# SCIENCE AND ENGINEERING BEYOND MOORE'S LAW (SEBML)

**Goal**: Position the U.S. at the forefront of communications and computation capability beyond the physical and conceptual limitations of current technologies.

**Description and Rationale**: The transistor was demonstrated in 1947, and once multiple devices were simultaneously fabricated, the packing density of devices on a chip began to increase. Moore's Law is the empirical observation, made in 1965, by the co-founder of Intel, Gordon E. Moore, that semiconductor device density, and therefore computer processing power, doubles about every 18 months. Currently, many innovations are being pursued to prolong the scalability of computer processing power, but with silicon technology the fundamental physical and conceptual limits of Moore's Law are likely to be reached in 10 to 20 years.

To take computation *beyond* Moore's Law requires new scientific, mathematical, engineering, and conceptual frameworks. Long term basic research across many disciplines will lead to the new hardware and architectures needed to address challenges such as efficient input and output, data storage and communication, and reduction of energy consumption, as well as sheer computing power. Further, there are also great potential increases in speed of basic computations due to innovative new algorithms and software, and new mathematical frameworks for computation. In the near term, massively parallel machines require a fundamental shift from the traditional sequential model of computation in order to utilize distributed paradigms such as grid and cloud computing. In the longer term, a completely new physical and conceptual foundation of computing will likely be needed.

SEBML is a multidisciplinary research investment with strong ties to future economic competitiveness and potential for long term transformation. Tied to nanotechnology, computer science, chemistry, mathematics, materials science, and physics, it builds on past NSF investments and energizes them with new directions and challenges. Connections to the communications and computer industries ensure that SEBML will directly address economic benefits to the Nation. This research will also enhance NSF investments in both the National Nanotechnology Initiative (NNI) and Networking and Information Technology Research and Development (NITRD).

**Potential for Impact, Urgency, and Readiness**: The U.S. has fundamental strengths in computers and information systems. In today's globalized enterprise, however, many other countries dominate parts of the hardware and software markets. The areas where the U.S. currently excels are in innovative state-of-the-art components, which require a continual investment in research and development. The reward of this approach has been continual leadership in the areas of the largest economic return. To continue U.S. leadership, a paradigm shift is required in the physical foundations of computing. For more details, see: www.er.doe.gov/bes/reports/files/GC_rpt.pdf, www.itrs.net/Links/2009ITRS/Home2009.htm, and www.calyptus.caltech.edu/qis2009/documents/FederalVisionQIS.pdf

Fundamental research will focus on a number of areas, including:

- *New materials, devices, and processes* that exploit the capability to create and manipulate specific quantum states. Some possible candidates include optical and photonic systems, spin-based or single electron transistors, atom condensates, ions, non-equilibrium devices, and molecular-based approaches including biologically inspired systems.
- *New architectures*, particularly multi-core processors, with new control principles, massive parallelism, and designed asynchronicity and indeterminacy. Advances may be applicable to other communication, distribution, and computing systems, leading to truly transformational outcomes.
- *New algorithms* that exploit hardware and architecture characteristics to optimize computing power, including those that exploit quantum behavior. The consideration of biological and social systems may lead to new approaches.

- *New software* that allows the effective use of new devices. New programming models will be needed, along with languages and compilers to support them. Tools for analyzing, monitoring, debugging, and documenting software on these parallel and distributed systems will be essential.
- *New paradigms* that take us from bits (binary logic) to quantum bits or qubits (non-binary logic). These programming models are shifts in thinking that change the conceptual base of computing.
- *New awareness* of power and energy considerations throughout the "computation stack" from physical devices to architectures to software and applications.

**Integration of Research and Education**: SEBML has the potential to take computing and communications to new levels of capability, making the development of a workforce trained in these new areas particularly important. All activities will seek creative ways to engage students and, as appropriate, take new ideas into formal and informal learning environments.

**Leveraging Collaborations**: NSF has proven partnerships among its directorates, connections with other communities (notably other governmental funding organizations and industry), and collaborations with international partners. Strong potential exists for interagency partnering with organizations such as the Department of Defense, Department of Energy, National Aeronautics and Space Administration (NASA), National Institutes of Science and Technology and the intelligence community. NSF, in particular the Directorate for Mathematical and Physical Sciences (MPS), Engineering (ENG), and Computer and Information Science and Engineering (CISE), and the Office of Cyberinfrastructure (OCI) has the broad responsibility for support of fundamental research needed to have a significant technological impact.

In FY 2010, MPS invested more than expected in SEBML ($59.12 million actual versus $18.68 million estimated) due to an increase in proposals in this area from the scientific community. In FY 2012, MPS will partner with ENG, CISE, and the Nanoelectronics Research Initiative — a consortium of companies in the Semiconductor Industry Association — to fund $20.0 million in nanoelectronics.

**Evaluation and Management**: While it may be 10 to 20 years before the full impact of the investment is known, indicators of success will be developed and monitored along the way. Indicators of a growing capability to conduct research in SEBML include: increased numbers of students involved in SEBML projects and related data on breadth/diversity of participation, degree completion, opportunities to participate in interdisciplinary teaming, and progression to higher levels of education or first professional jobs; increased numbers of researchers involved in SEBML projects; numbers of collaborative projects that span disciplines or institutions; increased partnerships with national labs and private sector organizations; and the development of curricular materials or informal education activities that convey aspects of SEBML research. Indicators of research progress include highlights demonstrating progress from NSF awards; publications and patents resulting from NSF awards; and public or private sector adoption of ideas from NSF awards in developing new technologies that stimulate innovation. External review panels and new Science of Science and Innovation Policy tools will be involved in evaluating progress on SEBML research and education.

**SEBML Funding**

(Dollars in Millions)

| | FY 2010 Omnibus Actual | FY 2010 Enacted/ Annualized FY 2011 CR | FY 2012 Request |
|---|---|---|---|
| CISE | $15.00 | $15.00 | $20.00 |
| ENG | 10.00 | 10.00 | 31.00 |
| MPS | 59.12 | 18.68 | 42.18 |
| OCI | - | 3.00 | 3.00 |
| **Total, SEBML** | **$84.12** | **$46.68** | **$96.18** |