Bayesian decision network for monitoring p50 in critically-ill patients

Victoria Volodina[1]*, Alejandro Diaz De La O[1], and Samiran Ray[1]
[1]Clinical Operational Research Unit, Department of Mathematics, UCL *v.volodina@ucl.ac.uk

Introduction and context

- At ICU, a colossal amount of data about patients from monitoring equipment is collected and stored.
- Only a small fraction of data is used to inform the decisions around patients' care.
- Complex computational models are increasingly used in the numerical modelling of the biological systems surrounding chronic diseases.
- Clinicians are interested to synthesise these various sources of information to develop new and more effective treatment plans.

Methods

We propose to employ a Bayesian decision network (BDN) [1,2] to systematically integrate this complex array of information. The graph in Figure 1 captures the relationships between health indicators (variables), denoted as $\mathbf{Y} = (Y_1, Y_2, Y_3, Y_4)$, and is specified based on consultations with clinicians and modellers.

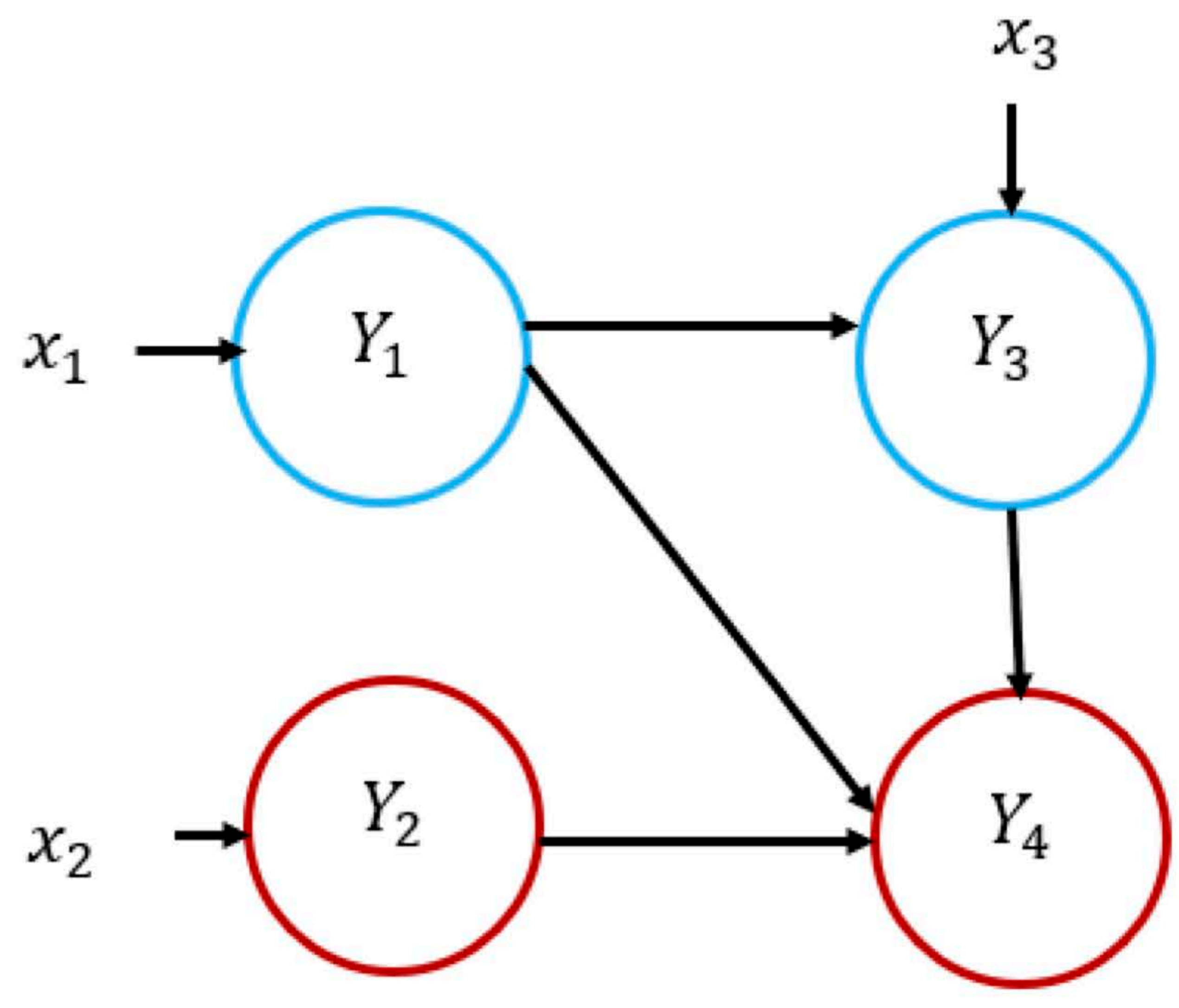

Figure 1: **A directed acyclic graph (DAG) for a Bayesian graphical network model.**

To perform the inference about **Y**, generally we require:

joint probability density function

$$p(\mathbf{Y}|\mathbf{x}) = \prod_{v \in V} p(Y_v | \mathbf{Y}_{pa(v)}, \mathbf{x}), \quad (1)$$

where V is the set of vertices and $pa(v)$ is the set of parents of v and $\mathbf{x} = (x_1, x_2, x_3)$.

In practice, Equation (1) doesn't have a closed-form. Decision-makers are mainly interested in a few small summaries of key indicators of interest, for a example a few low-order moments.

We can iteratively compute

law of total expectation (tower rule):

$$E(Y_v|\mathbf{x}) = E\Big(E(Y_v|\mathbf{Y}_{pa(v)}, \mathbf{x})\Big) \quad (2)$$

and **law of total variance:**

$$V(Y_v|\mathbf{x}) = E\Big(V(Y_v|\mathbf{Y}_{pa(v)}, \mathbf{x})\Big) + V\Big(E(Y_v|\mathbf{Y}_{pa(v)}, \mathbf{x})\Big) \quad (3)$$

to obtain low-order moments of variables of interest **Y**.

Clinical Application

- Haemoglobin transports oxygen around the body from lungs to the tissues.
- The affinity with which haemoglobin (Hb) binds oxygen (O2) depends on the concentration of oxygen (partial pressure, PaO2) and is defined by the **oxygen dissociation curve** (see Figure 2).
- The curve is characterised by a single number, **p50** = the PaO2 when the Hb oxygen saturation (SaO2) is 50%.

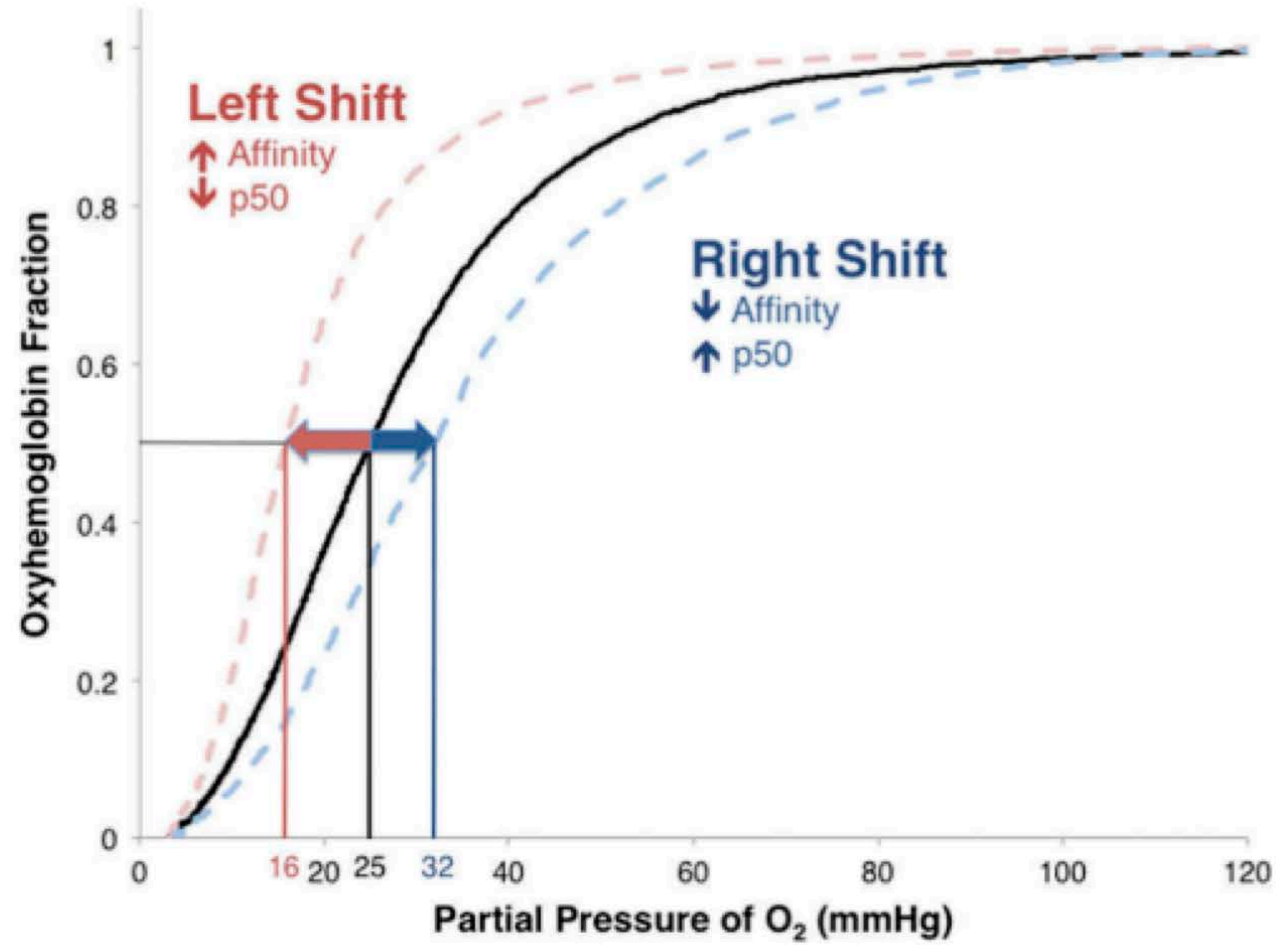

Figure 2: **The oxygen dissociation curve. Adopted from [3].**

A number of factors such as changes in pH, CO2, temperature and 2,3 DPG can shift the curve and change p50 as demonstrated in Figure 3.

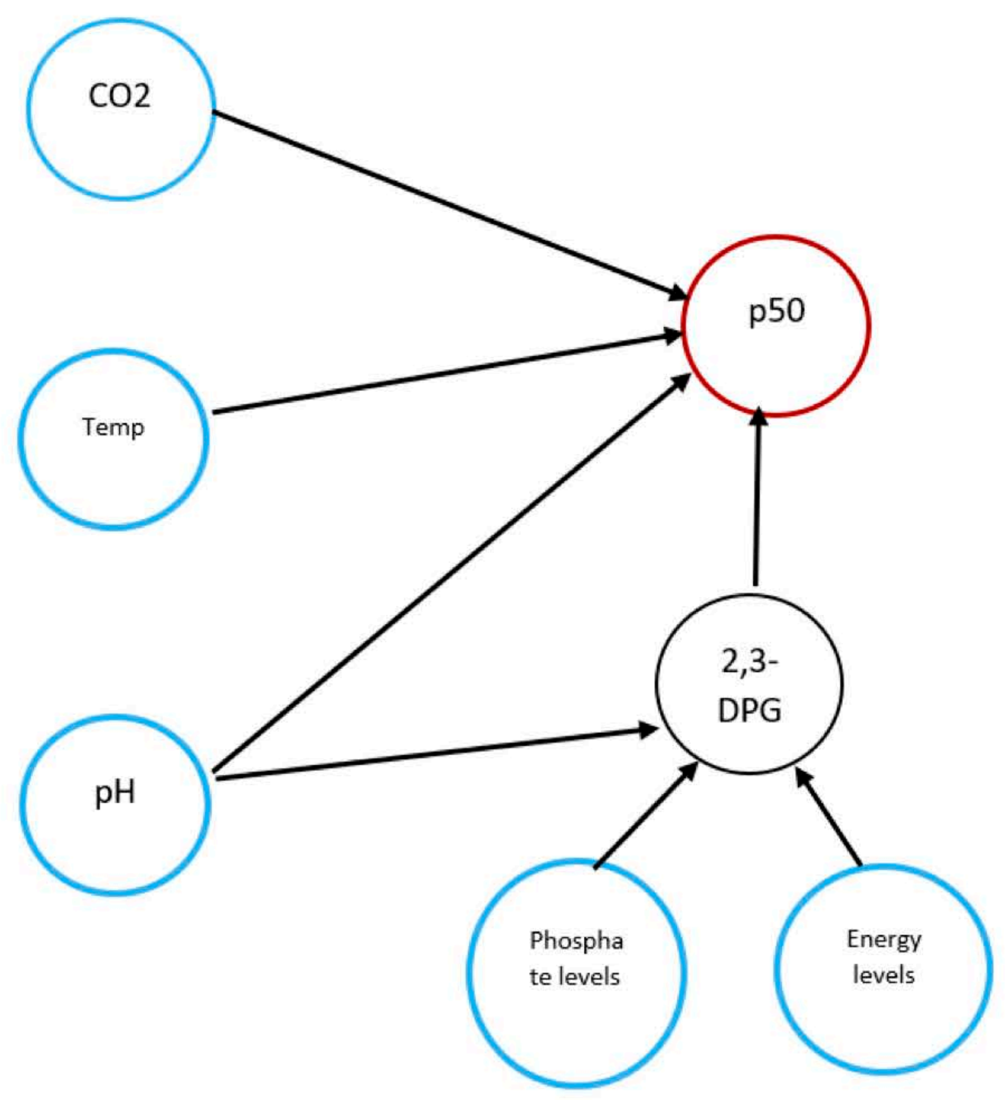

Figure 3: **DAG for clinical application (nodes in blue and red are informed by patient's data and computational model respectively).**

Future plans and research questions

- Use time-series data and computational model output to fit the parameters of the Bayesian network.
- Investigate the effects of ICU interventions (blood transfusion and ventilation) on p50.
- Investigate the effect of patient's condition (COVID-19/no COVID-19) on p50.

References