

Mirror World

The land between
the Meta- and the Omniverse

Jan M. Rabaey
UC Berkeley and imec

[image courtesy NOW, 2020]

NEW YORK TIMES BESTSELLING AUTHOR
OF QUICKSILVER

NEAL
STEPHENSON



SNOW CRASH

"STEPHENSON HAS NOT STEPPED.
HE HAS VAULTED ONTO THE LITERARY
STAGE WITH THIS NOVEL."

—Los Angeles Reader

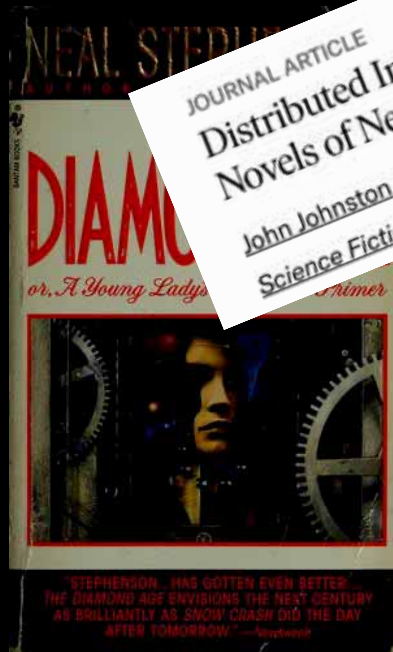
1992: Neil Stephenson introduced the *Metaverse*, a virtual reality successor to the Internet. In his vision, humans represented by avatars frequent and explore an alternative world.

JOURNAL ARTICLE

Distributed Information: Complexity Theory in the
Novels of Neal Stephenson and Linda Nagata

John Johnston

Science Fiction Studies, Vol. 28, No. 2 (Jul., 2001), pp. 223-245 (23 pages)



cryptonomicon
THE INFORMATIONAL BESTSELLER
NEAL STEPHENSON

#1 NEW YORK TIMES BESTSELLING AUTHOR

Neal
Stephenson

FALL

or, Dodge in Hell



The Metaverse

NY Times, Febr. 2023

Applications

- Gaming
- Travel & tourism
- Real estate
- Education and learning
- Remote working
- Healthcare
- ...

The Next Hot Housing Market Is Out of This World. It's in the Metaverse.



Challenge: Disconnect between real and alternative worlds

Mirror World*

A representation of the real world in digital form

- that attempts to map real-world structures and activity in an (geographically) accurate way, similar to the concept of a **digital twin**

Differs from **virtual worlds**

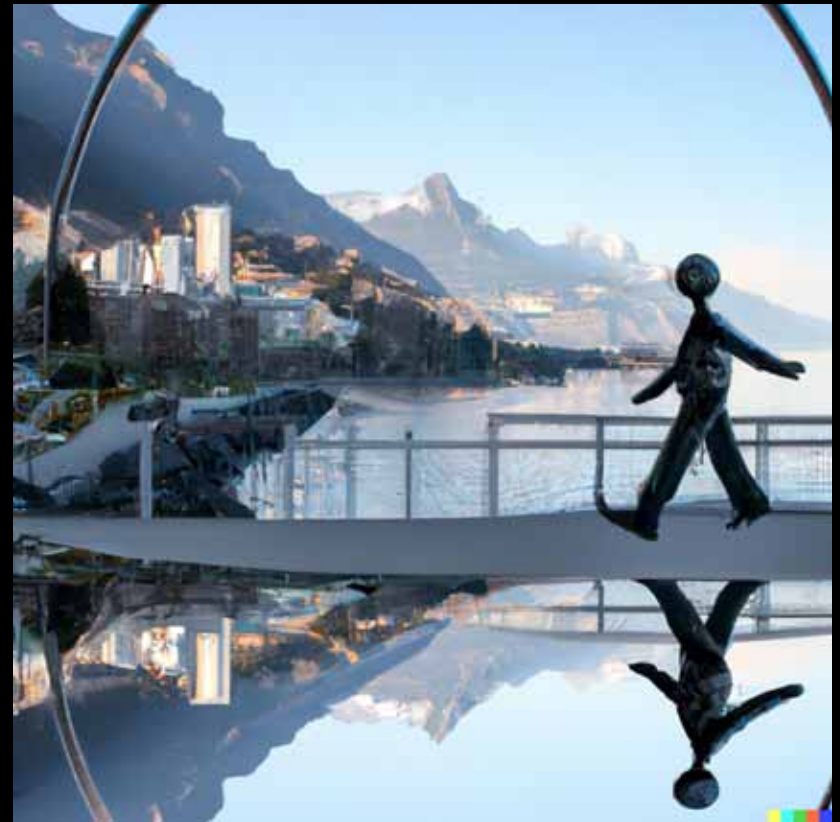
- in that these have few direct connections to real models and thus are described more as fictions

Is **bidirectional** – **MORE THAN A TWIN****

- *Actions in Mirror World (may) reflect in Real World and vice versa*

* Term first popularized by David Gelertner
[Mirror Worlds, Oxford Univ Press, 1991]

** This departs from the original definition



[Image created with Dall·E (openai.org)]

Digital Twin

Example: Google Earth



Google

98%

Data SIO, NOAA, U.S. Navy, N...

3,000 km

Camera: 25,587 km 46°26'53"N 6°55'32"E



3D



AR Will Spark the Next Big Tech Platform—Call It Mirrorworld

We are building a 1-to-1 map of almost unimaginable scope. When it's complete, our physical reality will merge with the digital universe.

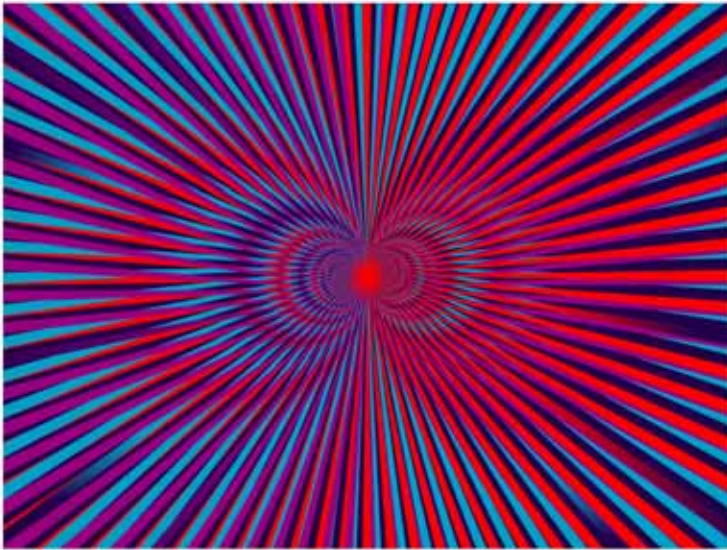


ILLUSTRATION: STORYTK

The Narrow Definition

“The mirrorworld doesn’t yet fully exist, but it is coming. Someday soon, every place and thing in the real world—every street, lamppost, building, and room—will have its full-size digital twin in the mirrorworld. For now, only tiny patches of the mirrorworld are visible through AR headsets.”

[Wired Magazine, Febr 2019]

Mirror World is much more!

Fully intertwined with the real world

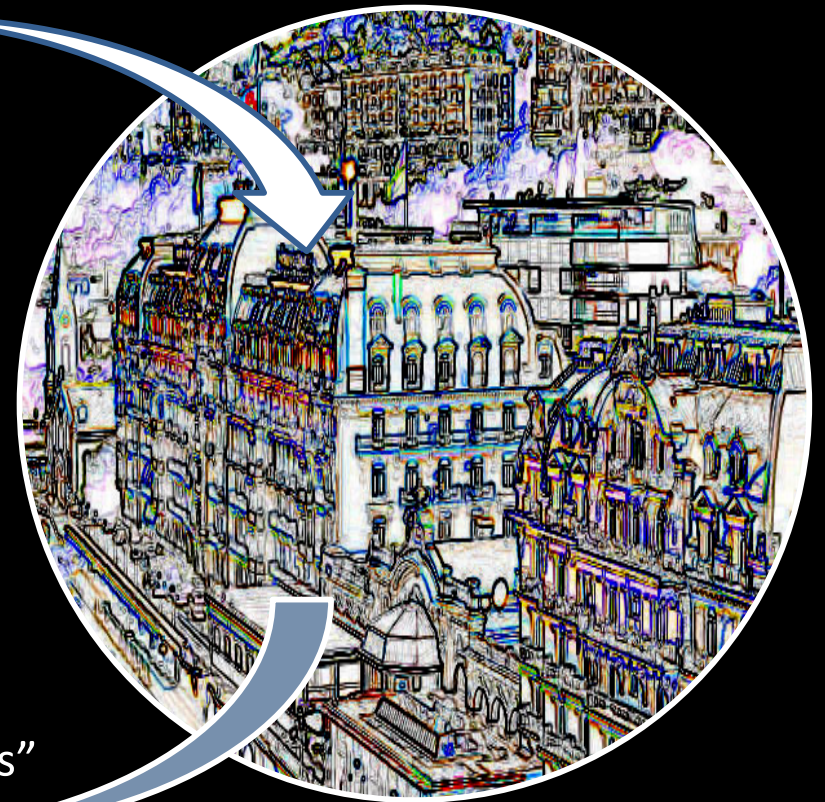
IoT
Wearables
Swarms

Mirror World

Models
Simulators
Generators



“sensors”

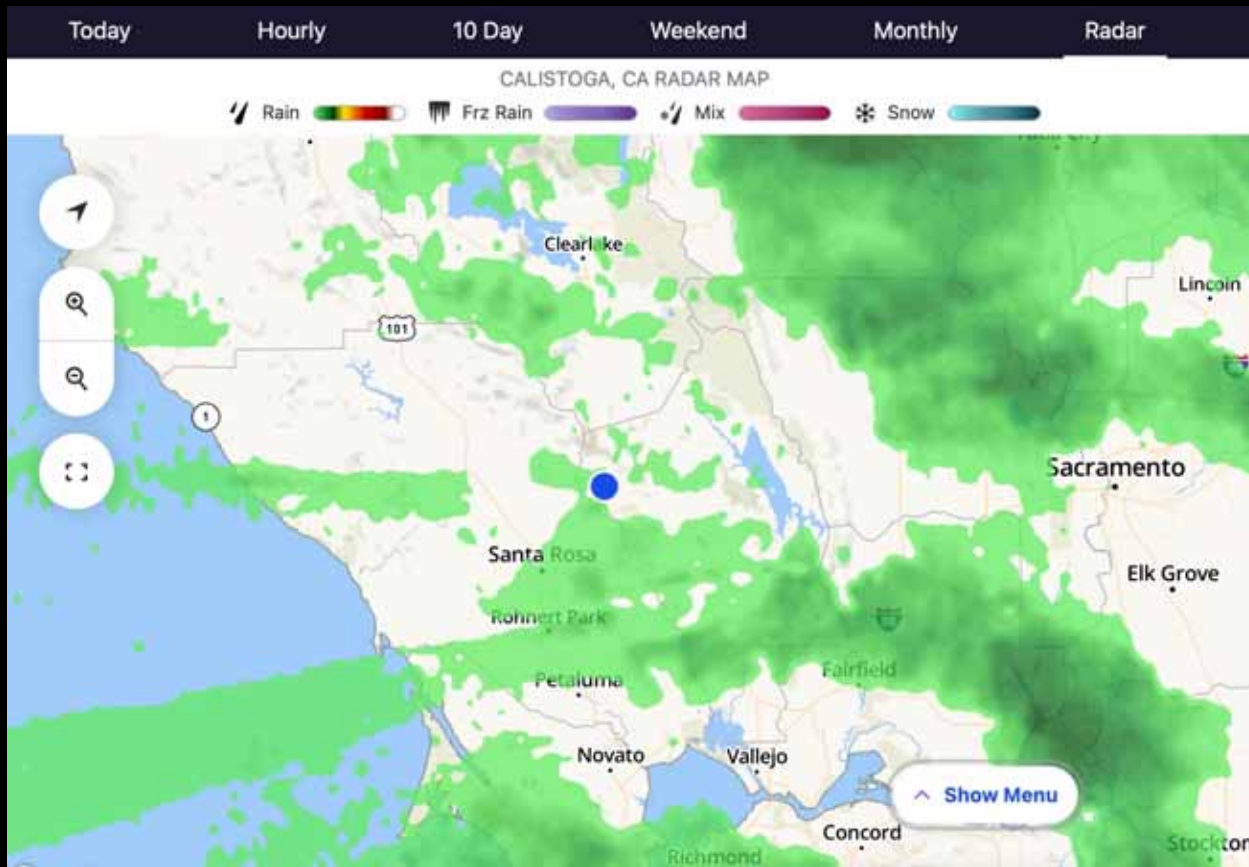


“actuators”

Mirror World Instantiations

- Environment/Agriculture
- Weather and climate
- Energy networks
- Automation
- (Electronic) system design/operation
- Mobility
- (Very) Smart homes
- Health and wellness

Weather in Mirror World



[Monday March 13, 2023]

Virtual movie of rainfall
obtained from sensors
(Doppler radar) and
models

Goes backward and
forward in time

Provokes actions in Real
World

rachio

Rain Skip

83.0 Gallons Saved*

Source: California State Water Resources Control Board (CSWRCB) - 2/13/23

It's raining today, no watering needed

Expected precipitation in the next 88 hour period exceeds your current Rain Skip threshold of 5.125 inches. Weather Intelligence determined no additional watering is necessary.

0.29"	0.29"	0.29"
Observed	Predicted	Total (obs + pred)

Mobility in the Mirror World



[Courtesy:Black Sheep Production]

[see also: Gerhard Fettweis, "Tactile Internet", 2015]

Not really extraordinary



One balmy evening in Hue, Vietnam (July 2018)

Driving in the Mirror World



Tesla FSD Beta v10

Local 3D reconstruction of environment
around car (using only video cameras)



Expanding the scale

Intersection Control



[Courtesy: A. Bayen, UCB]



[619,442 vehicles, 1,102 signalized and 10,622 unsignalized intersections]

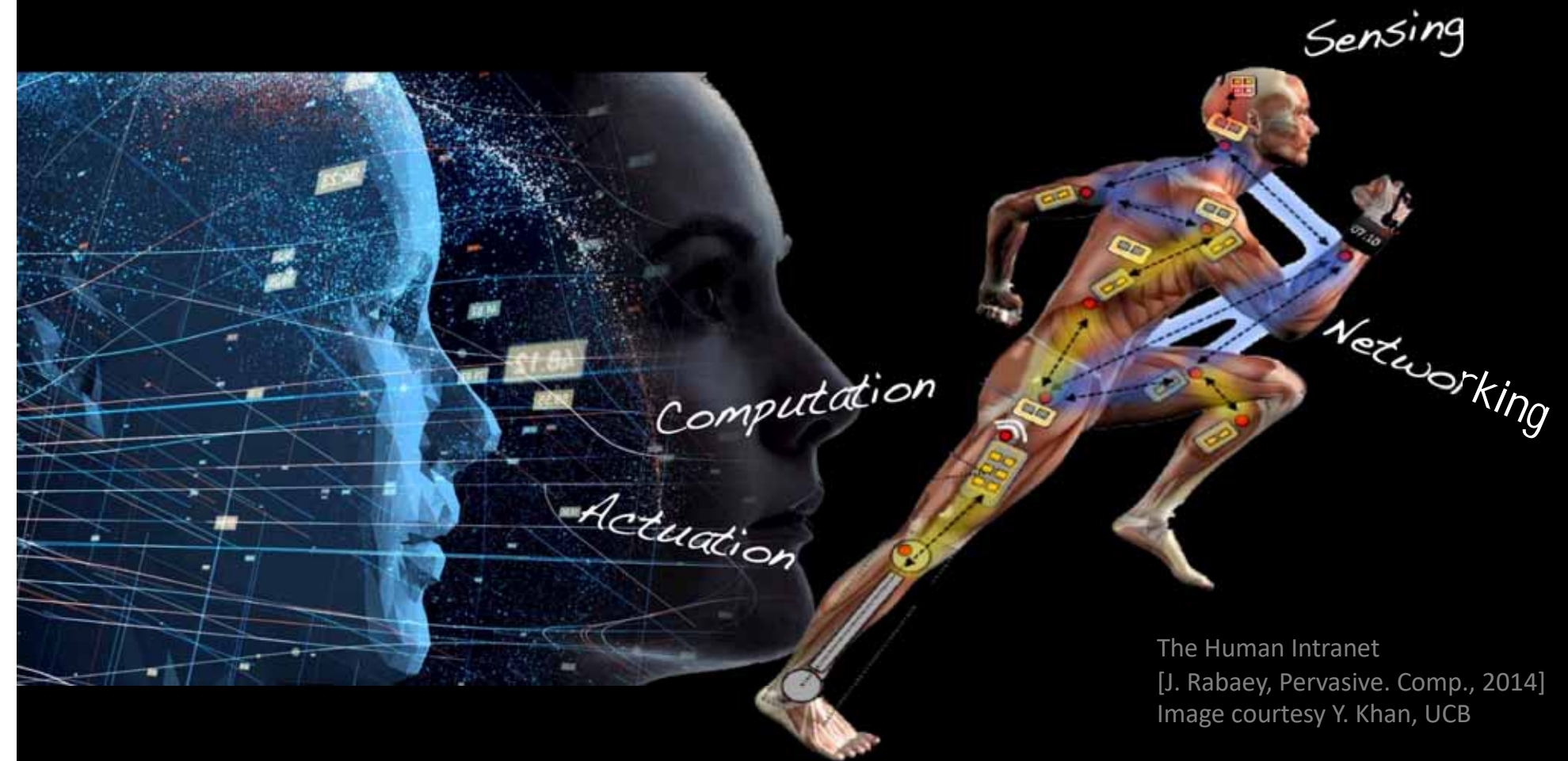
[INRO Software]

Humans in the Mirror World



[Meta Quest 2, 2023]

Humans in the Mirror World

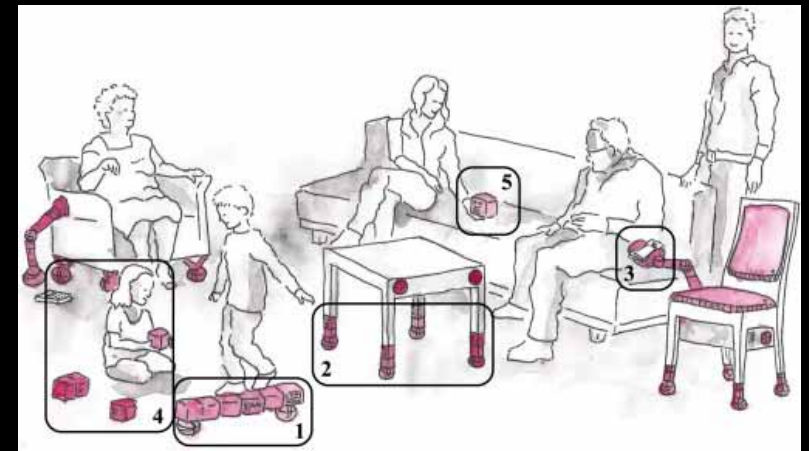


The Human Intranet
[J. Rabaey, Pervasive. Comp., 2014]
Image courtesy Y. Khan, UCB

Humans in the Mirror World



'Digital Twins' Could Be the Future of Personalized Medicine [Debenedette, 2021]



[Roombots, Ijspeert EPFL 2020]

Human-Machine Interaction

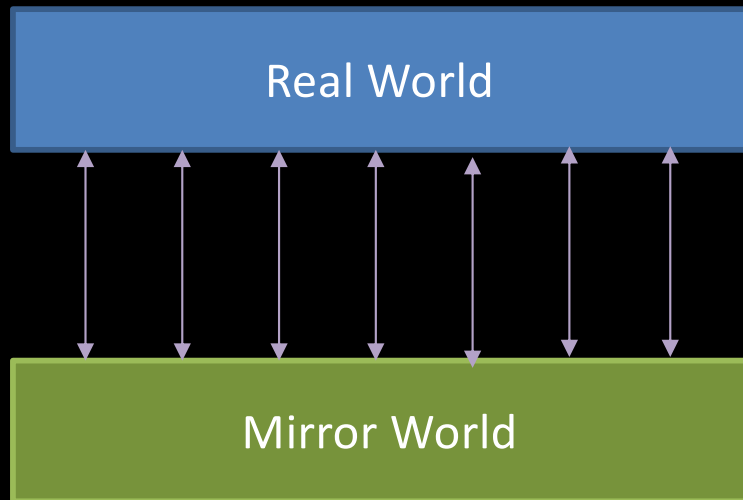


There is **no single** Mirror World

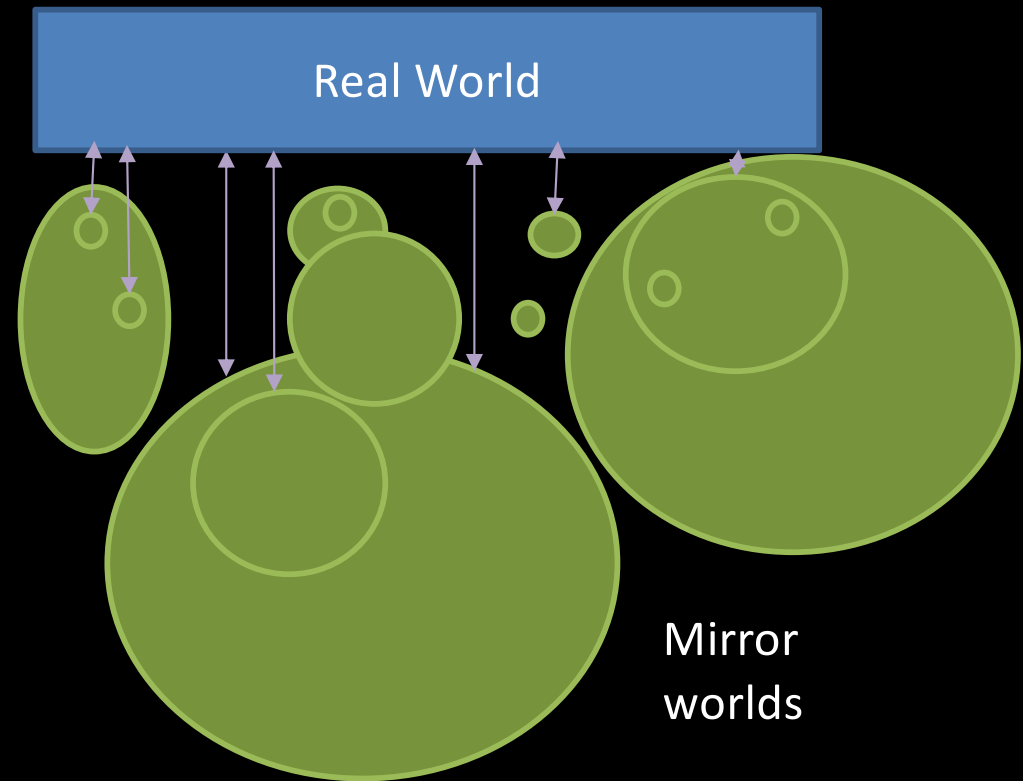
- There are **MANY**
- Personal, local, regional, global
- They may (or may not) be connected
- They co-exist and co-evolve
- Operate at different scales in time

“The omniverse(s)”

Mirror World Complexity



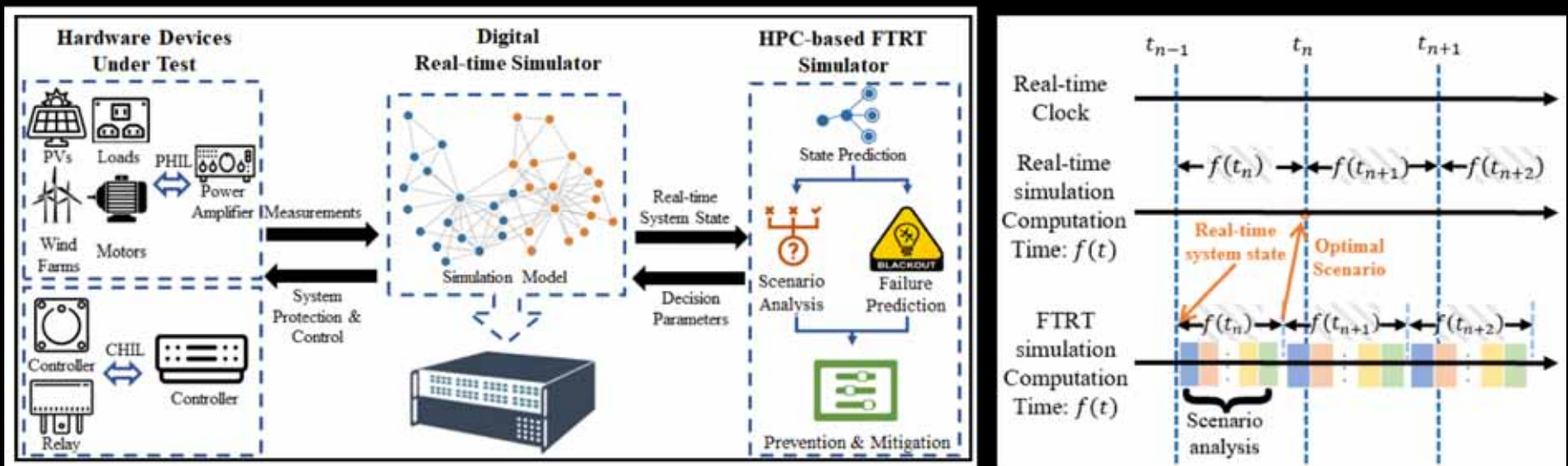
Infinite bandwidth
Infinite complexity



Mirror
worlds

MirrorWorld Time : Predicting the future

- Faster than real time (FTRT) simulation



[Liu et al., Arxiv:2104.04149, 2021]

Possibility of evaluating many scenarios

MirrorWorld Time : Predicting the future

- Generative models

Probabilistic Forecasting using Deep Generative Models

Alessandro Fanfarillo^{a,*}, Behrooz Roozitalab^b, Weiming Hu^c, Guido Cervone^{c,a}

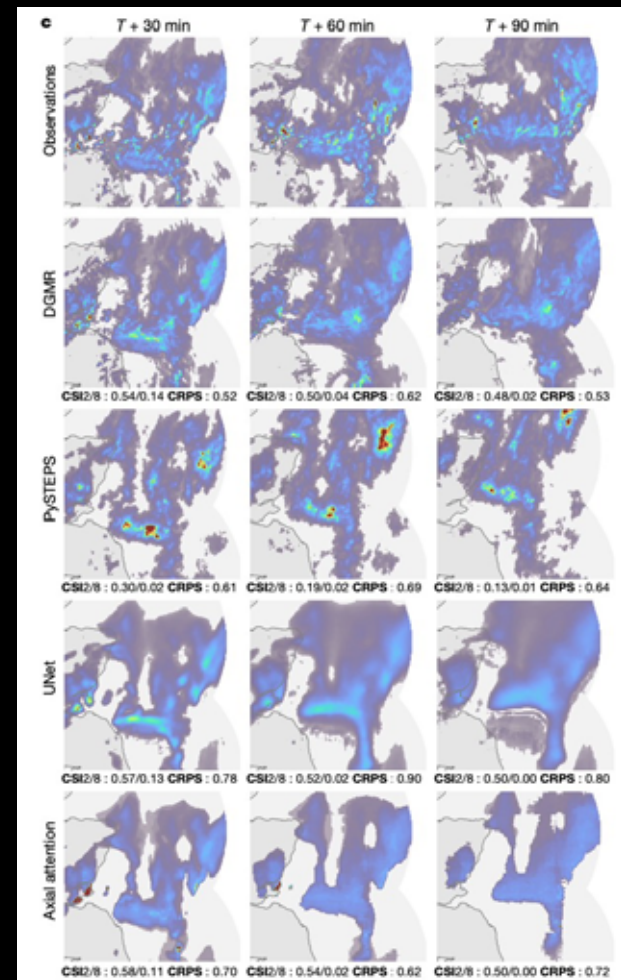
^aResearch Applications Laboratory, National Center for Atmospheric Research, Boulder, CO

Challenge: large enough data sets (?),
robustness and trustworthiness

[Ravuri et al, Skilful precipitation nowcasting using deep generative models of radar, Nature, 2021]

CSI: Critical success index

CRPS: Continuously ranked probability score



MirrorWorld Time: Going Back or Replay

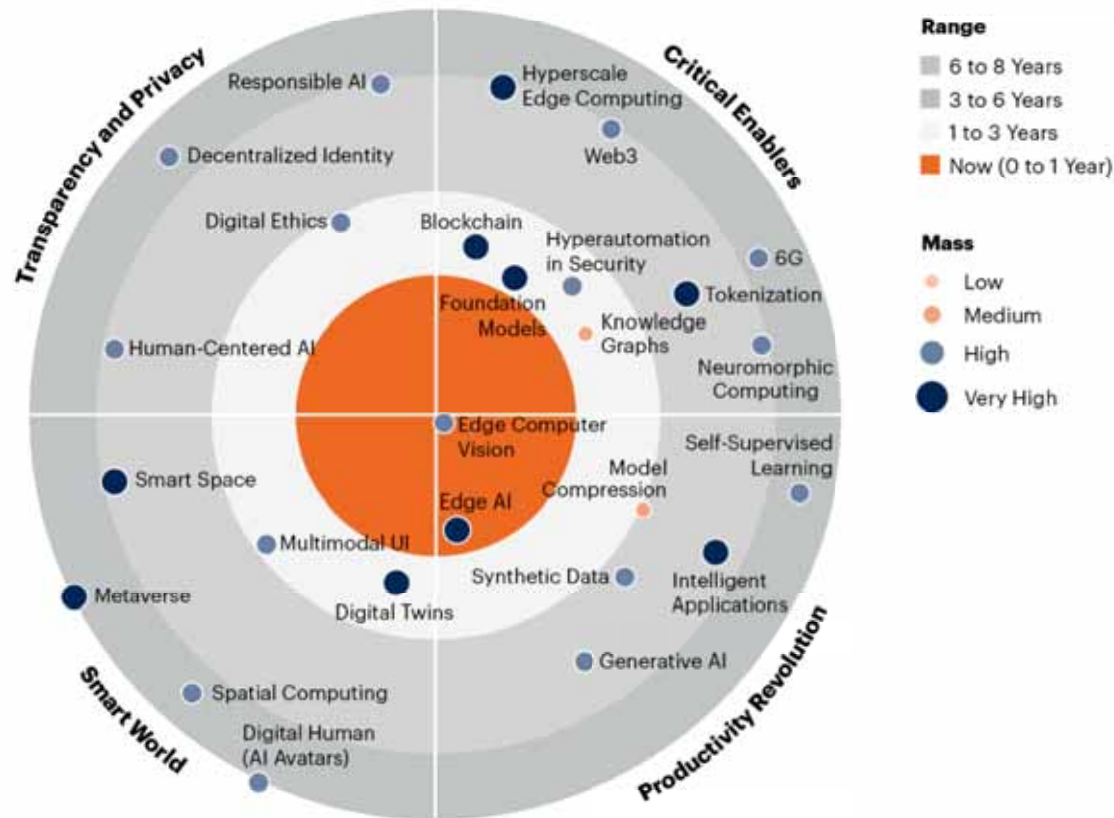


Mirror World has memory – and allows for reconstruction of the past

Storage???

["Belgian police releases video of Brussels Airport Suspect," nytimes, April 2016]

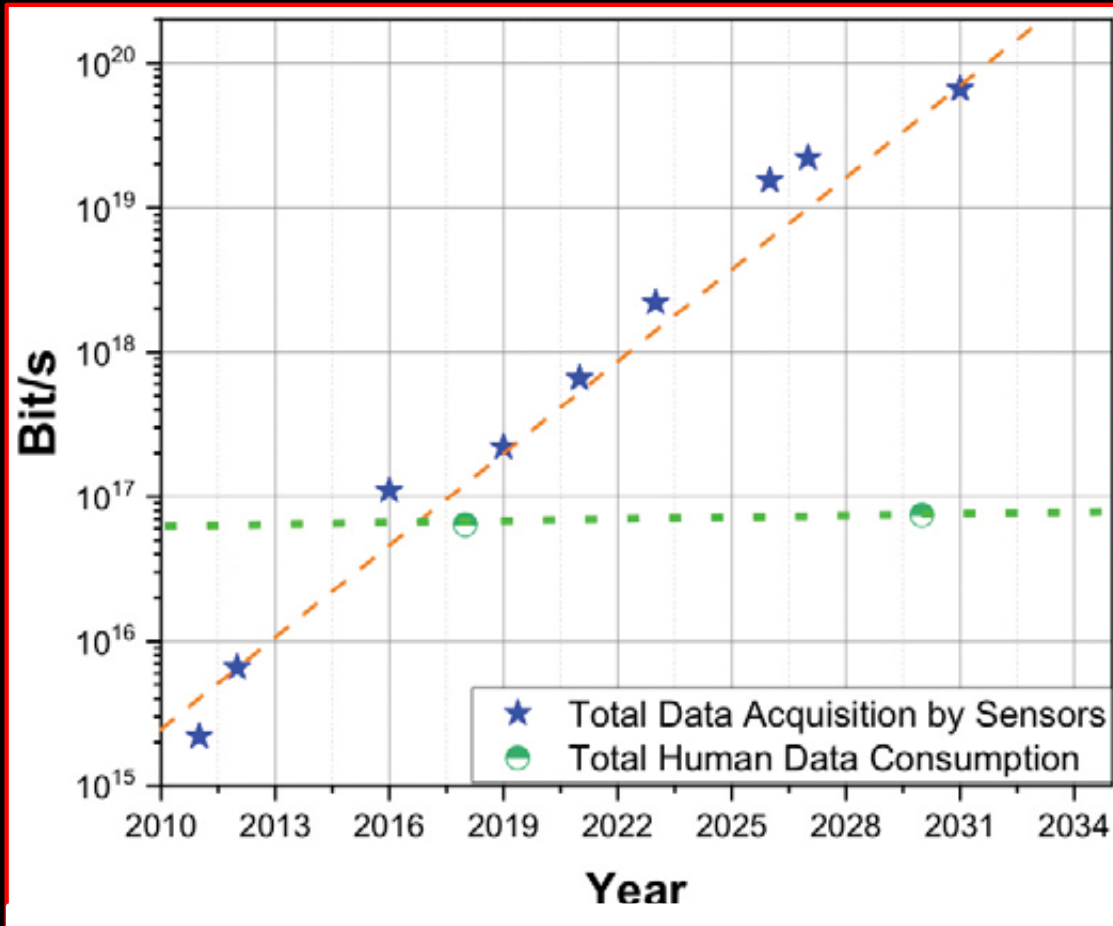
2023 Gartner Emerging Technologies and Trends Impact Radar



gartner.com

Needed:
full spectrum of
innovation

Sensory overflow



By 2032:

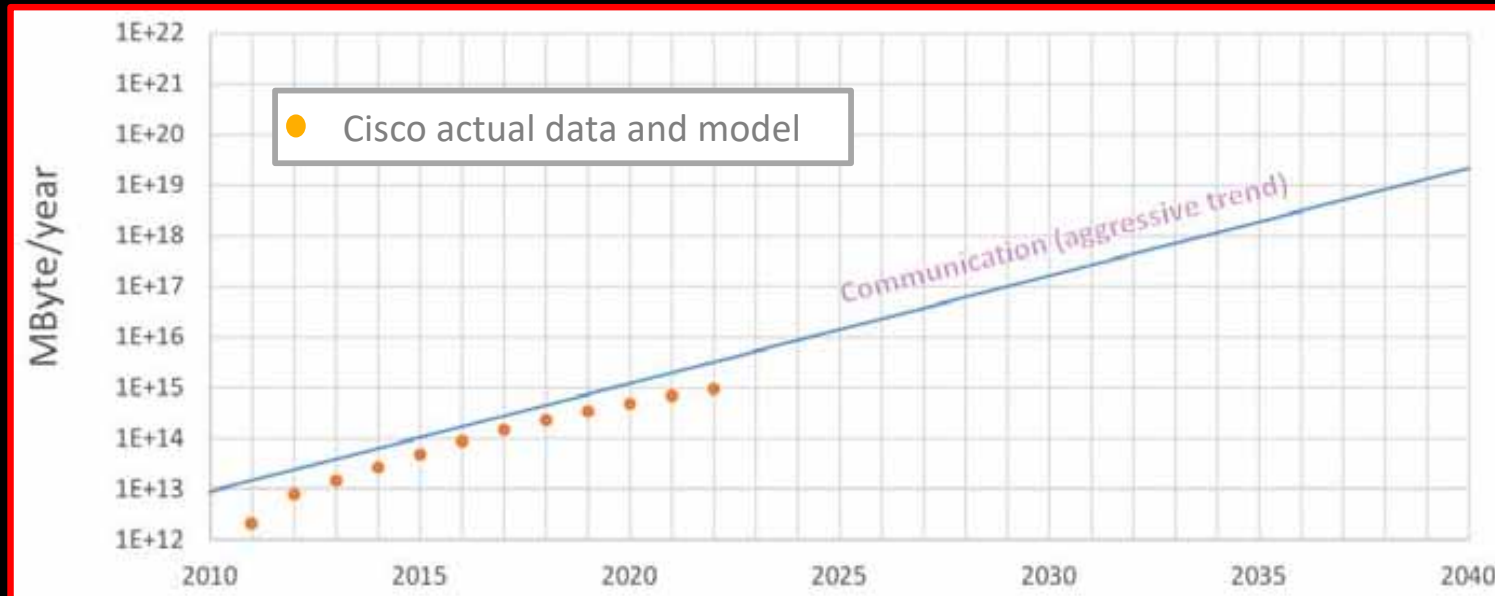
1 BrontoByte per year
(or 10^{20} bits/sec)

Human data consumption: ~ 70 GigaByte/day
(or 6.5×10^6 bits/sec)

Increases 5% per year

[SRC/SIA 2030 Decadal Plan]

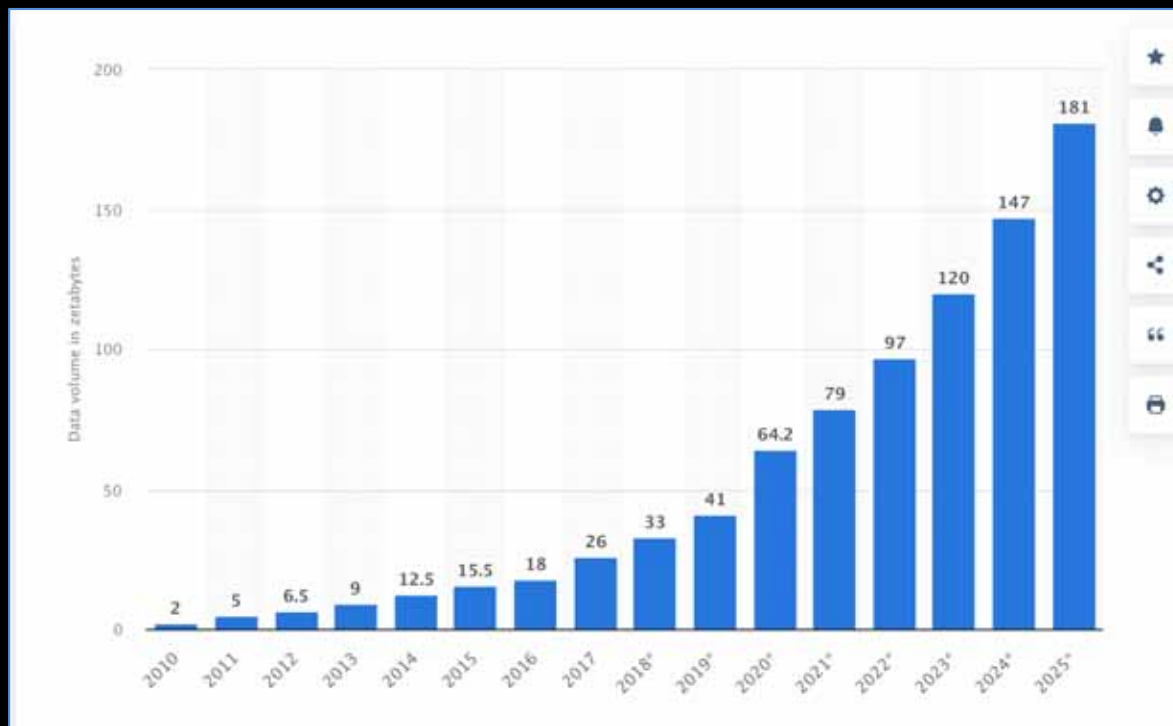
Wireless Capacity Estimates



[SRC/SIA 2030 Decadal Plan]

2030 sensor data: $3 \cdot 10^{19}$ bit/sec
communication capacity: $5 \cdot 10^{16}$ bit/sec

Volume of data/information created, captured, copied, and consumed worldwide from 2010 to 2020 (in Zettabytes)



[Source: Statistica, 2023]

Need smart storage
Store information, not
data

Storing (reconstructing) the past



Parts of the brain active during perception are also active during recall of memories.

When memory of an image is stored, **only the highest levels are kept**, and lower levels are reconstructed (less precise)

[How your brain distinguishes memories from perceptions, WIRED, Jan. 2023]

Computational Load



Communication

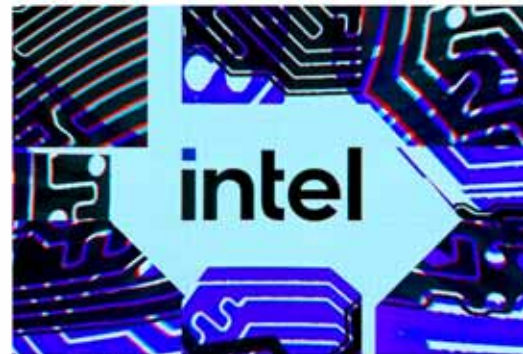
Earth's Complexity Is Non-Computable: The Limits of Scaling Laws, Nonlinearity and Chaos

Sergio Rubin ^{*} and Michel Crucifix

Earth is a complex system because it instantiates life at a planetary scale ...

TECH / INTEL / VIRTUAL REALITY

Intel thinks the metaverse will need a thousand-fold increase in computing capability



/ A reality check for computing's next big leap

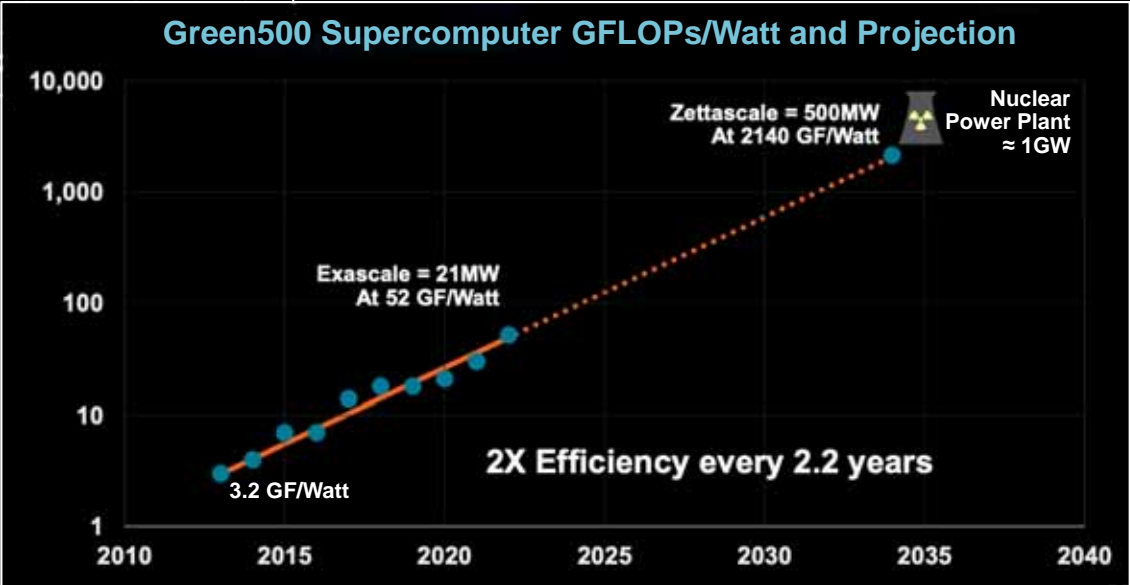
By CHAIM GARTENBERG / @cgartenberg
Dec 16, 2021 at 5:19 AM GMT-8 | 0 Comments / 0 Likes



Illustration by Alex Castro / The Verge

Computational Requirements

[Lisa Su, AMD, ISSCC 2023]

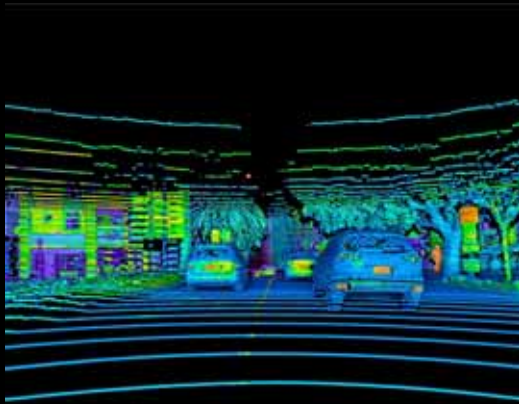


Energy the limiting factor

(see "Fall" – energy to download/run a brain)

Mirror World is distributed

- Computing on the sensor, at the edge and in the cloud

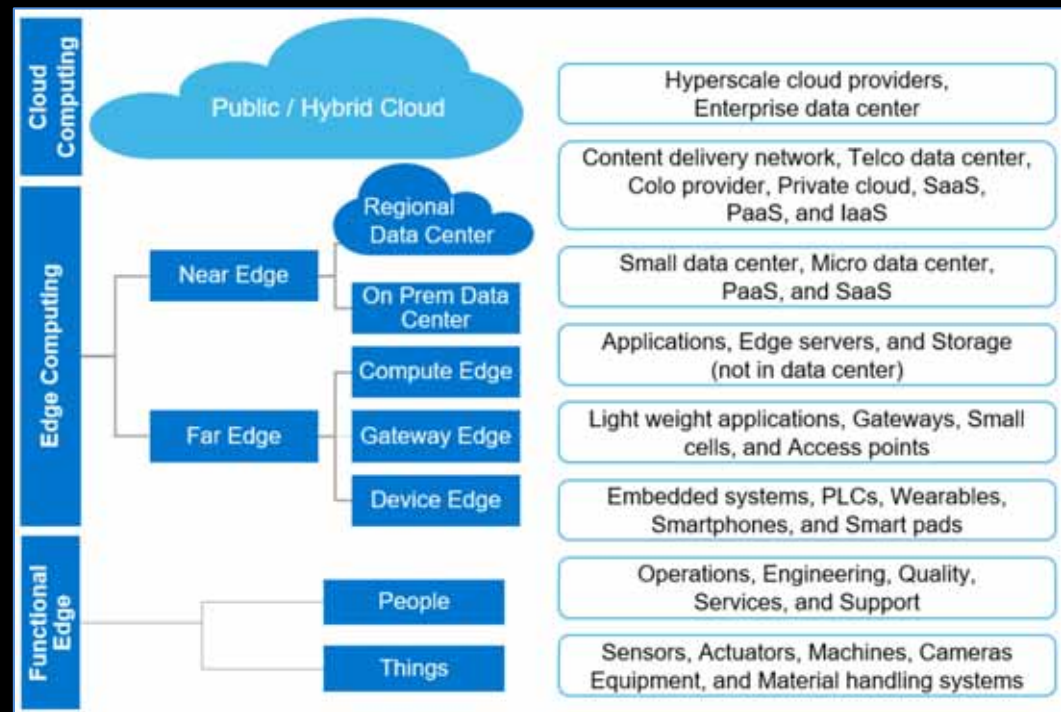


The Compute Continuum*

“An interconnected ecosystem allowing complex applications to be executed from IoT Edge devices to the HPC Cloud”

An emerging paradigm in digital distributed compute infrastructures

Move computation to where relevant data resides and resources are available at minimum cost



[Dell Technologies, 2022]

* Also known as digital continuum or transcontinuum

von Neumann

M(G)Watts

Tbits data rates

Millions of centralized nodes

Cyber World

Compute Continuum

The Edge

Natural world

Trillions of distributed nodes

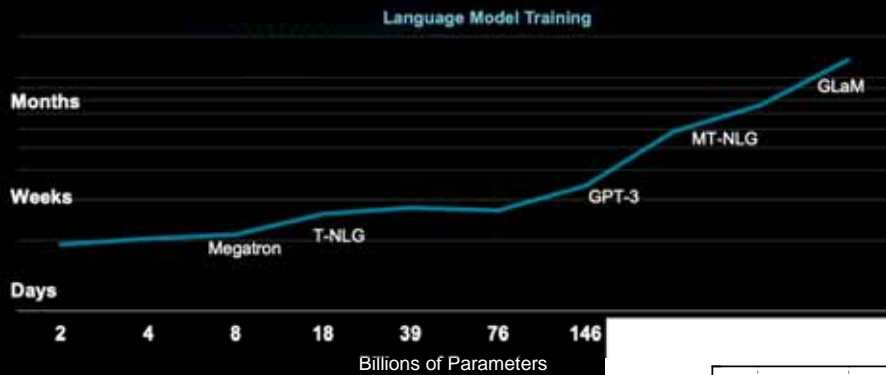
Kbits data rates

nWatts

Physical computing



New leaps in computational efficiency?



[Lisa Su, AMD, ISSCC 2023]

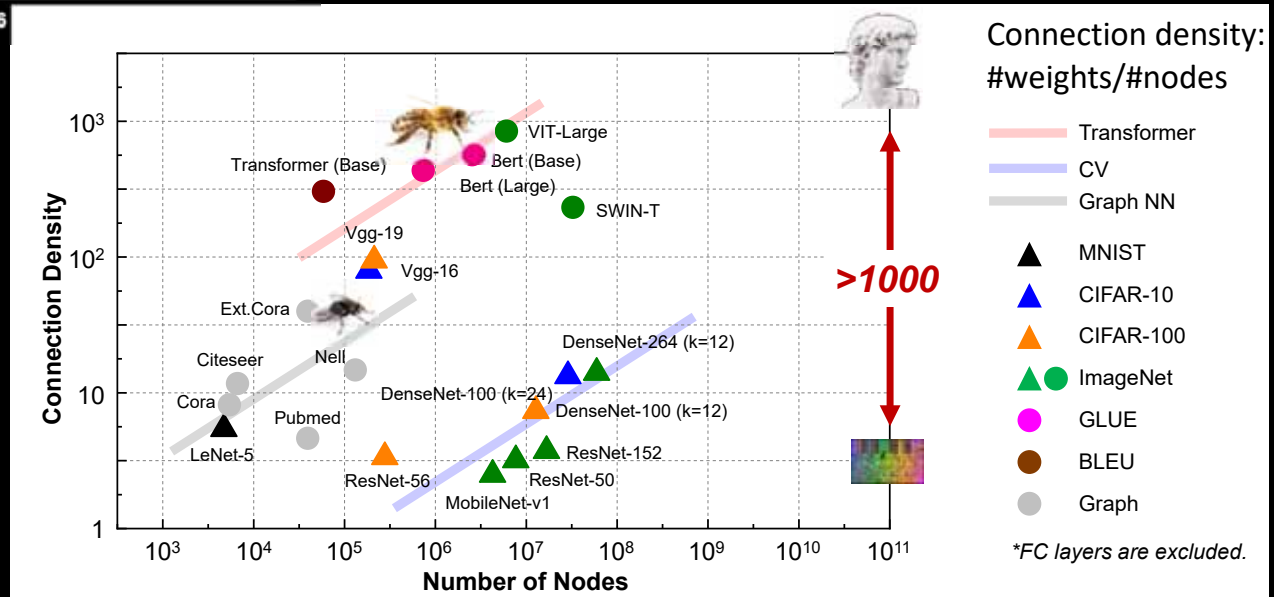
Voices > Editorials

The human brain is the most complex structure in the universe. Let's do all we can to unravel its mysteries

New techniques are producing great excitement among neuroscientists

Wednesday 02 April 2014 20:11 · [Comments](#)

[🔗](#) [f](#) [t](#) [✉](#)



[Courtesy Kevin Cao, ASU, 2023]

Largest Challenge: Stovepiping

- Interoperability, resource access, discovery, robustness, security
 - *{Apple, Amazon, Tesla, YourGov, ...} World*
- The obvious solutions
Standards, Interfaces, Modularity, Distributed Management
IoT, smart home, Industry 4.0



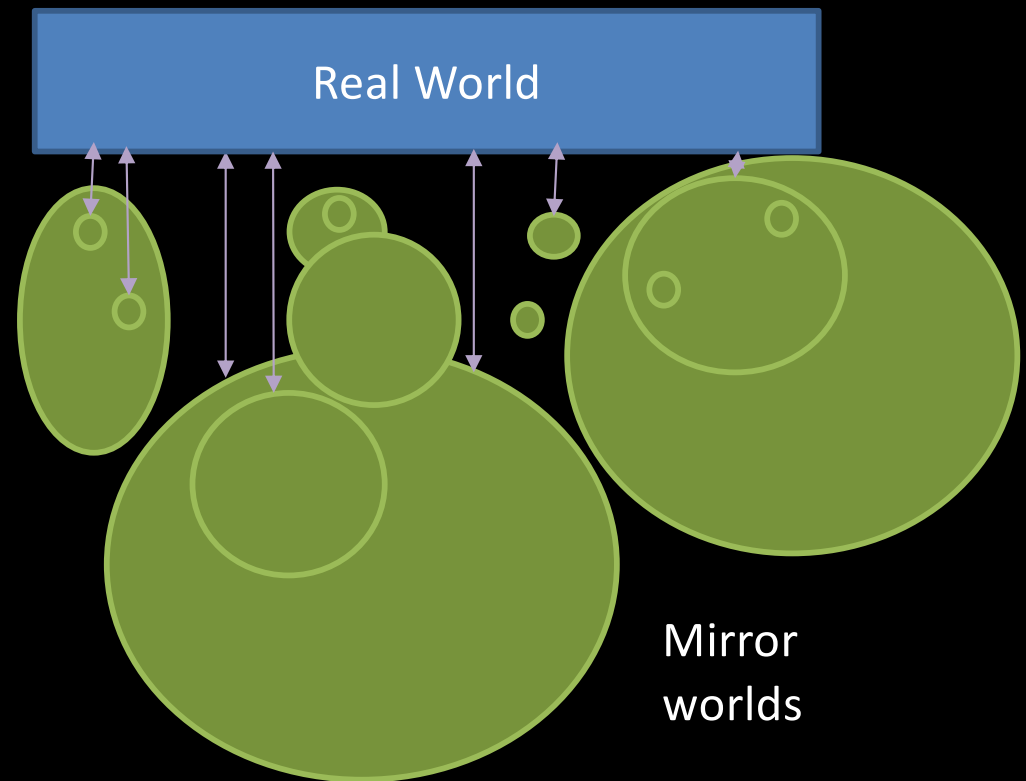
The ethics and policies of Mirror World

- How to avoid multitude of disasters?

Trust, Robustness/Reliability
Authentication/Identity/Ownership
Privacy, Security

Divide and conquer

Need to be handled on a
“per-bubble” space – data/compute
sandboxes



Final Thoughts



MirrorWorld

is happening already

Building on IoT, xG and AI

Scattered, fractured, focused,
constrained

Too many parallel universes

Amazingly powerful and scary ...

Pushing the limits on integrated
system design