R Getting Started

```
install.packages('tidyverse')
```

```
library('tidyverse')
```

```
## -- Attaching packages ------------------------------------ tidyverse 1.3.1 --

## v ggplot2 3.3.3     v purrr   0.3.4
## v tibble  3.1.2     v dplyr   1.0.6
## v tidyr   1.1.3     v stringr 1.4.0
## v readr   1.4.0     v forcats 0.5.1

## -- Conflicts ----------------------------------------- tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()
```

Read in data Often the first step is to connect to the data:

```
con <- DBI::dbConnect(RMySQL::MySQL(),
  host = "database.company.com",
  user = "user_name",
  password = rstudioapi::askForPassword("Database password")
)

A_DATA_TBL <- tbl(con, "table_name")
```

```
A_DATA <- readRDS('A_DATA.RDS')
A_DATA <- readxl::read_excel('A_DATA.xlsx')
```

```
A_DATA <- readr::read_csv('A_DATA.csv')
```

```
##
## -- Column specification -------------------------------------------
## cols(
##   .default = col_double(),
##   Gender = col_character(),
##   Race = col_character(),
##   USAF = col_character(),
##   Birth_Country = col_character(),
##   Grade_Level = col_character(),
##   Grade_Range = col_character(),
##   Marital_Status = col_character(),
##   Pregnant = col_character(),
##   Household_Icome = col_logical(),
##   Family_Income = col_logical(),
##   yr_range = col_character(),
##   BMIHEAD = col_logical(),
##   BMAUPREL = col_logical(),
##   BMAUPLEL = col_logical(),
##   BMALLKNE = col_logical(),
##   BMDSTATS = col_logical(),
##   BMDRECUF = col_logical(),
##   BMDSUBF = col_logical(),
##   BMDTHICF = col_logical(),
##   BMDLEGF = col_logical()
##   # ... with 46 more columns
## )
## i Use `spec()` for the full column specifications.
```

Transform and Summarise Data Use dplyr and the tidyverse to get summary data

```
A_DATA %>%
  mutate(over_50 = if_else(Age > 50, 1, 0)) %>%
  group_by(DIABETES, over_50) %>%
  summarise(n = n(),
            mean_age = mean(Age, na.rm = TRUE),
            .groups = 'keep')
```

```
## # A tibble: 6 x 4
## # Groups:   DIABETES, over_50 [6]
##   DIABETES over_50     n mean_age
##      <dbl>   <dbl> <int>    <dbl>
## ## 1        0       0 68703     19.5
## ## 2        0       1 20037     66.3
## ## 3        1       0  1373     38.8
## ## 4        1       1  5434     67.3
## ## 5       NA       0  4938     2.77
## ## 6       NA       1   831     66.8
```

```
A_DATA %>%
  filter(!is.na(Grade_Level)) %>%
  group_by(Gender, Race, Grade_Level) %>%
  tally()
```

```
## # A tibble: 188 x 4
## # Groups:   Gender, Race [10]
##    Gender Race  Grade_Level                    n
##    <chr>  <chr> <chr>                      <int>
## ## 1 Female Black 10th grade                  278
## ## 2 Female Black 11th grade                  305
## ## 3 Female Black 12th grade, no diploma       75
## ## 4 Female Black 1st grade                   284
## ## 5 Female Black 2nd grade                   315
## ## 6 Female Black 3rd grade                   276
## ## 7 Female Black 4th grade                   279
## ## 8 Female Black 5th grade                   318
## ## 9 Female Black 6th grade                   347
## ## 10 Female Black 7th grade                  293
## # ... with 178 more rows
```

```
A_DATA %>% saveRDS('A_DATA.RDS')
A_DATA %>% openxlsx::write.xlsx('A_DATA.xlsx')
A_DATA %>% readr::write_csv('A_DATA.csv')
```

Stats
t-test
ks-test
chi-square test
anova
Models
glm
Model Evaluation
Comments with \iffalse (and closing \fi) You shouldn't see anything in the output PDF here (although there is an equation in the Rmarkdown document).
A "Big" Test of Equations Source: Griffith Quantum Mechanics Time Dependent Perturbation theory CheatSheet (UCB 137B final) on www.overleaf.com
TIPT

$$H = H_0 + H'$$
$$E_n = E_n^0 + E_n^1$$
$$|\psi_n\rangle = |\psi_n^0\rangle + |\psi_n^1\rangle$$
$$E_n^1 = \langle\psi_n^0|H'|\psi_n^0\rangle$$
$$|\psi_n^1\rangle = \sum_{m\neq n} \frac{\langle\psi_m^0|H'|\psi_n^0\rangle}{E_n^0 - E_m^0}|\psi_m^0\rangle$$

Degenerate Case

$$\text{Degenerate space: } \{|i\rangle\} \to E$$
$$W_{ab} = \langle a|H'|b\rangle \text{ Non-Diagonal}$$
$$\text{Eigenvalue and Eivenvectors} \to E_n^1, |\hat{i}\rangle$$

Variational Method

$$\langle H\rangle(\lambda) = \frac{\langle\psi(x,\lambda)|H|\psi(x,\lambda)\rangle}{\langle\psi(x,\lambda)|\psi(x,\lambda)\rangle}$$
$$\langle H\rangle(\lambda) \geq E_{.g.s}$$
$$\frac{d}{d\lambda}\langle H\rangle(\lambda_0) = 0 \Rightarrow \langle H\rangle(\lambda_0) \approx E_{.g.s}$$

WKB Method

$$\frac{d^2\psi(x)}{dx^2} = -k^2(x)\psi(x)$$
$$k(x) = \frac{1}{\hbar}\sqrt{2m(E - V(x))}$$
$$\phi(x) = \int^x k(x)dx$$
$$\psi(x) = \frac{1}{\sqrt{k(x)}}(C_+ e^{i\phi(x)} + C_- e^{-i\phi(x)})$$
$$= \frac{1}{\sqrt{k(x)}}(C_1 \sin\phi(x) + C_2 \cos\phi(x))$$

Energy Level

$$\int_{R_{classical}} k(x)dx = n\pi$$
$$\text{one } \infty \text{ wall} \quad n \to n - 1/4$$
$$\text{No } \infty \text{ wall} \quad n \to n - 1/2$$

Tunneling

$$T = e^{-2\gamma}$$
$$\gamma = \int_{R_{forbidden}} k(x)dx$$

TDPT

$$H = H_0 + V(t)$$
$$\text{Eigenstate of } H_0: |n\rangle, E_n$$
$$\text{transition: } |i\rangle \to |f\rangle$$
$$V_{fi}(t) = \langle f|V(t)|i\rangle$$
$$\omega_{fi} = (E_f - E_i)/\hbar$$
$$c_f(T) = \frac{-i}{\hbar}\int_0^T V_{fi}(t)e^{-i\omega_{fi}t}dt$$

Constant Perturbation

$$V(t) = \begin{cases} V, & 0 \leq t \leq T \\ 0, & \text{otherwise} \end{cases}$$
$$V_{fi}(t) = constant$$
$$P_{i\to f}(t) = |c_f(t)|^2 = 4\frac{|V_{fi}|^2}{\hbar^2}\frac{\sin^2(\omega_{fi})t/2}{\omega_{fi}^2}$$
$$\omega_{fi} \to 0 \quad \text{(degenerate states):}$$
$$|c_f(t)|^2 = \frac{|V_{fi}|^2}{\hbar^2}t^2$$

Absorption

$$V(t) = V\sin(\omega t)$$
$$P_{i\to f}(t) = \frac{|V_{fi}|^2}{\hbar^2}\frac{\sin^2((\omega_{fi} - \omega)t/2)}{(\omega_{fi} - \omega)^2}$$

Simulated Emission

$$E_i > E_f, \quad \omega_{fi} < 0$$
$$P_{i\to f}(t) = \frac{|V_{fi}|^2}{\hbar^2}\frac{\sin^2((\omega_{fi} + \omega)t/2)}{(\omega_{fi} + \omega)^2}$$

Fermi Golden Rule

$$E_i \to E_f \text{ (continuous states)}$$
$$P_{i\to f} = \frac{2\pi}{\hbar}|\langle f|V|i\rangle|^2\rho(E_f)t$$

Selection Rule For spherical symmetric potential:

$$\langle n', l', m'|\vec{r}|n, l, m\rangle \neq 0 \text{ when:}$$
$$\Delta l = \pm 1 \text{ and:}$$
$$\Delta l = \pm 1 \text{ or } 0$$

Scattering

$$\psi(r, \theta) = e^{ikz} + f(\theta)\frac{e^{ikr}}{r}, \text{ for large r}$$
$$k = \frac{\sqrt{2mE}}{\hbar}$$
$$\frac{d\sigma}{d\Omega} = |f(\theta)|^2$$
$$\sigma = \int d\omega \frac{d\sigma}{d\Omega}$$

Born Approximation

$$f(\theta) = -\frac{m}{2\pi\hbar^2} \int V(\vec{r}) e^{i(\vec{k}'-\vec{k})\cdot\vec{r}} d^3\vec{r}$$

Low Energy:

$$f(\theta) = -\frac{m}{2\pi\hbar^2} \int V(\vec{r}) d^3\vec{r}$$

Spherical symmetric:

$$f(\theta) = -\frac{2m}{\hbar^2 \kappa} \int_0^\infty r V(r) \sin(\kappa r) dr$$

$$\kappa = 2k\sin(\theta/2)$$

Yukawa Potential

$$V(r) = V_0 \frac{e^{-r/R}}{r}$$

$$f(\theta) = -\frac{2mV_0 R^2}{\hbar^2} \frac{1}{1+4k^2 R^2 \sin^2(\theta/2)}$$

$$\sigma = (\frac{2mV_0 R^2}{\hbar^2})^2 \frac{4\pi}{1+4k^2 R^2}$$

Rutherford Scattering
Let $V_0 = q_1 q_2/4\pi\epsilon_0$, $R = \infty$:

$$f(\theta) = -\frac{2mq_1 q_2}{4\pi\epsilon_0 \hbar^2 \kappa^2}$$

Partial Waves

$$f(\theta) = \frac{1}{k} \sum_{i=0}^{\infty} (2l+1) e^{i\delta_l} \sin(\delta_l) P_l(\cos(\theta))$$

$$\sigma = \frac{4\pi}{k^2} \sum_{l=0}^{\infty} (2l+1)\sin^2(\delta_l)$$

Optical Theorem

$$Im[f(0)] = \frac{k\sigma}{4\pi}$$

Hard Ball

$$\delta_l = \tan^{-1}(\frac{j_l(ka)}{\eta_l(ka)})$$

$$ka << 1 \rightarrow \sigma = 4\pi a^2$$

Useful Models
Density of States

$$E = \hbar^2 k^2/2m$$

$$dN = \frac{L^3}{(2\pi)^3} d^3k = \frac{L^3}{(2\pi)^3} d\Omega dk$$

$$dN = \frac{L^3}{(2\pi)^3} 4\pi \frac{m}{\hbar^2 k} dE$$

$$\rho(E) = \frac{dN}{dE} = \frac{L^3}{2\pi^2} \frac{mk}{\hbar^2}$$

infinite square well

$$H(x) = \frac{p^2}{2m} + \begin{cases} 0, & 0 \le x \le a \\ \infty, & \text{otherwise} \end{cases}$$

$$E_n = \frac{1}{2m}(\frac{n\pi\hbar}{a})^2$$

$$\psi_n = \sqrt{\frac{2}{a}}\sin(\frac{n\pi x}{a}) e^{-iE_n t/\hbar}$$

Harmonic Oscillator

$$H(x) = \frac{p^2}{2m} + \frac{1}{2}m\omega^2 x^2$$

$$E_n = (n+1/2)\hbar\omega$$

$$\psi_n(x) = \frac{1}{\sqrt{2^n n!}} (\frac{m\omega}{\pi\hbar})^{1/4} e^{-\zeta^2/2} H_n(\zeta)$$

$$\zeta = \sqrt{\frac{m\omega}{\hbar}} x$$

Virial Theorem

$$2\langle T\rangle = \langle \vec{r}\cdot\nabla V\rangle \quad \text{(3D)}$$

$$2\langle T\rangle = \langle x\frac{dV}{dx}\rangle \quad \text{(1D)}$$

$$2\langle T\rangle = n\langle V\rangle \quad (V \propto r^n)$$

$$\langle T\rangle = -E_n, \quad \langle V\rangle = 2E_n \quad \text{(hydrogen)}$$

$$\langle T\rangle = \langle V\rangle = E_n/2 \quad \text{(harmonic oscillator)}$$

Math
Legendre Polynomials
Domain: $(-1, 1)$ \ Even, Odd, Even, Odd . . .

$$P_0(x) = 1$$
$$P_1(x) = x$$
$$P_2(x) = \frac{1}{2}(3x^2 - 1)$$
$$P_3(x) = \frac{1}{2}(5x^3 - 3x)$$

Hankel Functions
Solution to Radial Shrodinger Equation:

$$-\frac{\hbar^2}{2m}\frac{1}{r^2}\frac{\partial}{\partial r}(r^2 R_{El}) + [V(r) + \frac{\hbar^2 l(l+1)}{2mr^2}]R_{El} = ER_{El}$$

$$V = 0 \rightarrow R_{El} = j_l(kr)$$
$$V \ne 0 \rightarrow R_{El} = j_l(kr + \delta_l)$$
$$r \rightarrow \infty \Rightarrow R_{El} = \frac{\sin(kr - l\pi/2 + \delta_l(E))}{kr}$$

When $kr >> 1$

$$j_l(kr) \rightarrow \frac{\sin kr - l\pi/2}{kr}$$

$$\eta_l(kr) \rightarrow \frac{-\cos kr - l\pi/2}{kr}$$

$$h_l(kr) \rightarrow \frac{e^{i(kr - l\pi/2)}}{ikr}$$

$$h_l^*(kr) \rightarrow \frac{e^{-i(kr - l\pi/2)}}{-ikr}$$

$$j_l(kr) = \frac{1}{2}(h_l(kr) + h^*(kr))$$

Hermite Polynomials
Domain: $(-\infty, \infty)$ \ Even, Odd, Even, Odd . . .

$$H_0(x) = 1$$
$$H_1(x) = 2x$$
$$H_2(x) = 4x^2 - 2$$
$$H_3(x) = 8x^3 - 12x$$

Spherical Harmonics

$$|l, m\rangle = Y_l^m(\theta, \phi)$$

$$Y_0^0(\theta, \phi) = \frac{1}{2}\frac{1}{\sqrt{\pi}}$$

$$Y_1^0(\theta, \phi) = \frac{1}{2}\sqrt{\frac{3}{\pi}}\cos\theta$$

$$Y_1^{-1}(\theta, \phi) = \frac{1}{2}\sqrt{\frac{3}{2\pi}}\sin\theta e^{-i\phi}$$

$$Y_1^{-1}(\theta, \phi) = -\frac{1}{2}\sqrt{\frac{3}{2\pi}}\sin\theta e^{i\phi}$$

Green's Function
For a Linear Operator $\hat{D}_x$

Homogeneous solution: $\hat{D}_x \psi_0(x) = 0$

Hard Problem: $\hat{D}_x \psi(x) = f(x)$

Simple Problem: $\hat{D}_x G(x, x') = \delta(x - x')$

$$\psi(x) = \psi_0(x) + \int_{\text{f Domain}} G(x, x') f(x') dx'$$

Some Integrals

$$\Gamma(n+1) = n!$$
$$\Gamma(z+1) = z\Gamma(z)$$

$$\int_0^\infty x^n e^{-ax} dx = \frac{n!}{a^{n+1}}$$

$$\int_0^\infty e^{-ax^b} dx = a^{-1/b}\Gamma(1/b + 1)$$

$$\int_0^\infty e^{-ax}\sin bx\, dx = \frac{b}{a^2 + b^2}$$

$$\int_0^\infty e^{-ax}\cos bx\, dx = \frac{a}{a^2 + b^2}$$

$$\int_{-\infty}^\infty e^{-ax^2 + bx} dx = \sqrt{\frac{\pi}{a}} e^{\frac{b^2}{4a}}$$

$$\int_0^\infty e^{-ax^2} x^n dx = I_n(a)$$

$$I_0 = \frac{1}{2}\sqrt{\frac{\pi}{a}}, I_1 = \frac{1}{2a}, I_2 = \frac{1}{4a}\sqrt{\frac{\pi}{a}}, I_3 = \frac{1}{2a^2}$$

A "Big" Test of Words
Source: `clipr::write_clip(stringi::stri_rand_lipsum(10))`

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Fermentum libero dolor nibh vitae metus in elit hac vulputate! Tempus id tempor netus vestibulum lectus et, donec! Habitasse arcu pulvinar viverra eleifend gravida dui sit volutpat in inceptos. Quis nibh elit purus ac ultrices. Lacinia, cursus parturient ut purus et, et ullamcorper quis viverra et nulla in. Ac semper risus. Est vel dapibus vitae aliquet felis ullamcorper ut augue cubilia blandit ipsum. Vitae porttitor eros dignissim neque habitant habitasse laoreet erat. Etiam diam elit vitae vel dui. Vitae gravida felis ante platea eget vestibulum tristique, in suscipit ac. Lacus convallis neque fermentum primis taciti duis non, vitae euismod, est velit porttitor libero ridiculus. Iaculis quis nam viverra ac aliquet urna montes. Sed congue accumsan, est lacus proin sed pellentesque facilisis ac. Amet ipsum penatibus ex dolor tincidunt massa. Dictum nec vestibulum et vel ultricies potenti ligula himenaeos ac eu pellentesque. Nascetur mi ut tortor orci? Nascetur at cubilia finibus luctus, in maximus dolor porta. Proin porttitor tincidunt in suscipit et, class ac eu, sed fames. Quisque habitant, venenatis nec pulvinar ante ad lobortis fames a dictumst maecenas dictumst nisl sed. Conubia conubia platea lectus sem ut vitae proin nisl. Orci curae, per dolor lacus mollis. Posuere lacinia ultrices at tempor, aliquam tellus quam, sed enim. Aliquet a sem semper duis etiam suspendisse, eget enim et dolor cras. In porta turpis sit imperdiet eros sed vitae est. Sed vehicula mauris vivamus. Consectetur lectus urna mi penatibus. Ut consectetur erat ac justo habitasse praesent primis. Erat at tempor nam augue nulla ut ridiculus rhoncus, dapibus. Urna eros quam ut, nulla finibus mauris interdum mauris justo. Vestibulum hac adipiscing nunc sagittis ligula, varius enim a. Amet, feugiat nulla mauris netus aptent diam. Ut malesuada nulla condimentum nam dignissim. Nec magna volutpat, magna in. 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potenti, et. Egestas, condimentum laoreet donec, pharetra nec. Ut quis faucibus sed. Rutrum quis lorem in ut. Sollicitudin, inceptos posuere parturient class magnis neque id sed etiam. Pulvinar finibus ullamcorper, scelerisque imperdiet conubia et vitae. Aliquet tortor mi sed commodo senectus ante nunc ut mattis ornare cursus tempus.