

APPENDIX C

STATE ESTIMATION AND THE MEANING OF LIFE

The discipline of the scholar is a consecration to the pursuit of the truth.

—Norbert Wiener [Wie56, p. 358]

The truth will set you free.

—Jesus Christ [John 8:32]

This appendix places state estimation in a larger, more meaningful context in the life of the reader. At first glance, state estimation may not seem to have much to do with The Meaning of Life. After all,

- State estimation is the concern of engineers (and in particular, control engineers). The Meaning of Life is the concern of philosophers.
- State estimation deals with mathematical and physical realities. The Meaning of Life is concerned with spiritual realities.
- State estimation is concerned with the things of this world (the planet Earth and its immediate surroundings). The Meaning of Life is concerned with the things of God.

However, in spite of these superficial differences, it is my contention that state estimation is intimately connected with The Meaning of Life. After all, there is only one reality, and both state estimation and The Meaning of Life are both a part of that reality.¹ An analogy from physics can be brought to bear on this point. If we look at a banana and an airplane, they would appear on the surface to be two completely different things with very little in common. However, at a deeper level they are actually similar in many ways. They are both part of the same reality. In fact, both bananas and airplanes are made up of exactly the same electrons, protons, neutrons, and other subatomic particles. Similarly, on a superficial level it appears that state estimation and The Meaning of Life may not have a lot in common. However, at a deeper level they are closely related. Consider the following:

- The Meaning of Life is based on philosophical and theological truth. State estimation is based on mathematical truth.
- God created the universe and all that is in it. This includes philosophical and theological truth, and it also includes mathematical truth.

Many readers will have reasonable doubts about the existence of God, and whether or not he² created the universe. Nevertheless, the vast majority of people believe in something or someone that they call God. Without this assumption, I don't think we can go any farther, and so we will use God's existence as a working assumption for now. We will return to the question of this assumption's validity at the end of this appendix.

To be fair, I should also state that I write as a Christian. That is, I believe that the Bible is God's Word, I believe that Jesus Christ offers rescue from evil and death, and I believe the host of other doctrines that historically have characterized evangelical Christianity. Nevertheless, I believe that other religions and worldviews also have a lot of truth, and I believe that all religions (including Christianity) have more similarities with each other than differences (recall the banana/airplane analogy). So although I am a follower of Jesus, I choose to focus in this appendix on the commonalities of all religions and worldviews.

Another implicit assumption that I have made is that The Meaning of Life exists. That is, I am assuming that there is some meaning to life. Again, many readers will have reasonable doubts about this assumption, but the majority of people believe that life does have some meaning. So what is the meaning of life? Philosophies and religions have given a variety of answers to this question. Most of them include something like the following.

- The meaning of life is to pursue pleasure.
- The meaning of life is to love and serve others.
- The meaning of life is to know God.
- The meaning of life is to grow and improve as a person.

¹At this point I begin making assumptions, such as the assumption here that there is only one reality. Most of the implicit assumptions made in this appendix are widely accepted, but it should be noted that they are indeed assumptions rather than proven facts.

²There is no intent here to classify God as male. The pronoun "he" is used for purely historical reasons.

Many religions and worldviews would agree (to at least some extent) with each of these hypotheses for The Meaning of Life.

If God exists, and he created everything (including philosophical, spiritual, and mathematical truth), it follows that there may be some underlying connections between the two seemingly disparate ideas of state estimation and The Meaning of Life.

Consider another analogy. If a certain artist paints a portrait one week, and a landscape the next week, the two paintings may appear upon initial examination to be quite different. But since they were both painted by the same artist, a close examination of the paintings will reveal similarities in style and other interesting connections. Similarly if an author writes a novel one year, and a biography the next year, the two books may appear on the surface to be quite different. But since they were both written by the same author, a close examination of the books will reveal similarities in style and other interesting connections. So we see that if the same God creates both theological truth and mathematical truth, there may not be any apparent connection between the two sets of truth. But since they were both created by the same God, a close examination of the two sets of truth will reveal similarities in style and other interesting connections. Some thought shows that there are indeed interesting connections between state estimation and The Meaning of Life. These connections are explored in the following sections.

Forgiveness and noise suppression

Forgiveness is an essential part of The Meaning of Life. God's nature is such that he forgives humans, and he also requires his followers to forgive others. Many people have a shallow view of forgiveness, thinking that forgiveness of an offense is equivalent to ignoring that offense (hence the popular but damaging phrase "forgive and forget"). A careful examination of religious philosophy shows that forgiveness is actually active rather than passive. Far from ignoring or forgetting an offense, true forgiveness consists of confronting the offense, recognizing it as the wrong that it truly is, actively seeking to benefit the offender, and consciously revoking any attempts at revenge. A person who refuses to forgive hurts himself more than the offender, for the unforgiving person allows a destructive root of hate and bitterness to grow inside him.

Noise suppression in state estimation is similar to forgiveness. A state estimator that does not consider noise is incomplete and does not reflect an accurate view of reality. In fact, noise suppression (filtering) can be considered as one of the primary purposes of state estimation. A state estimator that ignores the presence of noise might exhibit undesirable oscillatory behavior or even instability. The estimator might operate wonderfully in a noise-free environment, but the introduction of noise could render the system useless. A state estimator that is designed to perform well in the presence of noise is like a person who acknowledges the presence of sin in the world but does not allow it to ruin him. Just as the spiritual person deals with offense in a constructive and active way, the optimal state estimator minimizes the effects of noise.

Discernment and bandwidth

In order to grow spiritually, we need to listen and learn from a variety of sources (from all religions and worldviews) because we never know when and how God may try to speak to us. In that sense we need to be essentially open to the data that comes into our lives from others. But if we listen to everything that is within earshot we will be “tossed back and forth by the waves, and blown here and there by every wind of teaching.”³ We need to reject unhealthy data in order to prevent ourselves from being misled. In other words, we can’t believe everything we hear or read.⁴ We need to strike a healthy balance between skepticism and acceptance of the views of others. We need to exercise discernment in order to allow ourselves to be influenced by beneficial information while rejecting data that may be detrimental.

The band-limited frequency response of a state estimator is similar to spiritual discernment. A state estimator needs to be responsive to input measurements, yet it also needs to reject those parts of the measurements that consist of noise. A state estimator that rejects all measurements is clearly ineffective. Yet a state estimator that is equally sensitive to all measurement data will be “tossed back and forth by the waves, and blown here and there by every wind of measurement.” The state estimator needs to strike a healthy balance between acceptance of information content and rejection of the noisy part of measurements.

Fellowship and persistent excitation

People need to be actively involved in fellowship (i.e., spiritually constructive friendships with others) in order to grow spiritually. We need to interact with others, share insights and burdens, and receive the encouragement that others offer. Many people adopt the “Lone Ranger” approach to religion and consider themselves beyond the need for fellowship. But they are like the scientist who tries to conduct research without considering the contributions of the past. We need to be aware that interaction with others will enrich our spiritual lives as we draw on the variegated experiences and insights of others. We will make more progress in our spiritual lives if we stand on the shoulders of the giants who went before us (or at least on the shoulders of the average sized people who accompany us).

Persistent excitation in system identification is similar to spiritual fellowship. In order to estimate the state of a system, we need to have a mathematical model of that system (in general). Even in those systems in which estimation can be performed without a mathematical model, the availability of an accurate system model will always improve estimation performance. One way to obtain a system model is to execute some sort of system identification algorithm. But in order for the system identification algorithm to be effective, it must be excited by an adequate variety of input signals. This is called the “persistent excitation” condition for system identification methods [Jua93, Lju98]. The system model will not be accurate unless the inputs are persistently exciting. Likewise, our lives as spiritual persons will not be all that they can be unless we receive sufficient input from others.

³Ephesians 4:14.

⁴Of course, you can’t take my word for it.

Spiritual growth and adaptive state estimation

As spiritual beings, we need to grow spiritually in order to be healthy as balanced individuals. Many people appear to be satisfied with their present spiritual status, but God requires us to grow on a continual basis throughout our lives. God is more concerned about the spiritual *direction* that we are moving in than he is with our present spiritual condition. In other words, he is more concerned with velocity than position. We should adopt a mindset that is never complacent but rather continually looks for areas in our lives where we can grow and improve. One of the apostles of the early Christian church, Saint Paul, said toward the end of his life, “Not that I have already obtained all this, or have already been made perfect, but I press on ... forgetting what is behind and straining toward what is ahead, I press on toward the goal...”⁵

Adaptive state estimation is similar to spiritual growth. Some state estimators are static and unchanging in their dynamic characteristics. But a variety of adaptive state estimators have been proposed over the past few decades that exhibit continuous improvement in performance. These adaptive algorithms are never satisfied with their present performance, but continually adjust their parameters in order to obtain incremental improvements over time (see Section 10.4). These adaptive estimators promise the benefit of improved performance and robustness relative to more traditional estimators. In a similar manner, the person who constantly maintains a lookout for areas of possible growth has the promise of many spiritual benefits.

Spiritual perfection and estimator optimality

God requires us to be perfect. To the control engineer, this statement raises the questions, “Perfect in what way? What is the standard for perfection?” Jesus told his followers, “Be perfect, therefore, as your heavenly Father is perfect.”⁶ So we see that it is God himself who provides the standard for perfection. God himself is the divine objective function. Some people will disagree with the statement that “God requires us to be perfect” because of its obvious impossibility. But in spite of its impossibility, it is a standard toward which God requires us to strive. We will never reach the standard of perfection (at least in this life), but we can continually get (asymptotically) closer to it throughout our lives.⁷

Optimality in state estimation is similar to perfection in life. An optimal state estimator attempts to minimize some objective function. Theoretically, optimality can be achieved. But practically speaking, optimality will never be attained. This is because of modeling errors, incomplete knowledge of noise statistics, sampling and resolution limitations, and other deviations from ideal conditions. Although optimality will never be completely attained, optimal estimators are still quite effective in practice. We do not give up on the notion of optimality just because it is not completely attainable. We continue with our efforts toward optimality, thankful for the performance that we can obtain. The state estimator churns away in its quest for optimality, never quite attaining it, yet continually getting closer

⁵Philippians 3:12-14.

⁶Matthew 5:48.

⁷Those who claim to have already achieved perfection are referred to the paragraphs above.

and never giving up. In a similar manner, we churn away in our quest for spiritual perfection, never quite attaining it, yet continually getting closer and never giving up.

The one true way and the single best estimator

In this book we have discussed a number of different estimators (e.g., Kalman filtering, H_∞ filtering, robust filtering, unscented filtering, and particle filtering). Which filter is the best approach for a given problem? It is not an easy question because one filter may be computationally more effective, another filter may be better from an RMS error viewpoint, another filter may be better from a worst-case error viewpoint, and yet another filter may be better from some other viewpoint. Nevertheless, if the problem and the optimality criterion are well defined, then there is a single filter that is the best. We may not know what the best filter is, but there is a single best filter for the problem. One reason that we may never find the best filter for our problem is because we are stuck on a specific filtering approach and are unable to take the time to learn other competing approaches. If we are comfortable with filter x and we have never been exposed to competing approaches, then we will probably use filter x for every problem. This will prevent us from obtaining the better performance that we might have gotten with a different filter. To some extent this problem is unavoidable. After all, who has the time or energy to learn every filtering algorithm that has ever been proposed? But to some extent this problem is avoidable. After all, with some expenditure of effort on our part we can learn about new filters and have a better chance of knowing the right filter for new problems that we encounter.

As we spend our lives searching for The Meaning of Life, we are confronted with the question of which worldview is the best approach to use in our search. It is not an easy question because one worldview may be better from one point of view, while another worldview may be better from another point of view. Nevertheless, there is a single worldview that is ultimately the best. We may end our lives never having found the best worldview, but it is out there somewhere. One reason that we may never find the best worldview is because we are stuck on the specific worldview that we grew up with and are unable to take the time to learn about others. To some extent this problem is unavoidable. After all, who has the time or energy to conduct an exhaustive study of every religion and philosophy that has ever been proposed? But to some extent this problem is avoidable. After all, with some expenditure of effort on our part we can learn about the most widely adopted religions and have a better chance of knowing the best approach to finding The Meaning of Life.

Conclusion

Earlier in this appendix (page 494) I promised to return to the question of the validity of the assumption of God's existence. In order to deal with this question, we turn to Occam's razor. William of Occam, who lived in the 14th century, was an English philosopher and Christian theologian. He is most famous for the invention of Occam's razor, also called the principle of parsimony. The idea of Occam's razor is that the simplest explanation is the most reasonable explanation. Occam's razor is used to "shave off" those concepts that are not really needed to explain

some observed phenomenon. This idea is used in system identification to accept the simplest model structure that fits the observed data. Occam's razor is used implicitly in all fields of science and engineering (and in everyday life as well) to support the simplest explanation for observed data.

Consider the following example. If I come home and find crayon marks on the wall, I can theorize that a mysterious chemical reaction caused the paint on the wall to change color, or perhaps a burglar broke into the house and colored my walls, or perhaps my young daughter with a fondness for coloring did it. Which explanation is most likely? Occam's razor says to accept the simplest explanation. The simplest explanation is not always correct, but experience has taught us that it is usually correct, and it is certainly more satisfying (although it is not necessarily more satisfying to my daughter).

When we look at the complexity of life with its underlying unity, Occam's razor says to accept the simplest explanation. Bananas and airplanes are both made from the same stuff, and state estimation and *The Meaning of Life* have an underlying commonality. We see two paintings with similar artistic styles. We see two books with similar writing styles. Is it a coincidence, or is there a simpler explanation? Occam's razor says to accept God as the simplest explanation. The underlying unity that we see in the complexity of life is an evidence for the existence of God.

Some would say that God is more complicated than anything that we directly observe. Therefore, introducing God as an explanation introduces unwarranted complexity and thus actually violates Occam's razor. In this brief appendix, I have neither the time nor the ability to delve into the many deep philosophical arguments for and against the existence of God. Nevertheless, I believe that the existence of God explains so many things that we observe in life that it is a clear example of Occam's razor. Although God is certainly complicated and cannot be proven to be necessary, the addition of one complicated factor to explain a million simple observations is appealing from both an aesthetic and an engineering viewpoint.