

Midterm Formula Sheet

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1 Exam formula sheet

1.1 Epi 202: Probability

$$\begin{aligned}\text{Var}(\tilde{a} \cdot \tilde{X}) &= \text{Var}\left(\sum_{i=1}^n a_i X_i\right) \\ &= \tilde{a}^\top \text{Var}(\tilde{X}) \tilde{a} \\ &= \sum_{i=1}^n \sum_{j=1}^n a_i a_j \text{Cov}(X_i, X_j)\end{aligned}$$

1.2 Epi 203: Statistical inference

$$\mathcal{L}(\theta) \stackrel{\text{def}}{=} p(\tilde{X} = \tilde{x} | \Theta = \theta)$$

$$\ell \stackrel{\text{def}}{=} \log\{\mathcal{L}(\tilde{x}|\theta)\}$$

$$\ell' \stackrel{\text{def}}{=} \frac{\partial}{\partial \theta} \ell(\tilde{x}|\theta)$$

$$\ell'' \stackrel{\text{def}}{=} \frac{\partial}{\partial \tilde{\theta}} \frac{\partial}{\partial \tilde{\theta}^\top} \ell(\tilde{x}|\tilde{\theta})$$

$$\ell''_{ij} = \frac{\partial}{\partial \theta_i} \frac{\partial}{\partial \theta_j} \ell(\tilde{X} = \tilde{x} | \tilde{\theta})$$

$$\begin{aligned}I &\stackrel{\text{def}}{=} -\ell''(\tilde{x}|\tilde{\theta}) \\ \mathcal{I} &\stackrel{\text{def}}{=} \mathbb{E}[I(\tilde{x}|\theta)]\end{aligned}$$

$$\hat{\theta}_{ML} \sim N\left(\theta, [\mathcal{I}(\tilde{\theta})]^{-1}\right)$$

1.3 Epi 204: Generalized linear models

Generalized linear models have three components:

1. The **outcome distribution** family: $p(Y|\mu(\tilde{x}))$
2. The **link function**: $g(\mu(\tilde{x})) = \eta(\tilde{x})$
3. The **linear component**: $\eta(\tilde{x}) = \tilde{x} \cdot \beta$

$$\left[\pi \stackrel{\text{def}}{=} \Pr(Y = 1 | \tilde{X} = \tilde{x}) \right] \underbrace{\xrightarrow{\frac{\pi}{1-\pi}}}_{\text{expit}(\eta)} \left[\omega \stackrel{\text{def}}{=} \text{odds}(Y = 1 | \tilde{X} = \tilde{x}) \right] \underbrace{\xrightarrow{\log\{\omega\}}}_{\text{exp}\{\eta\}} \left[\eta(\tilde{x}) \stackrel{\text{def}}{=} \text{log-odds}(Y = 1 | \tilde{X} = \tilde{x}) \right]$$

Figure 1: Diagram of logistic regression link and inverse link functions

$$\theta(\tilde{x}, \tilde{x}^*) = \exp\{(\Delta \tilde{x}) \cdot \tilde{\beta}\}$$

1.3.1 Estimates of odds ratios from 2x2 contingency tables

$$\hat{\theta} = \frac{ad}{bc}$$

1.3.2 Survival analysis

Probability distribution functions

Table 1: Probability distribution functions

Name	Symbols	Definition
Probability density function (PDF)	$f(t), p(t)$	$p(T = t)$
Cumulative distribution function (CDF)	$F(t), P(t)$	$P(T \leq t)$
Survival function	$S(t), \bar{F}(t)$	$P(T > t)$
Hazard function	$\lambda(t), h(t)$	$p(T = t T \geq t)$
Cumulative hazard function	$\Lambda(t), H(t)$	$\int_{u=-\infty}^t \lambda(u) du$
Log-hazard function	$\eta(t)$	$\log\{\lambda(t)\}$

Diagram of survival distribution function relationships

$$\begin{array}{ccccccc}
 & f(t) & \xleftarrow[\text{S}(t)\lambda(t)]{-S'(t)} & S(t) & \xleftarrow{\exp\{-\Lambda(t)\}} & \Lambda(t) & \xleftarrow[\text{exp}\{\eta(t)\}]{\int_{u=0}^t \lambda(u) du} \lambda(t) \\
 & \xleftarrow[\int_{u=t}^{\infty} f(u) du]{f(t)/\lambda(t)} & & \xrightarrow[-\log S(t)]{} & & \xrightarrow[\Lambda'(t)]{} & \xrightarrow[\log\{\lambda(t)\}]{} \\
 & f(t) & & S(t) & \Lambda(t) & \lambda(t) & \eta(t)
 \end{array}$$

Survival likelihood contributions, assuming non-informative censoring

$$\begin{aligned}
 p(Y = y, D = d) &= [f_T(y)]^d [S_T(y)]^{1-d} \\
 &= [\lambda_T(y)]^d [S_T(y)]
 \end{aligned}$$

Nonparametric time-to-event distribution estimators

$$\hat{\lambda}_i = \frac{d_i}{n_i}$$

$$\hat{S}_{KM}(t) \stackrel{\text{def}}{=} \prod_{\{i: t_i < t\}} [1 - \hat{\lambda}_i]$$

$$\hat{\Lambda}_{NA}(t) \stackrel{\text{def}}{=} \sum_{\{i: t_i < t\}} \hat{\lambda}_i$$

Proportional hazards model structure

Joint likelihood of data set: $\mathcal{L} \stackrel{\text{def}}{=} p(\tilde{Y} = \tilde{y}, \tilde{D} = \tilde{d} | \mathbf{X} = \mathbf{x})$

Marginal likelihood contribution of obs. $i : \mathcal{L}_i \stackrel{\text{def}}{=} p(Y_i = y_i, D_i = d_i | \tilde{X}_i = \tilde{x}_i)$

Independent Observations Assumption: $\mathcal{L} = \prod_{i=1}^n \mathcal{L}_i$

Non-Informative Censoring Assumption: $T_i \perp\!\!\!\perp C_i | \tilde{X}_i$

$$\mathcal{L}_i \propto [f_T(y_i | \tilde{x}_i)]^{d_i} [S_T(y_i | \tilde{x}_i)]^{1-d_i} = S_T(y_i | \tilde{x}_i) \cdot [\lambda_T(y_i | \tilde{x}_i)]^{d_i}$$

Survival function: $S(t | \tilde{x}) \stackrel{\text{def}}{=} P(T > t | \tilde{X} = \tilde{x}) = \int_{u=t}^{\infty} f(u | \tilde{x}) du = \exp\{-\Lambda(t | \tilde{x})\}$

Probability density function: $f(t | \tilde{x}) \stackrel{\text{def}}{=} p(T = t | \tilde{X} = \tilde{x}) = -S'(t | \tilde{x}) = \lambda(t | \tilde{x}) S(t | \tilde{x})$

Cumulative hazard function: $\Lambda(t | \tilde{x}) \stackrel{\text{def}}{=} \int_{u=0}^t \lambda(u | \tilde{x}) du = -\log\{S(t | \tilde{x})\}$

Hazard function: $\lambda(t | \tilde{x}) \stackrel{\text{def}}{=} p(T = t | T \geq t, \tilde{X} = \tilde{x}) = \Lambda'(t | \tilde{x}) = \frac{f(t | \tilde{x})}{S(t | \tilde{x})}$

Hazard ratio: $\theta(t | \tilde{x} : \tilde{x}^*) \stackrel{\text{def}}{=} \frac{\lambda(t | \tilde{x})}{\lambda(t | \tilde{x}^*)}$

Log-Hazard function: $\eta(t | \tilde{x}) \stackrel{\text{def}}{=} \log\{\lambda(t | \tilde{x})\} = \eta_0(t) + \Delta\eta(t | \tilde{x})$

Proportional Hazards Assumption:

$$\begin{aligned}\lambda(t | \tilde{x}) &= \lambda_0(t) \cdot \theta(\tilde{x}) \\ \Lambda(t | \tilde{x}) &= \Lambda_0(t) \cdot \theta(\tilde{x}) \\ \eta(t | \tilde{x}) &= \eta_0(t) + \Delta\eta(\tilde{x})\end{aligned}$$

Logarithmic Link Function Assumption:

- **Link function:**

$$\log\{\lambda(t | \tilde{x})\} = \eta(t | \tilde{x})$$

$$\log\{\theta(\tilde{x})\} = \Delta\eta(\tilde{x})$$

- **Inverse link function:**

$$\lambda(t | \tilde{x}) = \exp\{\eta(t | \tilde{x})\}$$

$$\theta(\tilde{x}) = \exp\{\Delta\eta(\tilde{x})\}$$

Linear Predictor Component:

$$\eta(t | \tilde{x}) = \eta_0(t) + \Delta\eta(t | \tilde{x})$$

$$\Delta\eta(t | \tilde{x}) = \tilde{x} \cdot \tilde{\beta}$$

Linear Predictor Component Functional Form Assumption:

$$\Delta\eta(t | \tilde{x}) = \tilde{x} \cdot \tilde{\beta} \stackrel{\text{def}}{=} \beta_1 x_1 + \cdots + \beta_p x_p$$

Proportional hazards model partial likelihood formula:

$$\mathcal{L}_i^* = \frac{\theta(\tilde{x}_i)}{\sum_{k \in R(t_i)} \theta(\tilde{x}_k)}$$
$$\mathcal{L}^* = \prod_{\{i: d_i=1\}} \mathcal{L}_i^*$$

Proportional hazards model baseline cumulative hazard estimator:

$$\hat{\Lambda}_0(t) = \sum_{t_i < t} \frac{d_i}{\sum_{k \in R(t_i)} \theta(x_k)}$$