

1016-351-03  
Probability

In-class exercise

2010 January 19

Consider a continuous random variable with the uniform probability density function

$$f(x) = \begin{cases} \frac{1}{B-A} & A < x < B \\ 0 & \text{otherwise} \end{cases}$$

a. Verify that  $f(x)$  is normalized, i.e., that

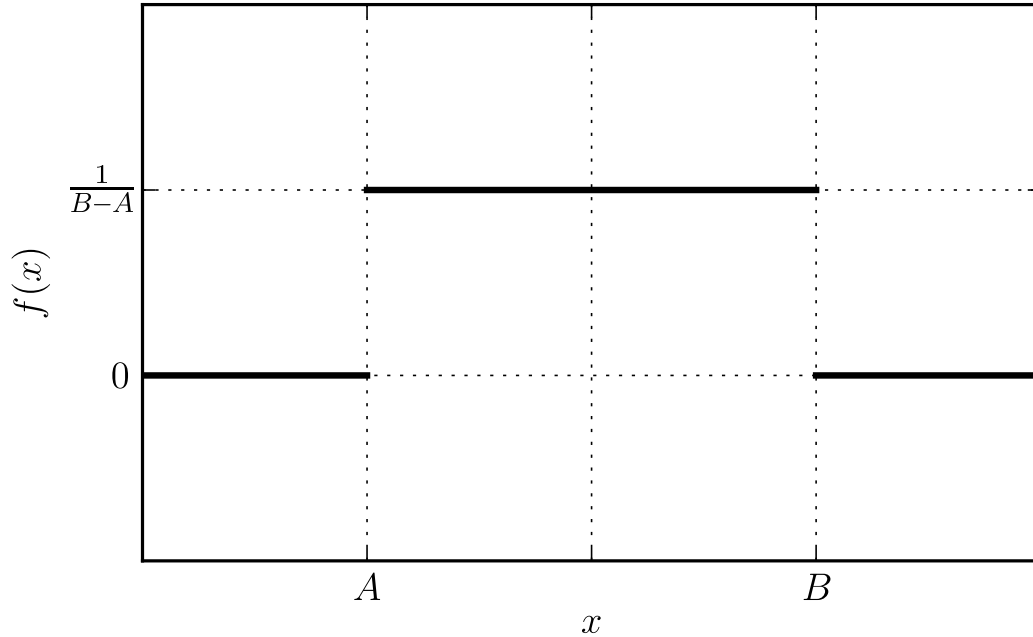
$$\int_{-\infty}^{\infty} f(x) dx = 1$$

The integral is

$$\begin{aligned} \int_{-\infty}^{\infty} f(x) dx &= \int_{-\infty}^A f(x) dx + \int_A^B f(x) dx + \int_B^{\infty} f(x) dx = 0 + \int_A^B \frac{1}{B-A} dx + 0 \\ &= 0 + \left. \frac{x}{B-A} \right|_A^B + 0 = \frac{B-A}{B-A} = 1 \end{aligned}$$

so  $f(x)$  is indeed normalized.

b. Sketch the graph of  $f(x)$ . Label the axes.



(There are other possible choices of which tickmarks get which labels, but I wanted the 0 values to be clearly visible.) Note that the pdf is discontinuous, which is fine. Note also that it doesn't really matter what value the pdf  $f(x)$  takes on at those points ( $x = A$  and  $x = B$ ), since  $f(x)$  always gets put under an integral to convert it into a probability.

c. Find the cumulative distribution  $F(x)$ .

The cdf is the probability

$$F(x) = P(X \leq x) = \int_{-\infty}^x f(y) dy$$

Note that we have to call the integration variable  $y$  rather than  $x$  because  $x$  is the upper limit of the integral. If you have a *definite* integral, the integration variable should never appear in the limits of integration, nor anywhere outside the integral.

Because  $f(x)$  has a different form for  $x \leq A$ , for  $A \leq x \leq B$ , and for  $B \leq x$ , the results of the integral will be different depending on where  $x$  lies:

$$\text{If } x \leq A, \quad F(x) = \int_{-\infty}^x f(y) dy = 0$$

because the integrand is zero over the whole range of integration.

$$\text{If } A \leq x \leq B, \quad F(x) = \int_{-\infty}^A f(y) dy + \int_A^x f(y) dy = 0 + \left. \frac{y}{B-A} \right|_A^x = \frac{x-A}{B-A}$$

Finally,

$$\text{If } B \leq x, \quad F(x) = \int_{-\infty}^A f(y) dy + \int_A^B f(y) dy + \int_B^x f(y) dy = 0 + 1 + 0 = 1$$

Putting it all together,

$$F(x) = \begin{cases} 0 & x \leq A \\ \frac{x-A}{B-A} & A \leq x \leq B \\ 1 & B \leq x \end{cases}$$

**Alternate solution using indefinite integrals:**

Note that you can also do this by noting that since  $F'(x) = f(x)$ ,

$$F(x) = \int f(x) dx$$

where now this is an indefinite integral. Then we have to take the antiderivative of the form of  $f(x)$  in each interval:

$$\text{If } x \leq A, \quad F(x) = \int 0 dx = C_1$$

$$\text{If } A \leq x \leq B, \quad F(x) = \int \frac{1}{B-A} dx = \frac{x}{B-A} + C_2$$

$$\text{If } B \leq x, \quad F(x) = \int 0 dx = C_3$$

Because these are indefinite integrals, we have to include an arbitrary constant ( $C_1$ ,  $C_2$  and  $C_3$ , respectively), which is in general different for each integral. Then we need to find the values of these constants which ensure that  $F(-\infty) = 0$  and that  $F(x)$  is continuous, which it must be for a continuous random variable. (We can then check that  $F(\infty) = 1$ , which must be the case if the pdf  $f(x)$  was properly normalized, and we didn't make any mistakes.) We find  $C_1$  from

$$F(-\infty) = C_1 = 0$$

so that

$$\text{If } x \leq A, \quad F(x) = 0$$

and then find  $C_2$  from continuity at  $x = A$

$$F(A) = 0 = \frac{A}{B-A} + C_2$$

so that

$$C_2 = -\frac{A}{B-A}$$

and

$$\text{if } A \leq x \leq B, \quad F(x) = \frac{x}{B-A} - \frac{A}{B-A}$$

We then find  $C_3$  from continuity at  $x = B$

$$F(B) = \frac{B}{B-A} - \frac{A}{B-A} = 1 = C_3$$

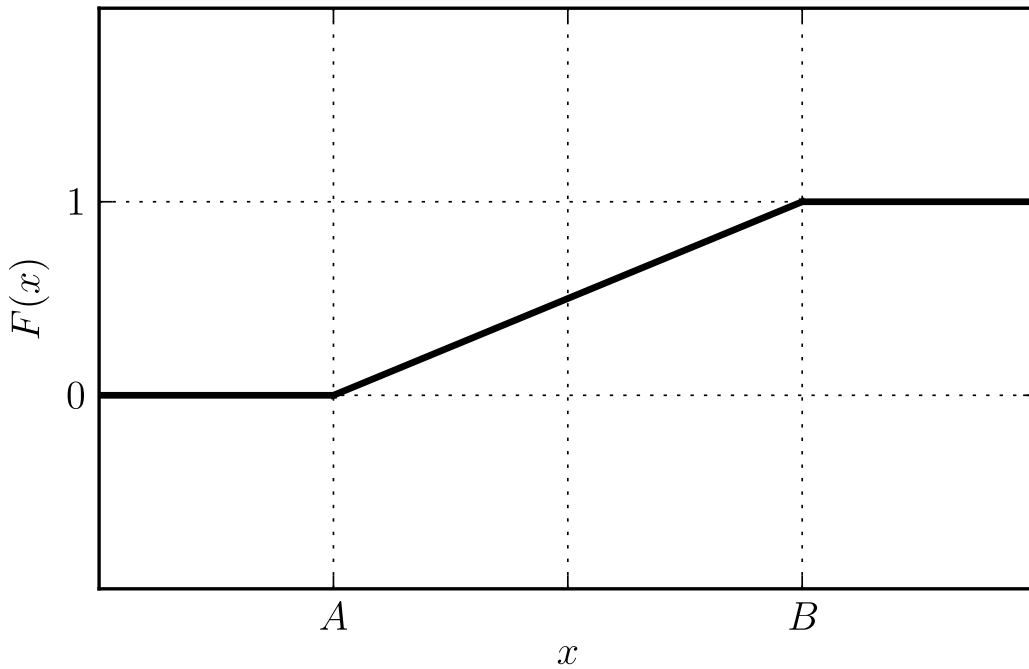
and thus

$$\text{If } B \leq x, \quad F(x) = 1$$

Finally, we can then see that  $F(\infty) = 1$ , so everything is consistent.

In the end the indefinite integral approach gives the right answer (of course) if you're careful about the integration constants. Personally, I find the approach with definite integrals to be easier, since the matching happens automatically.

**d. Sketch the graph of  $F(x)$ . Label the axes.**



Notice that the graph is continuous, as it must be for a continuous random variable.

**e. Calculate the expected value  $E(X)$  in terms of  $A$  and  $B$ .**

$$\begin{aligned} E(X) &= \int_{-\infty}^{\infty} x f(x) dx = \int_A^B \frac{x}{B-A} dx = \frac{1}{B-A} \frac{x^2}{2} \Big|_A^B = \frac{B^2 - A^2}{2(B-A)} \\ &= \frac{(B+A)(B-A)}{2(B-A)} = \frac{A+B}{2} \end{aligned}$$

f. Calculate the variance  $V(X)$  in terms of  $A$  and  $B$ .

The easiest way to do this is to calculate

$$\begin{aligned} E(X^2) &= \int_{-\infty}^{\infty} x^2 f(x) dx = \int_A^B \frac{x^2}{B-A} dx = \frac{1}{B-A} \left. \frac{x^3}{3} \right|_A^B = \frac{B^3 - A^3}{3(B-A)} \\ &= \frac{(B^2 + AB + A^2)(B-A)}{3(B-A)} = \frac{B^2 + AB + A^2}{3} \end{aligned}$$

And then

$$\begin{aligned} V(X) &= E(X^2) - (E(X))^2 = \frac{B^2 + AB + A^2}{3} - \left( \frac{A+B}{2} \right)^2 = \frac{B^2 + AB + A^2}{3} - \frac{A^2 + 2AB + B^2}{4} \\ &= \frac{4B^2 + 4AB + 4A^2 - 3A^2 - 6AB - 3B^2}{12} = \frac{B^2 - 2AB + A^2}{12} = \frac{(B-A)^2}{12} \end{aligned}$$