Free Open Source Software Stacks and Open Hardware Technologies: Revolutionizing the World

by: Tassadaq Hussain

Professor Department of Electrical Engineering

Director Centre for AI and BigData

Namal University Mianwali

Collaborations:

Barcelona Supercomputing Center, Spain

European Network on High Performance and Embedded Architecture and Compilation

Pakistan Supercomputing Center

- **Trainer and Centre Introduction**
- **Past Present and Future** of AI and Big Data
- **Addressing Challenges** with Open Source Software and Hardware Technologies
- **Namal Centre for AI and BigData**: Strength and Achievements

Introduction

Education:

PhD. Barcelona-Tech
Microsoft Research, Infineon Technologies France, Microsoft Research Cambridge, IBM

Suspenseful record of academic management as Professor and Dean

Enhanced Education Quality by Inculcating Outcome Based Education by Applied and Sustainable Projects

Experience:

19+ year's versatile experience in the area of Computer Architecture, AI, Software Architecture, Big-Data Architecture
Served National and International Academia, Industry and Government

- **Barcelona Science Park Spain**
- **Cambridge Science Park UK**
- **Technopolis Of Sofia-Antipolis, France**

Innovation, Research and Commercialization

Innovation and Research

- **110+ Million Pkr National and Int'l Funding.**
  - Supercomputing and Artificial Intelligence
  - Smart Electric Motor Controllers
  - Biomedical Applications
- **80+ Publications**
- **10 Patents**
- **10 MVPs**
- **5 Int'l Collaborations**

- ## Development & Commercialization

60+ Million of Industrial Investments.
Developed Digital Systems for Industry.
Transform Idea into product.
Innovation and Commercialization for Sustainable economic and industrial development.

- ## Capacity Building:

Conducted more than **50 national and international workshops** and **training on Commercializable research, Writing successful grant proposal, and research and innovation.**

Provides Consultancy and Support for Entrepreneurship, Start-ups, Business Innovation and Technology transfer.

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

UVHC
UNIVERSITE DE VALENCIENNES ET DU HAINAUT - CAMBRESIS

NEW ZEALAND COLLEGE OF CHIROPRACTIC
graduating hands, hearts & minds

PAKISTAN SUPERCOMPUTING

EntrepreneurialPark
Research Innovation Commercialization

Foot Analytic

ComputingPark

Int'l Projects

- Design Ultra Low Cost Display Camera Interface for Mobile Baseband XGold Chip **(Infineon Techonogies, 200 million single chip)**

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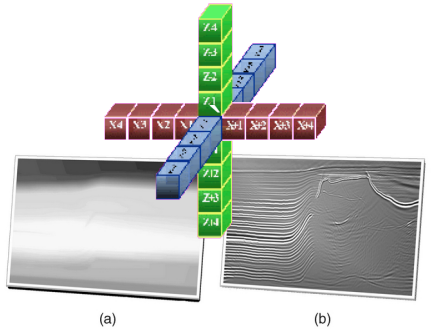
- Implementation of Reverse Time Migration on FPGAs
  (BSC-REPSOL, PLDA Italia, Cambridge Science Park)



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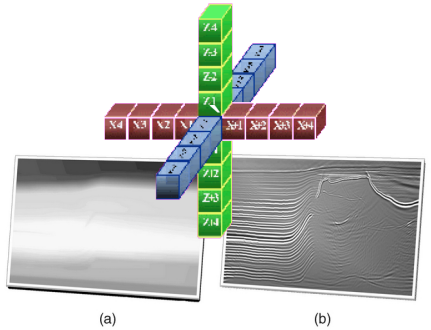
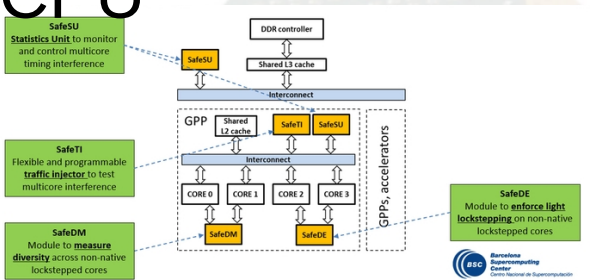


- Open source European full-stack ecosystem based on a new RISC-V CPU
  (Barcelona Supercomputing Center)



Current Challenge and Sustainable and Scalable Solutions

- World **Data Size = 170 Zettabytes**, doubling every 18 months.
- To handle big-data, **AI algorithms** are the only solution.
- The computational demands of AI algorithms are experiencing exponential growth. **(ExaFLOPS/Day)**
- **Supercomputing** is the only solution to store big-data and process the AI.

Secure
Indigenous Commercializable
Industrial Development
Well being

Centre for AI and BigData

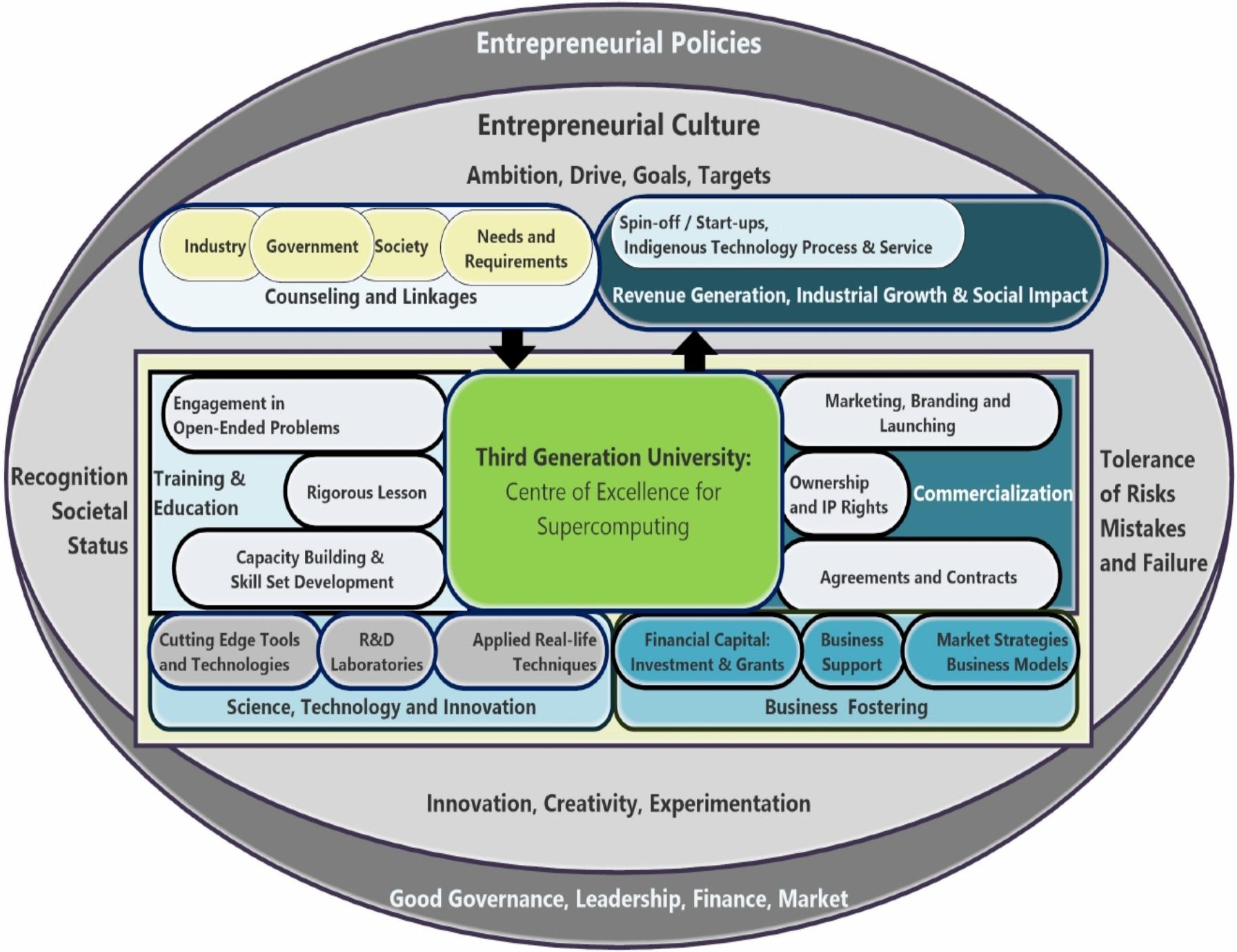
Vision:

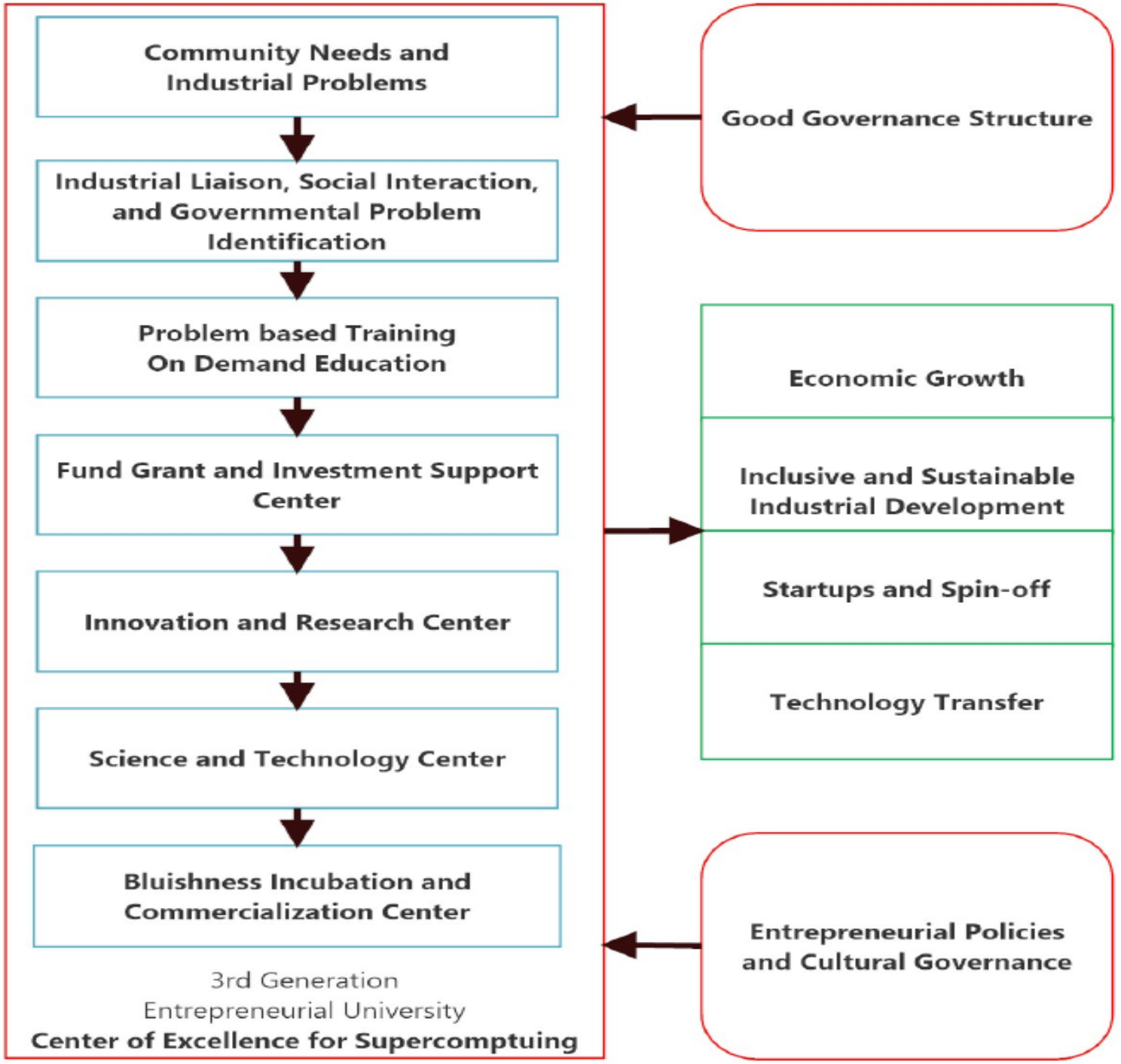
Solve local compute-intensive problems using smart solutions and high-performance technologies.

Mission

To provide indigenous digital solutions for multi-disciplinary local problems.

Acquire analog data, digitize, store it and propose a technological solution for analysis, classification, prediction, control and simulation.


Entrepreneurial Policies
Entrepreneurial Culture
Ambition, Drive, Goals, Targets
Industry
Government
Society
Needs and Requirements
Counseling and Linkages
Spin-off / Start-ups,
Indigenous Technology Process & Service
Revenue Generation, Industrial Growth & Social Impact
Recognition
Societal
Status
Engagement in
Open-Ended Problems
Training &
Education
Rigorous Lesson
Capacity Building &
Skill Set Development
Third Generation University:
Centre of Excellence for
Supercomputing
Marketing, Branding and
Launching
Ownership
and IP Rights
Commercialization
Agreements and Contracts
Tolerance
of Risks
Mistakes
and Failure
Cutting Edge Tools
and Technologies
R&D
Laboratories
Applied Real-life
Techniques
Science, Technology and Innovation
Financial Capital:
Investment & Grants
Business
Support
Market Strategies
Business Models
Business Fostering
Innovation, Creativity, Experimentation
Good Governance, Leadership, Finance, Market


Community Needs and Industrial Problems
Industrial Liaison, Social Interaction, and Governmental Problem Identification
Problem based Training On Demand Education
Fund Grant and Investment Support Center
Innovation and Research Center
Science and Technology Center
Bluishness Incubation and Commercialization Center
3rd Generation
Entrepreneurial University
Center of Excellence for Supercomptuing
Good Governance Structure
Economic Growth
Inclusive and Sustainable Industrial Development
Startups and Spin-off
Technology Transfer
Entrepreneurial Policies and Cultural Governance

Targets

a) Specialized Training
b) Linkages and Collaborations
c) Research and Publications
d) Innovation and Prototype
e) Fund Grant Hunting
g) Services and Consultancy
h) Technology Transfer
i) Revenue Generated

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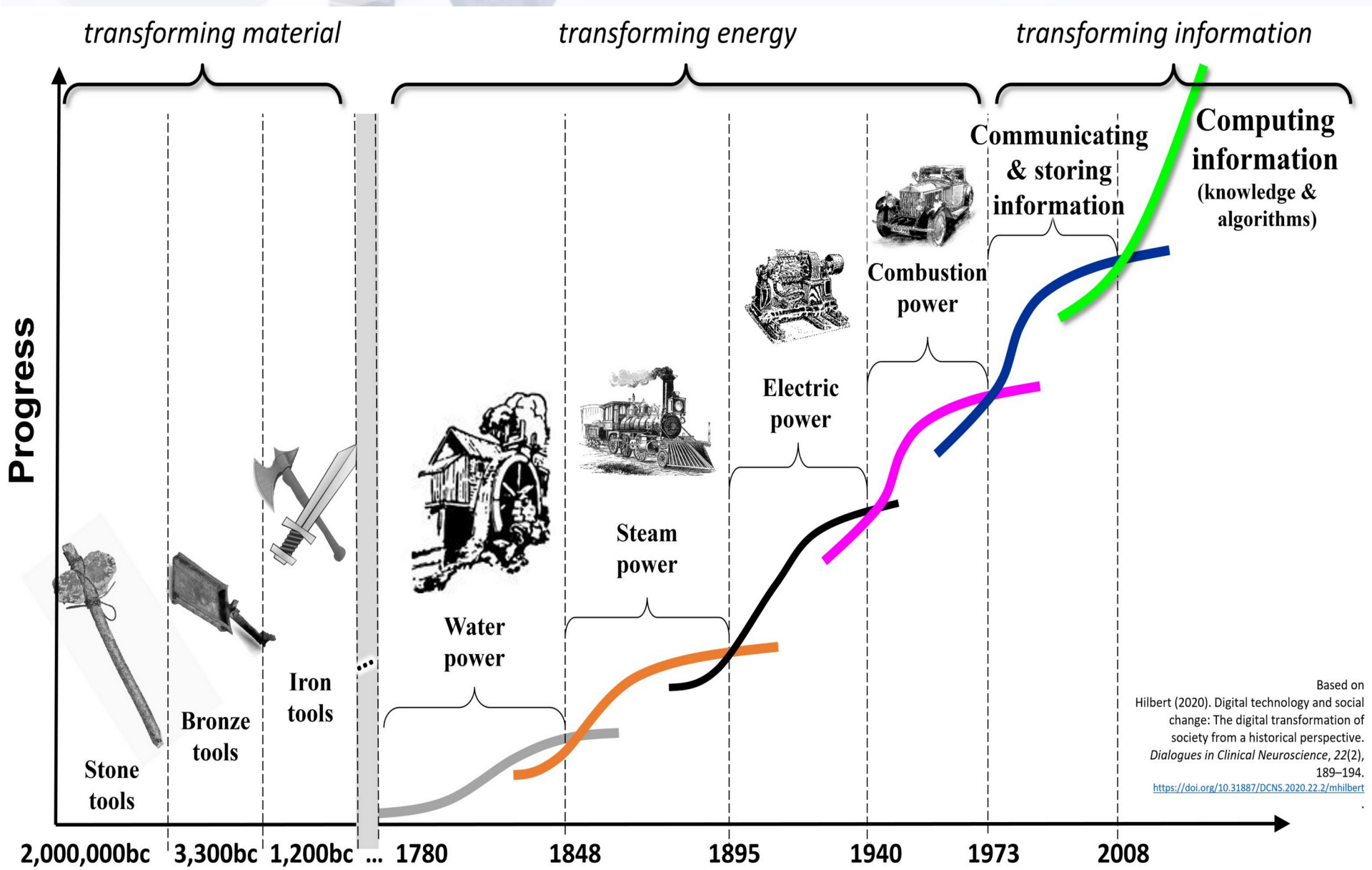
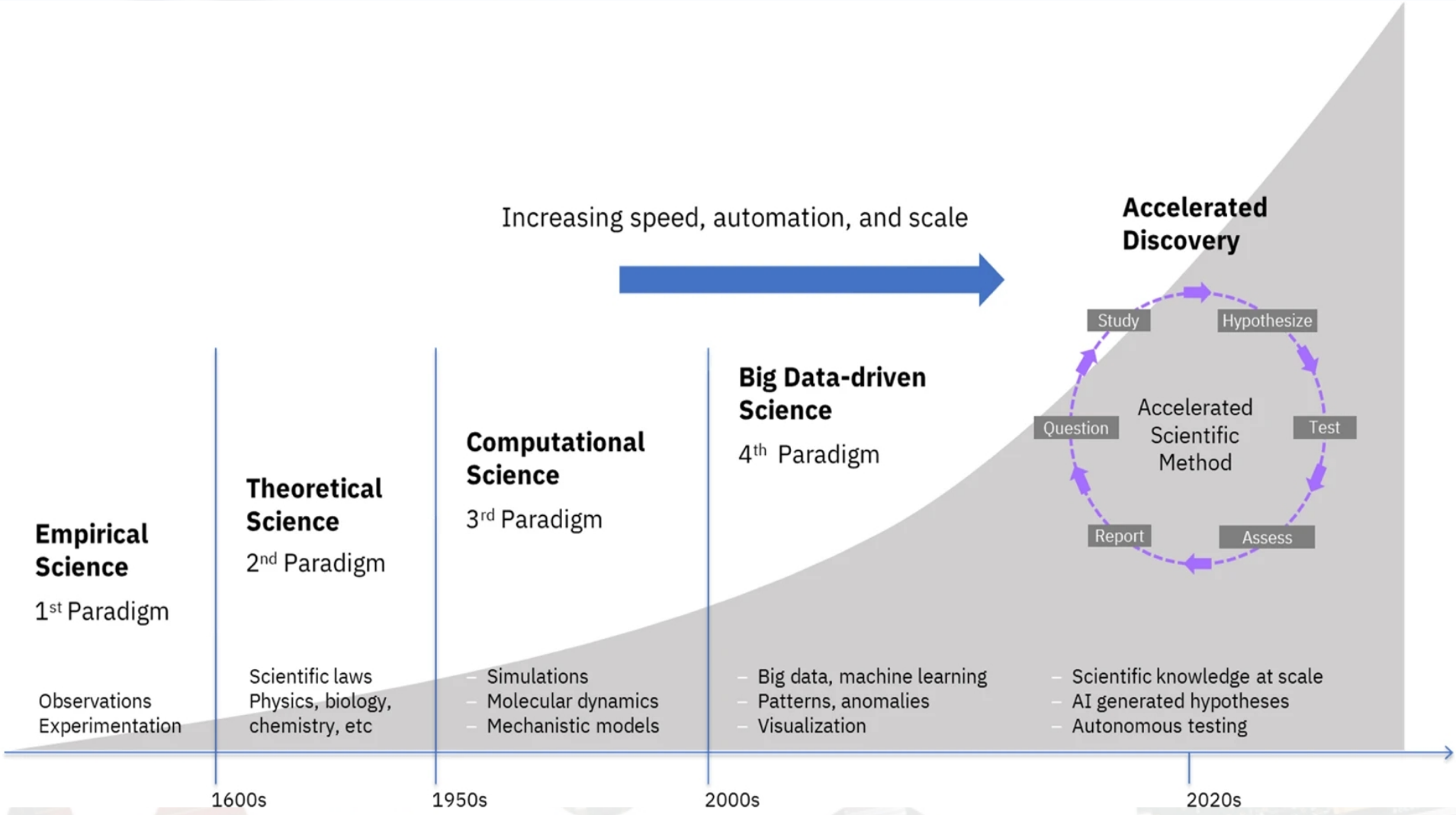
Mankind Progress



Based on Hilbert (2020). Digital technology and social change: The digital transformation of society from a historical perspective. *Dialogues in Clinical Neuroscience*, *22*(2), 189–194. https://doi.org/10.31887/DCNS.2020.22.2/mhilbert .

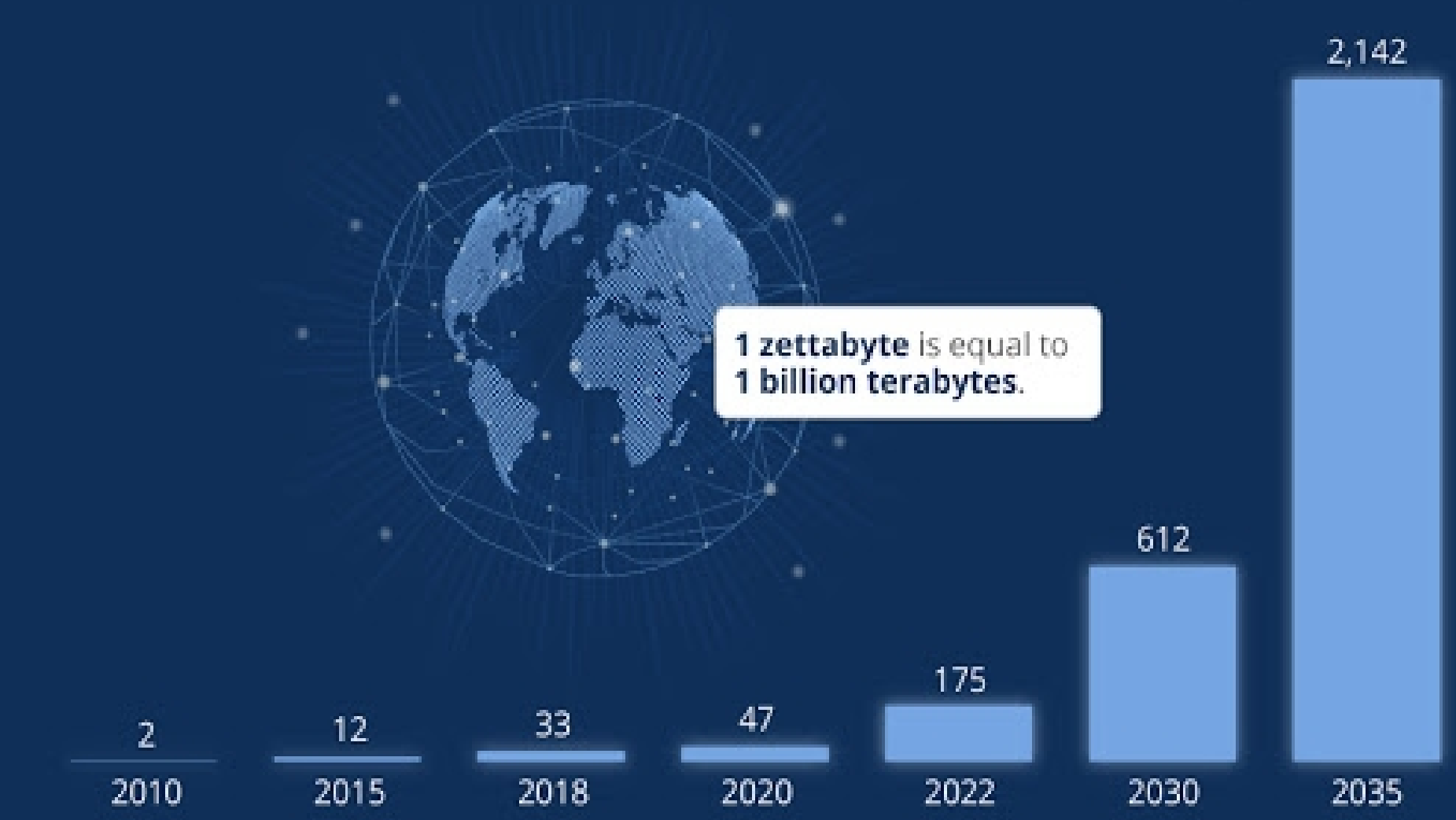
From Age of Empirical Science to Data-Science



https://www.nature.com/articles/s41524-022-00765-z/figures/1

Global Data Creation is About to Explode

Actual and forecast amount of data created worldwide 2010-2035 (in zettabytes)

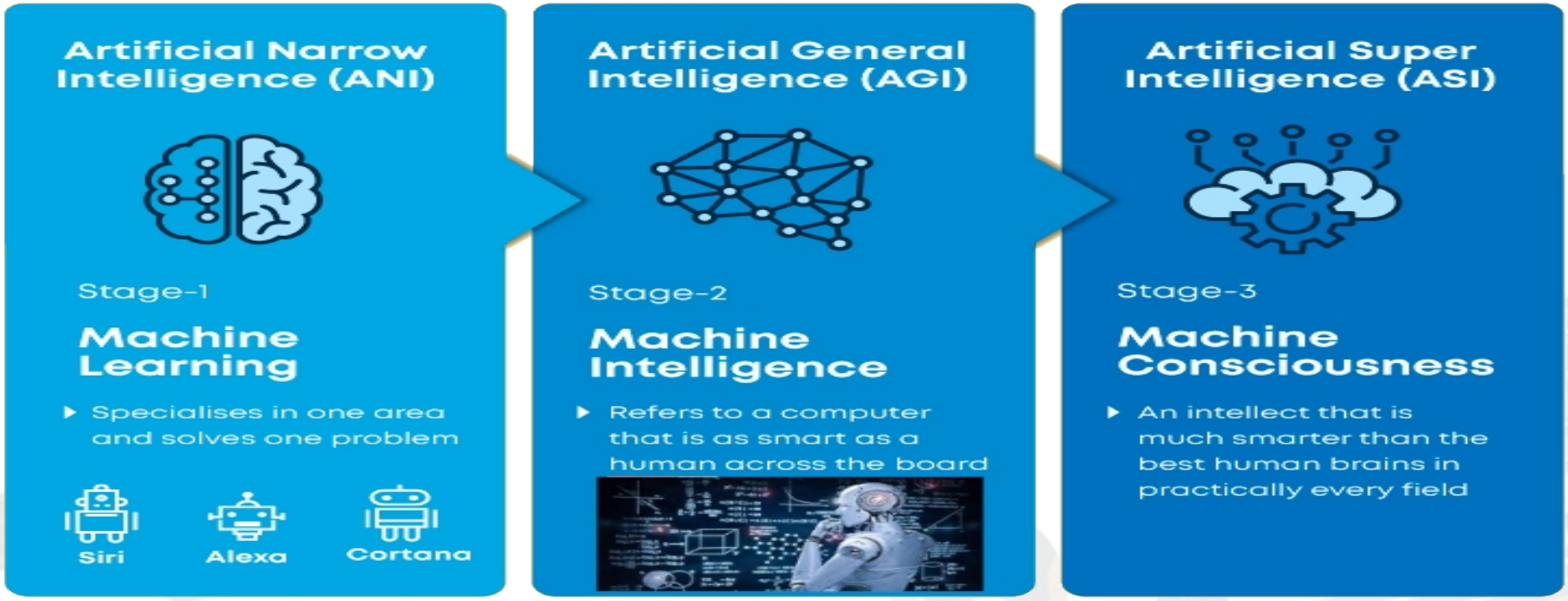


57.76 US$

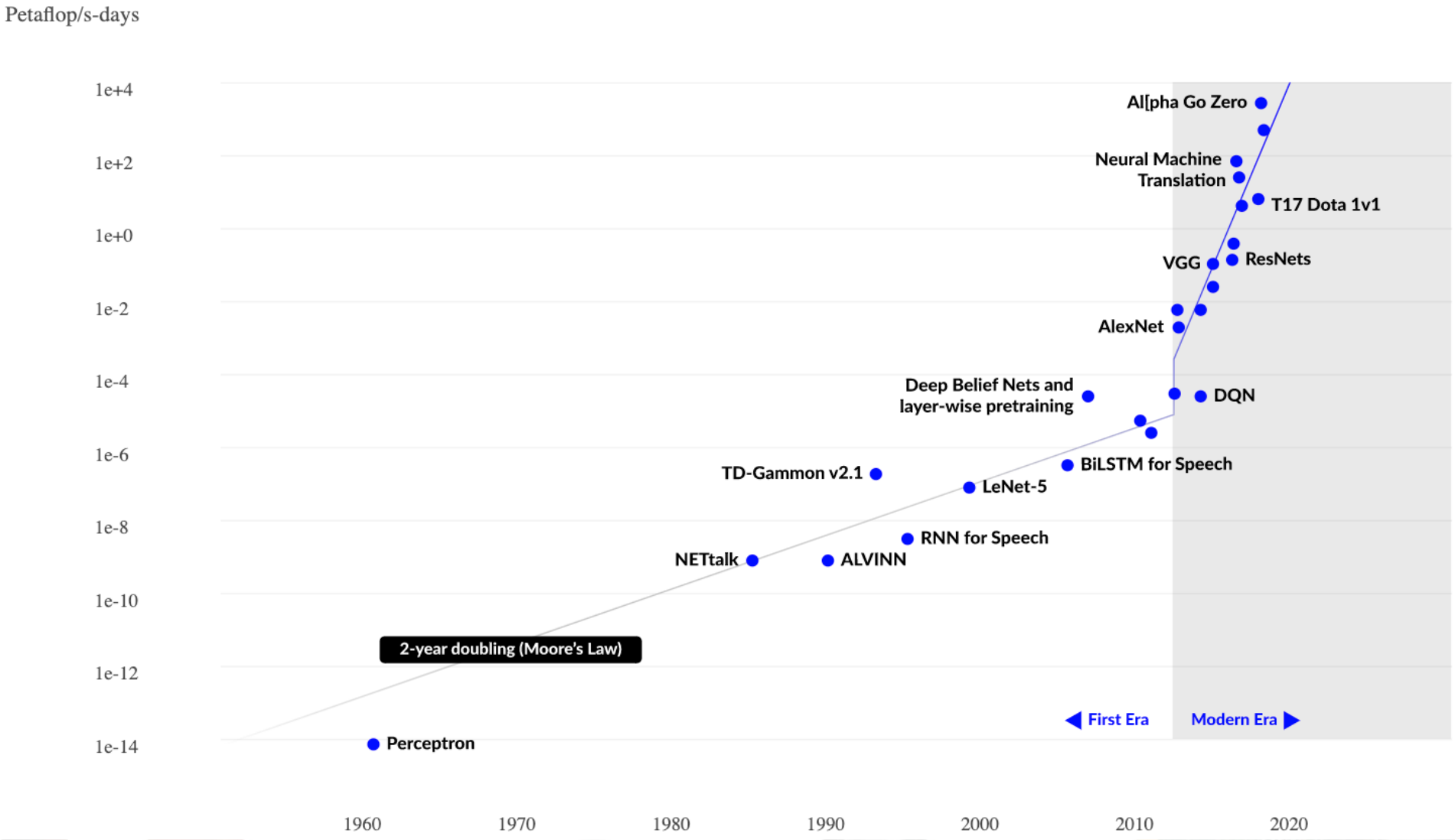
statista

BigData and AI Algorithms

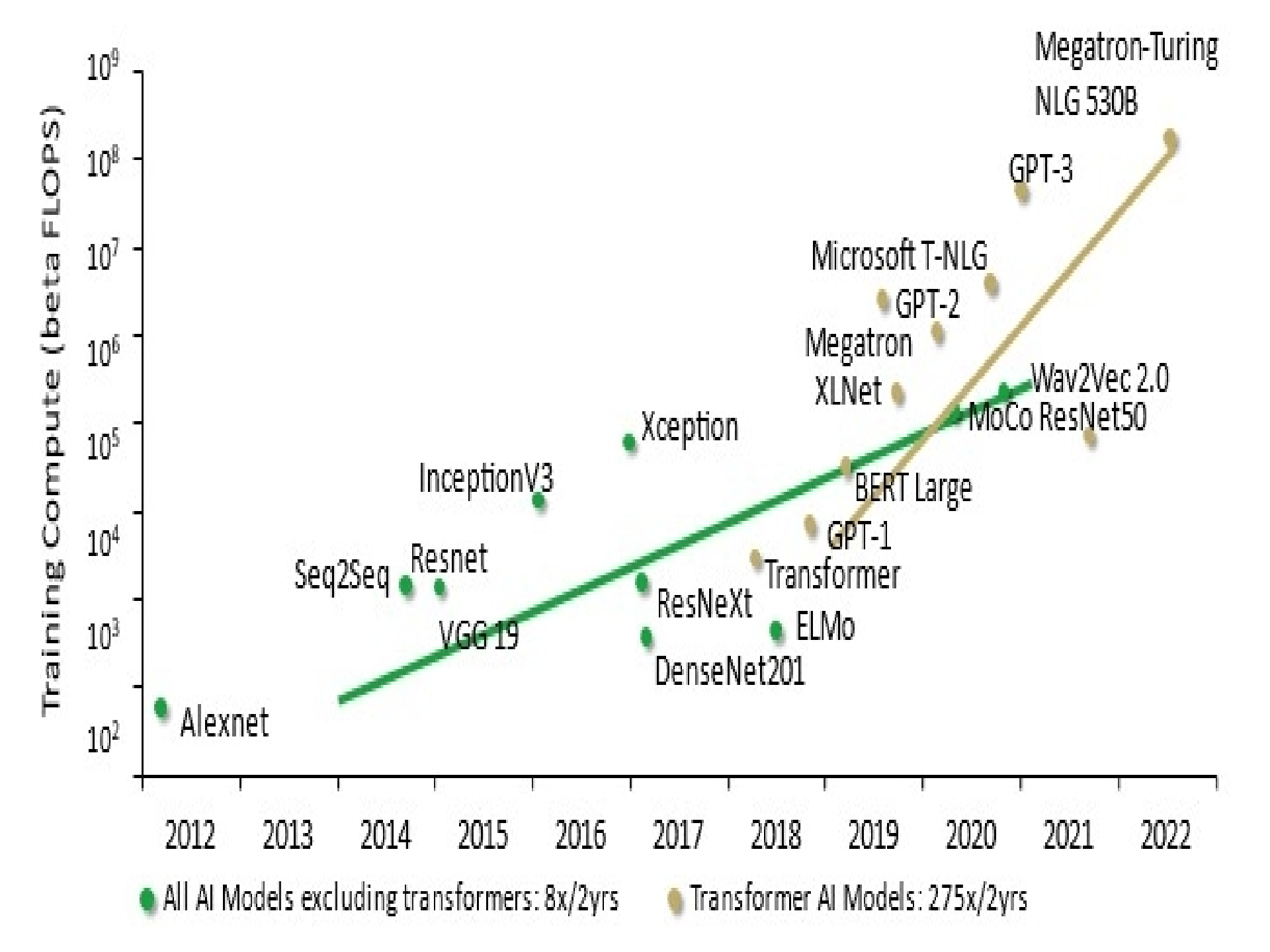
- **Performance**
  - **Execution Time**
  - **Accuracy** “The accuracy of the model is inherently tied to the quality, diversity, and representativeness of the data used for training and evaluation."
  - **Scalability** “Methods that scale with computation are the future of Artificial Intelligence” — Rich Sutton,



Computation Demand



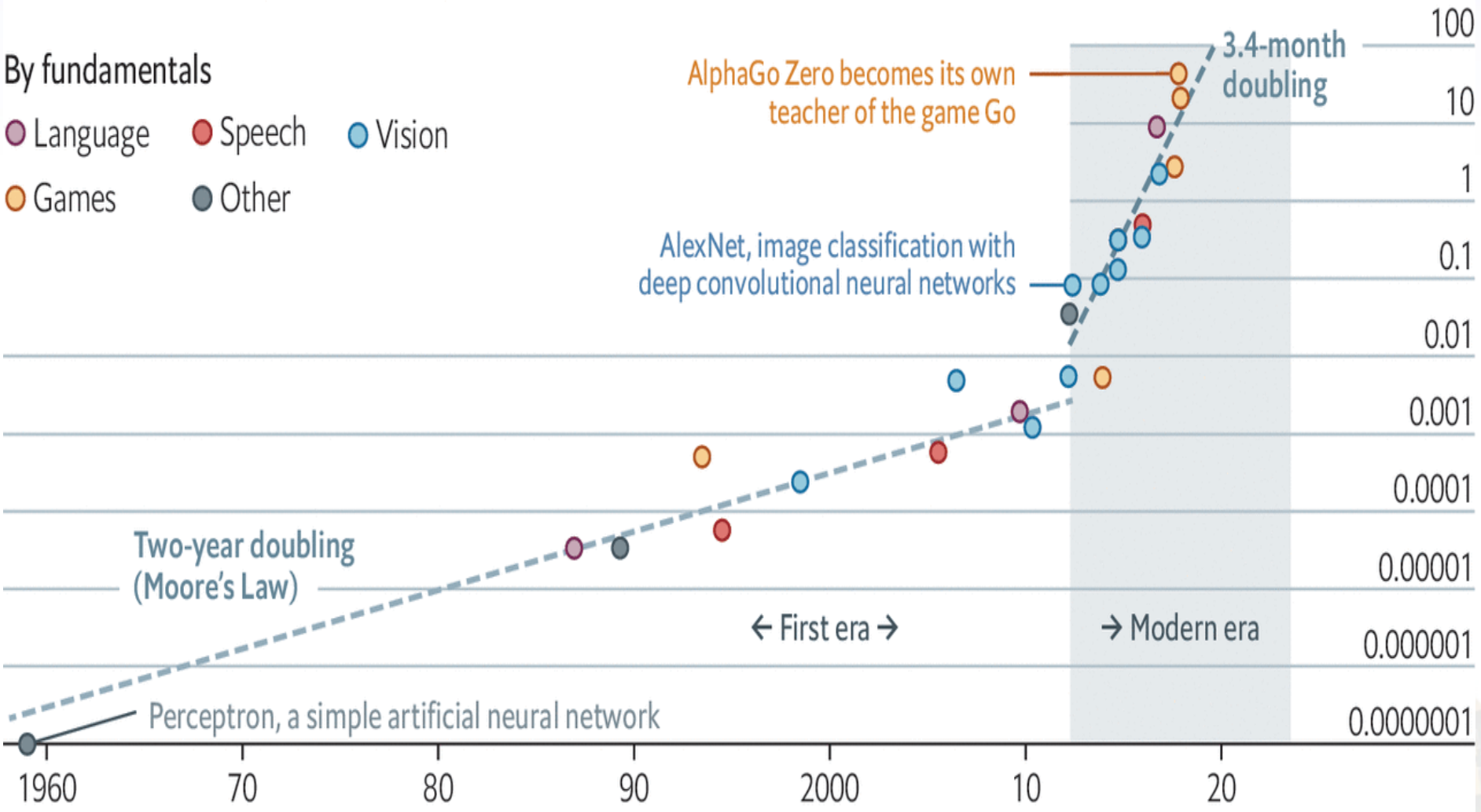
The total amount of compute, in petaflop/s-days,[2] used to train selected results that are relatively well known, used a lot of compute for their time, and gave enough information to estimate the compute used.


Training Compute (beta FLOPS)
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
Megatron-Turing NLG 530B
GPT-3
Microsoft T-NLG
GPT-2
Megatron
XLNet
Wav2Vec 2.0
MoCo ResNet50
Xception
InceptionV3
BERT Large
GPT-1
Transformer
Seq2Seq
Resnet
ResNeXt
ELMo
VGG 19
DenseNet201
Alexnet
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
All AI Models excluding transformers: 8x/2yrs
Transformer AI Models: 275x/2yrs

Deep and steep

Computing power used in training AI systems

Days spent calculating at one petaflop per second*, log scale

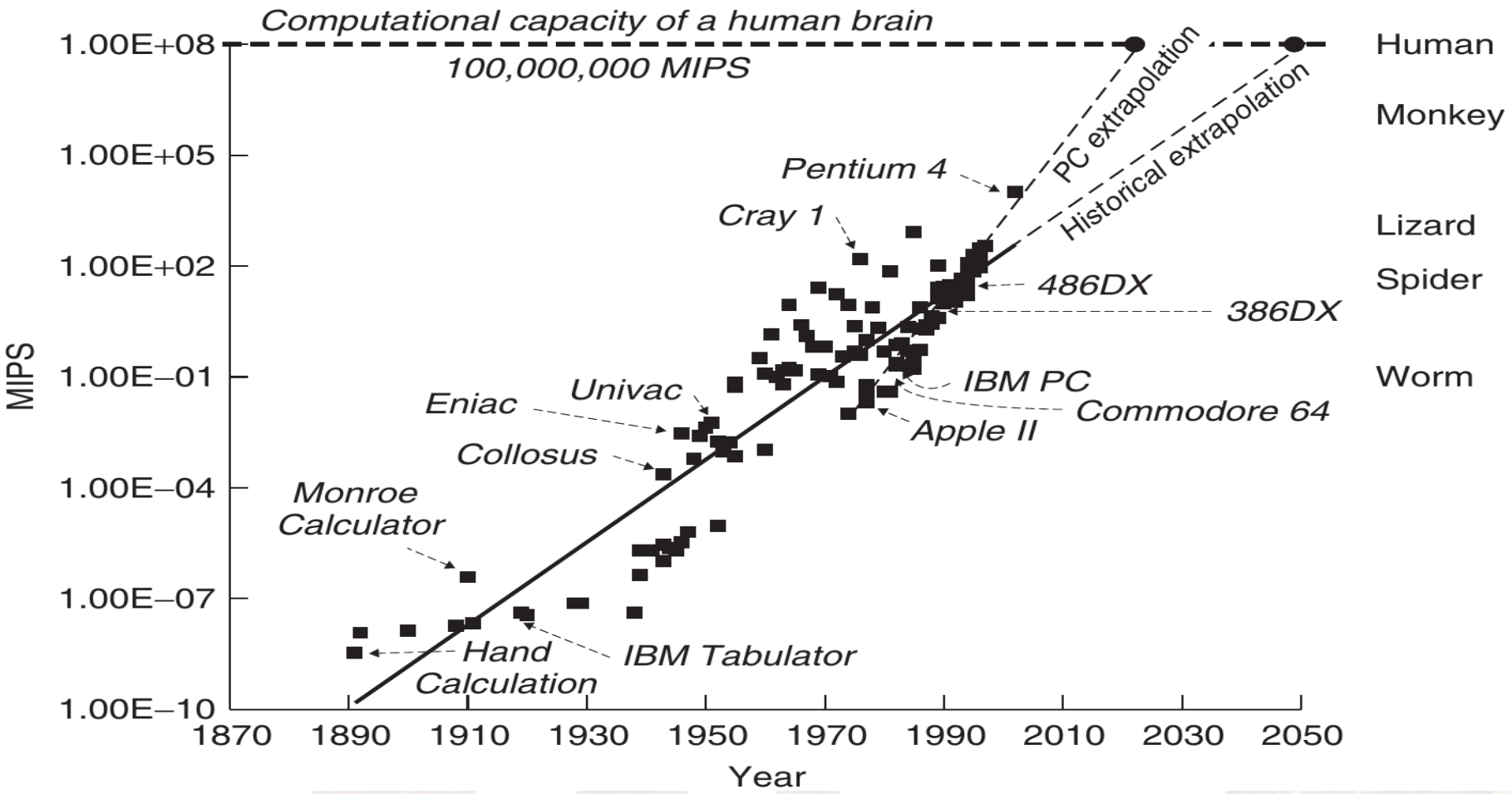


Source: OpenAI

*1 petaflop=10^{15} calculations

The Economist

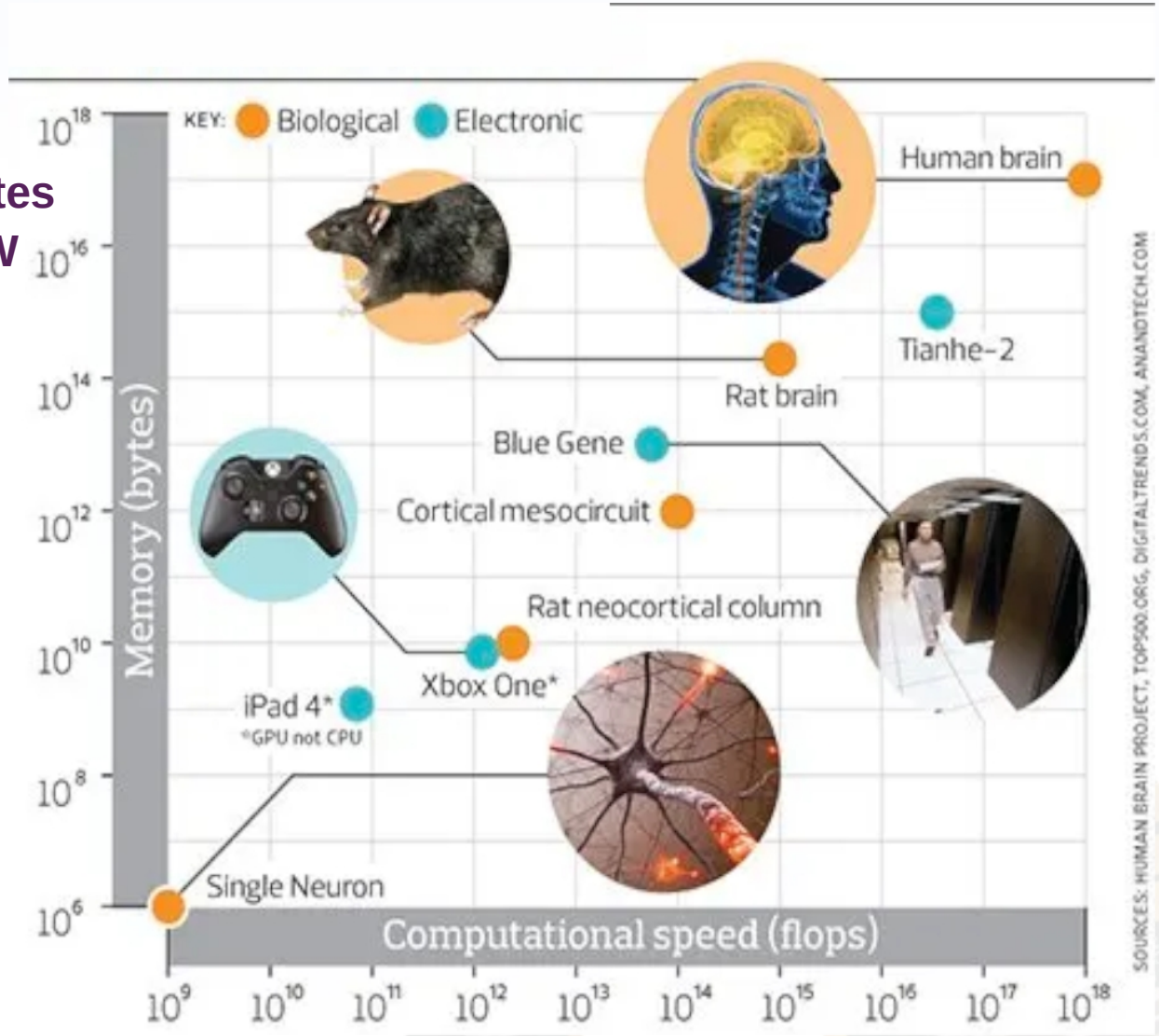
AI Algorithms and Intellectuality:
By Enhancing Computational Capability ?



It is estimated that sometime between the years **2025 and 2050**, a **personal computers** will exceed the calculation power of a human brain.

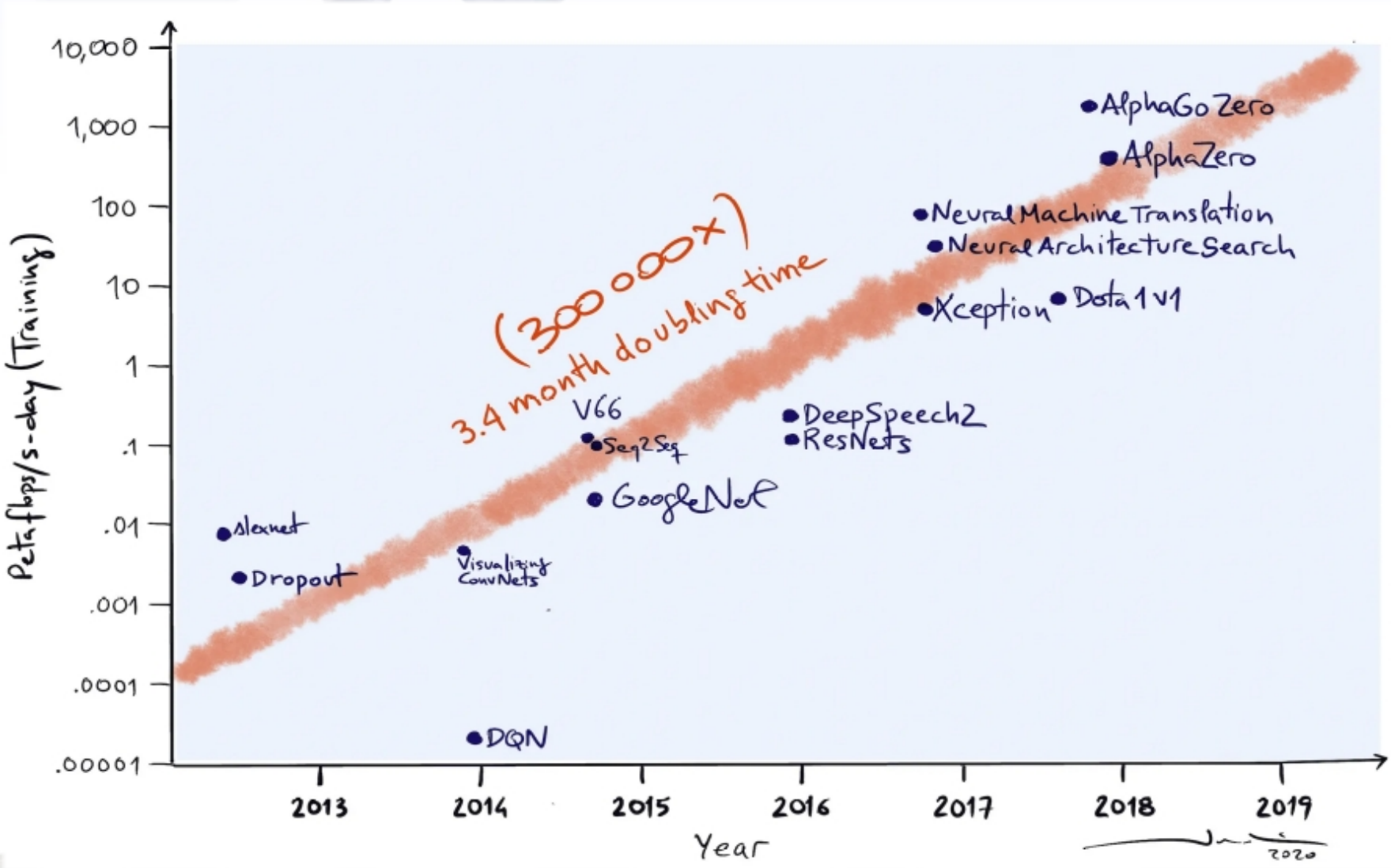
Compute Vs Intellectual Capability

- **Human Brain:**
- **1 Exa FLOPS**
- **Memory 100 Peta bytes**
- **100 Tera OPS @ 10 W**



https://www.theguardian.com

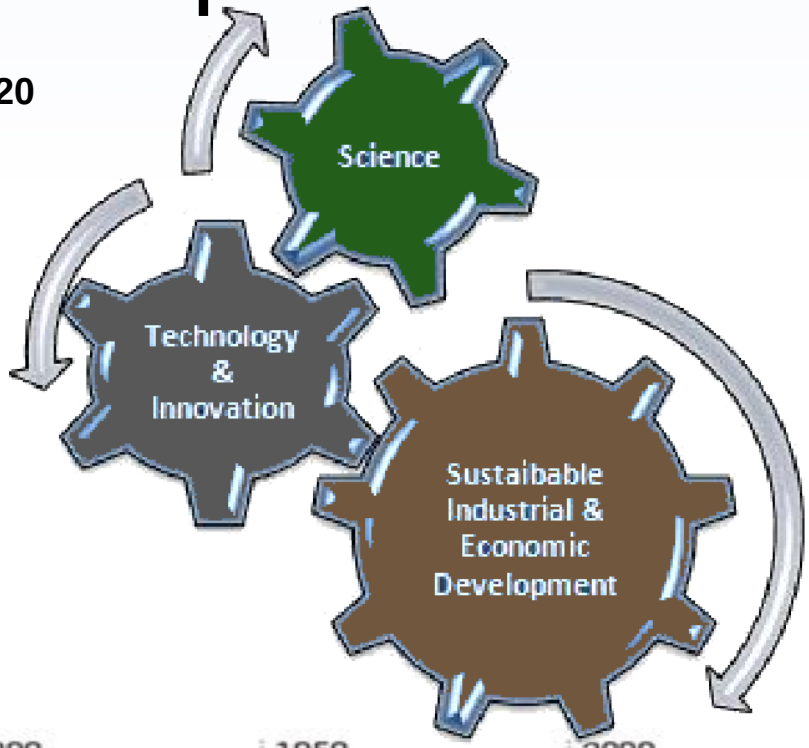
AI Computational Requirements

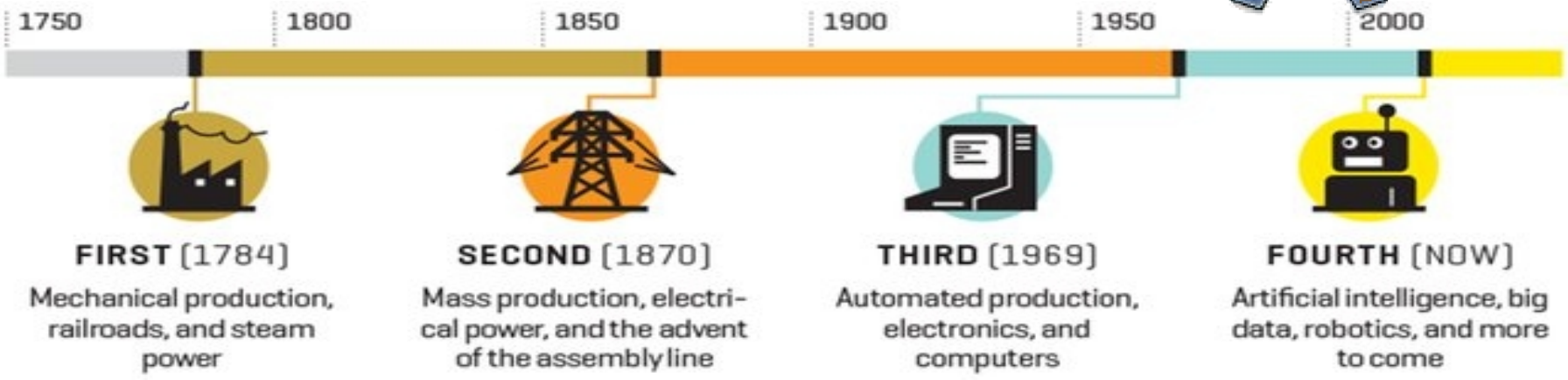


https://towardsdatascience.com/artificial-intelligence-is-a-supercomputing-problem-4b0edbc2888d

Industrial Revolutions and Sustainable Developments

Top 10 Biggest Companies By Market Size From 2010 - 2020





Ecosystem of Modern Industry

Life Science

Earth Science

Social Science

Science

175 ZByte @2025

80%
Data-Sciences

Data

100 ExaFLOPS
@2020

87.04 B$

234.6 B$ @2025

AI

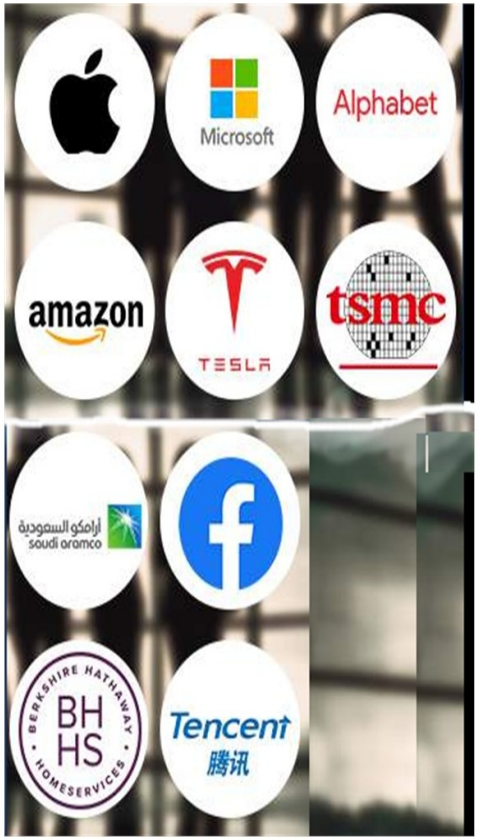
Top500 List
8 PetaFLOPS
@2022

uProcessor
100 B$ @2020

30% Cell Phone
20% Embedded
App
50 Servers, PCs etc.

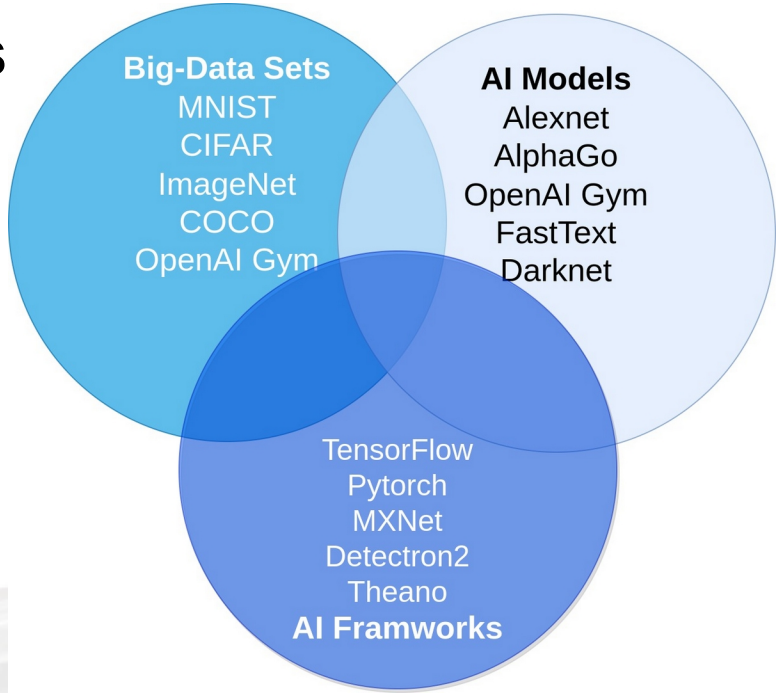
Computing

Digital Industrial Age
5.5 Trillion $ Revenue@2021

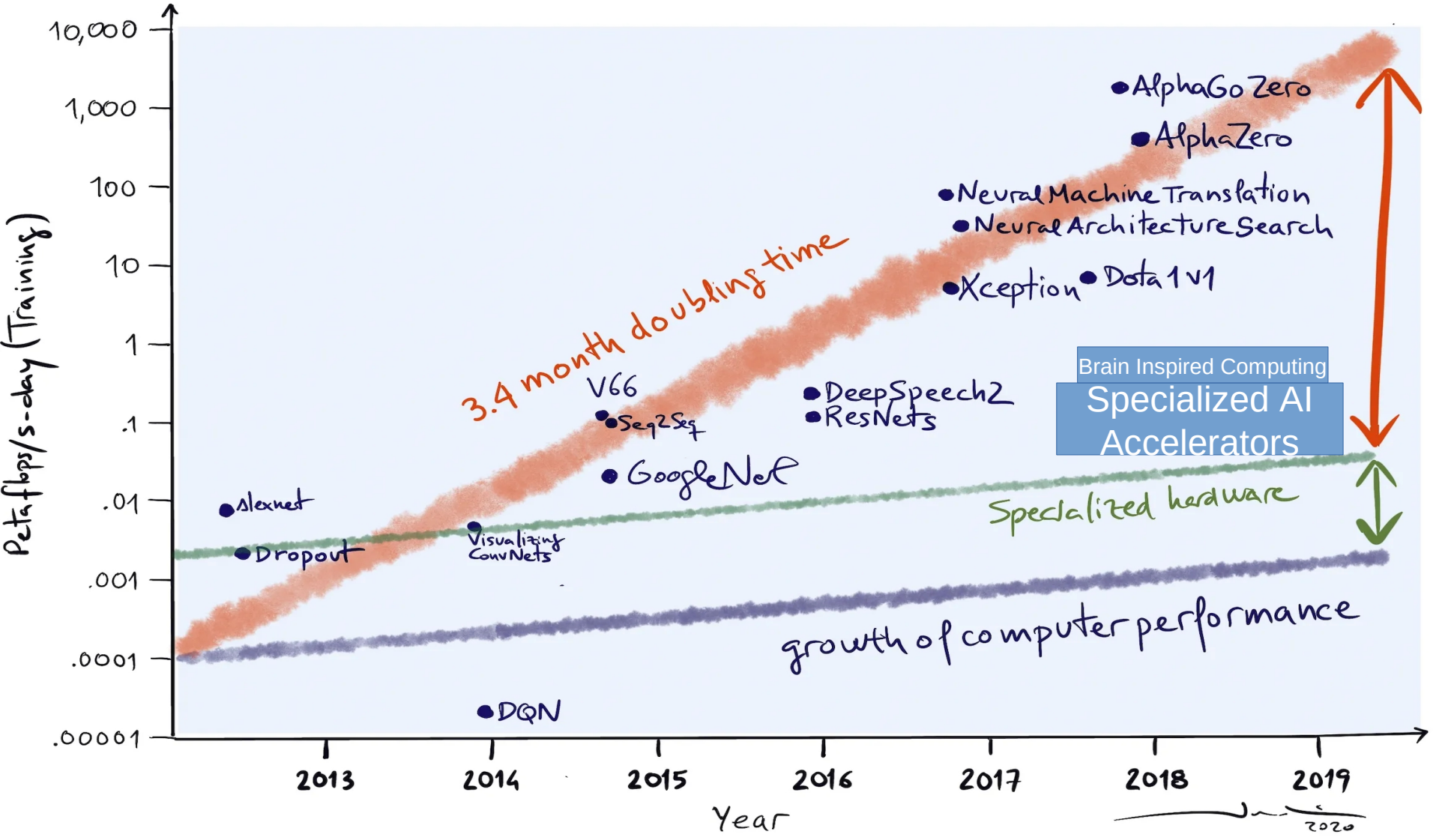


Open source tools democratizing the world

- GCC has **revolutionized** the software industry.
- Linux has **revolutionized** computing industry.
- AI models have **revolutionized** intelligent computing.
  - **Open-source AI Frameworks**
  - **Open-source Data-source**
  - **Open-source AI Models**



AI and Specialized Accelerators Performance Gap



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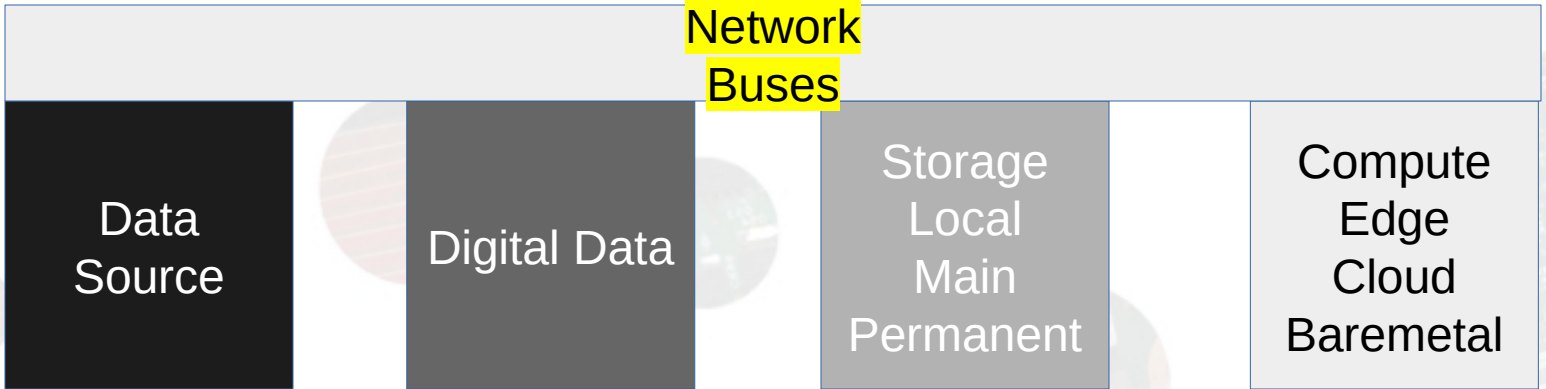
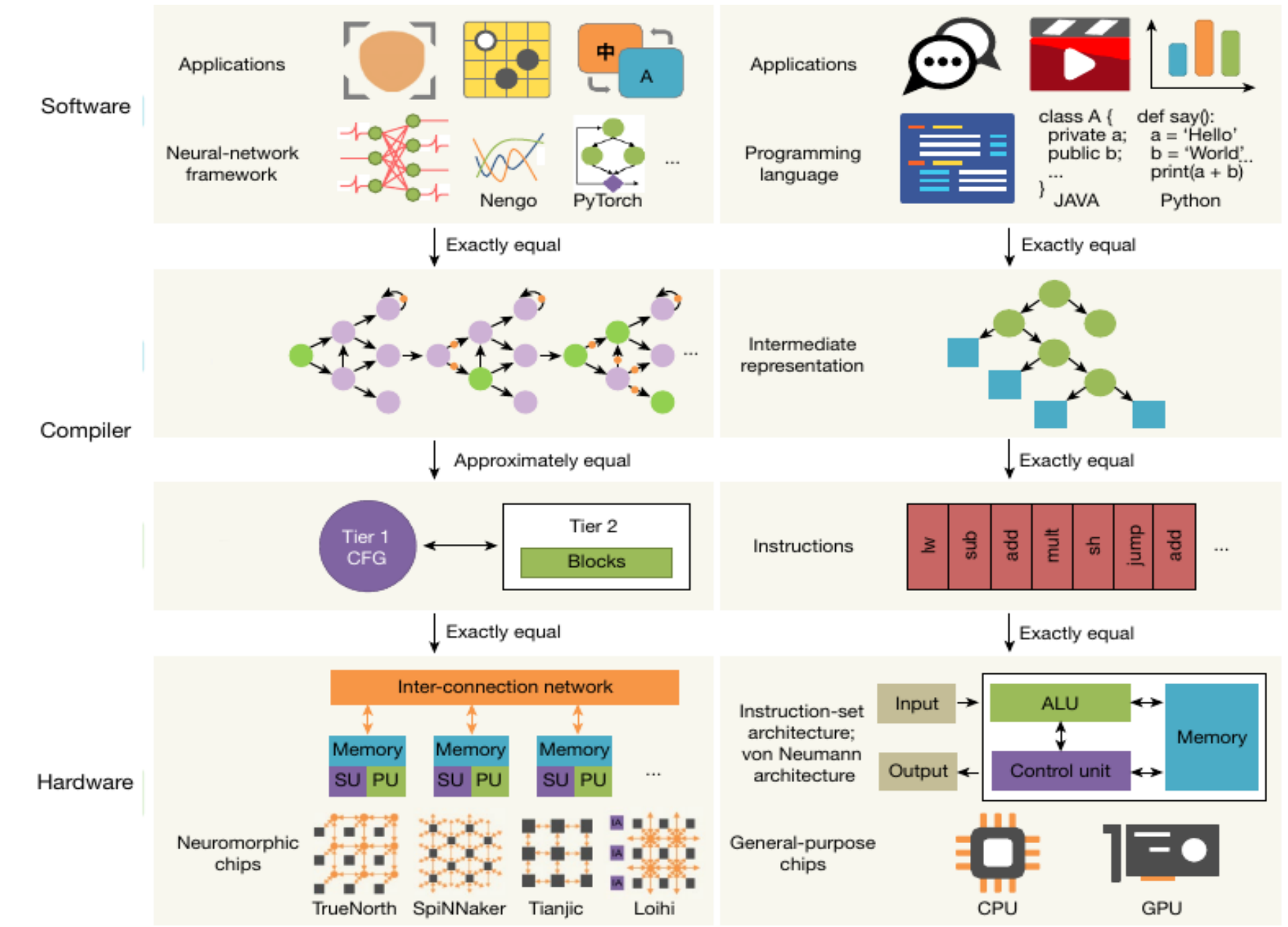
Computing Architectures to Solve AI Problems

- Smart Sensors
- Processor in Memory (PIM)
- Processing-in-Storage
- Processor in NIC (Network Interface Card)
- Compute-in-Edge Devices
- Brain Inspired Computers




Software
Applications
Neural-network framework
Nengo
PyTorch
...
Applications
Programming language
class A {
private a;
public b;
...
}
JAVA
def say():
a = 'Hello'
b = 'World'
print(a + b)
Python
Exactly equal
Exactly equal
Compiler
...
Intermediate representation
Approximately equal
Exactly equal
Tier 1 CFG
Tier 2
Blocks
Instructions
lw
sub
add
mult
sh
jump
add
...
Exactly equal
Exactly equal
Hardware
Inter-connection network
Memory
SU
PU
Memory
SU
PU
Memory
SU
PU
...
Neuromorphic chips
TrueNorth
SpiNNaker
Tianjic
Loihi
Instruction-set architecture; von Neumann architecture
Input
Output
ALU
Control unit
Memory
General-purpose chips
CPU
GPU

Democratization in Microelectronics

- GCC has **revolutionized** the **Software Industry**.
- Linux has **revolutionized** Computing Industry.
- AI models have **revolutionized** Intelligent Computing.
- Open Hardware is **revolutionizing** the Secure Computing.
- Open Silicon is next => Indigenous Development.

The Power of Open Source: Innovation, Flexibility, and Security

Research and Innovation

Customization and Flexibility

Reducing Costs

Accelerating Development

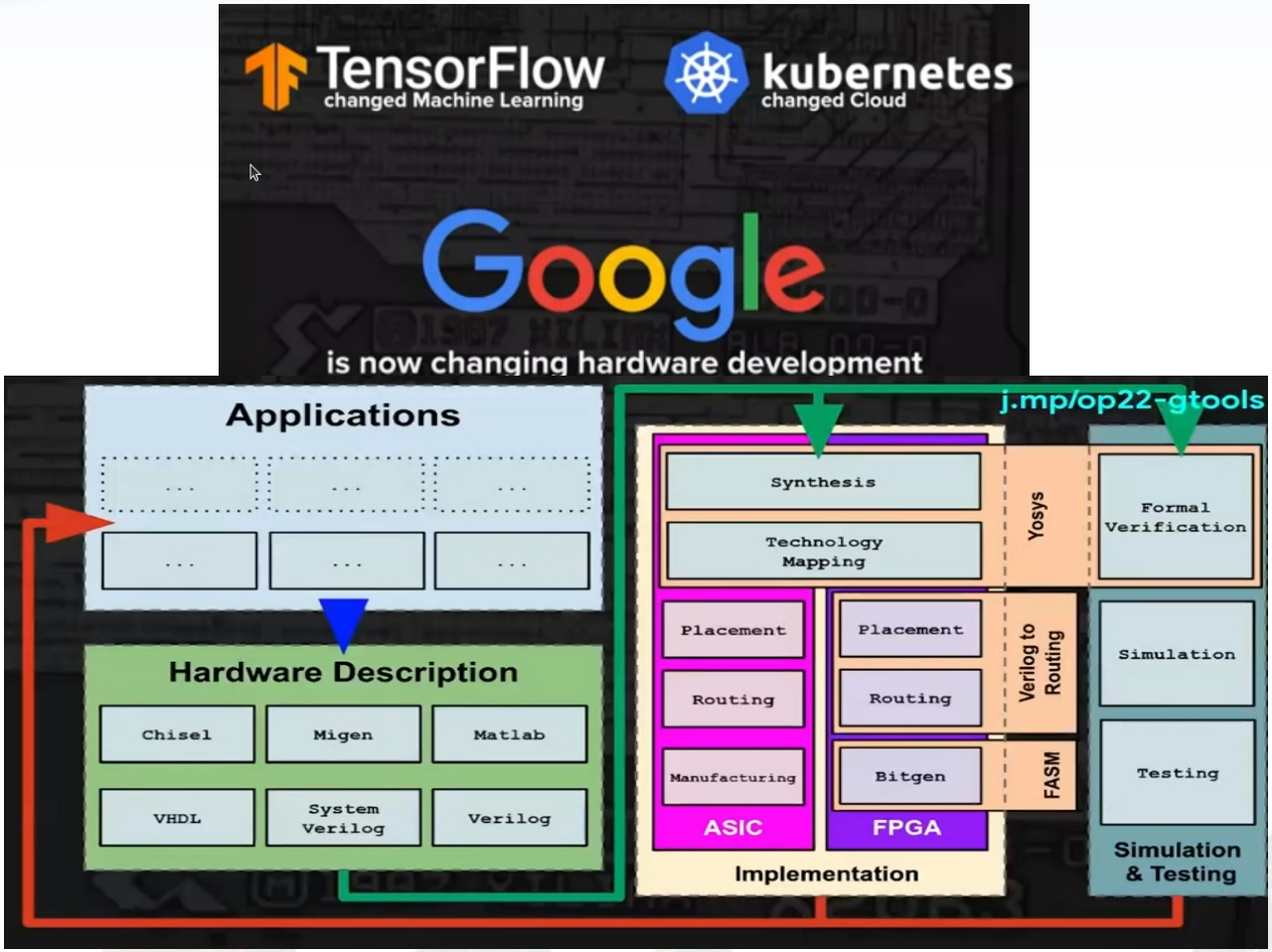
Community Collaborations

Transparency and Trustworthiness

Reduced Dependence on Proprietary Solutions

Secure and Trusted Execution

Open Source Tool for Hardware Development



SkyWater PDK (Process Design Kit), in collaboration with organizations like eFabless

Hardware Design Going to Follow Journey of Software Design

Open-Source	Software	Hardware
High-Level Languages	Python, Ruby, R, Javascript, Julia	**Chisel, PyMTL, PyRTL, Myhdl, JHDL, Cλash, Calyx, Dfiant**
Libraries	C++ Stl, Python Std Libs	**Basejump**
Tool Chains	GCC, LLVM, CPython, MRI, PyPy, V8	**Icarus Verilog, Verilator, Qflow, Yosys, Timberwolf, Qrouter, Magic, Klayout, Ngspice**
Standards	POSIX	**RISC-V ISA, ROCC, Tilelink**
Systems	Linux, Apache, Mysql, Memcached	**RocketChip, Pulp/Ariane, OpenPiton, ChipYard, BOOM, FabScalar, MIAOW, Nyuzi**
Methodologies	Agile Software Design	**Agile Hardware Design**
Cloud	IaaS, Elastic Computing	**IaaS, Elastic Cad**

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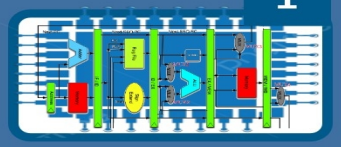


1

Digital System and Microprocessor Architecture

OpenHardware, Processor Architecture and ISA

RISC-V

open source hardware

2

3

QEMU

gem5

Simulation and FPGA Testing

Programming Assembly Embedded C

ASM

C Embedded

4

SoC Architecture, CH32V00

5

Single Board Computer (SoC, MMU, Memory Mapping)

6

7

Embedded Linux Compiler and Tool Chain

Python

GCC

Linux

IoT

EDGE COMPUTING

Edge Computing Sensors Network, IoT

8

9

Cloud Computing

openstack

Distributed Operating System

openHPC

Baremetal Distributed Computing Suprecomputing

10

data analytics

MACHINE LEARNING

11

Machine Learning Python Hadoop, Spark

Large Vision Models

LLM

TensorFlow

Deep Learning LVM, LLMs

12

13

Distributed Deep Learning

HOROVOD

deepspeed

Distributed TensorFlow

OpenMP

MPI

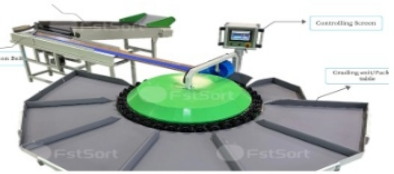
Distributed and Offloading Programming

14

Cloud and Cluster As a Service

Chip Design Cluster
Agri-tech Cloud
Health Science Baremetal

15



Sensors Netowrk, IoT, Automation Fields, Farms, Processing Units and Research Labs

Real Time Computing
Decision Support System

Edge Computing Network

Edge Computing
Basic Analysis, Pre-Processing
Weak-AI, Machine Learning

Edge-to-Cloud Connectivity

Cloud Computing
Classification, Prediction
Deeap Learning

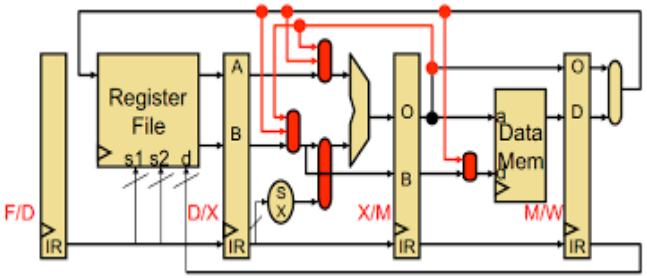
Cloud-to-Bare Metal Network.

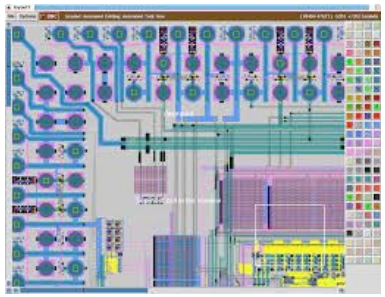
Supercomputing
HPC, Big-Data Processing
Deep/Reinforcement Learning

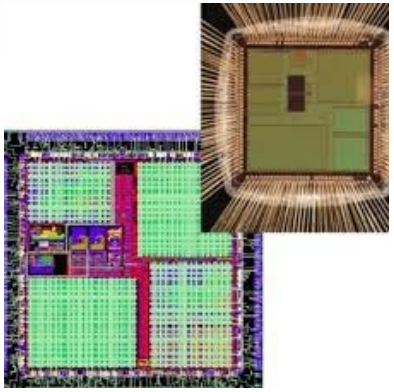
User Access
Baremetal: ssh namal-hpc@10.0.0.154
Cloud Application: http://10.0.0.153:8501/

Centre for AI and BigData

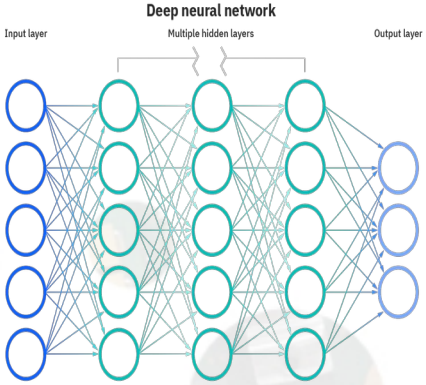
- **OpenSource Full-Stack Ecosystem for Secure Digital Systems**





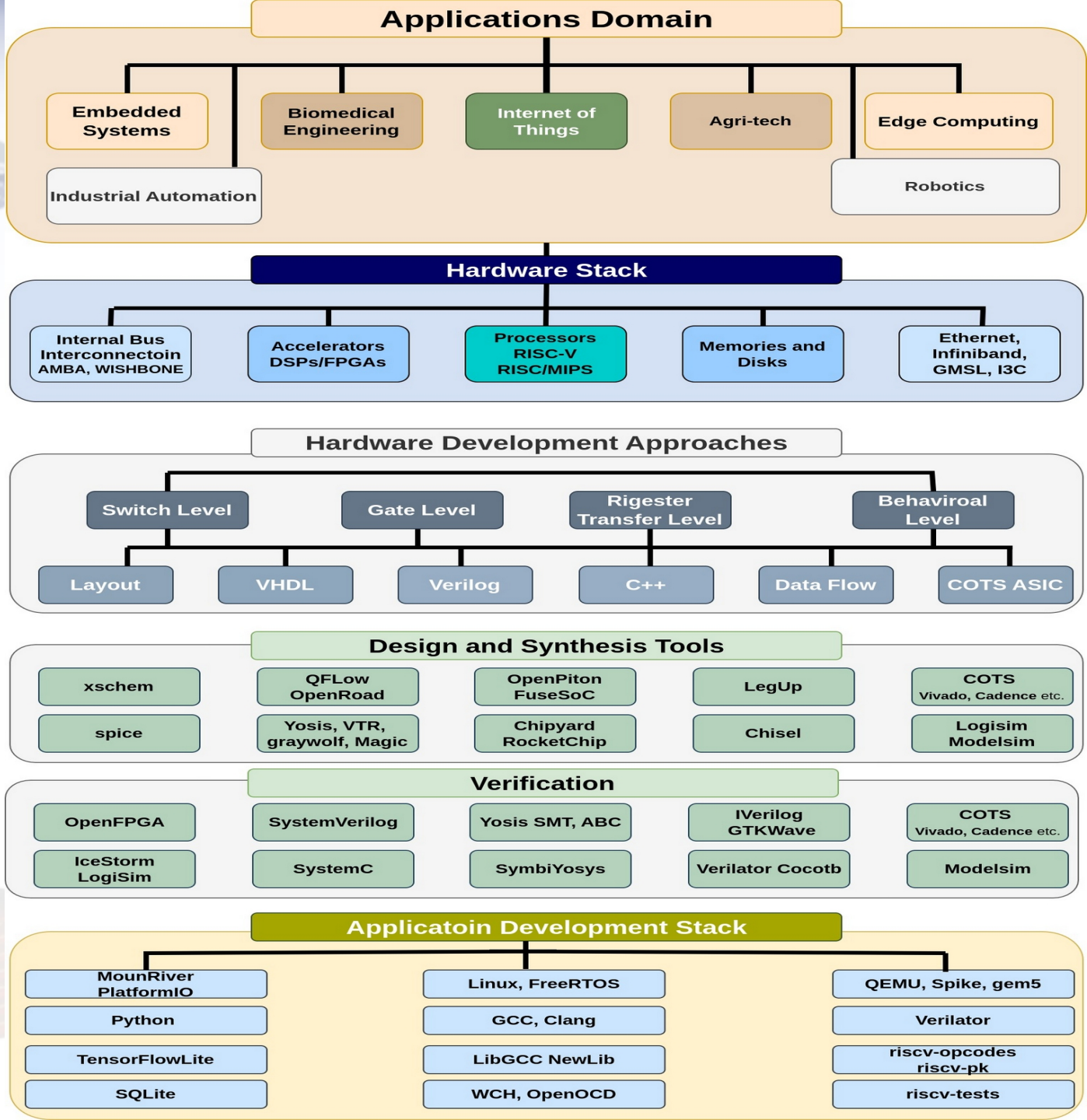


- **Supercomputing for AI and BigData Applications**



OpenSource Full-Stack Ecosystem for Secure Processor Architecture

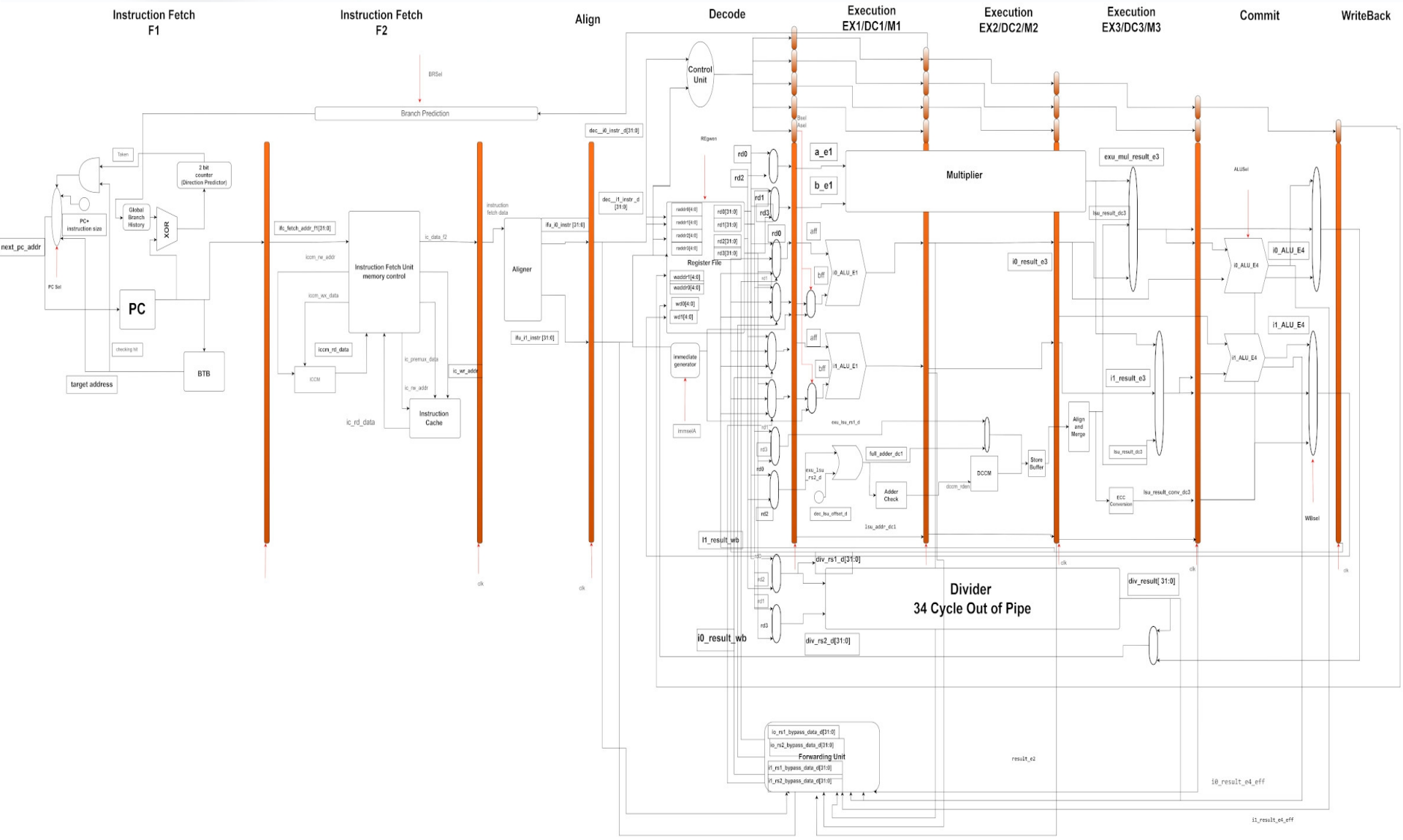
- **Hardware Architecture**
  - Low Power and Low Cost Digital System
  - Uni/Multi Core System on a Chip
- **Single Board Computer**
  - Hardware Software Co-Design
  - High Performance Computing
- **Intelligent and Real-time Applications**
  - Industrial Automation
  - Machine Learning


Applications Domain
Embedded Systems
Biomedical Engineering
Internet of Things
Agri-tech
Edge Computing
Industrial Automation
Robotics
Hardware Stack
Internal Bus Interconnectoin AMBA, WISHBONE
Accelerators DSPs/FPGAs
Processors RISC-V RISC/MIPS
Memories and Disks
Ethernet, Infiniband, GMSL, I3C
Hardware Development Approaches
Switch Level
Gate Level
Rigester Transfer Level
Behaviroal Level
Layout
VHDL
Verilog
C++
Data Flow
COTS ASIC
Design and Synthesis Tools
xschem
QFLow OpenRoad
OpenPiton FuseSoC
LegUp
COTS Vivado, Cadence etc.
spice
Yosis, VTR, graywolf, Magic
Chipyard RocketChip
Chisel
Logisim Modelsim
Verification
OpenFPGA
SystemVerilog
Yosis SMT, ABC
IVerilog GTKWave
COTS Vivado, Cadence etc.
IceStorm LogiSim
SystemC
SymbiYosys
Verilator Cocotb
Modelsim
Applicatoin Development Stack
MounRiver PlatformIO
Python
TensorFlowLite
SQLite
Linux, FreeRTOS
GCC, Clang
LibGCC NewLib
WCH, OpenOCD
QEMU, Spike, gem5
Verilator
riscv-opcodes riscv-pk
riscv-tests

Digital System Design Flow

- Diagramming
- Simulation and Emulation
- Digital System Design
- System Integration
- Functional Verification
- Formal Verification
- Timing Analysis
- FPGA Prototyping
- Physical Design

Diagramming Micro-Architecture

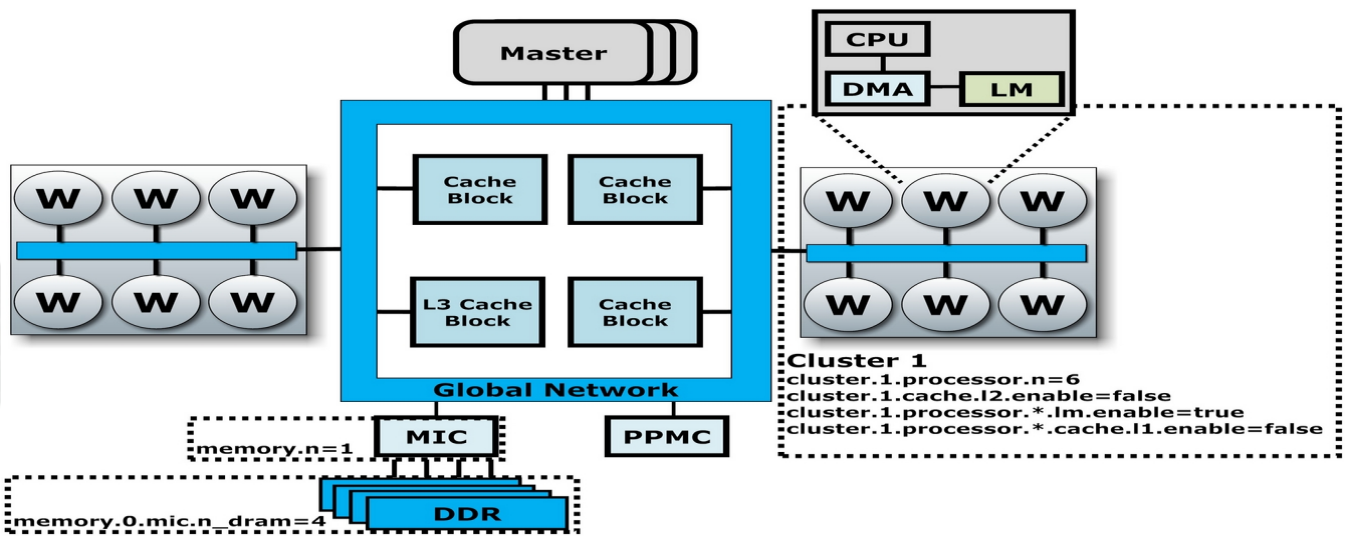


Simulation and Emulation

Spike: Functional, instruction-level accurate simulator for RISC-V ISA.

QEMU: Functional simulator with instruction-level accuracy for various architectures.

Gem5: Cycle-level accurate simulator for modeling detailed microarchitecture and system performance.



Digital System Design

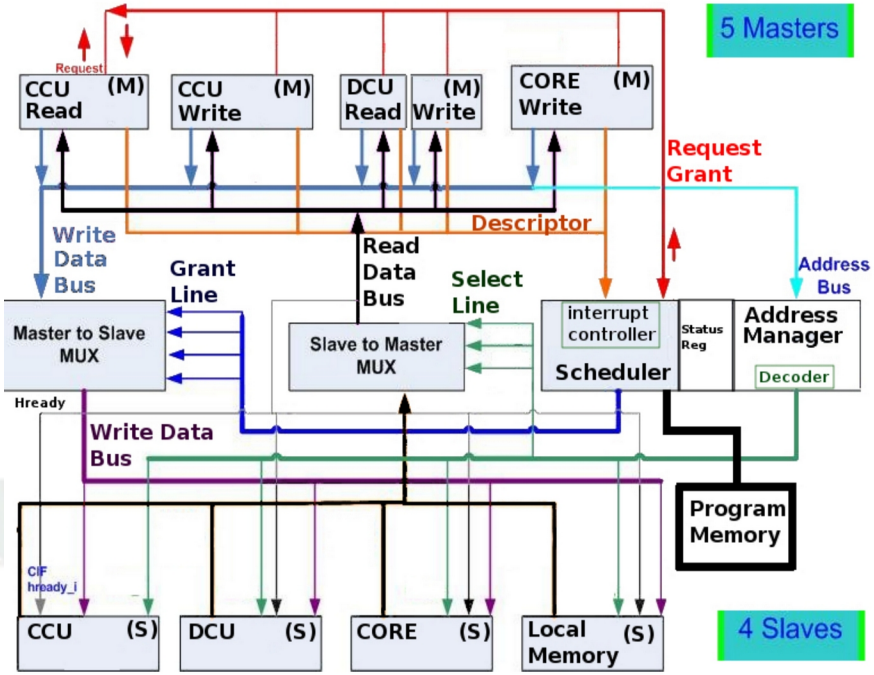
- Switch Level
- Gate Level
- Register Transfer Level
- System / High Level

System Integration (SoC)

FuseSoC: A hardware IP management tool and build system that simplifies the integration of reusable IP blocks and automates the FPGA and ASIC build processes..

OpenPiton: A scalable, open-source manycore processor framework that can be integrated into custom research and industrial applications.

LiteX: A flexible and efficient framework for creating SoC designs using open-source hardware IPs and toolchains, with support for a variety of FPGAs and CPUs.



Functional Verification

Cocotb (Cocotestbench): A coroutine-based Python testbench framework for verifying HDL designs using high-level, Python-driven simulations.

SVUnit: A SystemVerilog unit testing framework designed for functional verification of hardware designs through automated test generation and execution.

Formal Verification, Physical Design and Timing Analysis:

SymbiYosys (Sby) integrates with backend tools such as Yosys and SMT solvers to formally verify properties like safety and liveness in hardware circuits. It helps to ensure correctness by exhaustively checking the design against specified constraints.

OpenSTA and OpenTimer for Timing Analysis.

Physical Design: OpenRoad, QFlow, Yosys, and Magic

Supercomputing Platform for AI and BigData Applications

- **Bare-Metal and Containerized Cluster Infrastructure:**
  - Distributed Hardware Interfacing, Network Configuration and Distributed Computing Software Deployment
- **Data Center and Cloud Infrastructure:**
  - Storage systems, networking equipment, and software configuration
- **AI Applications for Scientific and Engineering Problems**
  - Distributed AI applications for multi-node bare-metal system
- **HPC Application Parallel Programming**
  - Heterogeneous multi-node parallel processing using parallel programming models

Applications Services

- Data Sciences
- Health Science
- Social Sciences
- Agriculture
- High Performance Computing
- Modeling and Simulation
- Web (IoT, VLSI Design)

Development Frameworks and Libraries

- Interactive
- GCC
- Python
- OpenMP
- MPI
- CUDA
- OpenACC
- OpenCL
- TensorFlow
- Horovod
- Hadoop
- PowerAI
- DeepSpeed
- Spark

Distributed System & Software Stack

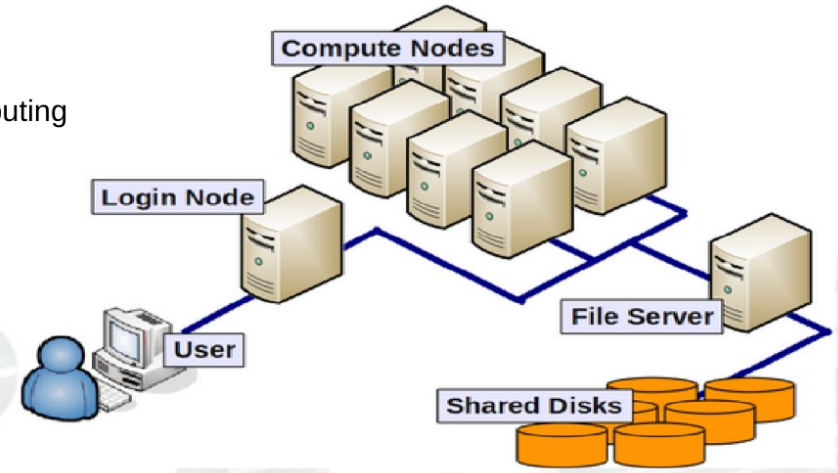
- OpenHPC, ROCKS
- OpenShift, xCAT Nutanix Acropolis
- Open-Stack Kubernetes
- Linux Kernel: OpenPBS, PBS-Pro, SLURM, Ganglia , Open vSwitch, warewolf, Lustre, BeeGFS, Ceph, Mellanox OFED, IPoIB, OpenEth, Network Information Service, ACPI
- Rolls, Singularity Image, Docker, Contrainer

Hardware System

- Intelligent RACK infrastructure PDU, PMS
- Accelerators GPU/TPU/FPGAs
- Multi-core CISC/SuperScalar
- SAN/NAS, SSDs/NVMe
- High-Speed Ethernet, Infiniband

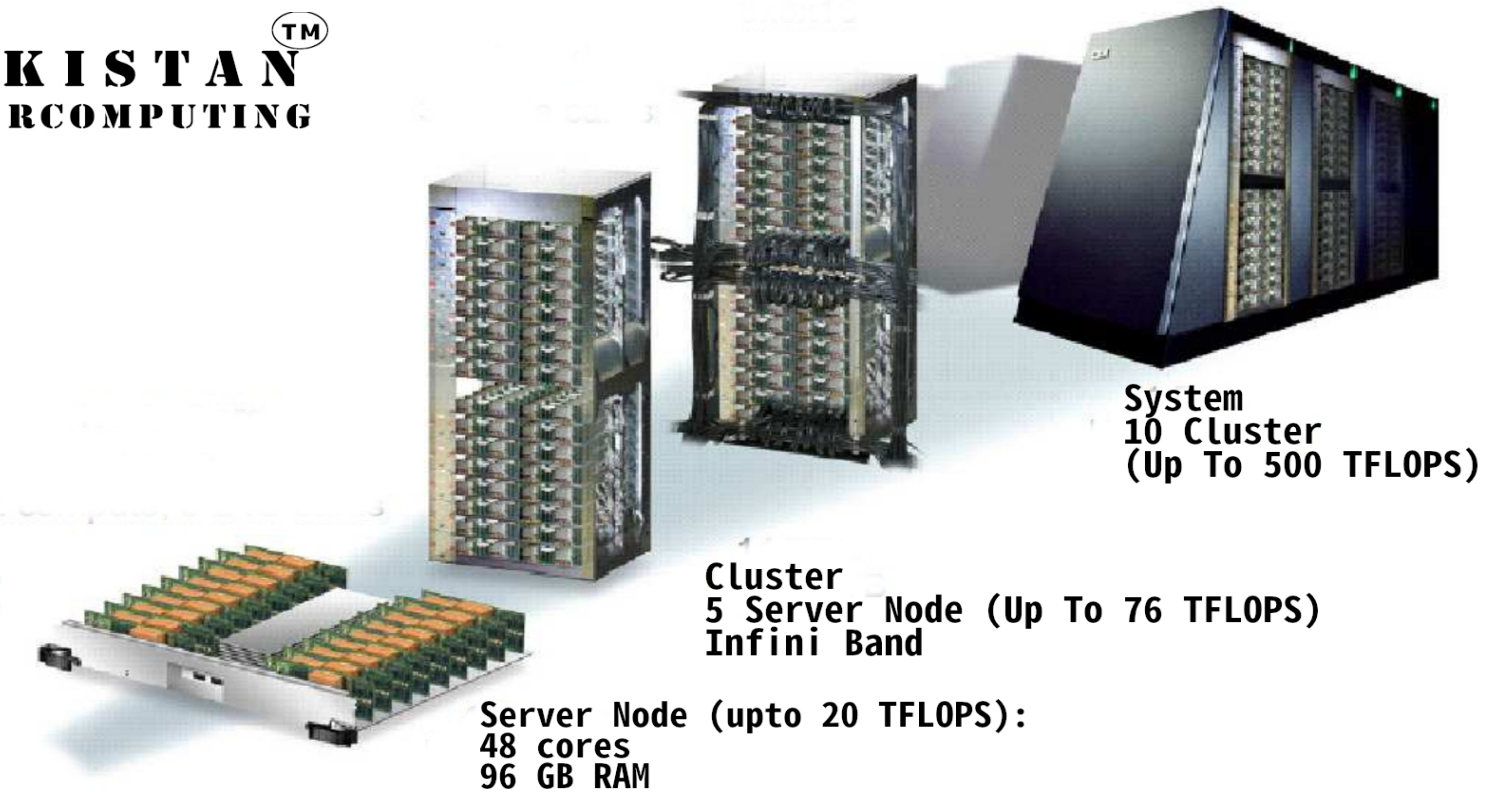
Supercomputing Platform with 20 Servers Compute Nodes

- **Each node having:**
  - Two XEON processors Intel(R) E5-2673 v4, 128 GB Main Memory
  - NVIDIA GPUs Ada Architecture 24GDDR
- **Storage: 50 TByte SSD**
- **Linux Operating system**
- **Interconnection Fast Ethernet**
- **Open Source Software stack**
  - Cloud, Baremetal and Embedded System
  - Parallel Programming and Scientific Computing
  - Chip Design
  - Distributed Artificial Intelligence
- **Application Development**
  - Digital System and VLSI Design
  - Parallel Processing, AI and BigData
  - IoT, Edge Computing
  - Modeling and Simulations



Developing Supercomputing for AI

PAKISTAN SUPERCOMPUTING™



System
10 Cluster
(Up To 500 TFLOPS)

Cluster
5 Server Node (Up To 76 TFLOPS)
Infini Band

Server Node (upto 20 TFLOPS):
48 cores
96 GB RAM
1 TB Disk
2 GPUs

CentOS Linux

Chip
4 cores
XEON Processor

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

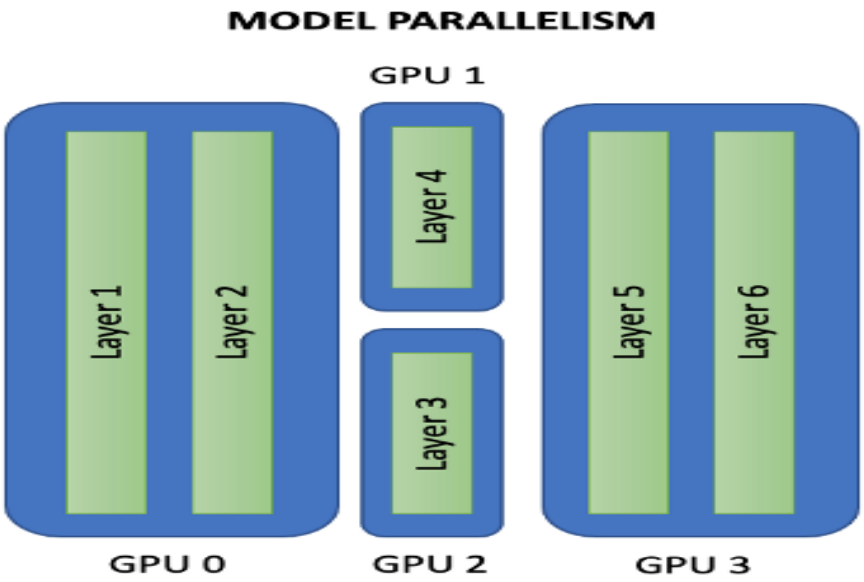
AI Model Parallelism

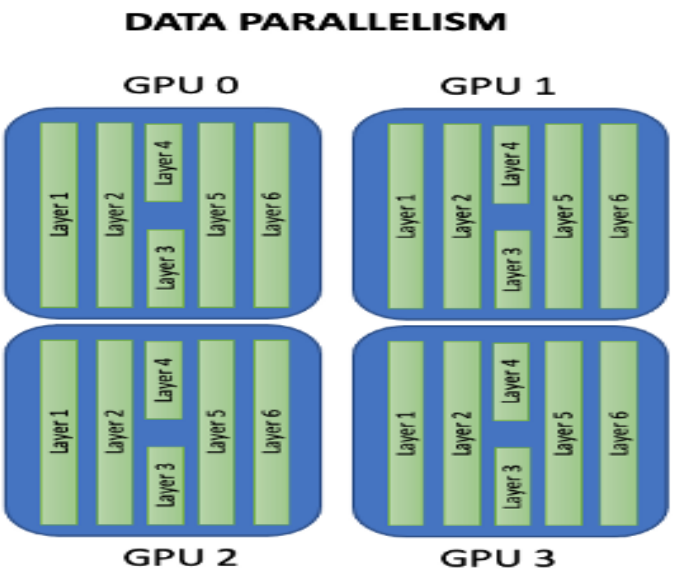
- **Model Parallelism**

  Different layers of the network distributed across different devices

- **Data Parallelism**

  Same model in every one of the GPUs, each processing a separate piece of the data, a separate portion of the mini-batch.





Achievement

Bare-metal Cluster

- 1 Peta FLOPS
  - Chip Design FOSSS RTL-GDS

Cloud Applications

- Agri-Rice Classification (Online Application Industrial Partner Alkaram Rice)
- Live Stock Breed Identification (Application Punjab LiveStock)
- Soil Analysis (Completed App)
- Foot Analytic for Rehabilitation (Startup)

Digital Systems

- FPGA based Computer Vision System for Rice Color Sorting (Funding Secured)
- BLDC Motor Controller

Sept 2023 – June 2024

a) Specialized Training

- **4 Schools and Workshop**
- **20 Talks**

b) Linkages and Collaborations

50+ Organizations

c) Research and Publications

- **1 I.F. Journal**
- **3 Conference Paper**

d) Innovation and Prototype

- **4 MVP**
- **6 FYPs (Cloud Applications)**

f) Fund Grant Hunting

- **Submitted 24 Million PKR**

g) Services and Consultancy

h) Technology Transfer

i) Revenue Generated

- **1.5 Million PKR**

Free Open Source Software Stacks and Open Hardware Technologies: Revolutionizing the World

by: Tassadaq Hussain

Professor Department of Electrical Engineering

Director Centre for AI and BigData

Namal University Mianwali

Collaborations:

Barcelona Supercomputing Center, Spain

European Network on High Performance and Embedded Architecture and Compilation

Pakistan Supercomputing Center