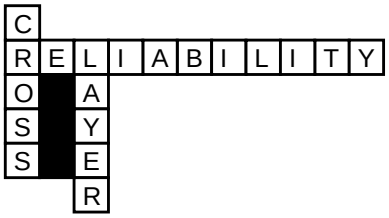

January 2010

ImmunoLogics: Sustaining Healthy Growth of the Silicon Economy

(Non-Technical Executive Summary of the CCC Visioning Study on Cross-Layer Reliability)

ImmunoLogics: *The study of layered computer systems designed to identify and neutralize hardware errors. Analogous to the human immune system that has innate and adaptive systems to provide immediate and long-term responses to invading pathogens.*

Problem: As our computer systems grow in size and capabilities while transistors, which are the most basic element of computation, continue to shrink, they become increasingly prone to failure and early death. Over the past half century, shrinking transistors have allowed the capacity and speed of computer systems to double roughly every two years, which is a phenomenon known as Moore's Law. This amazing trend has enabled incredible American economic innovation, including Google Search, Photoshop, iPods, Facebook, E-banking, Smart Phones, personal GPSs, digital video recorders, and many, many others. However, these tiny transistors are now at a breaking point: if we make them much smaller, they become noticeably less reliable. Today's computers can too easily fail or die when just a few transistors fail, and tomorrow's transistors will be even more likely to fail. If we hope to enable the next round of American innovation in computer systems and consumer electronics, we must find ways for our systems to cope with failing transistors.

Unlike today's computers, our biological systems can tolerate dead or misbehaving cells, eliminate them, and actively respond to pathogens that attempt to damage our system. The key to this robustness is an immune system that provides multiple layers of response to upsets to the biological system. Today's computer and electronic systems are fragile precisely because they lack a robust immune system to tolerate and repair damage. The lack of an immune system was tolerable when the transistors were large and reliable and when computers were not so widely used for critical functions. However, as computational capacity grows and becomes the glue that supports our modern infrastructure, frequent failure and manual repair cease to be viable options. *We must develop an automated immune system for computations to allow further transistor scaling and guarantee that our computers, communication, and automation are not incapacitated at inopportune times.*

Tomorrow's smaller transistors have a higher likelihood of misbehaving than their larger and slower predecessors, causing computers to burn excessive energy, heat up, slow down, age rapidly, fail often, and die early. In the past, these symptoms were mild, and we could treat them with brute-force remedies including safety margins and replication. However, as the symptoms become more severe, it will cost too much energy to stabilize the devices using traditional remedies, and we risk unreasonably high rates of failure and wearout. Even today these effects cause one of the world's largest supercomputers to crash an average of three times a day.[1] Recovering from these crashes reduces the work it can perform by 20%. Alternately, an immune-system-like response strategy that works at multiple levels to efficiently detect failures, adapt to changes, and reconfigure around unhealthy components to effect repairs provides a more promising path to support larger, more capable, and more trustworthy computing systems. At the lowest level, transistors are expected to

[1] 131,072 CPU BlueGene/L at Lawrence Livermore National Laboratory–*Supercomputing '07*

fail. At intermediate levels, innate systems rapidly detect misbehavior and recover the computation. Rather than demanding that a single layer or mechanism catch all errors, multiple layers and mechanisms cooperate, each catching the problems that are easiest for it to detect. Meanwhile, higher level systems learn the best way to adapt the computation for long-term health and efficiency.

Why it Matters: Moore's Law transistor size reduction and increasing integrated circuit capabilities have been an engine of growth for the U.S. economy, enabling new products and services, creating new value and wealth, increasing safety, and removing menial tasks from our daily lives. The silicon health problems identified above could spell the end of transistor scaling, depriving us of further economic, safety, and quality-of-life benefits. The U.S. has consistently created and monetized new value in computing and automation technology over the past several decades. The multi-level mitigation techniques discussed above are essential if we are to continue to reap the benefits of Moore's Law, including the continued value creation that energizes and sustains the U.S. economy.[2] Furthermore, U.S. health, transportation, finance, commerce, intelligence, and military superiority all rely heavily on harnessing advancing computing technology.

Recommendations: We recommend the support of a robust, long-term research and education effort to invent, develop, and refine ImmunoLogics systems. Specific components of this research and education effort include:

1. Repairable hardware architectures
2. Cross-layer information sharing
3. Multi-layer error filtering
4. Multi-layer tradeoffs for error handling
5. Differential reliability
6. Techniques, theories, and platforms that are scalable and adaptive to a wide range of error rates and error types
7. Graceful degradation
8. Embedding reliability and ImmunoLogics engineering into Electrical Engineering, Computer Engineering, and Computer Science curricula

The Role of the U.S. Government: U.S. Government leadership is necessary for this important work to move forward. Robust ImmunoLogics responses cross the entire computing system stack from integrated circuits to software applications. With today's horizontal companies, no one vendor or research laboratory can effect this revolutionary change alone. Furthermore, since an individual consumer cannot reasonably assess the risks and benefits of today's highly complex computer systems, normal market forces alone are insufficient to produce solutions that adequately ensure public safety. Industry-wide standards and safety ratings[3] can give consumers and integrators the insight they need into the resilience of complex silicon technology and incentivize responsible industry development of trustworthy technology.

Learn More: `http://www.relxlayer.org`

Acknowledgment: This material is based upon work supported by the National Science Foundation (NSF) under Grant 0637190 to the Computing Research Association (CRA) for the Computing Community Consortium (CCC). The opinions, findings, conclusions, and recommendations expressed in this material are those of the study leaders and do not necessarily reflect the views of the NSF, CRA, CCC, or the employers of the study leadership or participants.

[2] Consumer Electronics alone contributes 5–10% of the U.S. GDP according to the Consumer Electronics Association <`http://www.ce.org/PDF/CEA_Final_Report_20080401_Lo-Res.pdf`>

[3] *c.f.* 5-star automotive crash ratings