Why

We can cast various common probabilistic regression models into the probabilistic errors linear model by mentioning the input space and feature maps. This unifies our analysis.

Definition

A *line fit model* has input space $\mathbf{R}$ and output space $\mathbf{R}$. We use a regression function $\phi : \mathbf{R} \to \mathbf{R}^2$ defined by $\phi(t) = (1, t)^\top$.

We think of $t \in T \subset \mathbf{R}$ as a "dose level" (T is an interval). Given dose levels $t_1, \ldots, t_\ell$ and repetitions $n_1, \ldots, n_\ell$ we obtain the design matrix. Here the regression function generates a line segment embedded in the plane $\mathbf{R}^2$. We call the parameters the *intercept parameter* and *slope parameter*.

A *parabola fit model* has input space $\mathbf{R}$ and output space $\mathbf{R}$. We use a regression function $\phi : \mathbf{R} \to \mathbf{R}^3$ defined by $\phi(t) = (1, t, t^2)^\top$. Here the regression space is a segment of a parabola embedded in space $\mathbf{R}^3$ (since $t \in T$ an interval).

These two are instance of *polynomial fit models* of degree $d \geq 1$, in which the regression function becomes $\phi : \mathbf{R} \to \mathbf{R}^{d+1}$ defined by $\phi(t) = (1, t, t^2, \ldots, t^d)^\top$. In this case, the regression range $\phi(T)$ is a one-dimensional curve embedded in $\mathbf{R}^{d+1}$. In cases in which it is clear that the input space is a single real variable t, a linear model for a line fit (parabola fit, polynomial fit of degree d) is called a *first-degree model* (*second-degree model*, *dth degree model*).

m-way models

We can generalize to *m-way dth degree polynomial fit models* in which the input space is $X \subset \mathbf{R}^m$ and the regression function $\phi : \mathbf{R}^m \to \mathbf{R}^k$ (k is $d + m$ choose d) is the vector of all monomials of degree d in m variables.

For example, a two-way third-degree model has a regression function

$$\phi(t_1, t_2) = \begin{bmatrix} 1 & t_1 & t_2 & t_1^2 & t_1 t_2 & t_2^2 & t_1^3 & t_1^2 t_2 & t_1 t_2^2 & t_2^3 \end{bmatrix}^\top.$$

Or consider a three way second-degree model with regression function

$$\phi(t_1, t_2, t_3) = \begin{bmatrix} 1 & t_1 & t_2 & t_3 & t_1^2 & t_1 t_2 & t_1 t_3 & t_2^2 & t_2 t_3 & t_3^2 \end{bmatrix}^\top.$$

Both models will result in parameter vectors of size ten. We call these models *saturated* because they have every possible dth degree power or cross product of variables. In generally, a m-way dth degree model has $d + m$ choose d mean parameters.

In contrast to saturated models we can talk about *nonsaturated* models. For example, a nonsaturated two-way second-degree model has $\phi :$ $\mathbf{R}^2 \to \mathbf{R}^4$ where $\phi(t_1, t_2) = (1, t_1, t_2, t_1^2)^\top$.