Developing a Framework for Multi-Scale Modeling of the Digital Patient

Charles Donald Combs, Eastern Virginia Medical School, Norfolk, VA, USA

ABSTRACT

The Digital Patient is an analytic platform that has the potential to transform personal and public health care, pharmaceutical and device development, research, and patient and professional education. It is the ultimate Big Data project in healthcare; however, its power will derive not from the volume of data, but from the integration of disparate sources of data into valid and reliable intelligence—about biological processes, social context and treatment efficacy. That integration, in turn, is largely dependent on the evolving theoretical approaches known as systems biology and convergence that lead to the successful meshing of multi-scale models. This paper provides an overview of the digital patient, the domains of systems biology and multi-scale modeling, the evolving efforts to promote convergence and the implications for personalized medicine.

KEYWORDS

Big Data, Convergence, Digital Patient, Multi-Scale Modeling, Personalized Healthcare, Systems Biology

INTRODUCTION

What is a Digital Patient? It is a digital representation of ‘health’ and ‘disease’ and a powerful decision support technology that can be customized to represent each one of us, individually or collectively (Combs, Sokolowski, & Banks, Eds., 2016). Imagine a “virtual twin” of sorts, living in digital form, inside a computer.

That virtual twin is shaped by your medical history. It keeps inside a digital record of your insulin levels, which are constantly tracked by that micro-sensor the doctors installed when they did your angioplasty and stented one of your carotids. Your virtual twin is a bit sleep-deprived, just like you, since you are not sleeping so well due to that back injury. It is allergic to some antibiotics and has ‘let itself go,’ after overeating for the past few years (Díaz-Zuccarini, Alimohammadi, & Pichardo-Almarza, 2016).

This description represents a compelling vision of a comprehensive approach to personalized medicine, which was at the heart of the international DISCIPULUS project. That project was given the task of engaging the European Union (EU) research community in order to develop a Roadmap towards the Digital Patient, a key component and conceptual child of the Virtual Physiological Human (VPH) initiative (www.vph-institute.org). Within the scope of DISCIPULUS, the Digital Patient was defined as “a technological framework that, once fully developed, will make it possible to create a computer representation of the health status of each citizen that is descriptive and interpretive, integrative and predictive” (Díaz-Zuccarini, Viceconti, Stroetmann, & Kalra, Eds., 2013). That definition continues to be useful and to underlie this article.

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An illustration outlining the stages involved in developing the Digital Patient framework is shown in Figure 1 (Díaz-Zuccarini, Viceconti, Stroetmann, & Kalra, Eds., 2013).

Biologists have traditionally sought to understand living entities by investigating their constituent parts. For example, they studied individual genes, proteins, or signaling molecules to learn everything they could about the structure and function of a single biological entity. The emerging scientific strategies of systems of systems analysis and convergence add a new dimension to this traditional approach. Researchers seek to understand both each constituent of a biological network and how all of a network’s constituents function together. They use cutting-edge technologies to gather as much information as they can about a biological system. They then use this information to build mathematical and graphical models that account for the behavior of the system. They test these models by gathering additional data, often by introducing genetic or environmental changes and observing the changes on a particular biological system. In this way, they build an understanding of biological systems that can be used to explore what goes wrong when a biological system becomes diseased and how to treat or prevent that disease. Increasingly, they also take into account the influence of behavior and social context on the biological system. For example, there is increasing understanding of the impact of the behavior of family and friends on individual lifestyle choices and health.

Privacy, synchronicity (the timeliness with which models produce actionable information) and clarity of data organization and analysis are fundamental challenges that must be addressed in completing the Digital Patient platform. Further complicating the construction of the Digital Patient is the current lack of agreement on how we categorize patient information. As shown in Figure 2, an individual patient’s data includes molecular data, clinical data, and social context data and the three data sets are not often integrated in a manner that is understandable or easily usable by patients.

Figure 1. The Process for Achieving the Digital Patient
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