Worksheet 16

To accompany Chapter 6.3 The Inverse Z-Transform

Colophon

This worksheet can be downloaded as a PDF file (https://cpjobling.github.io/eg-247-textbook/worksheets/worksheet16.pdf). We will step through this worksheet in class.

An annotatable copy of the notes for this presentation will be distributed before the second class meeting as **Worksheet 9** in the **Week 4: Classroom Activities** section of the Canvas site. I will also distribute a copy to your personal **Worksheets** section of the **OneNote Class Notebook** so that you can add your own notes using OneNote.

You are expected to have at least watched the video presentation of Chapter 6.3 (https://cpjobling.github.io/eg-247-textbook/dt_systems/3/i_z_transform) of the notes (https://cpjobling.github.io/eg-247-textbook) before coming to class. If you haven't watch it afterwards!

After class, the lecture recording and the annotated version of the worksheets will be made available through Canvas.

Agenda

- Inverse Z-Transform

- Examples using PFE

- Examples using Long Division

- Analysis in MATLAB

The Inverse Z-Transform

The inverse Z-Transform enables us to extract a sequence $f[n]$ from $F(z)$. It can be found by any of the following methods:

- Partial fraction expansion
- The inversion integral
- Long division of polynomials

Partial fraction expansion

We expand $F(z)$ into a summation of terms whose inverse is known. These terms have the form:

$$k, \quad \frac{r_1 z}{z - p_1}, \quad \frac{r_1 z}{(z - p_1)^2}, \quad \frac{r_3 z}{z - p_2}, \ldots$$

$$k, \quad \frac{r_1 z}{z - p_1}, \quad \frac{r_1 z}{(z - p_1)^2}, \quad \frac{r_3 z}{z - p_2}, \ldots$$

where k is a constant, and r_i and p_i represent the residues and poles respectively, and can be real or complex[1].

Notes

1. If complex, the poles and residues will be in complex conjugate pairs

$$\frac{r_i z}{z - p_i} + \frac{r_i^* z}{z - p_i^*}$$

$$\frac{r_i z}{z - p_i} + \frac{r_i^* z}{z - p_i^*}$$

Step 1: Make Fractions Proper

- Before we expand $F(z)F(z)$ into partial fraction expansions, we must first express it as a *proper* rational function.
- This is done by expanding $F(z)/zF(z)/z$ instead of $F(z)F(z)$
- That is we expand

$$\frac{F(z)}{z} = \frac{k}{z} + \frac{r_1}{z - p_1} + \frac{r_2}{z - p_2} + \cdots$$

$$\frac{F(z)}{z} = \frac{k}{z} + \frac{r_1}{z - p_1} + \frac{r_2}{z - p_2} + \cdots$$

Step 2: Find residues

- Find residues from

$$r_k = \lim_{z \to p_k} (z - p_k) \frac{F(z)}{z} = (z - p_k) \frac{F(z)}{z} \bigg|_{z = p_k}$$

$r_k = \lim$

Step 3: Map back to transform tables form

- Rewrite $F(z)/z$:

$$z \frac{F(z)}{z} = F(z) = k + \frac{r_1 z}{s - p_1} + \frac{r_2 z}{s - p_2} + \cdots$$

Example 1

Karris Example 9.4: use the partial fraction expansion to compute the inverse z-transform of

$$F(z) = \frac{1}{(1 - 0.5z^{-1})(1 - 0.75z^{-1})(1 - z^{-1})}$$

MATLAB solution

See example1.mlx (matlab/example1.mlx). (Also available as example1.m (matlab/example1.m).)

Uses MATLAB functions:

- `collect` – expands a polynomial
- `sym2poly` – converts a polynomial into a numeric polymial (vector of coefficients in descending order of exponents)
- `residue` – calculates poles and zeros of a polynomial
- `ztrans` – symbolic z-transform
- `iztrans` – symbolic inverse ze-transform
- `stem` – plots sequence as a "lollipop" diagram

In [ ]:

```
clear all
cd matlab
format compact
```

In [ ]:

```
syms z n
```

The denoninator of $F(z)$

In [ ]:

```
Dz = (z - 0.5)*(z - 0.75)*(z - 1);
```

Multiply the three factors of Dz to obtain a polynomial

In [ ]:

```
Dz_poly = collect(Dz)
```

Make into a rational polynomial

z^2

In [ ]:

```
num = [0, 1, 0, 0];
```

$z^3 - 9/4z^2 - 13/8z - 3/8$

In [ ]:

```
den = sym2poly(Dz_poly)
```

Compute residues and poles

In [ ]:

```
[r,p,k] = residue(num,den);
```

Print results

- `fprintf` works like the c-language function

In [ ]:

```
fprintf('\n')
fprintf('r1 = %4.2f\t', r(1)); fprintf('p1 = %4.2f\n', p(1));...
fprintf('r2 = %4.2f\t', r(2)); fprintf('p2 = %4.2f\n', p(2));...
fprintf('r3 = %4.2f\t', r(3)); fprintf('p3 = %4.2f\n', p(3));
```

Symbolic proof

$$f[n] = 2\left(\frac{1}{2}\right)^n - 9\left(\frac{3}{4}\right)^n + 8$$

In [ ]:

```
% z-transform
fn = 2*(1/2)^n-9*(3/4)^n + 8;
Fz = ztrans(fn)
```

In [ ]:

```
% inverse z-transform
iztrans(Fz)
```

Sequence

In [ ]:

```
n = 1:15;
sequence = subs(fn,n);
stem(n,sequence)
title('Discrete Time Sequence f[n] = 2*(1/2)^n-9*(3/4)^n + 8');
ylabel('f[n]')
xlabel('Sequence number n')
```

Example 2

Karris example 9.5: use the partial fraction expansion method to to compute the inverse z-transform of

$$F(z) = \frac{12z}{(z+1)(z-1)^2}$$

MATLAB solution

See example2.mlx (matlab/example2.mlx). (Also available as example2.m (matlab/example2.m).)

Uses additional MATLAB functions:

- `dimpulse` – computes and plots a sequence $f[n]$ for any range of values of n

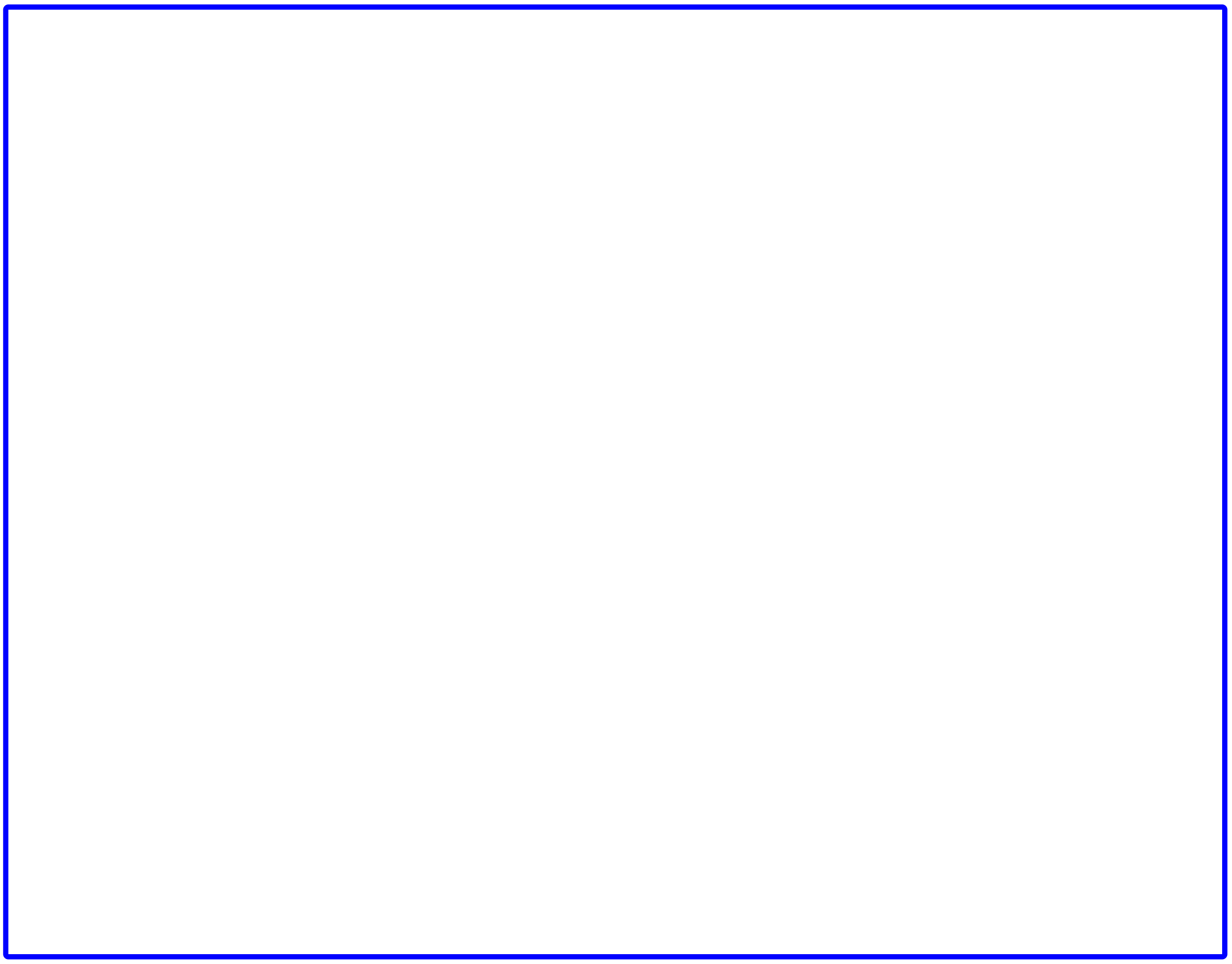
In [ ]:

```
open example2
```

Example 3

Karris example 9.6: use the partial fraction expansion method to to compute the inverse z-transform of

$$F(z) = \frac{z+1}{(z-1)(z^2+2z+2)}$$



MATLAB solution

See [example3.mlx (matlab/example3.mlx)](matlab/example3.mlx). (Also available as [example3.m (matlab/example3.m)](matlab/example3.m).)

In [ ]:

```
open example3
```

Inverse Z-Transform by the Inversion Integral

The inversion integral states that:

$$f[n] = \frac{1}{j2\pi} \oint_C F(z) z^{n-1}\, dz$$

where C is a closed curve that encloses all poles of the integrant.

This can (*apparently*) be solved by Cauchy's residue theorem!!

Fortunately (:-), this is beyond the scope of this module!

See Karris Section 9.6.2 (pp 9-29—9-33) if you want to find out more.

Inverse Z-Transform by the Long Division

To apply this method, $F(z)$ must be a rational polynomial function, and the numerator and denominator must be polynomials arranged in descending powers of z.

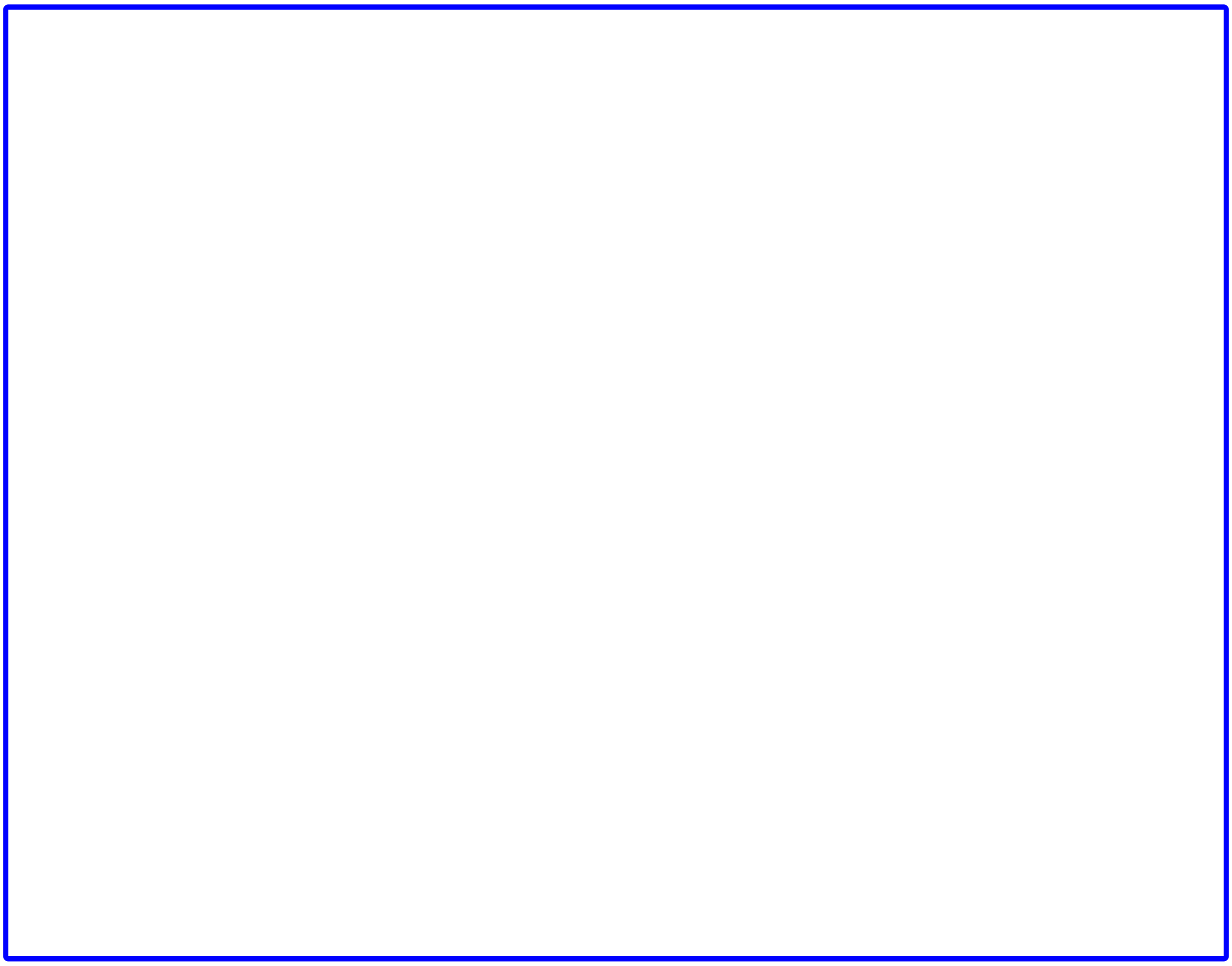
We will work through an example in class.

[Skip next slide in Pre-Lecture]

Example 4

Karris example 9.9: use the long division method to determine $f[n]$ for $n = 0,\ 1,\ \text{and}\, 2$, given that

$$F(z) = \frac{1 + z^{-1} + 2z^{-2} + 3z^{-3}}{(1 - 0.25z^{-1})(1 - 0.5z^{-1})(1 - 0.75z^{-1})}$$



MATLAB

See [example4.mlx (matlab/example4.mlx)](matlab/example4.mlx). (also available as [example4.m (matlab/example4.m)](matlab/example4.m).)

In [ ]:

```
open example4
```

Methods of Evaluation of the Inverse Z-Transform

Partial Fraction Expansion

Advantages

- Most familiar.
- Can use MATLAB `residue` function.

Disadvantages

- Requires that $F(z)$ is a proper rational function.

Inversion Integral

Advantage

- Can be used whether $F(z)$ is rational or not

Disadvantages

- Requires familiarity with the *Residues theorem* of complex variable analaysis.

Long Division

Advantages

- Practical when only a small sequence of numbers is desired.
- Useful when z-transform has no closed-form solution.

Disadvantages

- Can use MATLAB `dimpulse` function to compute a large sequence of numbers.
- Requires that $F(z)$ is a proper rational function.
- Division may be endless.

Summary

- Inverse Z-Transform
- Examples using PFE
- Examples using Long Division
- Analysis in MATLAB

Coming Next

- DT transfer functions, continuous system equivalents, and modelling DT systems in Matlab and Simulink.