MAS-1
Study Review

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- Probability Review
- Stochastic Processes
- Life Contingencies
- Simulation
- Statistics
- Extended Linear Model
- Time Series

Lesson 1 : Probability Review

- **Bernouilli Shortcut :** If a random variable can only assume two values a and b with probability q and $1-q$, then is variance is $q(1-q)(b-a)^2$

Lesson 2 : Parametric Distributions

- **Transformations :**
  - Transformed : $\tau > 0$
  - Inverse : $\tau = -1$
  - Inverse-Transformed : $\tau < 0, \tau \neq 1$

Lesson 4 : Markov Chains

- **Chapman-Kolmogorov :**
$$P_{ij}^{(n+m)} = \sum_{k=0}^{\infty} P_{ik}^{(n)} P_{kj}^{(m)}$$
- **Gambler's ruin :**
$$p_j = \begin{cases} \frac{j}{N} & , r = 1 \\ \frac{r^j - 1}{r^N - 1} & , r \neq 1 \end{cases}$$
où $r = \dfrac{q}{p}$, p : winning prob.
- **Algorithmic efficency :** with N_j = number of steps from j^{th} solution to best solution.
$$\mathrm{E}[N_j] = \sum_{i=1}^{j-1} \frac{1}{i}$$
$$\mathrm{Var}(N_j) = \sum_{i=1}^{j-1} \left(\frac{1}{i}\right)\left(1 - \frac{1}{i}\right)$$
As $j \to \infty$, $\mathrm{E}[N_j] \to \ln j$, $\mathrm{Var}(N_j) \to \ln j$

Lesson 5 : Markov Chain Classification

- An **absorbing** state is one that cannot be exited.
- State j is **accessible**$(i \to j)$ from state i if $p_{ij}^n > 0$,
$\forall n \geq 0$.
- Two states **communicate** if $i \leftrightarrow j$.
- A **class** of states is a maximal set of state that communicate with each other.
- A Markov chain is **irreductible** if it has only one class.
- A state (class) is **recurrent** if the probability of reentering the state is 1. $\sum_{n=1}^{\infty} p_{ii}^{(n)} = \infty$
- A state (class) si **transcient** if it is not recurrent.
$\sum_{n=1}^{\infty} p_{ii}^{(n)} < \infty$
- A finite Markov Chain must have at least one recurrent class. If it is irreductible, then it is recurrent.

Lesson 6 : Markov Chains Limiting Probability

- A chain is **positive recurrent** is the expected number of transitions untils the state occur is finite, **null recurrent** otherwise. Null recurrent mean that the long-term proportion of time in each state is 0.
- A chain is **periodic** when states occur every n periode for n > 1.
- A chain is **aperiodique** when the periode is 1. In other world, $P_{ii}^{(1)} > 0, \forall i$
- A chain is **ergodic** when the chain is aperiodique and positive irreductible recurrent.
- **Stationary probability :**
$$\pi_j = \sum_{i=1}^{n} P_{ij}\pi_i \qquad \sum_{i=1}^{n} \pi_i = 1$$
- **Limiting probabilities :** is the chain is ergodic, then
$$\mathbf{P}^{(\infty)} = \begin{pmatrix} \pi_1 & \pi_2 & \pi_3 \\ \pi_1 & \pi_2 & \pi_3 \\ \pi_1 & \pi_2 & \pi_3 \end{pmatrix}$$

Lesson 7 : Time in Transient States

- Tips : Inverting a matrix
- $\mathbf{S} = (\mathbf{I} - \mathbf{P}_{\text{transcient}})^{-1}$, where s_{ij} is the time in state j given that the current state is i.
- $f_{ij} = \frac{s_{ij} - \delta_{i,j}}{s_{jj}} = \sum_{n=1}^{\infty} f_{ij}^{(n)}$, where f_{ij} is the probability that state i ever transitions to state j.

Lesson 8 : Branching Processes

- A branching process is a special type of Markov chain representing the growth or extinction of a population.
- $\mathrm{E}[X_n] = \mathrm{E}[Z]^n$, where $\mathrm{E}[Z]$ is the expected number of people born in a generation.
- $\mathrm{Var}(X_n) = \mathrm{Var}(Z) \cdot \mathrm{E}[Z]^{n-1} \sum_{k=1}^{n} \mathrm{E}[Z]^{k-1}$
- If $X_0 \neq 1$ mean and variance of X_n need to be multiplicated by X_0.
- **Probability of extinction :**
$$\pi_0 = \sum_{j=1}^{\infty} p_j \pi_0^j$$
  - $\mu \leq 1 \Rightarrow \pi_0 \geq 1$,if $X_0 = 1$.
  - $\mu > 1 \Rightarrow \pi_0 < 1$,if $X_0 = 1$.

For cubic equation, it guaranteed to factor $(\pi_0 - 1)$. Tips : Synthetic Division

Lesson 9 : Time Reversible

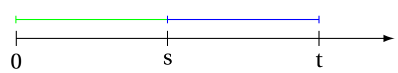
- If **Q** is the reverse-time Markov chain for ergodic **P**, then
$$\pi_i Q_{ij} = \pi_j P_{ji}$$
with $P_{ii} = Q_{ii}$ and if $p_{ij} = 0 \Leftrightarrow Q_{ji} = 0$
- If **Q** = **P**, then **P** is said to be **time-reversible**.

Lesson 10 : Exponential Distribution

- **Lack of memory :**
$$\Pr(X > k + x | X > k) = \Pr(X > x)$$
- **Minimum :** if $X_i \sim \mathrm{Exp}(\lambda_i)$, then
$$\min(X_1, X_2, ..., X_n) \sim \mathrm{Exp}\left(\sum_{i=1}^{n} \lambda_i\right)$$
- The sum of 2 Exponentials randoms variables is the sum of the maximum and the minimum, since one must be the min and the other the max.
$$X_1 + X_2 = \min(X_1, X_2) + \max(X_1, X_2)$$

Lesson 11 : Poisson Process

- $X(t) \sim \mathrm{Poisson}[m(t)]$,where $m(t)$ is **mean value function** representing the mean of the number events before time t.
- Poisson process can't deacrease over time. $N(t) \geq N(s)$
- $N(0) = 0$
- Increament are **independent** :



$$\Pr[N(t) - N(s) = n | N(s) = k] = \Pr[N(t) - N(s) = n]$$
- **Non-homogeneous Poisson process :**
$$m(t) = \int_0^t \lambda(u)\,\mathrm{d}u$$
where $\lambda(t)$ is the **intensify function**
- **Homogeneous Poisson process :** The Poisson process is said to be homogeneous when the intensify function is a constant.
$$m(t) = \int_0^t \lambda\,\mathrm{d}u = \lambda t$$
We then say that the process have **stationary increments**.
$$\Pr[N(s)] = \Pr[N(t) - N(s)]$$

Lesson 12 : Poisson Process Time To Next Events

- T_n is the time between the n[e] event and the (n-1)[e] event.
- $S_n = \sum_{i=1}^{n} T_i$, is the time for the n[e] event.
- $F_{T_1}(t) = 1 - e^{-\int_0^t \lambda(u)\,\mathrm{d}u}$
- For homogeneous process :
$$T_n \sim \mathrm{Exp}(\lambda)$$
$$S_n \sim \mathrm{Gamma}(n, \lambda)$$

Lesson 13 : Poisson Process Counting Special Type

- If event of type 1 occur with probability $\alpha_1(t)$, then the event follow a Poisson process with intensity $\lambda(t)\alpha_1(t)$.
$$m(t) = \int_0^t \lambda(u)\alpha_1(u)\,\mathrm{d}u$$

Lesson 14 : Poisson Process Other Characteristics

- Only for homogeneous Poisson processes.
- The probability of k event from process 1 is given by :
$$k \sim \text{Binomial}(k+l-1, \frac{\lambda_1}{\lambda_1+\lambda_2})$$
Then the probability that k event from process 1 occur before l from process 2 is :
$$\sum_{i=k}^{k+l-1} \binom{k+l-1}{i} \left(\frac{\lambda_1}{\lambda_1+\lambda_2}\right)^i \left(\frac{\lambda_2}{\lambda_1+\lambda_2}\right)^{k+l-1-i}$$
- Given that exactly $N(t) = k$ Poisson events occured before time t, the join distribution of event time is the joint distribution of k independent uniform random variable on $(0,t)$.
$$F_{S_1,\dots,S_n|n(t)}(s_1,\dots s_n|k) = \frac{k!}{t^k}$$
- For k independent uniform random variable on $(0,t)$, the expected value of the j^th^ order statistics is : $E[T^{(j)}] = \frac{jt}{(k+1)}$.
- Tips : Statistic Order

Lesson 15 : Poisson Process Sums and Mixtures

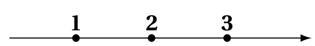
- A **Sums** of independent Poisson random variables is a Poisson random with intensify function $\lambda(t) = \sum \lambda_i(t)$. Warning : Substraction dont give a Poisson random variable.
- A **Mixture** of Poisson processes is not a Poisson processes.
  - **Discrete** mixture :
  $$F_{X(t)}(t) = \sum_i w_i F_{X_i(t)}(t)$$
  where $w_i > 0, \sum w_i = 1$
  - **Continuous** mixture :
  $$F_{X(t)}(t) = \int F_{\{X_u(t)\}}(t) f(u)\,\mathrm{d}u$$
  - If $N(t)|\lambda$ is a Poisson random variable and $\lambda \sim \text{Gamma}(\alpha,\theta)$, then $N(t) \sim \text{NegBin}(r=\alpha, \beta=\theta t)$.

Lesson 16 : Compound Poisson Processes

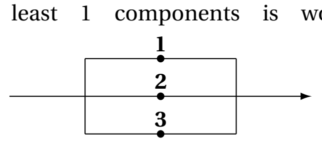
- A **compound** random variable S is define by $S = \sum_{i=1}^N X_i$ where N is the **primary** distribution and X the **secondary** distribution.
- If $N(t)$ is a Poisson process, then $S(t)$ is a compound Poisson process with :
  - $\mathrm{E}[S(t)] = \lambda t \mathrm{E}[X]$
  - $\mathrm{Var}(S(t)) = \lambda t \mathrm{E}[X^2]$
- If X_i is discrete, we can separate the process into a sum of subprocess view in LESSON 13.
- **Sums of compound** homogeneous Poisson process is also a Poisson process with :
  - $N(t) \sim \text{Pois}(\sum \lambda_i)$
  - $F_X(x) = \sum_i w_i F_{X_i(t)}(t), \quad w_i = \frac{\lambda_i}{\sum \lambda_i}$

Lesson 17 : Reliability Structure Functions

- $\phi(\mathbf{x})$ is the **structure** function for a systeme. It equal 1 if the systeme function, 0 otherwise.
- A **series** system is define as a **minimal path set**. The system is working if all components are working.



The serie structure function is define as
$$\phi(\mathbf{x}) = \prod_{i=1}^n x_i$$
- A **parallel** system is define as a **minimal cut set**. The systeme is working if at least 1 components is working.



The parallel structure function is define as
$$\phi(\mathbf{x}) = 1 - \prod_{i=1}^n (1-x_i)$$
- Tips : Minimal path set is all way for the system to work, and the minimal cut set is all the way for the system to not work.
- Tips : If set is $\{1,2,3\}$ and $\{1,2\}$, the *minimal* mean we only take $\{1,2\}$.
- Tips : *Minimal cut* is a serie of parallel structure and *minimal path* is a parallel of serie structure.

Lesson 18 : Reliability Probabilities

- $r(\mathbf{p})$ is the same polynomial as $\phi(\mathbf{x})$.
- Inclusion/exclusion bounds using minimal path :
$$r(\mathbf{p}) \leq \sum A_i$$
$$r(\mathbf{p}) \geq \sum A_i - \sum A_i \cup A_j$$
$$r(\mathbf{p}) \leq \sum A_i - \sum A_i \cup A_j + \sum A_i \cup A_j \cup A_k$$
where $A_i = \sum p_i$ is the probability of the i^e^ minimal path set work.
- Inclusion/exclusion bounds using minimal cut :
$$1 - r(\mathbf{p}) \leq \sum A_i$$
$$1 - r(\mathbf{p}) \geq \sum A_i - \sum A_i \cup A_j$$
$$1 - r(\mathbf{p}) \leq \sum A_i - \sum A_i \cup A_j + \sum A_i \cup A_j \cup A_k$$
where $A_i = \sum(1-p_i)$ is the probability of the i^e^ minimal cut set work.
- Bounds using intersections :
$$\prod \phi(\mathbf{X})^{\textbf{min. cut}} \leq r(\mathbf{p}) \leq \prod \phi(\mathbf{X})^{\textbf{min. path}}$$
- **Random graph** :
$$1 - P_n = \sum_{k=1}^{n-1} \binom{n-1}{k-1} q^{k(n-k)} P_k$$
$$1 - P_n \leq (n+1)q^{n-1}$$
$$P_1 = 1$$

Lesson 19 : Reliability Time to Failure

- Expected amound of time to failure :
$$\mathrm{E}[\textbf{system life}] = \int_0^\infty r(\bar{\mathbf{F}}(\mathbf{t}))\,\mathrm{d}t$$
where,
  - For serie system :
  $$r(\bar{\mathbf{F}}(\mathbf{t})) = \prod_{i=1}^n \bar{F}_i(t)$$
  - For parallel system :
  $$r(\bar{\mathbf{F}}(\mathbf{t})) = 1 - \prod_{i=1}^n F_i(t)$$
- *Shortcut* : k out of n system with exponentials(θ) : $\mathrm{E}[T] = \theta \sum_{i=k}^n \frac{1}{i}$
- **Hazard rate function** (*failure rate function*) :
$$h(t) = \frac{f(t)}{\bar{F}(t)}$$
and we say that the distribution
  - is an increasing failure rate if $h(t)$ is non-deacreasing function of t.
  - is an deacreasing failure rate if $h(t)$ is non-increasing function of t.
- **Cumulatice hazard function** :
$$H(t) = \int_0^t h(u)\,\mathrm{d}u = -\ln \bar{F}(t)$$
with $\frac{H(t)}{t}$ the average of the hazard rate.

Lesson 20 : Survival Models

- ${}_tp_x = \frac{\ell_{x+t}}{\ell_x}, \quad {}_tq_x = \frac{\ell_x - \ell_{x+t}}{\ell_x}$
- ${}_{t|u}q_x = \frac{\ell_{x+t} - \ell_{x+t+u}}{\ell_x}$
- ${}_{t+u}p_x = {}_up_x \cdot {}_tp_{x+u}$
- ${}_{t|u}q_x = {}_{t+u}q_x - {}_tq_x = {}_tp_x \cdot {}_uq_{x+t}$
- Let be N_x the number of life surviving to age x, then
$$(N_{x+t}|N_x = n) \sim \text{Bin}(n, {}_tp_x)$$
- **Force of mortality** :
$$\mu_{x+t} = \frac{f_{T_x}(t)}{{}_tp_x} = -\frac{\mathrm{d}}{\mathrm{d}t} \ln {}_tp_x$$

- **Linear interpolation(D.U.D) :**
  $$\ell_{x+t} = (1-t)\,\ell_x + t\,\ell_{x+1}$$
  Shortcut : $\forall t \in (0,1)$, $\forall x \in \mathbb{N}$, $x < x+t < x+1$:
  - ➟ ${}_tq_x = t \cdot q_x$
  - ➟ $\mu_{x+t} = \frac{q_x}{1-t\cdot q_x}$
- **Expected life time :** Let $k_x = \lfloor T_x \rfloor$, the *full years* until death. Then e_x is the **curtate life expectancy** and $\mathring{e}_x$ the **complete life expectancy**. ω is the age where $\ell_\omega = 0$ and $\omega = \infty$ by convention is nothing is said.
  $$e_x = \mathrm{E}[K_x] = \sum_{k=1}^{\omega-x-1} {}_kp_x$$
  $$\mathring{e}_x = \mathrm{E}[T_x] = \int_0^{\omega-x} {}_tp_x\,\mathrm{d}t \overset{\text{D.U.D}}{=} e_x + 0.5$$

Lesson 21 : Contingent Payments

The contract here are define with K_x to pay at the end of death year. All same contract can be define with T_x to pay at the moment of death. Then we use integral instead of sum and use
$$\Pr(K=k) = {}_kp_x\,q_{x+k} \Rightarrow f_{T_x}(t) = {}_tp_x\mu_{x+t}$$

- **Life Insurance :**
  - Whole Life insurance :
    $$A_x = \sum_{k=0}^{\infty} v^{k+1}\,{}_kp_x\,q_{x+k}$$
  - Term Life insurance :
    $$A^{1}_{x:\overline{n}|} = \sum_{k=0}^{n} v^{k+1}\,{}_kp_x\,q_{x+k}$$
  - Deferred insurance :
    $${}_{m|}A_x = \sum_{k=m}^{\infty} v^{k+1}\,{}_kp_x\,q_{x+k}$$
  - Endowment insurance :
    $$A_{x:\overline{n}|} = A^{1}_{x:\overline{n}|} + {}_nE_x$$
  - Pure Endowment :
    $${}_nE_x = v^n\,{}_np_x$$
- **Life Annuities :**
  - Whole Life annuity
    $$\ddot{a}_x = \sum_{k=0}^{\infty} v^k\,{}_kp_x$$
  - Temporary Life annuity
    $$\ddot{a}_{x:\overline{n}|} = \sum_{k=0}^{n} v^k\,{}_kp_x$$
  - Deferred annuity
    $${}_{m|}\ddot{a}_x = \sum_{k=m}^{\infty} v^k\,{}_kp_x$$
  - Certain and life annuity
    $$\ddot{a}_{\overline{x:\overline{n}|}} = \ddot{a}_{\overline{n}|} + {}_{m|}\ddot{a}_x$$
- **Illustrative Life Table :**
  - $A_x = v^n\,q_x + p_x\,A_{x+1}$
  - $\ddot{a}_x = 1 + v\,p_x\,\ddot{a}_{x+1}$
  - $A^{1}_{x:\overline{n}|} = A_x - {}_nE_x\,A_{x+n}$
  - $\ddot{a}_{x:\overline{n}|} = \ddot{a}_x - {}_nE_x\,\ddot{a}_{x+n}$
  - ${}_{m|}A_x = {}_mE_x\,A_{x+m}$
  - ${}_{m|}\ddot{a}_x = {}_mE_x\,\ddot{a}_{x+m}$
  - $\ddot{a}_x = 1 + a_x$
  - $A_x = 1 - d\,\ddot{a}_x$

- **Joint life annuity**($\ddot{a}_{xy}$) make payments until the earliest death pf two lives.
- **Last survivor annuity**($\ddot{a}_{\overline{xy}}$) make payments until the last death of two lives.
  $$\ddot{a}_x + \ddot{a}_y = \ddot{a}_{xy} + \ddot{a}_{\overline{xy}}$$
- **Premiums :**
  $$M \cdot A_x = P\,\ddot{a}_x$$
  $$P = \frac{M\cdot A_x}{\ddot{a}_x} = \frac{M}{\ddot{a}_x} - M\cdot d$$

Simulation-Inverse Method

Appendix

Inverting a matrix

$$\begin{pmatrix} a & b \\ c & d \end{pmatrix}^{-1} = \frac{1}{ad-bc}\begin{pmatrix} d & -b \\ -c & a \end{pmatrix}$$

Ajouter pour une matrice 3x3

Synthetic Division

Exemple : Factorize $x^3 - 12x^2 - 81$

	1	-12	0	-81
3		3	-27	-81
	1	-9	-27	0

then, $x^3 - 12x^2 - 81 = (x-3)(x^2 - 9x - 27)$

Deductible and Limite

$$\begin{aligned} X &= \min(X;d) + \max(0;X-d) \\ \mathrm{E}[X] &= \mathrm{E}[\min(X;d)] + \mathrm{E}[\max(0;X-d)] \\ &= \mathrm{E}[(X \wedge d)] + \mathrm{E}[(x-d)_+] \\ &= \mathrm{E}[(X \wedge d)] + e_x(d) \cdot S_x(d) \end{aligned}$$

Statistic Order

- $Y_1 = \min(X_1, ..., X_n)$
$$f_{Y_1}(y) = nf(y)[S(y)]^{n-1}$$
$$S_{Y_1}(y) = \prod_{i=1}^{n} \Pr\left(X_i > x\right)$$
- $Y_n = \max(X_1, ..., X_n)$
$$f_{Y_n}(y) = nf(y)[F(y)]^{n-1}$$
$$F_{Y_n}(y) = \prod_{i=1}^{n} \Pr\left(X_i \leq x\right)$$
- $Y_k \in (Y_1, ..., Y_k, ..., Y_n)$
$$f_{Y_k}(y) = \frac{n!}{(k-1)!(n-k)!} f(y)[F(y)]^{k-1}[S(y)]^{n-k}$$
$$\begin{aligned} F_{Y_k}(y) &= \Pr\left(\text{at least k of n } X_i \text{ are} \leq \text{y}\right) \\ &= \sum_{i=k}^{n} \binom{n}{i} [F(y)]^i [S(y)]^{n-j} \end{aligned}$$
- $x + y = \min(x, y) + \max(x, y)$, since one is for sure the max and the other the min.

Mode : Most likely probability

- $g(x) = f(x)$ or some time $g(x) = \ln f(x)$
- **Mode** is the x that respects : $g'(x) = 0$

Normal Approximation

- $F_X(x) = \Phi\left(\frac{X - \mathrm{E}[X]}{\sqrt{\mathrm{Var}(X)}}\right)$
- **Continuity correction** is necessary when X is discrete. $F_X(x) = \Phi\left(\frac{(X \pm k) - \mathrm{E}[X]}{\sqrt{\mathrm{Var}(X)}}\right)$ where k is the mid-point of the discrete value.