12550	145748.74
$((R_4 \times R_1) \bowtie R_3) \bowtie R_2$	20000	30250	1250250	12550	145748.74
$R_4 \bowtie ((R_2 \bowtie R_1) \bowtie R_3)$	20000	28100	301000	270	115170.15
$R_4 \bowtie ((R_2 \bowtie R_1) \bowtie R_3)$	20000	28100	301000	270	115170.15
$(R_4 \times R_2) \bowtie (R_1 \bowtie R_3)$	20000	26500	10012500	5512	88581.42
$((R_4 \times R_2) \bowtie R_1) \bowtie R_3$	20000	25000	2527500	8500	68937.57
$((R_4 \times R_2) \bowtie R_1) \bowtie R_3$	20000	25000	2527500	8500	68937.57
$R_4 \bowtie ((R_2 \bowtie R_3) \bowtie R_1)$	20000	48000	500000	24150	400260.01
$R_4 \bowtie ((R_2 \bowtie R_3) \bowtie R_1)$	20000	48000	500000	24150	400260.01
$(R_4 \times R_2) \bowtie (R_3 \bowtie R_1)$	20000	26500	10012500	6700	88581.42
$((R_4 \times R_2) \bowtie R_3) \bowtie R_1$	20000	72500	3002500	65500	821200.31
$((R_4 \times R_2) \bowtie R_3) \bowtie R_1$	20000	72500	3002500	65500	821200.31
$R_4 \bowtie ((R_3 \bowtie R_1) \bowtie R_2)$	20000	32000	610000	6030	162368.90
$R_4 \bowtie ((R_3 \bowtie R_1) \bowtie R_2)$	20000	32000	610000	6030	162368.90
$(R_4 \bowtie R_3) \bowtie (R_1 \bowtie R_2)$	20000	22600	276000	3042	39663.15
$((R_4 \bowtie R_3) \bowtie R_1) \bowtie R_2$	20000	32500	1050000	15030	171875.89
$((R_4 \bowtie R_3) \bowtie R_1) \bowtie R_2$	20000	32500	1050000	15030	171875.89
$R_4 \bowtie ((R_3 \bowtie R_2) \bowtie R_1)$	20000	48000	500000	25230	400260.01
$R_4 \bowtie ((R_3 \bowtie R_2) \bowtie R_1)$	20000	48000	500000	25230	400260.01
$(R_4 \bowtie R_3) \bowtie (R_2 \bowtie R_1)$	20000	22600	276000	3150	39663.15
$((R_4 \bowtie R_3) \bowtie R_2) \bowtie R_1$	20000	72500	775000	63030	819480.79
$((R_4 \bowtie R_3) \bowtie R_2) \bowtie R_1$	20000	72500	775000	63030	819480.79