

include more terms. Away from the jumps, we safely approach  $SW(x) = 1$  or  $-1$ . At  $x = \pi/2$ , the series gives a beautiful alternating formula for the number  $\pi$ :

$$1 = \frac{4}{\pi} \left[ \frac{1}{1} - \frac{1}{3} + \frac{1}{5} - \frac{1}{7} + \cdots \right] \quad \text{so that} \quad \pi = 4 \left[ \frac{1}{1} - \frac{1}{3} + \frac{1}{5} - \frac{1}{7} + \cdots \right]. \quad (9)$$

The Gibbs phenomenon is the overshoot that moves closer and closer to the jumps. Its height approaches  $1.18 \dots$  and it does not decrease with more terms of the series! Overshoot is the one greatest obstacle to calculation of all discontinuous functions (like shock waves in fluid flow). We try hard to avoid Gibbs but sometimes we can't.

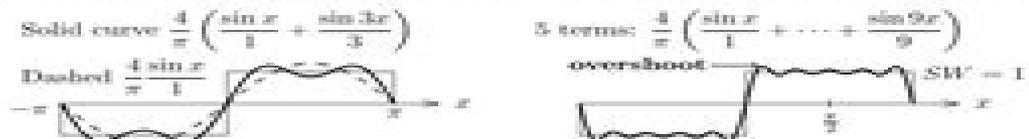


Figure 4.2: Gibbs phenomenon: Partial sums  $\sum_{n=1}^N b_n \sin nx$  overshoot near jumps.

### Fourier Coefficients are Best

Let us look again at the first term  $b_1 \sin x = (4/\pi) \sin x$ . This is the **closest possible approximation** to the square wave  $SW$ , by any multiple of  $\sin x$  (closest in the least squares sense). To see this optimal property of the Fourier coefficients, minimize the error over all  $b_1$ :

The error is  $\int_0^\pi (SW - b_1 \sin x)^2 dx$ . The  $b_1$  derivative is  $-2 \int_0^\pi (SW - b_1 \sin x) \sin x dx$ .

The integral of  $\sin^2 x$  is  $\pi/2$ . So the derivative is zero when  $b_1 = (2/\pi) \int_0^\pi SW(x) \sin x dx$ . This is exactly equation (6) for the Fourier coefficient.

Each  $b_n \sin nx$  is as close as possible to  $SW(x)$ . We can find the coefficients  $b_n$  one at a time, because the sines are orthogonal. The square wave has  $b_2 = 0$  because all other multiples of  $\sin 2x$  increase the error. Term by term, we are "projecting the function onto each axis  $\sin kx$ ."

### Fourier Cosine Series

The cosine series applies to even functions with  $C(-x) = C(x)$ :

$$\text{Cosine series} \quad C(x) = a_0 + a_1 \cos x + a_2 \cos 2x + \cdots = a_0 + \sum_{n=1}^{\infty} a_n \cos nx. \quad (10)$$

# Chapter 4 Fourier Series And Integrals Mit

**Jin-Ying Zhang**



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