Censoring

Censoring

- Censoring occurs when event is know to have occurred only within certain interval.
- Censoring comes in many forms.
  - Right censoring
  - Left censoring
  - Interval censoring

Right censoring

- Subject's survival time is known only to be greater than a certain value (censoring time).
- Let T^o be survival time, and C_r censoring time.
- Right censored, if $T^o > C_r$.
- Often occurs in biomedical studies.
- Reasons for right censoring
  - Withdraw from the study (moves, side effects, refuses participation)
  - Death due to unrelated cause (car accident)
  - Still alive at the end of the study

Right censoring

- If our data contains only uncensored and right-censored observations, we can represent it by triplets (i, t_i, δ_i):
  - i : index for subject
  - t_i: observed time; event time or censoring time
  - δ_i: event/censoring indicator: δ_i = 1 if uncensored; δ_i = 0 if censored.
- That is, if δ_i = 1, $t_i = T_i^0$ = true event time; δ_i = 0, $t_i = C_i$ censoring time.

Left censoring

- Subject's survival time is known only to be less than a certain value (censoring time).
- Let T^0 be survival time, and C_l censoring time.
- Left censored, if $T^0 < C_l$
- Event of interest has already occurred at the observation time, but it is not known exactly when.
- Examples of left censoring
  - Time at which teenagers begin to drink alcohol.
  - Onset of a pre-symptomatic disease such as cancer.

Interval censoring

- Subject's survival time is known only to be within an interval.
- Let T^0 be true survival time, and $C_r < C_l$ censoring times.
- Interval censored, if $C_r < T^0 < C_l$.
- Exact event time is unknown, but an interval bounding it is known.
- Interval censoring occurs often due to infrequent follow-up.
- Examples
  - Test for HIV infection annually.
  - Machine breakdown during Christmas holiday.

Types of right censoring

Depending on the nature of the censoring time, we further consider the following three types of right-censoring.

- Type I censoring: C_r is a fixed, pre-specified, but could be different among individuals.
- Type II censoring: C_r is random.
- Random censoring: C_r is random.

Type I censoring

- Type I censoring: the censoring time is fixed.
- But censoring times can vary across individuals.
- Examples
  - Mouse were scarified at two different times.
  - Patients still alive at the end of study.

Type II censoring

- Type II censoring occurs when the study continues until a pre-specified number of events have occurred.
- For example, a researcher running an experiment with 100 rats and may decide that the experiment will stop when 50 of them have died.
- This type of censoring can occur in clinical trials. In some clinical trails, it is designed to run until r events, and a hypothesis is performed at that time.
- Then the censoring time is the r-th order statistics of the survival times, which is a random variable.

Random censoring

- The survival times $T_1^0, \ldots, T_n^0$ i.i.d. with density $f(t)$.
- The censoring times $C_1^0,\ldots,C_n^0$ i.i.d. with density $g(t)$.
- Assume the censoring times are all independent of survival times.
- Occurs when censoring is due to some unplanned or unexpected cause: car accident, relocation, or withdraw from study due to reasons that unrelated to survival time..

Key assumption: non-informative censoring

- All statistical methods in this course assume that censoring is non-informative for survival time.
- It means that, being censored at time c, only tells that $T^0 > c$, no any additional information regarding the survival beyond censoring time c.
- Individuals who are censored at c should be representative of all individuals who survive to c.

Non-informative censoring

- Example (Type Censoring)
- The mouse were scarified at two different times.
- Non-informative censoring: mouse are randomly selected for scarification.
- Example (Random Censoring)
- Non-informative censoring: The distribution of C does not depend on the distribution of T.

An example

An Informative censoring example

- Study time to divorce
- Couples are right censored if drop-out of study

The censoring is informative if those who drop out are more likely to experience marital difficulties.

Summary

- Censoring: only partial information available
- Right censoring: three different types
- Non-informative censoring