The YEG Object

Ed Fomalont

April 6, 1992

Introduction

The YEG is the '(u-v) data' object. It contains the observed (uncalibrated) data and it is linked to the Telescope Model Object which contains the description of the telescope. By mysterious means (at this point) the description of the telescope model can be improved so that the YEG data object can ultimately transform the observed data into calibrated data. This memo is a first pass attempt to define the fundamental organization and contents of the YEG.

1. The Fundamental Coordinate of the YEG: t

The independent coordinate for each YEG is t, time. Each YEG is associated with one and only one time and a YEG includes all of the data at that time. How this time is labelled is unimportant as long as there is an association between the label and the true value of this fundamental coordinate. It need not be regularly spaced. For example, the time coordinate could be $(1, 2, \ldots, T)$ with a table relating the indices to a time.

Since data are usually averaged over an interval of time, we shall define t as the average value of the sampled data over a generally small interval of time, and Δt, is the duration over which the data was actually collected. Furthermore, not all quantities are sampled and averaged in time in the same manner. However, we shall assume that either; 1) all data in the YEG and in the Telescope Model are critically sampled and can be interpolated to any desired time; or 2) the data can be given an undefined valued and dealt with intelligently.

2. The Fundamental Data Organization of a YEG:

For arrays, the fundamental data is a complex number, the visibility function. It is associated with two antennas, labelled by i and j; we should not rule out $i = j$. There should also be a real number associated with each visibility function which gives some indication of its relative merit (weight), and there should be a duration, Δt, over which the data were integrated. Perhaps, the weight and duration are redundant in many cases.

The visibility function, weight and duration are each a multi-dimensional set of numbers spanning over frequency, polarization, delay, and sky offset. We shall denote this collection of uncalibrated visibilities at time t for antenna pairs (i, j) as

$$V_u(t : i, j; l, m, n, o)$$

where

$l = 1, 2, \ldots, L$	The label associated with the frequency ν
$m = 1, 2, 3, 4$	The label associated with the polarization p
$n = 1, 2, \ldots, N$	The label associated with the delay τ
$o = 1, 2, \ldots, O$	The label associated with the sky location s

The ':' and ';' separation in the argument of the visibility function indicates the difference between the time and the antenna pair and the other four quantities. Time is the independent variable, the antenna pair are not true dimensions because they are coupled;

the remaining four quantities are orthogonal dimensions in the data. The weights and durations have the same structure as the visibility data.

These labels must be associated with values in some manner, perhaps as tables in the Telescope Model Class:

1. A table of antenna names corresponding to the antenna index. This is not a true dimension of the visibility data as those which follow. The array, by its nature, couples the response between antennas in complicated ways. The antennas could be in different instruments; egs, subarrays at the VLA, and share in the Telescope Model. In this case a visibility function between two antennas not in the same array is undefined. This scheme could be useful if one subarray calibrates some needed parameters in the other subarray.

2. A table of the average observing frequency corresponding to the frequency index, l. In principle each antenna could have a different observing frequency. There is no assumed regularity in the frequency coordinate. It could be a combination of several bands, each with an number of closely spaced frequencies.

3. A table of polarization parameters, corresponding to the index p, which describe the general ellipticity of the radiation accepted by the antenna. It is often the case that the two antennas have different polarization parameters. This index is generally limited to no more than four entries.

4. A table of delays corresponding to the delay index, n. This is the additional time lag introduced in each antenna before correlation. It is generally used in VLBI observations. It turns out that if there are some time inconsistencies among elements in the YEG, this coordinate may 'fix' things up.

5. A table of sky offsets coresponding to the offset index, o. These could be associated with multi-beam arrays, mozaicing, or with VLBI observations in which more than one field is correlated.

This fundamental organization of the YEG should be questioned. Is this suggested organization of the visibility data (deeply time oriented, antenna-pair connected, with four independent dimensions of frequency, polarization, delay and sky position) sufficiently general to cover all anticipated array observations and reductions? Is it organized in a convenient form for calibration, imaging, self-calibration, mozaicing, and isoplanicity problems?. How flexible should the underlying software be. Could more dimensions be added? Should we be able to transpose some of the coordinates; ie. could frequency be the fundamental coordinate, with time one of the four dimensions? Is the extension to non-array, or mixed single dish-array data sets possible? If not, why not?

3. Yeg Interaction with the Telescope Model

At the highest level the YEG interaction with the Telescope Model is simple and direct. The YEG sends seven numbers (pointers) (t, i, j, l, m, n, o) to the Telescope Model which returns a complex gain $G(t : i, j; l, m, n, o)$. The calibrated visibility data $V_c(t : i, j; l, m, n, o)$ is simply the complex product of the gain with the uncalibrated visibility function.

$$V_c(t : i, j; l, m, n, o) = G(t : i, j; l, m, n, o) \times V_u(t : i, j; l, m, n, o)$$

Whether this product is implicitly or explictly made is not important. How the Telescope Model copes with the seven pointers in order to determine the complex gain, is of no concern to the YEG.

The preceding paragraph is an oversimplification which we will get to in a moment. The most important point is that the calibration of visibility data at any time depends only the on the YEG elements at that time and the complex gain function of the Telescope Model at that time. If the calibration of data at time t required knowledge of the data at time t' or the state of the telescope model at t', then the present formulation of the YEG would not be satisfactory.

On the other hand, the determination of the Telescope Model and all of the details of the gain depends on the proper analysis of a large collection of data made over long periods of time. This is of no concern to the YEG. Somehow, there is a mysterious SOLVE which knows what to do with lots of YEG and can determine the Telescope Model.

The above expression also assumes that the calibration of the visibility function in any state (particular value of i, j, l, m, n, o) depends only on that state. This is not strictly true and it is the reason why polarization correction is a nuisance. Although the details of this belong in the relevant place of the Telescope Model, the polarization correction combines, in general, the different values of the polarization index m for any baseline and time. Any other cross talk amongst the baselines, or frequencies, etc, requires a more general form of the gain correction

$$V_c(t : i, j; l, m, n, o) = \sum_{all'} G(t : i, i', j, j'; k, k', l, l', m, m', o, o') \times V_u(t : i', j'; l', m', n', o')$$

where the Gain term now includes all possible cross talk. Even more generally, the gain term is an arbitrary gain function. It can be more than a complex multiplier. For example, there are some additive corrections to visibility data; egs. correlator offset signals and some kinds of closure errors. Some amplitude corrections are non-linear when the source noise rivals the system noise. However, these complications are rarely met and they are handled by the time-oriented form of the YEG.

It will turn out that much of the calibration terms are separable into individual antennas, frequencies, polarization, delay and sky offset functions. That is

$$G(t : i, j; l, m, n, o) = G_\nu(t : i; l) \times G_\nu^*(t : j; l) \times G_p(t : i, m) \times G_p^*(t : j, m)$$
$$\times G_d(t : i; m) \times G_d^*(t : j; m) \times G_s(t : i; o) \times G_s^*(t : j; o)$$

where * indicates the complex conjugate. It seems likely that the Telescope Model will assume the above simple form and add complexities as needed. However, the ability to do the arbitrary gain function correction should not be excluded.

The flagging or editting of the data can be handled in several ways. The weights associated with the visibility data in the YEG can be modified as an indication of the new quality of the data. Alternatively, the Telescope Model can contain a Flag function (or table) $F(t : i, j; l, m, n, o)$ with any degree of complication. It may be a binary-valued function (0 or 1) or it may contain quality assessments in some way.

4. YEG interaction with the Inverter

There is little to discuss here. The calibrated data must be passed to the Inverter in order to create an image. Additional parameters, such as the spatial frequencies (u, v, w), will probably reside in the Telescope Model. At this point calibrated visibility data over a long period of time, at several pointing, or from several telescopes is collected and can be subsequently modified (gridding, tapering the data) for use in the Inverter algorithm. YEG simply transfers the calibrated data under some controller outside of the scope of the YEG object.

5. YEG interaction with Self-calibration

The time-oriented YEG Class is compatible with the self-calibration technique. Although there are variations among the self-calibration tecnhiques, the following steps generally occur:

1). Use a model image which is an approximation of the image associated with the visibility data. The origin and form of the image is immaterial. For normal calibration, it is a point source at the phase center.

2). Given the state $(i, j : l, m, n, o)$ of the YEG at any time, t, the Predictor Object(?) calculates the visibility data for the model image. Access to the telescope model will be needed by Predictor in order to compute the visibility data; however, the pointer $(i, j : l, m, n, o)$ at any time should be sufficient to find the appropriate data.

3). The complex ratio (calibrated YEG / predicted YEG) is formed. Wide ranges in the signal to noise, because the non-linearity of the division, can occur and must be dealt with properly. If the data were perfectly calibrated, the complex ratio would be equal to unity. Alternatively, the complex ratio (uncalibrated YEG / predicted YEG) can be formed and compared with the gain function used to calibrate the data. Both procedures are almost identical.

3). Data averaging over time, frequency, polarization, etc. is important because self-calibration only works if the sky signals are larger than the noise signals. Averaging of the YEG in this way produces a related YEG with less frequently sample visibility data and, perhaps, fewer dimensions.

4). A intelligent piece of code interprets the departure from unity of the calibrated / predicted visibility function in terms of modification of the gain function. The decision of which terms in the gain function can and should be modified is extremely complicated.

Conclusion

This memo has discussed the form of a possible YEG object used for synthesis reductions. This YEG comprises all of the visibility data at one time and is generally a small part of the entire data base. It is suggested that all interactions with the Telescope Model can be made on a time by time basis and interactions with imaging and self-calibration processes can also be handled with this basic YEG.