PicoRio: An Open-Source, RISC-V Small-Board Computer to Elevate the RISC-V Software Ecosystem

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Abstract: PicoRio™ is an open-source project stewarded by the RISC-V International Open Source (RIOS) laboratory—rioslab.org—a nonprofit research lab at Tsinghua-Berkeley Shenzhen Institute (TBSI). The RIOS Lab uses collaborative engineering from both academia and industry to elevate the RISC-V software and hardware ecosystem. In PicoRio, we create an open, affordable, Linux-capable RISC-V hardware platform to aid software developers in porting many modern programs that require Javascript or GPUs. PicoRio will build upon high-quality IPs and software components from expert industry engineers and academic researchers. PicoRio is not proprietary to any specific vendor and platform, and will have complete documentation that can help people to build quality products in a short amount of time. Our plan is to ship PicoRio 1.0 in 1H2021.

1 Background

RISC-V has led to many free and open source processor designs, a free and open software stack, and an international foundation (riscv.org) that maintains and promotes the instruction set. While key pieces of an open source ecosystem for RISC-V already exist, many parts are missing to match the completeness of ecosystems for the older, proprietary instruction sets.

For example, the RISC-V ecosystem has a GCC based compiler, but less support on just-in-time compiler and managed languages. It has an RISC-V Linux kernel support, but it is missing many userland applications supplied with in popular Linux distributions.

One problem is the lack of affordable RISC-V hardware that supports modern software development.

Today people must pay \$500–\$1000 to get a Linux-capable commercial RISC-V dev-board. The long tail of developers who are developing for a few different ISAs will not spend that much for the nascent RISC-V ISA. Moreover, the RISC-V community has long awaited an open platform that allows exploration of new hardware and software ideas beyond an open instruction set.

Last but not least, an RISC-V board like Raspberry Pi with good documentation could help people to ramp up mass production of RISC-V in a very short time, even during a crisis[1].

2 Proposal

Inspired by the Raspberry Pi, we propose the *PicoRio*† project, whose goal is to produce RISC-V based small-

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† The "rios" part of the lab name is Spanish for rivers. Rivers collect resources from many lands to create a strong force that changes a landscape, which we hope the RIOS lab will do for the information technology landscape. As the Latin word "pico" means 10^{-12} in the metric system, "pico rio" means "small river", an appropriate name for a small board computer from the RIOS Lab.

board computers at an affordable price point. PicoRio has the following features:

• **Independently maintained:** The RIOS Lab will be the solo nonprofit organization that governs the architecture development, ensures compliance, and will publish the design. The RIOS Lab will be the gatekeeper for both hardware and software, from SoC and firmware/drivers to high-level software and documentation. PicoRio will be vendor agnostic and not proprietary, and the RIOS Lab will work with academic and commercial organizations that will commit to its expansion and volume manufacturing.

• **Open source:** Unlike Raspberry Pi, which uses proprietary Broadcom SoCs, PicoRio will open source as many components as possible, including the CPU and main SoC design, chip package and board design files, device drivers, and firmware. The exceptions are foundry related IPs (e.g., TSMC SRAM configurations), commercial high-speed interfaces, and complex commercial IP blocks like GPU. Nevertheless, our goal is to reduce the commercial closed source IPs for each successive release of PicoRio, with the long term goal of having a version that is as open as practical.

• **High-quality IPs:** A major goal of the RIOS Lab is to develop open source, industrial strength hardware IP to help the RISC-V ecosystem catch up with those of the older, proprietary ISAs. Thus, PicoRio aims at a high-quality silicon release using open-source IP. The IPs will have gone through rigorous real tapeout verifications that meet industry quality. The openness of PicoRio will not come at the cost of lower quality IP blocks. In addition, we will open source our verification process, which will help to improve transparency and trustworthiness.

• **Modern software stack support:** PicoRio utilizes a heterogeneous multicore architecture and is Linux-capable (RV64GC). We also designed PicoRio hardware to run modern managed languages such as JavaScript/WebAssembly as well as graphical applications like the Chrome web browser. At the RIOS Lab, PicoRio is also the hardware platform for several other open-source software projects, like the RISC-V ports for the V8 Javascript engine and the Chromium OS.

• **Low-power and low-cost:** The target metrics of PicoRio are long battery life and low cost, which is a better match to RISC-V today, instead of high performance and large memory. In contrast, Raspberry Pi uses more power hungry ARM processors. For example, the idle power consumption has risen from 0.4 Watts to 2.7 Watts in the latest version of Raspberry Pi[2].

3 Three Phases of the PicoRio Development

Focusing on such an effort, it helps to have concrete targets. We aim to release a new PicoRio version every year. We divide the development of PicoRio into three phases:

(1) First phase (PicoRio 1.0): We include a basic 64-bit quad-core cache-coherent design (RV64GC) that runs full Linux. We have already booted a Chromium OS kernel in command line mode. A standalone version of Chrome V8 Javascript engine will run directly on the kernel. We expect an early beta release late this year. This "headless" version of PicoRio should be fine for software development.

(2) Second phase (PicoRio 2.0): In addition to improving the v1.0 hardware, we are working with Imagination to include a complete display pipeline (including a GPU) with video encode/decode capabilities to run graphics intensive applications like web browsers.

(3) Third phase (PicoRio 3.0): Building upon the v2.0 hardware, we plan to further improve the CPU performance to bring PicoRio to the level of a pad computer/laptop.

An example of what could be done with PicoRio 3.0 is a RISC-V based pad computer/laptop, where all application software and storage run in the Cloud (like a Chromebook). Such devices are much more popular than conventional laptops in K-12 schools because they are cheaper to purchase as well as much easier to maintain, since no system administration is required. Another benefit of this platform is that since most of computing and storage are in the cloud, it can use slower, cheaper processors, less storage, and it needs much less software to be ported to it.

References

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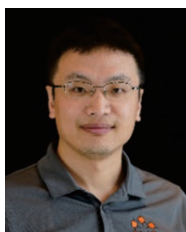
Zhangxi Tan is the co-director of the RIOS Lab, an adjunct professor at TBSI, and the founder and president of RiVAI Technologies Co. LTD. Prior to these roles. He joined Pure Storage as the company's first chip designer, and successfully guided the delivery of FlashBladeTM. He holds more than 20 US patents, and he is also the inventor of the FPGA-based architecture simulator (RAMP Gold). He earned bachelor and master degrees in electrical engineering and computer science from Tsinghua University, and the master and PhD degrees in computer science from University of California, Berkeley, where he was supervised by Prof. David Patterson.

Lin Zhang is the executive director of RIOS Lab, a professor and doctoral supervisor of Tsinghua university. His research interests include communication networks, wireless sensor networks, sensor data mining, and artificial intelligence systems. In recent years, he made several breakthroughs in the implementation and development processes of many National Natural Science Foundation projects, "863" Projects, and major national engineering, and has played important roles in the Olympic Game related projects as well as the promotion of smart city informatization. He has served as the chairman of the Graduate School Student Association of Tsinghua University, executive chairman of the National Association of Students, deputy director of the Department of Electronic Engineering of Tsinghua University, and has been awarded as "Excellent Teachers" title in Tsinghua University Graduate School. He is a member of the Chinese Institute of Electronics (Information Theory Branch), and a senior member of the IEEE. He has published more than 100 academic papers in journals and conferences in China and at abroad, and has won the IEEE/ACM Sensys 2010, 2016, CASE 2013, IPSN 2014, and IEEE PES 2017 Best Paper / Technical Presentation Award.

David Patterson is the pardee professor of Computer Science, emeritus at the University of California at Berkeley, where he joined after graduating from UCLA in 1976. He is now a distinguished Engineer at Google, a position he held since 2016, and serves as the vice chair of the Board of Directors of the RISC-V Foundation. He is also the director of RIOS Lab.

Throughout his 44-year career, he holds about 40 awards at research, teaching, and service, including the ACM A.M. Turing Award, the C&C Prize, the IEEE von Neumann Medal, the IEEE Johnson Storage Award, the SIGMOD Test of Time award, the ACM-IEEE Eckert-Mauchly Award, and the Katayanagi Prize. The best-known projects were Reduced Instruction Set Computers (RISC), Redundant Array of Inexpensive Disks (RAID), and Networks of Workstations (NOW), each of which helped lead to billion-dollar industries.

Yi Li is the assistant director of RIOS Lab. She was leading programs for Amazon AI Services and new technology incubation, successfully launched several innovative products at AWS re Invent, including Amazon Prime Photos and API-driven service Amazon Rekognition for image and video processing. Before Amazon, she has performed as Chief Executive Officer (CEO) for Orbeus Inc (acquired by Amazon). As the first Chinese team funded by the top US incubator (TechStar), Orbeus taps the power of deep learning to provide scalable image and face recognition solutions for businesses and consumers. With expertise in state-of-the-art machine learning and ImageNet (award winners in 2013 and 2014), Orbeus developed ReKognition API (a cutting-edge facial and image recognition platform), and managed the invention of PhotoTime (a mobile application for auto-tagging and search photos). Orbeus got acquired by Amazon in late 2015.