Fugaku as the Centerpiece of Society5.0 Revolution

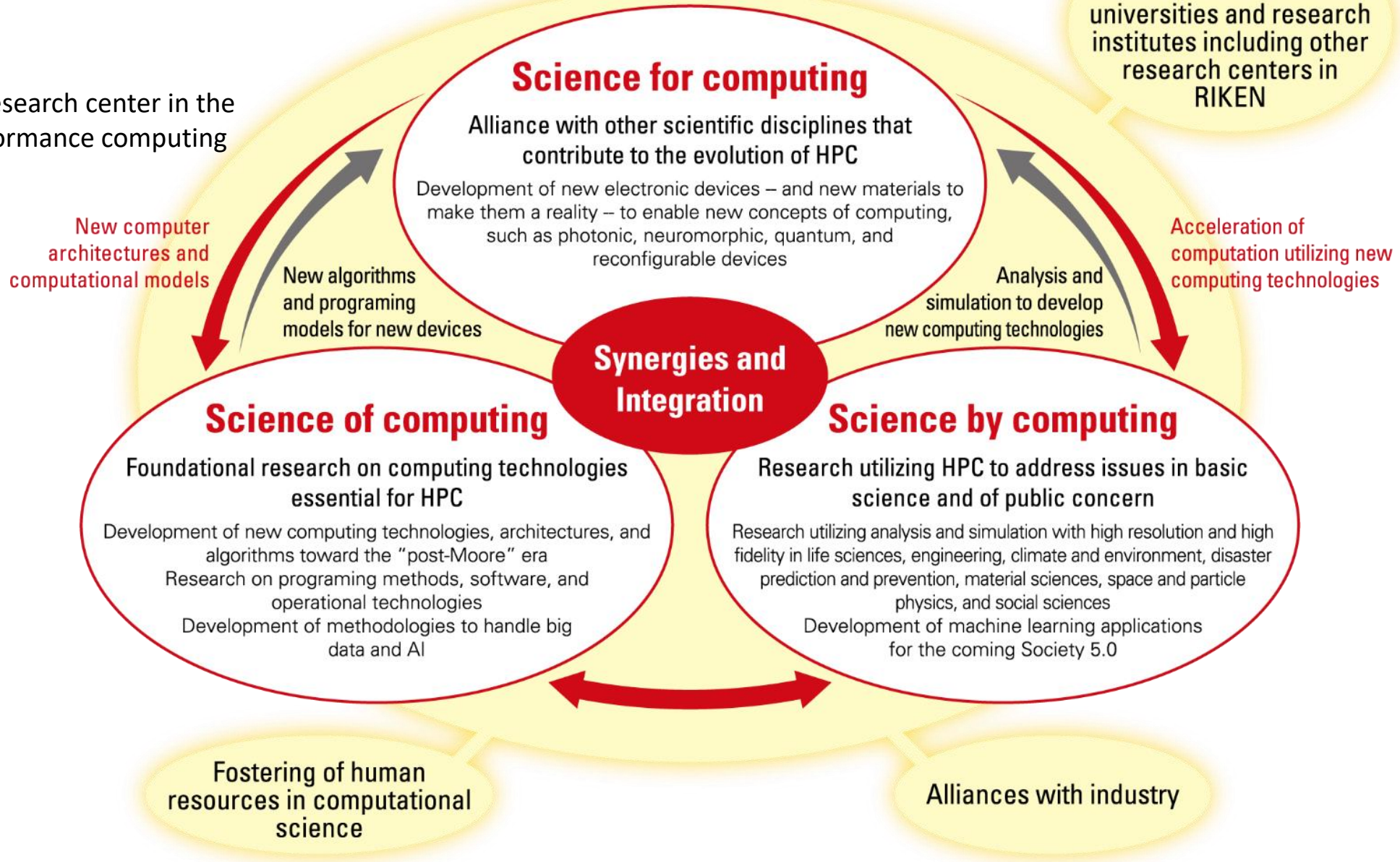
- *Satoshi Matsuoka*
- *Director, RIKEN Center for Computational Science*

- **20200218 R-CCS Symposium Keynote @ Kobe**

Science of Computing by Computing for Computing

R-CCS

International core research center in the science of high performance computing (HPC)



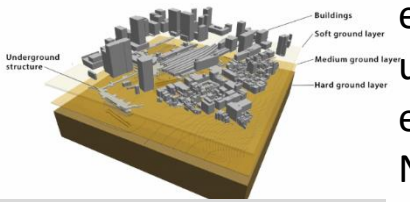
III Achievements

First 'Exascale' SC: Fugaku R&D

Fugaku/post- K rack, CPU (prototype) ©Fujitsu

- R&D started since the genesis of the center, to **design & build world's first "exascale" supercomputer**
- Fugaku construction official approval to build by the government on Nov. 2018
- **Installation start Dec. 2019, operations to start early 2021**

Groundbreaking Apps: E.g., Large-scale Earthquake disaster simulation w/HPC & AI



Modeling of bldgs., underground structures, with geological layers ©Tokyo Univ.

Ultra large scale earthquake simulation using AI for massive scale earthquake in Tokyo area. Nominated as **finalist of Gordon bell 2018**. Winning **SC16, 17 Best Poster Award.**

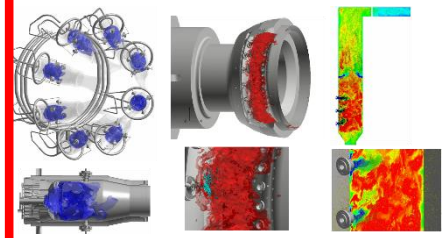
Top-Tier Awards HPC

High Speed algorithm for analyzing social networks won **Best paper Award** at HiPC.

Contribution of Dr. Matsuoka has awarded at **ACM HPDC 2018 Achievement Award** also **Asia HPC Leadership Award** at supercomputing Asia 2019.

Industry outreach e.g. RIKEN Combustion System CAE Consortium

RIKEN Consortium to develop next generation CAE for combustors has established with **11 industries and 9 academia** members. It would expand the users of **R-CCS Software** as well as **Fugaku**.



Simulation CAE examples

K computer (decommissioned Aug. 16, 2019)

Specifications

- Massively parallel, general purpose supercomputer
- No. of nodes: 88,128
- Peak speed: 11.28 Petaflops
- Memory: 1.27 PB
- Network: 6-dim mesh-torus (Tofu)

Top 500 ranking

LINPACK measures the speed and efficiency of linear equation calculations.
Real applications require more complex computations.

- No.1 in Jun. & Nov. 2011
- No.20 in Jun 2019

First supercomputer in the world to retire as #1 in major rankings (Graph 500)

Graph 500 ranking

"Big Data" supercomputer ranking
Measures the ability of data-intensive

- No. 1 for 9 consecutive editions since 2015

HPCG ranking

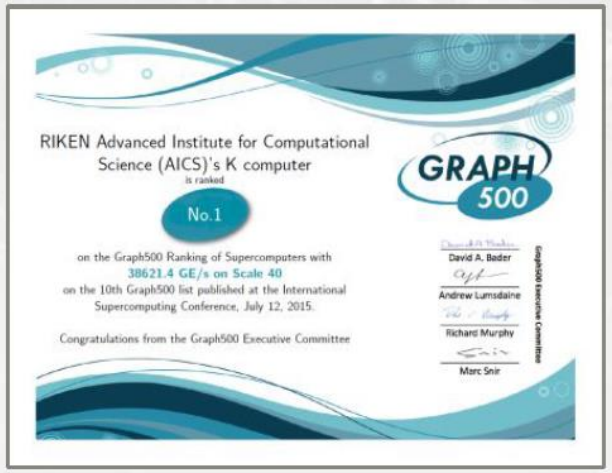
Measures the speed and efficiency of solving linear equation using HPCG
Better correlate to actual applications

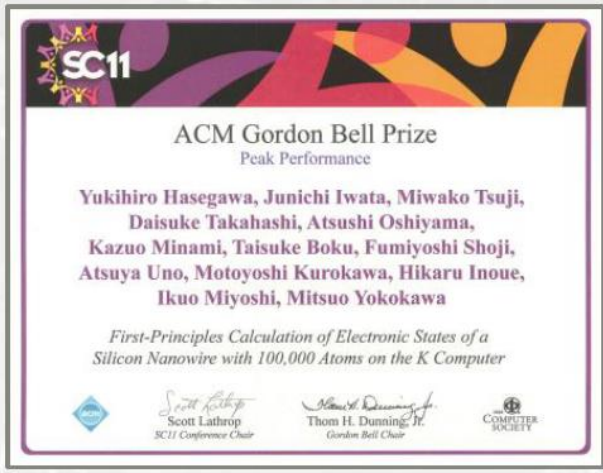
- No. 1 in Nov. 2017, No. 3 since Jun 2018

ACM Gordon Bell Prize

"Best HPC Application of the Year"

- Winner 2011 & 2012. several finalists





K-Computer Shutdown Ceremony 30 Aug 2019

2019年（令和元年）8月31日（土曜日）　12版　企業1　12

スパコン「京」歴史に幕

7年で計算速度一時トップ

「京」の前でメッセージを掲げる高校生（30日、神戸市）

理化学研究所は30日、神戸市の拠点でスーパーコンピューター「京（けい）」の電源を停止してシャットダウンした。2012年に本格稼働し、一時は計算速度の性能ランキングで世界首位に輝いた京だが、各国でスパコンの開発競争と性能の向上が急速に進むなかで、およそ7年の歴史に幕を下ろした。

30日午後に京が設置されている理研の計算科学研究センターでセレモニーがあり、理研や官公庁、企業などの関係者ら約200人が出席した。理研の松本紘理事長は「たいへん使いやすい良いコンピューターだった。一抹のさみしさはあるが（後継のスパコン）富岳（ふがく）に精神を引き継ぎたい」と述べた。

京の開発元である富士通の時田隆仁社長も「様々な分野で多くの成果を創出できたことを誇りに思う。京は今も世界最高クラスの技術を誇っており、技術的アプローチが正しかった」と話した。

その後、多数の装置が並ぶ京の計算機室で、代表4人の手で電源のスイッチが順に落とされ、出席者が見守るなか、午後3時25分ごろに計算機の発する機械音が鳴りやみ、機能を停止した。

京は近く解体が始まり、同じ場所に富岳が設置される。京の最大100倍以上という計算速度を目指し、21年ごろに運用が始まる予定だ。

ソニーと資

オリンパスにも

ソニーは30日、保有するオリンパス株すべてを売却したと発表した。ソニーが投資ファンドの米サード・ポイントにオリンパス株の売却を求められていた一方、オリンパスにも米ファンドの影がみえる。両社は共同出資会社を通じた医療機器事業は継続する。既に発売した2製品に続く道筋を両社で示せるかが問われている。

オリンパスが実施した自社株買いに応募し、ソニーは約800億円で全株を売却した。500億円で取得したオリンパス株を、2回に分けて計1500億円で売却した格

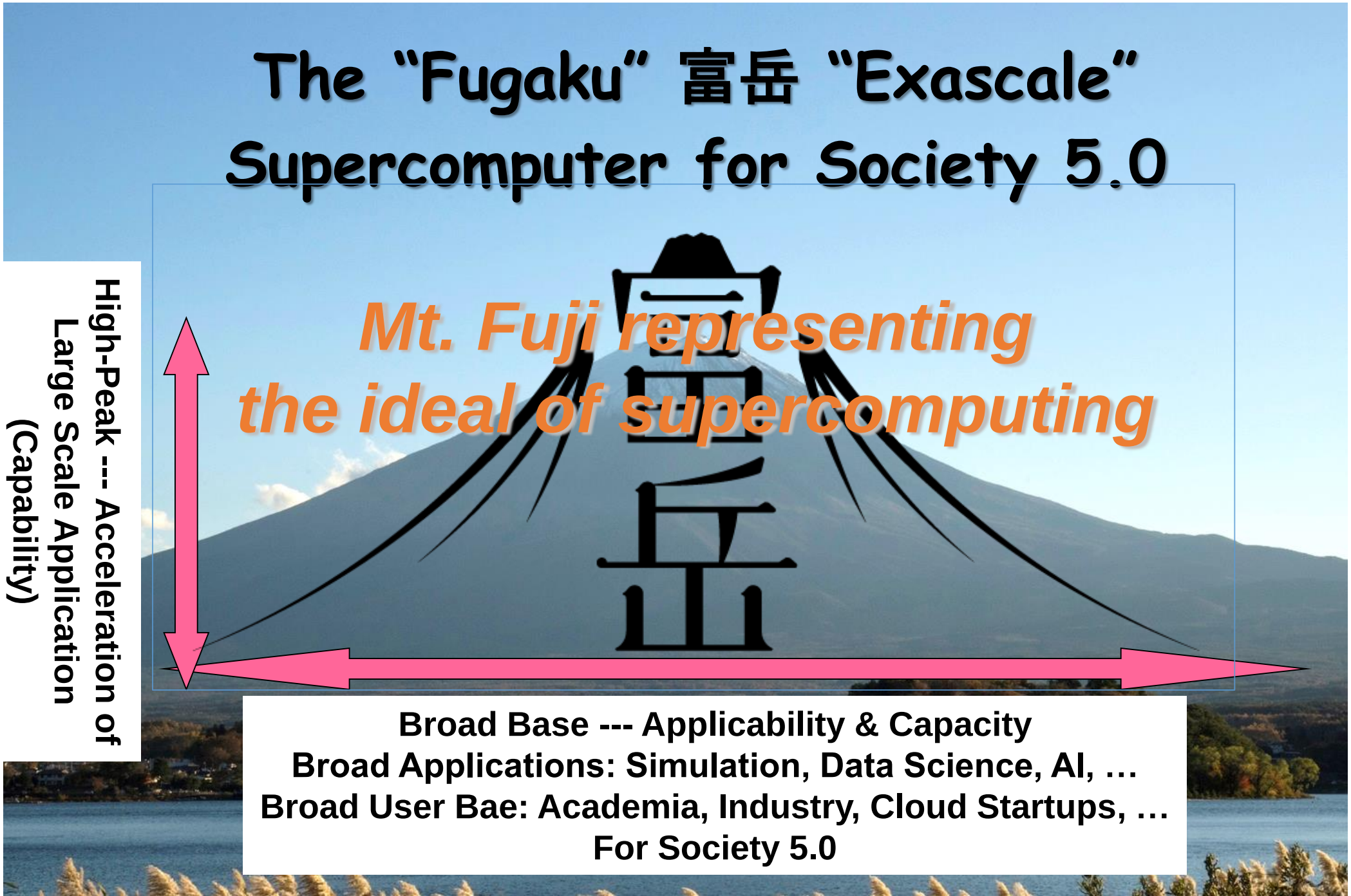
From K to Fugaku: Dramatic Change

Fundamental Change
Towards Society5.0

Fugaku

- **K: Focus mainly on Basic Science & Simulations**
  - Pro: Modernized Japanese SC to massively parallel
  - Con: Large-scale simulations are ‘transient’: great results but leaves success to scientific ‘chance’
    - Impact to IT, industry and society moderate
- **Fugaku: Centerpiece to Society 5.0**
  - Designed to have continuum to IT infrastructure at large (Arm, RHEL Linux, Container, Cloud)
  - High impact & ROI to IT, industry & society
  - Can sustain towards future for its value, fostering both basic science & Society 5.0 usage

The "Fugaku" 富岳 "Exascale" Supercomputer for Society 5.0

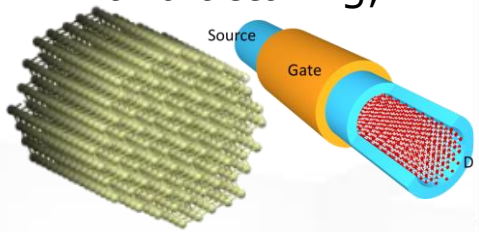


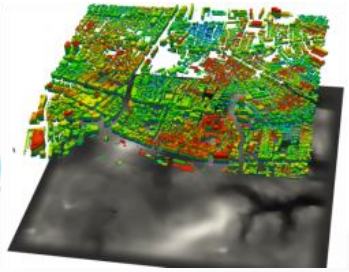
Co-Design Activities in Fugaku

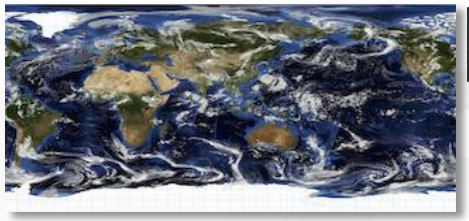
Multiple Activities since 2011

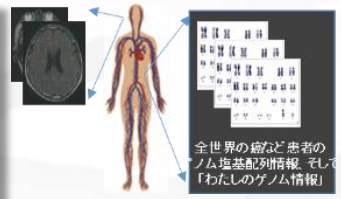
Science by Computing

・9 Priority App Areas: High Concern to General Public: Medical/Pharma, Environment/Disaster, Energy, Manufacturing, …









Select representatives from 100s of applications signifying various computational characteristics

Science of Computing

Design systems with parameters that consider various application characteristics

富岳

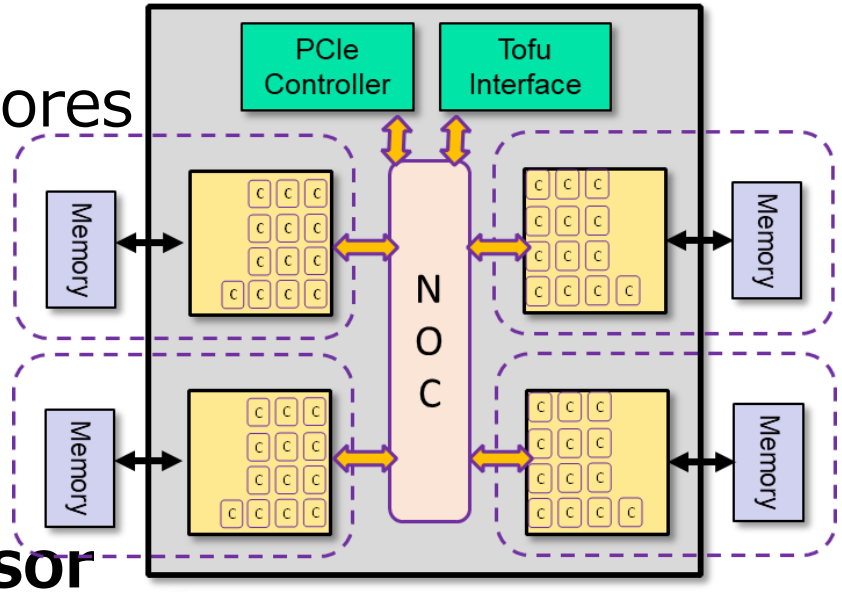
- **Extremely tight collabrations between the Co-Design apps centers, Riken, and Fujitsu, etc.**
- **Chose 9 representative apps as “target application” scenario**
- **Achieve up to x100 speedup c.f. K-Computer**
- **Also ease-of-programming, broad SW ecosystem, very low power, …**

Arm64fx & Fugaku 富岳 /Post-K are:

- **Fujitsu-Riken design A64fx ARM v8.2 (SVE), 48/52 core CPU**
  - ***HPC Optimized:*** Extremely high package high memory BW (1TByte/s), on-die Tofu-D network BW (~400Gbps), high SVE FLOPS (~3Teraflops), various AI support (FP16, INT8, etc.)
  - Gen purpose CPU – Linux, Windows (Word), other SCs/Clouds
  - Extremely power efficient – > **10x power/perf efficiency for CFD benchmark** over current mainstream x86 CPU
- **Largest and fastest supercomputer to be ever built circa 2020**
  - > 150,000 nodes, superseding LLNL Sequoia
  - > 150 PetaByte/s memory BW
  - Tofu-D 6D Torus NW, 60 Petabps injection BW (10x global IDC traffic)
  - 25~30PB NVMe L1 storage
  - The first 'exascale' machine (not exa64bitflops =>apps perf.)
  - **Acceleration of HPC, Big Data, and AI for Society 5.0**

Fugaku's FUjitsu A64fx Processor is…

- **an Many-Core ARM CPU…**
  - 48 compute cores + 2 or 4 assistant (OS) cores
  - Brand new core design
  - Near Xeon-Class Integer performance core
  - ARM V8 --- 64bit ARM ecosystem
  - Tofu-D + PCIe 3 external connection



- **…but also an accelerated GPU-like processor**
  - SVE 512 bit x 2 vector extensions (ARM & Fujitsu)
    - Integer (1, 2, 4, 8 bytes) + Float (16, 32, 64 bytes)
  - Cache + scratchpad-like local memory (sector cache)
  - HBM2 on package memory – Massive Mem BW (Bytes/DPF ~0.4)
    - Streaming memory access, strided access, scatter/gather etc.
  - Intra-chip barrier synch. and other memory enhancing features

- **GPU-like High performance in HPC, AI/Big Data, Auto Driving…**

Green500, Nov. 2019

A64FX prototype –
Fujitsu A64FX 48C 2GHz
ranked #1 on the list

768x general purpose A64FX CPU w/o accelerators

- 1.9995 PFLOPS @ HPL, 84.75%
- 16.876 GF/W
- Power quality level 2

The GREEN 500

HOME GREEN500 LISTS RESOU

Home / Lists / November 2019

NOVEMBER 2019

- The most energy-efficient system and No. 1 on the Green500 is a new Fujitsu A64FX prototype installed at Fujitsu, Japan. It achieved 16.9 GFlops/Watt power-efficiency during its 2.0 Pflop/s Linpack performance run. It is listed on position 160 in the TOP500.
- In second position is the NA-1 system, a PEZY Computing / Exascaler Inc. system which is currently being readied at PEZY Computing, Japan for a future installation at NA Simulation in Japan. It achieve 16.3 GFlops/Watt power efficiency. It is on position 421 in the TOP
- The No 3 on the Green500 is AiMOS, a new IBM Power systems at the Rensselaer Polytechnic Ins Computational Innovations (CCI), New York, USA. It achieved 15.8 GFlops/Watt and is listed at pos


富岳 省エネ世界一 スパコン「京」の後継

富士通と理化学研究所は18日、スーパーコンピューター「京」の後継となる「富岳」の試作機が、スパコンの省エネ性能のランキング「グリーン500」で世界1位になったと発表した。消費電力1ワット当たり毎秒16.8億回の計算を達成した。

最新鋭の中央演算処理装置（CPU）＝イメージ図・富士通提供＝を768個搭載し、装置間の通信を効率的にするソフトを開発したことが奏功した。

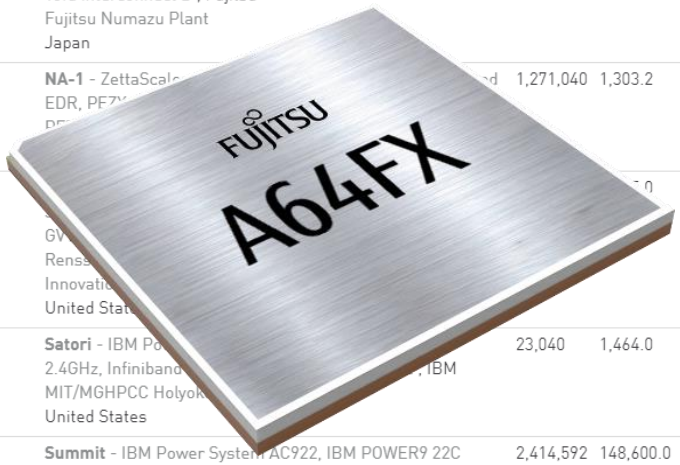
富岳は2021年ごろの運用開始を予定している。

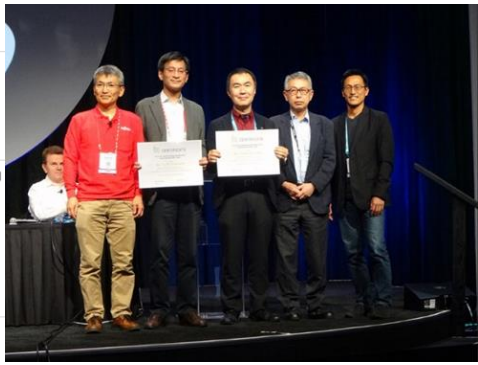
Green500 List for November 2019

Listed below are the November 2019 The Green500's energy-efficient supercomputers ranked from

Note: Shaded entries in the table below mean the power data is derived and not meassured.

Rank	TOP500 Rank	System	Cores	Rmax (TFlop/s)	Power (kW)	Power Efficiency (GFlops/watts)
1	159	**A64FX prototype** - Fujitsu A64FX, Fujitsu A64FX 48C 2GHz, Tofu interconnect D , Fujitsu Fujitsu Numazu Plant Japan	36,864	1,999.5	118	16.876
2	420	**NA-1** - ZettaScal… EDR, PEZ…	1,271,040	1,303.2	80	
3	24	Rens… Innovati… United Stat…			510	
4	373	**Satori** - IBM Po… 2.4GHz, Infiniband… MIT/MGHPCC Holyok… United States	23,040	1,464.0	94	
5	1	**Summit** - IBM Power System AC922, IBM POWER9 22C 3.07GHz, NVIDIA Volta GV100, Dual-rail Mellanox EDR	2,414,592	148,600.0	10,096	14,719

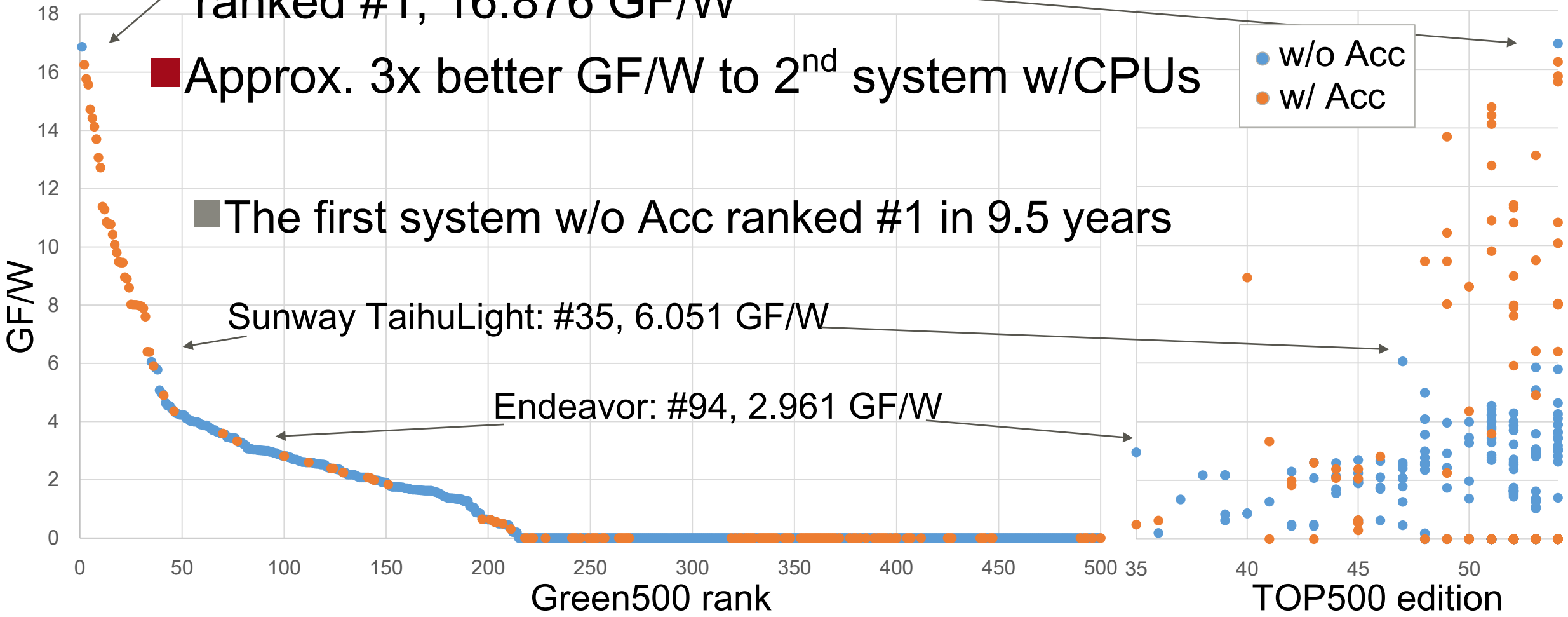




SC19 Green500 ranking and 1st appeared TOP500 edition

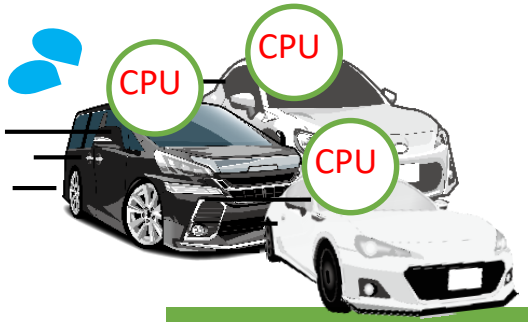
FUJITSU

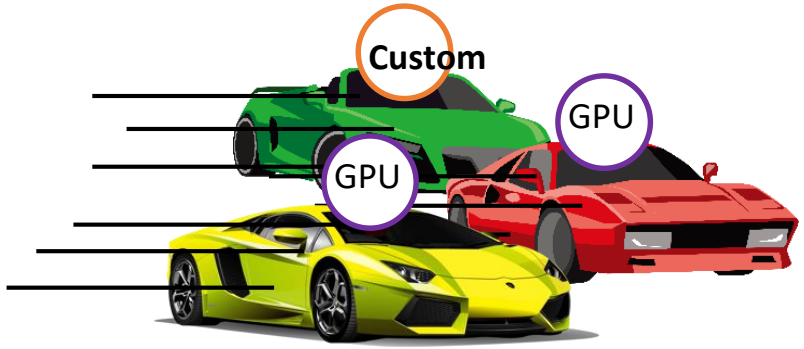
- "A64FX prototype", prototype of Supercomputer Fugaku, ranked #1, 16.876 GF/W
- Approx. 3x better GF/W to 2nd system w/CPUs
- The first system w/o Acc ranked #1 in 9.5 years



Significance of Green500 Achievement

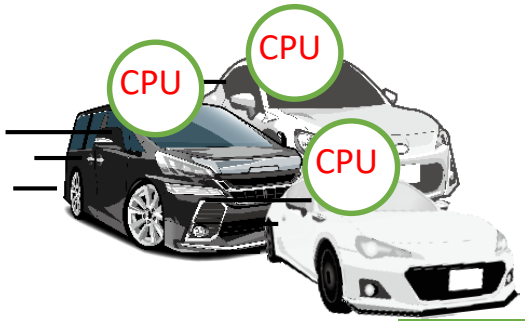
- **Green500 until now**

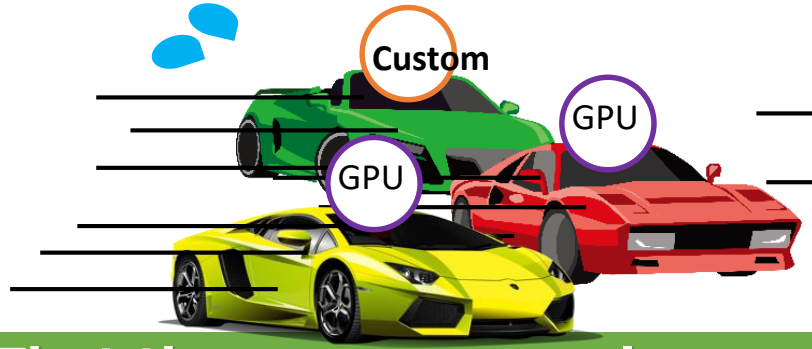


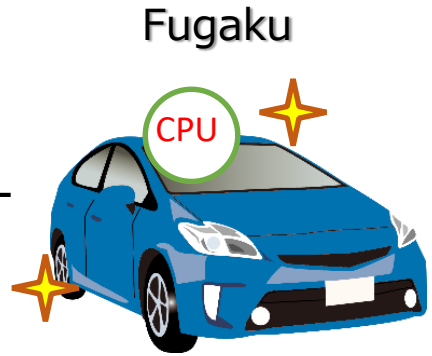


Specialized Architectures e.g. GPUs dominated

- **Green500 w/Fugaku**





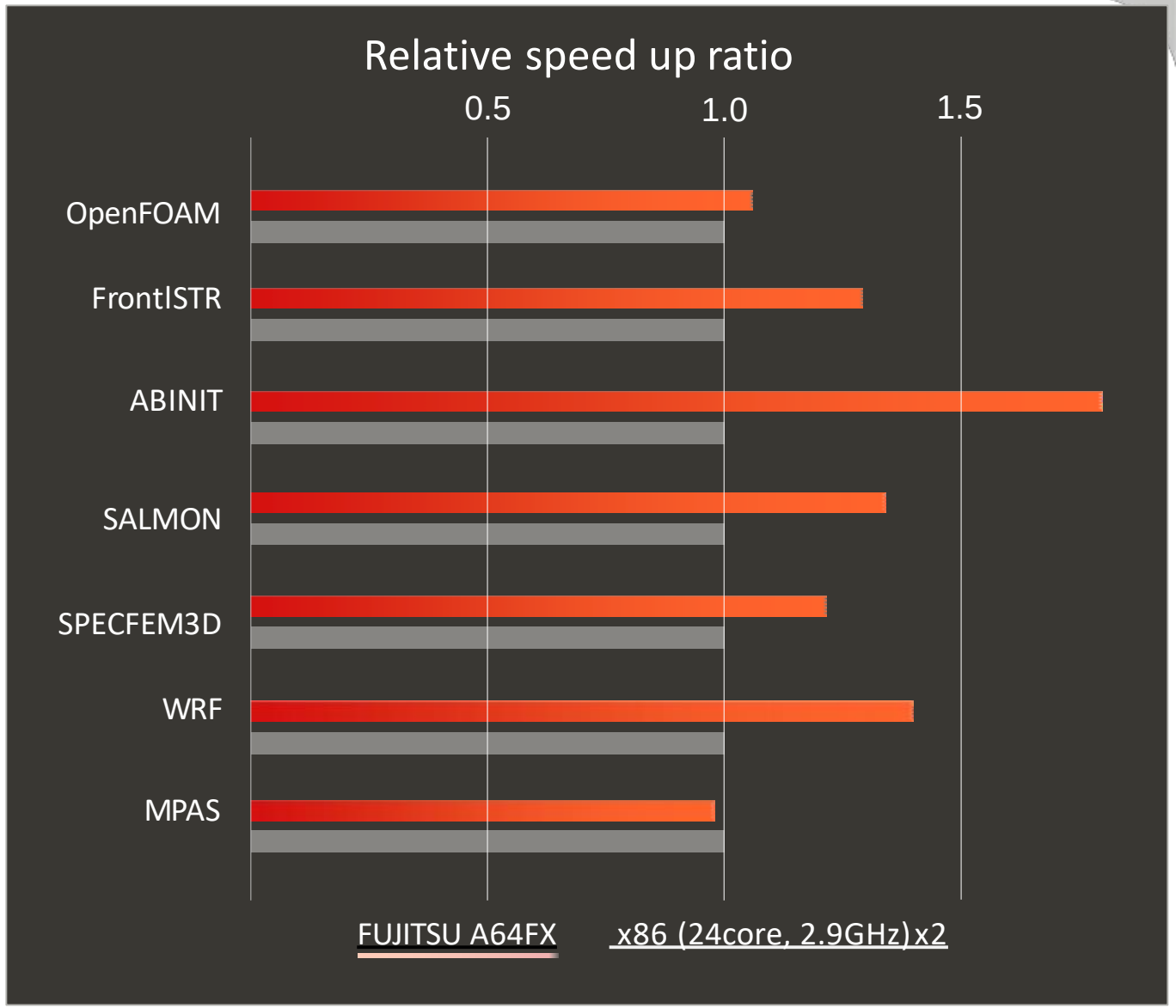


First time ever general purpose CPU became #1

A64FX CPU performance evaluation for real apps

FUJITSU

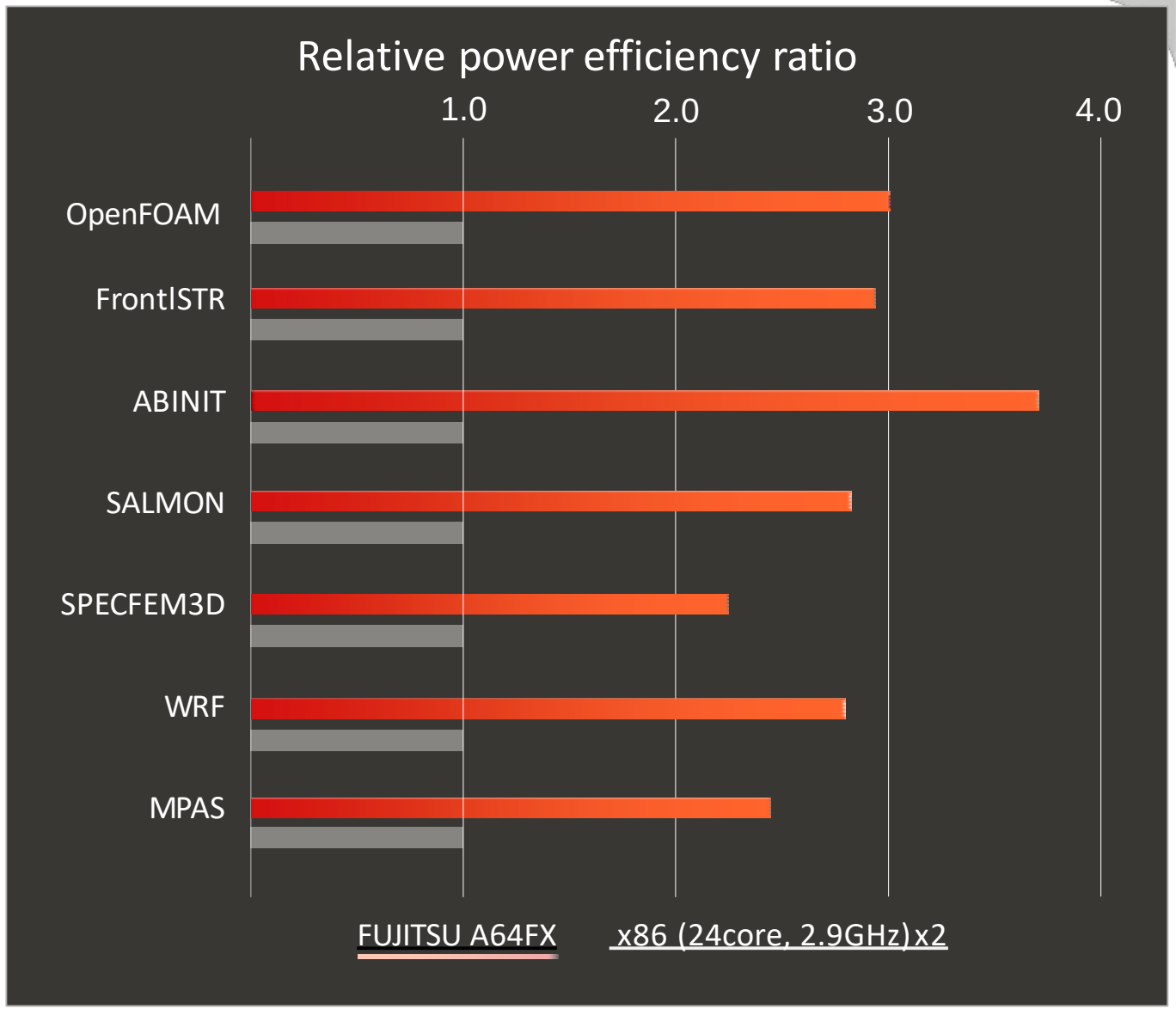
- Open source software, Real apps on an A64FX @ 2.2GHz
- Up to 1.8x faster over the latest x86 processor (24core, 2.9GHz) x 2, or 3.6x per socket
- High memory B/W and long SIMD length of A64FX work effectively with these applications



A64FX CPU power efficiency for real apps

FUJITSU

- Performance /Energy consumption on an A64FX @ 2.2GHz
- Up to 3.7x more efficient over the latest x86 processor (24core, 2.9GHz) x2
- High efficiency is achieved by energy-conscious design and implementation



Fugaku is a Year's worth of IT in Japan

	Smartphones		IDC Servers incl Clouds		Fugaku		K Computer
Units	**20 million** (2/3 annual shipments in Japan)	=	**300,000** (2/3 annual shipments in Japan)	=	**1**		**30~100**
Power	10W×20 mil = **200MW**	=	600-700W x 30K= **200MW** (incl cooling)	> >	**30MW**		**15MW**
CPU ISA System SW	**Arm iOS/ Android Linux**		**x86/Arm Linux (Red Hat etc.)/Win**		**Arm Linux (Red Hat etc.)**		**Sparc Proprietary Linux Low generality**
AI Acceleration	**Custom ASIC Inference Only**		**Gen. Purpos Accelerator e.g. GPU**		**Gen. CPU SVE instructions**		**None**

Fugaku Performance Estimate on 9 Co-Design Target Apps

Performance target goal

- ✓ 100 times faster than K for some applications (tuning included)
- ✓ 30 to 40 MW power consumption

Peak performance to be achieved

	PostK	K
Peak DP (double precision)	>400+ Pflops (34x +)	11.3 Pflops
Peak SP (single precision)	>800+ Pflops (70x +)	11.3 Pflops
Peak HP (half precision)	>1600+ Pflops (141x +)	--
Total memory bandwidth	>150+ PB/sec (29x +)	5,184TB/sec

Geometric Mean of Performance Speedup of the 9 Target Applications over the K-Computer

> 37x+

As of 2019/05/14

Category	Priority Issue Area	Performance Speedup over K	Application	Brief description
Health and longevity	1. Innovative computing infrastructure for drug discovery	**125x +**	GENESIS	MD for proteins
	2. Personalized and preventive medicine using big data	8x +	Genomon	Genome processing (Genome alignment)
Disaster prevention and Environment	3. Integrated simulation systems induced by earthquake and tsunami	45x +	GAMERA	Earthquake simulator (FEM in unstructured & structured grid)
	4. Meteorological and global environmental prediction using big data	**120x +**	NICAM+ LETKF	Weather prediction system using Big data (structured grid stencil & ensemble Kalman filter)
Energy issue	5. New technologies for energy creation, conversion / storage, and use	40x +	NTChem	Molecular electronic simulation (structure calculation)
	6. Accelerated development of innovative clean energy systems	35x +	Adventure	Computational Mechanics System for Large Scale Analysis and Design (unstructured grid)
Industrial competitiveness enhancement	7. Creation of new functional devices and high-performance materials	30x +	RSDFT	Ab-initio simulation (density functional theory)
	8. Development of innovative design and production processes	25x +	FFB	Large Eddy Simulation (unstructured grid)
Basic science	9. Elucidation of the fundamental laws and evolution of the universe	25x +	LQCD	Lattice QCD simulation (structured grid Monte Carlo)

Fugaku Programming Environment

- **Programing Languages and Compilers provided by Fujitsu**
  - Fortran2008 & Fortran2018 subset
  - C11 & GNU and Clang extensions
  - C++14 & C++17 subset and GNU and Clang extensions
  - OpenMP 4.5 & OpenMP 5.0 subset
  - Java

    GCC and LLVM will be also available
- **Parallel Programming Language & Domain Specific Library provided by RIKEN**
  - XcalableMP
  - FDPS (Framework for Developing Particle Simulator)
- **Process/Thread Library provided by RIKEN**
  - PiP (Process in Process)
- **Script Languages provided by Linux distributor**
  - E.g., Python+NumPy, SciPy
- **Communication Libraries**
  - MPI 3.1 & MPI4.0 subset
    - Open MPI base (Fujitsu), MPICH (RIKEN)
  - Low-level Communication Libraries
    - uTofu (Fujitsu), LLC(RIKEN)
- **File I/O Libraries provided by RIKEN**
  - Lustre
  - pnetCDF, DTF, FTAR
- **Math Libraries**
  - BLAS, LAPACK, ScaLAPACK, SSL II （Fujitsu）
  - EigenEXA, Batched BLAS （RIKEN）
- **Programming Tools provided by Fujitsu**
  - Profiler, Debugger, GUI
- **NEW: Containers (Singularity) and other Cloud APIs**
- **NEW: AI software stacks (w/ARM)**
  - Optimized PyTorch, TensorFlow, etc.
- **NEW: DoE Spack Package Manager**

New PRIMEHPC Lineup

FUJITSU

PRIMEHPC FX1000

Supercomputer optimized for large scale computing

High Scalability | High Density | Superior power efficiency

A64FX processor
384 nodes/Rack
Tofu-D Interconnect

PRIMEHPC FX700

Supercomputer based on

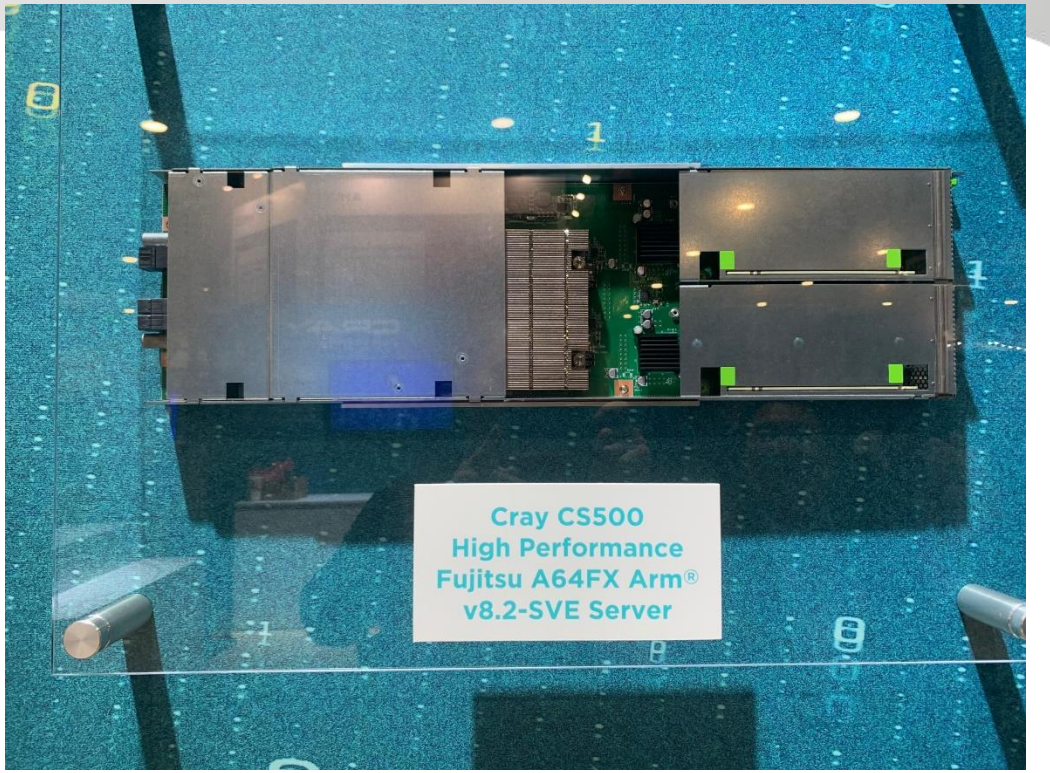
Ease to use | Installation

A64FX Processor
8 nodes/2U Rackmount

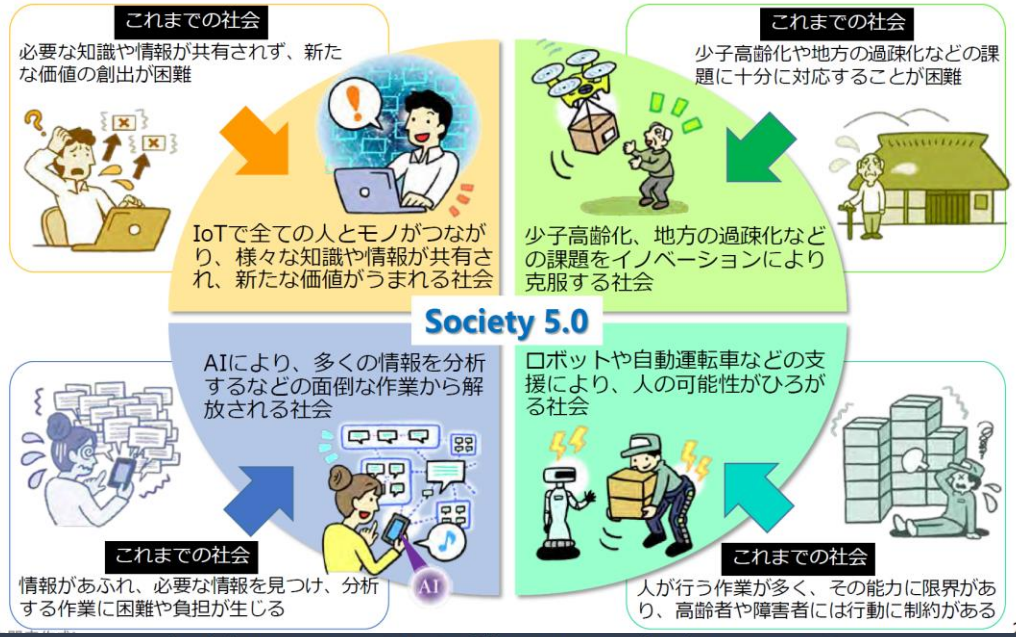
ITED

Introducing the Cray CS500 - Fujitsu A64FX Arm Server

- Next generation Arm® solution
- Cray Fujitsu Technology Agreement
- Supported in Cray CS500 infrastructure
- Cray Programming Environment
- Leadership performance for many memory intensive HPC applications
- GA in mid'2020



Society 5.0で実現する社会



2

経済発展と社会的課題の解決の両立

イノベーションで創出される**新たな価値**により、格差なくニーズに対応したモノやサービスを提供することで、**経済発展**と**社会的課題を解決**を両立

[内閣府作成]

5

経済発展と社会的課題の解決を両立する「Society 5.0」へ

経済発展	社会的課題の解決
● エネルギーの需要増加	●温室効果ガス（GHG）排出削減
● 食料の需要増加	●食料の増産やロスの削減
● 寿命延伸、高齢化	●高齢化に伴う社会コストの抑制
● 国際的な競争の激化	●持続可能な産業化の推進
● 富の集中や地域間の不平等	●富の再配分や地域間の格差是正

IoT、ロボット、人工知能（AI）、ビッグデータ等の先端技術を
あらゆる産業や社会生活に取り入れ、
格差なく、多様なニーズにきめ細かに対応したモノやサービスを提供

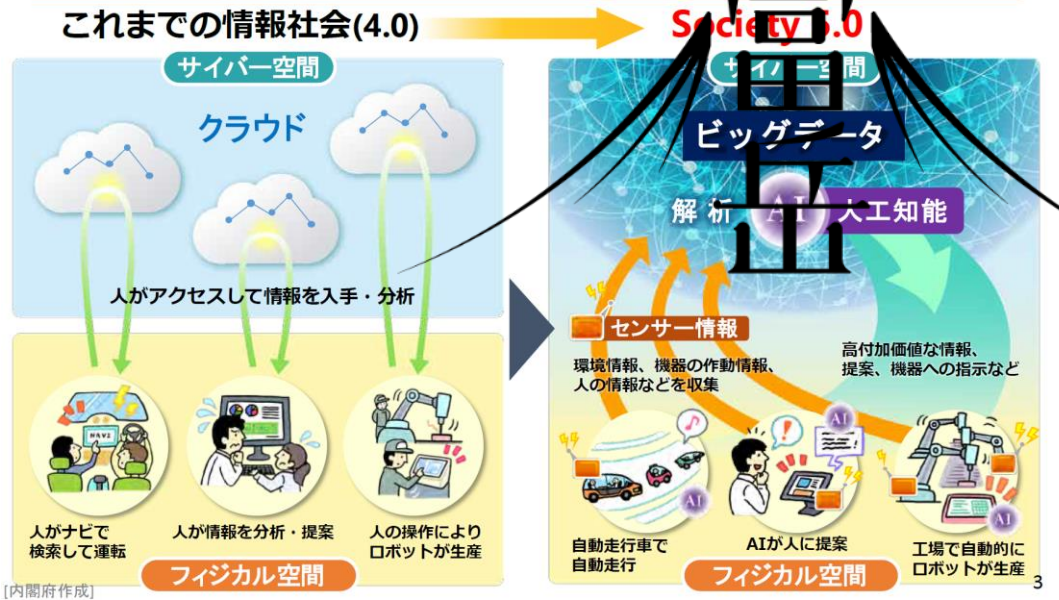
経済発展と社会的課題の解決を両立

[内閣府作成]

4

サイバー空間とフィジカル空間の高度な融合

フィジカル（現実）空間から**センサー**と**IoT**を通じてあらゆる情報が集積（**ビッグデータ**）
人工知能（AI）がビッグデータを解析し、高付加価値を**現実空間にフィードバック**



[内閣府作成]

3

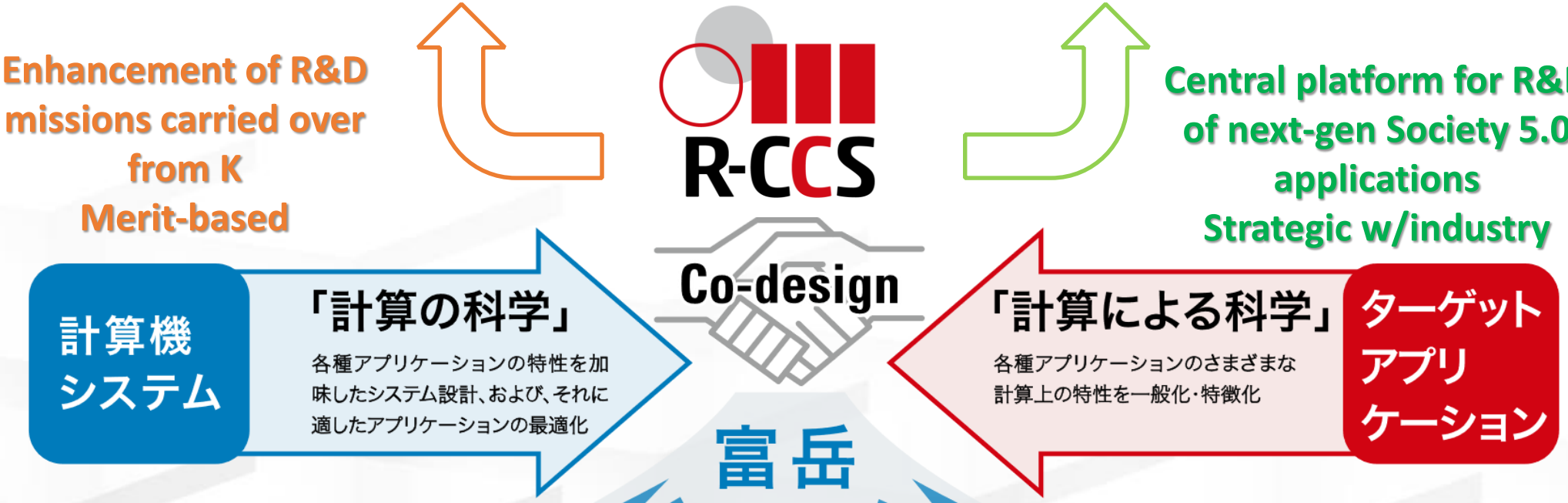
Two-fold Fugaku Missions

Carryover mission of K: Large-scale Simulation etc.
Support of Basic Sciences

Society 5.0 mission imposed by CSTI
Rapidly deliver rapid tangible results of high interest to the society and SDG

Enhancement of R&D missions carried over from K
Merit-based

Central platform for R&D of next-gen Society 5.0 applications
Strategic w/industry



Society5.0 will Fundamentally Change the Internet (1)

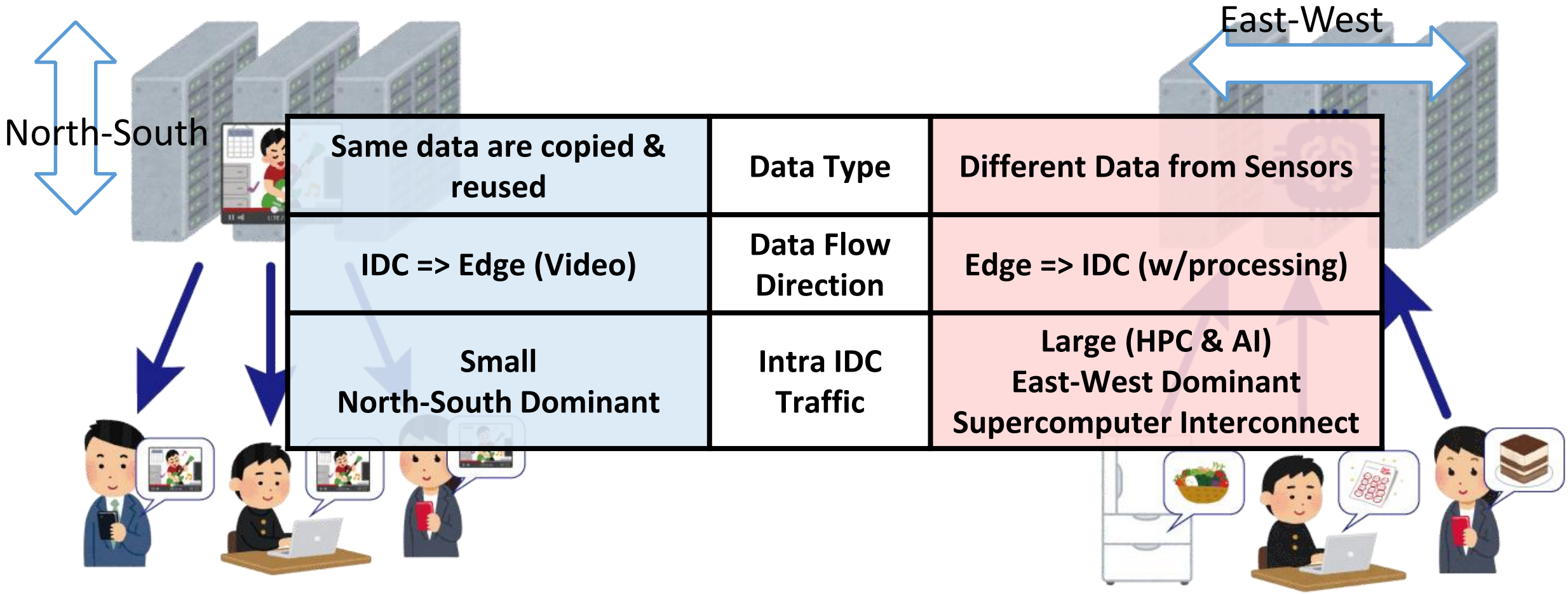
- **Current Internet: more than 90% of traffic IDC=> edge, video traffic (YouTube, NetFlix, etc.), caching optimization**
  - As such IDC+Internet+Edge (Smartphones, PCs) are optimized as CDN (Contents Delivery Network)
    - Same data used many times: (e.g. YouTube, Netflix)-> moderate demand for storage
    - Intra-IDC traffic is mainly 'North-South' i.e., between storage nodes in the IDC towards the outgoing traffic to the edge. Intra-IDC traffic 'East-West' is mostly for control, does not need high performance interconnect as is with supercomputers
    - Exo-IDC traffic is downstream outgoing. Since the same data are sent repeatedly, caching traffic in the Internet is effective e.g. Akamai
    - *Low affinity with scientific big data (-_-;)*
- **How will this chage with Society 5.0?**

Society5.0 will Fundamentally Change the Internet (2)

- **Future Internet: Traffic will reverse, Edge=>IDC, variety of sensor data, in-flight processing**
  - IDC+Internet+Edge: A real-time **data analytics infrastructure**
    - Raw edge data are all different, no way to store them all (CAGR of storage devices ~ 15%) -> must 'throw away' data
      - Sophisticated AI real-time analytics necessary, not just simple compression
    - Intra-IDC Network require high performance as is SC, due to AI+HPC centric workloads (IDCs to become supercomputers)
    - Inter-IDC Network IDC: Edge->IDC upstream ingest, caching does not work, need continuous real-time processing to 'throw away' data => from data-centric to compute centric
    - Compression is largely 'feature detection'. Data analytics mainly (1) correlelative analysis between data, and (2) data reconstruction from features
- **High affinity with scientific instrumentation and data analytics ☺**

Society5.0 and Internet

Current Internet		Society5.0 Internet
Same data are copied & reused	Data Type	Different Data from Sensors
IDC => Edge (Video)	Data Flow Direction	Edge => IDC (w/processing)
Small North-South Dominant	Intra IDC Traffic	Large (HPC & AI) East-West Dominant Supercomputer Interconnect



CDN dominated by Video (YouTube)

From Data Centric to Compute Centric

Can Simulation be the Core Society5.0 Technology?

- **Society5.0 (def. by MIA) "Human-centric society where convergence of cyber space (virtual world) and physical space (real world) resulting in for economic development as well as resolution of societal issues."**
- **Simulation models physical world in cyberspace => *fundamental* to Society5.0**
  - That is why major US IT companies are pushing HPC
- **But Society 5.0 is mainly sensing=>analytics=>actuation**
  - Here, simulation is DIFFICULT TO APPLY due to cost
  - => AI surrogates & AI-reduced simulation models
  - => we must train the AI through simulation
- **As such HPC+AI would be fundamental: winning formula against GAFA, including R-CCS**

Fugaku will be a centerpiernce of Society 5.0 by CyberPhysical Assimilation of Data & Simulation of HPC and AI

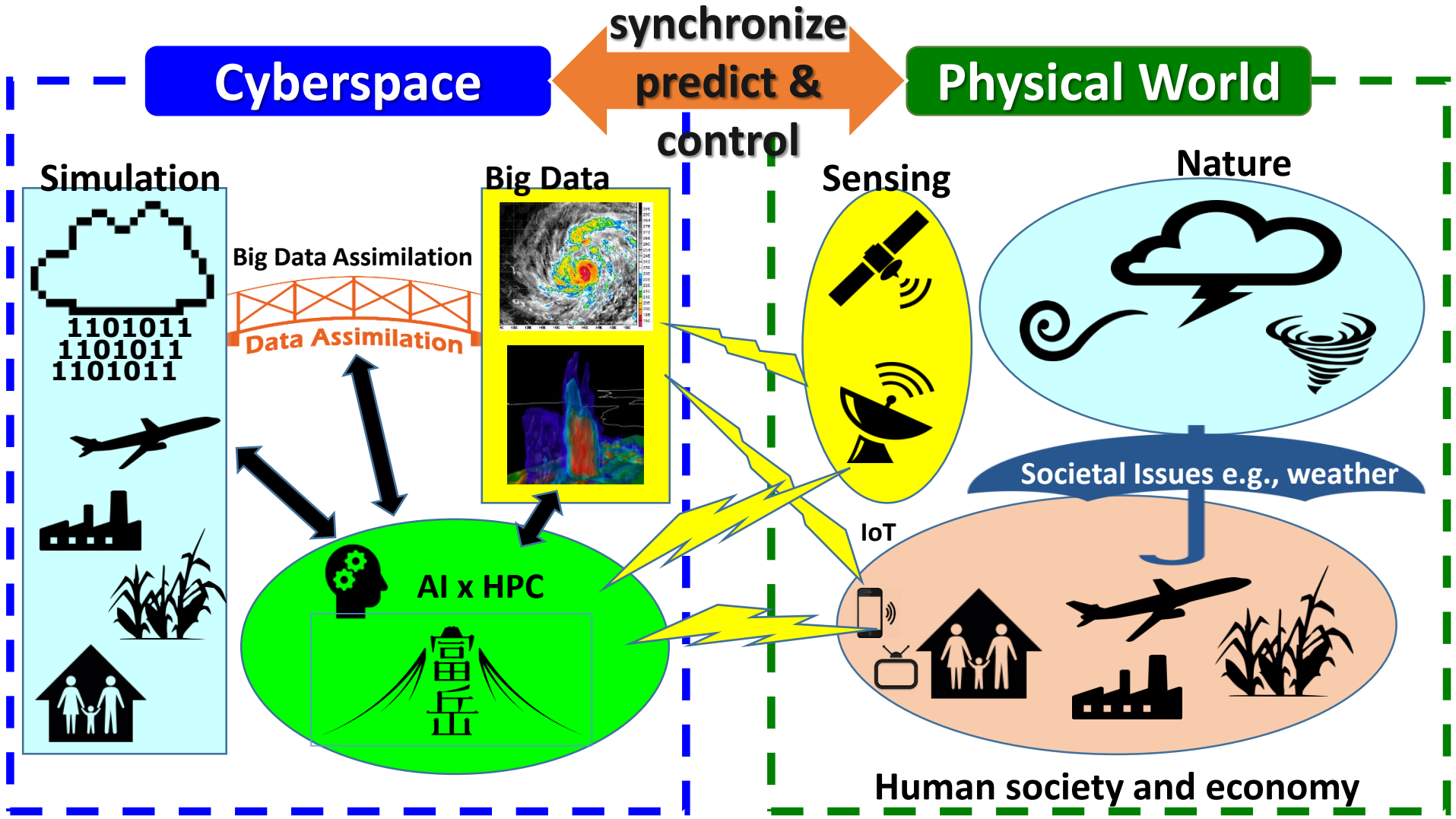
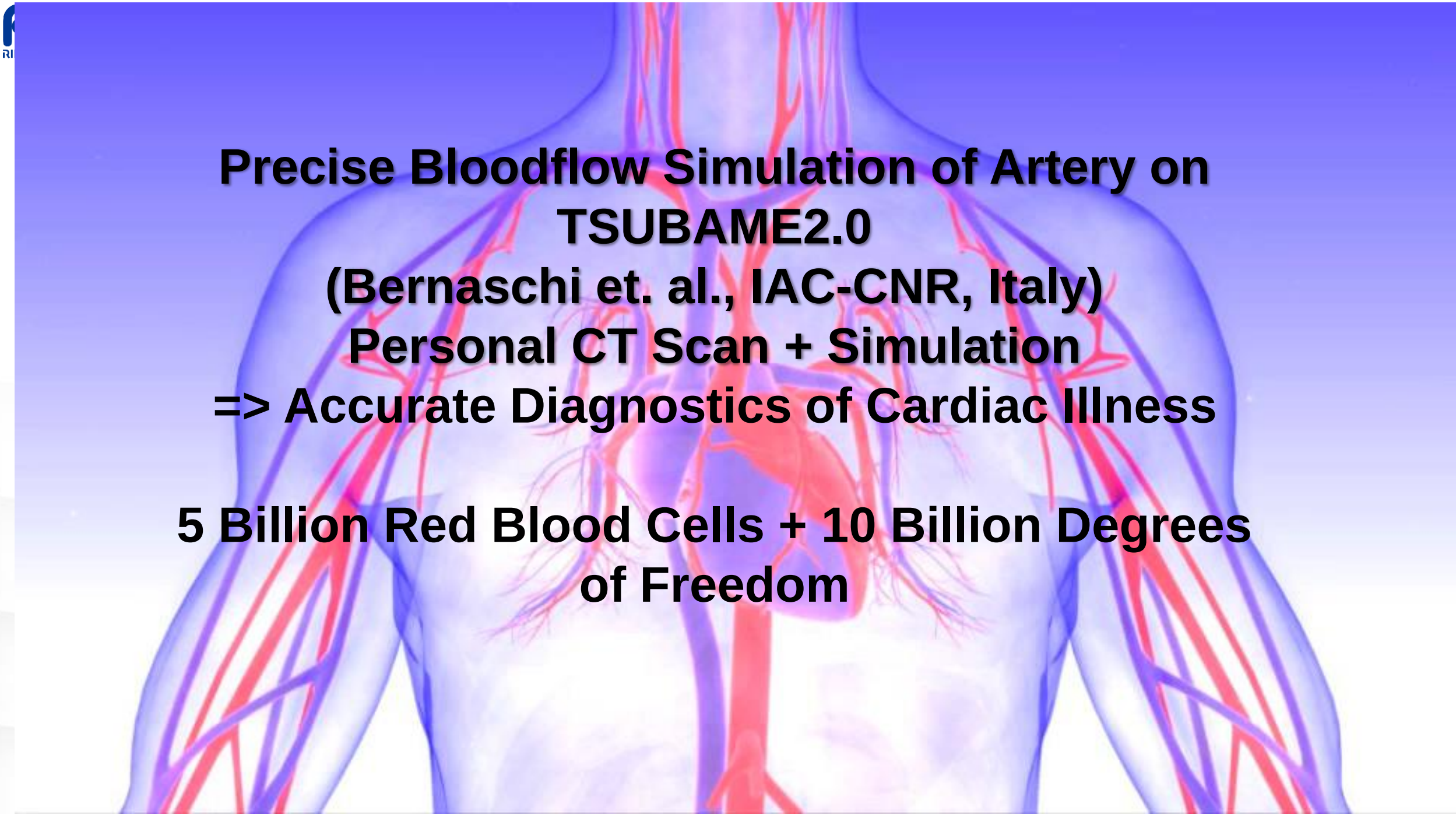
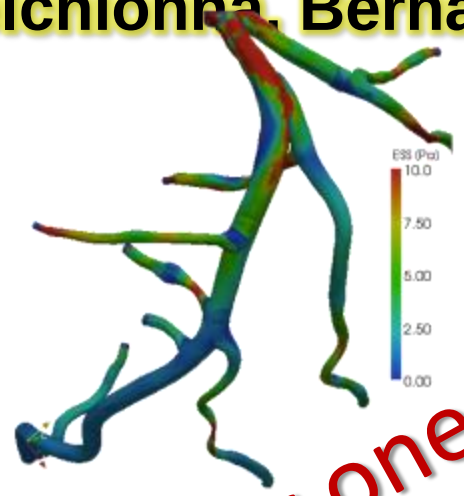


Figure originally by Takemasa Miyoshi, R-CCS


Precise Bloodflow Simulation of Artery on TSUBAME2.0
(Bernaschi et. al., IAC-CNR, Italy)
Personal CT Scan + Simulation
=> Accurate Diagnostics of Cardiac Illness
5 Billion Red Blood Cells + 10 Billion Degrees of Freedom

MUPHY: Multiphysics simulation of blood flow
(Melchionna, Bernaschi et al.)

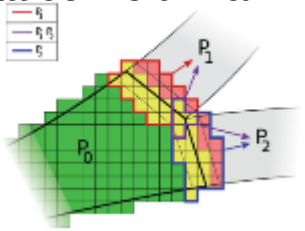


48 Hours for one heartbeat

Multiphyics simulation with *MUPHY* software

Fluid: Blood plasma

Lattice Boltzmann

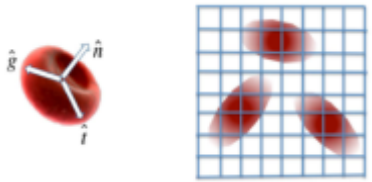


Irregular mesh is divided by using PT-SCOTCH tool, considering cutoff distance

coupled

Body: Red blood cell

Extended MD



Red blood cells (RBCs) are represented as ellipsoidal particles

Combined Lattice-Boltzmann (LB) simulation for plasma and Molecular Dynamics (MD) for Red Blood Cells

Realistic geometry (from CAT scan)

Two-levels of parallelism: CUDA (on GPU) + MPI

- 1 Billion mesh node for LB component
- 100 Million RBCs

ACM Gordon Bell Prize 2011 Honorable Mention

4000 GPUs, 0.6Petaflops

Patient-specific cardiac blood flow simulation is scientifically significant, but cannot be utilized directly to clinical diagnostics due to cost

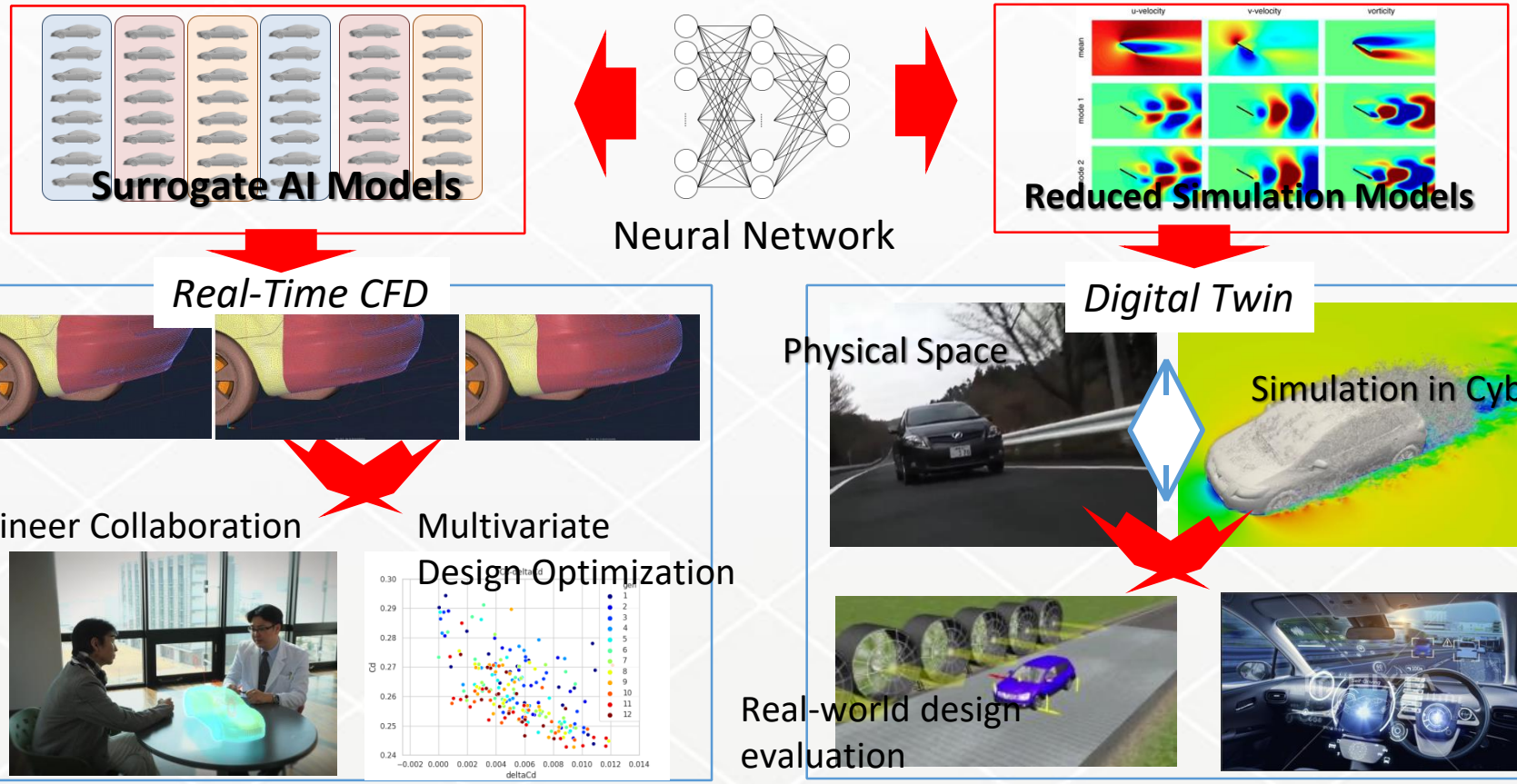
- **Tsubame2 requires 48 hours to simulate ONE heartbeat**
- **To compute in one hour on Fugaku requires 150 racks**
  - BW bound algorithm: TSUBAME2 ~= Fugaku 3 racks x 48
  - Need $1 bil over 6 years => At most 40,000 patients => at least $25K per patient just for diagnosis, not feasible
- **Large-scale simulation is beneficial when (1) results are fairly predicable, and (2) result can be utilized broadly, but…**
- **Most science, both fundamental and applied, involve numerous & repetitive experimentations due to cost**
  - Basic science: large simulations cannot be executed often so probability of new discoveries become low
  - Society 5.0 cience application: too costly to be economically feasible

AI to the Rescue: Role of AI in Society5.0 (1)

- **IT infrastructure for real time sensing->analysis->actuation**
- Analytics and decision-making by surrogate AI is lightweight -> appropriate for the actual use in cyber-physical apps
- **But AI needs to be trained: we DON'T NEED to collect large data blindly. Rather, appropriate sampling of the model space**
- **But simple observations nor apriori rules insufficient, especially to cover low probability 'rare events'**
  - E.g., a pedestrian jumping in front of a car in auto-driving
- **We use simulation to generate rare events**
  - High-level simulation capabilities essential
  - Search strategies in parameter space achieved by AI methods
  - High cost of repeated simulation amortized by multiple uses of the trained network

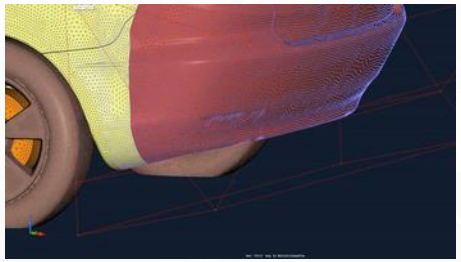
HPC and AI Convergence for Society 5.0 Manufacturing [Tsubokura et. al., R-CCS]

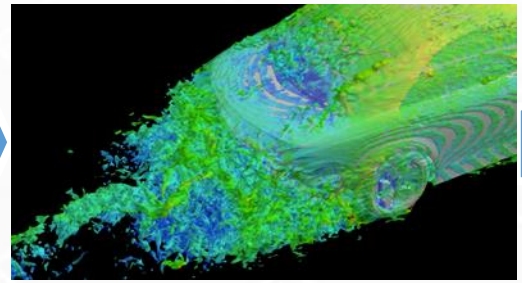
- **Combining ML/Deep Learning, Data Assimilation, Multivariate Optimization with Simulation for new generation manufacturing**
- **Use output of high-resolution simulation data to train AI**
  - Construct AI surrogate model training on simulation data, allowing real-time CFD to facilitate designer-engineer collaboration, multivariate design optimization, etc.
  - Use NN to derive reduced simulation model, allowing digital twin in cyberspace corresponding to entities in physical space for real-time interactions

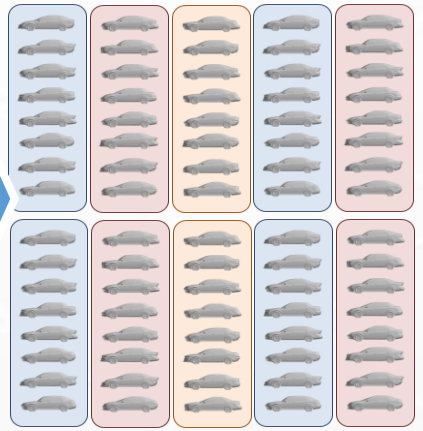


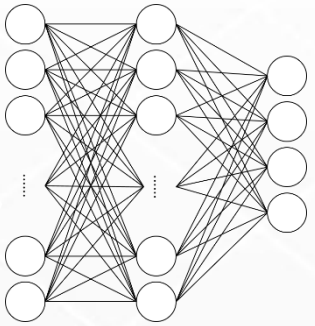
Example: Automotive Multivariate CFD Design using HPC & AI

- **Train AI with Simulation Inputs to create AI Surrogate Model**
  - Hundreds of CFD simulations on variable car designs to generate training input data
  - Surrogate NN: body design input => Aerodynamic properties



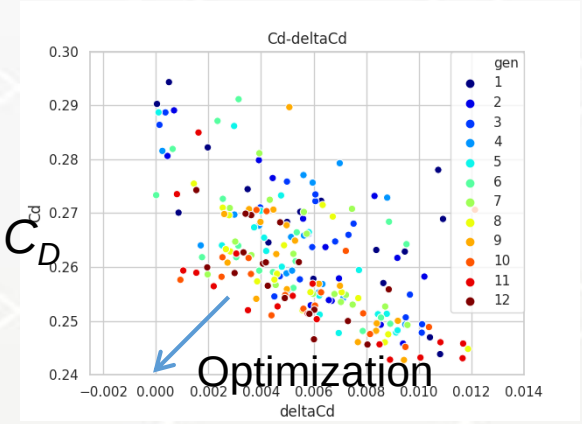






Max epoch	10000
Batch size	100

- **Multivariate optimization w/genetic algorithm**
  - Derive multiple optimal car designs rapidly



Fuel Efficient Design

Wind shear Resistant Design

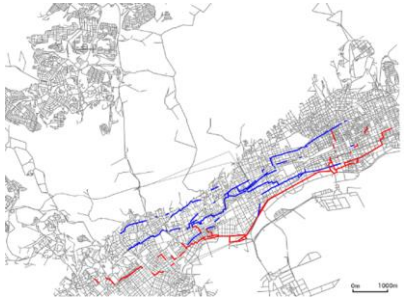
Smart Cities and High Performance Computing [Ito et. al., R-CCS

Social phenomena are complex, and have too many DOF and regimes/phases.
HPC with AI is a powerful tool to attack the complexity.

Example: car traffic in Kobe city
～30,000 roads, ～100,000 cars/day

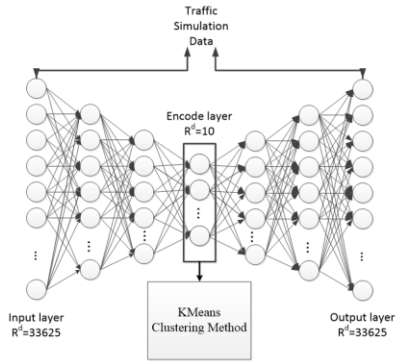
Multivariate analysis of simulation results

No.1 factor(colored)→
explain 10% of traffic
and following
～300 factors
from 5000 simulations.

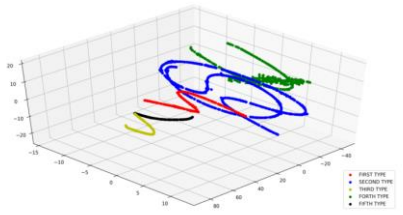


Deep Neural Network analysis

Learning of 30,000 dimensional results
↓ of Kobe traffic simulations



Classification of
↓ city traffic modes

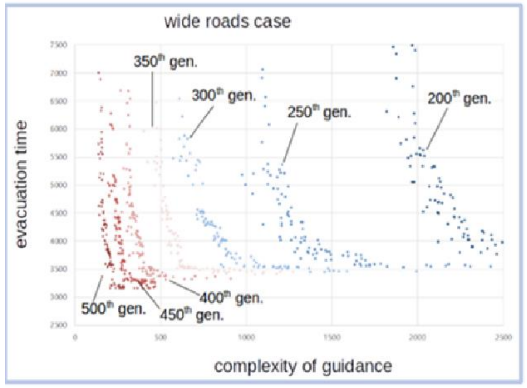


Example: Tsunami evacuation planning
of Nishi-yodogawa ward in Osaka

～9,000 roads
86 safe places
～50,000
evacuees from
146 regions

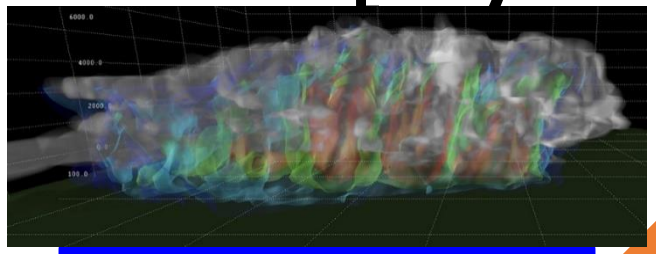
Genetic Optimizations of Evacuation simulations

GA code of evacuation plan
Evolve towards
"simple" and
"effective" plan
Pareto optimum plans



"**Big data**" through **G5** and the followings, not only be monitored,
but also be used on **HPC and AI** for **optimization and redesign of our society**.

Revolutionizing Weather Prediction for Tokyo Olympics [Miyoshi et. al., R-CCS]



1-h-lead downpour forecast
refreshed every 30 seconds
at 100-m mesh

BDA BIG DATA ASSIMILATION

Cyberspace

synchronize
predict & control

Real world

Simulation

1101011
1101011
1101011

Big Data Assimilation

Data Assimilation

Big Data

AI x HPC

Sensing

Nature

Prepared for weather

IoT

Human society and economy

Society5.0 innovates Big Data from being pure data centric to becoming compute centric

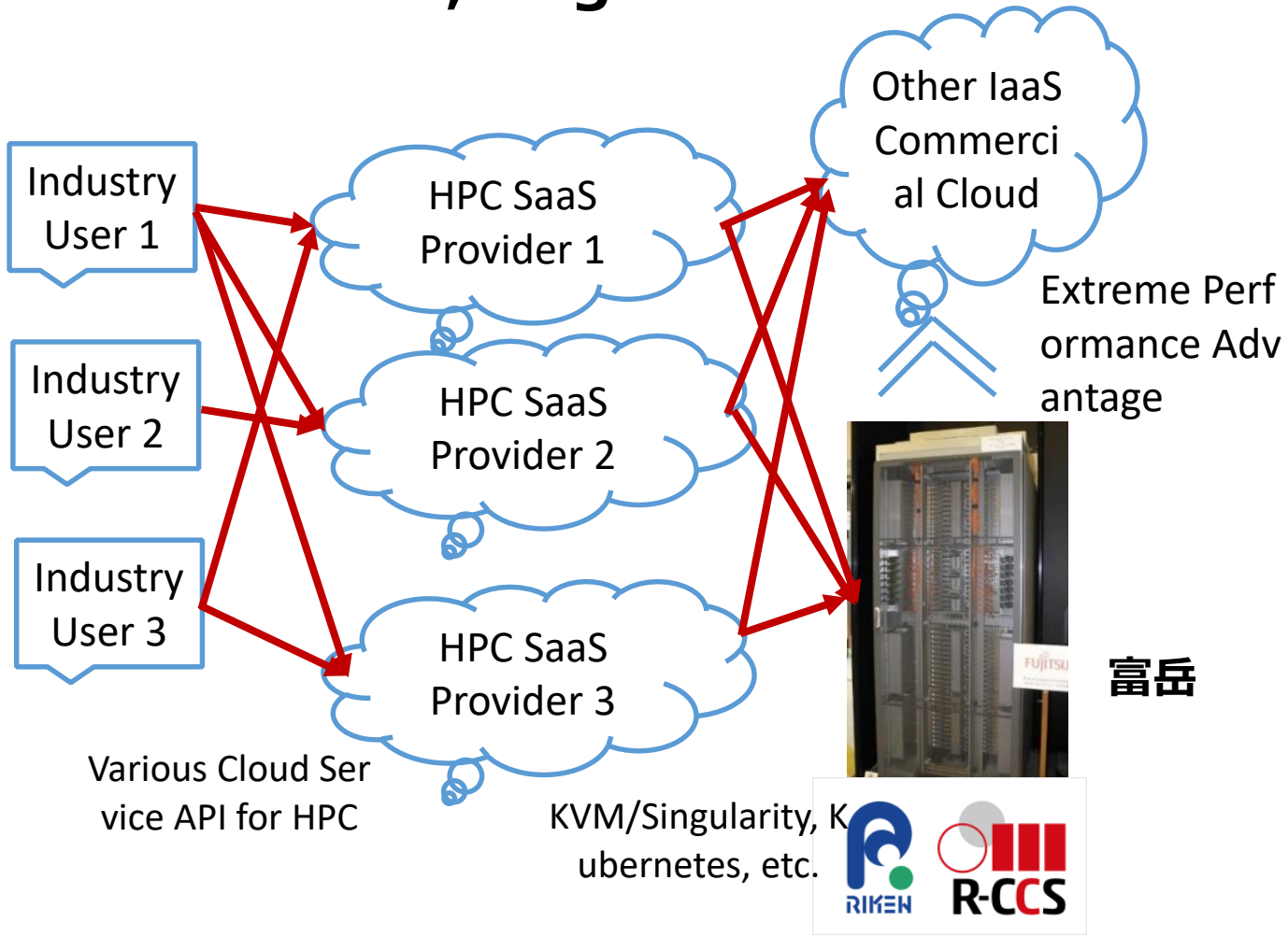
- **Society5.0 incurs big change in big data, to be thrown away**
  - Simple disposal: simple data selection, compression, etc
  - Correct disposal: extract the minimum set of features to allow for necessary analysis as well as reconstruction of data
    - Such extraction to be performed multiple times from edge=>IDC
    - E.g. Extract CAD data from the photos of a building
  - Data reconstruction methodologies
    - Simulation: from physical models parameterized by the features
    - Generative AI, e.g. GAN
    - Both expensive, appropriate for HPC
- **Seamless integration required Society5.0 -> true HPC&AI**

R-CCS & Fugaku Society 5.0 Values

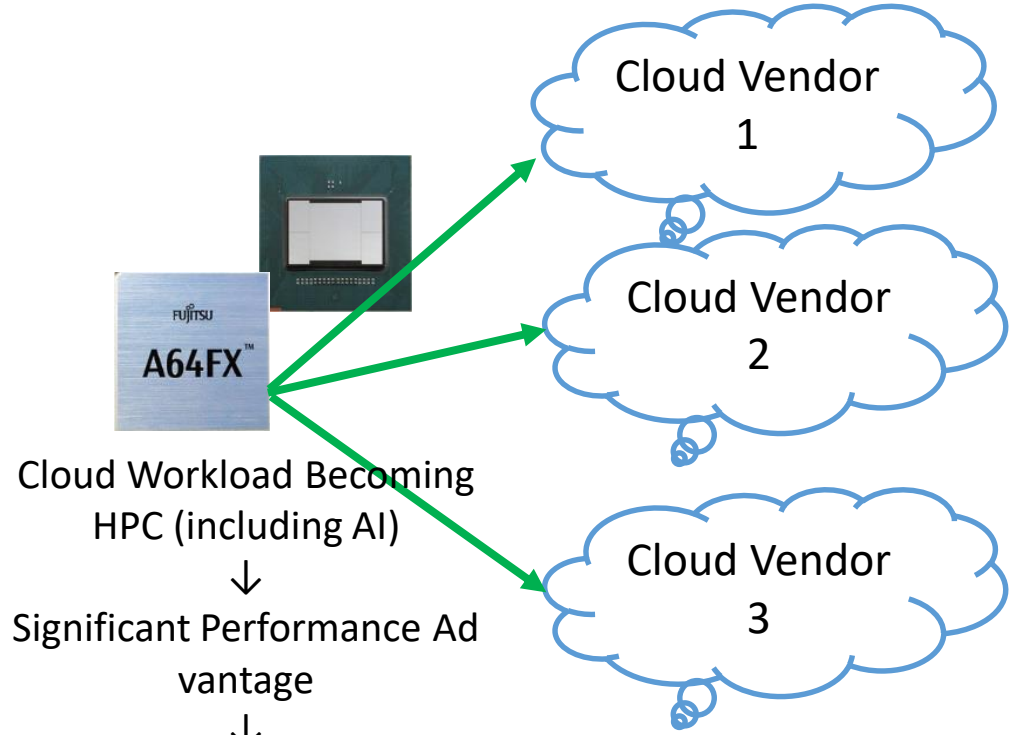
- “Fugaku Arm” Pinnacle of Arm Ecosystem dominant for IOT
  - A64fx CPU: World’s fastest gen-purpose CPU (but can run PowerPoint)
  - Converged HPC, Cloud, AI, IoT Software Stack
  - Support modern SW e.g. VM, Container, Packaging (Spack), etc.
- “Fugaku AI” Development
  - PyTorch, TensorFlow based on SVE & DNNL for A64fx, Eigen, …
  - Collaboration Between Fujitsu (Lab&Product), Arm, Riken (R-CCS, …)..
  - Other research efforts on convergence of HPC & AI
- “Fugaku Cloud” facilitates broad cloud-style services
  - Collaboration with cloud service providers -> 8 companies accepted
  - 2020 experimental services, 2021 production
- “Fugaku Live Stream” provides multipkle live data streams to Society5.0 IoT applications
  - Variety of live data from multiple sources stored for certain period for R&D of Society 5.0 apps as well as basic science apps
  - Collaboration with various public & private sectors

Fugaku Cloud Strategy

- **Industry use of Fugaku via intermediary cloud SaaS vendors, Fugaku as IaaS**



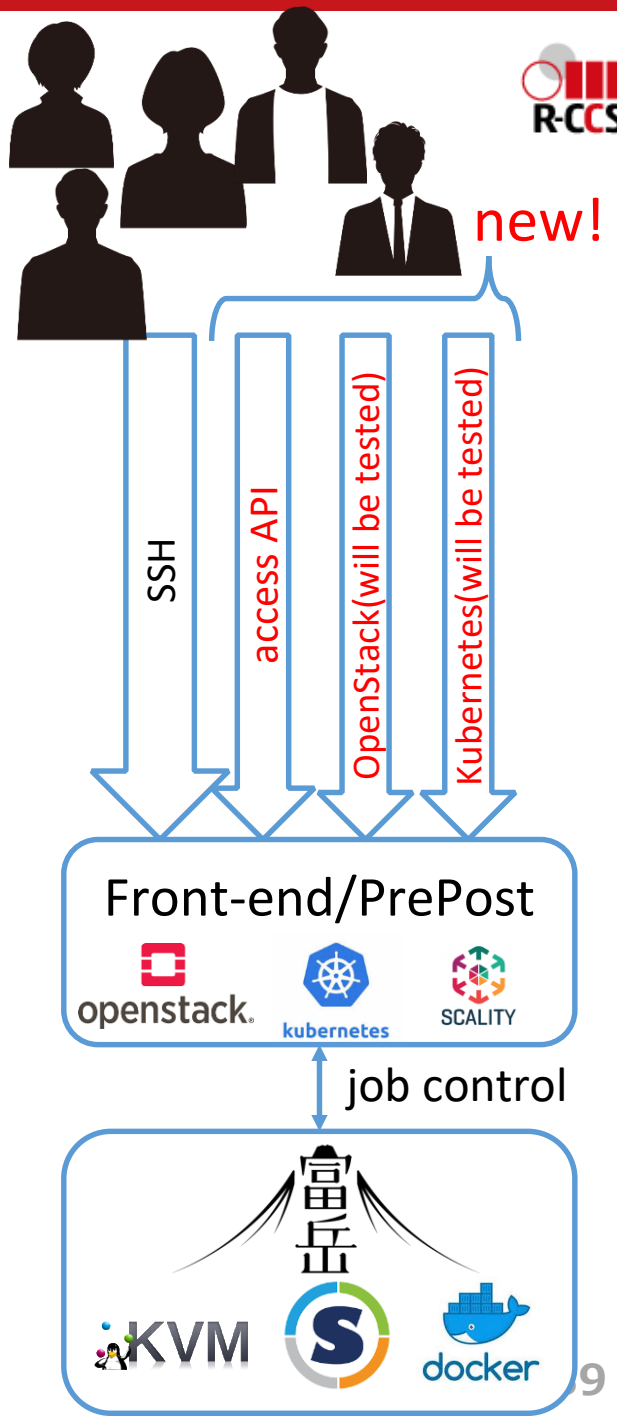
- **A64fx and other Fugaku Technology being incorporated into the Cloud**



Fugaku accessibility with Cloud APIs

- **Compute nodes**
  - Jobs can be executed via Fujitsu batch job scheduler
    - CUI and access API(NEWT2.0 based) are available
    - interactive use is also available under batch job scheduling
  - KVM and Singularity will be tested

- **Front-end/PrePost environment**
  - Multi architecture based
    - x86(w/ GPU), arm TX2(w/ GPU), A64FX(48 nodes)
    - interactive/batch/OpenStack/Kubernetes (will be tested)
  - Amazon S3 compatible object storage (under procurement)



Cloud Service Providers Partnership

https://www.r-ccs.riken.jp/library/topics/200213.html (in Japanese)

HPC SOLUTIONS

HPC SYSTEMS

Altair

XTREME-D

NIMBIX

FOCUS 公益財団法人 計算科学振興財団

exa EXA CORPORATION

×

富岳

RIKEN R-CCS RIKEN Center for Computational Science

Action Items

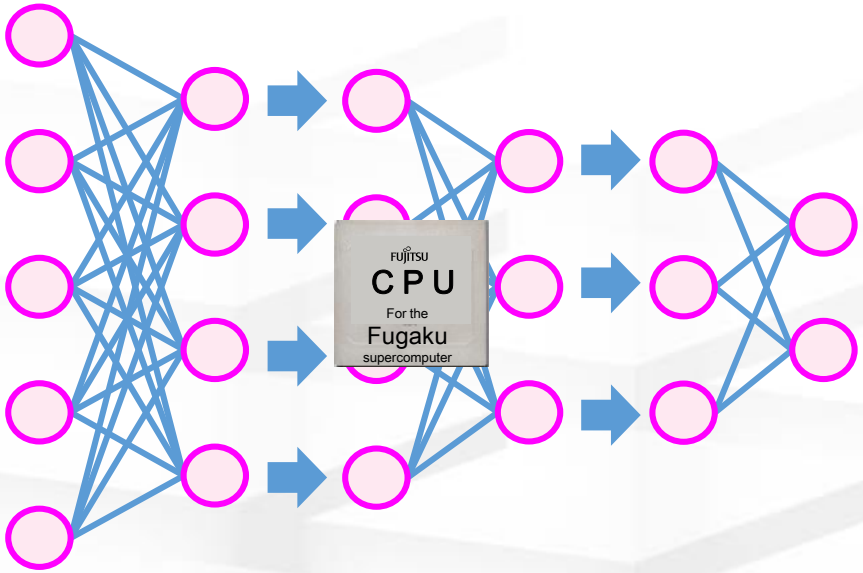
- Cool Project name and logo!
- Trial methods to provide computing resources of Fugaku to end-users via service providers
- Evaluate the effectiveness of the methods quantitatively as possible and organize the issues
- The knowledges gained will be feedbacked to scheme design of Fugaku by the government

Massive Scale Deep Learning on Fugaku

Fugaku Processor

- High perf FP16&Int8
- **High mem BW for convolution**
- **Built-in scalable Tofu network**

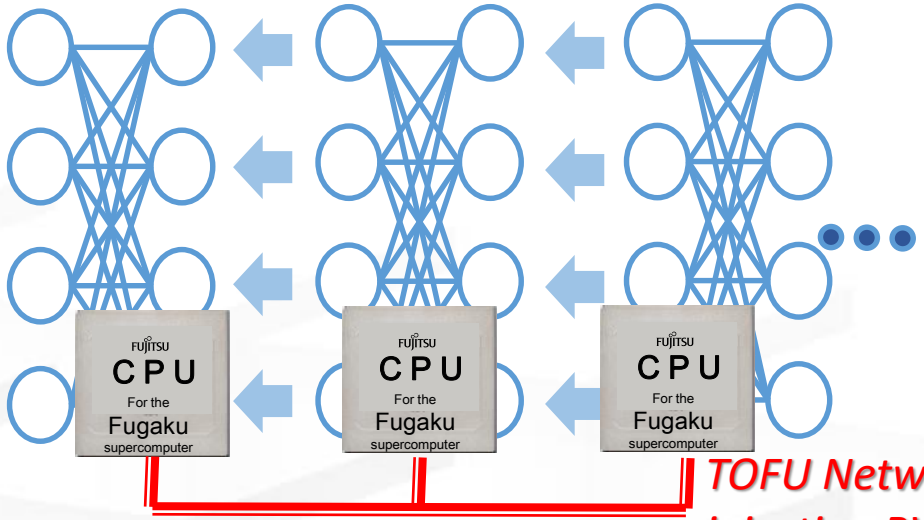
High Performance DNN Convolution



Low Precision ALU + High Memory Bandwidth + Advanced Combining of Convolution Algorithms (FFT+Winograd+GEMM)

Unprecedened DL scalability

High Performance and Ultra-Scalable Network for massive scaling model & data parallelism



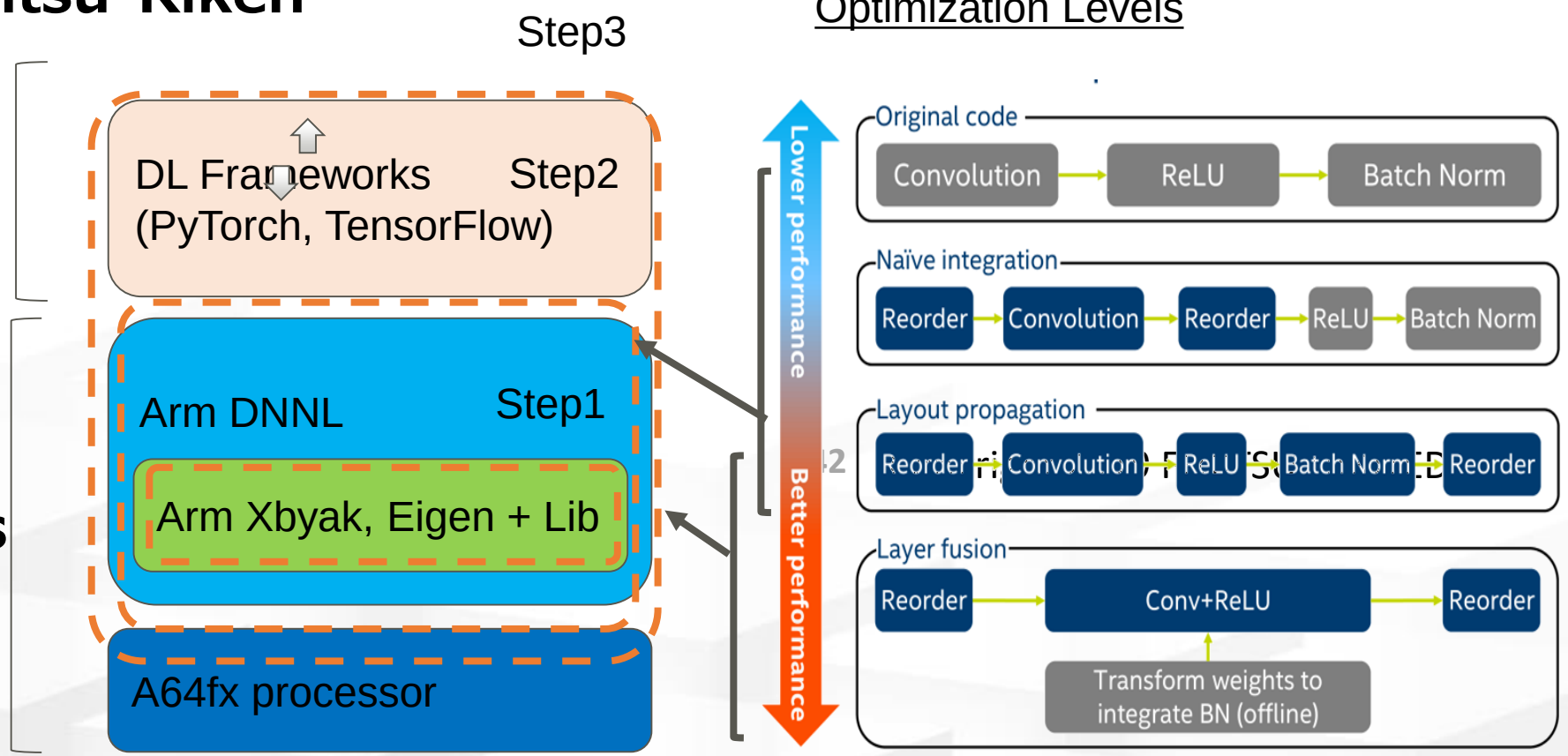
TOFU Network w/high injection BW for fast reduction

Unprecedented Scalability of Data/

Fujitsu-Riken-Arm joint effort on AI framework development on SVE/A64FX

- **MOU Signed Fujitsu-Riken Nov. 25, 2019**

- **w/Arm in works**



Exaops of sim, data, and AI on Fugaku and Cloud

Large Scale Public AI Infrastructures in Japan

Inference 838.5PF
Training 86.9 PF

vs. Summit
Inf. 1/4
Train. 1/5

	Deployed	Purpose	AI Processor	Inference Peak Perf.	Training Peak Perf.	Top500 Perf/Rank	Green500 Perf/Rank
Tokyo Tech. TSUBAME3	July 2017	HPC + AI Public	NVIDIA P100 x 2160	45.8 PF (FP16)	22.9 PF / 45.8PF (FP32/FP16)	8.125 PF #22	13.704 GF/W #5
U-Tokyo Reedbush-H/L	Apr. 2018 (update)	HPC + AI Public	NVIDIA P100 x 496	10.71 PF (FP16)	5.36 PF / 10.71PF (FP32/FP16)	(Unranked)	(Unranked)
U-Kyushu ITO-B	Oct. 2017	HPC + AI Public	NVIDIA P100 x 512	11.1 PF (FP16)	5.53 PF/11.1 PF (FP32/FP16)	(Unranked)	(Unranked)
AIST-AIRC AICC	Oct. 2017	AI Lab Only	NVIDIA P100 x 400	8.64 PF (FP16)	4.32 PF / 8.64PF (FP32/FP16)	0.961 PF #446	12.681 GF/W #7
Riken-AIP Raiden	Apr. 2018 (update)	AI Lab Only	NVIDIA V100 x 432	54.0 PF (FP16)	6.40 PF/54.0 PF (FP32/FP16)	1.213 PF #280	11.363 GF/W #10
AIST-AIRC ABCI	Aug. 2018	AI Public	NVIDIA V100 x 4352	544.0 PF (FP16)	65.3 PF/544.0 PF (FP32/FP16)	19.88 PF #7	14.423 GF/W #4
NICT (unnamed)	Summer 2019	AI Lab Only	NVIDIA V100 x 1700程度	~210 PF (FP16)	~26 PF/~210 PF (FP32/FP16)	????	????
C.f. US ORNL Summit	Summer 2018	HPC + AI Public	NVIDIA V100 x 27,000	3,375 PF (FP16)	405 PF/3,375 PF (FP32/FP16)	143.5 PF #1	14.668 GF/W #3
Riken R-CCS Fugaku	2020 ~2021	HPC + AI Public	Fujitsu A64fx > x 150,000	> 4000 PO (Int8)	>1000PF/>2000PF (FP32/FP16)	> 400PF #1 (2020?)	> 15 GF/W ???
ABCI 2	2022	AI	Future GPU	Similar	similar	~100PF	25~30GF/W

Fugaku LiveStream: Society 5.0 Data Storage & Analysis Platform

センサーデータ

ゲノムデータ

気象データ

交通データ

beats

logstash

ZABBIX

Apache Flink

elastic

kibana

re:dash

オブジェクトストレージ（S3互換）

ファイルストレージ（Lustreベース）

公開

富岳

AI+HPC+BD

Analysis

Analysis

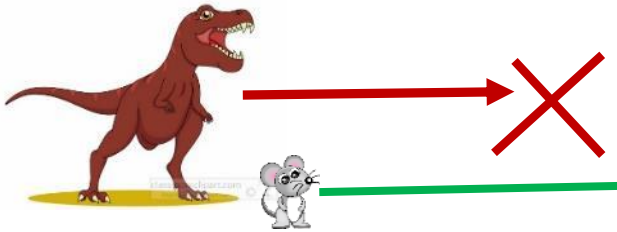
Analysis

Analysis

jupyter

様々な学術機関・研究所・企業と連携し、実際のIoT/ストリームデータを多数一定期間格納し、Society5.0アプリの開発、及び社会実装へ

Many Core Era



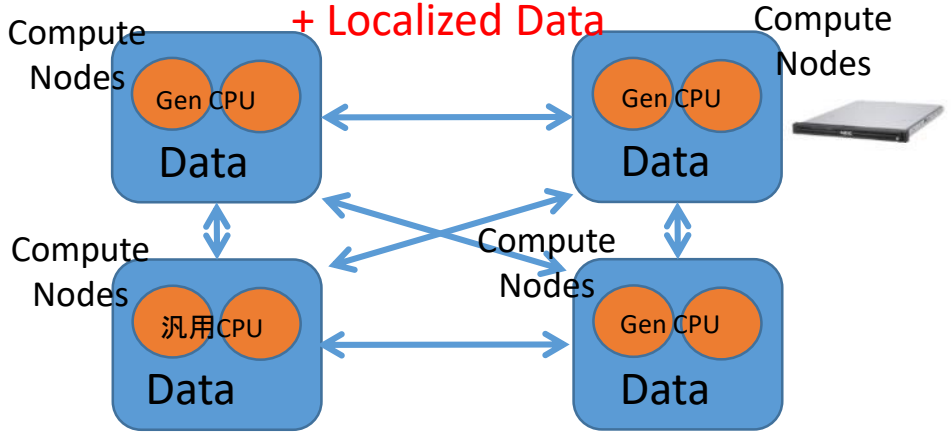
Post Moore
Cambrian Era

Flops-Centric Monolithic Algorithms and Apps

Flops-Centric Monolithic System Software

Hardware/Software System APIs
Flops-Centric Massively Parallel Architecture

Homogeneous General Purpose Nodes
+ Localized Data



Loosely Coupled with Electronic Interconnect

Transistor Lithography Scaling
(CMOS Logic Circuits, DRAM/SRAM)

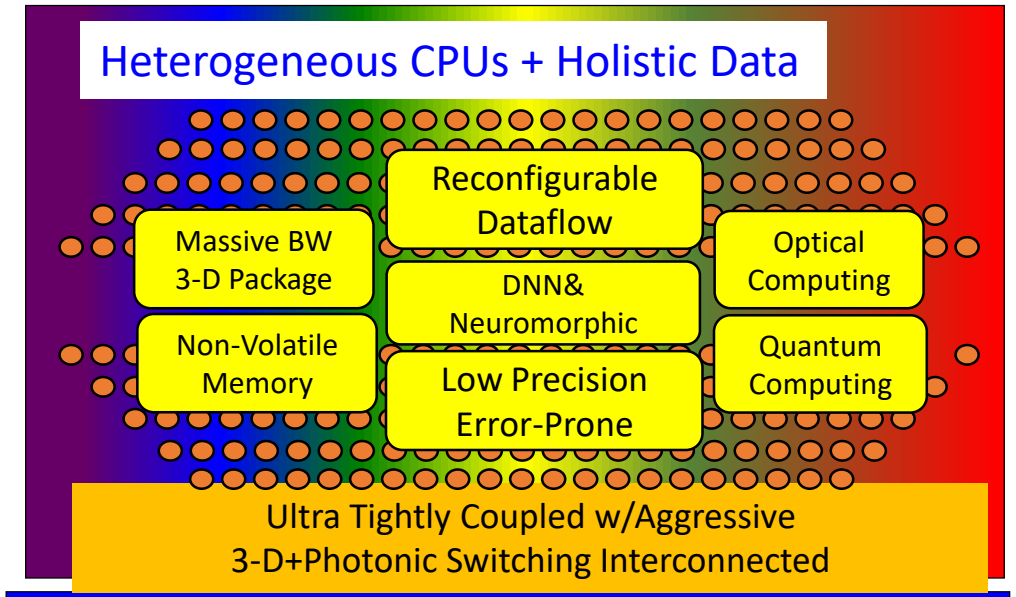
~2025
M-P Extinction Event

Cambrian Heterogeneous Algorithms and Apps

Cambrian Heterogeneous System Software

Hardware/Software System APIs
"Cambrian" Heterogeneous Architecture

Heterogeneous CPUs + Holistic Data



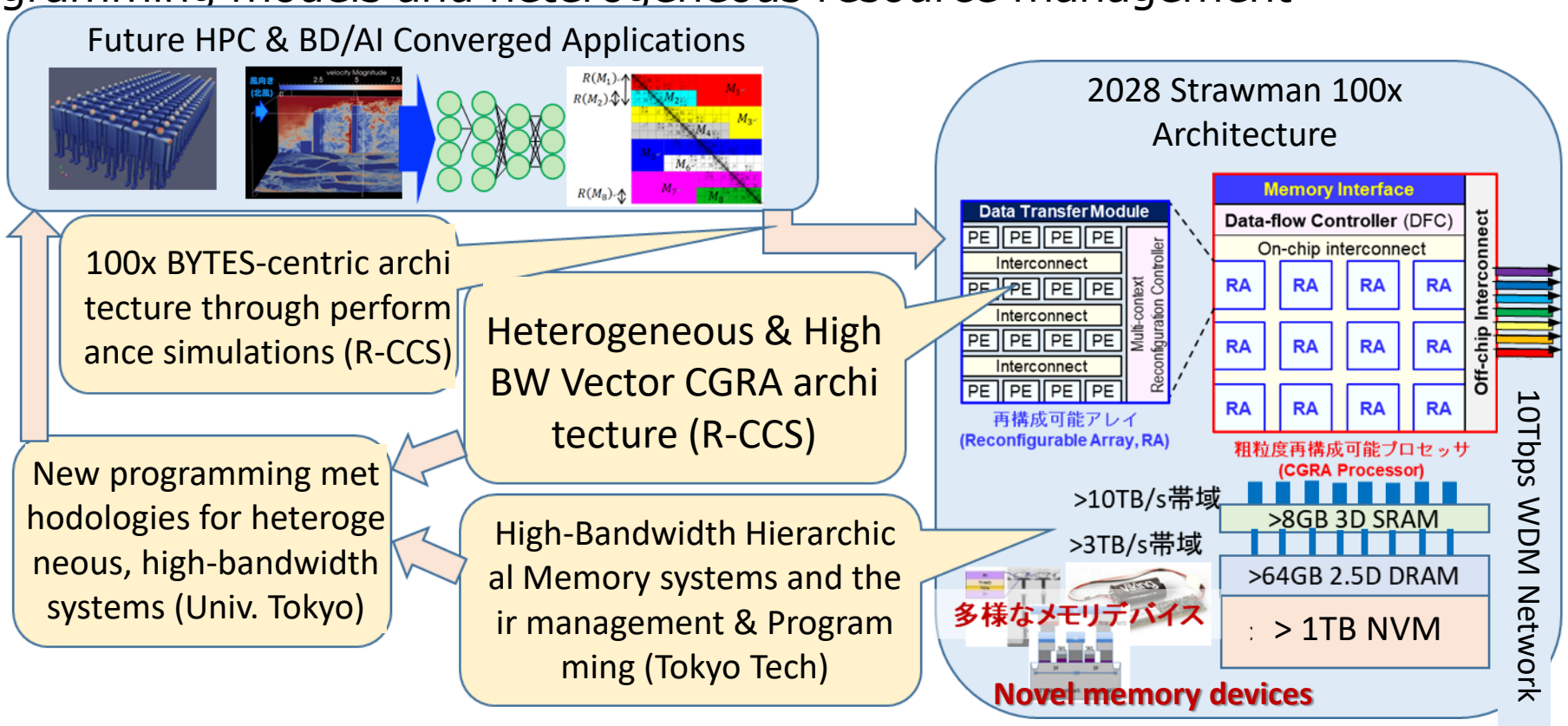
Ultra Tightly Coupled w/Aggressive
3-D+Photonic Switching Interconnected

Novel Devices + CMOS (Dark Silicon)
(Nanophotonics, Non-Volatile Devices etc.)

NEDO 100x Processor Project
Riken (R-CCS)/U-Tokyo/Tokyo Tech

Towards 100x processor in 2028

- Various combinations of CPU architectures, new memory devices and 3-D technologies
- Perf. measurement/characterization/models for high-BW intra-chip data movement
- Cost models and algorithms for horizontal & hierarchical data movement
- Programming models and heterogeneous resource management



12 Apr, 2019