Probabilistic Logic Models and Their Application to Breast Cancer

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Motivation

Breast cancer is one of the most common forms of cancer and diagnosis may require:

- **mammogram** most commonly used technique to detect patients at risk.
- **biopsy** image-guided core needle biopsy of the breast performed to decide on surgery.
- **excision** in the cases where biopsies yield non-definitive results.

5–15% of all biopsies are non-definitive but **only 15–20%** of those are malignant.

Benefits of PILP in medical data analysis:

- Medical data is suitable for relational data mining due to the **complex interactions** existing between different entities.
- PILP combines the relational nature of medical data with the ambiguity of human interpretation of medical imaging.
- PILP models can be used as an automated decision support system, conducive to rigorous and **accurate risk estimation** of rare events.

PILP and Medical Data

Probabilistic Inductive Logic Programming (PILP) extends ILP by:

- dealing with **probabilistic** facts and rules.
- learning FOL theories which predict a **probabilistic** value.

PILP (and ILP) are suitable tools to analyse **medical data** because:

- the FOL models are easily **interpretable** by human experts.
- they can be used as an automated **decision support system** to aid physicians during diagnostic.

Methodology

The dataset includes:

- 130 biopsies from Jan 06 to Dec 11 collected from the School of Medicine and Public Health of the University of Wisconsin-Madison (21 malignant and 109 benign cases).
- Domain knowledge annotated both prospectively and retrospectively by **experts of different areas**.
- **Demographic-related variables** about the patient and the biopsy procedure and BI-RADS annotations.

Probabilistic data was added to:

- Probabilistic Examples: the **confidence in malignancy** given by a multidisciplinary group of physicians (before excision).
- Probabilistic Background Knowledge (PBK): breast cancer **literature values** were used to complement the information on the characteristics of masses.

The model induced outputs a probabilistic value for the malignancy of a case, according to the physicians' mental model.

Why train the model using physicians' predictions?

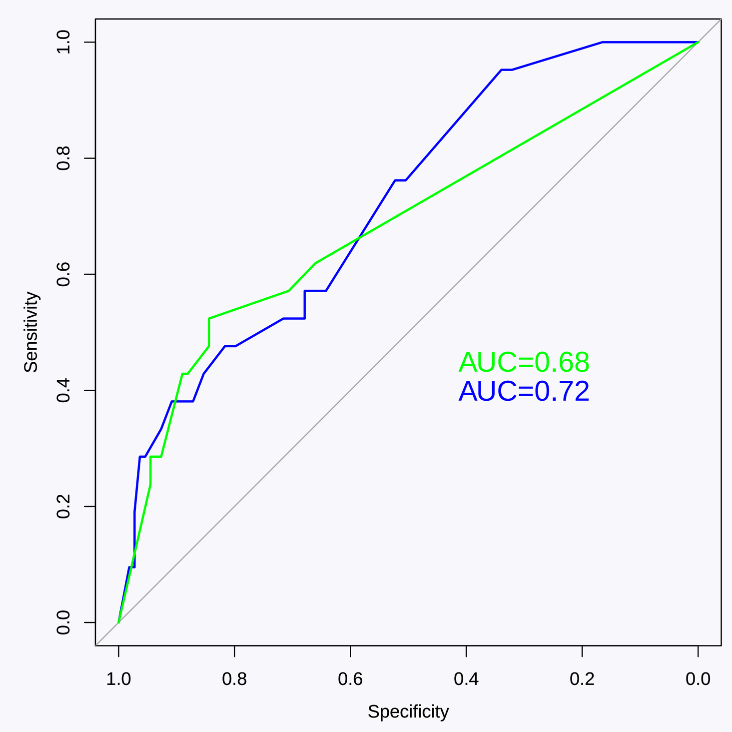
- Probabilities are better **calibrated** with physicians' estimates.
- When predictions are far from the ground truth, the model can be analysed to determine why and the reason given to the experts.

Experiments

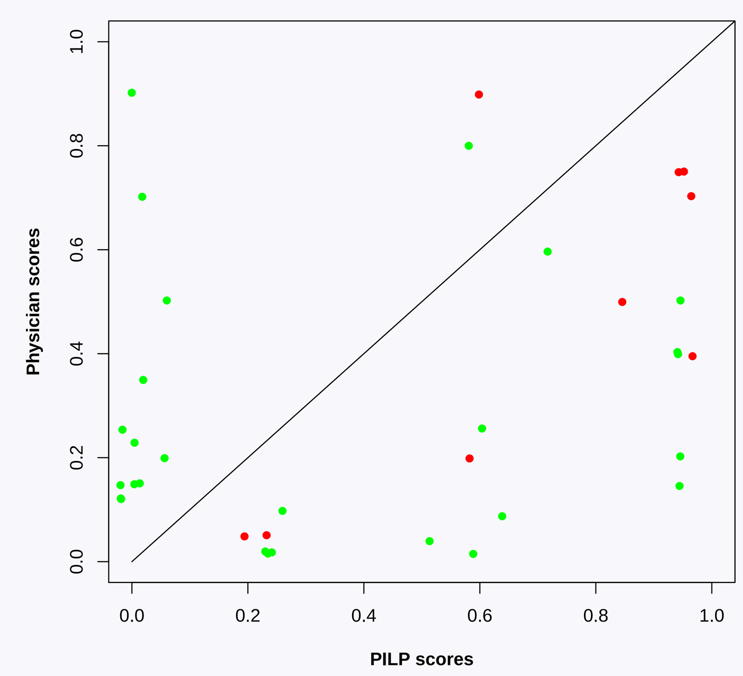
The following experiments were performed:

1. predicting ground truth using the PILP model and the physicians' predictions and compare the ROC curves.
2. analysing predictions for cases where the PILP and the physicians' predictions are divergent.
3. conducting an exploratory analysis of the dataset.

Experimental Results



p-value using DeLong's test for two correlated ROC curves: 0.4476 PILP and a physician predictions are statistically indistinguishable



For 8 of the 9 malignant cases, PILP predicts a **significantly higher** malignancy value than physicians do (red points under the diagonal line).

Model

```
is_malignant(Case):-
    biopsyProcedure(Case,usCore),
    changes_Sizeinc(Case,missing),
    feature_shape(Case).

is_malignant(Case):-
    assoFinding(Case,asymmetry),
    breastDensity(Case,scatteredFDensities),
    vacuumAssisted(Case,yes).

is_malignant(Case):-
    needleGauge(Case,9),
    offset(Case,14),
    vacuumAssisted(Case,yes).
```

Conclusion

In this work:

- We combine FOL with probabilistic data in order to obtain **interpretable models**.
- Results show that a PILP model predictions on the test sets are **statistically indistinguishable** of the experts' predictions.
- When PILP predictions differ from expert values, PILP consistently assigns **high malignancy probabilities** to malignant cases.
- The model explicitly uses **well-known medical features** to explain malignancy.

Future work includes comparing against other methods to predict malignancy and adding other relevant medical literature values to the model.

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