University of New South Wales

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Assignment 2

Measure Theory

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1.1

Let μ and ν be probability measures on $(\mathbb{R}, \mathcal{B}(\mathbb{R}))$. We wish to show that the convolution

$$\mu * \nu(B) = \int \nu(B - x)\mu(dx) \tag{1}$$

of these two measures is well defined in the sense that $\nu(B - x)$ is measurable in x and the integral exists. Firstly see that

$$\begin{aligned}\nu(B - x) &= \int \chi_{B-x}(y)\nu(dy) &(2)\\ &= \int \chi_B(x + y)\nu(dy) &(3)\end{aligned}$$

and by seeing that $\phi(x, y) = \chi_B(x+y)$ is $\mathcal{B}(R)\otimes\mathcal{B}(R)$ measurable and so applying Tonelli's theorem $\nu(B-x)$ is measurable.
We now need to show that the integral exists. This is clear because

$$0 \le \nu(B - x) \le 1 \tag{4}$$

and thus

$$\begin{aligned}\int \nu(B - x)\mu(dx) &\le \int 1\mu(dx) &(5)\\ &= 1 &(6)\end{aligned}$$

because μ is a probability measure.

1.2

Suppose there exists a bounded set $F \in \mathcal{B}(\mathbb{R})$ such that

$$\mu * \nu(F) = 1 \tag{7}$$

we wish to show that there exists bounded sets $G, H \in \mathcal{B}(\mathbb{R})$ such that

$$\mu(G) = 1 \quad \text{and} \quad \nu(H) = 1. \tag{8}$$

See that if

$$\begin{aligned}1 &= \mu * \nu(F) &(9)\\ &= \int \nu(F - x)\mu(dx) &(10)\\ &= \int\int \chi_F(x + y)\nu(dy)\mu(dx) &(11)\end{aligned}$$

Now as F is bounded there there exist intervals $G = [a, b]$ and $H = [c, d]$ such that

$$\int\int \chi_F(x + y)\chi_G(x)\chi_H(y)\nu(dy)\mu(dx) \tag{12}$$

and further

$$1 = \int\int \chi_F(x+y)\chi_G(x)\chi_H(y)\nu(dy)\mu(dx) \leq \int\int \chi_G(x)\chi_H(y)\nu(dy)\mu(dx) \tag{13}$$

$$= \int \chi_H(y)\nu(dy)\int \chi_G(x)\mu(dx) \tag{14}$$

[1] which implies that

$$\int \chi_G(x)\mu(dx) = 1 \quad \text{and} \quad \int \chi_H(y)\nu(dy) = 1 \tag{15}$$

that is $\mu(G) = 1$ and $\nu(H) = 1$.
Suppose that F is now countable but such that $\mu * \nu(F) = 1$. Then

$$1 = \int \nu(F - x)\mu(dx) \tag{16}$$

$$= \int\int \chi_F(x+y)\nu(dy)\mu(dx) \tag{17}$$

now since $F = \{(x_k, y_k)\}_{k\in\mathbb{N}}$ is countable then there must exist countable sets $G = \{x_k\}_{k\in\mathbb{N}}$, $H = \{y_k\}_{k\in\mathbb{N}}$ such that

$$\int\int \chi_F(x+y)\nu(dy)\mu(dx) = \int\int \chi_F(x+y)\chi_G(x)\chi_H(y)\nu(dy)\mu(dx) \tag{18}$$

and further

$$1 = \int\int \chi_F(x+y)\chi_G(x)\chi_H(y)\nu(dy)\mu(dx) \leq \int\int \chi_G(x)\chi_H(y)\nu(dy)\mu(dx) \tag{19}$$

$$= \int \chi_H(y)\nu(dy)\int \chi_G(x)\mu(dx) \tag{20}$$

which as before implies $\mu(G) = 1$ and $\nu(H) = 1$.
Then argument above also holds for finite F with exactly the same construction and so if F is finite and such that $\mu * \nu(F) = 1$ then there must exist finite sets G and H such that $\mu(G) = 1$ and $\nu(H) = 1$.

2

2.1

Suppose u and ν are σ-finite *positive* measures on $(\Omega, \mathcal{F})$. Then suppose that $\mu << \nu$ and $\nu << \mu$. Then for $A \in \mathcal{F}$ we have that $\mu(a) = 0 \Rightarrow \nu(A) = 0$ and $\nu(A) = 0 \Rightarrow \mu(A)$. That is to say that $\nu(A) = 0 \Leftrightarrow \mu(A) = 0$. That is to say that ν and μ have the same null sets. This argument is symmetric so it is clear that the reverse implication also holds.
We now wish to show that there is an $\mathcal{F}$-measurable function g that satisfies $0 < g(\omega) < +\infty$ at each $\omega \in \Omega$ and is such that $\nu(A) = \int_A g d\mu$ for all $A \in \mathcal{F}$.
Now suppose that there is a $\mathcal{F}$ measurable function $0 < g(\omega) < \infty$ such that $\nu(A) = \int_A g d\mu$.
Suppose $\nu(A) = 0$ then

$$0 = \nu(A) = \int_A g d\mu \tag{21}$$

$$= \int \chi_A g d\mu \tag{22}$$

[1] Note that the reason we could split up the integrals to a product in both cases is because $\int \chi_H(y)\nu(y)$ is a constant with respect to x.

Now as $\chi_A g >= 0$ and μ is a positive measure then by theorem 2.18 (3) we must that $\chi_A g = 0$, $\mu-$a.e. As $g > 0$ we have that $\chi_A = 0$ μ-a.e. which means that $\mu(A) = 0$. So $\mu \ll \nu$.
We claim that $\nu \ll \mu$ as well. Suppose $\mu(A) = 0$ then note that as g is a measurable function we have that by Theorem 2.11 $g(\omega) = \lim_{n \longrightarrow \infty} s_n(\omega)$ for all ω and a sequence of increasing simple functions. That is

$$\int_A g d\mu = \int_A \lim_{n \longrightarrow \infty} s_n d\mu. \tag{23}$$

Further by the monotone convergence theorem we have that

$$\int_A \lim_{n \longrightarrow \infty} s_n d\mu = \lim_{n \longrightarrow \infty} \int_A s_n d\mu. \tag{24}$$

Now for some simple function s we have that if $\mu(A) = 0$ then

$$\begin{aligned}
\int_A s d\mu &= \int_A \sum_{k=1}^{N} \alpha_k \chi_{B_k} d\mu & (25)\\
&= \sum_{k=1}^{N} \alpha_k \int_A \chi_{B_k} d\mu & (26)\\
&= \sum_{k=1}^{N} \alpha_k \int \chi_{B_k \cap A} d\mu & (27)\\
&\leq \sum_{k=1}^{N} \alpha_k \int \chi_A d\mu & (28)\\
&= \sum_{k=1}^{N} \alpha_k 0 & (29)\\
&= 0 & (30)
\end{aligned}$$

thus if $\mu(A) = 0$ then $\int_A s_n d\mu = 0$ for all n and so $\lim_{n \longrightarrow \infty} \int_A s_n d\mu = 0$ and hence $\nu(A) = 0$. This means that $\nu \ll \mu$ as well.

2.2

Let $\{B_n\}_{n \in \mathbb{N}}$ be a covering of Ω by disjoint sets with $0 < \mu(B_n) < \infty$ for all n. Such a covering exists because μ is σ-finite. Now select a sequence of constants $\{\alpha_n\}_{n \in \mathbb{N}}$ such that $\alpha_n > 0$ for all n and

$$\sum_{n=1}^{\infty} \alpha_n = 1. \tag{31}$$

For example we could select $\alpha_n = 2^{-n}$.
We claim that the function $\nu : \mathcal{F} \longrightarrow \mathbb{R}$ defined by

$$\nu(A) = \sum_{n=1}^{\infty} \alpha_n \frac{\mu(A \cap B_n)}{\mu(B_n)} \tag{32}$$

is a probability measure with the same null sets as μ. Firstly we show that it is a measure, that is we show σ-additivity.
For a collection of disjoint sets $\{A_n\}_{n \in \mathbb{N}}$ we have that

$$\nu\left(\bigcup_{n \in \mathbb{N}} A_n\right) = \sum_{k=1}^{\infty} \alpha_k \frac{\mu\left(\bigcup_{n=1}^{\infty} A_n \cap B_k\right)}{\mu(B_k)} \tag{33}$$

and by σ-additivity of μ we get

$$\sum_{k=1}^{\infty} \alpha_k \frac{\mu\left(\bigcup_{n=1}^{\infty} A_n \cap B_k\right)}{\mu(B_k)} = \sum_{k=1}^{\infty} \alpha_k \frac{\sum_{n=1}^{\infty} \mu\left(A_n \cap B_k\right)}{\mu(B_k)} \tag{34}$$

$$= \sum_{n=1}^{\infty} \sum_{k=1}^{\infty} \alpha_k \frac{\mu\left(A_n \cap B_k\right)}{\mu(B_k)} \tag{35}$$

$$= \sum_{n=1}^{\infty} \nu(A_n). \tag{36}$$

The interchange of the order of summation can be justified by the fact that $\mu(A_n \cap B_k) \geq 0$ and

$$\sum_{k=1}^{\infty} \alpha_k \frac{\sum_{n=1}^{\infty} \mu\left(A_n \cap B_k\right)}{\mu(B_k)} < \infty \tag{37}$$

which we prove now (by proving ν is a probability measure).
See that

$$\nu(\Omega) = \sum_{k=1}^{\infty} \alpha_k \frac{\mu(\Omega \cap B_k)}{\mu(B_k)} \tag{38}$$

$$= \sum_{k=1}^{\infty} \alpha_k \frac{\mu(B_k)}{\mu(B_k)} \tag{39}$$

$$= \sum_{k=1}^{\infty} \alpha_k \tag{40}$$

$$= 1. \tag{41}$$

We now just have to show that μ and ν share the same null sets.
Suppose $\mu(A) = 0$ then

$$\mu(A) = \sum_{k=1}^{\infty} \alpha_k \frac{\mu(A \cap B_k)}{\mu(B_k)} \tag{42}$$

$$\leq \sum_{k=1}^{\infty} \alpha_k \frac{\mu(A)}{\mu(B_k)} \tag{43}$$

$$= 0 \tag{44}$$

and thus $\nu \ll \mu$. Now suppose $\nu(A) = 0$ then

$$\sum_{k=1}^{\infty} \alpha_k \frac{\mu(A \cap B_k)}{\mu(B_k)} = 0 \tag{45}$$

and as $\mu(B_k) < \infty$ for all k this implies that $\mu(A \cap B_k) = 0$ for all k. Now

$$
\begin{aligned}
0 &= \sum_{k=1}^{\infty} \mu(A \cap B_k) && (46)\\
&= \mu\left(\bigcup_{k=1}^{\infty} (A \cap B_k)\right) && (47)\\
&= \mu\left(A \cap \bigcup_{k=1}^{\infty} B_k\right) && (48)\\
&= \mu(A \cap \Omega) && (49)\\
&= \mu(A). && (50)
\end{aligned}
$$

Thus $\mu \ll \nu$.
So ν is a finite measure on $(\Omega, \mathcal{F})$ which is equivalent to μ.

3

3.1

Firstly note that the definition of the characteristic function is

$$\hat{\mu}_X(u) = \mathbb{E}[\exp(i\langle X, u\rangle)] \tag{51}$$

and so for the random vector cX with $c \in \mathbb{R}$ we have that

$$
\begin{aligned}
\hat{\mu}_{cX}(u) &= \mathbb{E}[\exp(i\langle cX, u\rangle)] && (52)\\
&= \mathbb{E}[\exp(i\langle X, cu\rangle)] && (53)\\
&= \hat{\mu}_X(cu) && (54)
\end{aligned}
$$

3.2

By definition we have that

$$\hat{\mu}(\mathbf{u}) = \int \exp(i\langle \mathbf{x}, \mathbf{u}\rangle) d\mathbb{P}_X(\mathbf{x}). \tag{55}$$

We can say that

$$\frac{d^\alpha \hat{\mu}(\mathbf{u})}{d\mathbf{u}^\alpha} = \frac{d^\alpha}{d\mathbf{u}^\alpha} \int \exp(i\langle \mathbf{x}, \mathbf{u}\rangle) d\mathbb{P}_X(\mathbf{x}). \tag{56}$$

We wish to justify taking this derivative through the integral sign. To do this we use an extension of corollary 2.28 (2) from the notes.

Claim
If the partial derivative

$$\frac{\partial^\alpha}{\partial \mathbf{u}^\alpha} f(\mathbf{x}, \mathbf{u}) \tag{57}$$

exists for all $(\mathbf{x}, \mathbf{u}) \in X \times [a, b]^d$ and if there is a function $g \in L^1(\mu)$ such that

$$\left| \frac{\partial^\alpha}{\partial \mathbf{u}^\alpha} f(\mathbf{x}, \mathbf{u}) \right| \leq g \tag{58}$$

for every $\mathbf{x} \in X$ and $\mathbf{u} \in (a, b)^d$ then

$$\frac{d^\alpha}{d\mathbf{u}^\alpha} \int f(\mathbf{x}, \mathbf{u}) d\mu(\mathbf{x}) = \int \frac{\partial^\alpha}{\partial \mathbf{u}^\alpha} f(\mathbf{x}, \mathbf{u}) d\mu(\mathbf{x}) \qquad \text{for } \mathbf{u} \in (a, b)^d. \tag{59}$$

Proof We induct on $|\alpha|$. For $|\alpha| = 0$ the result is degenerate. Suppose it is true for $|\alpha|$ we wish to show that it is true for $|\alpha| + 1$.

We have that

$$\frac{\partial^\alpha}{\partial \mathbf{u}^\alpha} \exp(i\langle \mathbf{x}, \mathbf{u}\rangle) = i^{|\alpha|} \prod_{k=1}^{d} x_k^{\alpha_k} \exp(i\langle \mathbf{x}, \mathbf{u}\rangle) \tag{60}$$

and that

$$\left| \frac{\partial^\alpha}{\partial \mathbf{u}^\alpha} \exp(i\langle \mathbf{x}, \mathbf{u}\rangle) \right| \leq \underbrace{\prod_{k=1}^{d} |x_k|^{\alpha_k}}_{\circledast}. \tag{61}$$

Now because

$$\mathbf{E}\left(\prod_{k=1}^{d} |X_k|^{\alpha_k} \right) = \int \prod_{k=1}^{d} |x_k|^{\alpha_k} \, d\mathbb{P}_X(\mathbf{x}) < \infty \tag{62}$$

then $\circledast \in L^1(\mathbb{P}_X)$ and so we can apply our claim (the DCT) to get

$$\frac{\partial^\alpha \hat{\mu}(\mathbf{u})}{\partial \mathbf{u}^\alpha} = \int \frac{\partial^\alpha}{\partial \mathbf{u}^\alpha} \exp(i\langle \mathbf{x}, \mathbf{u}\rangle) d\mathbb{P}_X(\mathbf{x}) \tag{63}$$

$$= \int i^{|\alpha|} \prod_{k=1}^{d} x_k^{\alpha_k} \exp(i\langle \mathbf{x}, \mathbf{u}\rangle) d\mathbb{P}_X(\mathbf{x}) \tag{64}$$

$$= i^{|\alpha|} \int \prod_{k=1}^{d} x_k^{\alpha_k} \exp(i\langle \mathbf{x}, \mathbf{u}\rangle) d\mathbb{P}_X(\mathbf{x}) \tag{65}$$

and so

$$\left. \frac{\partial^\alpha \hat{\mu}(\mathbf{u})}{\partial \mathbf{u}^\alpha} \right|_{\mathbf{u}=\mathbf{0}} = i^{|\alpha|} \int \prod_{k=1}^{d} x_k^{\alpha_k} \exp(i\langle \mathbf{x}, \mathbf{0}\rangle) d\mathbb{P}_X(\mathbf{x}) \tag{66}$$

$$= i^{|\alpha|} \int \prod_{k=1}^{d} x_k^{\alpha_k} d\mathbb{P}_X(\mathbf{x}) \tag{67}$$

$$= i^{|\alpha|} \mathbb{E}(X^\alpha) \tag{68}$$

3.3

Notice that as the distribution is symmetric we have that

$$\hat{\mu}(u) = \int e^{iux} f(x)dx \tag{69}$$
$$= \int f(x)(\cos(ux) + i\sin(ux))dx \tag{70}$$
$$= \int f(x)cos(ux)dx \tag{71}$$

Now notice that

$$\left|\frac{\partial}{\partial u} f(x)\cos(ux)\right| = |xf(x)sin(xu)| \tag{72}$$

Now notice that

$$\int |xf(x)\sin(ux)|dx = \underbrace{\int_{-K}^{K} |xf(x)\sin(ux)|dx}_{\leq M_1} + \int_{-\infty}^{-K} |xf(x)\sin(ux)|dx + \int_{K}^{\infty} |xf(x)\sin(ux)|dx \tag{73}$$

for some constant M_1 and a constants K and J chosen such that

$$\int_{K}^{\infty} |xf(x)\sin(ux)|dx \leq \int_{K}^{\infty} \frac{|\sin(ux)|}{Jx}dx. \tag{74}$$

We can therefore say that

$$'\int |xf(x)\sin(ux)|dx \leq M_1 + 2\int_{K}^{\infty} \frac{|\sin(ux)|}{Jx}dx. \tag{75}$$

Now appealing to a result in special functions we can say that

$$\int_{K}^{\infty} \frac{|\sin(ux)|}{Jx}dx = \lim_{x\longrightarrow\infty} \mathrm{Si}(ux)\,\mathrm{sgn}(\sin(ux)) - \mathrm{Si}(uK)\,\mathrm{sgn}(\sin(uK)) \tag{76}$$

and it turns out that $\frac{1}{J}\lim_{x\longrightarrow\infty} \mathrm{Si}(ux)\,\mathrm{sgn}(\sin(ux)) < \infty$ which means that

$$\left|\frac{\partial}{\partial u} f(x)\cos(ux)\right| \in L^1(\mu) \tag{77}$$

for every u. We can then apply the dominated convergence theorem corollary 2.28 (2) to say that $\hat{\mu}(u)$ is differentiable for all u and not just at 0.

4

Let μ be the binomial distribution with n trials and probability of success p, that is $\mu = \mathrm{Bin}(n,p)$, and let ν be the Poisson distribution with mean $\lambda > 0$.

4.1

We wish to verify that $\hat{\mu}(u) = (1-p+pe^{iu})^n$. Because the binomial distribution is just the convolution of identical independent Bernoulli distributions then we just have to verify that $(1-p+pe^{iu}$ is the characteristic function for $Bernoulli(p)$.

If ν is the Bernoulli measure and X has law ν then

$$\begin{aligned}
\hat{\nu}(u) &= \mathbb{E}[\exp(iuX)] && (78)\\
&= \sum_{k\in\{0,1\}} e^{iuk}\nu_X(k) && (79)\\
&= pe^{iu} + (1-p). && (80)
\end{aligned}$$

Then by repeated application of the convolution theorem we get that $\hat{\mu}(u) = (1-p+pe^{iu})^n$.

4.2

We wish to verify that $\hat{\nu}(u) = \exp(\lambda(e^{iu}-1))$. The probability mass function of the Poisson distribution is

$$\frac{\lambda^k}{k!}e^{-\lambda} \tag{81}$$

and thus

$$\begin{aligned}
\mathbb{E}[\exp(iuX)] &= \sum_{k=0}^{\infty} \frac{\lambda^k}{k!}e^{-\lambda}e^{iuk} && (82)\\
&= e^{-\lambda}\sum_{k=0}^{\infty} \frac{\lambda^k}{k!}(e^{iu})^k && (83)\\
&= e^{-\lambda}\sum_{k=0}^{\infty} \frac{(\lambda e^{iu})^k}{k!} && (84)\\
&= e^{-\lambda}e^{\lambda e^{iu}} && (85)\\
&= e^{\lambda(e^{iu}-1)} && (86)
\end{aligned}$$

4.3

We wish to show that if p_n is a sequence in $[0,1]$ such that $p_n \downarrow 0$ and $np_n \longrightarrow \lambda$ then $\mu_n \longrightarrow \nu$ in the weak sense where $\mu_n = \text{Bin}(n, p_n)$. Let $f \in C_b$ then

$$\begin{aligned}
\lim_{n\longrightarrow\infty} \sum_{k=0}^{n} f(k)\binom{n}{k}p_n^k(1-p_n)^{n-k} &= \lim_{n\longrightarrow\infty} \sum_{k=0}^{\infty} \chi_{k\leq n}\cdot f(k)\binom{n}{k}p_n^k(1-p_n)^{n-k} && (87)\\
&= \sum_{k=0}^{\infty} \lim_{n\longrightarrow\infty} \chi_{k\leq n}\cdot f(k)\binom{n}{k}p_n^k(1-p_n)^{n-k}. && (88)
\end{aligned}$$

The interchange of the order of the limit and the sum is justified by the uniform convergence of the sum. To see this let $M = \sup_{k\in\mathbb{N}^0} f(k)$ (which exists because $f \in C_b$) and then note that

$$\begin{aligned}
\sum_{k=0}^{\infty} \chi_{k\leq n}\cdot f(k)\binom{n}{k}p_n^k(1-p_n)^{n-k} &\leq \sum_{k=0}^{\infty} \chi_{k\leq n}\cdot M\binom{n}{k}p_n^k(1-p_n)^{n-k} && (89)\\
&= M < \infty && (90)
\end{aligned}$$

and so by the Weierstrass M test the series converges uniformly.

Now as $np_n \longrightarrow \lambda$ or $p_n \longrightarrow \frac{\lambda}{n}$ we get

$$\begin{aligned}
\sum_{k=0}^{\infty} \lim_{n\longrightarrow\infty} \chi_{k\leq n} \cdot f(k)\binom{n}{k} p_n^k(1-p_n)^{n-k} &= \sum_{k=0}^{\infty} \lim_{n\longrightarrow\infty} \chi_{k\leq n} \cdot f(k)\frac{n!}{k!(n-k)!} p_n^k(1-p_n)^n(1-p_n)^{-k} && (91)\\
&= \sum_{k=0}^{\infty} \lim_{n\longrightarrow\infty} \chi_{k\leq n} \cdot f(k)\frac{n^k+O(n^{k-1})}{k!} p_n^k(1-p_n)^n(1-p_n)^{-k} && (92)\\
&= \sum_{k=0}^{\infty} f(k) \lim_{n\longrightarrow\infty} \frac{n^k+O(n^{k-1})}{k!} p_n^k(1-p_n)^n \underbrace{(1-p_n)^{-k}}_{\longrightarrow 0} && (93)\\
&= \sum_{k=0}^{\infty} f(k) \lim_{n\longrightarrow\infty} \underbrace{\frac{n^k+O(n^{k-1})}{k!} p_n^k}_{\longrightarrow \frac{\lambda^k}{k!}}(1-p_n)^n && (94)\\
&= \sum_{k=0}^{\infty} \frac{\lambda^k}{k!} f(k) \lim_{n\longrightarrow\infty} \underbrace{(1-\frac{\lambda}{n})^n}_{\longrightarrow e^{-\lambda}} && (95)\\
&= \sum_{k=0}^{\infty} \frac{\lambda^k}{k!} e^{-\lambda} f(k). && (96)
\end{aligned}$$

This proves the weak convergence.

4.4

This argument holds whether one takes the integral (sum) or not. So $\mu_n(\{k\}) \longrightarrow \nu(\{k\})$ for all $k \in \mathbb{N}^0$.

5

5.1

We wish to show that $\mathbb{P}(B_n) = 1/2$ for every $n \geq 1$. Note that

$$B_n = \bigcup_{k=0}^{2^{n-1}-1} \Big[\frac{2k}{2^n}, \frac{2k+1}{2^n}\Big) \tag{97}$$

and thus

$$\begin{aligned}
\mathbb{P}(B_n) &= \mathbb{P}\left(\bigcup_{k=0}^{2^{n-1}-1} \Big[\frac{2k}{2^n}, \frac{2k+1}{2^n}\Big)\right) && (98)\\
&= \sum_{k=0}^{2^{n-1}-1} \mathbb{P}\left(\Big[\frac{2k}{2^n}, \frac{2k+1}{2^n}\Big)\right) && (99)\\
&= \sum_{k=0}^{2^{n-1}-1} \frac{1}{2^n} && (100)\\
&= 2^{n-1}\frac{1}{2^n} && (101)\\
&= \frac{1}{2}. && (102)
\end{aligned}$$

5.2

We now wish to show that the sequence of events B_n form an infinite sequence of independent events. Take a finite subset $J \subset \mathbb{N}$ with $|J| = m$ and $\max J = r$ then

$$\mathbb{P}\left(\bigcap_{n\in J} B_n\right) = \mathbb{P}\left(\bigcap_{n\in J}\bigcup_{k=0}^{2^{n-1}-1}\left[\frac{2k}{2^n}, \frac{2k+1}{2^n}\right)\right) \tag{103}$$

$$= \mathbb{P}\left(\bigcup_{k=0}^{2^{r-m}-1}\left[\frac{2k}{2^r}, \frac{2k+1}{2^r}\right)\right) \tag{104}$$

$$= \sum_{k=0}^{2^{r-m}-1}\mathbb{P}\left(\left[\frac{2k}{2^n}, \frac{2k+1}{2^n}\right)\right) \tag{105}$$

$$= 2^{r-m}\frac{1}{2^r} \tag{106}$$

$$= \frac{1}{2^m} \tag{107}$$

$$= \prod_{n\in J}\mathbb{P}\left(B_n\right) \tag{108}$$

and so the sequence of events B_n form an infinite sequence of independent events.

5.3

We wish to show / argue that the probability that a randomly sampled number ω will have the sequence 5825 occur infinitely often in its decimal expansion is 1.
We use the Borel-Cantelli lemma. Ignoring possible overlaps (on the 5s) we can see that we can break any decimal expansion of ω up into blocks of 4 digits.
Then by we can define E_i as the probability of obtaining 5285 in the i-th block possition. By the same argument as above these events are independent.
The for any i we have that $\mathbb{P}(E_i) = \frac{1}{10000}$ (the same argument as above applied to a decimal expansion). Then clearly

$$\mathbb{P}(E_i) = \infty. \tag{109}$$

By the Borel-Cantelli lemma this implies

$$\mathbb{P}(\limsup_n(E_n) = 1. \tag{110}$$

Now

$$\limsup_n(E_n) = \bigcap_{n=1}^{\infty}\bigcup_{j=n}^{\infty} E_j \tag{111}$$

can be intuatively read as E_j happens infinitely often. Which is to say that 5285 occurs *blockwise* in the expansion of ω infinitely often. Clearly as allowing for overlaps allows for more configurations then the probability is 1 (it can be no more).