UMIPS: A Semiconductor IP Repository for IC Design Research and Education

Michael S. McCorquodale and Richard B. Brown

Department of Electrical Engineering and Computer Science
Center for Wireless Integrated Microsystems
University of Michigan
Ann Arbor, Michigan 48109-2122

Abstract

Semiconductor intellectual property (IP) and design reuse have recently become cornerstones of commercial integrated circuit (IC) development because they enable significant gains in design productivity. Common IP blocks can be instantiated and reused within a variety of integrated circuits and thus the design effort can be focused on the new or critical functions that have been implemented by the development team. However, within the electrical engineering research and education community, efforts to develop and utilize IP are in their infancy. To address that fact, one of the first academic IP repositories has been launched, the *University of Michigan Intellectual Property Source* (*UMIPS*). *UMIPS* presents a significant academic enrichment opportunity for students in both the areas of course work and research. Students who submit designs to *UMIPS*, even as part of their introductory IC design course work, can potentially have their designs fabricated into large-scale ICs by graduate student researchers. The student researchers also benefit through the availability of IP for their designs and thus the focus of their efforts can be on the fundamental and contributory aspects of their research. Additionally, students may mix and match exciting breakthroughs from their research activities and associated IP with IP from other researchers, thus realizing novel systems that could never be developed in a timely manner through individual research pursuits. In an effort to support such activities, *UMIPS* has been launched with broad support for IP components including entries spanning from complete microprocessor cores to individual microelectromechanical system (MEMS) components. To date, several of these components have been withdrawn from the repository and deployed into large-scale integrated circuits. These activities have led to significant strides in collaborative student research and developments in integrated circuit design automation and methodology. In this paper, *UMIPS* is presented as both an instrument for advancing IC research and a tool for IC education.

I. An overview of semiconductor intellectual property

It has recently been estimated that semiconductor design productivity is increasing at a rate of 28% annually while semiconductor capacity is increasing at a rate of 58% annually[1]. This trend quantifies the now well-known productivity-capacity gap in semiconductor development. Many electronic design automation (EDA) tools have been developed to reduce this gap, but one particular solution that has received significant attention is design reuse with intellectual property (IP)[2]. For example, it has been reported that application specific integrated circuit (ASIC) design productivity increased by a factor of 2.5 from 1996 to 2000 while system-on-chip (SoC) development productivity increased 7 times within the same time frame. Most of the gains realized in SoC development have been attributed to IP design and reuse, clearly indicating the importance of IP to accelerating design time and increasing design productivity[3].

Although the benefits associated with IP design and reuse are clear, the challenges of its use are many. Reports in the field point to the importance of IP repositories and a standardized IP framework for component development[4]. Indeed a lack of these repositories and standards, both internal and external to organizations, is a significant bottleneck toward IP use and design productivity acceleration[5]. Industry has clearly identified this problem and is taking strides toward its solution where several commercial IP repositories now exist such as the *Virtual Component Exchange* (*VCX*) and *Design & Reuse*. However, research institutions have not yet pursued similar initiatives.

One of the first research IP repositories, the *University of Michigan Intellectual Property Source* (*UMIPS*), has been launched with a focus on microsystem and SoC design, which comprises a large portion of the semiconductor research pursued at Michigan. Microsystems technology has been defined as an intelligent miniaturized system comprising sensing, processing, and/or actuating functions where two or more of the following technologies are combined onto a single or multichip hybrid: electrical, magnetic, mechanical, optical, chemical, or biological[6]. Thus, although the vast majority of commercially available IP components are digital, the mission of *UMIPS* is to support digital, analog, mixed-signal, MEMS, computer-aided design (CAD), and design methodology IP, including standardization of the deliverables for IP of these types. The current demand for IP of this nature far outweighs its availability[7] and thus *UMIPS* can accelerate microsystems and SoC research while preparing students and researchers with experience developing IP components and using these components in an IP design framework that will almost certainly become ubiquitous in future microsystems and SoC development.

II. Recent research developments and the founding of *UMIPS*

Several independent but related University of Michigan research projects were combined in order to develop the microsystem recently presented by Senger, *et al.*[8] This microsystem was developed with a focus on sensor control applications, although it retains enough flexibility for a variety of other general-purpose uses. The system was developed in the 0.18μm mixed-mode process available from *Taiwan Semiconductor Manufacturing Company* (*TSMC*). This microsystem is comprised of five major subsystems: a processor core, peripherals, memory, an analog front end, and a monolithic clock reference. In fact, the design contains digital, analog, MEMS, and RF circuitry. As such, several challenges were faced and addressed throughout the development effort, the details of which were presented by McCorquodale, *et al.*[9] The collaborate effort associated with this project brought with it several advances in mixed-signal and microsystem development and thus constituted research contributions well beyond those that could be achieved independently. In fact, the effort resulted in four publications[8,9,10,11] that discuss the development and design methodology associated with this microsystem. Consequently, the development team quickly evaluated strategies for the development of the second generation microsystem.

An IP-based development approach emerged as the best opportunity. By packaging each functional component into an IP block and per a set of specifications that had been rather arbitrarily developed in the original design, each block could be instantiated much more easily. In fact, the blocks could be easily instantiated into *any* design. This design approach was not foreign to the design team since first, this approach occurred rather naturally throughout the development of the original microsystem and second, the original design was completed with several blocks of third party IP including components such as input-output drivers and bonding pads. Thus, the team was accustomed to this strategy. These observations led to the founding of *UMIPS* where the original goal was to minimize design time. However, the vision of what the repository could be grew quite rapidly. It became evident that *UMIPS* could certainly serve the integrated circuit research community as a whole.

A second generation of the project, pictured in Figure 1, was developed but with additional functionality as compared to the original design. This design was completed by converting all of the previously disparate projects into IP blocks per a developed specification. These blocks marked the founding contributions to the repository, the details of which were presented by McCorquodale, *et al.*[10] Shortly after its founding, *UMIPS* has received several submissions from both within and outside of the University of Michigan.

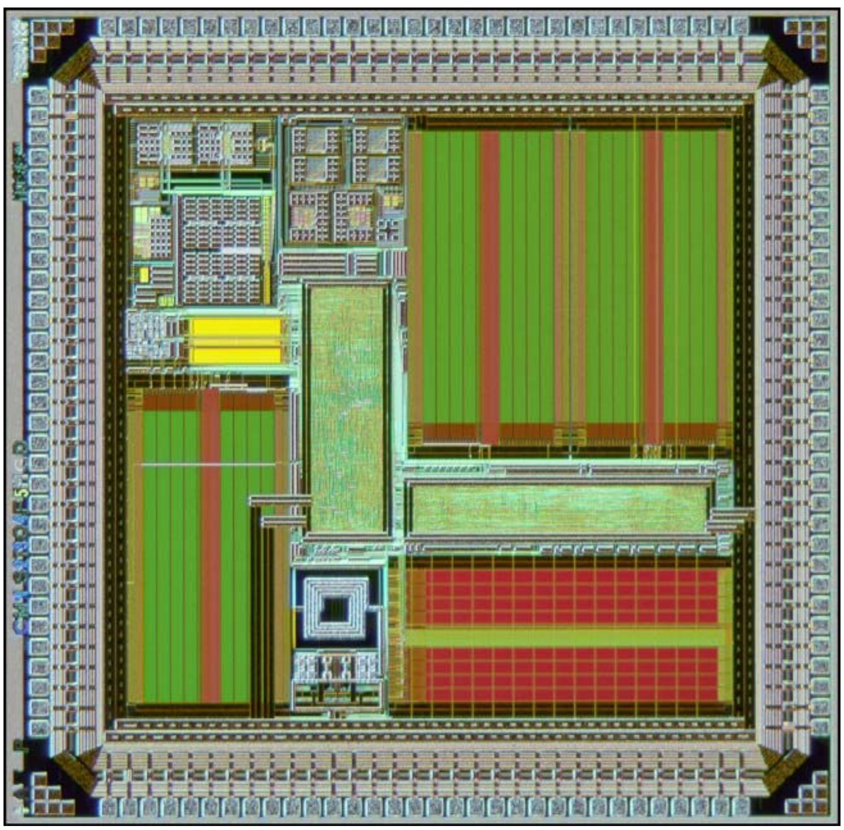

Figure 1. Die micrograph of the fabricated microsystem developed from independent research projects that were converted to IP blocks and submitted to *UMIPS*. The design was completed in *TSMC*'s 0.18μm MM/RF process through the *MOSIS* service. The die area is 12.8mm^2 and the transistor count is over 3.5 million.

III. *UMIPS* standards and framework

A. Mission and goals

UMIPS is a collaborative effort between Electrical Engineering and Computer Science students, faculty, and researchers to leverage each others' integrated circuit development in the pursuit of cutting-edge microsystems and SoC research. The motivation for *UMIPS* launch is design reuse and its benefits to research and education.

The value to research projects includes the elimination of repetitive basic design activities that are applicable to all projects, consequently enabling meaningful research productivity to be substantially increased. Second, an IP repository within the research community lends itself nicely to participation from a breadth of disciplines in semiconductor research including activities in analog, mixed-signal, digital, and MEMS development as well as design methodology and CAD. Third, it is now imperative that students gain experience with an IP-based design methodology as they will almost certainly encounter this development approach in industry. Similarly, design activities are almost never initiated from a blank slate, so students who are able to utilize IP components in their research gain valuable experience for any future design activity.

B. Supported IP

UMIPS currently supports both functional and structural IP in hard, soft, and design methodology formats. The details of these format types can be found in the full technical description of *UMIPS* presented by McCorquodale, *et al*.[10] and at the main *UMIPS* internet portal[12].

UMIPS IP is organized by function and by process technology. The majority of researchers at Michigan use the *MOSIS* multi-project service for IC fabrication, and thus *UMIPS* supports all process technologies offered by this service. In the near future, *UMIPS* will support IP specific to our own internal solid-state electronics laboratory as well as MEMS foundries.

C. *UMIPS* interface and access

UMIPS is managed internally at Michigan, but it is currently accessible by all researchers in the academic community for noncommercial use. *UMIPS* has received and posted submissions from both the University of Michigan and other research institutions. The repository can be viewed via the main internet portal, pictured in Figure 2, where nonproprietary descriptions of the IP components are listed and organized by function and process technology. Researchers wishing to utilize IP in their designs submit a request for IP to the management team and authentication information is provided to that researcher for the specific IP of interest.

D. *UMIPS* standards and quality control

IP is added to the repository through an audit process where the founding management team reviews weekly submissions to the repository to ensure that the baseline deliverables are included for each IP component. This is, of course, quite time consuming, thus the process will be automated as the standards are formalized and the repository framework matures. Some previously reported automation techniques[13,14] may be employed in the future.

Figure 2. The *UMIPS* main internet portal (*http://www.eecs.umich.edu/umips*). From here users may browse non-proprietary descriptions of all IP. Registered users can authenticate and download specific IP blocks and supporting materials.

E. Deliverables for all IP formats

A specific set of baseline deliverables is required for each IP format and is described thoroughly at the *UMIPS* web portal[12] and by McCorquodale, *et al.*[10]

F. Qualification Metrics

IP components are incorporated into *UMIPS* as either "pre-silicon" or "post-silicon" verified. Pre-silicon components must include detailed simulation performance data in the specification. Post-silicon verified components must include the same data from test. The specification must also include a test plan and set-up.

IP components are also qualified as either "instantiated" or "uninstantiated" components. This designation indicates whether the component has been developed into a larger design. Instantiated components have been through at least one design cycle and thus the deliverables have been utilized for development, which indicates that they are adequate for design. Similarly, design methodologies must have been utilized within at least one design cycle that has led to fabrication and test with predictable results. This ensures that no aspect of the design flow or methodology has been overlooked, such as antenna effects or timing approximation errors.

G. Challenges

A number of challenges are associated with *UMIPS* management, participation, and technical support. Extensive management is required in order for the repository to operate successfully. Qualification and auditing are the most rigorous and time-consuming as well as the most important. Automation of portions of these activities can be accomplished in the future with software development. Participation is also difficult to stimulate. Many would-be contributors are deterred by the breadth of requirements for depositing IP into *UMIPS*. An incentive program is under development where the most highly utilized IP and the most novel IP submissions are granted awards. The goal is to stimulate participation from students in particular. However, the founders also anticipate that the repository will grow organically where participants that utilize *UMIPS* IP appreciate its value and are consequently compelled to contribute so as to ensure its sustainability.

H. Other resources

UMIPS also provides a variety of other pertinent data relating to design and reuse including published work using *UMIPS*, pertinent literature on design methodology, and links to related news in the field of IP. In general, the founders have aimed to develop *UMIPS* as the main source for IP-based design in the research community.

IV. Emerging developments with *UMIPS* in the classroom

Given the success of *UMIPS* within the research community, it was only natural to extend the repository's use into the classroom. The opportunities here are tremendous. For example, by submitting course design projects to *UMIPS*, students can potentially have their designs fabricated and tested, possibly within even larger designs than their own. This creates opportunities for publishing that normally would not exist for students who are not actively involved in research. Of course, skeptics may debate the likelihood that a course project would be utilized by a researcher, but consider the following. In an introductory analog design course at Michigan, every single student designs an operational amplifier (op-amp) per an aggressive and practical specification. The op-amp is, of course, the fundamental building block of analog design. Certainly the best designs that pass the *UMIPS* audit can be incorporated into the repository. A researcher can utilize this basic building block and focus on more advanced analog design work rather than developing the block from a blank slate. In fact, in the future, researchers could develop the specification that is distributed to the class per their own research objectives.

Five courses at the University of Michigan contain integrated circuit design components. Recently, the *UMIPS* founding team has collaborated with the faculty instructors of theses courses in order to promote submission of course designs to the repository. These courses are grouped by topic below. The title of each course and a description of the associated design project is listed. This listing provides a scope of the breadth of IP blocks that can developed and submitted to *UMIPS* from just within the University of Michigan.

Analog Integrated Circuits

Course Number: EECS 413
Title: Monolithic Amplifier Circuits
Project: Two-stage CMOS op-amp per specification

Course Number: EECS 522
Title: Analog Integrated Circuits
Project: Variety of communication circuits per performance specification
Sample projects: Voltage-controlled oscillator (VCO), Phase-locked loop (PLL), Mixer

Mixed-Signal Circuits

Course Number: EECS 598
Title: Data Conversion Circuits
Project: Analog-to-digital converters of various topologies per performance specification
Sample Projects: Analog-to-digital converters (ADC) of various topologies

Digital Integrated Circuits

Course Number: EECS 427
Title: VLSI Design I
Project: 16-Bit RISC processor per instruction set architecture (ISA) specification

Course Number: EECS 627
Title: VLSI Design II
Project: Although primarily a digital design course, any project may be pursued
Sample Projects: Encryption/decryption logic, Encoder/decoder, PLL

A call for participation with *UMIPS* has been developed and distributed to these classes. The *UMIPS* founding team is working with the instructors to develop project specifications in these courses that will meet some of the current needs within the IC research community. The founders anticipate at least one submission from each of the courses listed above. Exact results and statistics regarding success in this endeavor will be reported within the coming year.

V. Conclusion and Future Directions

IP design and reuse is becoming an indispensable aspect of integrated circuit development as it is certainly one of the most effective approaches for reducing design time. However, incorporating IP into research and education for EE students can be challenging. *UMIPS* has been developed to address this very challenge. With early success as a repository for researchers, *UMIPS* has recently been extended to the classroom where students can submit their designs with the potential for fabrication in research projects. The opportunities here are tremendous as a symbiotic relationship can be fostered where researchers specify basic blocks for course design projects and students gain the satisfaction of seeing their design put to practical use. Moreover, students whose designs are utilized gain authorship opportunities that would be otherwise unavailable to them.

In its early stages, *UMIPS* was intended for use only amongst University of Michigan researchers and students. Recently, the repository has been expanded to included participation with the integrated circuit research community as a whole. In the future, the founders intend to elevate the presence of *UMIPS* throughout this community and expand the early programs described here to other academic institutions.

VI. Acknowledgement

The authors wish to thank Eric Marsman, Robert Senger, Fadi Gebara, and Matthew Guthaus who demonstrated tremendous initiative and provided valuable support throughout the development of the *UMIPS* repository.

VII. References

1. H. Qi, *et al.*, "IP-Based SOC Design Methodology," *International Conference on Chip Design Automation*, 2000.
2. R. Abrishami, "Vendors must support IP reuse in SoC," *EETimes*, Dec. 19, 2002.
3. T. Maniwa, "EDAC panel marks path to productivity," *EEdesign*, April 11, 2001.
4. P. Clarke, "Repositories called linchpin of widespread design reuse," *EETimes*, March 21, 2000.
5. P. Rose, "Intellectual Property Reuse – A New Business Model," *D&R Industry Article*, 2002.
6. European Union 4th Framework, *ESPIRIT Workprogramme*, Sept. 1996.
7. S. Ohr, "Interest in analog IP outpaces execution," *EEdesign*, Feb. 11, 2003.
8. R. Senger, *et al.*, "A 16-Bit Mixed-Signal Microsystem with Integrated CMOS-MEMS Clock Reference," *Design Automation Conference*, 2003.
9. M. S. McCorquodale, *et al.*, "A Top-Down Microsystems Design Methodology and Associated Challenges," *Design Automation and Test Europe*, *Designer's Forum*, 2003.
10. M. S. McCorquodale, *et al.*, "Microsystem and SoC Design with UMIPS," *IFIP International Conference on VLSI-SoC*, 2003.
11. S. M. Martin, *et al.*, "A Low-Power Microinstument for Chemical Analysis of Remote Environments," *NASA Symposium on VLSI Design*, Coeur d'Alene, ID, 2003.
12. M. S. McCorquodale, *et al.*, *UMIPS: The University of Michigan Intellectual Property Source*, http://www.eecs.umich.edu/umips, 2003.
13. R. Seepold, "A Qualification Platform for Design Reuse," *International Symposium on Quality of Electronic Design*, 2002.
14. J. Haase, *et al.*, "Automated Qualification Flow for Soft IP," *Conference on Application-Oriented SoC Design*, 2001.

MICHAEL S. McCORQUODALE
MICHAEL S. McCORQUODALE received the B.S.E.E. degree with honors from the University of Illinois at Urbana-Champaign in 1997. For the following year, he was with the Government Sector of *Hughes Space & Communications Co.*, Los Angeles, where he was involved in high speed circuit design and test. In 1998, Michael came to the University of Michigan where he completed the M.S. degree in 2000. He is currently a doctoral candidate.

RICHARD B. BROWN
RICHARD B. BROWN received B.S. (with Highest Honors) and M.S. degrees from Brigham Young University in 1976, and after working in industry, his Ph.D. from the University of Utah in 1985, all in electrical engineering. He is currently a professor in the Electrical Engineering and Computer Science Dept. at the University of Michigan, and will become Dean of Engineering at the University of Utah July 1, 2004.