Chapter 1

Introduction

1.1 Scope of Electrical Engineering

In today's world, it's hard to go through a day without encountering some aspect of technology developed by electrical engineers. The impact has been so pervasive and ingrained in society that many revolutionary developments are taken for granted. For example, power transmission, electric lighting, and incandescent bulbs seem mundane, but were highly influential, pioneering developments. Radio, telephony, and television now also seem mundane but again are among the great inventions of modern times. However, in addition to these dated examples, the field of electrical engineering continues to be an exciting, rapidly developing, and influential area of technology. Computers and electronics have witnessed incredible advances over the last few decades and continue to do so. The internet, wireless communications, and multimedia are just a few examples of technologies in their infancy that have already had tremendous impact on society. Without a doubt, these and other aspects of information technology will continue to play vital roles for the foreseeable future.

So what is "electrical engineering"? The study of electricity and electric circuits have often been equated with "electrical engineering". However, these areas form a just small part of this broad field. In addition to studying the basic physical phenomena of electricity and magnetism, electrical engineers design, build, and analyze systems that deal with two basic entities: electric power and information. Although electrical power systems still play a critical role in the infrastructure of modern society, by far the bulk of effort and advances in electrical engineering in recent years has been in information technology. Hence, one simple and fairly representative answer is that electrical engineering is the field responsible for the technology driving the information revolution.

[†]Lecture Notes for ELE201 Introduction to Electrical Signals and Systems.
[‡]Thanks to Richard Radke for producing the figures.

1.2 A Signals and Systems Approach

We described electrical engineering as the design, building, and analysis of systems dealing with information or electrical power. However, we never defined what was meant by a system. This is a difficult term to define. The word "system" is used both in a general, non-technical sense such as that given in a standard dictionary, as well as in a rather precise and more technical sense as we will discuss in Chapter **??**. For now, we will consider only the more general use of the word "system". Our aim at the moment is to provide a very broad overview of the field of electrical engineering and give the describe the perspective we will take in our discussions.

In the most general sense, we will think of a system as simply being some portion of our physical world on which we wish to focus our attention. In engineering, we are interested in constructing systems to carry out various tasks. That is, the system is immersed in some environment and through interaction with the environment the system performs certain functions (see Figure 1.1). Usually, for a system to perform some useful function, something needs to be known about the environment. This information is provided by *sensors*. The sensors can be thought of as input devices that measure certain physical variables and pass on these *signals* (or data, information) for further processing. To carry out its task, the system must often alter or in same way interact with the environment. It does this through *actuators*, which can be thought of as output devices.

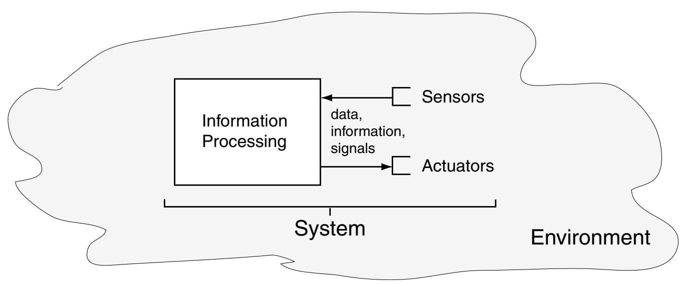

Figure 1.1: A general system immersed in its environment.

To get a sense of the field of electrical engineering, it is helpful to try to give a breakdown of the field based on certain criteria. One approach is to consider a breakdown by areas of application of systems designed by electrical engineers. However, there are so many applications in such a wide range of areas that this approach is difficult.

A second approach is to break down the field by the level of description of the generic system shown in Figure 1.1. One such breakdown might be into layers such as physical, device, component, algorithmic, and conceptual as in Figure 1.2. At the core is the physical layer that describes a system at the most detailed level in terms of the underlying physical phenomena and processes. At the next level, the description would be in terms of devices whose function can in turn be explained directly in terms of the underlying physics. The devices can be considered as building blocks of larger components of the system. These components can be explained in terms of the algorithms (or methods or high-level functions) that they use to accomplish their task. Finally, the algorithms can be considered as particular solutions or implementations of the underlying problems they are designed to solve. A description at the level of the underlying problems themselves constitutes the conceptual layer. This type of breakdown provides a useful categorization. Most advanced topics in electrical engineering can be placed in the context of these layers. For example, the study of quantum effects falls into the physical layer, circuits fall into the device layer, computer architecture falls into the component layer, etc.

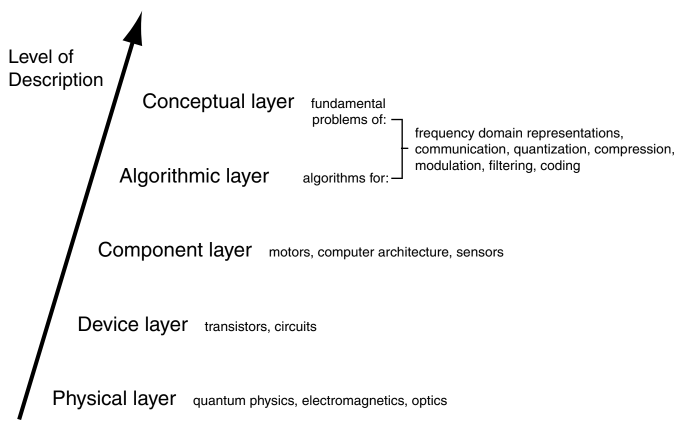

Figure 1.2: A breakdown of electrical engineering by level of description.

A third approach is to give a breakdown in terms of internal tasks that the system carries out. That is, internal to the system, there are a number of different processes or tasks that are often performed, and we can give a breakdown in terms of these processes (as opposed to the external task of the whole system itself, which would be like a breakdown by application). One of the first tasks is sensing: that is, converting physical variables into signals usable by the system. The signals often need to be stored for later use, and depending on the amount of data, the signals may need to be compressed for more efficient storage. Prior to storage, the signals may need to be filtered to eliminate noise or other degradations (in the signals). Once stored, a variety of general purpose computations on the data commonly need to be done. If the system consists of separated sub-systems, these sub-systems may need to communicate with one another. In certain cases there may be a need to protect the information to keep data private or to prevent either intentional or accidental degradation of the data. Sometimes the data needs to be analyzed or higher-level tasks such as object recognition need to be performed. Learning and adaptation are often useful in improving system performance over time or providing robustness to unanticipated changes. Issues of control and actuators are also important since the systems are generally designed to control some aspect of the environment or to provide displays or other outputs for users. Finally, there are some systems that are highly distributed. That is, there are a very large number of distinct units (sometimes mobile) that interact with each other. For these distributed and perhaps mobile systems, a number of new issues arise.

This breakdown by internal task is the approach we will follow. For the various internal tasks, we will give a description primarily from the conceptual and algorithmic layers.

1.3 Unreasonable Effectiveness and Breadth of Electrical Engineering

The Nobel Prize-winning physicist Eugene Wigner commented on the "unreasonable effectiveness of mathematics in the natural sciences." In a similar way, one might ponder the unreasonable effectiveness of electrical engineering in the applied sciences and technology. The tools and methods of electrical engineering have been far more effective than one might have prior reason to believe. Advances in electrical engineering have led to devices and components that are extremely small, fast, flexible, reliable, and economically feasible. This success has led to a paradigm in engineering systems of converting whatever physical phenomenon the system is dealing with into electrical signals (via sensors), performing any necessary manipulations on the electrical signals, and finally converting electrical signals back to physical actions (via actuators). Thus, even for many non-electrical applications, the core of the system may be largely based on electrical engineering with only the sensors and actuators serving as input and output interfaces with the environment. An interesting consequence of this wildly successful paradigm is that the studies of many information processing tasks in themselves have become parts of the field of electrical engineering. For example, in addition to just communication based on electrical principles, electrical engineering includes the study of the fundamental problem of communication in and of itself (independent of any particular implementation). This has greatly contributed to making electrical engineering an extremely broad field spanning a range of distinct subfields.

One way to get a sense of the breadth and range of electrical engineering activities is to consider its relationships with other fields of study. Among all traditional disciplines at a typical university, electrical engineering is perhaps the broadest in the sense that various subareas within electrical engineering are closely related to and/or overlap with subareas in many other traditional disciplines. For example,

- computer science: computer architecture, software, networks, algorithms
- physics: optics, quantum physics, semiconductors, electromagnetics
- material science: semiconductors

- mechanical engineering: systems theory, control, robotics
- statistics: detection, estimation, information theory, pattern recognition
- biomedical engineering: signal processing, medical imaging, prosthetic devices
- mathematics: differential equations, functional analysis, probability and random processes, algebra
- philosophy: inductive inference, learning theory, epistemology
- cognitive science: pattern recognition, learning, neural networks
- economics: time series analysis, game theory
- operations research: decision-making, optimization, stochastic modeling