Session Number 2408

The Switching Circuits of Biology

Kathleen M. Kaplan, D.Sc., Lt Col John J. Kaplan (Ph.D., J.D.) USAF

Howard University/USAF

Abstract

Teaching biology to undergraduate engineering students can be a daunting task. There are a range of concepts to learn that do not seem to have any relationship to engineering. But there is a mapping between engineering and biology that is applicable for engineering students to study. By using biological data in switching circuits, engineering students can relate biology to familiar concepts.

Specifically within switching circuit concepts, engineering students seem to enjoy creating state transition diagrams, mainly because they are easy to construct! Also, from state transition diagrams, state transition Tables can be created, and vice versa. By using biology as the data for switching circuits, engineering students can grasp the concepts of biology quicker because they use a tool that they enjoy. For example, given the well-known Table of the genetic code mapping of codons to amino acids, an engineering student may apply his or her knowledge of switching circuits to it. Perhaps an engineering student would create a state diagram for this mapping. In another application, an engineering student may create a state diagram for proteins, where a beginning state is methionine and the three final states would be stop codons. Or perhaps an engineering student will identify that the redundant sixty-four to twenty mapping of codons to amino acids becomes data for a switching circuit with "don't care" inputs. By looking at biological processes as switching circuits, the engineering student gains knowledge of biology and the full relevance of engineering principles to other disciplines.

This paper will explore some of the applications of biology to switching circuits. The information will include possible engineering student projects and assignments, and lessons learned from teaching biology to engineering students.

Proteins – Full of "Don't Cares"

A protein is a chain of amino acids. The twenty amino acids are given in Table 1 below with corresponding three-letter codes and names.

Table 1. Amino Acids [7]

	Three-Letter Code	Name
1	Ala	Alanine
2	Cys	Cysteine
3	Asp	Aspartic Acid
4	Glu	Gluetamic Acid
5	Phe	Phenylalanine
6	Gly	Glycine
7	His	Histidine
8	Ile	Isoleucine
9	Lys	Lysine
10	Leu	Leucine
11	Met	Methionine
12	Asn	Asparagine
13	Pro	Proline
14	Gln	Glutamine
15	Arg	Arginine
16	Ser	Serine
17	Thr	Threonine
18	Val	Valine
19	Trp	Tryptophan
20	Tyr	Tyrosine

DNA, deoxyribonucleic acid, the "code of life," specifies amino acids by nucleotide triplets, or codons. There are four distinct nucleotides, {A, C, G, T} in DNA and {A, C, G, U} in RNA, ribonucleic acid. (Think of DNA as a big reference book in a library. Only a few pages of this big book are needed and copied. In this example, RNA is the copied pages.) Thus, there are 4^3, or 64, possible codons. Yet, there are only twenty amino acids and three stop codons designated by nature. Therefore, there are a number of duplicates, with a 23:64 mapping. This mapping is seen in Table 2.

Table 2. Amino Acids and Stop Codons with Corresponding Codons [7]

First Position	Second Position G	Second Position A	Second Position C	Second Position U	Third Position
G	Gly	Glu	Ala	Val	G
	Gly	Glu	Ala	Val	A
	Gly	Asp	Ala	Val	C
	Gly	Asp	Ala	Val	U
A	Arg	Lys	Thr	Met	G
	Arg	Lys	Thr	Ile	A
	Ser	Asn	Thr	Ile	C
	Ser	Asn	Thr	Ile	U
C	Arg	Gln	Pro	Leu	G
	Arg	Gln	Pro	Leu	A
	Arg	His	Pro	Leu	C
	Arg	His	Pro	Leu	U
U	Trp	STOP	Ser	Leu	G
	STOP	STOP	Ser	Leu	A
	Cys	Tyr	Ser	Phe	C
	Cys	Tyr	Ser	Phe	U

Assignment 1: Switching Circuit Table of Amino Acids

Engineering students may look at this in a different way, and should be encouraged to do so. The redundancy of Table 2 can be reduced by utilizing standard switching circuit terminology. First of all, “x” can be used as the standard circuit switching “don’t care.” Also, set theory can be used for codons; parentheses can indicate a set of nucleotides where any element of the set can be used. Utilizing these two switching circuit concepts, Table 3 is obtained by the observant engineering student.

Table 3. Amino Acids and Stop Codons with Corresponding Switching Circuit Codons

	Three-Letter Code	Name	Codon
1	Ala	Alanine	GCx
2	Cys	Cysteine	UG{C,U}
3	Asp	Aspartic Acid	GA{C,U}
4	Glu	Gluetamic Acid	GA{G,A}
5	Phe	Phenylalanine	UU{C,U}
6	Gly	Glycine	GGx
7	His	Histidine	CA{C,U}
8	Ile	Isoleucine	AU{A,C,U}
9	Lys	Lysine	AA{G,A}
10	Leu	Leucine	CUx or UU{G,A}
11	Met	Methionine	AUG
12	Asn	Asparagine	AA{C,U}
13	Pro	Proline	CCx
14	Gln	Glutamine	CA{G,A}
15	Arg	Arginine	AG{G,A} or CGx
16	Ser	Serine	AG{C,U} or UCx
17	Thr	Threonine	ACx
18	Val	Valine	GUx
19	Trp	Tryptophan	UGG
20	Tyr	Tyrosine	UA{C,U}
STOP	STOP	STOP	UGA or UA{G,A}

In doing this, the engineering student identifies the relationship of engineering to another subject, in this case biology.

Assignment 2: State Diagram for Protein Synthesis

Given the information in assignment 1, and a little extra knowledge, the savvy engineering student will be able to create a state diagram for proteins. It should be noted that protein synthesis starts with the amino acid methionine [2] and ends with a stop codon. Using this knowledge incorporated with Table 3, an industrious engineering student should be able to complete a state diagram for protein synthesis, such as in Figure 1. In Figure 1, there are three states with nucleotide codons as inputs. These inputs can be either amino acids or stop codons. A valid protein consists of a starting amino acid of methionine and ends with a stop codon. Assume for this example that this is the minimum requirement for a protein.

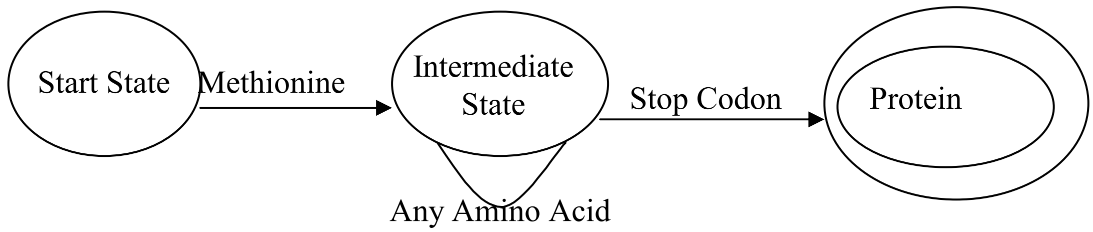

Figure 1. State Diagram of Amino Acids in Protein Synthesis

Of course, this isn't very industrious at all, but it is a first step. A more ingenious student would work at the nucleotide level and produce the state diagram in Figure 2. This state diagram uses RNA for input and identifies if the string of RNA is a valid code for a protein given that all proteins start with methionine (the sequence AUG) and end with a stop codon, assuming again that this is the minimum requirement.

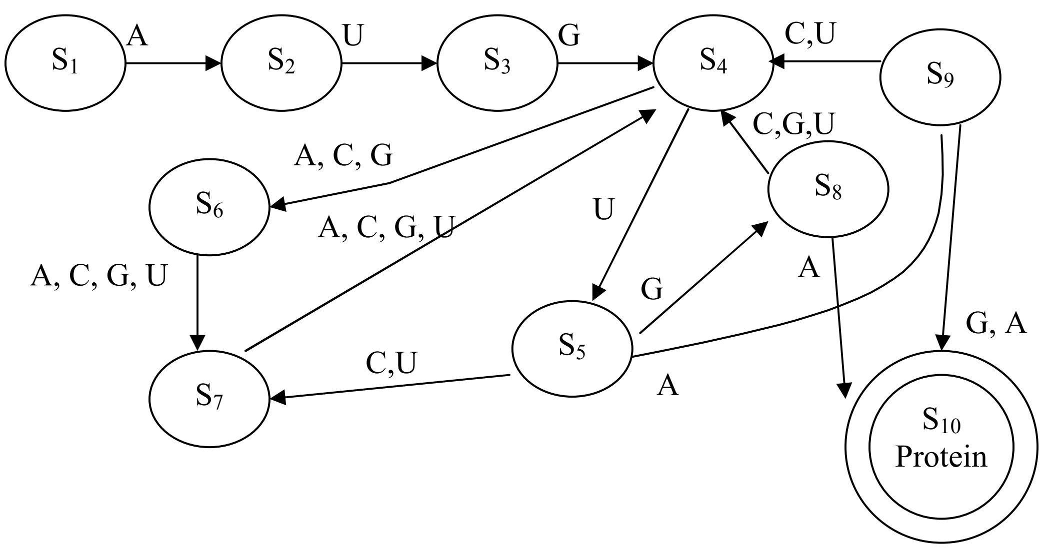

Figure 2. Identification of a Protein Given RNA

These state diagrams can become more complicated as the problem definition varies. Regardless of the problem, the engineering student will be able to identify the importance of circuit switching concepts in biology.

Assignment 3: Circuit for Protein Synthesis

Using the information in Figure 2, a context free grammar (CFG) can be constructed to identify protein synthesis.

AUG{{{A,C,G}{A,C,G,U}+U{C,U}}{A,C,G,U}+U{G{C,G,U}+A{C,U}}}* U{GA+A{G,A}}

Perhaps the engineering student can simplify his or her CFG!

Other Assignments

Once the engineering student learns more biology concepts, he or she will be able to fully utilize his or her engineering abilities with respect to the discipline. Given the information in this paper, and engineering professor can imagine many possible interesting assignments. For example, once the student obtains a state diagram for a certain biological process, he or she may build a circuit to fully realize the design. The state diagram in Figure 2 can be easily coded by assigning 00 for A, 01 for C, 10 for U, and 11 for G. Also, once a context free grammar is created, a circuit can be designed from this.

Lessons Learned

Teaching biology to engineering students can be a daunting task. Although engineering students have a good grasp of theory in relation to application, the complicated, unknown procedures of the body may cause some engineering students to question the application of engineering principles to such a discipline. It is also a difficult discipline to master, even for bioengineering students themselves, let alone introducing the material in a one-semester course. Therefore the authors suggest that engineering students be exposed to biology in a fun way and given projects related to the readings as soon as possible.

Learning Genetics Easily

One way to make the transition easy is to use fun references. Two of these are the Cartoon Guide to Genetics [4] and DNA for Beginners [6]. In using these conceptual books as references, the student can learn DNA concepts in a fun way. There are also coloring books for biology, microbiology, etc. These can be found easily with an internet search and one reference is given below [1]. Another important reference is the human genome website, genome.gov [3]; the completion of the full human genome sequence is available from the U.S. government [5].

Conclusion

Teaching biology to undergraduate engineering students does not have to be a difficult task. This paper has introduced some biology concepts relating to DNA and has shown that there is a mapping between engineering and biology that is applicable for engineering students to study. It has also been shown that this is germane to switching circuits. By using biological data in switching circuits, engineering students can relate biology to familiar concepts.

It has also been shown that introducing biological concepts need not be difficult. Three easy references are given in this paper. The more enjoyable the learning, the better the student will be able to grasp these concepts.

One engineering area that engineering students seem to enjoy is switching circuit concepts. Students seem to enjoy creating state transition diagrams, state transition Tables, and applying these concepts to create circuits. By using biology as the data for this area, engineering students can grasp the concepts of biology quicker as they are using an enjoyable tool.

This paper explored some of the applications of biology to switching circuits by giving possible engineering student projects and assignments. Also discussed were the lessons learned from teaching biology to engineering students.

Utilizing biology data in circuit switching can be fun for both the engineering student and professor.

References

[1] Alcamo, Lawrence M. Elson, *Microbiology Coloring Book*, Addison-Wesley, January, 1997.

[2] Davidson, Michael W., "Methionine," *Molecular Expressions: Exploring the World of Optics and Microscopy*, http://micro.magnet.fsu.edu/aminoacids/pages/methionine.html, accessed Jan. 2004.

[3] The National Human Genome Research Institute, http://www.genome.gov, accessed Jan. 2004.

[4] Gonick, Larry, and Mark Wheelis, The Cartoon Guide to Genetics, Harper & Row Publishers, 1983.

[5] National Center for Biotechnology Information (NCBI), Human Genome Resources, http://www.ncbi.nlm.nih.gov/genome/guide/human/, accessed Jan. 2004.

[6] Rosenfield, Israel, and Edward Ziff, DNA for Beginners, Writers and Readers Publishing, 1984.

[7] Setubal, Joao Carlos, and Joao Meidanis, *Introduction to Computational Molecular Biology*, PWS Publishing Company, 1997.

Biographical Information

KATHLEEN M. KAPLAN, D.Sc.
Dr. Kaplan is an Assistant Professor in the Department of Systems & Computer Science at Howard University. She is also a Registered Patent Agent licensed to practice before the United States Patent and Trademark Office. She can be reached at kkaplan@howard.edu.

JOHN J. KAPLAN, Ph.D., J.D.
Dr. Kaplan is a Lieutenant Colonel (Lt Col) in the United States Air Force and a Patent Attorney. Lt Col Kaplan is currently the Commander of the 694th Support Squadron. He can be reached at 694spts.cc@ft-meade.af.mil.