Center for High-Performance & Reconfigurable Computing (CHREC)

A CISE-funded Center

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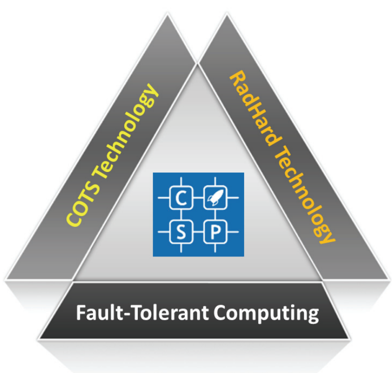
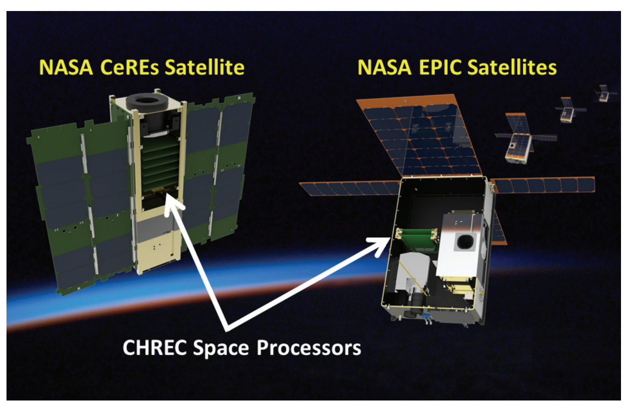
Space Processor

For over a half century, the United States space program has been a leading contributor to the health and growth of our nation from the perspectives of science, technology, economy, and defense. Given the nature and purpose of past, present, and future spacecraft, from earth science to space science and exploration to defense surveillance, one of the most critical needs and daunting challenges is on-board computing. The major challenges come in two major areas: compression and/or processing of data from on-board sensors; and, processing of data for autonomous-control functions such as landing and docking. In both areas, demands are rapidly accelerating because of technology advances in other areas and because conventional on-board computing technologies are lagging behind in terms of performance required in a harsh space environment. This is due to their size, weight, and power constraints, as well as the inherent hazards of radiation effects outside our planet's atmosphere.





Artist illustration of CeREs and EPIC Satellites with CHREC Space Processors.

Research on the CHREC Space Processor (CSP) takes a multifaceted approach to on-board computing for use in small satellites (CubeSats or NanoSats). The CSP is a scalable device that can support spacecraft of all sizes. Working closely with NASA, researchers in CHREC at the University of Florida and at Brigham Young University are developing hybrid space computers that feature an innovative combination of three technologies: commercial-off-the-shelf (COTS) devices, radiation-hardened (RadHard) devices, and fault-tolerant computing.

Modern COTS processors provide the utmost in performance and energy efficiency but are susceptible to ionizing radiation in space, whereas RadHard processors are virtually immune to this radiation but are more expensive, larger, less energy-efficient, and generations behind in speed and functionality. Using COTS devices for critical data processing, supported by simpler RadHard devices for monitoring and management of the COTS devices, and augmented with novel uses of fault-tolerant hardware, software, information, and networking within and between the COTS devices, the resulting system can maximize performance and reliability (called performability) while minimizing energy consumption and cost.

Based upon success to date with this CHREC research, the NASA Goddard Space Flight Center has adopted the CSP concept and technology with plans to feature CSP modules on two upcoming space missions: 1) a new technology mission (STP-H5/ISEM: Space Test Program, Houston 5, ISS SpaceCube Experiment Mini) on the International Space Station; and, 2) a new science mission (CeREs: Compact Radiation bElt Explorer to study charged Particle dynamics in Geospace) on a small NASA satellite. On these two space missions, and others expected to follow, such as a constellation of four satellites (EPIC: Earth Photosynthesis Imaging Constellation) that is proposed by NASA for earth science, CSP will provide an unprecedented combination of performance, reliability, size, weight, and low cost for space-based computing.

Economic Impact: The hybrid approach of CSP has the potential to dramatically increase capabilities and reduce costs associated with spacecraft and space-based processing. The breakthrough work could lead to significant economic impacts in the US space industry. In terms of direct economic impact, instead of having to develop new RadHard processor technologies (at an estimated cost of $20 million for each new processor) and then exclusively rely upon these expensive and slower RadHard devices for reliable space systems (an estimated $10K to $100K per unit), the CSP approach enables future systems to reliably achieve higher performance and lower cost and do so with less size, weight, and power. Moreover, for the first time, the space industry will be able to rapidly exploit technology breakthroughs from the consumer marketplace in the form of new and emerging COTS processors. The indirect economic impacts may even be more significant. By incorporating the space processor technology innovative space missions may be made more feasible. Major savings may come from spacecraft and launch vehicles that are smaller and less expensive than otherwise would be necessary, thus resulting in scientific discoveries and economic benefits that otherwise would have been lost. The nature and economic impacts of the latter are impossible to calculate.

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Novo-G: Reconfigurable Supercomputer

The Novo-G Reconfigurable Supercomputer is the most powerful computer capable of hardware reconfiguration in the world. Each of its 416 reconfigurable processors is highly adaptable in hardware structure to match the unique needs of each application. When compared to conventional supercomputers, Novo-G is orders of magnitude smaller in power, cooling, size, weight and cost.

Computers are at the forefront of technologies serving the needs of society in health, science, commerce, defense, entertainment, and more. In many of these areas demands for computing speed are insatiable, with ever increasing challenging problems requiring increasingly powerful machines, the pinnacle in 2013 being Petascale supercomputers completing quadrillions of complex operations per second.

Virtually all computers in the world today, from smartphones to supercomputers, are alike in terms of the nature of the processing devices employed. These processors (e.g., CPUs, GPUs) are predefined and inflexible in terms of their key architectural attributes such as: the format and precision of data and the mathematical operations supported in hardware; the width and depth of parallelism; the size of their processing cores and how they connect to one another; and, the structure of their memory systems. When applications are developed for these systems, they must be partitioned and mapped to these predefined features. With applications that cannot be mapped effectively, there is consequently much loss of efficiency, leading to systems that are much higher in power, size, weight, and cost than would be necessarily required.

The NSF CHREC Center (pronounced "shreck") conducts research on new and alternative forms of computers for the future. They feature processors with flexible structures that can be adapted to match the unique needs of a vast variety of applications. The foremost of these machines is Novo-G, which was created and is under continuing development by CHREC. It is the most powerful reconfigurable computer in the known world. Note: The Novo-G was awarded the Alexander Schwarzkopf Prize for Technological Innovation by the I/UCRC Association in 2012.

This Novo-G features more than 400 special processors known as field-programmable gate arrays (FPGAs), each of which is capable of being reconfigured with custom data types, operation types, width and depth of parallelism, cores, and core interconnects. A broad variety of applications can benefit from this approach, in domains such as signal and image processing, bioinformatics, computational finance, cryptology, and many more. In some cases, results on Novo-G are dramatic, achieving speeds comparable to the largest supercomputers in the world that are orders of magnitude higher in cost, power, size, and weight.

Since the first prototype crafted in 2009, Novo-G has continued to successfully fulfill its primary purpose, namely, to accelerate applications from diverse sets of domains. Recently, the machine has also shown promise and been selected for a new area of research known as behavioral emulation. The focus of this new research is exploration of future computers up to Exascale, a thousand-fold faster than Petascale, where unprecedented challenges lie ahead in basic research on new architectures, networks, systems, applications, tools, and services. The new research must reach this scale in reliable, energy-efficient, and sustainable manners.

Recognizing that existing analytical and simulative methods may not adequately scale to analyze these extremely massive systems of the future with the necessary accuracy in reasonable response times, CHREC researchers developed a fast and scalable approach for the study of future-generation supercomputers and applications up to Exascale. This new approach, which features behavioral emulation to mimic the behaviors of various objects in the system with the reconfigurable processors of Novo-G, is being funded by a $2 million, five-year grant (2014-2019) from the U.S. Department of Energy.

> **Economic Impact:** The Novo-G machine can rival the speed of the world's largest supercomputers on important applications at a tiny fraction of their cost, size, weight, power and cooling. Conventional supercomputers, some the size of a large building, can consume millions of watts of electrical power, generating massive amounts of heat. This is in contrast to the Novo-G, which is about the size of two home refrigerators and consumes only about 15 kilowatts. With the emerging field of reconfigurable computing, and innovative forms of reconfigurable machines like Novo-G, the potential exists to realize significant economic impact. By solving a broadening range of major problems required of computers, and doing so with hundreds or even thousands of times less resources, untold billions of dollars could be saved annually in energy and other costs versus conventional machines. Moreover, with severe limits in higher integrated-circuit density with ever smaller transistors being predicted for the coming decade, processors of the future must make more efficient use of each and every transistor, thereby making reconfigurable computing even more promising and economically important as a new solution. Finally, and perhaps most importantly, faster computers by nature lead to new solutions from evermore challenging problems too computational-intensive to be previously attempted. This is resulting in new knowledge that can revolutionize fields of study in the physical and health sciences and beyond. The benefits of such advances to science and the nation, made possible by innovations in reconfigurable computing, are difficult to quantify but will undoubtedly be substantial.

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