# Electrical and Physical Characterization of Nano- and Non-Linear Devices for Future Computing

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With the end of Moore's Law in sight, there is a great deal of angst in the information technology community over how computing can keep pace now that data is being generated and accumulated at an exponential rate. One solution is to perform exponentially more computation per unit of energy expended in a computer. This may very well require the exploitation of nonlinear dynamical systems to encode and process information in unconventional ways. Both nanoscale structures and neurons can display pathologically nonlinear responses such as chaos to a small stimulus, and in many ways the former can be used to emulate the latter. After a brief introduction to a couple of nonlinear electronic devices, i.e. passive or synaptic memristors and locally active or axonic memristors, I will describe the electronic and physical characterization tools and techniques that we have developed to characterize these systems. Standard electronic test and measurement systems are largely incapable of providing the appropriate time and/or frequency dependent information required to quantitatively characterize and model memristors. We have built flexible high-speed systems that enable us to watch the electronic switching in highly nonlinear systems in real-time from 10's of picoseconds to minutes. This type of data is critical to construct compact models for both the switching and the reliability of dynamical devices. We base our models, as much as possible, on the actual physical mechanisms that occur inside the devices as they operate. For this purpose, we have worked with both the Advanced Light Source at LBNL and the Stanford Synchrotron Radiation Laboratory to utilize the technique of Scanning Transmission X-ray Microscopy to examine functioning memristors *in situ* and *in operando* under controlled temperature and electrical bias conditions. We have imaged the structure and chemical composition of different conductance states of devices in order to determine what and how atoms move inside solid state devices as they are switching electrically under an external bias, whether that switching occurs via a phase transition or through drift, diffusion and thermophoresis of atomic species like oxygen. The electrical and mechanistic information come together in the compact device models that we supply to circuit architects so that they can faithfully and predictively simulate a wide range of circuits before they commit to a design that will be fabricated.