The NEEDS Story: 2012-2017

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Advances in electronics enabled by Moore's Law have transformed our world, but today, electronics is changing. Several companies are exploring new ways to advance computing as they also search for new markets and opportunities. Many more companies make use of the products of electronics companies, but some of these companies are becoming technology developers too. We are entering a new era of electronics that will touch a much wider range of industries and societal challenges, and that will be enabled by a much broader range of science. Electronics has become a pervasive, cross cutting technology. In this new era, problems and grand challenges addressed by multi-disciplinary teams with atoms to applications expertise will more and more often drive university research. As the way we do research changes, graduate education must change to prepare students for this new electronics and to support working engineers in a time of rapid change. NEEDS was established to set the stage for an exciting new era of electronics.

NEEDS (Nano-Engineered Electronic Device Simulation) is charged to advance electronics science and connect it to applications. NEEDS is a five-year initiative funded by the National Science Foundation and the Semiconductor Research Corporation consisting of teams at MIT, U.C. Berkeley, Stanford, and Purdue. Our goal was to create infrastructure to support end-to-end research and to bring the "simulate-model-design" paradigm that has been so successful in traditional electronics to new fields. Because of the short timeframe, we took a very focused approach centered on deeply physical compact models. These kinds of models connect fundamental research to applications. NEEDS has also created a comprehensive, online resource – a set of models, best practices and processes supported by a suite of tools and educational resources. NEEDS research advanced the science of nanodevices and integrated nanosystems while guiding the development of this infrastructure and benefitting from it.

NEEDS infrastructure includes:

1) Open-source, physics-based compact models for emerging nanodevices.
2) Tools and processes for creating, testing, and deploying compact models.
3) Open educational resources to support the new electronics.
4) A science gateway that leverages nanoHUB.org to disseminate resources and engage a broad community.

NEEDS has developed practices, processes, and standards to develop, test, and publish high quality, "simulation-ready" compact models. Work on 1) produced more than 40 models that have been published and downloaded more than 20,000 times. To support both compact model developers and those exploring novel systems (component 2), NEEDS developed three tools and a compact model publication/curation platform. MAPP (Model and Algorithm Prototyping Platform) is a MATLAB-based platform for creating, testing, and debugging compact models. It is also finding use for testing new simulation algorithms. VAPP, translates Verilog-A models to a MATLAB/MAPP format to facilitate testing and debugging. VALint checks Verilog-A models for syntax and best practices. The MAPP/VAPP package will be included in the next release of Xyce, the open source circuit simulation tool developed by Sandia. All NEEDS tools are open source, and their use by novices and experts in compact modeling and circuit simulation is growing. Using these tools and following NEEDS processes, anyone can now publish their model on the NEEDS site.

To address infrastructure component 3, NEEDS spearheads the nanoHUB-U initiative to bring to students and working engineers the new educational resources needed for 21st Century Electronics. More than 75,000 students and engineers registered for these courses. Training materials that introduce students to the art and practice of compact modeling were also developed. The NEEDS website supports infrastructure component 4. Hundreds of resources (models, tools, courses, training materials, seminars, etc.) have been developed and deployed, and thousands of researchers and engineers have accessed them. Leveraging the capabilities of nanoHUB.org, a unique resource for the electronic materials, devices, circuits, and systems community is being created.

The "infrastructure plus research" mission of NEEDS gives it a unique role in the research landscape. We develop tools, models, and educational resources to facilitate our own research. We then disseminate these open source / open content resources to enable and engage others. To produce truly useful infrastructure of this kind, it must be done with (preferably by) those who will use the infrastructure. Over the past five years, as we were creating special infrastructure, NEEDS research teams also advanced the science of devices and systems in areas such as advanced transistors, new computing paradigms, biosensors, heat flow at the nanoscale, energy conversion, and the design of systems with highly variable and unreliable components. Over 150 publications describe this NEEDS-supported research. During the final phase of the program, models and tools are being extended and enhanced and also being used to demonstrate the promise of a model-centric approach to application-driven, science to systems research.

NEEDS research will have value beyond the duration of the program; NEEDS infrastructure will too. The tools will endure and evolve as open-source codes. Our work has been forward-looking – developing compact models to explore possibilities. Some models may have short lives, but they will have served an important purpose. A few are likely to have lasting value. One has already been selected as an industry standard. The educational resources may become dated over time, but we hope they serve as a starting point for a more formal, self-sustaining, on-line educational program. The web site has been designed to be easy to support and could be operated by another entity, such as nanoHUB.org. (Although experience tells us that a domain expert is needed, at a minimum to support model developers and the curation processes.) Five years of work have created a strong set of tools, models, and related infrastructure of growing and continuing value.

While NEEDS infrastructure is of value, we see even more potential for NEEDS as a platform to support 21st Century Electronics. This new NEEDS (New Era Electronic Devices and Systems) is envisioned to be DARPA-like in its emphasis on supporting multi-disciplinary teams to solve the most challenging problems. This new NEEDS will provide intellectual leadership to select hard problems that are ripe for solutions and provide critical input to guide teams to success. It will support teams with simulation and modeling expertise and with tools that would evolve as needed by the research being done. The new NEEDS will be NSF-like in its emphasis on producing enduring knowledge and having broader impact. It would disseminate knowledge, tools, and approaches through tutorials, workshops, and on-line education. Such a leadership and infrastructure platform would increase the value of research already being done by providing a much-needed complement to existing research programs – something with the spirit of a Bell Labs in academia that would not only solve important problems, advance fundamental research, but also energize bright, talented young people and equip them with the experiences and education they need to become technology leaders for the 21st Century.