Fault-tolerant satellite computing with modern semiconductors

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For taking these first steps into a new frontier.

Front & Back cover: Illustrations by Dr. Nadia M. Murillo Mejías. Image of Europa taken by the Galileo spacecraft during its second orbit around Jupiter.

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Preface

Space: The Final Frontier

Humankind has been fascinated by the stars, and planets of our solar system, probably since before our species developed complex language. Many cultures have considered them to be ancestors, spirits of nature, and deities guiding our life and influencing our world. As humankind developed, people chose to see their heroes in the constellations, and these curious objects in the sky sometimes even were considered gods. Knowing what these gods wanted or liked could help a society prosper, or could doom it. Even more were we intrigued by the Sun, our neighboring planets, the Moon.

Technology has always been critical in our quest to understand our environment, and our world. Today, we are dependent upon the availability and correct functioning of our technology. It has enabled us to transform nature, but also to damage it and most likely change it for generations. And we are using technology even in our attempts to repair some of that same damage we inflict through it. Without technology, modern societies and our every day life would be unthinkable.

Humans are curious, and using our technology, we began exploring space just recently, considering the timescale of human existence. We operate vast telescopes on the ground and in space, which help us answer the most fundamental questions about how we came to be and where we are going. A few decades ago, we began launching satellites into space, which we today use for science, commerce, and education. Two superpowers conducted a great race to the Moon just a few decades ago, arrived there, took pictures, and then returned home. Today, this race is being rerun with more participants, resulting maybe in an extension to Mars, or better and more productively, to the Galilean Moons of Jupiter.

Satellites allow us to communicate with any point on the surface of the Earth in real-time, and with Mars with more than 10 minutes delay. Weather forecasts, communication services, flight information, and geolocation systems today are possible only due to information transmitted, or relayed by satellites. In many aspects, our modern life would be unimaginable without them.

We have outgrown our homeworld and its limited pool of resource already in many aspects, and most likely we even have to go to space to survive, like a young bird leaving its nest. Within the next few generations, we will reach out into space, begin to understand whatever we may find there, and utilize the vast resources which we may find within our solar system for the benefit of all. To design, construct, test, and operate the spacecraft that we will require we depend upon modern computer technology and electronics.

Electronics and semiconductor technology are indispensable in spacecraft design,

and microprocessors can be found in all major satellite subsystems. Spacecraft and computers represent the peak of our technology, the application of all our skills in engineering, and the result of all the combined interdisciplinary scientific knowledge we have as a species. The reliability of these components is mission critical; and directly or indirectly, lives depend upon them, even in unmanned spaceflight. Scientists and engineers therefore seek to invent, develop, and utilize computer designs which can guarantee sufficient robustness and reliability for a space mission. The topic of this thesis is to enable the use of modern computer technology manufactured in fine technology nodes, which at the time of writing can not be used aboard spacecraft in a reliable manner.