

# Lecture 13 Normal (Gaussian) Distribution

BIO210 Biostatistics

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**LIFE SCIENCES**

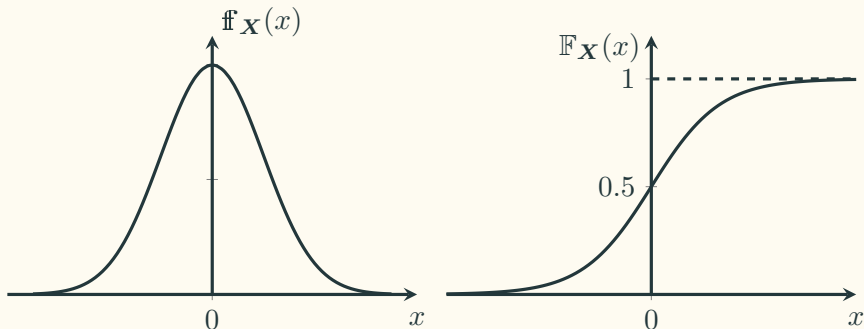
# The Normal (Gaussian) PDF

## The PDF of a normal distribution

$$\mathbb{f}_{\mathbf{X}}(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(x - \mu)^2}{2\sigma^2}}, \quad \mathbb{E}[\mathbf{X}] = \mu, \quad \mathbb{V}\text{ar}(\mathbf{X}) = \sigma^2$$

# The Standard Normal (Gaussian) PDF

**Standard Normal Distribution:**  $\mathcal{N}(0, 1)$ :  $f_{\mathbf{X}}(x) = \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}}$



**General Normal Distribution:**  $\mathcal{N}(\mu, \sigma^2)$ :  $f_{\mathbf{X}}(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$

# The Normal (Gaussian) PDF

We have the random variable  $X \sim \mathcal{N}(\mu, \sigma^2)$ . Now consider the following random variable:

$$Y = aX + b, \text{ where } a \text{ and } b \text{ are constant}$$

- What distribution does  $Y$  follow?
- $\mathbb{E}[Y] = ?$
- $\mathbb{V}\text{ar}(Y) = ?$

$$Y \sim \mathcal{N}(a\mu + b, a^2\sigma^2)$$

**Property: A linear function of a normal r.v. is also a normal r.v.**

# The Normal (Gaussian) PDF

We have the random variable  $X \sim \mathcal{N}(\mu, \sigma^2)$ . Now consider the following random variable:

$$Z = \frac{X - \mu}{\sigma}$$

- What distribution does  $Z$  follow?
- $\mathbb{E}[Z] = ?$
- $\text{Var}(Z) = ?$

$$Z \sim \mathcal{N}(0, 1)$$

# The Normal (Gaussian) PDF

Given that  $X$  and  $Y$  are two independent normal random variables, and  $X \sim \mathcal{N}(\mu_x, \sigma_x^2)$  and  $Y \sim \mathcal{N}(\mu_y, \sigma_y^2)$ , now consider the new random variable:

$$W = X + Y$$

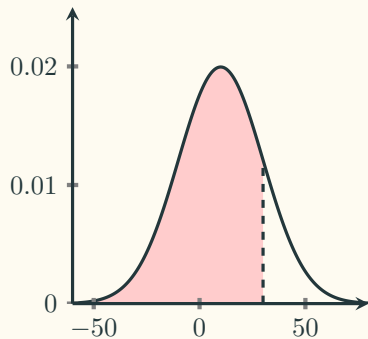
- What distribution does  $W$  follow?
- $\mathbb{E}[W] = ?$
- $\mathbb{V}\text{ar}(W) = ?$

$$W \sim \mathcal{N}(\mu_x + \mu_y, \sigma_x^2 + \sigma_y^2)$$

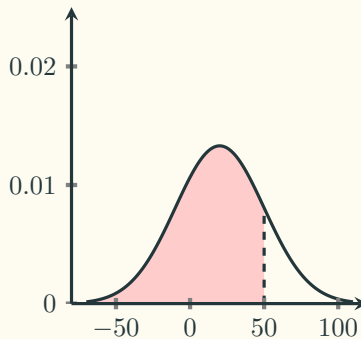
**Property: the sum of independent normal random variables is still normal.**

# Properties of normal PDFs

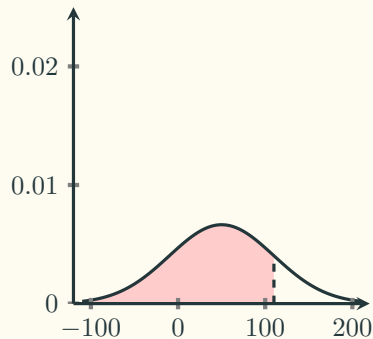
**Dotted line:** one standard deviation away from the mean.



$$\mu = 10$$
$$\sigma = 20$$

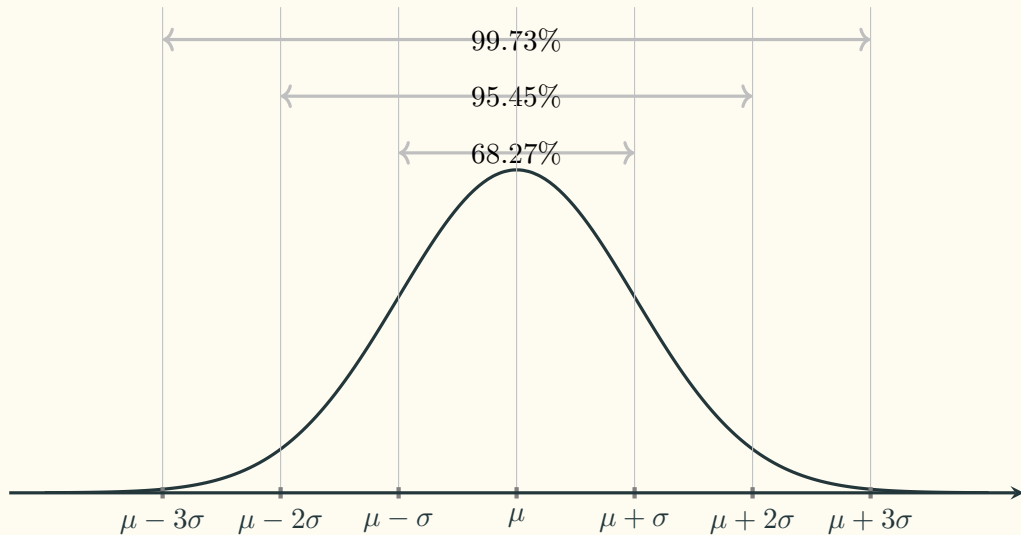


$$\mu = 20$$
$$\sigma = 30$$



$$\mu = 50$$
$$\sigma = 60$$

# The Empirical Rule

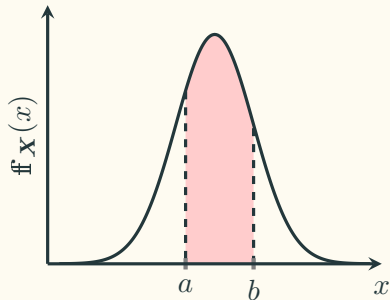


# Normal Distribution in real life

- **Commonly observed in many natural phenomena:**  
height, weight, blood pressure, chest measurements of Scottish soldiers, etc.
  - In many cases, you need to take the *log* value.
- **Noise or Error.**
  - An assumption.
- **Sum of many random variables.**
  - Only if they have equal weights.
- **Sample mean.**

TABLE 1: Chest measurement of Scottish soldiers

| Girth | Frequency |
|-------|-----------|
| 33    | 3         |
| 34    | 18        |
| 35    | 81        |
| 36    | 185       |
| 37    | 420       |
| 38    | 749       |
| 39    | 1,073     |
| 40    | 1,079     |
| 41    | 934       |
| 42    | 658       |
| 43    | 370       |
| 44    | 92        |
| 45    | 50        |
| 46    | 21        |
| 47    | 4         |
| 48    | 1         |



$$\mathbf{X} \sim \mathcal{N}(\mu, \sigma^2)$$

$$\begin{aligned}\mathbb{P}(a \leq \mathbf{X} \leq b) &= \int_a^b \mathbf{f}_{\mathbf{X}}(x) \, dx \\ &= \int_a^b \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \, dx\end{aligned}$$

**The solution is non-elementary!**

**Note:** we know  $\mathbb{P}(a \leq \mathbf{X} \leq b) = \mathbb{F}_{\mathbf{X}}(b) - \mathbb{F}_{\mathbf{X}}(a)$

and if  $\mathbf{X} \sim \mathcal{N}(\mu, \sigma^2)$ , then  $\frac{\mathbf{X}-\mu}{\sigma} \sim \mathcal{N}(0, 1)$ .

**Pre-computed table to the rescue!**

# Examples of the Standard Normal Table

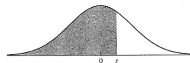
Appendix A Tables **A-9**

**TABLE A.3**

Areas in the upper tail of the standard normal distribution

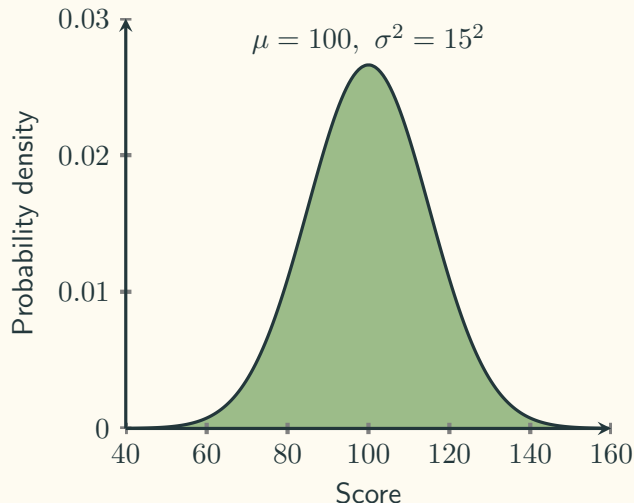
| z   | 0.00  | 0.01  | 0.02  | 0.03  | 0.04  | 0.05  | 0.06  | 0.07  | 0.08  | 0.09  |
|-----|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 0.0 | 0.500 | 0.496 | 0.492 | 0.488 | 0.484 | 0.480 | 0.476 | 0.472 | 0.468 | 0.464 |
| 0.1 | 0.460 | 0.456 | 0.452 | 0.448 | 0.444 | 0.440 | 0.436 | 0.433 | 0.429 | 0.425 |
| 0.2 | 0.421 | 0.417 | 0.413 | 0.409 | 0.405 | 0.401 | 0.397 | 0.394 | 0.390 | 0.386 |
| 0.3 | 0.382 | 0.378 | 0.374 | 0.371 | 0.367 | 0.363 | 0.359 | 0.356 | 0.352 | 0.348 |
| 0.4 | 0.345 | 0.341 | 0.337 | 0.334 | 0.330 | 0.326 | 0.323 | 0.319 | 0.316 | 0.312 |
| 0.5 | 0.309 | 0.305 | 0.302 | 0.298 | 0.295 | 0.291 | 0.288 | 0.284 | 0.281 | 0.278 |
| 0.6 | 0.274 | 0.271 | 0.268 | 0.264 | 0.261 | 0.258 | 0.255 | 0.251 | 0.248 | 0.245 |
| 0.7 | 0.242 | 0.239 | 0.236 | 0.233 | 0.230 | 0.227 | 0.224 | 0.221 | 0.218 | 0.215 |
| 0.8 | 0.212 | 0.209 | 0.206 | 0.203 | 0.200 | 0.198 | 0.195 | 0.192 | 0.189 | 0.187 |
| 0.9 | 0.184 | 0.181 | 0.179 | 0.176 | 0.174 | 0.171 | 0.169 | 0.166 | 0.164 | 0.161 |
| 1.0 | 0.159 | 0.156 | 0.154 | 0.152 | 0.149 | 0.147 | 0.145 | 0.142 | 0.140 | 0.138 |
| 1.1 | 0.136 | 0.133 | 0.131 | 0.129 | 0.127 | 0.125 | 0.123 | 0.121 | 0.119 | 0.117 |
| 1.2 | 0.115 | 0.113 | 0.111 | 0.109 | 0.107 | 0.106 | 0.104 | 0.102 | 0.100 | 0.099 |
| 1.3 | 0.097 | 0.095 | 0.093 | 0.092 | 0.090 | 0.089 | 0.087 | 0.085 | 0.084 | 0.082 |
| 1.4 | 0.081 | 0.079 | 0.078 | 0.076 | 0.075 | 0.074 | 0.072 | 0.071 | 0.069 | 0.068 |
| 1.5 | 0.067 | 0.066 | 0.064 | 0.063 | 0.062 | 0.061 | 0.059 | 0.058 | 0.057 | 0.056 |
| 1.6 | 0.055 | 0.054 | 0.053 | 0.052 | 0.051 | 0.049 | 0.048 | 0.047 | 0.046 | 0.046 |
| 1.7 | 0.045 | 0.044 | 0.043 | 0.042 | 0.041 | 0.040 | 0.039 | 0.038 | 0.038 | 0.037 |
| 1.8 | 0.036 | 0.035 | 0.034 | 0.034 | 0.033 | 0.032 | 0.031 | 0.031 | 0.030 | 0.029 |
| 1.9 | 0.029 | 0.028 | 0.027 | 0.027 | 0.026 | 0.026 | 0.025 | 0.024 | 0.024 | 0.023 |
| 2.0 | 0.023 | 0.022 | 0.022 | 0.021 | 0.021 | 0.020 | 0.020 | 0.019 | 0.019 | 0.018 |
| 2.1 | 0.018 | 0.017 | 0.017 | 0.017 | 0.016 | 0.016 | 0.015 | 0.015 | 0.015 | 0.014 |
| 2.2 | 0.014 | 0.014 | 0.013 | 0.013 | 0.013 | 0.012 | 0.012 | 0.012 | 0.011 | 0.011 |
| 2.3 | 0.011 | 0.010 | 0.010 | 0.010 | 0.010 | 0.009 | 0.009 | 0.009 | 0.009 | 0.008 |
| 2.4 | 0.008 | 0.008 | 0.008 | 0.008 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | 0.006 |
| 2.5 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 |
| 2.6 | 0.005 | 0.005 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 |
| 2.7 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 |
| 2.8 | 0.003 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 |
| 2.9 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.001 | 0.001 |
| 3.0 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| 3.1 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| 3.2 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| 3.3 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 3.4 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

**TABLE A.2** Cumulative normal distribution (continued)



| z   | 0.00  | 0.01  | 0.02  | 0.03  | 0.04  | 0.05  | 0.06  | 0.07  | 0.08  | 0.09  |
|-----|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 0.0 | .5000 | .5040 | .5080 | .5120 | .5160 | .5199 | .5239 | .5279 | .5319 | .5359 |
| 0.1 | .5398 | .5438 | .5478 | .5517 | .5557 | .5596 | .5636 | .5675 | .5714 | .5753 |
| 0.2 | .5793 | .5832 | .5871 | .5910 | .5948 | .5987 | .6026 | .6064 | .6103 | .6141 |
| 0.3 | .6179 | .6217 | .6255 | .6293 | .6331 | .6368 | .6406 | .6443 | .6480 | .6517 |
| 0.4 | .6554 | .6591 | .6628 | .6664 | .6700 | .6736 | .6772 | .6808 | .6844 | .6879 |
| 0.5 | .6915 | .6950 | .6985 | .7019 | .7054 | .7088 | .7123 | .7157 | .7190 | .7224 |
| 0.6 | .7257 | .7291 | .7324 | .7357 | .7389 | .7422 | .7454 | .7486 | .7517 | .7549 |
| 0.7 | .7580 | .7611 | .7642 | .7673 | .7704 | .7734 | .7764 | .7794 | .7823 | .7852 |
| 0.8 | .7881 | .7910 | .7939 | .7967 | .7995 | .8023 | .8051 | .8078 | .8106 | .8133 |
| 0.9 | .8159 | .8186 | .8212 | .8238 | .8264 | .8289 | .8315 | .8340 | .8365 | .8389 |
| 1.0 | .8413 | .8438 | .8461 | .8485 | .8508 | .8531 | .8554 | .8577 | .8599 | .8621 |
| 1.1 | .8643 | .8665 | .8686 | .8708 | .8729 | .8749 | .8770 | .8790 | .8810 | .8830 |
| 1.2 | .8849 | .8869 | .8888 | .8907 | .8925 | .8944 | .8962 | .8980 | .8997 | .9015 |
| 1.3 | .9032 | .9049 | .9066 | .9082 | .9099 | .9115 | .9131 | .9147 | .9162 | .9177 |
| 1.4 | .9192 | .9207 | .9222 | .9236 | .9251 | .9265 | .9279 | .9292 | .9306 | .9319 |
| 1.5 | .9332 | .9345 | .9357 | .9370 | .9382 | .9394 | .9406 | .9418 | .9429 | .9441 |
| 1.6 | .9452 | .9463 | .9474 | .9484 | .9495 | .9505 | .9515 | .9525 | .9535 | .9545 |
| 1.7 | .9554 | .9564 | .9573 | .9582 | .9591 | .9599 | .9608 | .9616 | .9625 | .9633 |
| 1.8 | .9641 | .9649 | .9656 | .9664 | .9671 | .9678 | .9686 | .9693 | .9699 | .9706 |
| 1.9 | .9713 | .9719 | .9726 | .9732 | .9738 | .9744 | .9750 | .9756 | .9761 | .9767 |
| 2.0 | .9772 | .9778 | .9783 | .9788 | .9793 | .9798 | .9803 | .9808 | .9812 | .9817 |
| 2.1 | .9821 | .9826 | .9830 | .9834 | .9838 | .9842 | .9846 | .9850 | .9854 | .9857 |
| 2.2 | .9861 | .9864 | .9868 | .9871 | .9875 | .9878 | .9881 | .9884 | .9887 | .9890 |
| 2.3 | .9893 | .9896 | .9898 | .9901 | .9904 | .9906 | .9909 | .9911 | .9913 | .9916 |
| 2.4 | .9918 | .9920 | .9922 | .9925 | .9927 | .9929 | .9931 | .9932 | .9934 | .9936 |
| 2.5 | .9938 | .9940 | .9941 | .9943 | .9945 | .9946 | .9948 | .9949 | .9951 | .9952 |
| 2.6 | .9953 | .9955 | .9956 | .9957 | .9959 | .9960 | .9961 | .9962 | .9963 | .9964 |
| 2.7 | .9965 | .9966 | .9967 | .9968 | .9969 | .9970 | .9971 | .9972 | .9973 | .9974 |
| 2.8 | .9974 | .9975 | .9976 | .9977 | .9977 | .9978 | .9979 | .9979 | .9980 | .9981 |
| 2.9 | .9981 | .9982 | .9982 | .9983 | .9984 | .9984 | .9985 | .9985 | .9986 | .9986 |
| 3.0 | .9987 | .9987 | .9987 | .9988 | .9988 | .9989 | .9989 | .9989 | .9990 | .9990 |
| 3.1 | .9990 | .9991 | .9991 | .9991 | .9992 | .9992 | .9992 | .9992 | .9993 | .9993 |
| 3.2 | .9993 | .9993 | .9994 | .9994 | .9994 | .9994 | .9994 | .9995 | .9995 | .9995 |
| 3.3 | .9995 | .9995 | .9995 | .9996 | .9996 | .9996 | .9996 | .9996 | .9996 | .9997 |
| 3.4 | .9997 | .9997 | .9997 | .9997 | .9997 | .9997 | .9997 | .9997 | .9997 | .9998 |
| 3.5 | .9998 | .9998 | .9998 | .9998 | .9998 | .9998 | .9998 | .9998 | .9998 | .9998 |
| 3.6 | .9998 | .9998 | .9999 | .9999 | .9999 | .9999 | .9999 | .9999 | .9999 | .9999 |

## Example: Exam Scores



$$\mathbb{P}(\mathbf{X} \geq 140) = ?$$

$$\mathbb{P}(130 \leq \mathbf{X} \leq 140) = ?$$

$$Z = \frac{\mathbf{X} - \mu}{\sigma} = \frac{140 - 100}{15} = 2.67$$

$$Z = \frac{\mathbf{X} - \mu}{\sigma} = \frac{130 - 100}{15} = 2$$

## A Historical Fact About The First Standard Normal Table

$$\int_0^x e^{-t^2} dt = F(x) = x - \frac{x^3}{1!3} + \frac{x^5}{2!5} - \frac{x^7}{3!7} + \frac{x^9}{4!9} - \dots$$

$$\int_x^\infty e^{-t^2} dt = G(x) = \frac{1}{x} - \frac{1}{2x^3} + \frac{1 \cdot 3}{4x^5} - \frac{1 \cdot 3 \cdot 5}{8x^7} + \frac{1 \cdot 3 \cdot 5 \cdot 7}{16x^9} - \dots$$

- Large gaps between  $F(x)$  and  $G(x)$
- First computed by the French astronomer **Christian Kramp** in 1799.
- Analyse des Réfractions Astronomiques et Terrestres (Analysis of Astronomical and Terrestrial Refractions)

# The Table by Christian Kramp

## TABLE PREMIERE.

Intégrales de  $e^{-t} dt$ , depuis une valeur quelconque de  $t$  jusqu'à  $t$  infinie.

| $t$  | Intégrale. | Diff. prem. | Diff. II. | Diff. III. |
|------|------------|-------------|-----------|------------|
| 0,00 | 0,88622692 | 999968      | 201       | 199        |
| 0,01 | 0,87622724 | 999767      | 400       | 199        |
| 0,02 | 0,86622957 | 999367      | 599       | 200        |
| 0,03 | 0,85623590 | 998768      | 799       | 199        |
| 0,04 | 0,84624822 | 997969      | 998       | 197        |
| 0,05 | 0,83626853 | 996971      | 1195      | 199        |
| 0,06 | 0,82629882 | 995776      | 1394      | 196        |
| 0,07 | 0,81634106 | 994382      | 1590      | 195        |
| 0,08 | 0,80639724 | 992792      | 1785      | 194        |
| 0,09 | 0,79646932 | 991007      | 1979      | 195        |
| 0,10 | 0,78655925 | 989028      | 2174      | 192        |
| 0,11 | 0,77666897 | 986854      | 2366      | 190        |
| 0,12 | 0,76680043 | 984488      | 2556      | 189        |
| 0,13 | 0,75695555 | 981932      | 2745      | 188        |
| 0,14 | 0,74713623 | 979187      | 2933      | 186        |
| 0,15 | 0,73734436 | 976254      | 3110      | 184        |
| 0,16 | 0,72758182 | 973135      | 3303      | 183        |
| 0,17 | 0,71785047 | 969832      | 3486      | 180        |
| 0,18 | 0,70815215 | 966346      | 3666      | 175        |
| 0,19 | 0,69848869 | 962680      | 3841      | 178        |
| 0,20 | 0,68886189 | 958839      | 4019      | 173        |
| 0,21 | 0,67927350 | 954820      | 4192      | 171        |
| 0,22 | 0,66972530 | 950628      | 4363      | 168        |
| 0,23 | 0,66021902 | 946265      | 4531      | 166        |
| 0,24 | 0,65075637 | 941734      | 4697      | 163        |
| 0,25 | 0,64133903 | 937037      | 4860      | 160        |
| 0,26 | 0,63196866 | 932177      | 5020      | 157        |
| 0,27 | 0,62264689 | 927157      | 5177      | 155        |
| 0,28 | 0,61337532 | 922080      | 5332      | 151        |
| 0,29 | 0,60415552 | 916648      | 5483      | 149        |
| 0,30 | 0,59498904 | 911165      | 5632      | 146        |
| 0,31 | 0,58587739 | 905533      | 5777      | 142        |
| 0,32 | 0,57682206 | 899756      | 5919      | 138        |

B 2

## INTÉGRALES DE $e^{-t} dt$ .

| $t$  | Intégrale.   | Diff. prem. | Diff. II. | Diff. III. |
|------|--------------|-------------|-----------|------------|
| 0,76 | 0,25032654   | 556981      | 8511      | 21         |
| 0,77 | 0,24475673   | 548470      | 8490      | 25         |
| 0,78 | 0,23927203   | 539980      | 8465      | 29         |
| 0,79 | 0,23387223   | 531515      | 8436      | 31         |
| 0,80 | 0,22855708   | 523079      | 8405      | 33         |
| 0,81 | 0,22332629   | 514674      | 8372      | 37         |
| 0,82 | 0,21817955   | 506302      | 8333      | 39         |
| 0,83 | 0,21311653   | 497967      | 8296      | 42         |
| 0,84 | 0,20813686   | 489671      | 8254      | 45         |
| 0,85 | 0,20324015   | 481417      | 8209      | 46         |
| 0,86 | 0,19842593   | 473208      | 8163      | 50         |
| 0,87 | 0,19369390   | 465045      | 8113      | 52         |
| 0,88 | 0,18904345   | 456932      | 8061      | 54         |
| 0,89 | 0,18447413   | 448871      | 8007      | 56         |
| 0,90 | 0,17998552   | 440864      | 7951      | 58         |
| 0,91 | 0,17557678   | 432913      | 7893      | 61         |
| 0,92 | 0,17124765   | 425020      | 7832      | 62         |
| 0,93 | 0,16699745   | 417188      | 7770      | 65         |
| 0,94 | 0,16282557   | 409418      | 7705      | 66         |
| 0,95 | 0,15873139   | 401713      | 7639      | 67         |
| 0,96 | 0,15471426   | 394074      | 7572      | 71         |
| 0,97 | 0,15077532   | 386502      | 7504      | 70         |
| 0,98 | 0,14690850   | 379001      | 7431      | 74         |
| 0,99 | 0,14311849   | 371570      | 7357      | 74         |
| 1,00 | 0,13940279   | 364213      | 7283      | 75         |
| 1,01 | 0,13576666   | 356930      | 7208      | 77         |
| 1,02 | 0,132219136  | 349722      | 7131      | 80         |
| 1,03 | 0,128769414  | 342591      | 7051      | 78         |
| 1,04 | 0,125426823  | 335540      | 6973      | 81         |
| 1,05 | 0,122191283  | 328567      | 6892      | 81         |
| 1,06 | 0,11862716   | 321675      | 6811      | 83         |
| 1,07 | 0,115154041  | 314864      | 6728      | 84         |
| 1,08 | 0,1117226177 | 308136      | 6645      | 85         |
| 1,09 | 0,10838041   | 301491      | 6560      | 85         |
| 1,10 | 0,10616550   | 294931      | 6475      | 86         |
| 1,11 | 0,10321610   | 288456      | 6389      | 88         |
| 1,12 | 0,10033163   | 282067      | 6304      | 85         |
| 1,13 | 0,09751096   | 275763      | 6216      | 87         |
| 1,14 | 0,09475333   | 269547      | 6129      | 89         |
| 1,15 | 0,09205786   | 263418      | 6040      | 87         |
| 1,16 | 0,08942368   | 257378      | 5953      | 89         |
| 1,17 | 0,08684990   | 251425      | 5864      | 89         |
| 1,18 | 0,08433365   | 245561      | 5775      | 89         |

## INTÉGRALES DE $e^{-t} dt$ .

| $t$  | Intégrale.    | Diff. prem. | Diff. II. | Diff. III. | Diff. IV. |
|------|---------------|-------------|-----------|------------|-----------|
| 2,47 | 0,00042311518 | 2186329     | 105795    | 4724       | 191       |
| 2,48 | 0,00040125189 | 2080554     | 101071    | 4533       | 183       |
| 2,49 | 0,00038044655 | 1979463     | 96553     | 4350       | 177       |
| 2,50 | 0,00036065192 | 1882925     | 92188     | 4173       | 171       |
| 2,51 | 0,00034182267 | 1790937     | 88015     | 4002       | 164       |
| 2,52 | 0,00032391530 | 1702722     | 84013     | 3838       | 160       |
| 2,53 | 0,00030688808 | 1618709     | 80197     | 3678       | 152       |
| 2,54 | 0,00029070099 | 1538534     | 76497     | 3526       | 148       |
| 2,55 | 0,00027531565 | 1462034     | 72971     | 3378       | 142       |
| 2,56 | 0,00026069528 | 1389066     | 69593     | 3236       | 137       |
| 2,57 | 0,00024680462 | 1319473     | 66357     | 3099       | 131       |
| 2,58 | 0,00023360980 | 1253116     | 63258     | 2968       | 128       |
| 2,59 | 0,00022107873 | 1189858     | 60290     | 2830       | 121       |
| 2,60 | 0,00020918015 | 1129568     | 57460     | 2749       | 119       |
| 2,61 | 0,00019788447 | 1072108     | 54711     | 2570       | 112       |
| 2,62 | 0,00018716339 | 1017397     | 52141     | 2498       | 118       |
| 2,63 | 0,00017693942 | 965256      | 49643     | 2380       | 105       |
| 2,64 | 0,00016733686 | 915613      | 47263     | 2275       | 101       |
| 2,65 | 0,00015818073 | 868350      | 44988     | 2174       | 95        |
| 2,66 | 0,00014949723 | 823662      | 42814     | 2079       | 94        |
| 2,67 | 0,00014126361 | 780548      | 40735     | 1985       | 88        |
| 2,68 | 0,00013345813 | 739813      | 38750     | 1897       | 85        |
| 2,69 | 0,00012606000 | 701063      | 36853     | 1812       | 83        |
| 2,70 | 0,00011904937 | 664210      | 35041     | 1729       | 78        |
| 2,71 | 0,00011240727 | 629169      | 33312     | 1651       | 76        |
| 2,72 | 0,00010611558 | 595857      | 31661     | 1575       | 71        |
| 2,73 | 0,00010015701 | 564196      | 30086     | 1504       | 70        |
| 2,74 | 0,00009451505 | 534110      | 28582     | 1434       | 67        |
| 2,75 | 0,00008917395 | 505528      | 27148     | 1367       | 64        |
| 2,76 | 0,00008411867 | 478380      | 25781     | 1303       | 59        |
| 2,77 | 0,00007933487 | 452599      | 24478     | 1244       | 60        |
| 2,78 | 0,00007480888 | 428121      | 23234     | 1184       | 56        |
| 2,79 | 0,00007052767 | 404887      | 22050     | 1128       | 53        |
| 2,80 | 0,00006647880 | 382837      | 20922     | 1075       | 51        |
| 2,81 | 0,00006263043 | 361915      | 19847     | 1024       | 49        |
| 2,82 | 0,00005903128 | 342068      | 18823     | 975        | 48        |
| 2,83 | 0,00005561060 | 323245      | 17848     | 927        | 43        |
| 2,84 | 0,00005237815 | 305397      | 16921     | 884        | 45        |
| 2,85 | 0,00004932418 | 288476      | 16037     | 839        | 39        |
| 2,86 | 0,00004643042 | 272439      | 15198     | 800        | 40        |
| 2,87 | 0,00004371563 | 257241      | 14398     | 760        | 38        |
| 2,88 | 0,00004114262 | 242843      | 13638     | 722        | 34        |
| 2,89 | 0,00003871419 | 229205      | 12916     | 688        | 36        |

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# Probability Mass/Density Function (PMF/PDF)

