SCIENCE AND ENGINEERING BEYOND MOORE'S LAW

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

Description and Scientific Rationale: Moore's Law refers to the empirical observation made in 1965 that computer processing power, based on semiconductor integrated circuits, doubles about every 18 months. With current silicon technology, the physical and conceptual limits of Moore's Law are likely to be reached in 10 to 20 years. To take computing power and communications *beyond* Moore's Law requires entirely new scientific, engineering, and conceptual frameworks. Fundamental research across many disciplines will lead to the new hardware, architectures, algorithms, and software needed to address challenges such as efficient input and output, data storage and internal communications, and reduction of energy dissipation, as well as sheer computing power.

Science and Engineering Beyond Moore's Law (SEBML) is a multidisciplinary research investment with strong ties to economic competitiveness and potential for transformation. Tied to nanotechnology, computer science, materials science, and physics, it builds on past NSF investments in these areas and energizes them with new directions and challenges. Connections to the communications and computer industries ensure that SEBML will directly address the American Competitiveness Initiative (ACI) and America COMPETES Act. SEBML 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: 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, non-equilibrium devices, and molecular-based approaches including biologically inspired systems.
- New architectures, including and especially multi-core processors, with new control principles, massive parallelism, and designed asynchronicity and indeterminacy. Advances here may be applicable to other kinds of 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 interactions. 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 the languages and compilers that support them. Tools for analyzing, monitoring, debugging, and documenting software on these parallel and distributed systems will be essential.

Integration of Research and Education: SEBML has the potential to take computing and communications to new levels of capability, making 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 in place proven partnerships among its directorates, connections with other communities (notably other governmental funding organizations and industry), and collaborations with international partners. NSF's effective and proven funding mechanisms of individual investigator, group, center, facilities, and instrumentation awards are well suited to the interdisciplinary approach required to tackle this complex problem. Strong potential exists for interagency partnering with organizations such as Department of Defense, NASA, NIST, and the intelligence community.

Urgency and Readiness: Maintaining global competitiveness requires faster, more efficient computing power. As discussed above, physical and conceptual limits of computing power are likely to be hit within the next 20 years. The Nation needs to start the development of the next generation of materials, algorithms, architectures, and software now to ensure competitiveness into the future. NSF leadership for NNI and NITRD has helped to create communities ready to take on the challenges of the future. SEBML will build on these past activities, leading them in important new directions.

Evaluation and Management: While it may be 10 to 20 years before the full impact of the investment will be 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 movement to higher levels of education or first professional jobs; increased numbers of researchers involved in SEBML projects; numbers of collaborative projects that reach across disciplines or institutions; increased partnerships with national laboratories 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 in SEBML; and public or private sector adoption of ideas from NSF awards in developing new technologies that stimulate innovation.

Principal Investigators and others active in SEBML will meet regularly. As a formal solicitation is developed, external contractors will be engaged to assist with design of data collection instruments and development of evaluation processes. Committees of Visitors and other external review panels involving all sectors of the economy will be involved in creating the evaluation of progress on SEBML research and education.

Funding: MPS funding includes SEBML as an area of emphasis in FY 2008. In FY 2009, the requested level of $20.0 million will allow NSF to create a truly coherent program across the Foundation with the funding to encourage transformational activities as well as creating partnering opportunities with the private sector and national laboratories to accelerate innovation.