Inverses of lower triangular Toeplitz matrices

William F. Trench, Trinity University
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Define $a_n = 0$ if $n < 0$ and assume that $a_0 \neq 0$. Let

$$T_N = (a_{r-s})_{r,s=1}^N, \quad N = 1, 2, \ldots,$$

be the family of lower triangular Toeplitz matrices generated by the formal power series

$$f(z) = \sum_{n=0}^{\infty} a_n z^n. \quad (1)$$

The family of inverses is given by

$$T_N^{-1} = (b_{r-s})_{r,s=1}^N, \quad N = 1, 2, \ldots,$$

where

$$g(z) = \sum_{n=0}^{\infty} b_n x^n \quad (2)$$

is the formal reciprocal of $f(z)$; that is, $b_n = 0$ if $n < 0$, $b_0 = 1/a_0$ and

$$\sum_{r=0}^{n} a_r b_{n-r} = 0, \quad n > 0.$$

This formula can be used to compute $\{b_n\}_{n=1}^{\infty}$ recursively:

$$b_n = -\frac{1}{b_0} \sum_{r=1}^{n} a_r b_{n-r}.$$

This seems to me to be the most practical way to proceed.

I can think of two “explicit” expressions for $b_n$; however, although they may be of some theoretical interest, they don’t seem very useful.

**FORMULA I.**

For every $n \geq 1$,

$$T_{n+1} \begin{bmatrix} b_0 \\ b_1 \\ \vdots \\ b_n \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \\ \vdots \\ 0 \end{bmatrix}.$$

Applying Cramer’s rule here yields

$$b_n = \frac{(-1)^n}{a_0^{n+1}} \begin{vmatrix} a_1 & a_0 & 0 & \cdots & 0 \\ a_2 & a_1 & a_0 & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ a_{n-1} & a_{n-2} & a_{n-3} & \cdots & a_0 \\ a_n & a_{n-1} & a_{n-2} & \cdots & a_1 \end{vmatrix}$$
FORMULA II.
Temporarily assume that (1) has a positive radius of convergence. Then so does (2). Moreover,
\[ a_n = \frac{f^{(n)}(0)}{n!} \quad \text{and} \quad b_n = \frac{g^{(n)}(0)}{n!}. \] (3)
\[
\frac{d^n}{dx^n} h(f(x)) = \sum_{k=1}^{n} h^{(k)}(f(x)) \sum_{\substack{k_1 + \cdots + k_n = k \text{ such that} \k1 + 2k_2 + \cdots nk_n = n}} \frac{n!}{k_1! \cdots k_n!} \left( \frac{f'(x)}{1!} \right)^{k_1} \left( \frac{f''(x)}{2!} \right)^{k_2} \cdots \left( \frac{f^{(n)}(x)}{n!} \right)^{k_n}.
\]
We’re interested in \( g(x) = 1/f(x) \); therefore, we take \( h(u) = 1/u \) in obtain
\[
\frac{d^n}{dx^n} g(x) = \sum_{k=1}^{n} \frac{(-1)^k k!}{(f(x))^{k+1}} \sum_{\substack{k_1 + \cdots + k_n = k \text{ such that} \k1 + 2k_2 + \cdots nk_n = n}} \frac{n!}{k_1! \cdots k_n!} \left( \frac{f'(x)}{1!} \right)^{k_1} \left( \frac{f''(x)}{2!} \right)^{k_2} \cdots \left( \frac{f^{(n)}(x)}{n!} \right)^{k_n}.
\]
Setting \( x = 0 \) here and recalling (3) yields
\[
b_n = \sum_{k=1}^{n} \frac{(-1)^k k!}{a_{k+1}^k} \sum_{\substack{k_1 + \cdots + k_n = k \text{ such that} \k1 + \cdots nk_n = n}} \frac{1}{k_1! \cdots k_n!} a_{k_1}^{k_1} a_{k_2}^{k_2} \cdots a_{k_n}^{k_n}.
\]
Although we derived this formula assuming that (1) has a positive radius of convergence, it is a purely algebraic result that doesn’t require this assumption.