Chapter 10

Geometric Simplification of Cyber–Physical Systems

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ABSTRACT

Human beings are always attracted to patterns, designs, and shapes. Even infants are attracted to the geometry around them. Angles, shapes, lines, line segments, curves, and other aspects of geometry are ubiquitous. Even the letters are constructed of lines, line segments, and curves. Nature also has an abundance of geometry. Patterns can be found on leaves, in flowers, in seashells, and many other places. Even the human bodies consist of patterns, curves, and line segments. Therefore, like many professions, the cyber-physical systems also require at least a foundational understanding of geometry. This chapter elucidates the use of geometry to simplify the design and analysis of cyber-physical systems to enhance the efficiency in social applications. The knowledge learned through the understanding of geometric principles provides not only an increase in safety but also an increase in the creation of tools, skill level enhancement, and aesthetically pleasing arrangements.

INTRODUCTION

Philosophy is written in this grand book - I mean the universe - which stands continually open to our gaze. But it cannot be understood unless one first learns to comprehend the language and interpret the characters in which it is written. It is written in the language of mathematics, and its characters are triangles, circles, and other geometric figures, without which it is humanly impossible to understand a single word of it. - Galileo Galilei, Il Saggiatore, 1623

Geometry roughly translates in Greek as “Earth Measurement”. It is a practical guide for measuring lengths, areas, and volumes.

Geometry is an original field of mathematics, and is indeed the oldest of all sciences, going back at least to the times of Euclid, Pythagoras, and other “natural philosophers” of ancient Greece. Initially, geometry was studied to understand the physical world we live in, and the tradition continues to this
day. However, geometry transcends far beyond physical applications, and it is not unreasonable to say that geometric ideas and methods have always permeated every field of mathematics.

Cyber-Physical Systems (Gopal, 2015a) is an emerging discipline that eludes a clear structuring of a code or a protocol that can be deemed correct. They are combinations of physical devices controlled by software systems. The primary requirement is high dependability assurance. However, a key challenge is to determine not only correct but also cost-effective dynamic operation (Lyndon, 2010, Partha, 2007) of all physical devices in the system in the context of real world constraints. The evolving complex software and its behavior in the Cyber - Physical Systems (Gopal, 2015b) are not readily amenable to a typical engineering code or a protocol that can simply be deployed and assumed safe if not correct. This chapter uses geometry to simplify the processing in the Cyber – Physical Space in a manner which reflects the natural thinking of human beings to provide the necessary assurance in their actions.

BACKGROUND

Roughly 2400 years ago, Euclid of Alexandria wrote Elements which served as the world’s geometry textbook until recently. Studied by Abraham Lincoln in order to sharpen his mind and truly appreciate mathematical deduction, it is still the basis of what we consider a first year course in geometry.

Euclidean Geometry is the study of geometry based on definitions, undefined terms (point, line and plane) and the assumptions of the mathematician Euclid. While many of Euclid’s findings had been previously stated by earlier Greek mathematicians, Euclid is credited with developing the first comprehensive deductive system. Euclid’s approach to geometry consisted of proving all theorems from a finite number of postulates (axioms).

Euclid introduced the idea of an axiomatic geometry when he presented his 13 chapter book titled *The Elements of Geometry*. The Elements he introduced were simply fundamental geometric principles called axioms and postulates. The most notable are Euclid five postulates which are stated in the next passage.

1. Any two points can determine a straight line.
2. Any finite straight line can be extended in a straight line.
3. A circle can be determined from any center and any radius.
4. All right angles are equal.
5. If two straight lines in a plane are crossed by a transversal, and sum the interior angle on the same side of the transversal is less than two right angles, then the two lines extended will intersect.

Euclidean Geometry is the study of flat space. We can easily illustrate these geometrical concepts by drawing on a flat piece of paper or chalkboard. In flat space, we know such concepts as:

- The shortest distance between two points is one unique straight line.
- The sum of the angles in any triangle equals 180 degrees.
- The concept of perpendicular to a line can be illustrated as seen in the picture at the right.

Geometry is the study of figures in a space of a given number of dimensions and of a given type. The most common types of geometry are plane geometry (dealing with objects like the point, line, circle, triangle, and polygon), solid geometry (dealing with objects like the line, sphere, and polyhedron), and
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