

Course on Artificial Intelligence and Intelligent Systems

Logical-Statistical models and parameter learning in the PRISM system

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1 Introduction

Here we give a brief introduction to the PRISM system based on small examples. For full information about the system, consult the publications [8, 9] and the PRISM web site [7]. Based on logic programming extended with random variables and parameter learning, PRISM appears as a powerful modeling environment, which subsumes a variety of statistically based machine learning approaches such as HMMs, discrete Bayesian networks, stochastic context free grammars, etc., all embedded in a declarative language.

The system can be downloaded for free and is easy to install as it includes its own underlying Prolog system. From version 1.11 (29 oct 2007) it is available in versions for Windows, Linux and Mac OS X.

In section 2, we give an introduction to the basic concepts and mechanisms of PRISM, taken from a paper describing a bioinformatics application of PRISM, which we also briefly mention. Section 3 goes into more details showing how to run and train a Bayesian network using PRISM.

2 Basic PRISM concepts

PRISM [8, 9] is a recent logic-statistical modelling system developed by T. Sato and Y. Kameya. The system is an extension to the Prolog programming language, more specifically the B-Prolog system [10], with discrete random variables called *multi-valued random switches*, abbreviated **msw**'s. The system is sound with respect to a probabilistic least Herbrand model semantics, provided that the different *msw*'s are independent (see the reference above for details). We illustrate the basic concepts by a very simple example; full details can be found in the PRISM users manual, available at the PRISM web site [7].

In the follow PRISM program, we declare by the **values** declaration a random variable **coin**, which may take two different values, **head** and **tail**. The following **set_sw** declaration assigns probabilities to the different possible values. (An **msw** can in general be declared to take an arbitrary number (> 2) of different values.)

```
values(coin, [head,tail]).
set_sw(coin,[0.501, 0.499]).
throw(X):- msw(coin,X).
```

The Prolog rule shows how an **msw** can be used by the call **msw(coin,X)**; when such a call is executed, the variable **X** will achieve one of the possible values, which may be different from time to time, but in the long run reflection the indicated probabilities. The predicate **throw/1** is called a *probabilistic predicate* as it depends on **msw**'s.

If a program execution contains more than one call of the same **msw**, the calls should be thought of as different event with different and independent random variables (but with the same probabilities). So for example, the fragment

```
..., msw(coin,X), msw(coin,Y), ...
```

may indicate an experiment where two coins are thrown, so that the value of $\langle X, Y \rangle$ represents the outcome of that experiment. The following is not good PRISM code,

```
..., msw(coin,X), msw(coin,X), ...
```

as it indicates a dependence between the two random variables indicated by the two `msw` calls.

Let us return to the program above, we can execute the following call,

```
?- throw(X).
```

which will give an answer, perhaps `X=head` and perhaps `X=tail`. The PRISM manual recommends that you query probabilistic predicate in the following way (but the direct way show above seems to work perfectly). or use the following

```
?- sample(throw(X)).
```

Learning probabilities in PRISM

The PRISM system includes advanced machine learning techniques so that it can learn probabilities from a file of sample. Let us consider the program above, but remove the explicit setting of probabilities; declarations are added which indicates that probabilities can be learned from observations of the `throw` predicate contained in a file with name `fileWithThrows.dat` (`.dat` is PRISM's standard extension for files of such observations).

```
values(coin, [head,tail]).
```

```
throw(X):- msw(coin,X).
```

```
target(throw,1).
```

```
data(fileWithThrows).
```

The file `fileWithThrows.dat` may have the following form.

```
throw(head).
```

```
throw(head).
```

```
throw(head).
```

```
throw(tail).
```

```
throw(tail).
```

```
throw(head).
```

```
...
```

```
throw(head).
```

```
throw(tail).
```

Now the command

```
?- learn.
```

When this command finishes, the system will contain probabilities that correspond to the relative frequencies of `heads` and `tails` indicated by the file. However, for more complicated programs as those we will show below, PRISM needs to apply more sophisticated learning algorithms that just counting and calculating averages.

Parameterized random variables as a way to simulate dependent random variables and conditional probabilities

Consider the following legal PRISM declarations.

```
values(rainfall(_), [wet,dry]).
values(sky, [cloudy,clear]).
```

The second one concerning `sky` is as we have seen above, but we include so we can show an example. The first one contains a Prolog variable in its name, at the meaning is that for any possible value of that variable, there exists an `msw` with, in principle, its own probabilities. We may say that it defines an infinite family of `msw`'s, which includes, e.g., `rainfall(monkey)`, `rainfall(monkey)`, and `rainfall(punkey(7))`.

However, in a give application we may often have a idea of which members of the family that are interesting. Consider the following code fragment (in which order of the calls is important).

```
msw(sky,S), msw(rainfall(S), X)
```

The first call will assign to `S` one of the possible values for `sky`, let us say this is `cloudy`. Now the subsequent call becomes `msw(rainfall(cloudy), X)`, and the the value of `X` is determined using the probabilities for `rainfall(cloudy)` whether it be given explicitly or learned. So for example, the probability that we get `S=wet` can be understood as the conditional probability $p(X = \text{wet} \mid S = \text{cloudy})$ or, for short, $p(\text{rain} \mid \text{yes})$.

If these declarations and the code fragment are included in a PRISM program, and we have a training file of samples indicating combinations of values of `sky` and `rainfall`, the learning phase may create a table of the following unconditional and conditional probabilities.

```
p(cloudy)
p(clear)
p(wet | cloudy)
p(wet | clear)
p(dry | cloudy)
p(dry | clear)
```

3 More on using PRISM illustrated by a Bayesian Network

This section gives enough details about PRISM so that the reader should be able to implement his or her own small application. We expect familiarity with the central example of Charniak's paper "Bayesian Networks without Tears" [1].

Let us assume that the program described piece by piece below is given in a file named `famOut.psm` on our computer, and that PRISM has been installed. The following clip from a dialogue with the computer shows how the system is started and the program loaded into the system.

```
$ prism
PRISM 1.9, Sato Lab, TITECH, All Rights Reserved. Mar. 2006
```

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B-Prolog Version 6.8-b3.2, All rights reserved, (C) Afany Software 1994-2005.
| ?- prism(famOut).

3.1 Defining a Bayesian network in PRISM

The following declarations using PRISM's `values` directive define the random variables in the network. We use the principle for indicating dependent variables (corresponding to conditional probabilities), cf. the previous section.

To make clear which variables depend on which, we have given different names to the values taken by each variable, so that “fo is *true*” is represented by the value `foTrue`.

```
values(fo,[foTrue, foFalse]).

values(bp,[bpTrue, bpFalse]).

values(lo(_),[loTrue, loFalse]).
% lo({foTrue,foFalse})

values(do(_,_),[doTrue, doFalse]).
% do({foTrue,foFalse}, {bpTrue,bpFalse})

values(hb(_),[hbTrue, hbFalse]).
% hb({doTrue,doFalse})
```

Notice that PRISM does not make it possible to indicate the intended values for the argument in variables that contain Prolog variables.¹ Therefore we have indicated this by means of comments.

So it appears that `fo` and `pb` are “basic” variables in the sense that they do not depend on other variables; `lo` depends on `fo`, `do` depends on `fo` and `bp`, and `hb` depends on `do`.

A given set of affairs (or a “world”) is given by instantiating the variables in an order that respects the dependencies. We can describe this by the following predicate definitions. We have defined two predicates, one top-level to indicate that we think of `lo` and `hb` as the only observables (cf. Charniak's paper).

```
world(L0, HB):-
    world(_, _, L0, _, HB).

world(F0, BP, L0, DO, HB):-
    msw(fo, F0),
    msw(bp, BP),
    msw(lo(F0), L0),
    msw(do(F0,BP), DO),
    msw(hb(DO), HB).
```

¹In fact, the lack of indication of argument values can be an advantage, as it allows a PRISM program to invent an unlimited number of random variables as it executes.

A call to `world/2` will instantiate a world and return the two observables. For example:

```
?- world(L0,HB).
L0 = loFalse
HB = hbFalse
```

Values have been created for all random variables by PRISM, making the choices using a pseudo-random number generator, but we only see the two observables in this way.

You may ask, where PRISM gets the probabilities from. Well, if you do not specify anything, PRISM assumes an even distribution which in the present example means 50% for either of the two possibilities. One way to provide probabilities to the model is by stating them explicitly as follows.

```
set_params:-
  set_sw(fo, [0.15, 0.85]),
  set_sw(bp, [0.01, 0.99]),

  set_sw(lo(foTrue), [0.6, 0.4]),
  set_sw(lo(foFalse), [0.05, 0.95]),

  set_sw(do(foTrue,bpTrue), [0.99, 0.01]),
  set_sw(do(foTrue,bpFalse), [0.9, 0.1]),
  set_sw(do(foFalse,bpTrue), [0.97, 0.03]),
  set_sw(do(foFalse,bpFalse), [0.3, 0.7]),

  set_sw(hb(doTrue), [0.7, 0.3]),
  set_sw(hb(doFalse), [0.01, 0.99]).
```

Calling now the `set_params` predicate will set the indicated probabilities. These probabilities are taken from Charniak's paper, and we can assume that he has got them either from a qualified statistician or he has postulated them, grounded on his expert knowledge in this problem domain.

Having set these probabilities, we can generate a lot of sample values, which may not be that funny after a while. Notice the *deductive* character of this way of using the network. We use given knowledge (probabilities and dependencies) to predict the expected observable output.

3.2 Estimating probabilities for hidden random variables

It may be more interesting to use the network for *abductive* reasoning: Given observables, i.e., values for `lo` and `hb`, let the model figure out what are the probabilities for different possible values of the hidden or "abducible" variables, say `fo` or `bp`.²

To do make this possible, PRISM implements a concept of *hindsight* probabilities.³ The predicate `chindsight/2` (for conditional hindsight) calculates the different probabilities for the possible instances of the second argument, given the values indicated by the first argument. Assume for example that we have observed that `lo` is true, and `hb` is false, and we want to know the probabilities for the different combinations of values for hidden variables. We can ask PRISM as follows.

²Charniak refers to this process as *evaluating* the net, given the evidence of the values for the observable variables.

³Check the PRISM User's Manual for a full explanation. The system contains a whole bunch of predicates concerned with hindsight probabilities; here we show only a few.

```
?- chindsight( world(loTrue, hbFalse), world(_,_,_,_,_)).
```

conditional hindsight probabilities:

```
world(foFalse,bpFalse,loTrue,doFalse,hbFalse): 0.440219169184873
world(foFalse,bpFalse,loTrue,doTrue,hbFalse): 0.057171320673360
world(foFalse,bpTrue,loTrue,doFalse,hbFalse): 0.000190571068911
world(foFalse,bpTrue,loTrue,doTrue,hbFalse): 0.001867211483271
world(foTrue,bpFalse,loTrue,doFalse,hbFalse): 0.133175546980298
world(foTrue,bpFalse,loTrue,doTrue,hbFalse): 0.363206037218994
world(foTrue,bpTrue,loTrue,doFalse,hbFalse): 0.000134520754526
world(foTrue,bpTrue,loTrue,doTrue,hbFalse): 0.004035622635767
```

It may be the case that we are not interested in the individual probabilities for each combination, but only the probabilities for one of the variables. If for example, our only interest is to find the probabilities for the `fo` variable, we should sum up probabilities for all those combinations that have a given value of `fo`, e.g., for `foTrue` add together probabilities for the following situations (still conditioned by the fixed values for the observables).

```
world(foTrue,bpFalse,loTrue,doFalse,hbFalse)
world(foTrue,bpFalse,loTrue,doTrue,hbFalse)
world(foTrue,bpTrue,loTrue,doFalse,hbFalse)
world(foTrue,bpTrue,loTrue,doTrue,hbFalse)
```

Prism has another predicate which does this for us.

```
?- chindsight_agg( world(loTrue, hbFalse), world(query,_,_,_,_)).
```

conditional hindsight probabilities:

```
world(foFalse,*,*,*,*): 0.499448272410416
world(foTrue,*,*,*,*): 0.500551727589584
```

The suffix “`_agg`” means aggregate value, and the argument indicated as “`query`” is the one we want to see the probabilities for.

So the teamwork between our model and the PRISM systems tells that given observations `loTrue` and `hbFalse`, the probability of `foTrue` is around one half (in fact a tiny little bit above one half, but a bit which is so small that no-one cares since the number concerns a probability).

3.3 Learning probabilities

PRISM contains advanced machine learning algorithms that we do not intend to explain here, but we will show from a user’s perspective how PRISM can learn probabilities from observation.

We continue the example above, and we will assume now, that we have no given probabilities for the random variables in our Bayesian network.

What we can do instead, is to observe the real world and record carefully observations about values of the different variables. We can use PRISM’s learning mechanisms to produce those probabilities that give the best likelihood for the observations.

In order to learn the different probabilities, it is not sufficient to have access to those variables that we referred to previously as observables, but we need access to all variables involved in the

model. Otherwise we would not be able to get any knowledge about the dependencies that lead “backwards” from the observables to hidden ones. PRISM can learn probabilities from data given as a list as well as read in from a file. We will show here how learning is done from data in a file.

For the purpose, we have prepared a file, `famOutData.dat` with 1000 facts about the `world/5` relation, and we assume the file has been produced from true observations.⁴ The file may look as follows.

```
world(foFalse,bpFalse,loFalse,doFalse,hbFalse).
world(foFalse,bpFalse,loFalse,doFalse,hbFalse).
world(foFalse,bpFalse,loTrue,doFalse,hbTrue).
...
world(foFalse,bpFalse,loFalse,doFalse,hbFalse).
world(foFalse,bpFalse,loFalse,doFalse,hbFalse).
world(foFalse,bpFalse,loFalse,doFalse,hbFalse).
```

To learn from the file, we need to include in our program file the following declarations, giving the name of the data file plus the name of the relation it is expected to contain facts about.

```
target(world,5).
data('famOutData.dat').
```

When these are given, we can start the learning phase by the following command.

```
?- learn.
```

Depending on the size of your data and the complexity of the network, it may take some time before an answer is produced (for the present example, the execution time for learning is negligible). You may get an answer that looks somewhat like this.

```
#goals: 0.(16)
#graphs: 0.(16)
#iterations: 0(Converged: -809.999162142)
Finished learning
    Number of tabled subgoals: 16
    Number of switches: 9
    Number of switch values: 18
    Number of iterations: 2
    Final log likelihood: -809.999162
    Total learning time: 0.001 seconds
    All solution search time: 0.000 seconds
    Total table space used: 15184 bytes
Type show_sw to show the probability distributions.
```

The PRISM manual explains the meaning of the different figures, some of them may be a bit difficult to understand. The important one is “Final log likelihood”: The larger negative number, the

⁴There is a slight confusion of terminology, as the PRISM manual refers to all random variables as “observables” in the parts on learning, whereas we used “observables” only for those that are given when the net is used for prediction of the unknowns that we called “hidden”.

more you can trust the generated probabilities. If you train with too few data or your model in some way does not fit the data very well, you get a bad log likelihood (close to 0). If you want to know more about likelihood, you need to read a book about statistics.

We notice that the answer tells how we can check the probabilities, so we do that.

```
?- show_sw.
```

```
Switch bp: unfixed: bpTrue (0.01) bpFalse (0.99)
Switch fo: unfixed: foTrue (0.19) foFalse (0.81)
Switch hb(doFalse): unfixed: hbTrue (0.006410256410256) hbFalse (0.993589743589744)
Switch hb(doTrue): unfixed: hbTrue (0.728723404255319) hbFalse (0.271276595744681)
Switch lo(foFalse): unfixed: loTrue (0.059259259259259) loFalse (0.940740740740741)
Switch lo(foTrue): unfixed: loTrue (0.589473684210526) loFalse (0.410526315789474)
Switch do(foFalse,bpFalse): unfixed: doTrue (0.25) doFalse (0.75)
Switch do(foFalse,bpTrue): unfixed: doTrue (0.8) doFalse (0.2)
Switch do(foTrue,bpFalse): unfixed: doTrue (0.884210526315789) doFalse (0.115789473684211)
Switch do(foTrue,bpTrue): unfixed: doTrue (0.99) doFalse (0.01)
```

We see that these probabilities are relative close to those that were set manually in the above, but in principle, these two sets of probabilities should be considered separately.⁵ We can now use the learned probabilities which are now part of the model, for predicting the probabilities for those variables we called hidden, given values of those we called observables.

```
?- chindsight_agg( world(loTrue, hbFalse), world(query,_,_,_,_)).
```

```
conditional hindsight probabilities:
world(foFalse,*,*,*,*): 0.494708194208929
world(foTrue,*,*,*,*): 0.505291805791071
```

Learning can be done in different ways; we will just mention an example of this. Let us stay with the same symbolic program, but assume it reflects a different system in the real world than the one explained in Charniak's paper. Let us consider the system being a sort of mechanical black box, so that for the learning phase, we have only access to `fo` and `pb` variables (which we can consider as input to the black box) and to `lo` and `hb` that play the role of output from the black box. The variable `do` is completely hidden inside the box, so it is not even available for the learning phase. It seems that our model is useless, but if it is the case that a conditional probability table is given for `do`, for example in the technical specification of the device, we can fix this probability in advance, and then run the learning phase from the available data.

3.4 A final remark on learning

We can consider the learning phase as a sort of *induction*, i.e., learning general principles from observations where the knowledge learned can be used later for prediction. However, learning probabilities only is only half the job that we can call induction in this context. In the example,

⁵We explained that the data file has been created from observations of reality, which they should be in any practical application, but for our little experiment, we used the PRISM to generate the data (in fact, with the probabilities shown above), but don't tell ;-)

we accepted the topology and (in-) dependencies in the model given in advanced, but we could consider also generating this part in an inductive way. In other words, we would ideally prefer an automaton which given a set of observations were able to produce the network as well as the associated probabilities.

Such methods exists (often with manual intervention) are described in, among others, [5, 6].

4 A research project using PRISM: testing gene finders

(This section may be skipped by readers with no interest in biological applications).

A *gene finder* is a program that analyzes genome sequences and generates suggestions for where the sequence the actual genes may be found. This is a very complex problem as a typical genome sequence is million of letters long and the genes comprise only a very small fraction; furthermore, there are no exact or foolproof methods for distinguishing a gene from the rest. There exist a number of competing gene finders, and it is well-known among biologists that they give quite different results.

We have made an experiment by using PRISM for building and training a model and used it for generation such test data; described in the paper [3]. We cite the abstract:

Programs for gene prediction in computational biology are examples of systems for which the acquisition of authentic test data is difficult as these require years of extensive research. This has lead to test methods based on semiartificially produced test data, often produced by *ad hoc* techniques complemented by statistical models such as Hidden Markov Models (HMM). The quality of such a test method depends on how well the test data reflect the regularities in known data and how well they generalize these regularities. So far only very simplified and generalized, artificial data sets have been tested, and a more thorough statistical foundation is required.

We propose to use logic-statistical modelling methods for machine-learning for analyzing existing and manually marked up data, integrated with the generation of new, artificial data. More specifically, we suggest to use the PRISM system developed by Sato and Kameya. Based on logic programming extended with random variables and parameter learning, PRISM appears as a powerful modelling environment, which subsumes HMMs and a wide range of other methods, all embedded in a declarative language. We illustrate these principles here, showing parts of a model under development for genetic sequences and indicate first initial experiments producing test data for evaluation of existing gene finders, exemplified by GENSCAN, HMMGene and genemark.hmm.

The following is the introduction to PRISM used in that paper, which indicates the style in which the genome model is developed; however, see the references paper for more details about the model applied for the experiment.

As an example, we can declare a class of msw's by selecting one out of four different letters at random as follows.

```
values( nextLetter(_), "ACGT").
```

Recall that a string such as "ACGT" is a list of character values, and in general the `values` directive describes a finite list of possible values. The term `nextLetter(_)` includes a logical variable which

means that, for any possible value which is plugged in for that variable, there exists an msw; e.g., `nextLetter(t1)`, `nextLetter(t2)`. The following fragment shows how an msw typically is used within a rule; the arrow-semicolon is Prolog’s generalized if-then-else construction; the notation `0’char` indicates the relevant character code.

```
msw( nextLetter(t1), Letter),
(Letter = 0'A -> ...
; Letter = 0'C -> ...
; Letter = 0'G -> ...
; Letter = 0'T -> ... )
```

The dots indicate the different actions taken for the different outcomes. In this way, it is straightforward to write HMM’s as PRISM programs (additional msw’s may govern state transitions), but the advantage of PRISM is that the full power of Prolog can be used for the modelling process, including recursion. Other models such as discrete Bayesian networks, Stochastic Context-Free Grammars [2], and Hierarchical HMM’s [4] can also be described in straightforward ways, and PRISM can be seen as a high-level tool for defining advanced and directly executable probabilistic models. Conditional probabilities are not supported but may to a large extent be simulated by generic msw names. So for example, $P(a = x|b = y)$ can be simulated by the code `msw(b,Y), msw(a(Y),X)`.

We will show a little example, which also illustrates the modular structure we apply in our model for genome sequences (described in [3]). For the example, we imagine sequences comprising three types of substrings `t1`, `t2`, `t3`, put together in random order and each being sequences of the letters `ACGT` but with different relative frequencies for each type. An annotated sequence may be described by a goal as follows, having the annotations in a separate argument, and numbering the sequence letters starting from 1.

```
sequence("AAAACGCGCG", [t1(1,4),t2(5,10)])
```

The annotation is a sequence of descriptors for each subsequence. The following msw’s govern the composition of subsequence of different types.

```
values( nextSubstringType(_), [t1,t2,t3] ).
values( continueSeq, [yes,no]).
```

The argument to the first one describes the type of a previous subsequence; the last one determines no. of subsequence, the higher probability for `yes`, the longer sequence.⁶ The following rule describes the composition at subsequence level. An arbitrary “previous type” called `start` is assumed for the first subsequence, and an extra argument, which keeps track of position in the string, is added; evidently this is a HMM with 5 states, the last one being the implicit final state.

```
seq(Seq,D) :- seq(start,Seq,D,1).
```

```
seq(PrevType,Seq,[D1|DMore],N) :-
  msw(nextSubstringType(PrevType), SubT),
  subSeq(SubT,D1,Seq,SeqMore,N,M),
  msw(continueSeq, YesNo),
  (YesNo=no -> SeqMore=[], DMore = []
; Mplus1 is M+1, seq(SubT,SeqMore,DMore,Mplus1)).
```

⁶As is well-known from HMMs this gives a geometric distribution of lengths.

For each type T , we need to add an appropriate clause `subSeq(T, ...):- ...`. To finish this example, we assume identical definition (but individual probabilities) for each type.

```
subSeq(Type, [L|SeqMore], SeqRest, N, M) :-
    msw(nextLetter(Type), L),
    msw(continueSub(Type), YesNo),
    (YesNo=no -> SeqMore=SeqRest, N=M
     ; Nplus1 is N+1, subSeq(Type, SeqMore, SeqRest, Nplus1, M)).
```

Notice that we assumed an additional class of `msw`'s to govern the length of each subtype (so this little model resembles a 2-level Hierarchical HMM). Such a program can be used in two ways in the PRISM system. In case the probabilities are given in some way or another, the program can be used to generate samples of annotated sequences by a query `?-sample(sequence(S,A))` where PRISM executes `msw` by using a random number generator adjusted to the given probabilities. PRISM can also run in *learner mode*, which means that the program is presented with a number of observed goals, from which it calculates the distribution of probabilities that provides the highest likelihood for explaining the observed data. PRISM uses some quite advanced algorithms and data structures in order to do this in an efficient way; these topics are outside the scope of this paper and we refer to [8, 9]. Training with a single observation (somewhat artificial) being the short annotated sequence above, we get for τ_1 prob. 1.0 for **A** and for τ_2 prob. 0.5 for each of **C** and **G**. After the training phase, sampling can be used to create *similar* sequences, where the applied notion of similarity is implied by the program, i.e., the model for sequence structure that we designed above. PRISM runs also on 64-bit architectures so it can address quite large amounts of storage. The current version (1.9, 2006) can, with programs as the one shown, easily handle data sets of around 10 sequences of 100,000 letters.

5 Exercises

5.1 Power supply, revisited with probabilities

(Identical to an exercise in a earlier note)

We consider the example of a power supply network that we used in an earlier exercises, where you should design an an abductive logic program which could be used to diagnose faults in the network. The text is rephrased here to make this exercise self-contained.

We consider a geographical region which has a power supply control centre that gets informed as soon as any village in the region is without electricity power. In such cases, the centre checks, using mobil phones, whether the remaining villages have electricity power. On the basis of this information, the centre must take the decision of where to send the repair teams. Our job is to develop a diagnosis system that given the information of which villages have or have not electricity power, can give suggestions for which wires or power plants that might be down, and thus are candidates for repair.

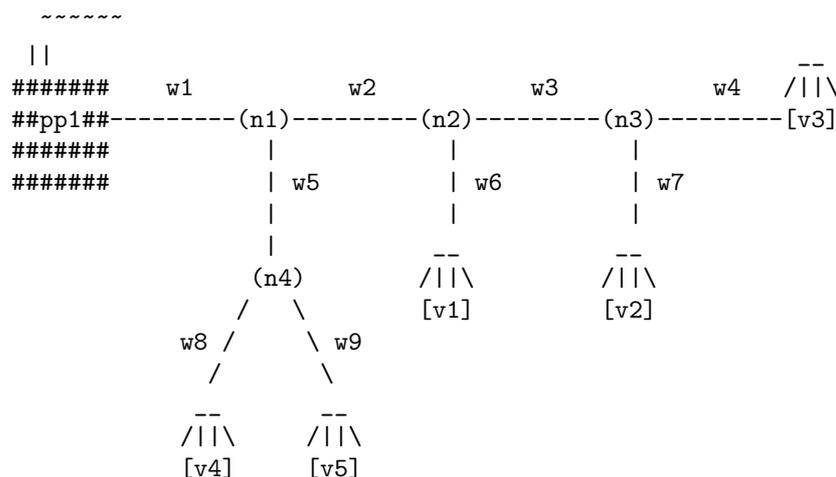
For this application, it seems reasonable to take the consistent fault assumption, as if a wire is down, it will stay down until it is repaired.

A given wire w will be in one of two states, `state(w,up)` or `state(w,down)`, so a diagnosis is a combination of abducibles concerning the different wires in the region. There is also a risk that

the power plants in the region can go down, so a diagnosis may also contain abducibles such as `state(pp,down)` where `pp` refers to a power plant.

Observations are sets of “goals” of the form `has_power(v)` or `has_no_power(v)` where `v` refers to a village. In a given situation, we may have such information about all or just some villages.

The electricity power network can be depicted as follows; `pp1` is the only power plant in this region, `w1–9` are the wires, `n1–4` are nodes in which a number of wires are connected, and `v1–v4` are the villages.



We have elementary probabilities for each wire as well as the power plant being up and down, and some conditional probabilities for nodes and villages of having electricity.

Draw a graph for the Bayesian network that describes the relationships between the different probabilities, and suggest reasonable conditional truth tables. NB: You do not need to use probabilities of 1.0 and 0.0 only as there may be positive (but likely small) probability that electricity do not propagate from one location to an adjacent even in case the connection wire is up.

Make a forward calculation using your network, to find the probability that `v4` has power, given that every component in the net is up.

5.2 Probabilistic abduction: Bayesian network in PRISM

Implement the Bayesian network that you produced in exercise 4.1 above in PRISM. Test it on queries that corresponds to the following situations to find out probabilities for the possible explanations.

- `v3` is the only one without power.
- `v3` is without power; we lack information about `v2`; anyone else has power.
- `v2` and `v3` are without power; anyone else has power.
- `v4` and `v5` has power; anyone else has no power.
- No-one has power.

- Is it possible to query you network for the following, and how: What is the probability that v2 has power, given that v3 has no power.

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