Today’s cloud-based FPGA instances, sometimes called FPGA-based acceleration-as-a-service, give the ability to rent time on an FPGA-equipped server instead of purchasing a board or integrated server. The foremost example is Amazon’s AWS EC2 F1 instance, but there are others. The question is: rent or buy—what are the advantages/disadvantages for both developers and end user deployment of FPGAs?

From FPGA Chips to the Cloud: A (Very) Short History of FPGA Application Development
For the last 30 years, designers have used FPGAs as a convenient and fast way to develop specialized hardware for applications that require more performance than software-programmed CPUs can deliver. Back when FPGAs were available in socketable DIP packages, it was easy to develop prototype hardware in the lab and then start FPGA development. The advent of larger, more advanced FPGAs with complex, high-current supply-voltage requirements; high-power cooling needs; and BGA surface-mount packaging have made FPGA prototyping essentially impossible, leading directly to FPGA-based boards where the hardware design and assembly have already been done. These boards allow FPGA developers to get a head start on the real task at hand: application design.

BittWare began providing these FPGA boards over a decade ago, with a focus on production-ready designs as opposed to “kits.” Developers create their application on a BittWare board and either directly deploy to their customer using the same boards or create a further refined hardware design—sometimes using BittWare as an ODM supplier.

On November 30, 2016, Amazon Web Services (AWS) launched the AWS EC2 F1 instance, which provides cloud-based access to Xilinx Virtex UltraScale+ VU9P FPGAs along with 64Gbytes of ECC-protected DDR4 SDRAM per FPGA on Amazon-designed boards plugged into Amazon’s AWS servers. Access to the AWS EC2 F1 instances requires only an Amazon AWS account. You can access AWS FPGA facilities anywhere there’s cloud access.

You develop applications directly on the Amazon EC2 F1 instance using Amazon-provided tools which initially included AWS’ FPGA Developer AMI (Amazon Machine Image) and HDK (Hardware Developer Kit), and Xilinx’s Vivado Tool Suite. In September, 2017, AWS added OpenCL development capability to its software development tool suite through an AWS version of the Xilinx SDAccel development environment. With the introduction of the AWS EC2 F1 instance (and others with similar offerings using Xilinx and Intel devices), FPGA developers now have a rent or buy decision to make.

The Rental Option: FPGA Development in the Cloud
The AWS EC2 F1 compute instance allows you to create custom hardware accelerators for your FPGA-accelerated application using server hardware in the AWS cloud based on one to eight Xilinx Virtex UltraScale+ VU9P FPGAs. You can develop extremely large and capable custom compute engines with this cloud-based FPGA technology. According to Amazon, use of the FPGA-accelerated AWS EC2 F1 instance can accelerate applications in diverse fields, such as genomics research, financial analysis, video processing, security/cryptography, and machine learning by as much as 30x over general-purpose CPUs.
Application-specific, FPGA-based accelerators developed by third parties are already available in the AWS Marketplace. For example, Ryft announced that it was offering its Ryft Cloud cloud-based search and analysis tools on Amazon’s FPGA-accelerated AWS EC2 F1 instance through Amazon’s AWS Marketplace in September, 2017. Edico Genome (now an Illumina company) announced that it was making its genetic analysis algorithm accelerators available on the AWS EC2 F1 instance that same month.

It's notable that both Ryft and Edico Genome originally developed their FPGA-based accelerators using on-premises Xilinx FPGA boards—such as those BittWare sells—and then later ported their accelerators to AWS EC2 F1. This allows their end users the option of reduced cost-of-entry for using their acceleration engine instantly through AWS cloud services. However, both companies realize the cloud rental model is not always the best option for their end users either, so they offer on-premises dedicated hardware as well. This makes sense for customers who wish to make heavy use of the algorithms on site or simply prefer the security and access of on-premise equipment over cloud-based services.

Clearly, Amazon’s AWS EC2 F1 instance offers notable advantages:

- Ready access to FPGA development tools and hardware requires nothing more than an AWS account and very little initial cost investment.
- Developer and customer access to the FPGA-accelerated applications can occur from anywhere there’s an internet connection.
- Dissemination of the finished accelerator through the AWS Marketplace for FAAS (FPGA/acceleration as a service) makes the finished design available for monetization to a worldwide audience. Note that this benefit doesn’t require developers themselves to be cloud-based except for final porting.

What's not to like?
In addition to these substantial advantages, there are some disadvantages to using Amazon’s AWS EC2 F1 instances. On a high level, using the AWS F1 instance limits users to a subset of the features/performance of dedicated hardware, such as 85 watts vs. the 200+ the hardware should be capable of. Let’s explore some of these in more detail.

First, use of the AWS EC2 F1 instance is based on data files and file I/O accessed by the user logic from the AWS Shell—a separate partition that consumes approximately 20% of the FPGA. Input data must first be stored as files on AWS S3 storage servers, and processed information generated by the FPGA application will also be stored in AWS file servers. There’s no concept of streaming data directly from the data source into the FPGA. All traffic to and from the FPGA is mediated by an AWS EC2 CPU, so acceleration using the AWS EC2 F1 instance is essentially batch file processing and is designed primarily for handling large, stored data sets, not real-time data. Put simply, there’s no real-time I/O allowed.

Another consideration is the limited feature set of F1 instances. While 64GB DDR4 is available per F1 instance, BittWare boards include up to 512GB DDR4 options. Specialized memory like QDR or HBM2 or interfaces like SDI for broadcast video are only available (or accessible) with dedicated hardware. Users seeking development of custom hardware or an accessory board would also highly benefit from physical access to the board.
For development, FPGA designers who have learned to use tools, such as the Xilinx Vivado tool chain and SDAccel, will now need to learn how to deal with AWS EC2 virtual machines and S3 storage. It’s not a huge bump in the road, but it is a diversion from accomplishing the real task at hand: FPGA application development.

Finally, there’s an FPGA power limitation with the AWS EC2 F1 instance. An FPGA’s power consumption depends on the design you place into it and how fast you clock that design. The AWS EC2 F1 instances limit the power consumption of their Xilinx Virtex UltraScale+ VU9P FPGAs to 85 watts. To put that into comparison, a typical VU9P-based dedicated board can safely run 200 watts or higher depending on the electrical and thermal design. If a loaded AFI (Amazon FPGA Image) created for the AWS EC2 F1 instance consumes over 85 watts, the F1 instance detects an AFI power violation and automatically switches off the FPGA’s input clocks (shutting down the application inside of the FPGA) to prevent errors within the FPGA caused by overheating.

BittWare regularly works with FPGA developers who use a significant portion of the available FPGA for their high-performance applications—cryptocurrency mining, for example, where faster compute times directly translate into more revenue. Some of these developers are indeed experiencing problems when their designs exceed the AWS EC2 F1 instance’s maximum allowed power.

When Clouds are Not Enough: On-Premise Equipment

Let’s be clear: Amazon’s AWS EC2 F1 instance changed the economics of FPGA acceleration by targeting a specific type of FPGA application developer: one that does not need real-time I/O and does not need to push the FPGA to its performance limits. It also has opened up a new interest in FPGA acceleration for end-users with the AWS Marketplace. However, the AWS EC2 F1 instance rental model may not be cost effective for applications that need to run all day, every day, and all year long. At some point in utilization, all else being equal, a rental model will be more expensive than buying.

For FPGA developers who cannot fit their applications into the AWS EC2 F1 FPGA sandbox and its limitations and for those who continue to prefer on-premise equipment for performance, board access, or security reasons, the purchase of FPGA-based hardware boards and systems remains a viable option. BittWare offers a range of accelerator boards and systems that bring the FPGA hardware in-house for applications that require more performance, including network packet processing, high-performance computing, and real-time signal and video processing.

For example, the XUPP3R PCIe FPGA board, shown in Figure 1, is a 3/4-length PCIe board based on the Xilinx Virtex UltraScale+ VU9P FPGA. It provides nearly the same hardware as a single-FPGA AWS EC2 F1 instance but with as much as 512Gbytes of ECC-protected DDR4 SDRAM plugged into the board’s four 288-pin DIMM slots. That’s eight times the memory compared to the 64Gbytes available to the FPGA in Amazon’s AWS EC2 F1 instance. In addition, even faster on-board memory for greater application performance is also an option by plugging as much as 288Mbytes of QDR-II+ SRAM into the XUPP3R board’s DIMM sockets. All of the Xilinx FPGA development tools, including the Vivado tool suite and SDAccel, are available for the XUPP3R PCIe FPGA board as well—with unrestricted access to the hardware.
Figure 1: BittWare’s XUPP3R PCIe Accelerator Board based on the Xilinx Virtex UltraScale+ VU9P FPGA

As shown on the left in Figure 1 above, the BittWare XUPP3R accelerator board can handle a significant amount of high-speed I/O through its four QSFP28 fiber-optic cages, which can be used to implement one 400GbE, four 100GbE, four 40GbE, sixteen 25GbE, or sixteen 10GbE Ethernet ports. That’s in addition to the XUPP3R board’s PCIe edge connector, which supports PCIe Gen3 x16.

On the lower-right side of Figure 1 beneath the BittWare logo, you can see an additional multi-pin connector. That’s the SEP (Serial Expansion Port) connector, which can be used to drive four additional QSFP cages, thus doubling the card’s high-speed serial I/O bandwidth to 800 Gb/s.

The SEP connector can also be used to link two XUPP3R boards together, which creates a 500 Gb/s board-to-board link that’s independent of the PCIe host bus. Speaking of PCIe, a third SEP accessory option adds a second PCIe Gen3 x16 interface on another slot.

A fourth SEP accessory brings 12G SDI video ports—eight of them—via video SFP cages. The interfaces can be any combination of in/out and support other SDI broadcast video standards such as 3G or 6G. The SEP allows BittWare to rapidly create other custom accessory boards.

All the XUPP3R I/O ports discussed above lead directly to the on-board Xilinx Virtex UltraScale+ VU9P FPGA. That means they’re designed for and adept at handling high-speed, high-bandwidth I/O for real-time applications, such as high-speed Ethernet packet streams or multichannel video. These applications cannot run on the AWS EC2 F1 instance due to I/O limitations.
Bigger FPGAs
If the XUPP3R PCIe board isn’t powerful enough for the target application, BittWare offers the XUPVV4 PCIe card shown in Figure 2, which is based on the larger Xilinx Virtex UltraScale+ VU13P FPGA, with approximately 50% more logic cells, almost double the number of DSP slices, and 30% more on-chip UltraRAM compared to the XUPP3R.

Figure 2: BittWare’s XUPVV4 PCIe Accelerator Board based on the Xilinx VU13P FPGA

The XUPVV4 board shares many of the features of the XUPP3R board, with the exception of the SEP connector. Instead, the XUPVV4 board has two industry-standard UltraPort SlimSAS expansion connectors, shown at the right edge of the board in Figure 2. Each of these connectors links directly to eight of the Xilinx VU13P FPGA’s SerDes ports, with each SerDes port operating at 25Gbps for an aggregate bandwidth of 400Gbps (16x 25G) in both the input and output directions. The UltraPort SlimSAS connectors can be connected to another XUPVV4 PCIe board, accessory boards similar to the XUPP3R, or other the OpenCAPI coherent application processor interface used by IBM’s POWER9 servers.

BittWare developed a special Viper passive cooling system for the XUPVV4 PCIe accelerator card that attaches heat pipes directly to the bare FPGA die fitted into Xilinx’s D2104 lidless package. The Viper platform allows the XUPVV4 board to accommodate massive, high-speed designs instantiated in the Xilinx VU13P FPGA. Both active and liquid cooling options are also available.

For FPGA accelerator designs that require even more performance, BittWare has developed the XUPVVP and XUPVVH boards. The XUPVVP is a liquid-cooled variant of the XUPVV4 that has two fewer DIMMS but provides approximately twice the power (300 amps) for extreme FPGA loads on a choice of VU9P or VU13P FPGAs. Viper cooling using liquid is standard, with passive also available (liquid cooling recommended for full performance).

The XUPVVH is based on the Xilinx Virtex UltraScale+ VU37P FPGA, which incorporates 8Gbytes of HBM2 (High-Bandwidth Memory, version 2) DRAM closely coupled to the FPGA die in the same package. Because of this close coupling, the FPGA and HBM2 DRAM can exchange data at 460Gbytes/sec. That’s nearly half a terabyte of data per second, which is roughly 20x faster than DDR4 SDRAM data rates.
Going Beyond the Cloud’s Edge
These BittWare FPGA-based PCIe accelerator boards offer capabilities that extend far beyond the edges of the cloud-based FPGA capabilities provided by the AWS EC2 F1 instance or other FPGA-based acceleration-as-a-service offerings:

- The XUPP3R board provides more and much faster I/O, has more dedicated SDRAM for handling larger data sets, and has the ability to handle larger designs in the FPGA that dissipate more power than allowed by the AWS EC2 F1 instance.
- The XUPVV4 board accommodates even larger FPGA designs with its on-board Xilinx VU13P FPGA and improved Viper cooling, while also providing more and faster real-time I/O and more dedicated SDRAM than the AWS EC2 F1 instance.
- The XUPVVP is essentially a high-power variant of the XUPVV4, minus two DIMMS but with 300A power supplies, designed with liquid cooling in mind, and either VU9P or VU13P FPGA.
- The XUPV VH board’s HBM2 DRAM, which is incorporated into the same package as the FPGA, provides substantially faster dedicated memory than is offered by the AWS EC2 F1 instance as well as real-time I/O.

Beyond choosing a board, going with an on-premises gives you a range of server options, from the high port density of the TeraBox 1100L to the high FPGA density of a 4U, 10-board server like the TeraBox 4000T.

Figure 3: The TeraBox 1100L 1U FPGA chassis brings 4x 100G ports and 20x 10G SFPs to the front panel from an XUPP3R

The TeraBox 1100L, shown in Figure 3, is a 1U PCIe FPGA board enclosure housing the XUPP3R, but bringing several additional 10 Gb/s SFPs to the front panel. The box is vapor-cooled with a customizable front panel for OEM designs.

The TeraBox 2000D, shown in Figure 4, is a 2U FPGA Server that combines:

- Chassis by Dell, including server integration and support
- One or two Intel Xeon server processors and as much as 3Tbytes of CPU memory
- As many as three of BittWare’s double-width FPGA cards or as many as eight low-profile FPGA cards
- As many as 16 2.5-inch mass-storage drives
- Dual power supplies
Figure 4: The TeraBox 2000D 2U FPGA chassis combines one or two Intel Xeon processors with as many as eight of BittWare’s FPGA-based PCIe cards.

For even larger, more powerful FPGA systems, there’s the BittWare 4000T, shown in Figure 5, which combines one or two Intel Xeon server processors with as many as 10 double-wide BittWare FPGA-based PCIe cards. This exposes an impressive 40x 100G ports on the rear panel. This server also supports a unique 21-board configuration of single-wide boards such as the Intel Arria 10 FPGA-equipped A10SA4 or the Xilinx-powered XUSP3S for an impressive 84x 100G ports in a 4U chassis!
Conclusion: Rent, Buy, or Both?

Ultimately, the rent-or-buy decision for FPGA-based application development is based on your unique needs. Many developers with minimal resources are finding cloud FPGA instances to be valuable early tools. You can start on day 1 in the cloud, then switch to on-premise equipment when your needs outgrow the capabilities of your provider due to I/O limitations, FPGA capacity restrictions, operating power and cooling restrictions, or because running your application on the cloud 24/7/365 simply becomes too costly from a rental perspective.

You can also start with the on-premise equipment if the application requires it, which often is the case for users seeking the highest performance possible or customized features like QDR or high-speed real-time interfaces. What’s important is that the FPGA application-development tools—the Xilinx Vivado Tool Suite and SDAccel development environment—and the skills needed to use those development tools will cross over easily between the AWS EC2 F1 instance and BittWare’s Xilinx-based FPGA products.

If you’d like assistance with your FPGA application development needs or would like to get more information about the high-performance FPGA-based products discussed, please contact us at BittWare.com.

Notes:

1 http://edicogenome.com/dragen-bioit-platform/
2 https://github.com/aws/aws-fpga/blob/master/FAQs.md
3 https://github.com/aws/aws-fpga/blob/master/hdk/docs/afi_power.md

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