problem sheet 5

discussion: week of Monday, 4.11.2019

5.1. **a)** Write a program with signature $y = \texttt{composite\_gauss}(n, L, q)$ that realizes a composite Gauss rule for integration over $(0, 1)$. The composite Gauss rule uses n points for each of the L subintervals that are given by

$$(0, q^{L-1}), (q^{L-1}, q^{L-2}), (q^{L-2}, q^{L-3}) \cdots, (q, 1)$$

Check your program with $f(x) = x^m$, $m = 0, 1, 2$. *Hint:* Gauss points and weights can be obtained by `numpy.polynomial.legendre.leggauss` or `gauleg.m` (see homepage).

b) Use your routine `composite_gauss` for $n = L = 1, \ldots, 20$ and the three choices $q \in \{0.5, 0.15, 0.05\}$ and the integrand

$$f(x) = x^{0.1} \log x.$$

(The exact integral is $\int_0^1 f(x)\, x = -1/1.1^2 \approx -0.82644$.) Plot semilogarithmically (`semilogy`) the quadrature error versus n for these 3 values of q. Which choice of q is the best one?

c) Fit (using `polyfit`) the error curves to the law Ce^{-bn}.

5.2. Give an explicit error bound (in dependence on n) for the Gaussian quadrature error

$$\left| \int_{-1}^{1} f(x)\, dx - Q_n^{Gauss}(f) \right| \quad \text{with } f(x) = (4 - x^2)^{-1}.$$

5.3. Show that the composite trapezoidal rule is exact for the evaluation of $\displaystyle\int_{-\pi}^{\pi} \sin x\, dx$.

Hint: Use, with the imaginary unit $\mathbf{i}$, the formula

$$\sum_{j=0}^{N-1} \exp(\pm \mathbf{i} j h) = 0 \quad \text{with} \quad h = \frac{2\pi}{N}, \qquad \sin x = \frac{\exp(\mathbf{i}x) - \exp(-\mathbf{i}x)}{2\mathbf{i}}$$

(*Remark:* analogous results hold for $\sin(mx)$ and $\cos(mx)$ if $N > m$, i.e., h is sufficiently small.)

5.4. (transformation techniques) we seek a quadrature formula for

$$\int_1^\infty f(x)\, dx.$$

Consider the specific case $f(x) = \log x/(x^\pi)$ with

$$\int_1^\infty \frac{\log x}{x^\pi}\, dx = \frac{1}{\pi^2 - 2\pi + 1}.$$

a) One possibility is to transform the integral to an integration over $(0, 1)$ using a suitable substitution. Formulate such a transformation. The transformed problem can then be treated with the quadrature formula of Problem 5.1.

b) Another option is the substitution $x = e^y$. One obtains an integral of the form

$$\int_{y=0}^\infty F(y)\, dy,$$

where the integrand decays rapidly so that the integral $\int_{y=0}^\infty F(y)\, dy$ can be approximated well by $\int_{y=0}^L F(y)\, dy$. Again, the integral can be computed with a composite Gauss rule with n points per subinterval where the L subintervals are given by

$$(0, Lq^{L-1}), (Lq^{L-1}, Lq^{L-2}), \cdots, (Lq, L)$$

Generate the composite quadrature rule using your program of Problem 5.1.

c) Plot the error using `semilogy` for both methods with $n = L = 1, \ldots, 20$. Choose $q = 0.15$.