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“Architectures and Algorithms for Self-Healing Autonomous Spacecraft”

Imagine spacecraft whose missions last three times the human lifespan. Imagine spacecraft with the ability to decide where to explore, how to plan a trajectory, and which data to record. These autonomous spacecraft will require computational systems whose fault tolerance and performance are orders of magnitude better than presently possible. This challenge has been recognized by NASA’s Dan Goldin as calling for revolutionary computations systems that depart radically from contemporary designs. We propose to develop a family of such systems, with emphasis on algorithms whereby the architecture heals itself. Highly autonomous spacecraft will require computations systems that tolerate a number of faults in proportion to the total number of components, hardware and software. This is orders of magnitude better than presently possible. To enable the combination of fault tolerance and performance, we envision a self-healing architecture. Self-healing architectures would naturally support fault tolerance, and are therefore amenable to scalable constructions. Self-healing architectures could be realized using a variety of technologies. The benefits of self-healing architectures extend to military and commercial applications. However, a self-healing architecture such as we prose has never been built, nor is it on the evolutionary horizon of the immediate decade. Our effort will identify properties for self-healing architectures that deliver at least 10^{15} operations per second per kilogram, and that tolerate a number of faults proportional to the number of components.

For Phase I, we propose to deliver a graphical, executable model of a highly fault tolerant, self-healing architecture prototype. The fidelity of this Phase I model with be sufficiently rich to demonstrate tolerance to a number of faults in proportion to the number of components. For Phase I, we foresee two major technical challenges: i) generalization and merging of results from configurations for fault tolerance, and ii) specification of a baseline programming model for a self-healing architecture. The next step would be to design and construct a self-healing architecture and attendant software. Looking to Phase II and beyond, realizing such an architecture will of necessity be multi-disciplinary, and will draw on the expertise of specialists in algorithms, testing, software engineering, circuits, power, packaging, radiation hardening, thermal and mechanical design, control, sensors, and mission planning.