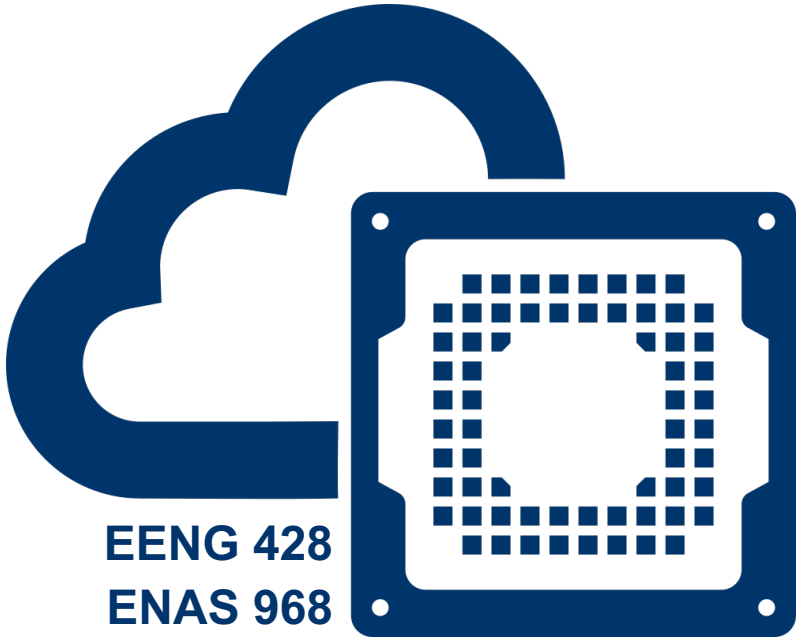
Cloud FPGA



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Lecture: Recent Cloud FPGA Advances – IBM

Prof. Jakub Szefer
Dept. of Electrical Engineering, Yale University

EENG 428 / ENAS 968
Cloud FPGA

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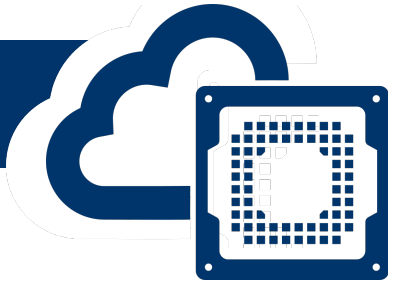
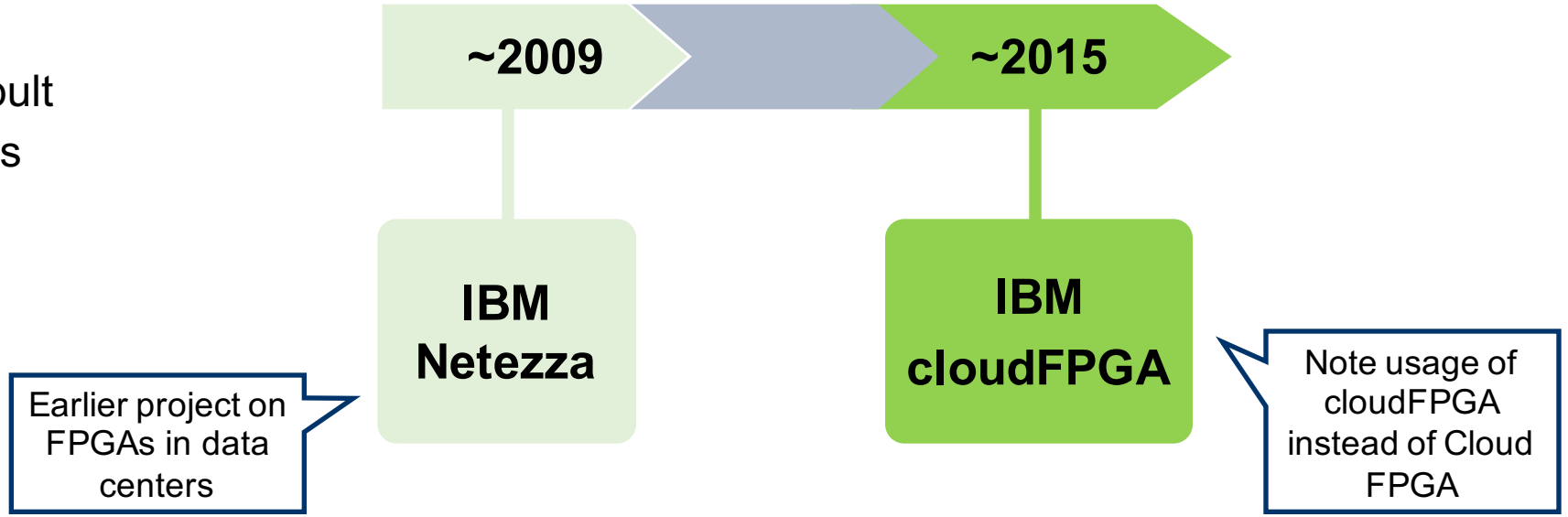
FPGAs in Data Centers



- Many companies have been exploring with FPGAs in data centers
  - Use of FPGAs has gone from accelerators to publicly available Cloud FPGAs
  - Major cloud providers: Amazon, Microsoft, etc.
- Other deployments of FPGAs in cloud data centers include **cloudFPGA project from IBM**
- IBM operates FPGAs in a public Cloud of the Zurich Research Laboratory (ZRL) referred to as Zurich Yellow Cloud 2 (ZYC2)
  - Ongoing research project
  - Similar to TACC and Catapult
  - Interesting features such as direct access of FPGAs to data center network



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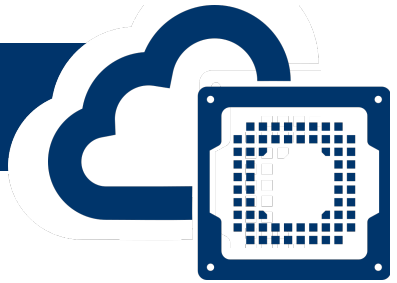
IBM Netezza



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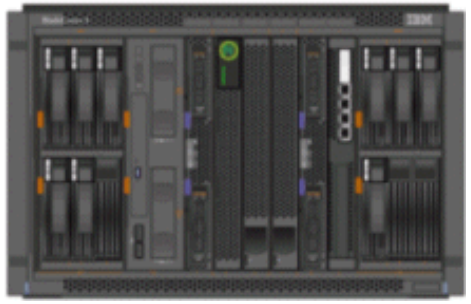
IBM Netezza

- Netezza offered a **data warehouse appliance (DWA)**
- A pre-installed and pre-optimized hardware and software for big data analysis
  - Not a publicly available cloud service
  - Instead a system sold to companies to use internally
- Part of the hardware were the S-Blades
  - An independent server that contains multi-core Intel-based CPUs and Netezza's proprietary high-throughput FPGAs
- Discontinued around 2019
  - Could not easily adapt to cloud computing paradigm



IBM Netezza 100 system, a single-chassis, single-host, system with one S-Blade

IBM PureData System for Analytics N1001 systems, with 4 to 14 S-Blades

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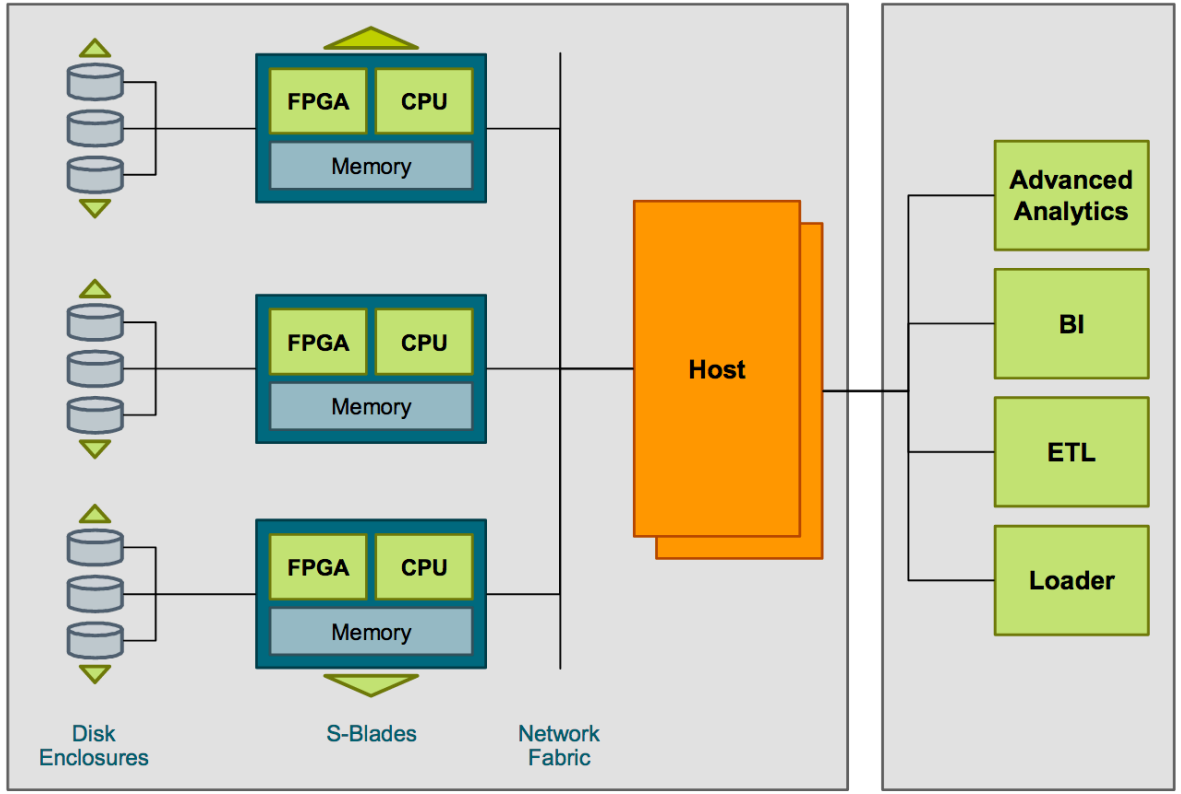
IBM Netezza FPGAs

- Netezza used a special field programmable gate array (FPGA) co-processor to speed up a heavily modified PostgreSQL database
- There were eight FPGAs on the accelerator blade - one for each x64 core on the paired serer blade
  - FPGAs were used to speed up the filtering of data moving off storage before being passed on to the database software
  - And doing complex sorting and joins of database tables as part of analytical routines



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Information from [5], image from [6]

IBM Netezza FPGA S-Blades

- Purpose of FPGA is to pre-process data coming in from memory
  - Filter or do basic functions as the speed of memory
  - Remainder of operations is done by CPU
- Effectively a custom, hardware data base processing engine

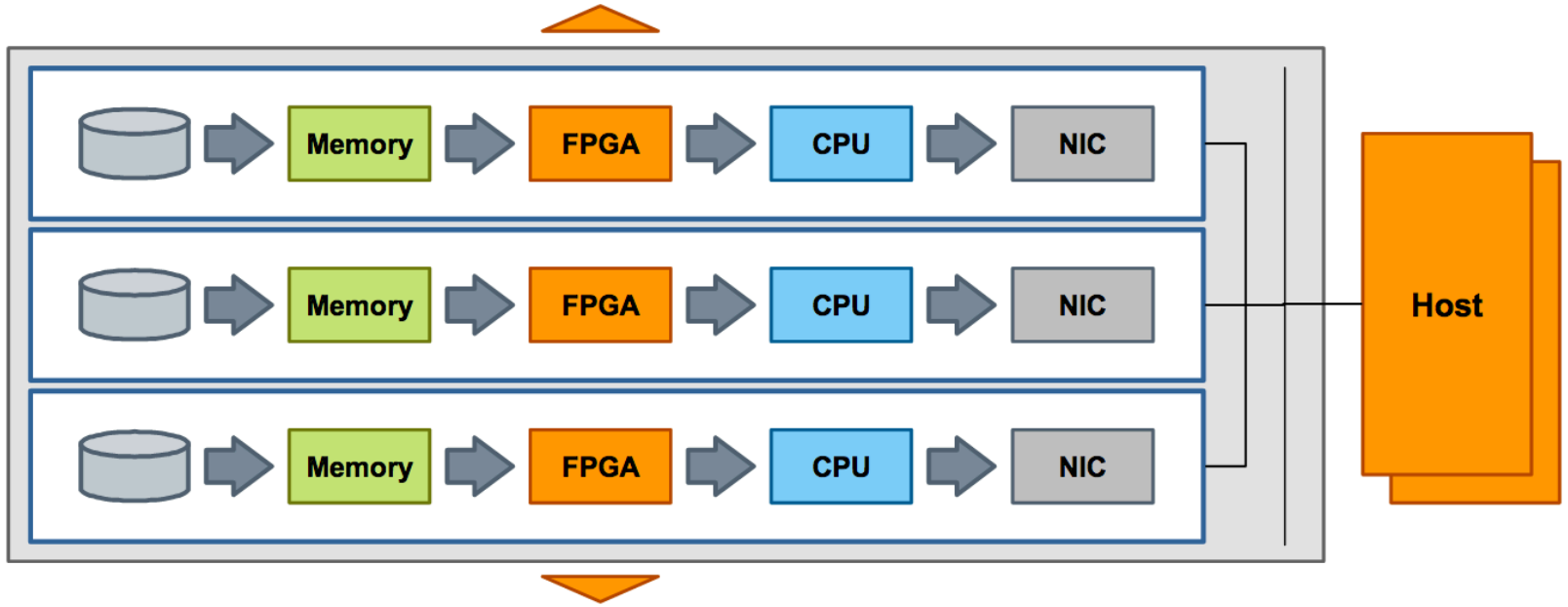

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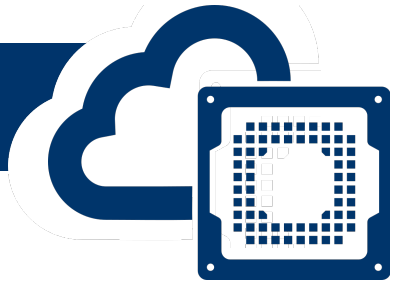
Image from [6]

“cloudFPGA” from IBM



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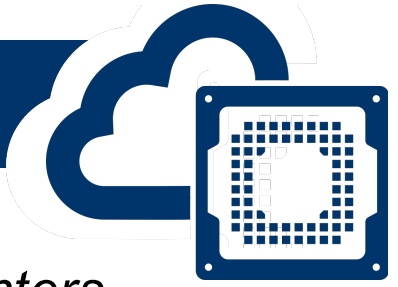
IBM and FPGAs in the Cloud



*The **cloudFPGA** project aims to provide FPGAs in cloud computing data centers in a disaggregated manner*

- A platform to deploy FPGA at large scale in data centers
  - Integrates FPGAs at the drawer/chassis layer
  - Combines passive and active water-cooling
  - Provides high density, energy efficiency and reduced costs
  - Fits 1024 FPGAs per data center rack

- Disaggregates FPGAs from the servers
  - FPGAs connect to the data center network over 10/40 Gb/s Ethernet
  - FPGA cards are stand-alone resources, independent of the number of servers
  - Makes FPGAs plentiful in data centers, users can rent and link them in any type of topology

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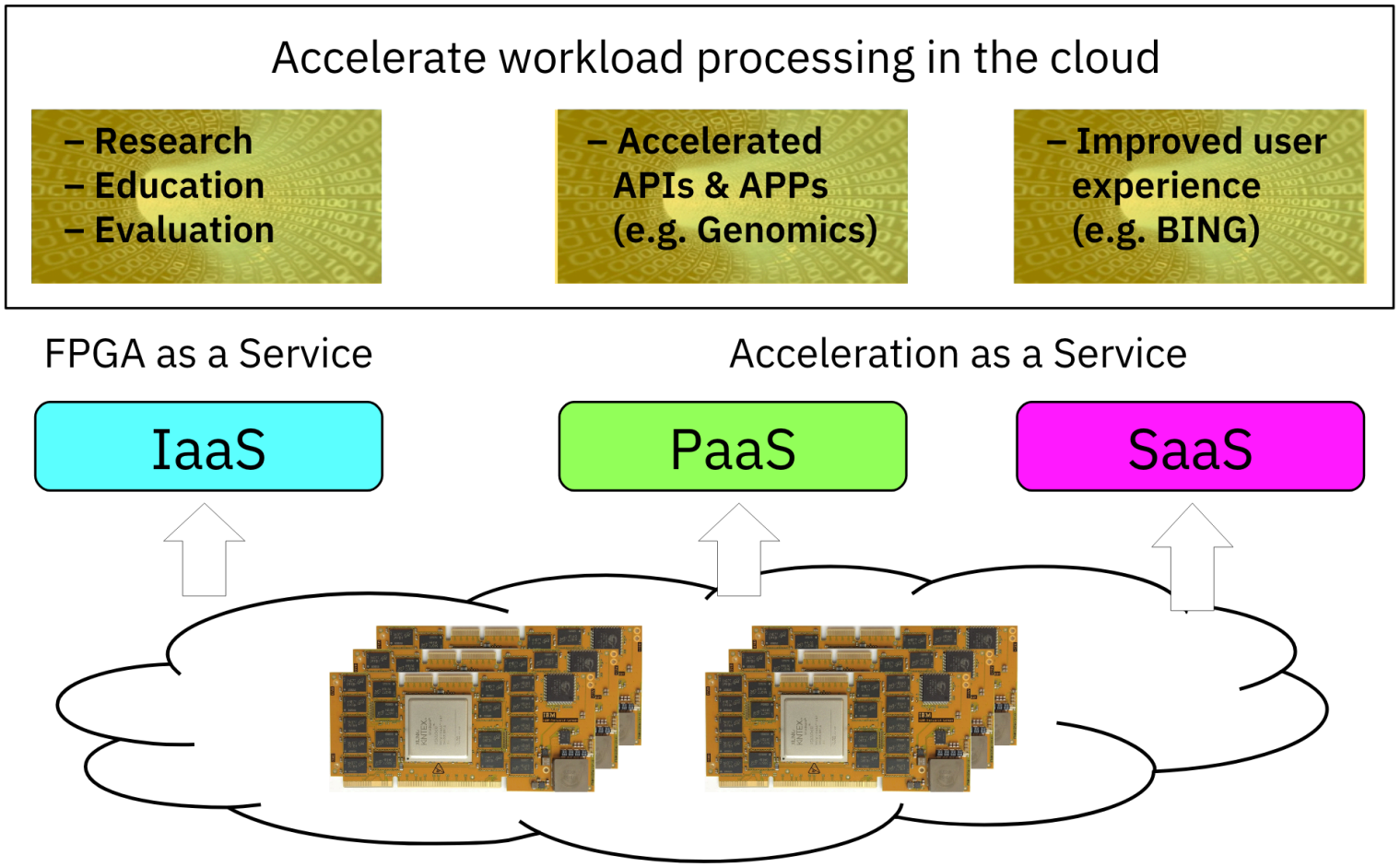
Enabling FPGA as a Service



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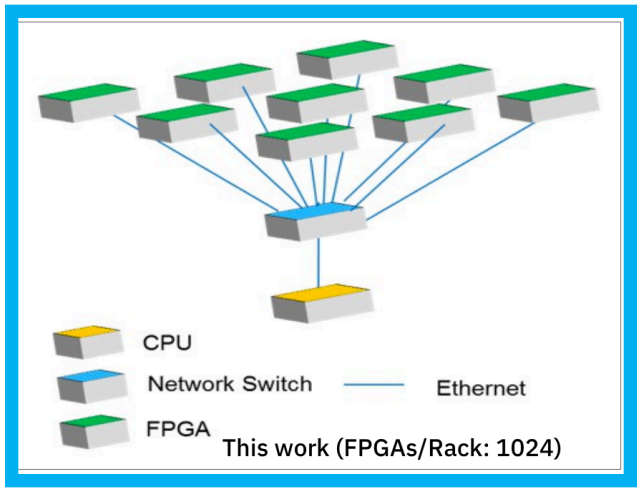
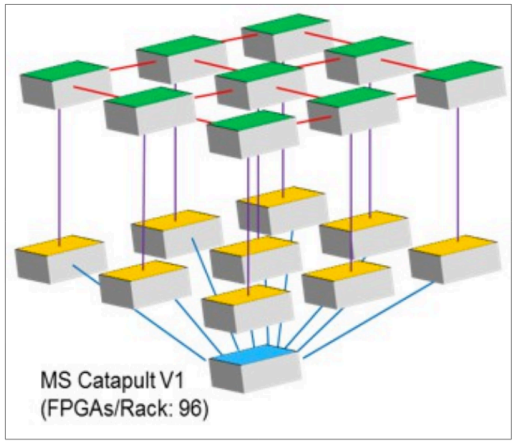
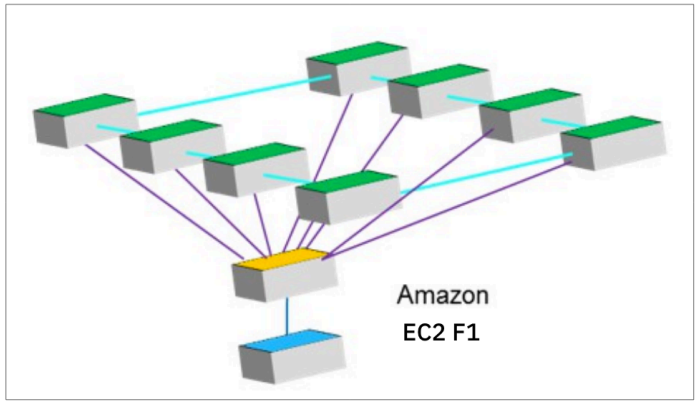
Based on slides provided courtesy of Francois Abel and Christoph Hagleitner, IBM Zurich, original slides available at: https://www.researchgate.net/project/cloudFPGA

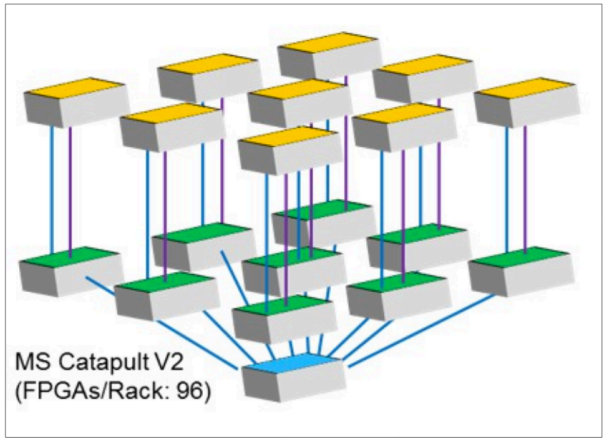
Comparison of FPGA Deployments in the Cloud

- Different companies and research projects take different approach to developing Cloud FPGA architectures
  - Attack FPGA to CPU
  - FPGA between network and CPU
  - FPGA attached directly to the network









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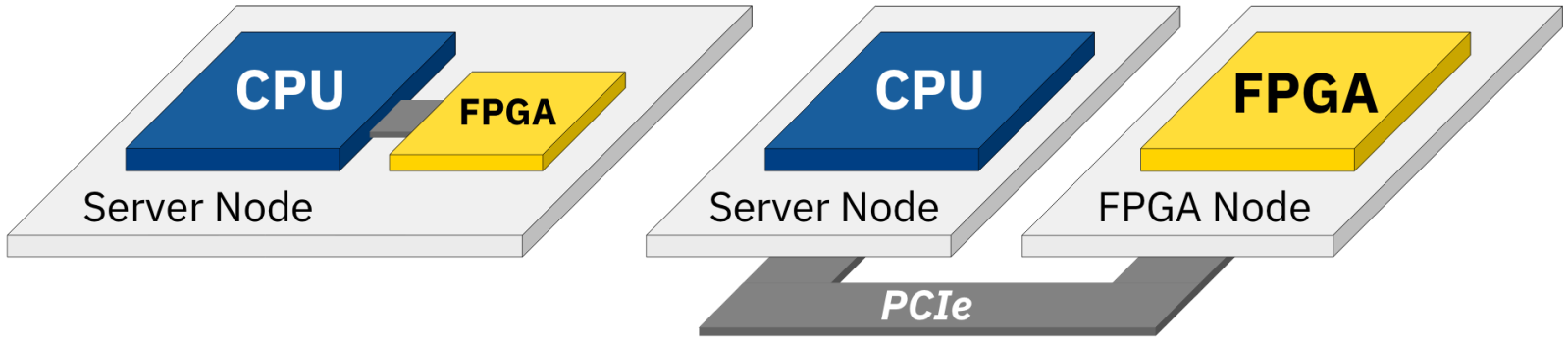
Typical Use of FPGAs as CPU Accelerators

- Most commonly FPGAs are deployed as accelerators used by the CPU
  - Connect to CPU on system bus
  - Connect to CPU via PCIe
- Limitation in terms of FPGAs per CPU
- Accelerator FPGAs depend on CPU for access to any resources
  - Memory, network, devices, etc.



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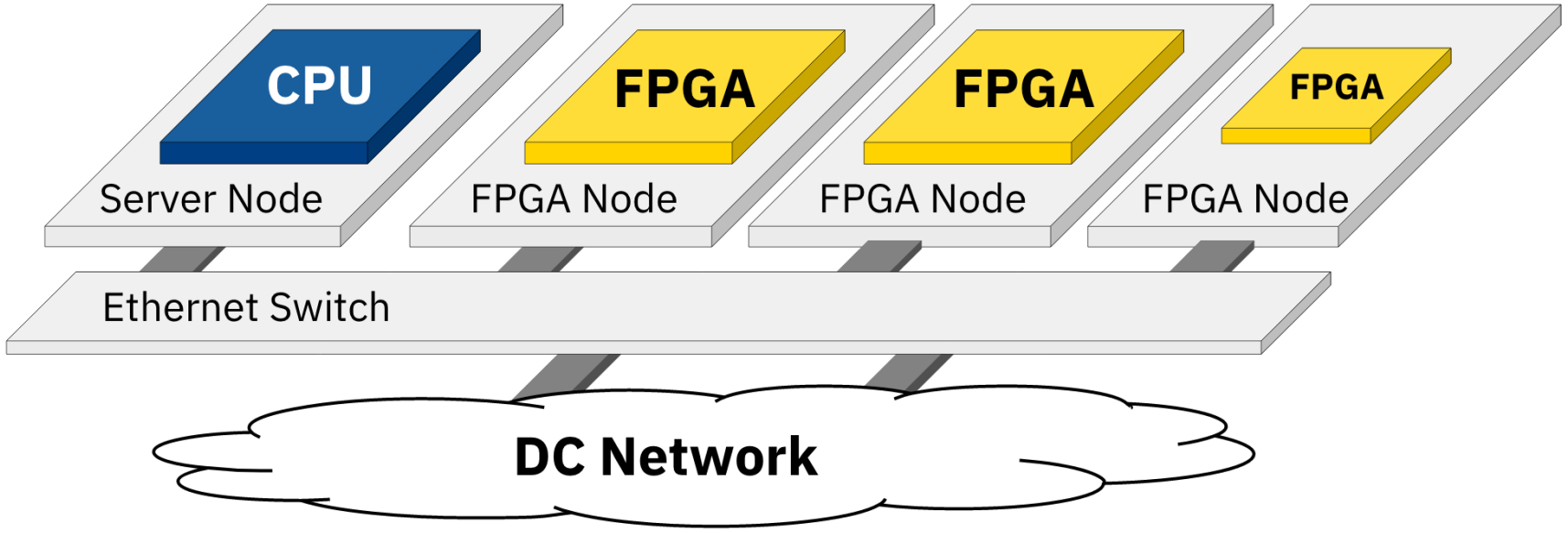
Towards Disaggregation of FPGAs

- Disaggregation of FPGAs is the idea to make FPGAs separate from CPUs
  - Each FPGA is a node on network
  - Can be accessed by any CPU or any other FPGA
  - Similar in idea to remote DRAMs, or remote GPUs



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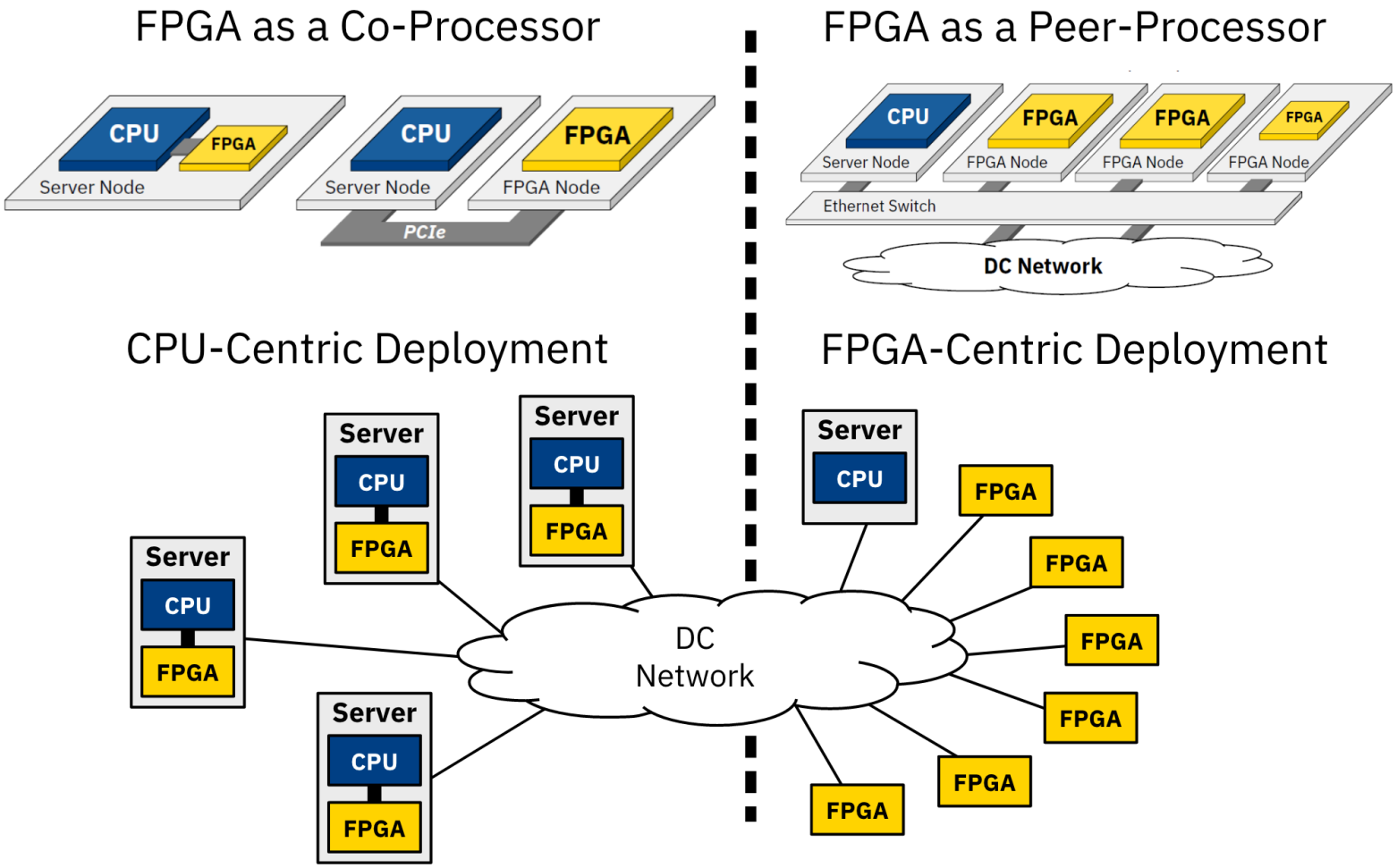
Towards Disaggregation of FPGAs



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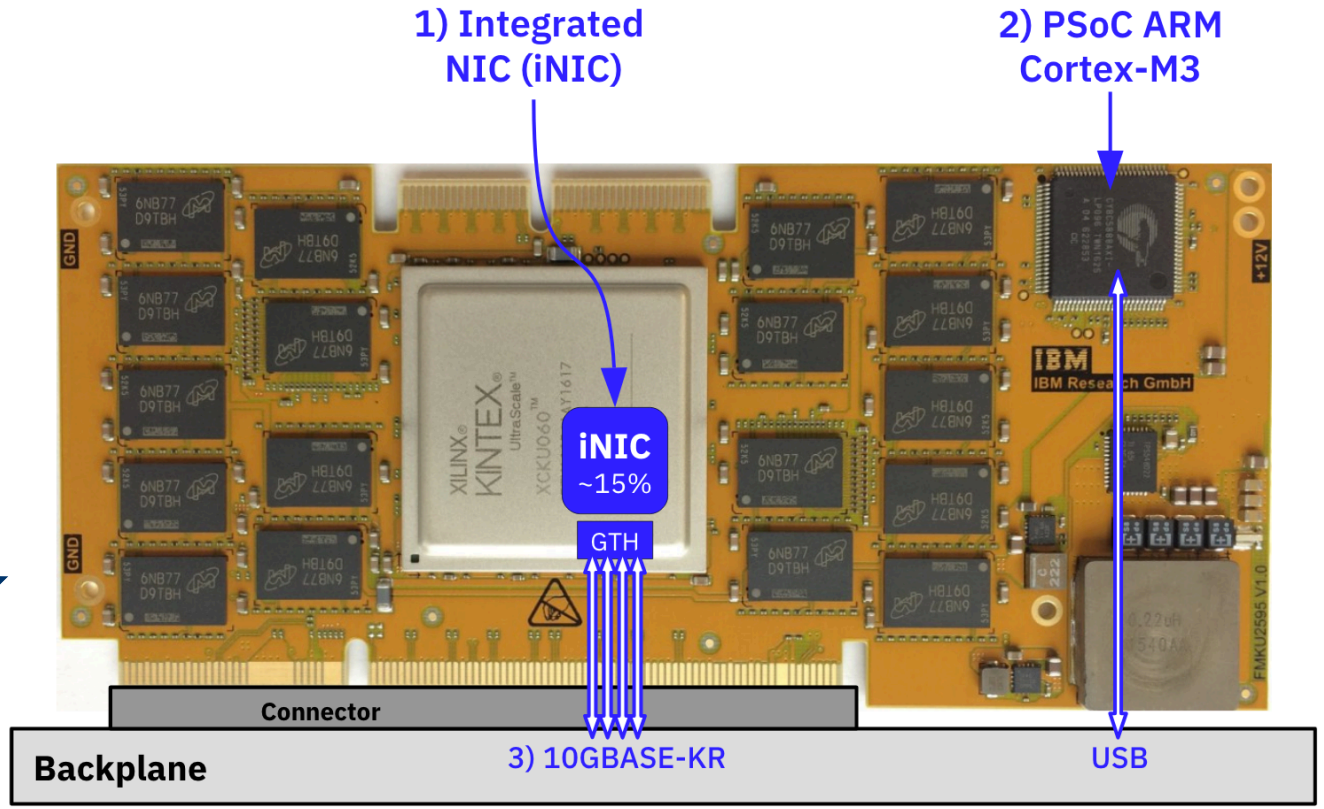
Network-Attached FPGAs

- To realize disaggregation of FPGAs, a network-attached FPGA is needed
- FPGA needs to be stand-alone device
  - Use direct network connection
  - Need way to program FPGA



Early Xilinx Kintex UltraScale KU060 used by cloudFPGA project form IBM

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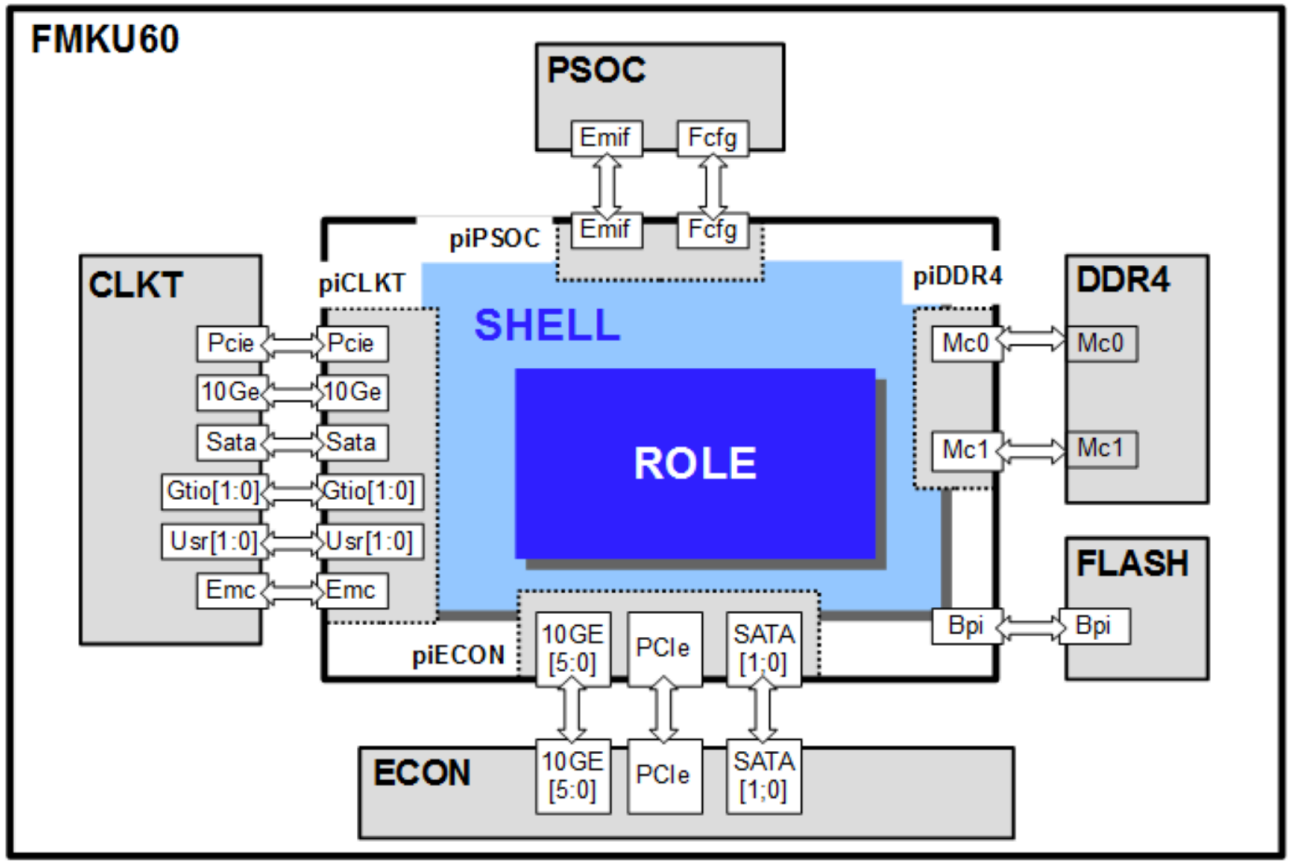
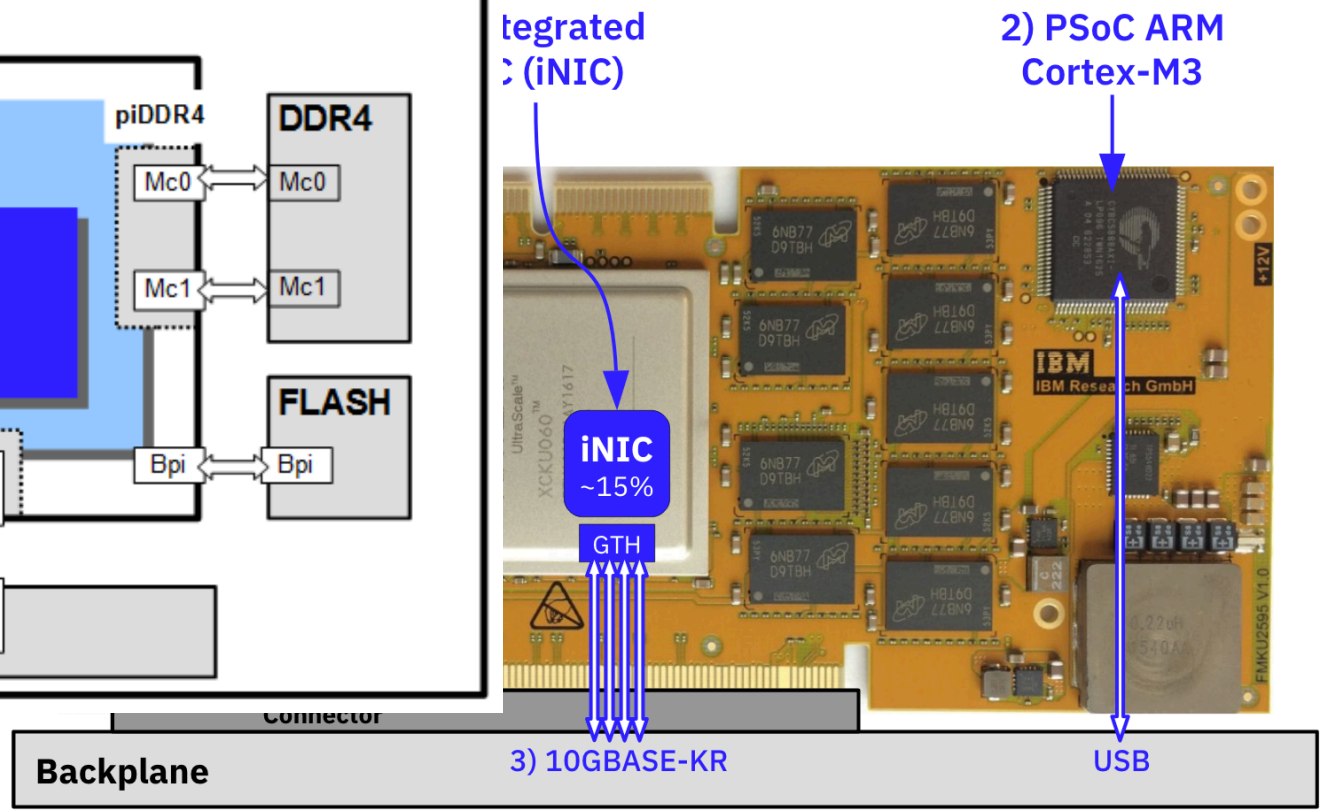
Shell and Role inside the FPGA



- IBM's Shell and Role are same to Amazon's Shell and CL



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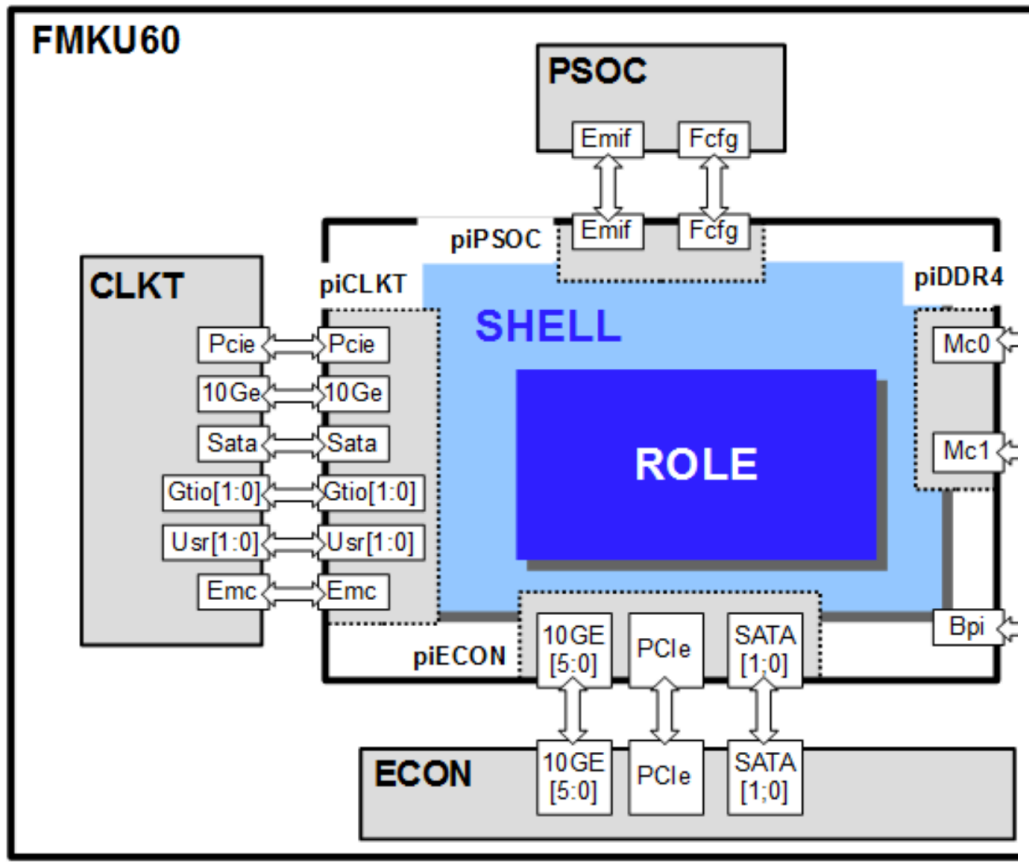

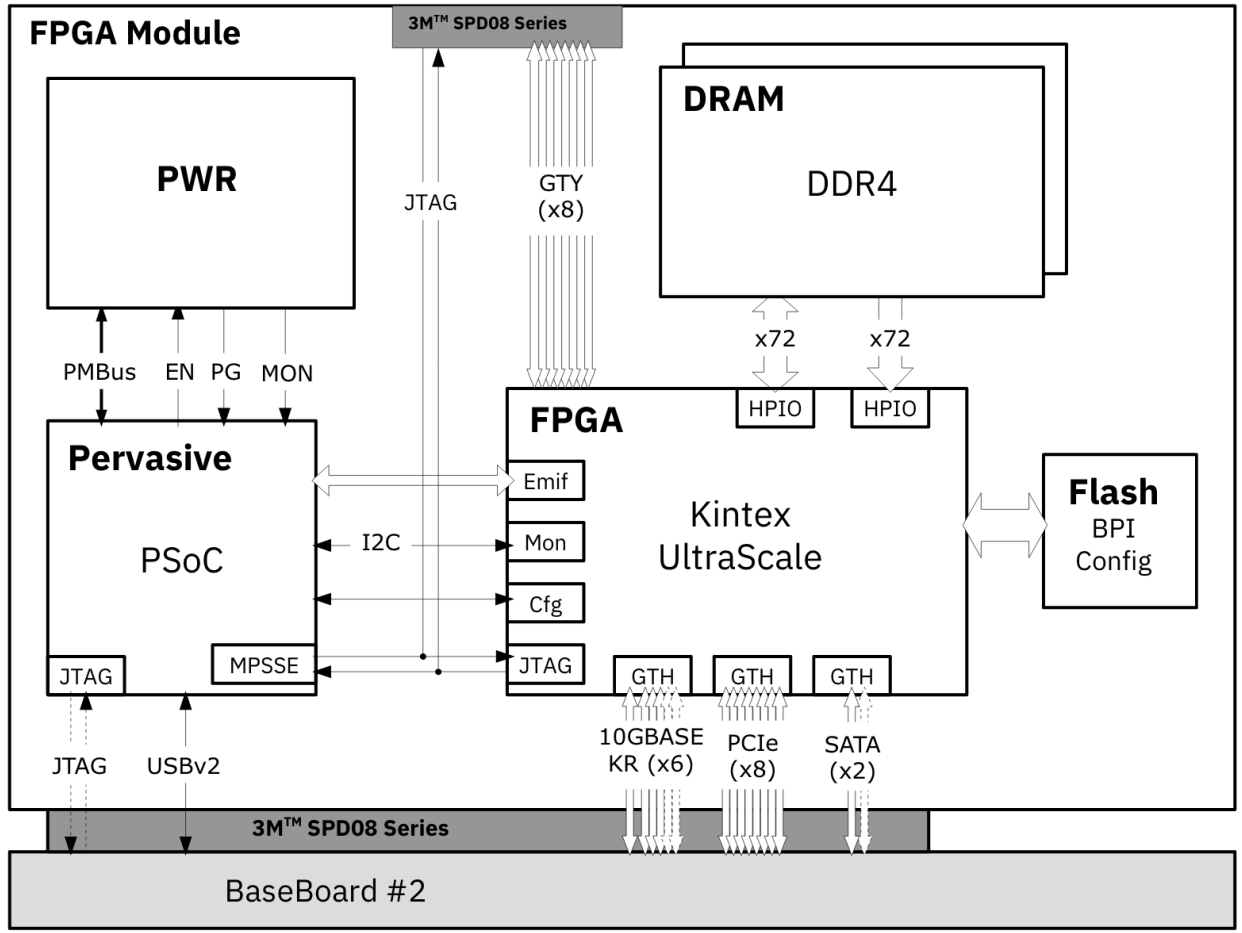

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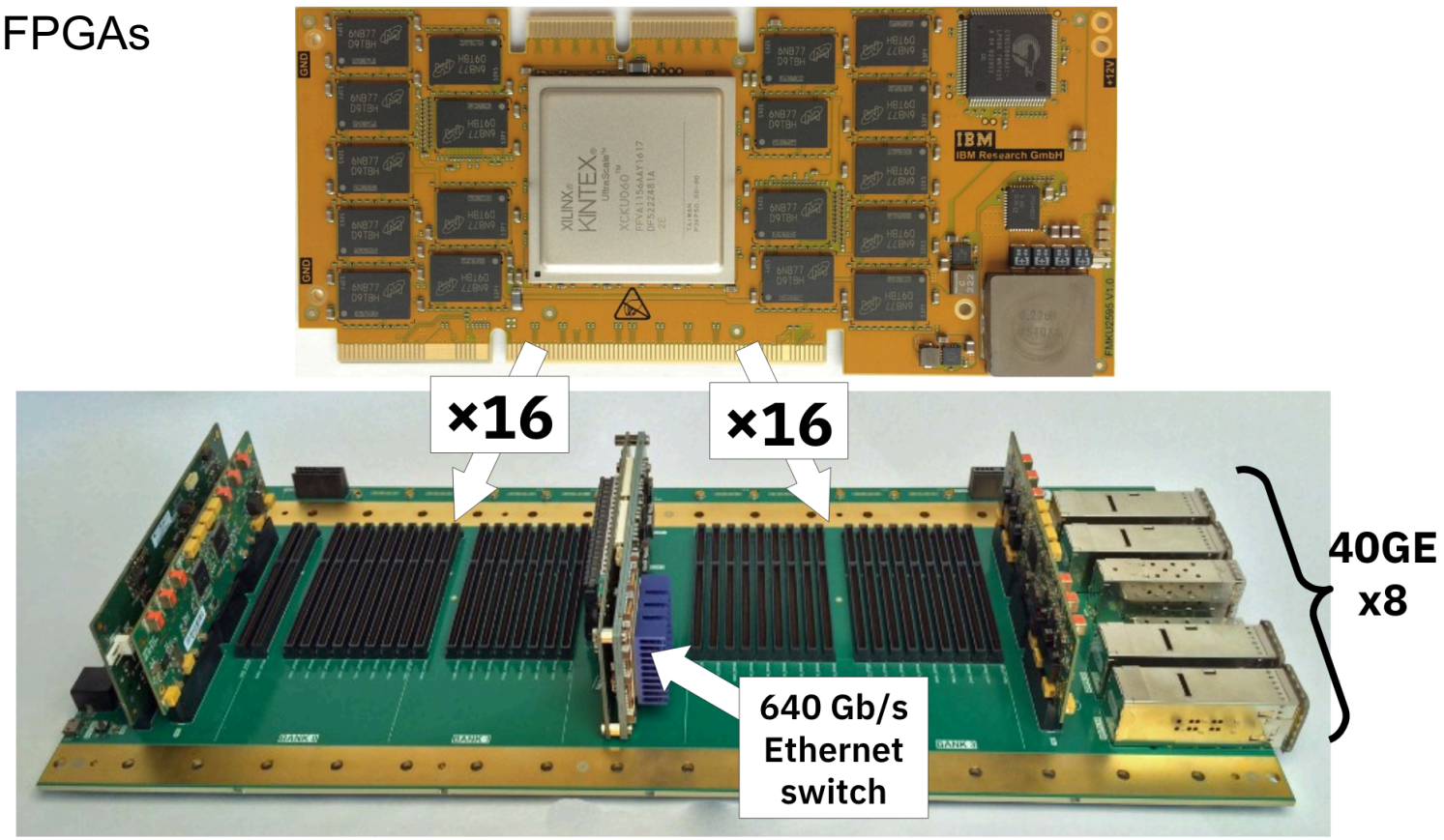
Network-Attached FPGA Carrier Module

- Through use of custom carrier module, 32 FPGAs are integrated into one module by IBM
  - Including networking switch
  - And USB for programming the FPGAs



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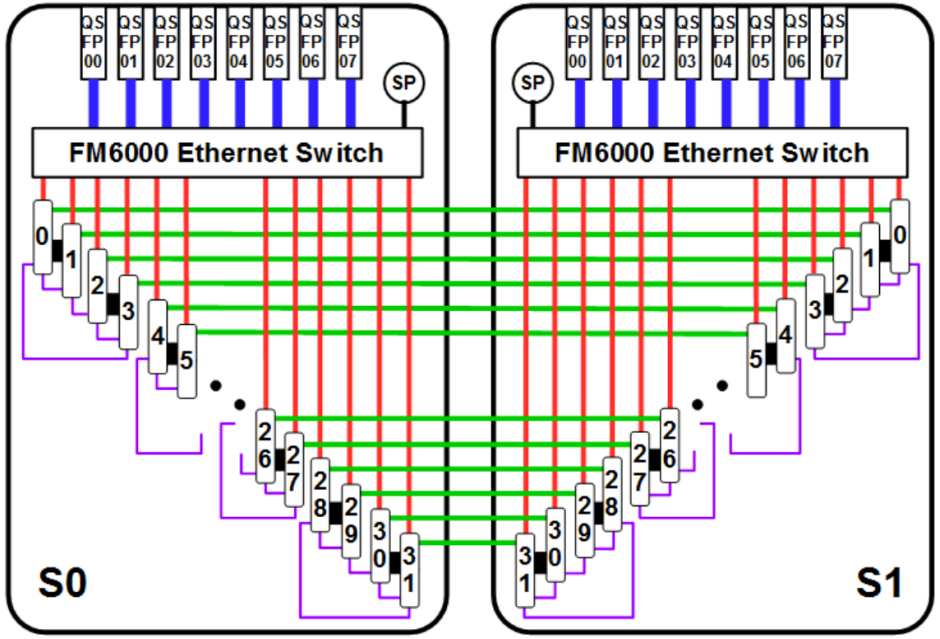
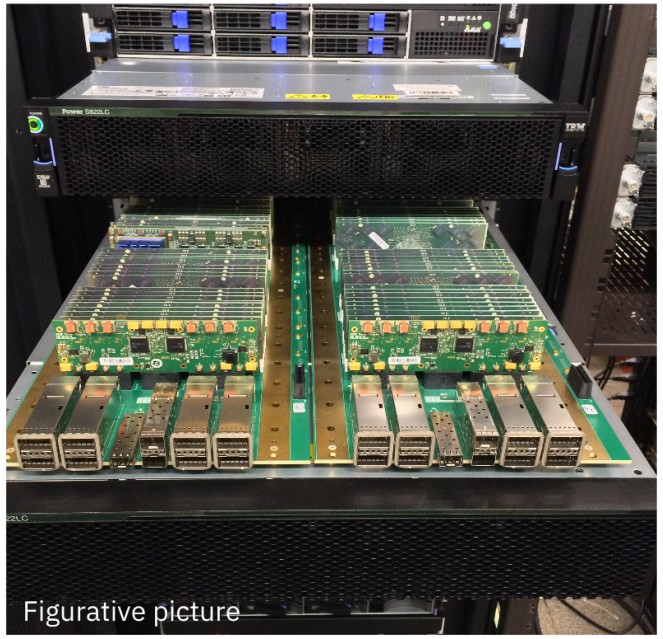
FPGA Carrier Modules in Server Rack Chassis

- Two carrier modules let IBM integrate 64 FPGAs per server rack chassis






```
Legend (per slice):
   [==]  x8 40GbE up links              (320 Gb/s)
   [--] x32 10GbE FPGA-to-Switch links (320 Gb/s)
   [--] x32 10GbE redundant links
   [--] x32 10GbE FPGA-to-FPGA links
   [▀▀] x16 PCIe x8 Gen3
    SP   x1 Service Processor
```

Balanced (i.e. no over-subscription) between the north and south links of the Ethernet switch

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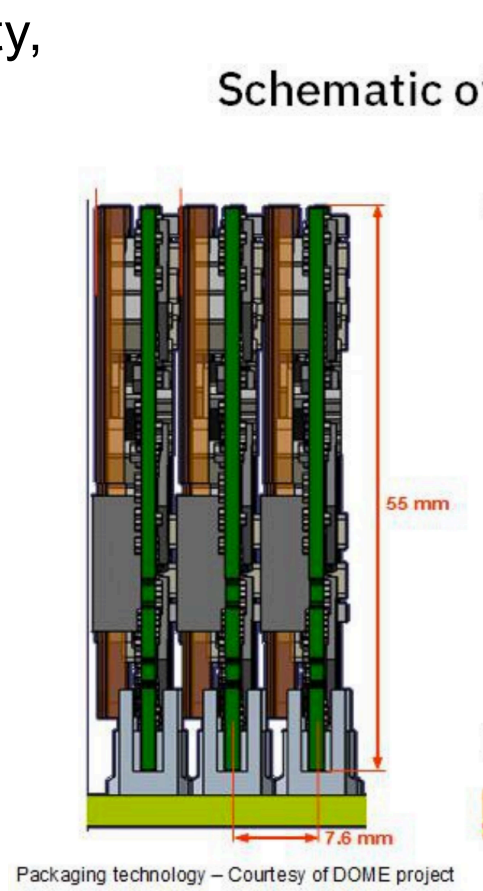
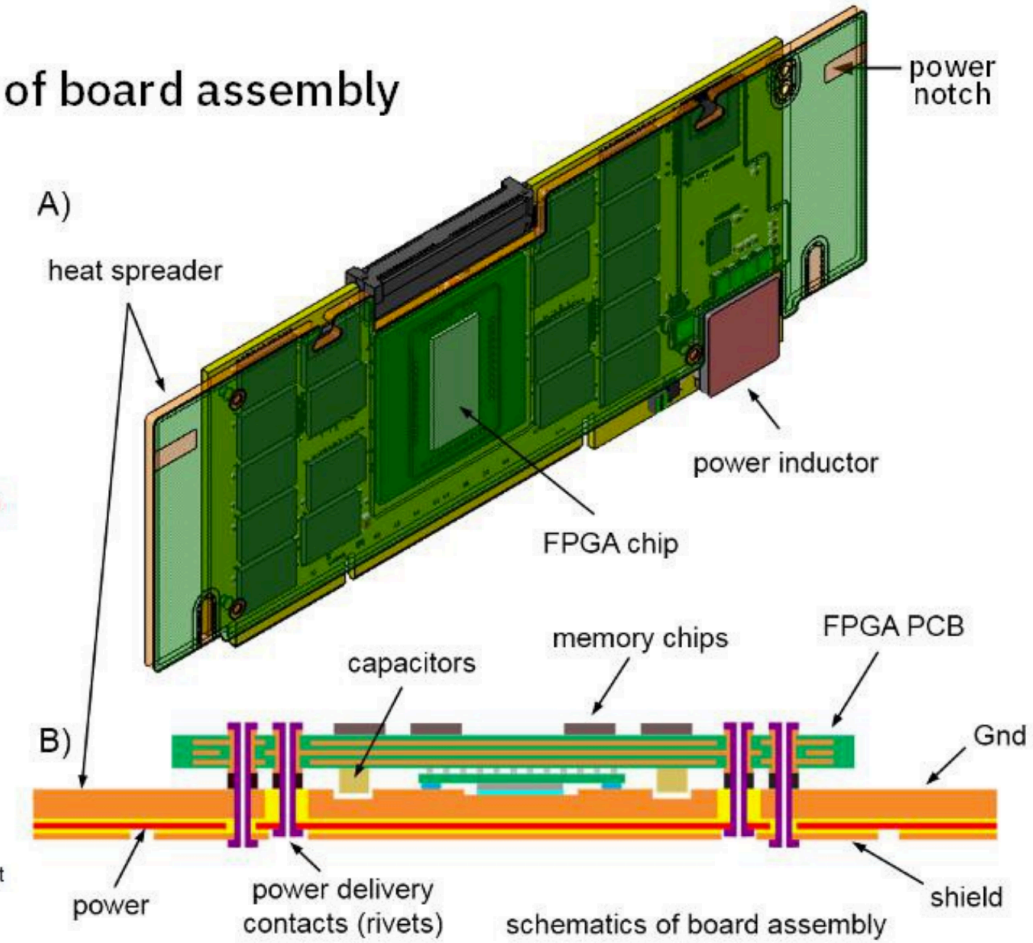
Solving Cooling Issues with High-Density FPGAs

- To achieve high FPGA density, passive cooling and water cooled servers are used
- Each FPGA board does not require a fan nor heat sink
- Use thermally conductive heat spreader…



Packaging technology – Courtesy of DOME project



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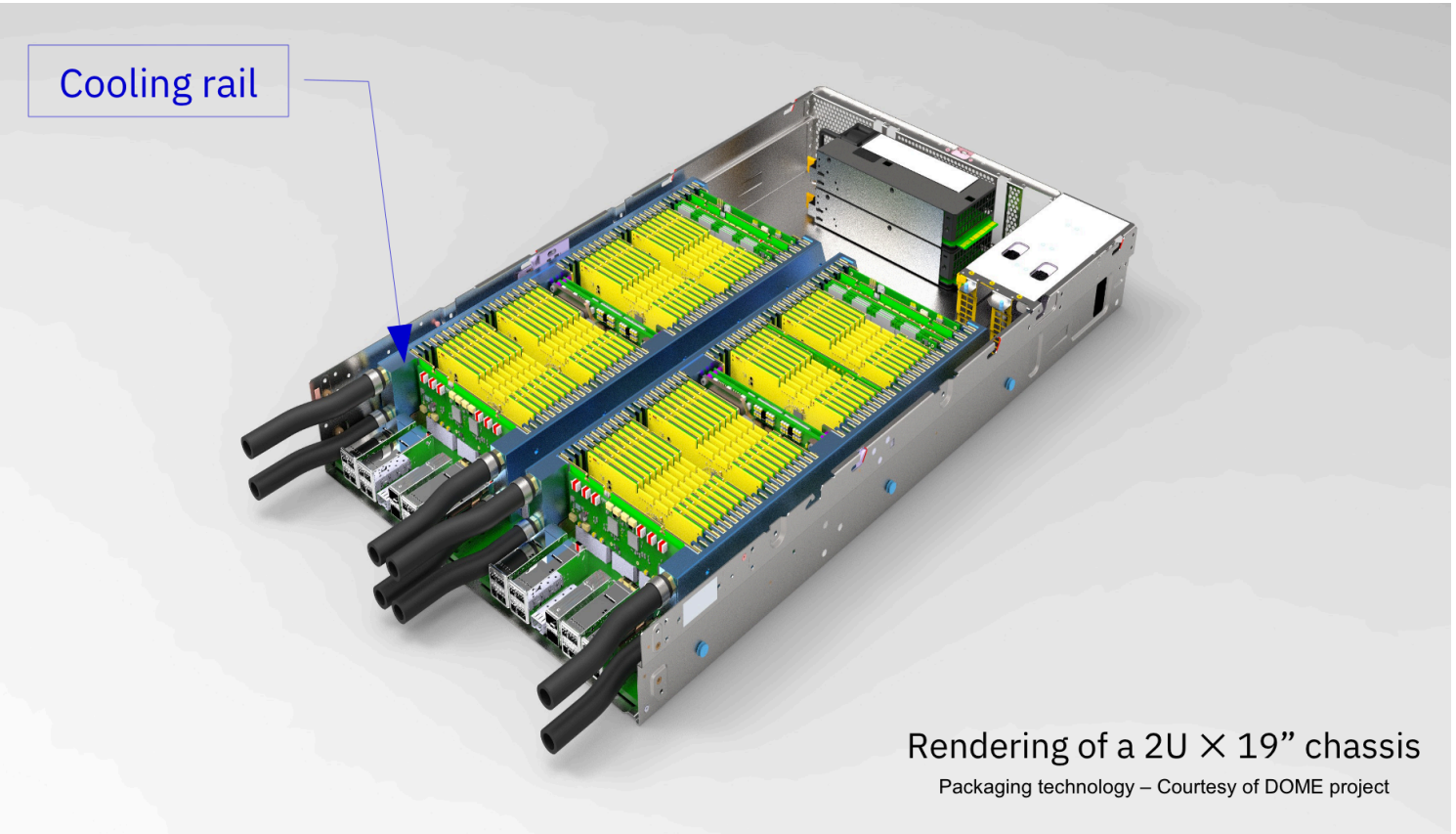
Solving Cooling Issues with High-Density FPGAs

- …heat spreader is connected to a cooling rail
- Use water cooling from server rack to extract heat from the system



Rendering of a 2U × 19” chassis

Packaging technology – Courtesy of DOME project

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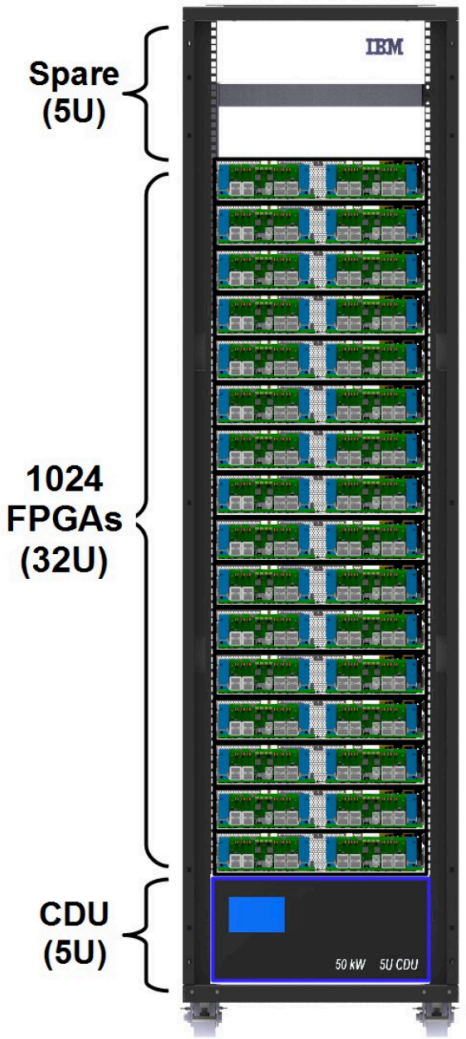
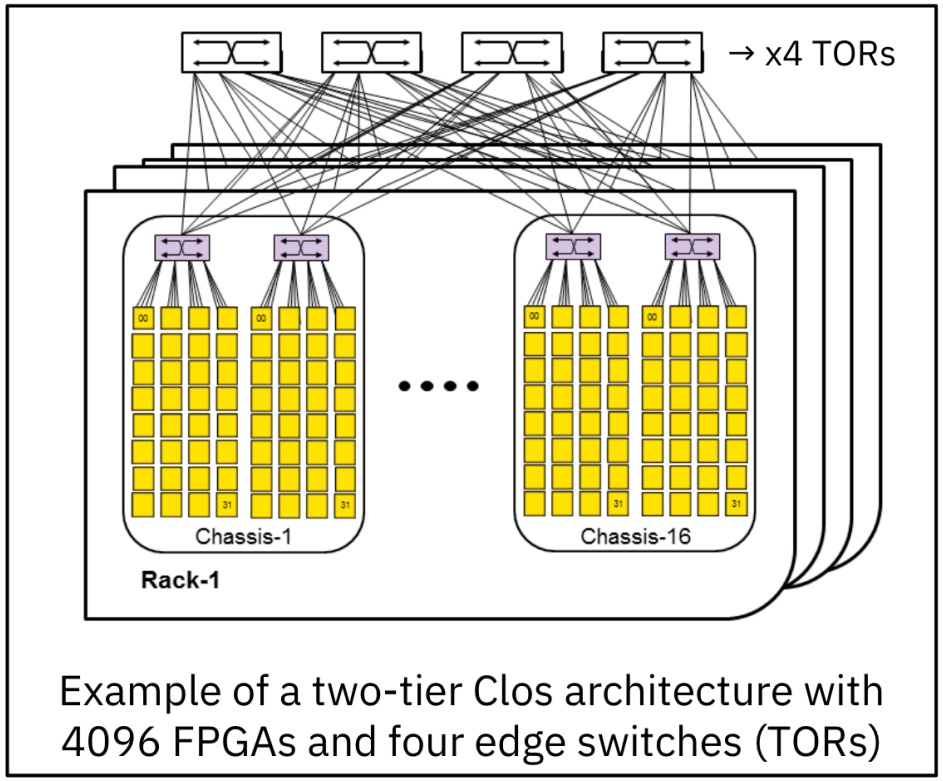
Towards 1024 FPGAs per Server Rack



1024 FPGAs → 2.8M DSPs,
$2x10^{15}$ Fixed-Point Multiply-Accumulates/s
10 Tb/s bi-sec. Bw – 16 TB DDR4 – 40 kW max.



Example of a two-tier Clos architecture with 4096 FPGAs and four edge switches (TORs)

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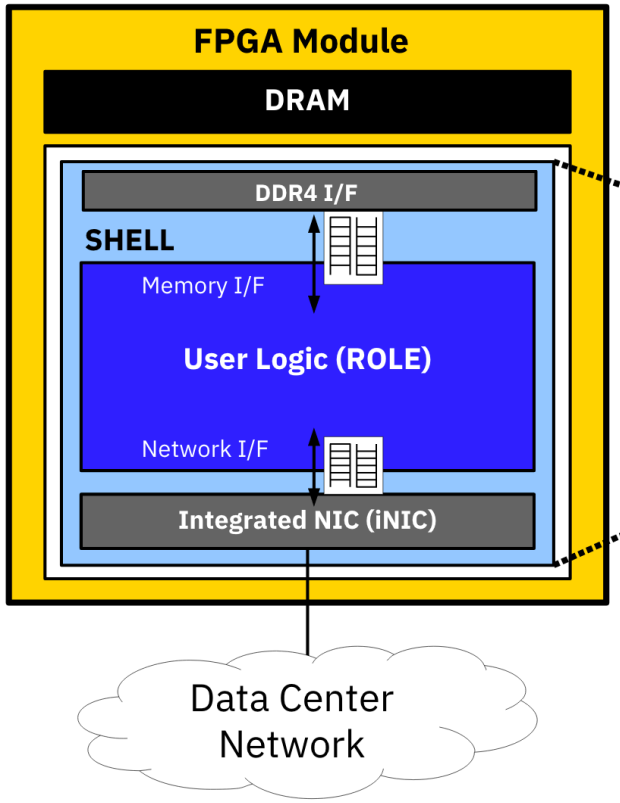
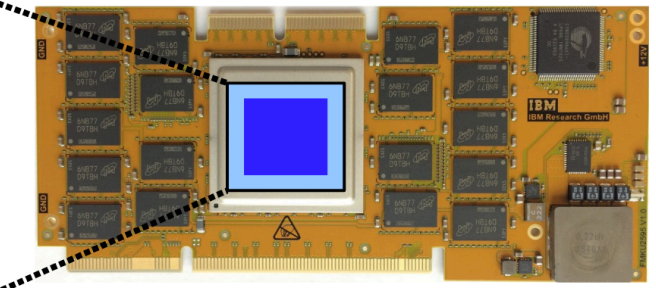
FPGA as a Service using Disaggregated FPGAs

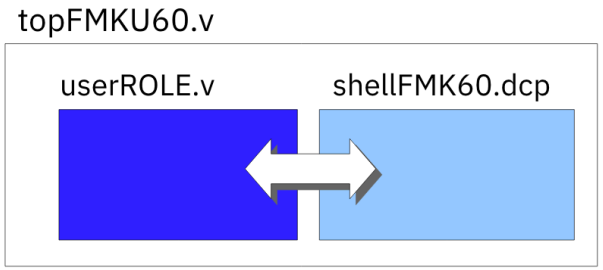
- The FPGAs from the server rack can be assigned to users to create FPGA as a Service setup
- User programs the FPGA with their desired logic



SHELL → abstracts the HW components of the FPGA and exposes standard AXI(S) interfaces to the user.

ROLE → embeds user's application logic.





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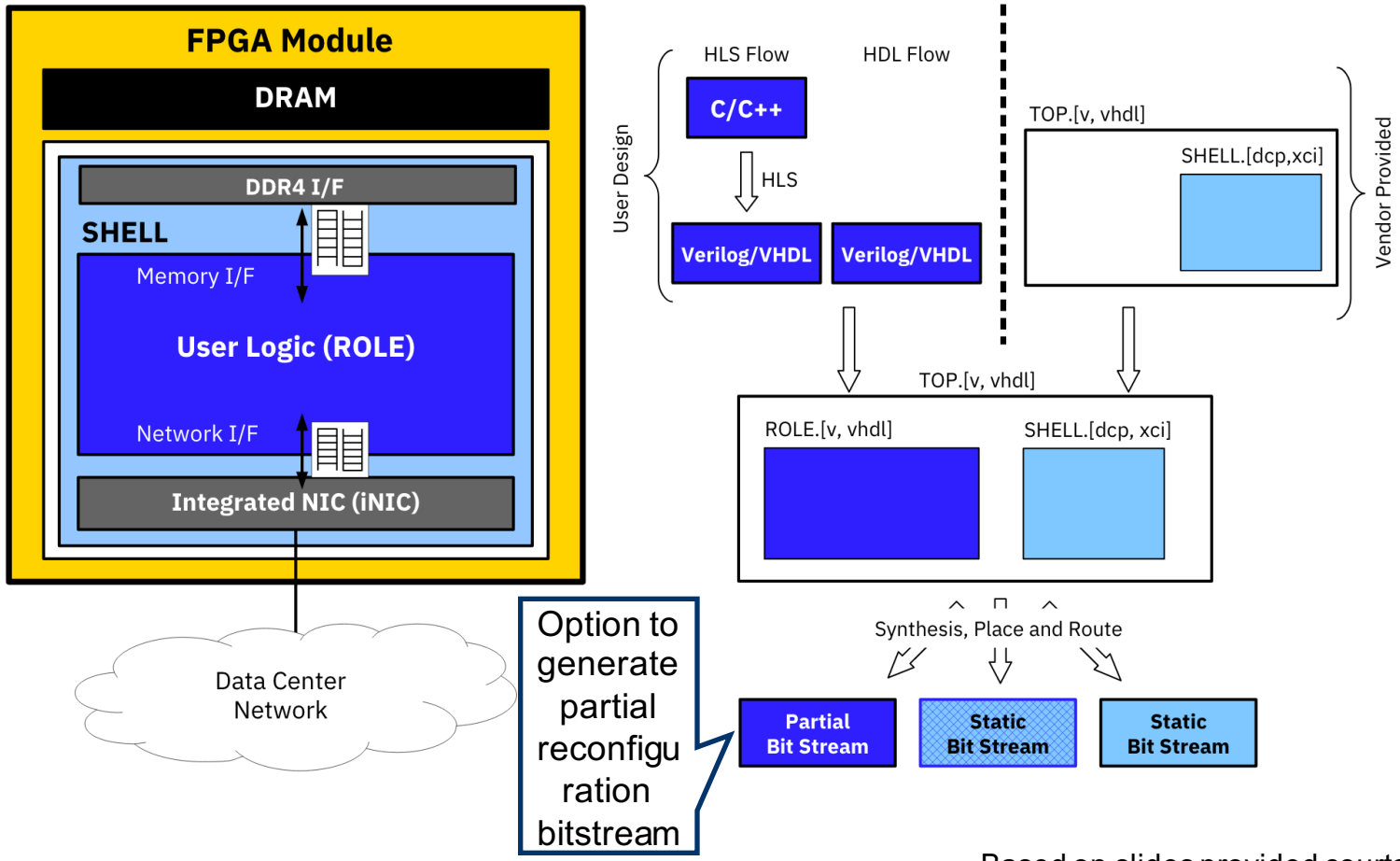
Programming Disaggregated FPGAs

- The FPGAs are programmed in similar manner to other Cloud FPGA deployments



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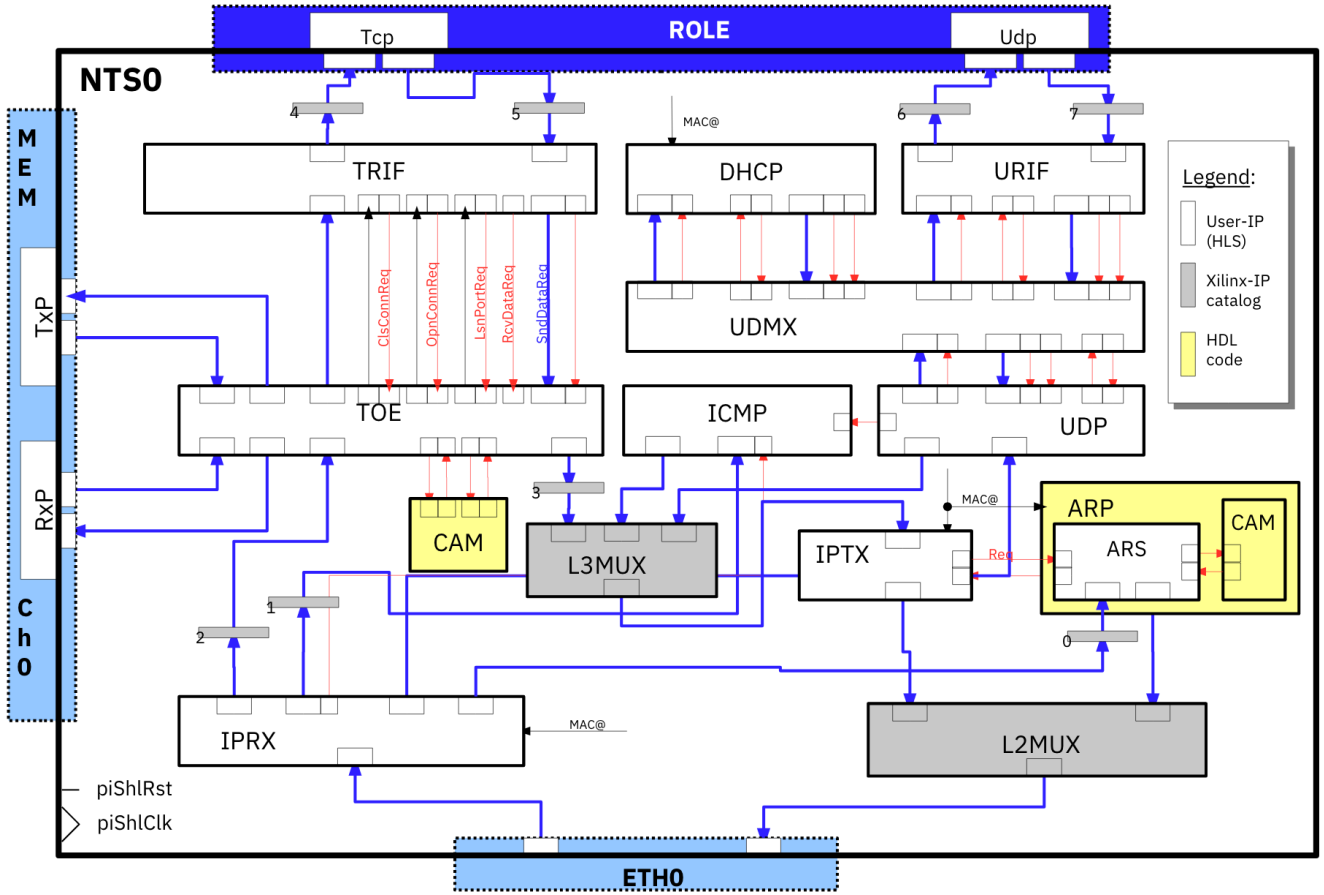
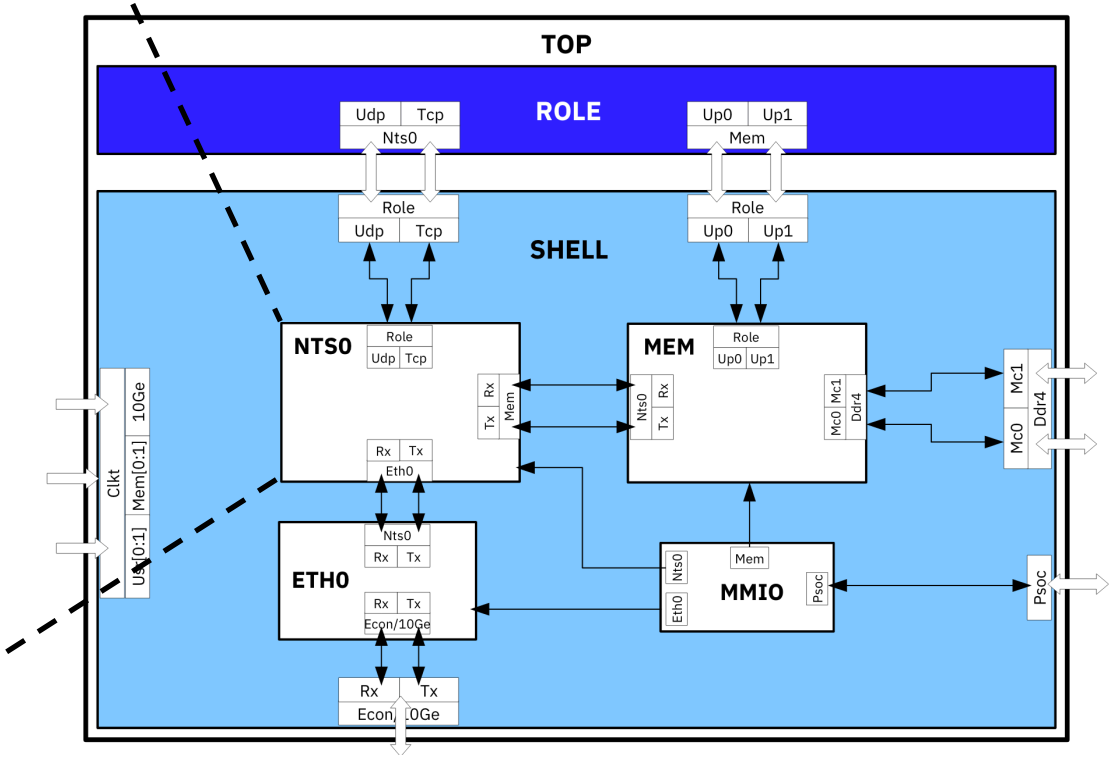
Shell Logic and Network-Transport-Session





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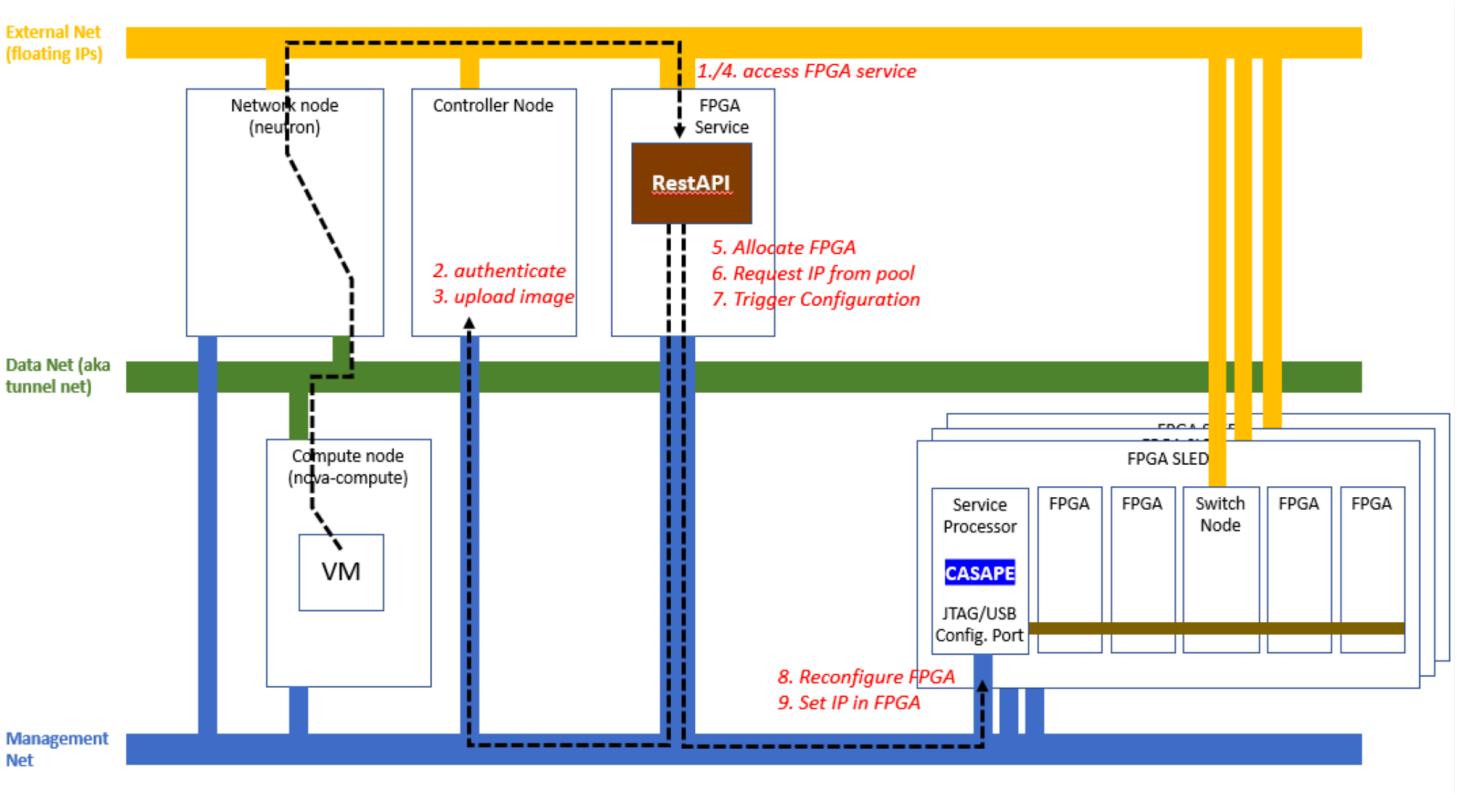
Networking of the FPGAs

- Separate networks inside the data center are used manage the FPGAs, and to let them communicate



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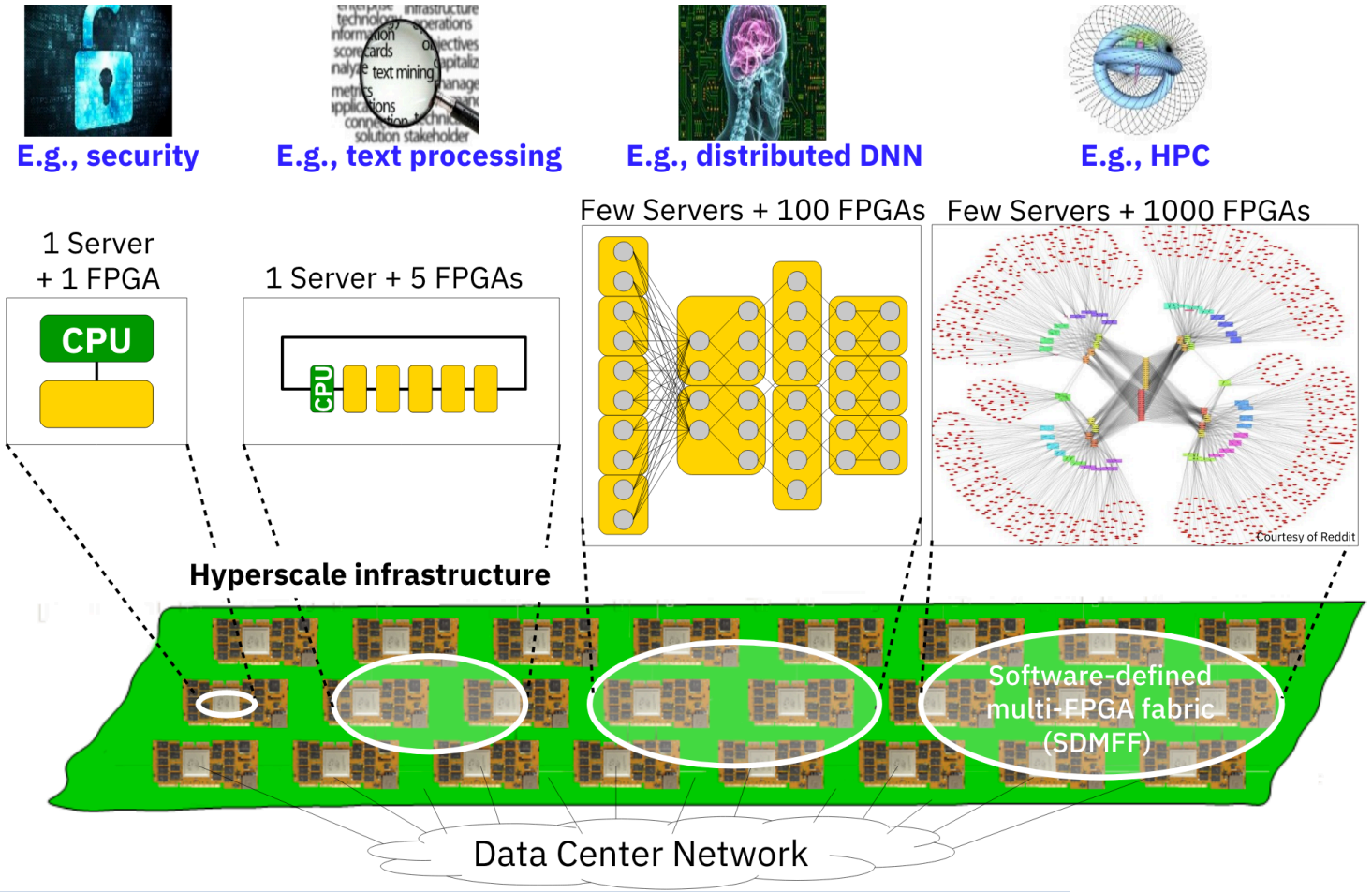
Towards Software-Defined Multi-FPGA Fabric

- Disaggregated FPGAs allow for arbitrary connection of the FPGAs to achieve different tasks



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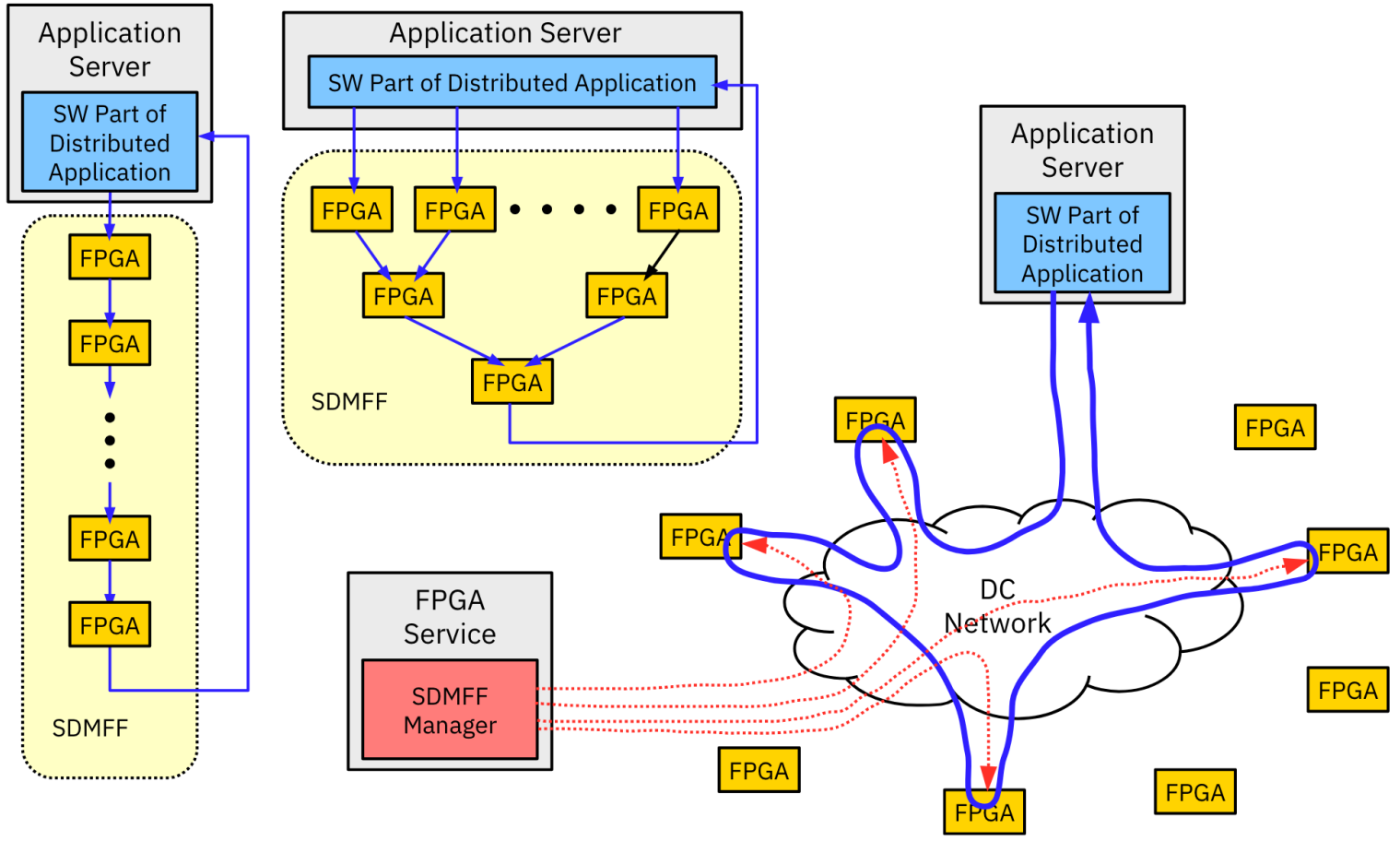
Towards Software-Defined Multi-FPGA Fabric

- FPGA and CPU interaction can be flexibly defined
  - No longer is it CPU controlling what FPGA does



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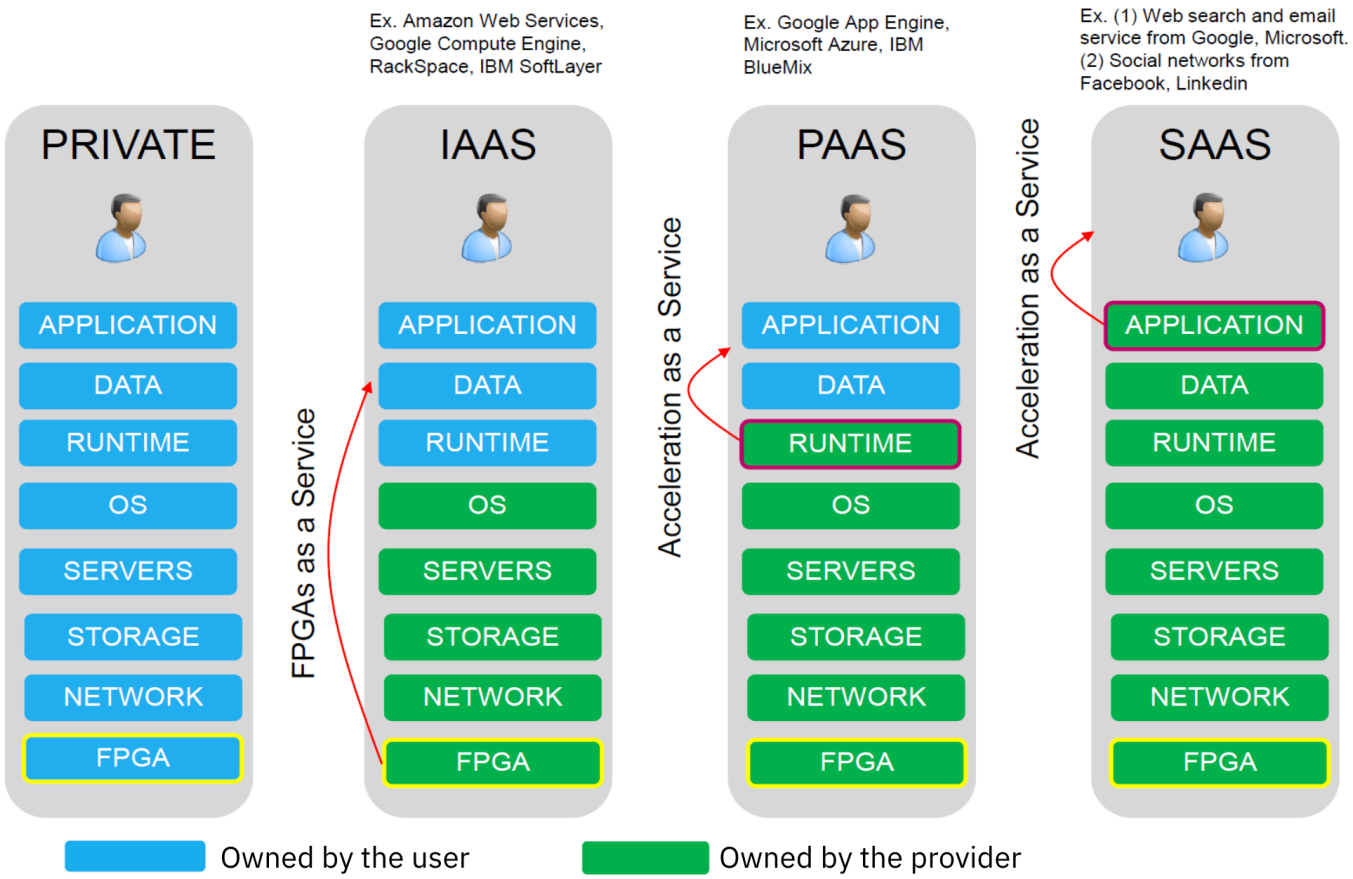
From FPGA as a Service to Acceleration as a Service

- FPGAs in data center can fit into the typical IaaS, PaaS, SaaS models:



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