Capita Selecta AI - Probabilistic Programming Inference for SRL

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Probabilistic Inference Using Weighted Model Counting

1.1   PGM to CNF

1.1.1   ENC 1

Our ENC1 encoding for the Cancer Bayesian network can be found in appendix 4.1.

1.1.2   ENC 2

Our ENC2 encoding for the Cancer Bayesian network can be found in appendix 4.2.

1.2   SRL to CNF

1.2.1   Encoding of Monty Hall as CNF

An encoding of problog programs can be generated by our program as follows:

```
python3 scripts/inference.py ——problog files/problog/monty_hall.pl
```

The CNF will be shown using the program's predicates. A version of the CNF in dimacs format will be shown as well. See `README.MD` for more information.

Our CNF encoding for the given Monty Hall ProbLog program is:

$\land (open\_door(2) \lor prize(2) \lor prize(3) \lor \neg p\_open\_door(2)\_0)$

$\land (open\_door(2) \lor prize(2) \lor \neg prize(3))$

$\land (\neg open\_door(2) \lor \neg prize(2) \lor \neg prize(2))$

$\land (\neg open\_door(2) \lor \neg prize(2) \lor prize(3))$

$\land (\neg open\_door(2) \lor \neg prize(3) \lor \neg prize(2))$

$\land (\neg open\_door(2) \lor \neg prize(3) \lor prize(3))$

$\land (\neg open\_door(2) \lor p\_open\_door(2)\_0 \lor \neg prize(2))$

$\land (\neg open\_door(2) \lor p\_open\_door(2)\_0 \lor prize(3))$

$\land (open\_door(3) \lor prize(2) \lor prize(3) \lor \neg p\_open\_door(3)\_0)$

$\land (open\_door(3) \lor prize(3) \lor \neg prize(2))$

$\land (\neg open\_door(3) \lor \neg prize(2) \lor \neg prize(3))$

$\land (\neg open\_door(3) \lor \neg prize(2) \lor prize(2))$

$\land (\neg open\_door(3) \lor \neg prize(3) \lor \neg prize(3))$

$\land (\neg open\_door(3) \lor \neg prize(3) \lor prize(2))$

$\land (\neg open\_door(3) \lor p\_open\_door(3)\_0 \lor \neg prize(3))$

$\land (\neg open\_door(3) \lor p\_open\_door(3)\_0 \lor prize(2))$

$\land (win\_keep \lor \neg prize(1))$

$\land (\neg win\_keep \lor prize(1))$

$\land (win\_switch \lor \neg prize(2) \lor open\_door(2))$

$\land (win\_switch \lor \neg prize(3) \lor open\_door(3))$

$\land (\neg win\_switch \lor prize(2) \lor prize(3))$

$\land (\neg win\_switch \lor prize(2) \lor \neg open\_door(3))$

$\land (\neg win\_switch \lor \neg open\_door(2) \lor prize(3))$

$\land (\neg win\_switch \lor \neg open\_door(2) \lor \neg open\_door(3))$

$\land (\neg prize(1) \lor \neg prize(2))$

$\land (\neg prize(1) \lor \neg prize(3))$

$\land (\neg prize(2) \lor \neg prize(3))$

$\land (prize(1) \lor prize(2) \lor prize(3))$

Weights:

$W(p\_open\_door(2)\_0) = 0.5$	$W(\neg p\_open\_door(2)\_0) = 0.5$
$W(p\_open\_door(3)\_0) = 0.5$	$W(\neg p\_open\_door(3)\_0) = 0.5$
$W(select\_door(1)) = 1.00$	$W(\neg select\_door(1)) = 0.00$
$W(prize(1)) = 0.33$	$W(\neg prize(1)) = 1.00$
$W(prize(2)) = 0.33$	$W(\neg prize(2)) = 1.00$
$W(prize(3)) = 0.33$	$W(\neg prize(3)) = 1.00$
$W(open\_door(2)) = 1.00$	$W(\neg open\_door(2)) = 1.00$
$W(open\_door(3)) = 1.00$	$W(\neg open\_door(3)) = 1.00$
$W(win\_keep) = 1.00$	$W(\neg win\_keep) = 1.00$
$W(win\_switch) = 1.00$	$W(\neg win\_switch) = 1.00$

1.3 Weighted Model Counting

1.3.1 Weighted model counters on above CNFs

We have selected MiniC2D and Cachet as weighted model counters. We have
executed the model counters on DIMACS versions of the CNFs. The DIMACS
files can be found under report/encodings. The output of the model counters
can be found in the listings below.

MiniC2D

MiniC2D needs to be executed with the $-W$ flag in order for it to do weighted
model counting. The resulting probability can be read next to "Count".

Listing 1.1: MiniC2D on ENC1 encoding of Cancer network

```
Constructing CNF... DONE
CNF stats:
  Vars=30 / Clauses=74
  CNF Time       0.000s
Constructing vtree (from primal graph)... DONE
Vtree stats:
  Vtree widths: con<=5, c_con=48 v_con=5
  Vtree Time     0.001s
Counting... DONE
  Learned clauses        0
Cache stats:
  hit rate       75.0%
  lookups        16
  ent count      4
  ent memory     0.2 KB
  ht   memory    152.6 MB
  clists         1.0 ave, 1 max
  keys           3.0b ave, 3.0b max, 3.0b min
Count stats:
  Count Time     0.000s
  Count          0.9999999999999999
Total Time: 0.012s
```

Listing 1.2: MiniC2D on ENC2 encoding of Cancer network

```
Constructing CNF... DONE
CNF stats:
  Vars=20 / Clauses=30
  CNF Time       0.000s
Constructing vtree (from primal graph)... DONE
Vtree stats:
  Vtree widths: con<=6, c_con=16 v_con=6
  Vtree Time     0.000s
Counting... DONE
  Learned clauses        0
Cache stats:
```

```
  hit  rate          23.1%
  lookups            26
  ent  count         20
  ent  memory        1.0 KB
  ht   memory        152.6 MB
  clists             1.0  ave ,  1 max
  keys               1.8b  ave ,  3.0b  max,  1.0b  min
Count  stats :
  Count  Time        0.000 s
  Count              1.0000000000000000
Total  Time:  0.012 s
```

Listing 1.3: MiniC2D on CNF encoding of Monty Hall

```
Constructing  CNF . . .  DONE
CNF  stats :
  Vars=10  /  Clauses=26
  CNF  Time          0.000 s
Constructing  vtree  (from  primal  graph ) . . .  DONE
Vtree  stats :
  Vtree  widths :  con<=4,  c_con=22  v_con=4
  Vtree  Time        0.000 s
Counting . . .  DONE
  Learned  clauses           0
Cache  stats :
  hit  rate          20.0%
  lookups            5
  ent  count         4
  ent  memory        0.2 KB
  ht   memory        152.6 MB
  clists             1.0  ave ,  1 max
  keys               3.2b  ave ,  4.0b  max,  3.0b  min
Count  stats :
  Count  Time        0.000 s
  Count              1.0000000000000000
Total  Time:  0.011 s
```

Cachet

For Cachet, there is no need to use extra parameters to get a probability. It is
reported next to "Satisfying probability".

Listing 1.4: Cachet on ENC1 encoding of Cancer network

```
Number  of  total  components            11
Number  of  split  components            2
Number  of  non−split  components        5
Number  of  SAT  residual  formula       12
Number  of  trivial  components          0
Number  of  changed  components          0
Number  of  adjusted  components         0
```

```
First  component  split  level              1

Number  of  Decisions                       11
Max  Decision  Level                         5
Number  of  Variables                        30
Original  Num  Clauses                       74
Original  Num  Literals                      172
Added  Conflict  Clauses                     0
Added  Conflict  Literals                    0
Deleted  Unrelevant  clauses                 0
Deleted  Unrelevant  literals                0
Number  of  Implications                     124
Total  Run  Time                             0.0163

Satisfying  probability                      8.72319e−08
Number  of  solutions                        93.6645
```

Listing 1.5: Cachet on ENC2 encoding of Cancer network

```
Number  of  total  components               11
Number  of  split  components                2
Number  of  non−split  components            5
Number  of  SAT  residual  formula           12
Number  of  trivial  components              0
Number  of  changed  components              0
Number  of  adjusted  components             0
First  component  split  level              1

Number  of  Decisions                        11
Max  Decision  Level                         5
Number  of  Variables                        20
Original  Num  Clauses                       30
Original  Num  Literals                      84
Added  Conflict  Clauses                     0
Added  Conflict  Literals                    0
Deleted  Unrelevant  clauses                 0
Deleted  Unrelevant  literals                0
Number  of  Implications                     72
Total  Run  Time                             0.017372

Satisfying  probability                      1
Number  of  solutions                        1.04858e+06
```

Listing 1.6: Cachet on WCNF encoding of Monty Hall

```
Number  of  total  components               4
Number  of  split  components                1
Number  of  non−split  components            2
Number  of  SAT  residual  formula           5
Number  of  trivial  components              0
Number  of  changed  components              0
```

Number of adjusted components	0
First component split level	2
Number of Decisions	4
Max Decision Level	4
Number of Variables	10
Original Num Clauses	26
Original Num Literals	73
Added Conflict Clauses	0
Added Conflict Literals	0
Deleted Unrelevant clauses	0
Deleted Unrelevant literals	0
Number of Implications	26
Total Run Time	0.016062
Satisfying probability	0.444444
Number of solutions	455.111

For ENC1, we see that with Cachet reports a satisfying probability of almost 0. Similarly, for Monty Hall, we see that we get a probability of 0.44. This is due to the fact that with ENC1, the weights of negated literals are 1, but Cachet expects that $weight(x) + weight(-x) = 1$. In the Monty Hall encoding, we also have weights of negated literals equalling 1, which gives the same problem as with ENC1.

1.3.2 Difference between the selected WMCs

MiniC2D Vs Cachet

MiniC2D and Cachet are weighted model counters that work in different ways. In short, MiniC2D is a top down compiler that compiles CNFs into SDDs, while Cachet uses formula caching combined with clause learning and component analysis [[1], [2]].

Both weighted model counters use concepts from the SAT literature. They both use clause learning and component caching in order to reuse components that later appear again during search.
Cachet also uses other methods from SAT literature, like an explicit on the fly calculation of connected components. This is different in MiniC2D, as it relies on vtrees to identify disconnected CNF components. MiniC2d creates vtrees for CNFs and then creates SDDs based on the created vtrees.

1.3.3 Overview of computational requirements

We have executed the model counters with various CNFs to build an overview of computational requirements. The files we used for testing can be found under report/encodings. We have used scripts to convert the ".dsc" files to ENC1 and ENC2 encodings in DIMACS format. We downloaded the ".dsc" files from http://www.bnlearn.com/bnrepository/.

Test 1: Cancer network (small)

	ENC1			ENC2		
	Prob	**Memory**	**Runtime**	**Prob**	**Memory**	**Runtime**
Minic2d	1.0	0.2 KB	0.155s	1.0	1.0 KB	0.000s
Cachet	0.0	?	0.016s	1.0	?	0.016s

Test 2: Asia network (small)

	ENC1			ENC2		
	Prob	**Memory**	**Runtime**	**Prob**	**Memory**	**Runtime**
Minic2d	1.0	0.9 KB	0.145s	1.0	2.0 KB	0.139s
Cachet	0.0	?	0.018s	1.0	?	0.017s

Test 3: Sachs network (small)

	ENC1			ENC2		
	Prob	**Memory**	**Runtime**	**Prob**	**Memory**	**Runtime**
Minic2d	0.99707	14.3 KB	0.184s	1.0	14.5 KB	0.154s
Cachet	0.0	?	0.019s	1.0	?	0.017s

Test 4: Earthquake network (small)

	ENC1			ENC2		
	Prob	**Memory**	**Runtime**	**Prob**	**Memory**	**Runtime**
Minic2d	1.0	0.6 KB	0.137s	1.0	1.0 KB	0.153s
Cachet	0.0	?	0.016s	1.0	?	0.017s

Test 5: Survey network (small)

	ENC1			ENC2		
	Prob	**Memory**	**Runtime**	**Prob**	**Memory**	**Runtime**
Minic2d	1.0	1.6 KB	0.125s	1.0	2.0 KB	0.125s
Cachet	0.0	?	0.016s	1.0	?	0.016s

Test 6: Alarm network (medium)

	ENC1			ENC2		
	Prob	**Memory**	**Runtime**	**Prob**	**Memory**	**Runtime**
Minic2d	0.999	819.4 KB	0.215s	0.999	147.2 KB	0.092s
Cachet	0.0	?	0.176s	1.0	?	0.222s

Test 8: Child network (medium)

	ENC1			ENC2		
	Prob	**Memory**	**Runtime**	**Prob**	**Memory**	**Runtime**
Minic2d	1.0	45.8KB	0.076	1.0	30.8 KB	0.059s
Cachet	0.0	?	0.03s	1.0	?	0.03s

Test 9: Hailfinder network (large)

	ENC1			ENC2		
	Prob	**Memory**	**Runtime**	**Prob**	**Memory**	**Runtime**
Minic2d	1.0	129.8 MB	0.999	1.0	13.1 MB	1.854
Cachet	val1	val2	a	b	val3	val4

Test 7: Andes network (very large)

	ENC1			ENC2		
	Prob	**Memory**	**Runtime**	**Prob**	**Memory**	**Runtime**
Minic2d	1.0	5.1GB	246.998s	1.0	364.1 MB	12.06s
Cachet	?	?	$> 4h(killed)$	b	val3	?

1.4 Knowledge compilation

Vtree with the most compact circuit

During our tests

Pattern for a good vtree

As a vtree is a binary tree, which means that a good vtree is compact. We want thus a vtree that is shallow.

Build an Inference Engine

2.0.1 Implementation

We have implemented the pipeline using python. Information about it can be found in `README.MD`.

2.0.2 Pipeline with previous tasks

Cancer Bayesian network

- Probability:

- Total runtime:

- Runtime of the separate parts:

- Number of variables in CNF:

- Number of lines in CNF:

- Depth of vtree:

- Number of edges and nodes in the circuit:

Monty Hall

- Probability:

- Total runtime:

- Runtime of the separate parts:

- Number of variables in CNF:

- Number of lines in CNF:

- Depth of vtree:

- Number of edges and nodes in the circuit:

2.0.3 Pipeline on Bayesian learning example

DAS NEN DIKKE VETTE TODO

- Probability:

- Total runtime:

- Runtime of the separate parts:

- Number of variables in CNF:

- Number of lines in CNF:

- Depth of vtree:

- Number of edges and nodes in the circuit:

2.0.4 Pipeline on alarm Bayesian network

GOD DAMN IT STOM VAK HOE MOETEN WIJ DIT IN 50 UUR DOEN? PROCESS WORDT GEWOON GEKILLED OMDAT DIE CNF GIGANTISCH GROOT WORDT.

- Probability:

- Total runtime:

- Runtime of the separate parts:

- Number of variables in CNF:

- Number of lines in CNF:

- Depth of vtree:

- Number of edges and nodes in the circuit:

Parameter Learning

learning

Appendix

4.1 ENC1

Indicator clauses:

$$(\neg\,\lambda_{PollutionLow} \lor \neg\,\lambda_{PollutionHigh}) \land (\lambda_{PollutionLow} \lor \lambda_{PollutionHigh}) \land (\neg\,\lambda_{SmokerTrue} \lor \neg\,\lambda_{SmokerFalse}) \land (\lambda_{SmokerTrue} \lor \lambda_{SmokerFalse}) \land (\neg\,\lambda_{CancerTrue} \lor \neg\,\lambda_{CancerFalse}) \land (\lambda_{CancerTrue} \lor \lambda_{CancerFalse}) \land (\neg\,\lambda_{XrayPositive} \lor \neg\,\lambda_{XrayNegative}) \land (\lambda_{XrayPositive} \lor \lambda_{XrayNegative}) \land (\neg\,\lambda_{DyspnoeaTrue} \lor \neg\,\lambda_{DyspnoeaFalse}) \land (\lambda_{DyspnoeaTrue} \lor \lambda_{DyspnoeaFalse})$$

Parameter clauses:

$$(\neg\,\lambda_{PollutionLow} \lor \theta_{PollutionLow}) \land (\lambda_{PollutionLow} \lor \neg\,\theta_{PollutionLow}) \land (\neg\,\lambda_{PollutionHigh} \lor \theta_{PollutionHigh}) \land (\lambda_{PollutionHigh} \lor \neg\,\theta_{PollutionHigh}) \land (\neg\,\lambda_{SmokerTrue} \lor \theta_{SmokerTrue}) \land (\lambda_{SmokerTrue} \lor \neg\,\theta_{SmokerTrue}) \land (\neg\,\lambda_{SmokerFalse} \lor \theta_{SmokerFalse}) \land (\lambda_{SmokerFalse} \lor \neg\,\theta_{SmokerFalse}) \land (\neg\,\lambda_{PollutionLow} \lor \neg\,\lambda_{SmokerTrue} \lor \neg\,\lambda_{CancerTrue} \lor \theta_{CancerTrue|PollutionLow,SmokerTrue}) \land (\lambda_{PollutionLow} \lor \neg\,\theta_{CancerTrue|PollutionLow,SmokerTrue}) \land (\lambda_{SmokerTrue} \lor \neg\,\theta_{CancerTrue|PollutionLow,SmokerTrue}) \land (\lambda_{CancerTrue} \lor \neg\,\theta_{CancerTrue|PollutionLow,SmokerTrue}) \land (\neg\,\lambda_{PollutionLow} \lor \neg\,\lambda_{SmokerTrue} \lor \neg\,\lambda_{CancerFalse} \lor \theta_{CancerFalse|PollutionLow,SmokerTrue}) \land (\lambda_{PollutionLow} \lor \neg\,\theta_{CancerFalse|PollutionLow,SmokerTrue}) \land (\lambda_{SmokerTrue} \lor \neg\,\theta_{CancerFalse|PollutionLow,SmokerTrue}) \land (\lambda_{CancerFalse} \lor \neg\,\theta_{CancerFalse|PollutionLow,SmokerTrue}) \land (\neg\,\lambda_{PollutionLow} \lor \neg\,\lambda_{SmokerFalse} \lor \neg\,\lambda_{CancerTrue} \lor \theta_{CancerTrue|PollutionLow,SmokerFalse}) \land (\lambda_{PollutionLow} \lor \neg\,\theta_{CancerTrue|PollutionLow,SmokerFalse}) \land (\lambda_{SmokerFalse} \lor \neg\,\theta_{CancerTrue|PollutionLow,SmokerFalse}) \land (\lambda_{CancerTrue} \lor \neg\,\theta_{CancerTrue|PollutionLow,SmokerFalse}) \land (\neg\,\lambda_{PollutionLow} \lor \neg\,\lambda_{SmokerFalse} \lor \neg\,\lambda_{CancerFalse} \lor \theta_{CancerFalse|PollutionLow,SmokerFalse}) \land (\lambda_{PollutionLow} \lor \neg\,\theta_{CancerFalse|PollutionLow,SmokerFalse}) \land (\lambda_{SmokerFalse} \lor \neg\,\theta_{CancerFalse|PollutionLow,SmokerFalse}) \land (\lambda_{CancerFalse} \lor \neg\,\theta_{CancerFalse|PollutionLow,SmokerFalse}) \land (\neg\,\lambda_{PollutionHigh} \lor \neg\,\lambda_{SmokerTrue} \lor \neg\,\lambda_{CancerTrue} \lor \theta_{CancerTrue|PollutionHigh,SmokerTrue}) \land (\lambda_{PollutionHigh} \lor \neg\,\theta_{CancerTrue|PollutionHigh,SmokerTrue}) \land (\lambda_{SmokerTrue} \lor \neg\,\theta_{CancerTrue|PollutionHigh,SmokerTrue}) \land (\lambda_{CancerTrue} \lor \neg\,\theta_{CancerTrue|PollutionHigh,SmokerTrue}) \land (\neg\,\lambda_{PollutionHigh} \lor \neg\,\lambda_{SmokerTrue} \lor \neg\,\lambda_{CancerFalse} \lor \theta_{CancerFalse|PollutionHigh,SmokerTrue}) \land (\lambda_{PollutionHigh} \lor \neg\,$$

$$\theta_{CancerFalse|PollutionHigh,SmokerTrue}) \wedge (\lambda_{SmokerTrue} \vee \neg$$
$$\theta_{CancerFalse|PollutionHigh,SmokerTrue}) \wedge (\lambda_{CancerFalse} \vee \neg$$
$$\theta_{CancerFalse|PollutionHigh,SmokerTrue}) \wedge (\neg \lambda_{PollutionHigh} \vee \neg \lambda_{SmokerFalse} \vee$$
$$\neg \lambda_{CancerTrue} \vee \theta_{CancerTrue|PollutionHigh,SmokerFalse}) \wedge (\lambda_{PollutionHigh} \vee \neg$$
$$\theta_{CancerTrue|PollutionHigh,SmokerFalse}) \wedge (\lambda_{SmokerFalse} \vee \neg$$
$$\theta_{CancerTrue|PollutionHigh,SmokerFalse}) \wedge (\lambda_{CancerTrue} \vee \neg$$
$$\theta_{CancerTrue|PollutionHigh,SmokerFalse}) \wedge (\neg \lambda_{PollutionHigh} \vee \neg \lambda_{SmokerFalse} \vee$$
$$\neg \lambda_{CancerFalse} \vee \theta_{CancerFalse|PollutionHigh,SmokerFalse}) \wedge (\lambda_{PollutionHigh} \vee \neg$$
$$\theta_{CancerFalse|PollutionHigh,SmokerFalse}) \wedge (\lambda_{SmokerFalse} \vee \neg$$
$$\theta_{CancerFalse|PollutionHigh,SmokerFalse}) \wedge (\lambda_{CancerFalse} \vee \neg$$
$$\theta_{CancerFalse|PollutionHigh,SmokerFalse}) \wedge (\neg \lambda_{CancerTrue} \vee \neg \lambda_{XrayPositive} \vee$$
$$\theta_{XrayPositive|CancerTrue}) \wedge (\lambda_{CancerTrue} \vee \neg \theta_{XrayPositive|CancerTrue}) \wedge$$
$$(\lambda_{XrayPositive} \vee \neg \theta_{XrayPositive|CancerTrue}) \wedge (\neg \lambda_{CancerTrue} \vee \neg$$
$$\lambda_{XrayNegative} \vee \theta_{XrayNegative|CancerTrue}) \wedge (\lambda_{CancerTrue} \vee \neg$$
$$\theta_{XrayNegative|CancerTrue}) \wedge (\lambda_{XrayNegative} \vee \neg \theta_{XrayNegative|CancerTrue}) \wedge (\neg$$
$$\lambda_{CancerFalse} \vee \neg \lambda_{XrayPositive} \vee \theta_{XrayPositive|CancerFalse}) \wedge (\lambda_{CancerFalse} \vee \neg$$
$$\theta_{XrayPositive|CancerFalse}) \wedge (\lambda_{XrayPositive} \vee \neg \theta_{XrayPositive|CancerFalse}) \wedge (\neg$$
$$\lambda_{CancerFalse} \vee \neg \lambda_{XrayNegative} \vee \theta_{XrayNegative|CancerFalse}) \wedge (\lambda_{CancerFalse} \vee$$
$$\neg \theta_{XrayNegative|CancerFalse}) \wedge (\lambda_{XrayNegative} \vee \neg \theta_{XrayNegative|CancerFalse}) \wedge$$
$$(\neg \lambda_{CancerTrue} \vee \neg \lambda_{DyspnoeaTrue} \vee \theta_{DyspnoeaTrue|CancerTrue}) \wedge (\lambda_{CancerTrue}$$
$$\vee \neg \theta_{DyspnoeaTrue|CancerTrue}) \wedge (\lambda_{DyspnoeaTrue} \vee \neg \theta_{DyspnoeaTrue|CancerTrue})$$
$$\wedge (\neg \lambda_{CancerTrue} \vee \neg \lambda_{DyspnoeaFalse} \vee \theta_{DyspnoeaFalse|CancerTrue}) \wedge$$
$$(\lambda_{CancerTrue} \vee \neg \theta_{DyspnoeaFalse|CancerTrue}) \wedge (\lambda_{DyspnoeaFalse} \vee \neg$$
$$\theta_{DyspnoeaFalse|CancerTrue}) \wedge (\neg \lambda_{CancerFalse} \vee \neg \lambda_{DyspnoeaTrue} \vee$$
$$\theta_{DyspnoeaTrue|CancerFalse}) \wedge (\lambda_{CancerFalse} \vee \neg \theta_{DyspnoeaTrue|CancerFalse}) \wedge$$
$$(\lambda_{DyspnoeaTrue} \vee \neg \theta_{DyspnoeaTrue|CancerFalse}) \wedge (\neg \lambda_{CancerFalse} \vee \neg$$
$$\lambda_{DyspnoeaFalse} \vee \theta_{DyspnoeaFalse|CancerFalse}) \wedge (\lambda_{CancerFalse} \vee \neg$$
$$\theta_{DyspnoeaFalse|CancerFalse}) \wedge (\lambda_{DyspnoeaFalse} \vee \neg \theta_{DyspnoeaFalse|CancerFalse})$$

Weights:
$W(\lambda_{PollutionLow}) = 1.00$
$W(\neg\lambda_{PollutionLow}) = 1.00$
$W(\lambda_{PollutionHigh}) = 1.00$
$W(\neg\lambda_{PollutionHigh}) = 1.00$
$W(\lambda_{SmokerTrue}) = 1.00$
$W(\neg\lambda_{SmokerTrue}) = 1.00$
$W(\lambda_{SmokerFalse}) = 1.00$
$W(\neg\lambda_{SmokerFalse}) = 1.00$
$W(\lambda_{CancerTrue}) = 1.00$
$W(\neg\lambda_{CancerTrue}) = 1.00$
$W(\lambda_{CancerFalse}) = 1.00$
$W(\neg\lambda_{CancerFalse}) = 1.00$
$W(\lambda_{XrayPositive}) = 1.00$
$W(\neg\lambda_{XrayPositive}) = 1.00$
$W(\lambda_{XrayNegative}) = 1.00$
$W(\neg\lambda_{XrayNegative}) = 1.00$
$W(\lambda_{DyspnoeaTrue}) = 1.00$
$W(\neg\lambda_{DyspnoeaTrue}) = 1.00$
$W(\lambda_{DyspnoeaFalse}) = 1.00$
$W(\neg\lambda_{DyspnoeaFalse}) = 1.00$

$W(\theta_{PollutionLow}) = 0.90$
$W(\neg\theta_{PollutionLow}) = 1.00$
$W(\theta_{PollutionHigh}) = 0.10$
$W(\neg\theta_{PollutionHigh}) = 1.00$
$W(\theta_{SmokerTrue}) = 0.30$
$W(\neg\theta_{SmokerTrue}) = 1.00$
$W(\theta_{SmokerFalse}) = 0.70$
$W(\neg\theta_{SmokerFalse}) = 1.00$
$W(\theta_{CancerTrue|PollutionLow,SmokerTrue}) = 0.03$
$W(\neg\theta_{CancerTrue|PollutionLow,SmokerTrue}) = 1.00$
$W(\theta_{CancerFalse|PollutionLow,SmokerTrue}) = 0.97$
$W(\neg\theta_{CancerFalse|PollutionLow,SmokerTrue}) = 1.00$
$W(\theta_{CancerTrue|PollutionLow,SmokerFalse}) = 0.00$
$W(\neg\theta_{CancerTrue|PollutionLow,SmokerFalse}) = 1.00$
$W(\theta_{CancerFalse|PollutionLow,SmokerFalse}) = 1.00$
$W(\neg\theta_{CancerFalse|PollutionLow,SmokerFalse}) = 1.00$
$W(\theta_{CancerTrue|PollutionHigh,SmokerTrue}) = 0.05$
$W(\neg\theta_{CancerTrue|PollutionHigh,SmokerTrue}) = 1.00$
$W(\theta_{CancerFalse|PollutionHigh,SmokerTrue}) = 0.95$
$W(\neg\theta_{CancerFalse|PollutionHigh,SmokerTrue}) = 1.00$
$W(\theta_{CancerTrue|PollutionHigh,SmokerFalse}) = 0.02$
$W(\neg\theta_{CancerTrue|PollutionHigh,SmokerFalse}) = 1.00$
$W(\theta_{CancerFalse|PollutionHigh,SmokerFalse}) = 0.98$
$W(\neg\theta_{CancerFalse|PollutionHigh,SmokerFalse}) = 1.00$
$W(\theta_{XrayPositive|CancerTrue}) = 0.90$
$W(\neg\theta_{XrayPositive|CancerTrue}) = 1.00$
$W(\theta_{XrayNegative|CancerTrue}) = 0.10$
$W(\neg\theta_{XrayNegative|CancerTrue}) = 1.00$
$W(\theta_{XrayPositive|CancerFalse}) = 0.20$
$W(\neg\theta_{XrayPositive|CancerFalse}) = 1.00$
$W(\theta_{XrayNegative|CancerFalse}) = 0.80$
$W(\neg\theta_{XrayNegative|CancerFalse}) = 1.00$
$W(\theta_{DyspnoeaTrue|CancerTrue}) = 0.65$
$W(\neg\theta_{DyspnoeaTrue|CancerTrue}) = 1.00$
$W(\theta_{DyspnoeaFalse|CancerTrue}) = 0.35$
$W(\neg\theta_{DyspnoeaFalse|CancerTrue}) = 1.00$
$W(\theta_{DyspnoeaTrue|CancerFalse}) = 0.30$
$W(\neg\theta_{DyspnoeaTrue|CancerFalse}) = 1.00$
$W(\theta_{DyspnoeaFalse|CancerFalse}) = 0.70$
$W(\neg\theta_{DyspnoeaFalse|CancerFalse}) = 1.00$

4.2   ENC2

Indicator clauses

$(\neg\,\lambda_{PollutionLow} \vee \neg\,\lambda_{PollutionHigh}) \wedge (\lambda_{PollutionLow} \vee \lambda_{PollutionHigh}) \wedge (\neg\,\lambda_{SmokerTrue} \vee \neg\,\lambda_{SmokerFalse}) \wedge (\lambda_{SmokerTrue} \vee \lambda_{SmokerFalse}) \wedge (\neg$

$\lambda_{CancerTrue} \lor \neg\, \lambda_{CancerFalse}) \land (\lambda_{CancerTrue} \lor \lambda_{CancerFalse}) \land (\neg$
$\lambda_{XrayPositive} \lor \neg\, \lambda_{XrayNegative}) \land (\lambda_{XrayPositive} \lor \lambda_{XrayNegative}) \land (\neg$
$\lambda_{DyspnoeaTrue} \lor \neg\, \lambda_{DyspnoeaFalse}) \land (\lambda_{DyspnoeaTrue} \lor \lambda_{DyspnoeaFalse})$

Parameter clauses

$(\neg\, \rho_{PollutionLow} \lor \lambda_{PollutionLow}) \land (\rho_{PollutionLow} \lor \lambda_{PollutionHigh}) \land (\neg$
$\rho_{SmokerTrue} \lor \lambda_{SmokerTrue}) \land (\rho_{SmokerTrue} \lor \lambda_{SmokerFalse}) \land (\neg$
$\lambda_{PollutionLow} \lor \neg\, \lambda_{SmokerTrue} \lor \neg\, \rho_{CancerTrue|PollutionLow,SmokerTrue} \lor$
$\lambda_{CancerTrue}) \land (\neg\, \lambda_{PollutionLow} \lor \neg\, \lambda_{SmokerTrue} \lor$
$\rho_{CancerTrue|PollutionLow,SmokerTrue} \lor \lambda_{CancerFalse}) \land (\neg\, \lambda_{PollutionLow} \lor \neg$
$\lambda_{SmokerFalse} \lor \neg\, \rho_{CancerTrue|PollutionLow,SmokerFalse} \lor \lambda_{CancerTrue}) \land (\neg$
$\lambda_{PollutionLow} \lor \neg\, \lambda_{SmokerFalse} \lor \rho_{CancerTrue|PollutionLow,SmokerFalse} \lor$
$\lambda_{CancerFalse}) \land (\neg\, \lambda_{PollutionHigh} \lor \neg\, \lambda_{SmokerTrue} \lor \neg$
$\rho_{CancerTrue|PollutionHigh,SmokerTrue} \lor \lambda_{CancerTrue}) \land (\neg\, \lambda_{PollutionHigh} \lor \neg$
$\lambda_{SmokerTrue} \lor \rho_{CancerTrue|PollutionHigh,SmokerTrue} \lor \lambda_{CancerFalse}) \land (\neg$
$\lambda_{PollutionHigh} \lor \neg\, \lambda_{SmokerFalse} \lor \neg\, \rho_{CancerTrue|PollutionHigh,SmokerFalse} \lor$
$\lambda_{CancerTrue}) \land (\neg\, \lambda_{PollutionHigh} \lor \neg\, \lambda_{SmokerFalse} \lor$
$\rho_{CancerTrue|PollutionHigh,SmokerFalse} \lor \lambda_{CancerFalse}) \land (\neg\, \lambda_{CancerTrue} \lor \neg$
$\rho_{XrayPositive|CancerTrue} \lor \lambda_{XrayPositive}) \land (\neg\, \lambda_{CancerTrue} \lor$
$\rho_{XrayPositive|CancerTrue} \lor \lambda_{XrayNegative}) \land (\neg\, \lambda_{CancerFalse} \lor \neg$
$\rho_{XrayPositive|CancerFalse} \lor \lambda_{XrayPositive}) \land (\neg\, \lambda_{CancerFalse} \lor$
$\rho_{XrayPositive|CancerFalse} \lor \lambda_{XrayNegative}) \land (\neg\, \lambda_{CancerTrue} \lor \neg$
$\rho_{DyspnoeaTrue|CancerTrue} \lor \lambda_{DyspnoeaTrue}) \land (\neg\, \lambda_{CancerTrue} \lor$
$\rho_{DyspnoeaTrue|CancerTrue} \lor \lambda_{DyspnoeaFalse}) \land (\neg\, \lambda_{CancerFalse} \lor \neg$
$\rho_{DyspnoeaTrue|CancerFalse} \lor \lambda_{DyspnoeaTrue}) \land (\neg\, \lambda_{CancerFalse} \lor$
$\rho_{DyspnoeaTrue|CancerFalse} \lor \lambda_{DyspnoeaFalse})$

Weights

$\mathrm{W}(\lambda_{PollutionLow}) = 1.00$
$\mathrm{W}(\neg\, \lambda_{PollutionLow}) = 1.00$
$\mathrm{W}(\lambda_{PollutionHigh}) = 1.00$
$\mathrm{W}(\neg\, \lambda_{PollutionHigh}) = 1.00$
$\mathrm{W}(\lambda_{SmokerTrue}) = 1.00$
$\mathrm{W}(\neg\, \lambda_{SmokerTrue}) = 1.00$
$\mathrm{W}(\lambda_{SmokerFalse}) = 1.00$
$\mathrm{W}(\neg\, \lambda_{SmokerFalse}) = 1.00$
$\mathrm{W}(\lambda_{CancerTrue}) = 1.00$
$\mathrm{W}(\neg\, \lambda_{CancerTrue}) = 1.00$
$\mathrm{W}(\lambda_{CancerFalse}) = 1.00$
$\mathrm{W}(\neg\, \lambda_{CancerFalse}) = 1.00$
$\mathrm{W}(\lambda_{XrayPositive}) = 1.00$
$\mathrm{W}(\neg\, \lambda_{XrayPositive}) = 1.00$
$\mathrm{W}(\lambda_{XrayNegative}) = 1.00$
$\mathrm{W}(\neg\, \lambda_{XrayNegative}) = 1.00$
$\mathrm{W}(\lambda_{DyspnoeaTrue}) = 1.00$
$\mathrm{W}(\neg\, \lambda_{DyspnoeaTrue}) = 1.00$
$\mathrm{W}(\lambda_{DyspnoeaFalse}) = 1.00$
$\mathrm{W}(\neg\, \lambda_{DyspnoeaFalse}) = 1.00$
$\mathrm{W}(\rho_{PollutionLow}) = 0.90$
$\mathrm{W}(\neg\, \rho_{PollutionLow}) = 0.10$

$W(\rho_{SmokerTrue}) = 0.30$

$W(\neg\ \rho_{SmokerTrue}) = 0.70$

$W(\rho_{CancerTrue|PollutionLow,SmokerTrue}) = 0.03$

$W(\neg\ \rho_{CancerTrue|PollutionLow,SmokerTrue}) = 0.97$

$W(\rho_{CancerTrue|PollutionLow,SmokerFalse}) = 0.00$

$W(\neg\ \rho_{CancerTrue|PollutionLow,SmokerFalse}) = 1.00$

$W(\rho_{CancerTrue|PollutionHigh,SmokerTrue}) = 0.05$

$W(\neg\ \rho_{CancerTrue|PollutionHigh,SmokerTrue}) = 0.95$

$W(\rho_{CancerTrue|PollutionHigh,SmokerFalse}) = 0.02$

$W(\neg\ \rho_{CancerTrue|PollutionHigh,SmokerFalse}) = 0.98$

$W(\rho_{XrayPositive|CancerTrue}) = 0.90$

$W(\neg\ \rho_{XrayPositive|CancerTrue}) = 0.10$

$W(\rho_{XrayPositive|CancerFalse}) = 0.20$

$W(\neg\ \rho_{XrayPositive|CancerFalse}) = 0.80$

$W(\rho_{DyspnoeaTrue|CancerTrue}) = 0.65$

$W(\neg\ \rho_{DyspnoeaTrue|CancerTrue}) = 0.35$

$W(\rho_{DyspnoeaTrue|CancerFalse}) = 0.30$

$W(\neg\ \rho_{DyspnoeaTrue|CancerFalse}) = 0.70$

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