The Hitchhiker's Guide to the Metaverse

SyMLab HKUST

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BibTex

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  year={2021},
  volume={abs/2110.05352}
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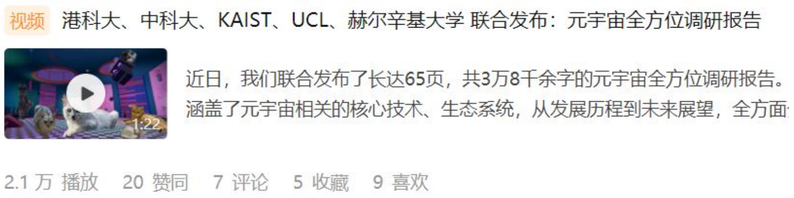
Lik-Hang Lee, Tristan Braud, Pengyuan Zhou, Lin Wang, Dianlei Xu, Zijun Lin, Abhishek Kumar, Carlos Bermejo, and Pan Hui (2021). All One Needs to Know about Metaverse: A Complete Survey on Technological Singularity, Virtual Ecosystem, and Research Agenda. *ArXiv, abs/2110.05352*.

Introduction & Background

All One Needs to Know about Metaverse

A Complete Survey on Technological Singularity, Virtual Ecosystem, and Research Agenda

More than **1,500** people have read it ***every week*** since the article was published.



Accumulated plays of introductory videos have been more than **21,000.**

Reported by Hong Kong Ming Pao, Washington Post and many other media


我们离元宇宙 Big Bang 有多近?

——专访科学家许彬

2021-10-31

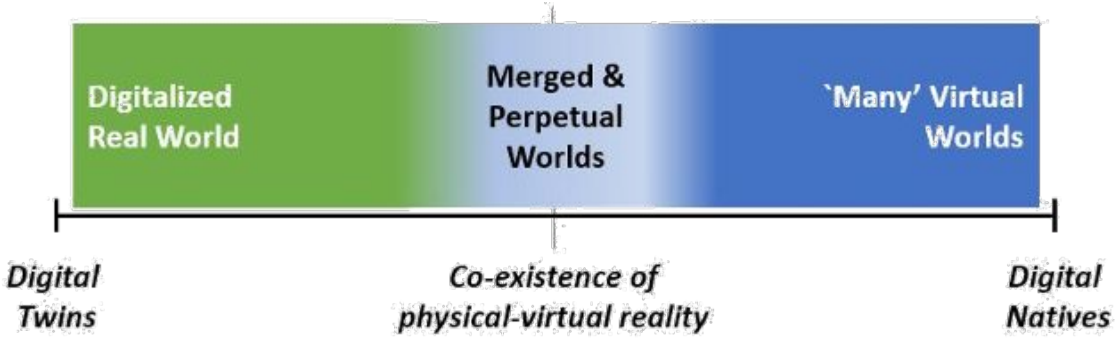
What is the Metaverse

- The scene of metaverse in Snow Crash has projected the duality of the real worlds and a copy of digital environments.

- In the metaverse, all individual users own their respective avatars, in analogy to the user's physical self, to experience an alternated life in the virtuality that is a metaphor of the user's real world.

Three phases of the Metaverse

1. Digital Twins
2. Digital Natives
3. Co-existence of Physical-virtual Reality



How to build the Metaverse?

How to build the Metaverse?

Physical World

Digital Twin

Metaverse

How to build the Metaverse?

Digital Twin

1. Digital Twins: a **large-scale** and **high-fidelity** digital models and entities, instead of a single object (e.g., nut and bolt), duplicated in virtual environment.

2. Digital Twins reflects the physical counterpart with various properties including the object motions, temperature, and even the functionality of such digital models and entities.

3. The connection between the virtual and physical twins is **tied by their data**.

How to build the Metaverse?

Content Creation

1. Content Creation depicts numerous content creators, perhaps represented by the avatars, which could be involed in digital creations inside **aforementioned digital worlds**.

2. Such digital creation can be **distinguishable from the physical counterpart**, or **even only exists in the digital world**.

3. Content Creation can also produce new economic activities.

How to build the Metaverse?

The metaverse

1. The metaverse could exist as a **self-sustaining** and **persistent** virtual world that co-exists and interoperates with the physical world with a high level of independence.

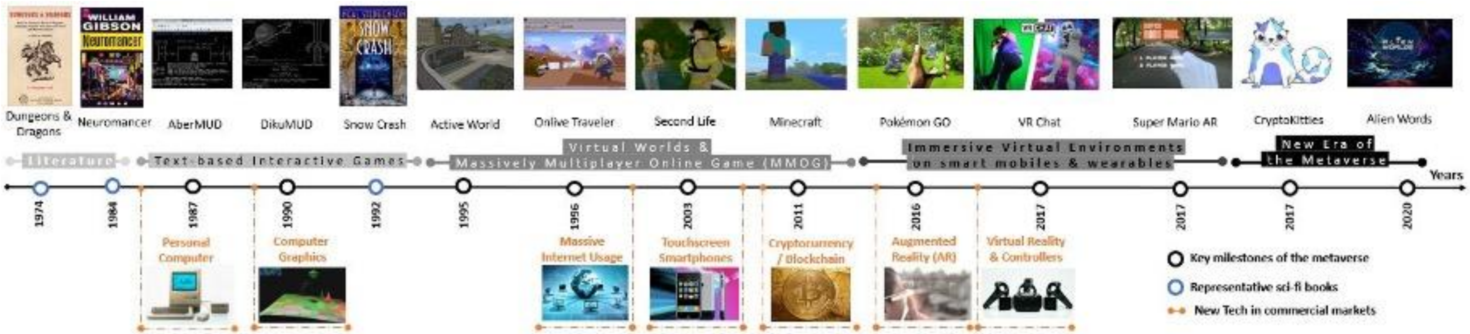
2. The avatars, or users in the physical world, can experience **heterogeneous activities in real-time** if they are in a same virtual world.

3. Theoretically, the metaverse is able to support **unlimited numbers of concurrent users** in a number of virtual worlds.

So, where are we?

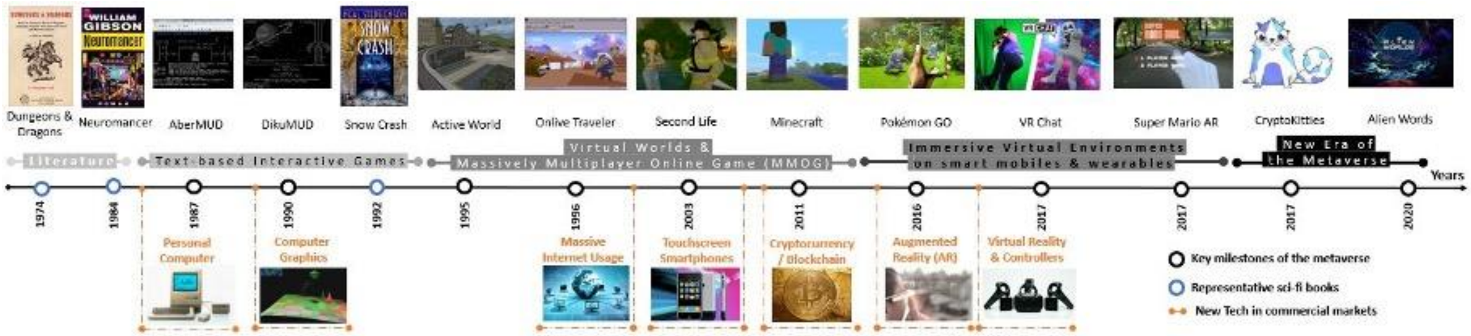
Metaverse Chronicle

The metaverse has experienced **four transitions** from text-based interactive games, virtual open worlds, Massively Multiplayer Online Game (MMOG), immersive virtual environments on smart mobiles and wearables, to the current status of the metaverse.



Where are we heading?

Obviously, **technologies** serve as the catalyst to drive such transitions. Nowadays, the research community is still on the way to exploring the metaverse development. Ideally, new technologies could potentially unlock additional features of the metaverse and drive the virtual environments towards a perceived virtual universe.



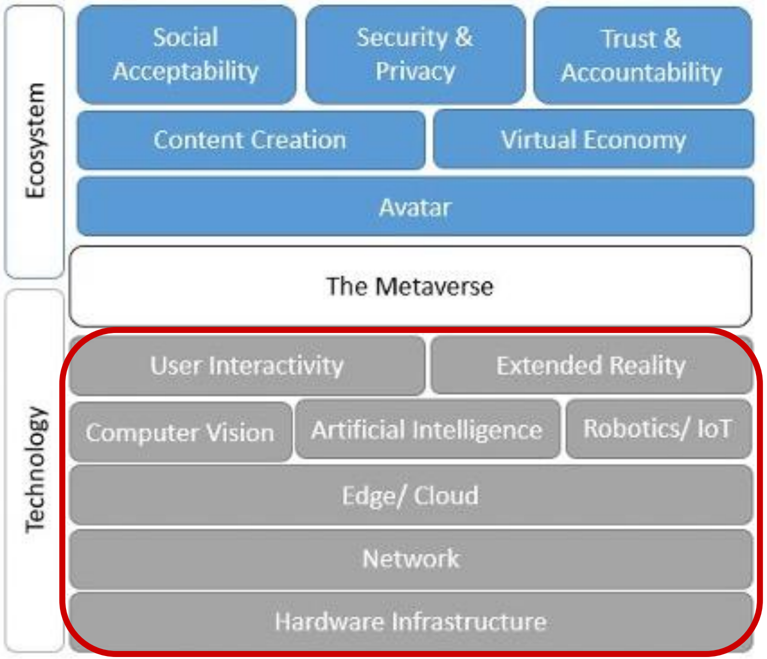
Cyberspace VS. Metaverse

(RW)(P)(CC)(S)/ Experience-Duality (ED)		The under-explored cyberspace (Opportunities of entering the Metaverse)								
(RW)(P)(CC)/ Social as Community (S)	Twitter	Instagram	Clubhouse	TikTok	Animal Crossing	Second Life	VR Chat	XSight	Pokémon Go	University
(RW)(P)/ Content Creation (CC)	Medium	Pixlr	Adobe Audition	YouTube	Super Mario Maker	Roblox	Quill	Adobe Aero	BIM	Soft Clay
(RW)/ Personalisation (P)	Xanga	Meitu	Spotify	Netflix	Diablo	Fortnite	VR Commerce	IKEA Place	Google Map AR	Shopping
Read & Write (RW)	SMS	Camera App	MMS	Zoom	S. Mario Bros	Simcity	Beat Saber	Skype	AR Translator	Mah Jong
	Text	Image	Audio	Video	Gaming	Virtual 3D	VR	MR	AR	Physical

Our vision:
Technology and Ecosystem

Vision on Technology

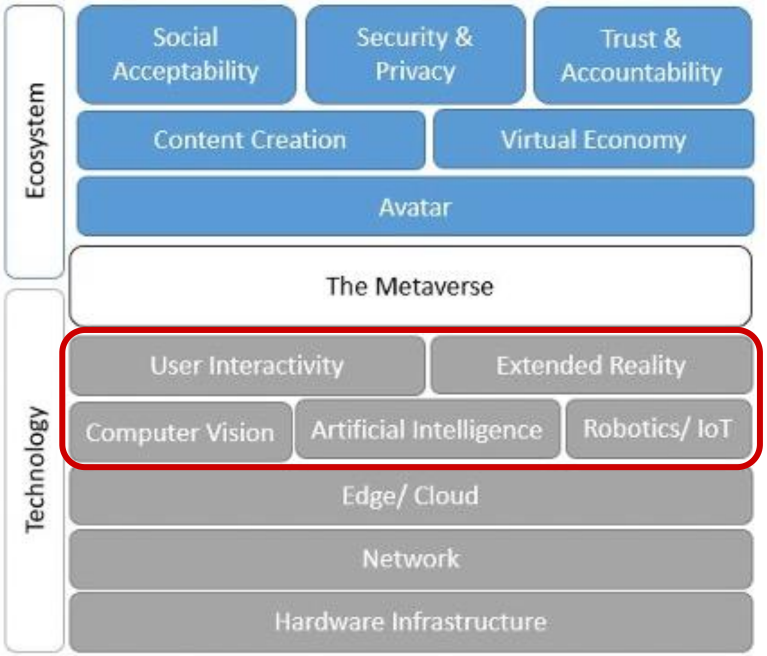
1. User Interactivity
2. Extended Reality
3. Computer Vision
4. Artificial Intelligence
5. Blockchain
6. Robotics/IoT
7. Edge/Cloud
8. Network



Vision on Technology

Under the technology aspect, human users can access the metaverse through extended reality (XR) and the techniques for user interactivity (e.g., manipulating virtual objects).

Next, the computer vision (CV), artificial intelligence (AI), and robotics/ Internet-of-Things (IoT) can work with the users to handle various activities inside the metaverse through the user interactivity and XR.

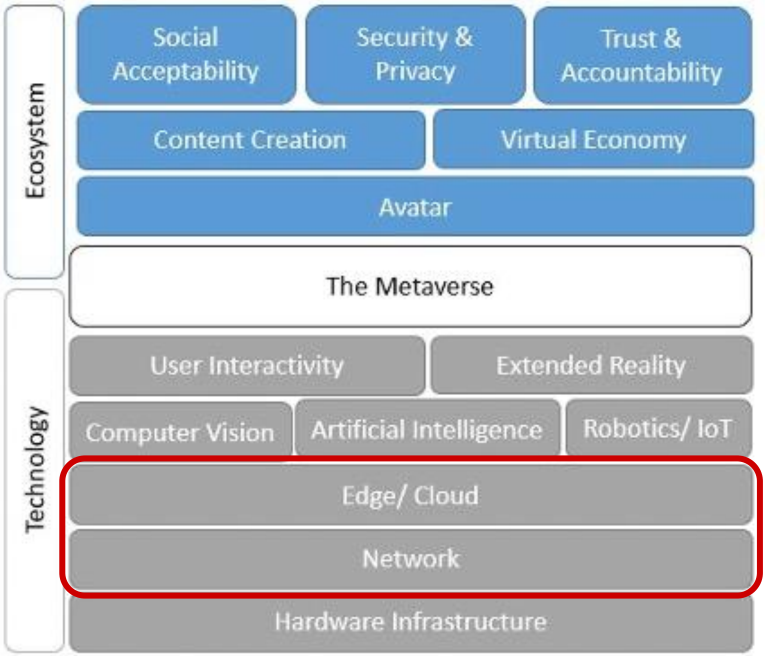


Vision on Technology

Edge computing aims to improve the performance of applications that are delay-sensitive and bandwidth-hungry, through managing the adjacent data source as pre-processing data available in edge devices.

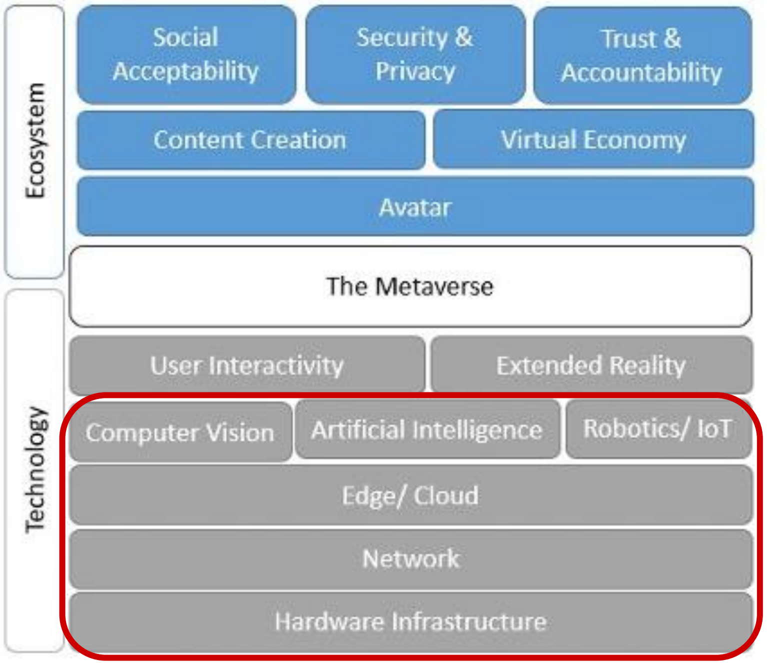
In the meanwhile. the cloud computing is well-recognised for its highly scalable computational power and storage capacity.

Leverging both the cloud-based and edge-based services can achieve synergy, such as maximising the application performance and hence user experiences.



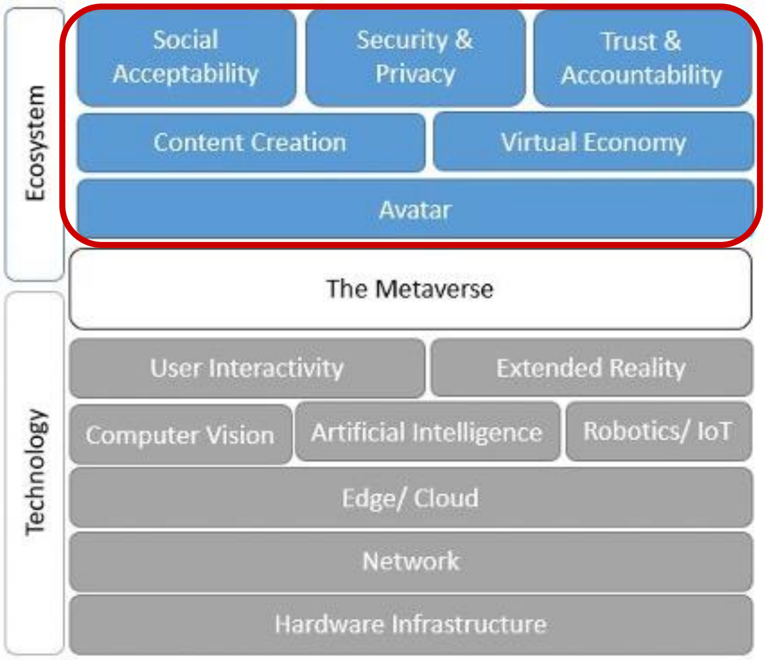
Vision on Technology

In sum, edge devices and cloud services with advanced network could be the tech-base to support those modern technologies on the top of appropriate hardware infrastructure, like CV, AI, robots, and IoT.



Vision on Ecosystem

1. Social Acceptability
2. Security & Privacy
3. Trust & Accountability
4. Content Creation
5. Virtual Economy
6. Avatar

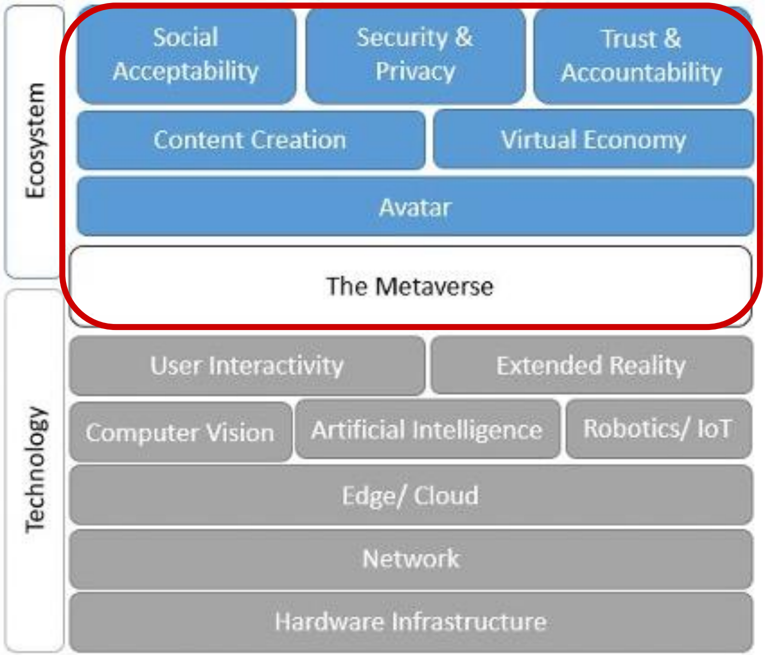


Vision on Ecosystem

The ecosystem describes an independent and meta-size virtual world, mirroring the real world. Human users with XR and the techniques for user interactivity, perhaps situated in the real world, can control their avatars for various collective activities, such as content creation.

Virtual economy is a spontaneous derivative of content creation activities in the metaverse.

We consider three focused areas of Social acceptability, security and privacy, as well as trust and accountability.

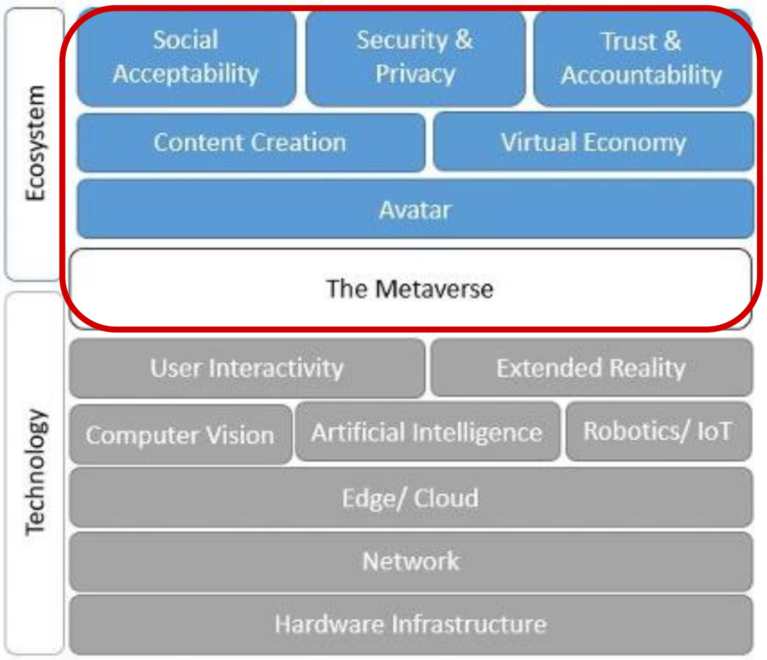


Vision on Ecosystem

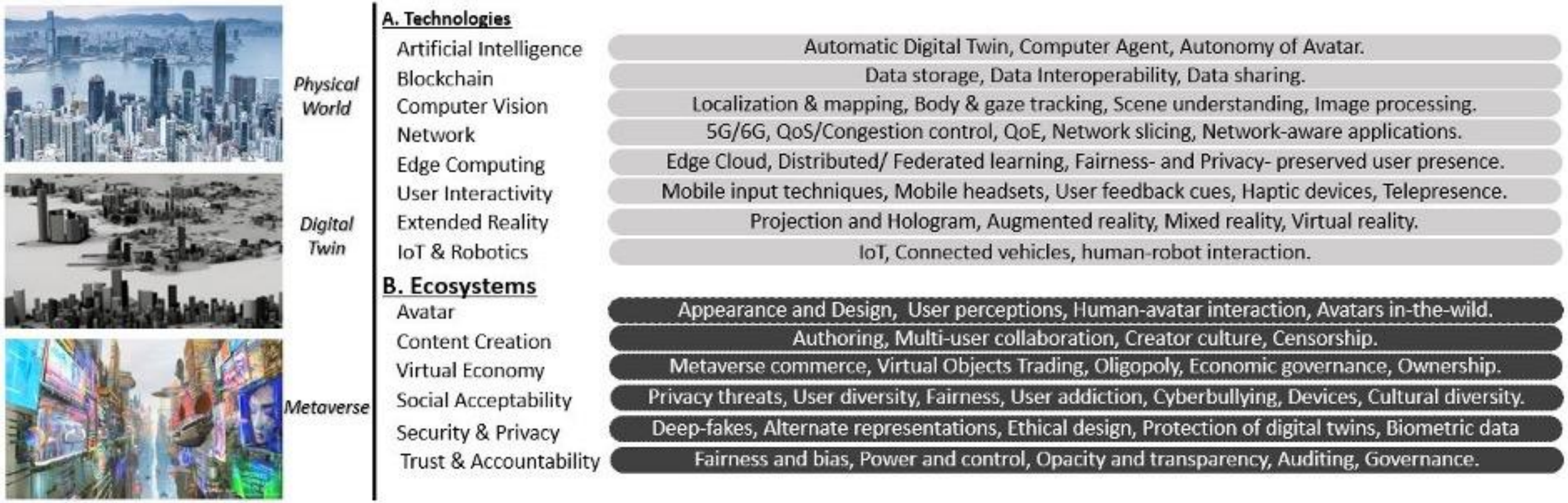
Analogue to the society in the real world, content creation and virtual economy should align with the social norms and regulations.

For instance, the production in the virtual economy should be protected by ownership, while such production should be accepted by other avatars (i.e. human users) in the metaverse.

Also, human users would expect that their activities are not exposed to privacy risk and security threats.

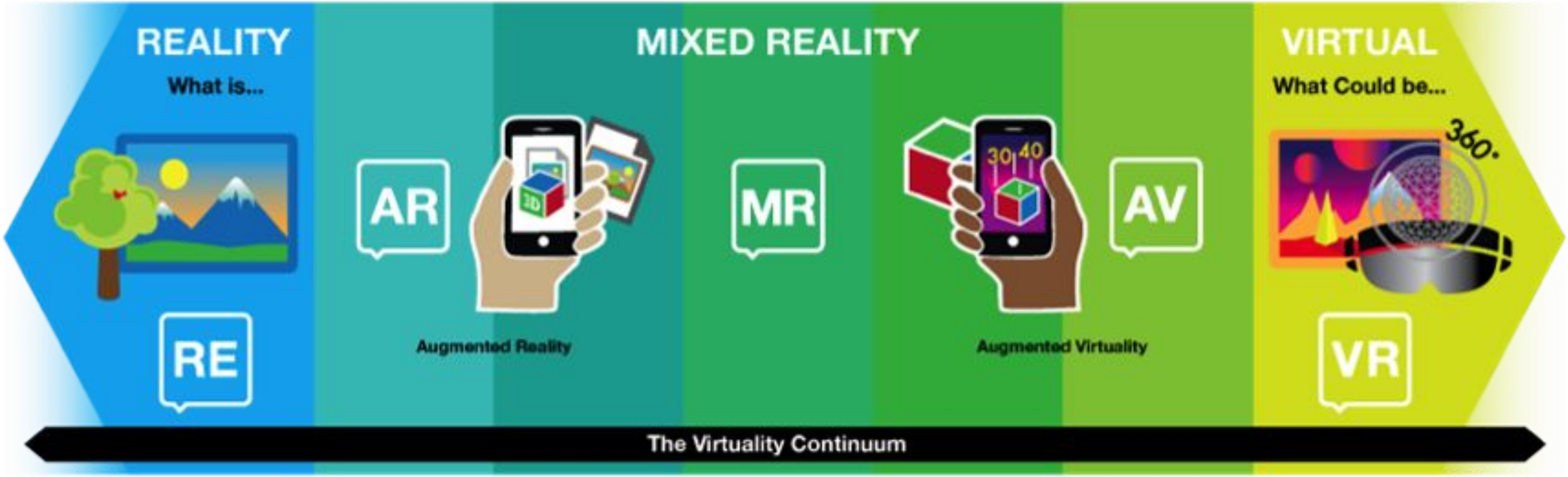


Metaverse Technology and Ecosystem



Metaverse technology: Extended Reality

Extended Reality – Overview



Virtual Reality

- VR owns the prominent features of totally synthetic views.

- The commercial VR headsets provide usual way of user interaction techniques, including head tracking or tangible controllers.

- Users in the metaverse will create contents aligned with digital twins. Nowadays, commercial virtual environments enable users to create contents, e.g., VR painting.

Virtual Reality

Multiple Users in such virtual environments can collaborate with each other in real-time. This aligns with the well-defined requirements of virtual environments:

1. A shared sense of space, a shared sense of presence, a shared sense of time (real-time interaction),
2. A way to communicate (by gesture, text, voice, etc.), and
3. A way to share information and manipulate objects.

Virtual Reality

Considering the ultimate stage of the metaverse, users situated in a virtual shared space should work simultaneously with any additions or interactions from the physical counterpart, such as AR and MR.

However, managing and synchronising the dynamic states/events at scale is a huge challenge, especially when we consider unlimited concurrent users collectively act on virtual objects and interact with each other without sensible latency.

Augmented Reality

AR delivers alternated experiences to human users in their physical surroundings, which focuses on the enhancement of our physical world.

In theory, computer-generated virtual contents can be presented through diversified perceptual information channels, such as audio, visuals, smell, and haptics.

Guaranteeing seamless and lightweight user interaction with such digital entities in AR is one of the key challenges, bridging human users in the world physical with the metaverse.

Augmented Reality

Freehand interaction techniques, as depicted in most science fiction films like *minority report*, illustrate intuitive and ready-to-use interfaces for AR user interactions.

Users with AR work in the physical environments and simultaneously communicate with their virtual counterparts in the metaverse.

- ➢ We can consider that the metaverse, via AR, will integrate with our urban environment, and digital entities will appear in plain and palpable ways on top of numerous physical objects in urban areas.

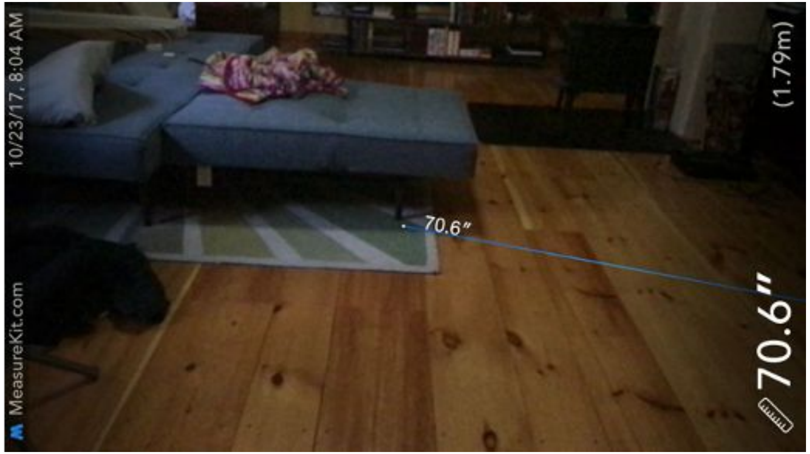
Augmented Reality

The recent AR headsets have demonstrated remarkable improvements, especially in user mobility. Users with lightweight AR headsets can receive visual and audio feedback cues indicating AR objects.

Augmented Reality

Key challenge:

AR requires significant efforts in the technologies of detection and tracking to map the virtual contents displayed with the corresponding position in the real environment.



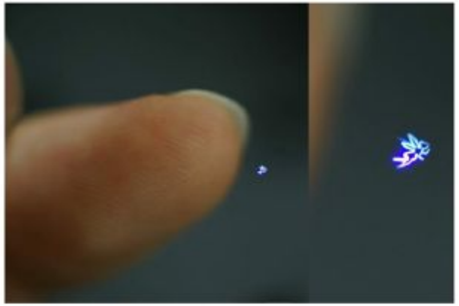
Mixed Reality – A stronger version of AR

MR stands between AR and VR, and allows user interaction with the virtual entities in physical environments

MR objects, supported by a strong capability of environmental understandings or situational awareness, can work with other tangible objects in various physical environments.

- For instance, a physical screwdriver can interact with digital entities of screws with slotted heads in MR,
- Demonstrating an important feature of interoperability between digital and physical entities.

Showing digital images in the real world: Large Display, Projection, and Holography



Vázquez-Martín, I., Marín-Sáez, J., Gómez-Climente, M., Chemisana, D., Collados, M.V., & Atencia, J. (2021). Full-color multiplexed reflection hologram of diffusing objects recorded by using simultaneous exposure with different times in photopolymer Bayfol® HX. *Optics and Laser Technology, 143*, 107303.
https://spectrum.ieee.org/femtosecond-lasers-create-3d-midair-plasma-displays-you-can-touch
Hartmann, J., Yeh, Y., & Vogel, D. (2020). AAR: Augmenting a Wearable Augmented Reality Display with an Actuated Head-Mounted Projector. *Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology*.

Metaverse technology: User Interactivity

User Interactivity

1. **Input**: enabling users to interact with digital entities in physical environments ubiquitously.

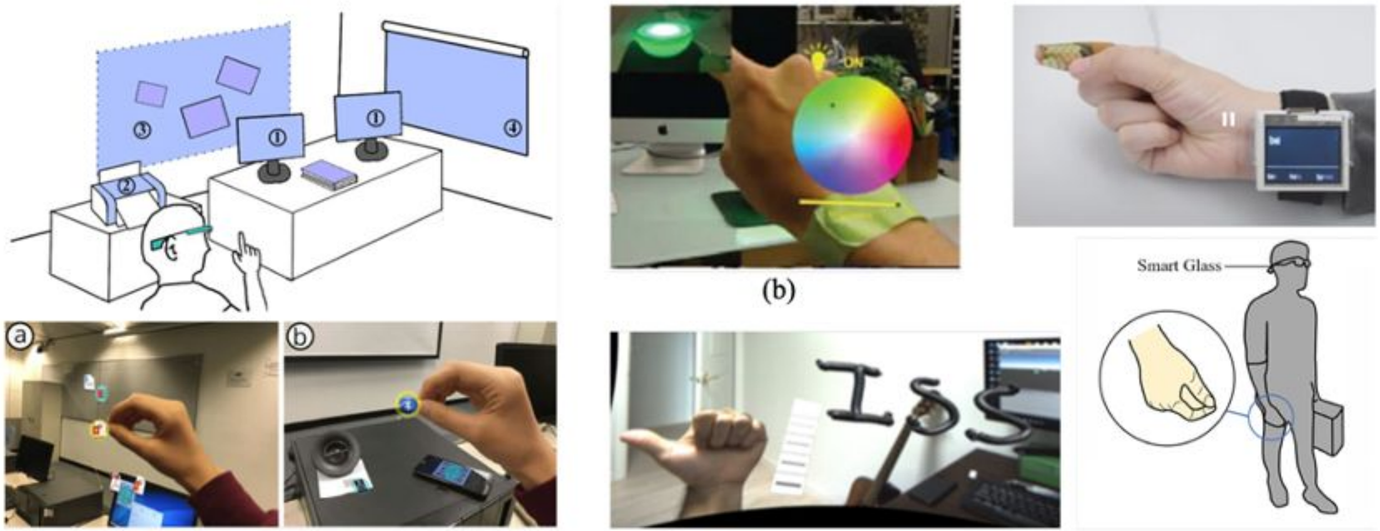
2. **Visual feedback**: display digital entities to human users.

3. Design of multiple user **feedback cues**:
   a. audios,
   b. haptics,
   c. muscle-force feedback, etc.

Lopes et al. 2018. Adding Force Feedback to Mixed Reality Experiences and Games using Electrical Muscle Stimulation. Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems. Association for Computing Machinery, New York, NY, USA, Paper 446, 1–13.

Mobile Input Techniques

Examples of on-body interaction techniques and everyday objects.



Lee, L., Braud, T., Hosio, S.J., & Hui, P. (2020). Towards Augmented Reality-driven Human-City Interaction: Current Research and Future Challenges. ACM CSUR.

Mobile Input Techniques

Smart Skins (Upper) and Smart Textiles

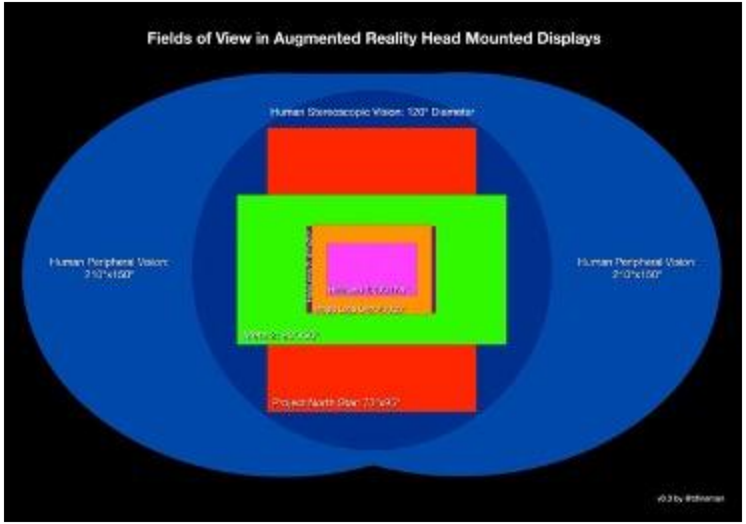
Lee, L., Braud, T., Hosio, S.J., & Hui, P. (2020). Towards Augmented Reality-driven Human-City Interaction: Current Research and Future Challenges. ACM CSUR.

Human Visions via Mobile Headsets

- Currently, the user immersiveness in the metaverse can be restricted by limited Field of View (FOV) on AR/MR mobile headsets.

- Narrowed FOVs can negatively influence the user experience, usability, and task performance.

- The MR/AR mobile headsets usually own FOVs smaller than 60 degrees. The limited FOV available on mobile headsets is far smaller than the typical human vision.



Lee, L., Braud, T., Hosio, S.J., & Hui, P. (2020). Towards Augmented Reality-driven Human-City Interaction: Current Research and Future Challenges. ACM CSUR.

Human Visions via Mobile Headsets

- For instance, the FOV can be equivalent to a 25-inch display 240 cm away from the user's view on the low-specification headsets such as Google Glass.
- The first generation of Microsoft Hololens presents a 30 × 17-degree FOV, which is a similar size as a 15-inch 16:9 display located around 60 cm away from the user's egocentric view.

Human Visions via Mobile Headsets

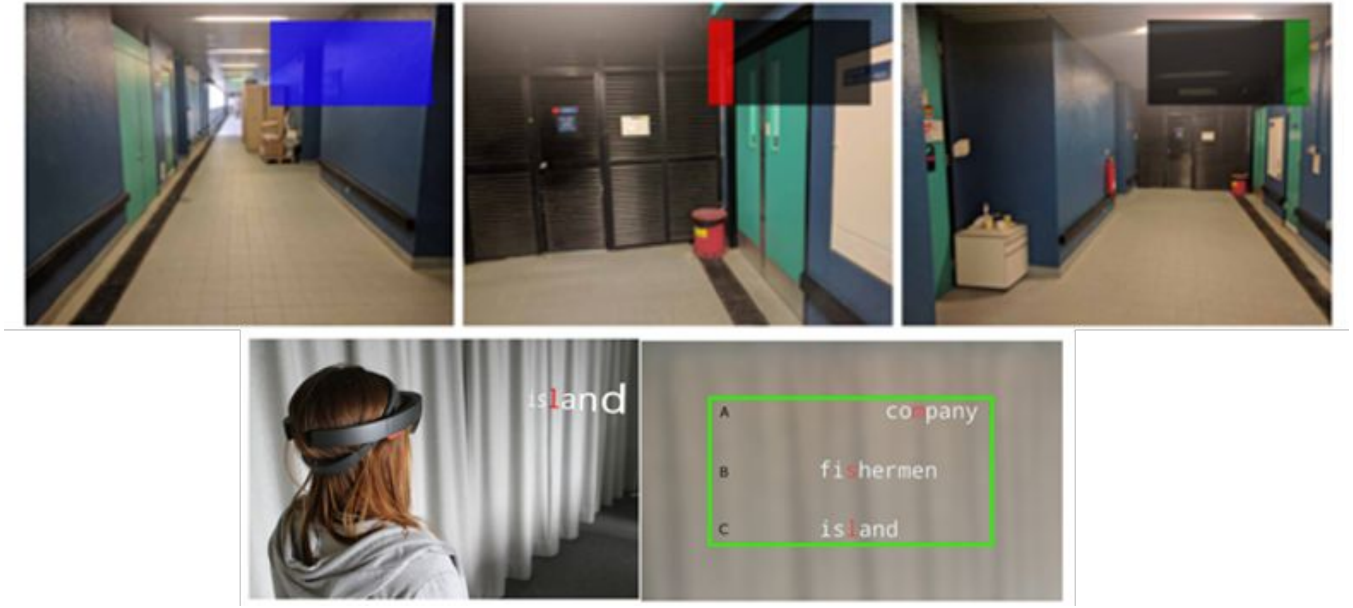
Smart Content Management and Display – select the right user contents – the user-interested objects in a particular environment.

- ➢ a restaurant (indoor, left)
- ➢ a street (outdoor, right)


Lam, K., Lee, L., Braud, T., & Hui, P. (2019). M2A: A Framework for Visualizing Information from Mobile Web to Mobile Augmented Reality. *2019 IEEE International Conference on Pervasive Computing and Communications (PerCom)*, 1-10.
Lam, K., Lee, L.H., & Hui, P. (2021). A2W: Context-Aware Recommendation System for Mobile Augmented Reality Web Browser. *Proceedings of the 29th ACM International Conference on Multimedia*.

Human Visions via Mobile Headsets

Carefully Design the visual AR objects to users inside the small-size display.

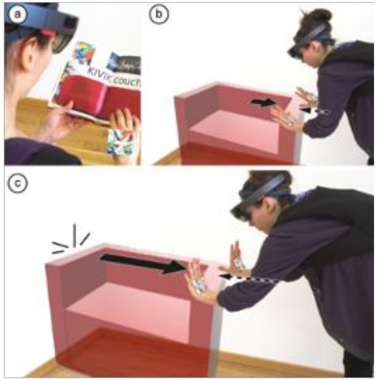


Lee, L., Braud, T., Hosio, S.J., & Hui, P. (2020). Towards Augmented Reality-driven Human-City Interaction: Current Research and Future Challenges. ACM CSUR.

Feedback Cues

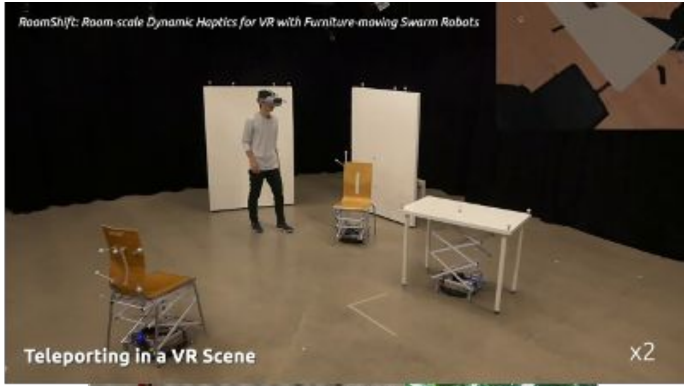
Digital contents become “untouchable” in virtual 3D worlds.

Feedback cues are highly relevant to the usability and the sense of realism in virtual-physical realm.



Sada, M.A., Jiang, K., Ranade, S., Kalkattawi, M., & Nakajima, T. (2019). HapticSnakes: multi-haptic feedback wearable robots for immersive virtual reality. *Virtual Reality, 24*, 191-209.
Lopes et al. 2018. Adding Force Feedback to Mixed Reality Experiences and Games using Electrical Muscle Stimulation. Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems. Association for Computing Machinery, New York, NY, USA,

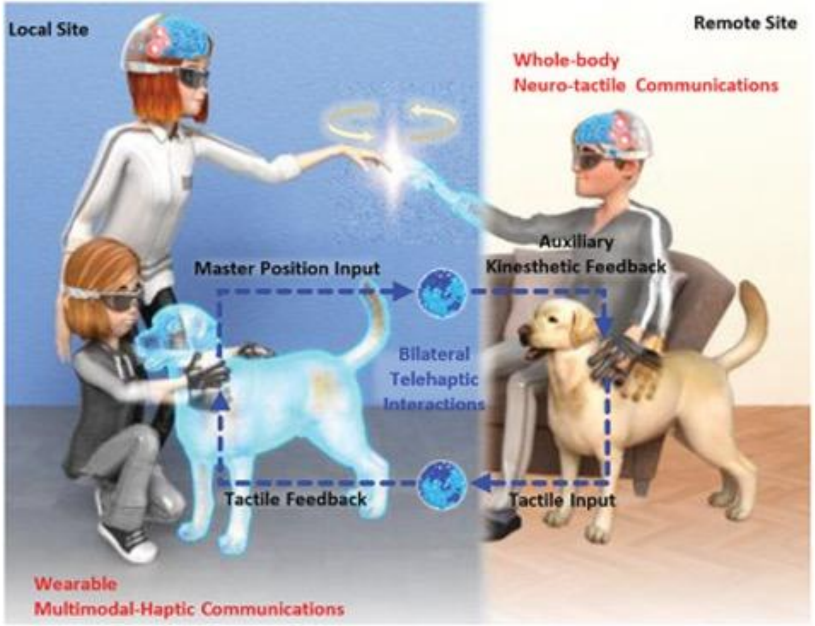
Feedback CuesFrom Drones and Low-cost Robots



Knierim, P., Kosch, T., Schwind, V., Funk, M., Kiss, F., Schneegaß, S., & Henze, N. (2017). Tactile Drones - Providing Immersive Tactile Feedback in Virtual Reality through Quadcopters. *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems.*
Suzuki, R., Hedayati, H., Zheng, C., Bohn, J.L., Szafir, D., Do, E.Y., Gross, M.D., & Leithinger, D. (2020). RoomShift: Room-scale Dynamic Haptics for VR with Furniture-moving Swarm Robots. *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems.*
Wang, Y., Chen, Z., Li, H., Cao, Z., Luo, H., Zhang, T., Ou, K., Raiti, J.G., Yu, C., Patel, S.N., & Shi, Y. (2020). MoveVR: Enabling Multiform Force Feedback in Virtual Reality using Household Cleaning Robot. *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems.*
Abtahi, P., Landry, B., Yang, J., Pavone, M., Follmer, S., & Landay, J.A. (2019). Beyond The Force: Using Quadcopters to Appropriate Objects and the Environment for Haptics in Virtual Reality. *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems.*

Telepresence

- The multi-feedback cues can achieve seamless user interaction with virtual objects as well as other avatars representing other human users.
- We consider the possible usage of such stimuli that paves the path towards telepresence through the metaverse.
- Challenges: Tactile Internet and Low-Latency Sensing (1ms)



Yang, T., Kim, J.R., Jin, H., Gil, H., Koo, J., & Kim, H.J. (2021). Recent Advances and Opportunities of Active Materials for Haptic Technologies in Virtual and Augmented Reality. *Advanced Functional Materials*, 2008831.

Metaverse technology: IoT and Robotics

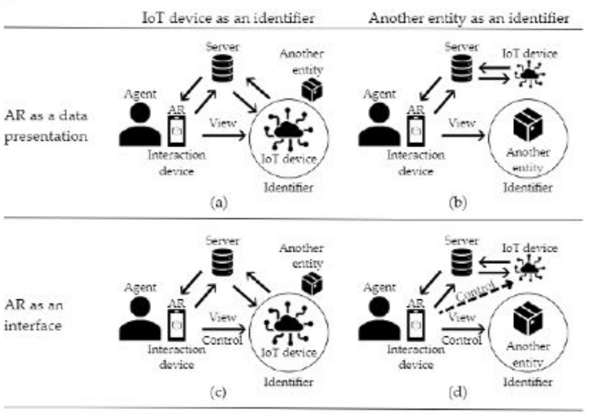
The metaverse with IoT, Connected Vehicle, Robotics

By 2025, the total IoT connected devices worldwide will reach 30.9 billion, with a sharp jump from the 13.8 billion expected in 2021.

Meanwhile, the diversity of interaction modalities is expanding.

- ➢ Therefore, many observers believe that integrating IoT and AR/VR/MR may be suitable for multi-modal interaction systems to achieve compelling user experiences, especially for non-expert users.

The reason is that it allows interaction systems to combine the real-world context of the agent and immersive AR content.



Kim, J.C., Laine, T.H., & Åhlund, C. (2021). Multimodal Interaction Systems Based on Internet of Things and Augmented Reality: A Systematic Literature Review. *Applied Sciences, 11*, 1738.

IoT In the metaverse

AR/VR/MR-directed IoT interaction systems.

Mid-air icons, menus, and virtual 3D objects allow users to control IoT devices with natural gestures.

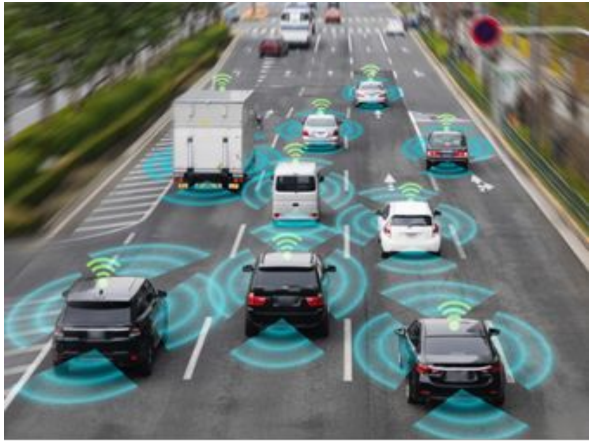
- ➢ The Floating Icons model, with the user gazing at the icon.
- ➢ The WIM model in scale mode, with a hologram being engaged with.
- ➢ The floating menu model, with three active items and three inactive items

Alce, G., Roszko, M., Edlund, H., Olsson, S., Svedberg, J., & Wallergård, M. (2017). [POSTER] AR as a User Interface for The Internet of Things—Comparing Three Interaction Models. *2017 IEEE International Symposium on Mixed and Augmented Reality (ISMAR-Adjunct)*, 81-86.

Connected Vehicle

- As nowadays vehicles are equipped with powerful computational capacity and advanced sensors, connected vehicles with 5G or even more advanced networks could go beyond the vehicle-to-vehicle connections, and eventually connect with the metaverse.

- Connected vehicles serves as an example of IoT devices as autonomous vehicles could become the most popular scenarios for our daily commute.



Graphic: Deloitte University Press | DUPress.com

Image source: https://www.smartcitiesworld.net/news/siemens-unveils-connected-vehicle-app-3194

Connected Vehicle

Considering vehicles are semi-public spaces with high mobility, drivers and passengers inside vehicles can receive enriched media.

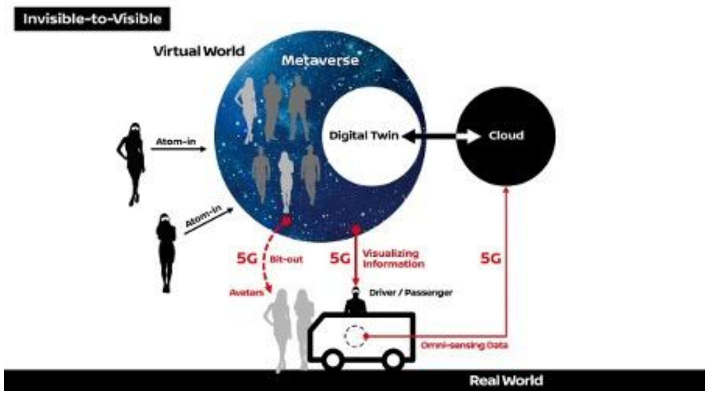
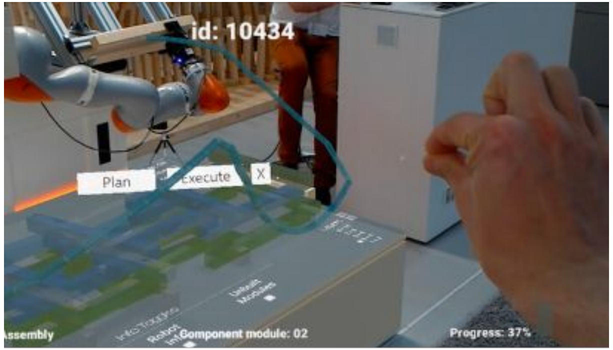


Image source: https://www.nissan-global.com/EN/TECHNOLOGY/OVERVIEW/i2v.html

Robotics in the metaverse

- Virtual environments such as AR/VR/MR are good solution candidates for opening the communication channels between robots and virtual environments, due to their prominent feature of visualising contents.

- In the metaverse through the lens of AR/VR/MR, human users build trust and confidence with the robots, leading to the paradigm shift towards human-robot collaboration.



Robotics in the metaverse

- The vision of the metaverse with collaborative robots is not only limited to leveraging robots as a physical container for avatars in the real world, and also exploring design opportunities of our alternated spatial with the metaverse.

- Virtual environments in the metaverse can also become the game changer to the user perception with collaborative robots.

Hietanen, A., Pieters, R., Lanz, M., Latokartano, J., & Kämäräinen, J. (2020). AR-based interaction for human-robot collaborative manufacturing. *Robotics Comput. Integr. Manuf., 63*, 101891.
Whitney, D., Rosen, E., Phillips, E., Konidaris, G.D., & Tellex, S. (2017). Comparing Robot Grasping Teleoperation Across Desktop and Virtual Reality with ROS Reality. *ISRR*.

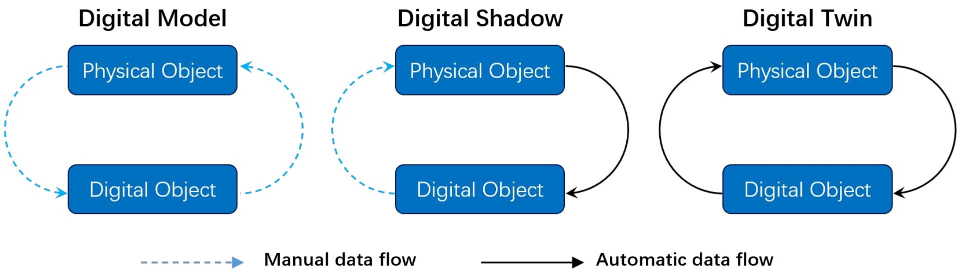
Metaverse technology: Artificial Intelligence

Digital Twin

- Digital model is the digital replication of a physical entity. No interaction between the metaverse and the physical world
- Digital shadow is the digital representation of a physical entity. Once the physical entity changes, its digital shadow changes accordingly
- Digital twin and the physical entity influence each other. Any change on any of them will lead to a change on the other one.
- Ideally, the digital design tools integrate into the real-world control of the production facility or the product or prototype in question. This permits testing different production scenarios and validating the changes before taking the new features into production.

Digital twins often consist of:

- Laws of physics
- Material properties
- Virtualized sensors
- Causality



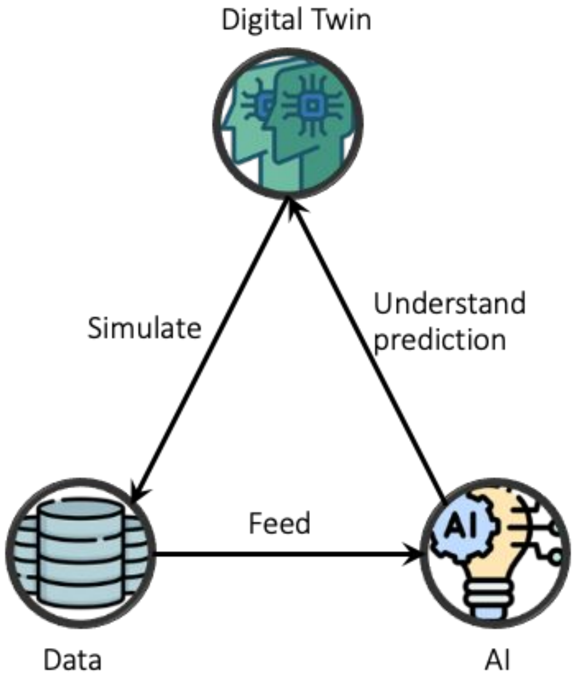
Aidan et al., Digital twin: Enabling technologies, challenges and open research. IEEE access, 8:108952–108971, 2020.

Digital Twin and AI

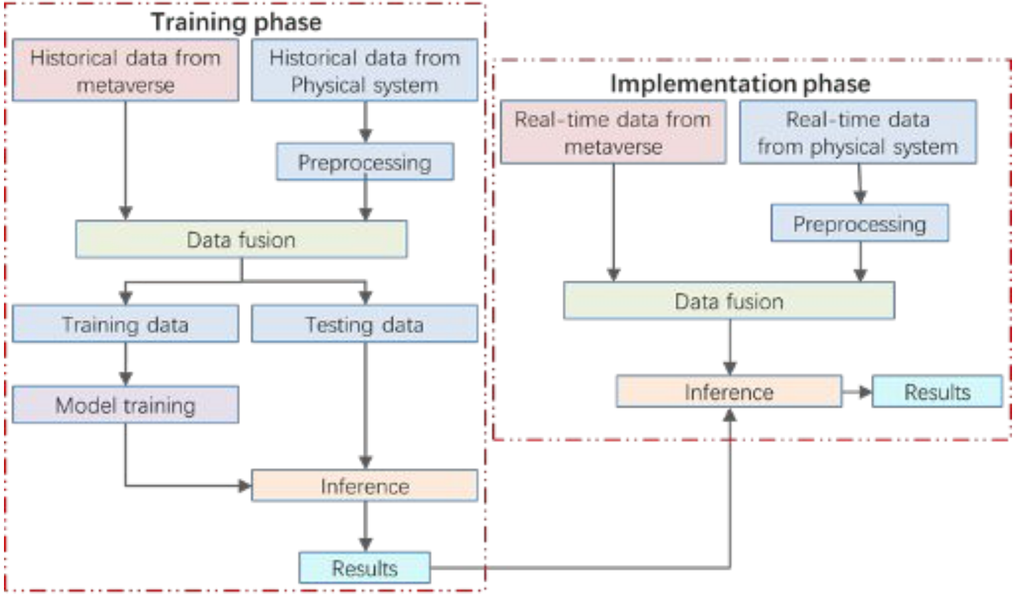
- Digital twin is able to produce simulated data. A virtual environment can go through an infinite number of repetitions and scenarios.

- The simulated data produced can then be used to train the AI model. And the AI system can be taught potential real-world conditions, that might otherwise be very rare or still in the testing phase.

- Such process can be more intelligent by getting more accurate data and predictions and understanding also visual and unstructured data.



DL enabled Digital Twin



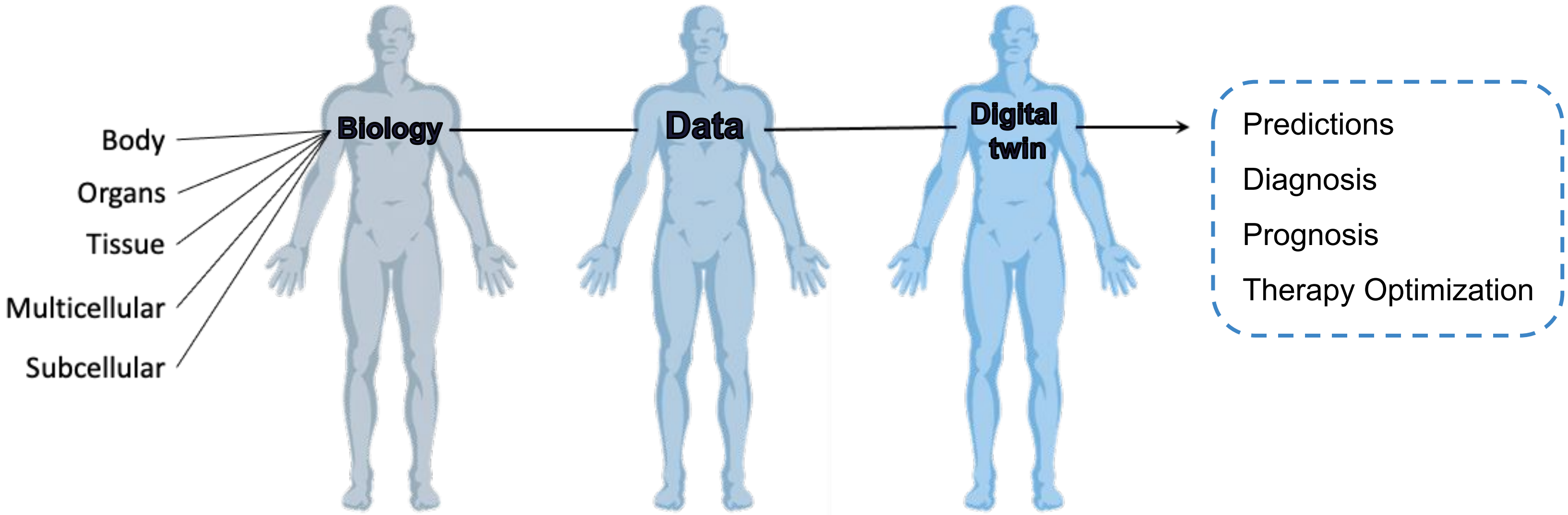
Deep learning based automatic digital twin

3 steps for DL enabled Digital Twin:

- Data collection
- Model training
- Model implementation

Jay et al., Integration of digital twin and deep learning in cyber-physical systems: towards smart manufacturing. IET Collaborative Intelligent Manufacturing, 2(1):34–36, 2020.

Smart Healthcare



DL enabled Digital Twin

- Smart healthcare requires interaction and convergence between physical and information systems to provide patients with quick-response and accurate healthcare services

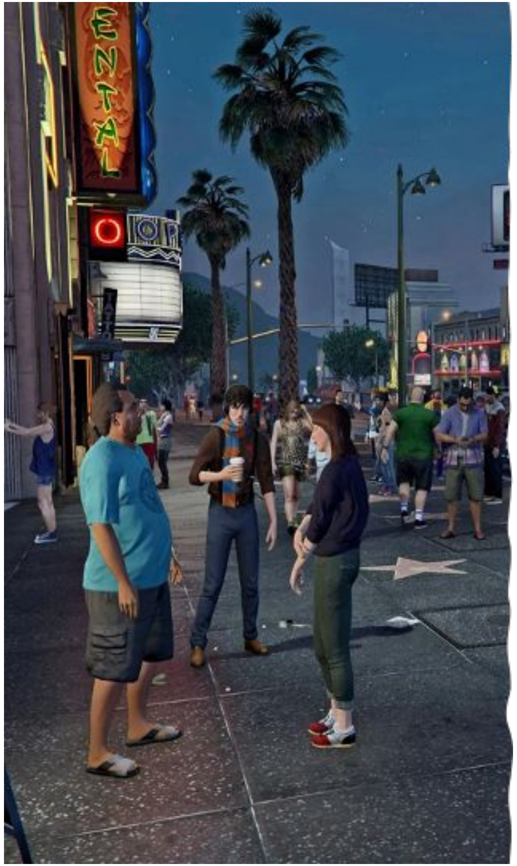
- Doctors create digital twin for patients and diagnose with AI algorithms. Surgery operations on the digital twin of patients will be repeated on patient with robotic arm.

Surgery with robotic arm on patients

Heikki et al., Prototyping a digital twin for real time remote control over mobile networks: Application of remote surgery. IEEE Access, 7:20325–20336, 2019..

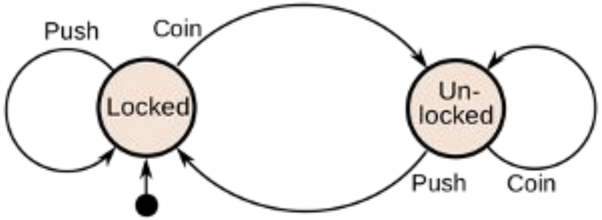
Computer Agent

- Also named Non-player Character (NPC)
- NPC is any character in a game that is not controlled by a player. The term originated in traditional tabletop role- playing games where it applies to characters controlled by the gamemaster or referee rather than by another player.
- In video games, this usually means a character controlled by the computer (instead of the player) that has a predetermined set of behaviors that potentially will impact gameplay.



Traditional control strategies: FSM

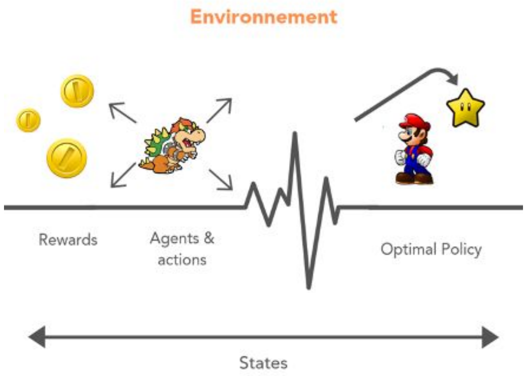
- Finite-state machine (FSM)
- FSM, is a computation model that can be used to simulate sequential logic, or, in other words, to represent and control execution flow.
- Key components include state, condition, action, next state.
- Not intelligent



Intelligent strategies

Two Questions:

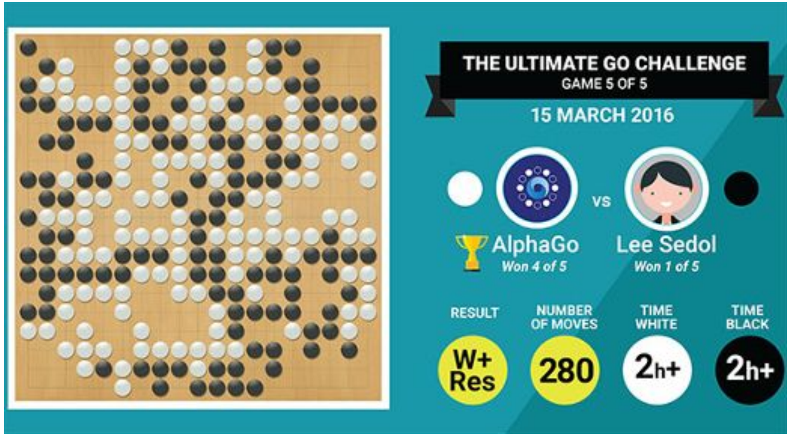
1. Will games be more fun if NPCs become smart?
2. How could NPCs become smart?



Strategies: **Reinforcement learning**

Intelligent strategies

Reinforcement learning is a classic machine learning algorithm on decision-making problems, which enables agents to automatically learn from the interaction experience with their surrounding environment.



Automatic Avatar

Avatar refers to the digital representation of players in the metaverse, where players interact with the other players or the computer agents through the avatar.

Players may create different avatars in different applications or games, e.g., human shape, imaginary creatures, or animals.

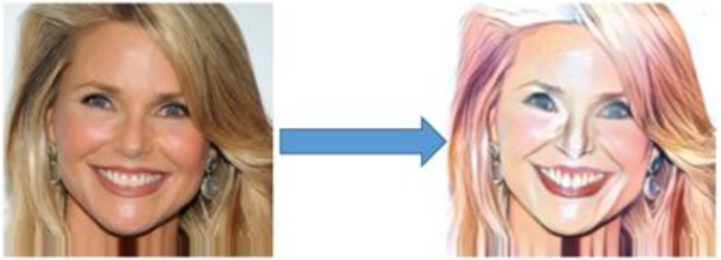
Some video games even allow players to leave behind their models of themselves when players are not in the game.

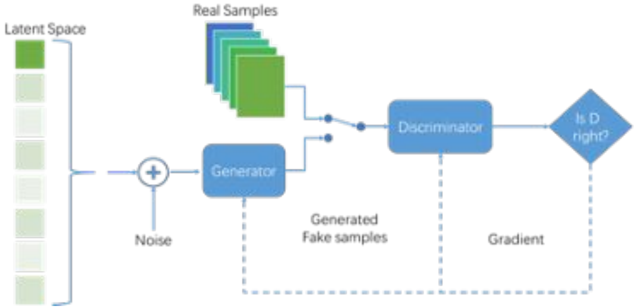
Avatar Generation

GAN is a type of neural network that can generate realistic data from random input data.

For image generation, a *generator* network creates images and tries to fool a ***discriminator*** network into believing that the images are real.

The discriminator network gets better at distinguishing between real and fake images over time, which forces the generator to create better and better images.





Roy et al., "Generating anime from real human image with adversarial training," in2019 1st International Conference on Advances in Science, Engineering and Robotics Technology (ICASERT). IEEE, 2019, pp. 1–5

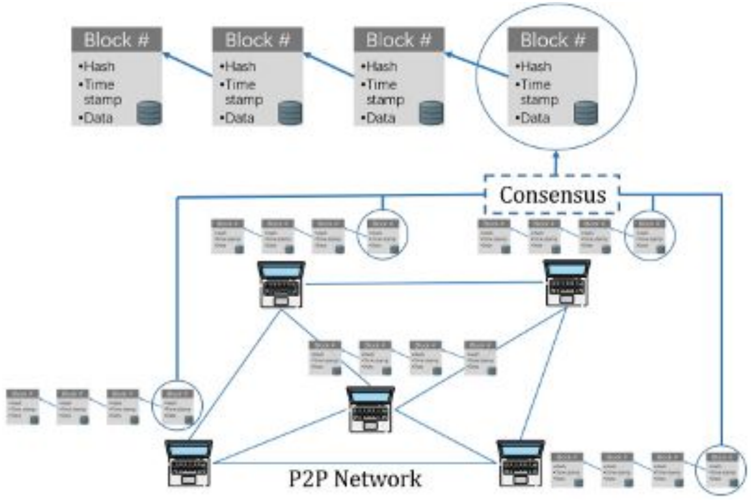
Metaverse technology: Blockchain

Blockchain

In metaverse, everything is digitised.

- Digital twins for physical entities and systems
- avatars for users
- map on various areas

Unfathomably vast amounts of data are generated. It is possible to apply blockchains to the data storage system to guarantee the decentralisation and security in the metaverse.



Wei et al., Decentralized applications: The blockchain-empowered software system. IEEE Access, 6:53019–53033, 2018.

Blockchain - Bitcoin as an example

- Decentralized digital currency, without a central bank or single administrator, that can be sent from user to user on the peer-to-peer bitcoin network without the need for intermediaries

- Transactions are verified by network nodes through cryptography and recorded in a public distributed ledger called a blockchain

- Bitcoins are created as a reward for a process known as mining. They can be exchanged for other currencies, products, and services

Version
Previous Block Hash
Merkel Root
Timestamp
Difficulty Target
Nonce

The format of block

Transaction ID
Transaction serial number
Timestamp
Payer address
Receiver address
Signature

The format of transaction

NFTs and Digital Ownership

- A NFT (Non-fungible Token) is a record of ownership of an object, whether digital or physical
- NFTs are stored on a blockchain, making such record distributed, intercompatible, and immutable
- With the physical-digital duality brought by the metaverse, NFTs will be an integral part of virtual and physical object trading.

Source: CryptoKitties – Blockchain cat-breeding game


Source: Axie Infinity – Trading and battling NFT game

Source: Lion Run – 2D NFT Avatars

Decentralized Finance

Supporting the economic ecosystem

- Similar to the web, the metaverse should be open and not rely on a single company or entity.
- Need for a common, distributed economic system.
- Smart Contracts and DeFi enable the establishment of a shared economy where each entity may leverage their own currency while enabling intercompatibilitybetween all ecosystems.
- Applications of DeFi such as decentralized exchanges, liquidity providing, lending platforms, stable coins, or wrapped tokens may enable advanced users to support the ecosystem

Blockchain and Governance

- Governance tokens are developed to enable users to take part in the future of a project or community.
- Changes are proposed, voted, and approved through on-chain protocols.
- Metaverse application developers may create their own governance tokens for the community of users to take part in the major decisions driving the application development.

New consensus protocols

- Although secure, proof-of-work consensus protocols display several issues:
  - Large energy consumption
  - Transaction rate dependent on the network's computing power
  - Recentralization of the network's computing power in the hands of a few major players (GPU and ASIC computing farms)
- Other solutions should be explored, for instance
  - GPU- and ASIC- resilient proof-of-work algorithms
  - Proof-of-stake: nodes compete to append blocks proportionally to their respective amount of cryptocurrency allocated (or staked)
  - Proof-of-space: leverages storages rather than computing power
  - Proof-of-time: nodes compete to append blocks based on random waiting times (requires specific hardware)
  - Proof-of-authority: blocks are approved by approved nodes only

Direct Acyclic Graphs

- DAGs contain vertrices and edges
  - More efficient data storage system than blockchain’s linear blocks
  - Nodes do not compete for blocks
- Transaction: confirmed when referenced by another transaction, down to the first transaction
  - No mining required
    - No or low transaction fees
  - Low calculation cost
    - Can be done even on low-power IoT devices
  - Conflict resolution
- Concerns regarding scalability without centralization

Metaverse technology: Computer Vision

Computer Vision

- Visual Localisation and Mapping
- Human Pose & Eye Tracking
- Holistic Scene Understanding
- Image Restoration and Enhancement

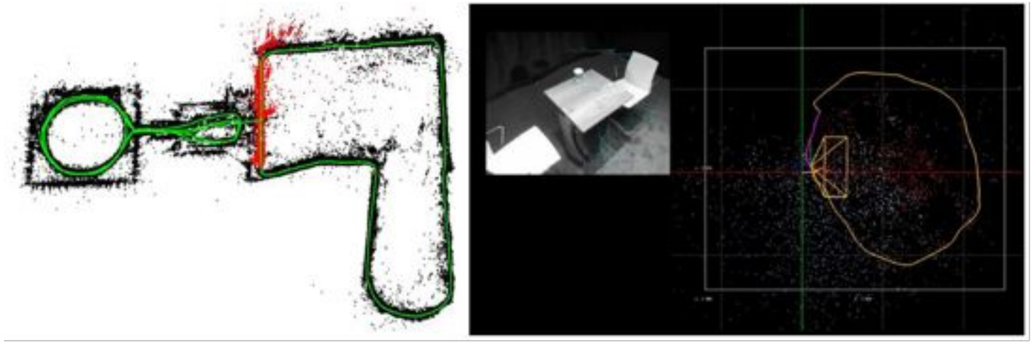
NVIDIA Omniverse Replicator DRIVE Sim

Image source: https://blogs.nvidia.com/blog/2021/11/09/drive-sim-replicator-synthetic-data-generation/

Visual Localization and Mapping

Objective: **Acquire the 3D structure of an unknown environment and sense its motion.**

SLAM is a common computer vision technique that estimates device motion and reconstructs an unknown environment.



ORBSLAM SLAM (ARCorev2)

Mur-Artal, R., & Tardós, J.D. (2017). ORB-SLAM2: An Open-Source SLAM System for Monocular, Stereo, and RGB-D Cameras. IEEE Transactions on Robotics, 33, 1255-1262.
https://developer.apple.com/videos/play/wwdc2018/602

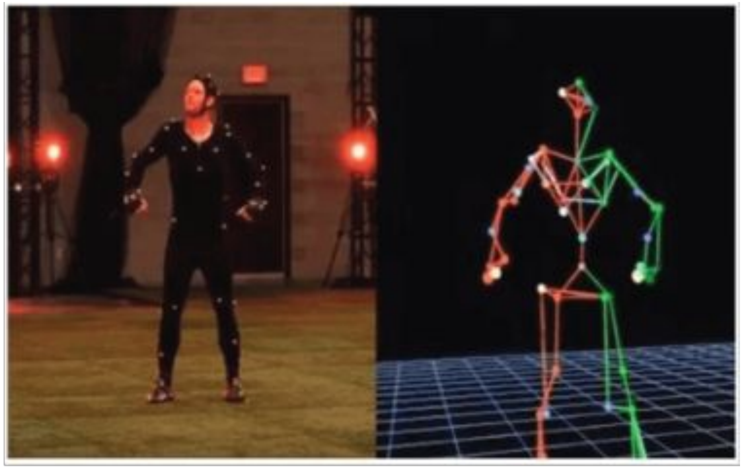
Body & Eye tracking

Objective: **In the metaverse, users are represented by avatars. Therefore, we have to consider the control of avatars in 3D virtual environments**

In VR and AR applications, the obtained visual information concerning human pose can usually be represented as joint positions or key points for each human body part. These key points reflect the characteristics of human posture, which depict the body parts, such as elbows, legs, shoulders, hands, feet, etc.

Body pose tracking problems:

- Occlusion problems
- Multi-user scenario
- Illumination variations



Openpose for pose tracking

Cao, Z., Hidalgo, G., Simon, T., Wei, S., & Sheikh, Y. (2021). OpenPose: Realtime Multi-Person 2D Pose Estimation Using Part Affinity Fields. IEEE Transactions on Pattern Analysis and Machine Intelligence, 43, 172-186.

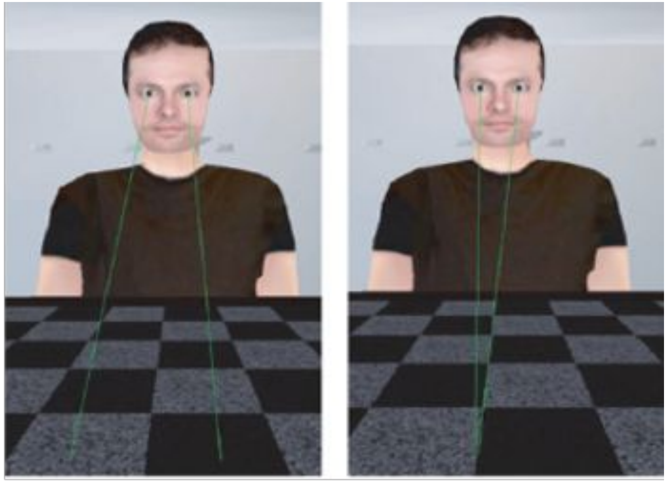
Body & Eye tracking

Objective: **In the metaverse, users are represented by avatars. Therefore, we have to consider the control of avatars in 3D virtual environments**

In metaverse, human avatars need to '**see**' the immersive 3D environment.

Problems:

- The lack of focus blur can lead to an incorrect perception of the object size and distance in the virtual environment.
- Ensure precise distance estimation with incomplete gaze due to the occlusion.
- Eye tracking may lead to motion sickness and eye fatigue.



eye tracking with no eye convergence   eye convergence

Murray, N., Roberts, D.J., Steed, A., Sharkey, P.M., Dickerson, P., & Rae, J.P. (2007). An assessment of eye-gaze potential within immersive virtual environments. ACM Trans. Multim. Comput. Commun. Appl., 3, 8:1-8:17.

Holistic Scene Understanding
Stereo Depth Estimation

In the metaverse, depth estimation is a key task in ensuring the precise positioning of objects and contents.

All users own their respective avatars, and both the digital and real contents are connected. Therefore, depth estimation in such a computer-generated universe is relatively challenging.

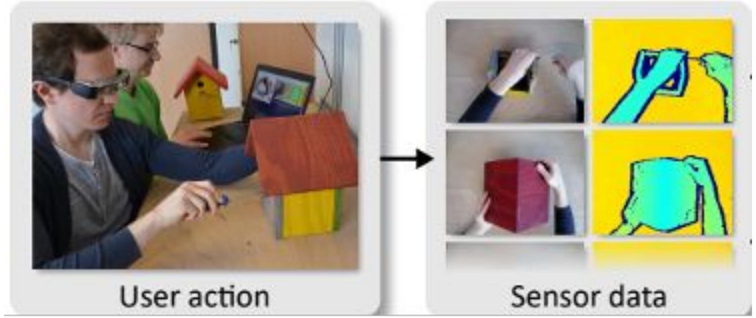
Environment Stereo depth estimation

Chaurasia et al., (2020) Passthrough+ realtime stereoscopic view synthesis for mobile mixed reality. ACM on CGIT.

Holistic Scene Understanding
Action Recognition

A human avatar needs to recognise the action of other avatars or objects so that the avatar can take the correct action accordingly in the 3D virtual spaces.

Human avatars need to emotionally and psychologically understand others and the 3D virtual world in the physical world

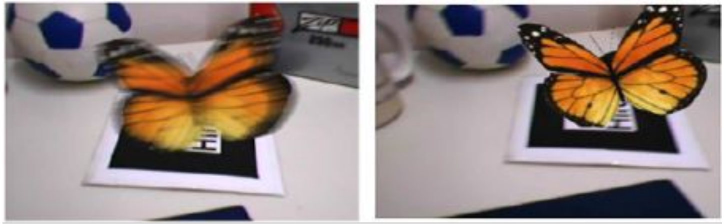


User action   Action Recognition

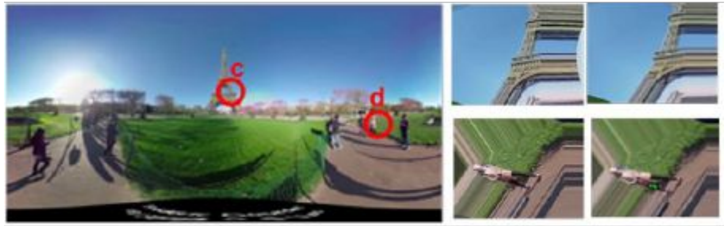
Schröder et al., (2017) Deep learning for action recognition in augmented reality assistance systems. In ACM SIGGRAPH 2017, Posters.

Image Restoration and Enhancement

The metaverse is connected seamlessly with the physical environments in real-time. In such a condition, an avatar needs to work with a physical person; therefore, it is important to display the 3D virtual world with less noise, blur, and high-resolution (HR) in the metaverse



Motion blur image   No motion blurred image



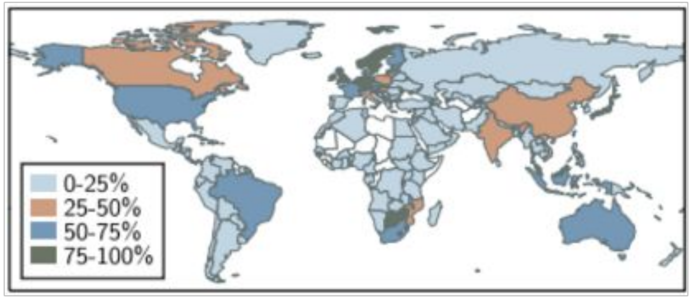
super-resolution

Fischer et al., (2006) Handling photographic imperfections and aliasing in augmented reality.
Li et al., (2021) Applying vertexshuffle toward 360-degree video super-resolution on focused-icosahedral-mesh. arXiv.

Metaverse technology: Edge and Cloud

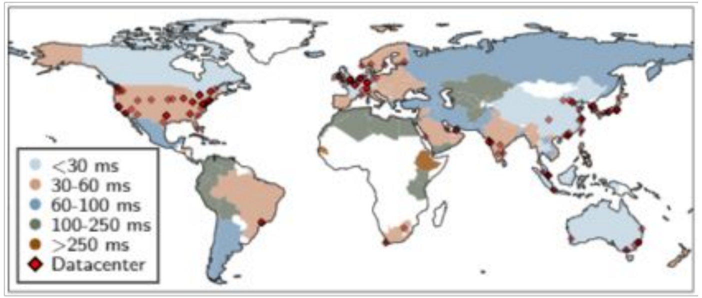
Latency of Cloud

Wired network



Only 24 countries out of 184 can consistently (75–100%) meet the timing deadline for MTP (20 ms).
https://labs.ripe.net/author/lorenzo-corneo/surrounded-by-the-clouds-a-comprehensive-cloud-reachability-study/

Wireless network



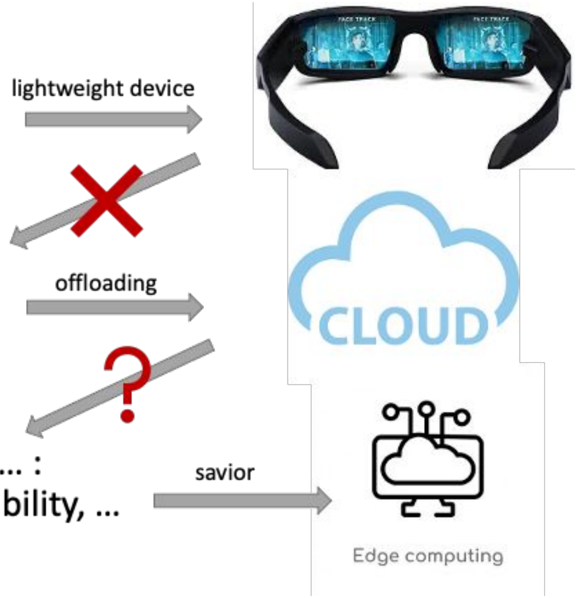
Only China out of 184 is able to achieve median RTT below MTP (20 ms) to the closest cloud datacenter.
https://cloudreachability.github.io/

Not good enough for the metaverse!

Corneo, Lorenzo, et al. "Surrounded by the Clouds: A Comprehensive Cloud Reachability Study." Proceedings of the Web Conference 2021.

Alternatives for the cloud

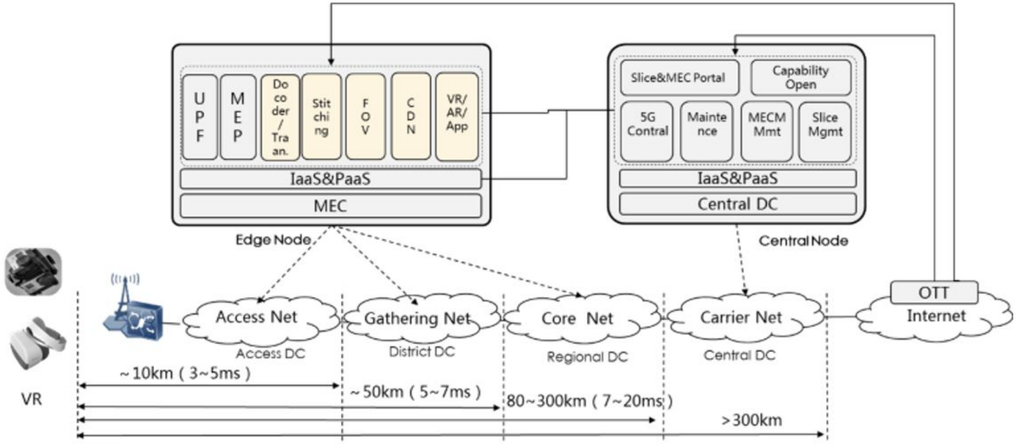
- Metaverse feature 1: convenient mobility
- Metaverse feature 2: intensive computation
- Metaverse feature 3,4,5, … : low latency, privacy, scalability, …



Low latency

Computes, stores, and transmits the data physically closer to end-users and their devices.	Transmits all data to a remote warehouse to do centralized data computation and storage.
Edge can govern the deployment of AR/VR related media and vision services	Cloud can provide data backup and resource orchestration services

Impact of end-to-end latency from **Edge** to **Cloud**



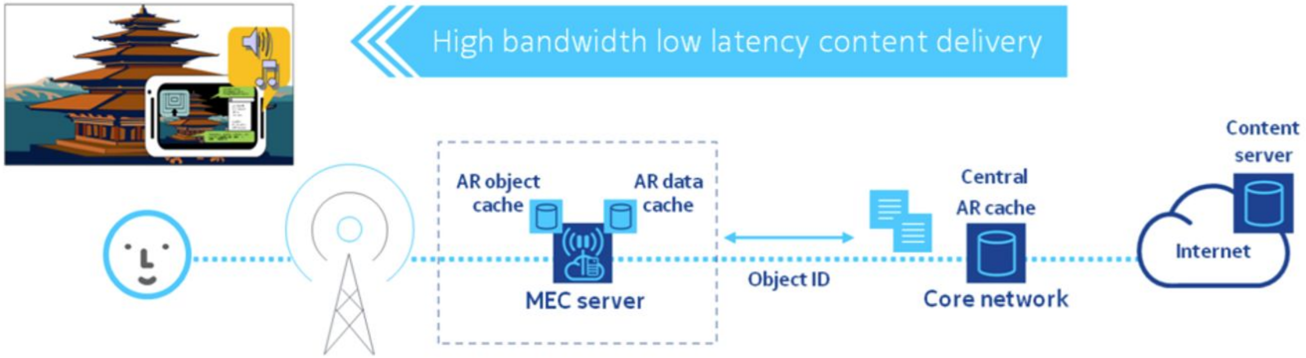
https://www.gsma.com/futurenetworks/wiki/cloud-ar-vr-whitepaper/

Deployment: MEC

MEC: A telecommunication-vendor centric edge cloud model proposed by the ETSI.

In MEC, the deployment, operation, and maintenance of edge servers is handled by an ISP operating in the area and commonly co-located with or one hop away from the base stations .

For example, 5G MEC servers can manage nearby users' AR content with only one-hop packet transmission and enable real-time user interaction for social AR applications such as Pokémon GO.



https://www.etsi.org/images/files/etsiwhitepapers/etsi_wp11_mec_a_key_technology_towards_5g.pdf

MEC: reality

HoloVerse is a worldwide project announced by DoubleMe, in which global mobile operators will test the optimal 5G MEC for the seamless deployment of various services using the metaverse.

Niantic is a famous company which has developed Pokémon GO' and 'Harry Potter: Wizards Unite', envisions building a "Planet-Scale AR". It has allied with worldwide telecommunications carriers, including Deutsche Telekom, EE, Globe Telecom, Orange, SK Telecom, SoftBank Corp., TELUS, Verizon, and Telstra, to boost their AR service performance utilising MEC.

NIANTIC

Planet-Scale AR

Privacy

Because the metaverse will collect more than ever user data, the consequence if things go south will also be worse than ever. One of the major concerns is the privacy risk.

The metaverse is likely to collect even more biometrics such as audio and iris recognition.

Pre-metaverse: if a user lost the password, may lose some data and reset the password, then it’s **OK**.

In-metaverse: once biometrics are compromised, they would be forever compromised and cannot be revoked, and the user would be in real **trouble**.

Current passwordless authentication with biometrics

Edge Versus (with) Cloud

Win at:
- lower latency thanks to its proximity to the end-users
- faster local orchestration for nearby users' interactions
- privacy-preservation via local data processing

Win at:
- long-term, large-scale metaverse data storage
- economic operations
- super-powerful computation capacity

An efficient **edge-cloud orchestrator** is a necessity to optimize the interaction between the edge and the cloud, to meet diversified and stringent requirements for different processes in the metaverse. The cloud can run extensive data management for latency-tolerant operations while the edge takes care of real-time data processing and exchange among nearby metaverse users. The orchestrator in this context can help schedule the workload assignment and necessary data flows between the cloud and the edge for better-integrated service to guarantee user's seamless experience.

An example: edge services process real-time student discussions in a virtual classroom at a virtual campus held by the cloud.

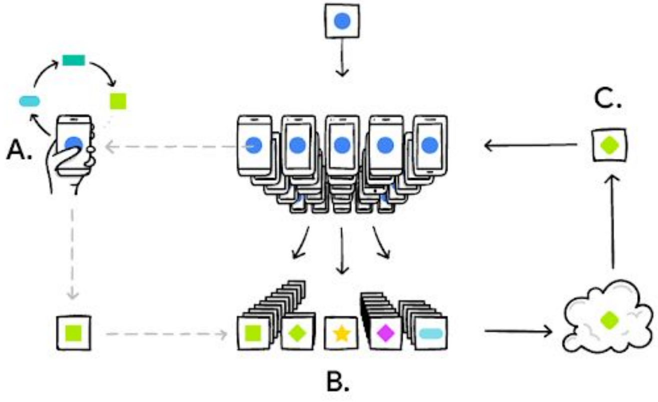
Edge Versus (with) Cloud

Edge and Cloud can collaborate for better global performance, and also guarantee individual users' benefits.

Edge-cloud collaborative data processing, e.g.:

Federated learning: a distributed learning methodology gaining wide attention, trains and keeps user data at local devices and updates the global model via aggregating local models.

It can run on the edge owned by the end users and conduct large-scale data mining over distributed clients without demanding user private data uploaded other than local gradients updates. This solution (train at the **edge** and aggregate at the **cloud**) can boost the security and privacy of the metaverse.



https://ai.googleblog.com/2017/04/federated-learning-collaborative.html

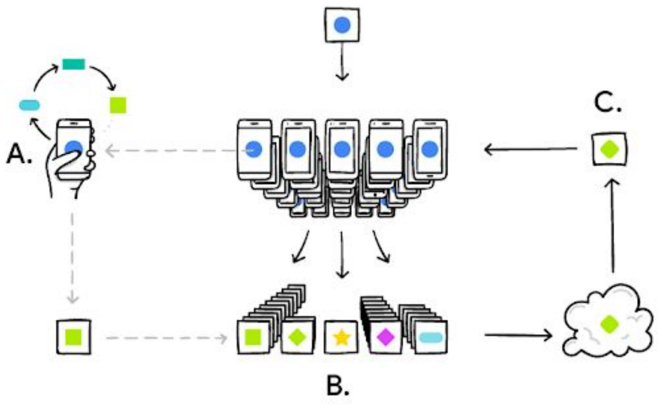
Edge Versus (with) Cloud

Edge and Cloud can collaborate for better global performance, and also guarantee individual users' benefits.

An example:

The eyetracking or motion tracking data collected by the wearables of millions of users can be trained in local edge servers (ideally owned by the users) and aggregated via a federated learning parameter server.

Hence, users can enjoy services such as visual content recommendations in the metaverse without leaking their privacy.



https://ai.googleblog.com/2017/04/federated-learning-collaborative.html

Metaverse technology: Network

5G Traffic Classes and Metaverse Applications

The Metaverse will leverage the full potential of 5G traffic classes, with applications spreading over all ends of the spectrum, namely:

Low-latency applications

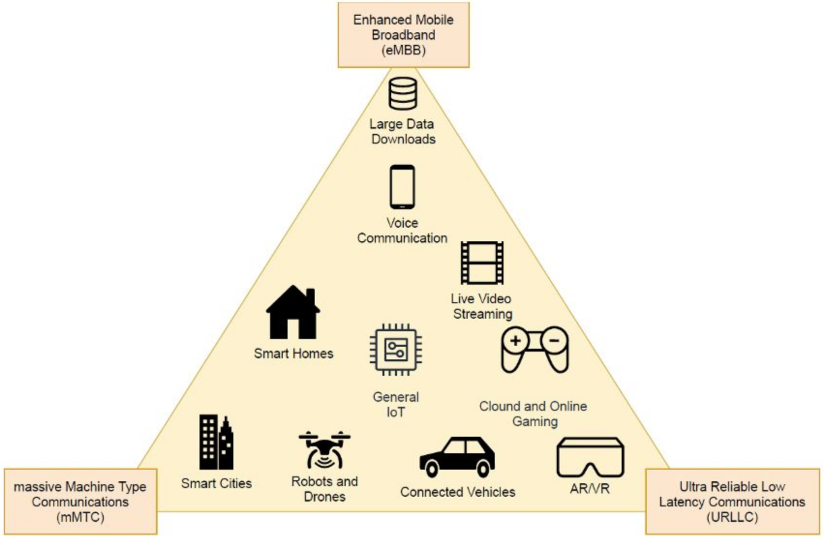
- Cloud gaming
- AR/VR
- Connected and Autonomous Vehicles

General Networking

- Voice communication
- Video Streaming

Massive MTC

- Smart Homes
- Smart Cities
- Drones Swarms
- Industry IoT



Requirements and Constraints

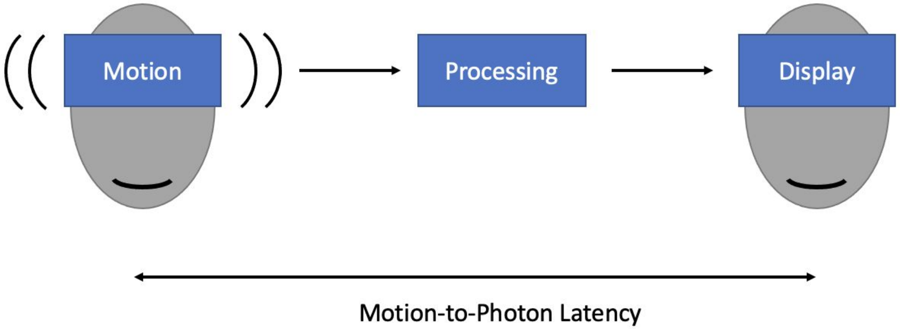
The Metaverse is highly user-centric:

- Performance requirements is directly driven by users' perception of the performance
- Performance metrics driven by the resolution of users' perceptorysystem

Extended Reality (XR) technology at the core have stringent network constraints:

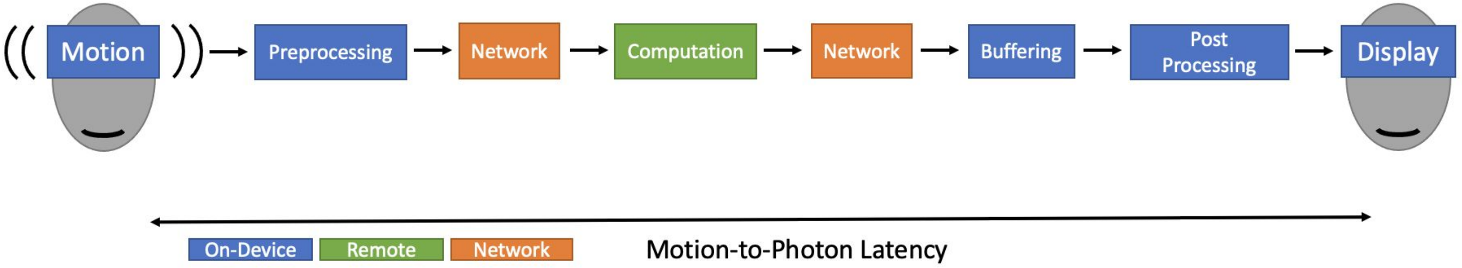
- Ultra-low motion-to-photon latency
  - Below 20ms
  - Ideally in the order of the ms
- Guaranteed, high, and stable framerate
  - Minimum 60FPS
  - Low jitter between frames to minimize buffering latency
- High resolution content
  - Minimum 2K, up to 16K
  - High throughput per device (25Mb/s at 2k, 200Mb/s at 16k)

Motion-to-Photon Latency



- The Motion-to-Photon latency is the delay for user motion to be fully reflected on-screen.
- In user-centric applications, motion-to-photon latency is a key metric of user experience.
- Examples:
  a. High latency between user head motion and updated display in VR -> motion sickness
  b. High latency between user input and action in a game -> poor performance
  c. High latency between user head motion and updated display in mixed reality -> alignment problems

Motion-to-Photon Latency in Networked Environment



Computation offloading = computation time ↓ + network and buffering latency ↑.

- Network latency → motion-to-photon latency ↑
- Network instability (jitter) → buffering latency ↑
- Throughput → motion-to-photon latency ↑ + framerate ↓

The challenge of low-latency networking

Current 5G networks fail to reach the latency requirements

- URLLC not implemented yet (0.5ms RAN latency)
- eMBB has 5ms RAN latency, but still running in Non-Standalone mode over 4G core network (adds 10-20ms)

Throughput still too low for the most extreme requirements

- Difficult to guarantee over 100Mb/s per device in all scenarios

Coverage should be spotless

- Sudden drop in network performance would significantly degrade experience
- mmWave can be used to patch dark spots in urban environments

Serving many users in the same location with guaranteed performance is challenging

- mmWave was leveraged

User-centric Networking

Even with 5G full predicted power, the requirements of the most constrained applications will still be difficult to meet.

Networked solutions need to be designed around the users' priorities:

- Which network metrics affect the user experience the most?
- What requirements have different types of content?
- How to regulate transmission in case of congestion while minimizing the impact on user experience?
- Which components can experience degraded quality, higher latency and jitter, without affecting the user experience?
- What techniques can be used to compensate for transient degradation in the network conditions?

Answering these questions would allow to devise novel QoE metrics adapted to the specifics of the applications

Mobility – A key factor in User-centric Networking

- **User mobility affects network performance:**
  - Coverage varies depending on location
  - Number of users connected to the base station varies
  - Obstacles lead to lower SNR
  - Handover lead to extended periods of service interruption

- **Mobility leads to significant bandwidth and latency variations, and high jitter.**

- **Mobility should be accounted for in the design of user-centric networked applications**

Network-aware applications

The 5G standard specifies mechanisms for the base station to communicate link characteristics to the user equipment.

- Finer measures of available resources than at client side
- How to transmit that to the server and account for the added lag?

Cross-layer operation can improve performance:

- Application layer can adapt content to send based on end-to-end path estimation
- Congestion control algorithms at transport layer can benefit for RAN information for finer bottleneck link characterization
- Application layer can communicate QoE parameters to the congestion control algorithms for user-optimized transmission

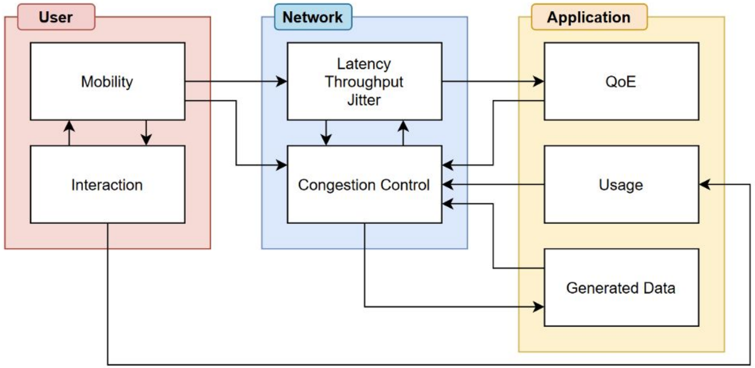
Combining User-centric and Network-aware Applications

Application and Network layer can collaborate towards optimizing the transmission of user-centric content.

The congestion control protocol considers both the user mobility and the application usage and requirements

The application communicates QoE and usage data to the congestion control protocol

The congestion control protocol exposes network measurements for the application to adapt content generation

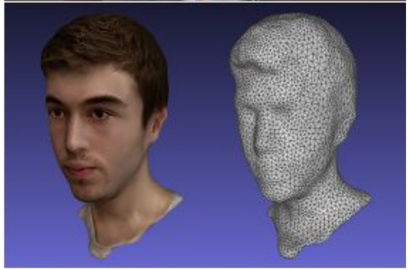


Metaverse ecosystem: Avatar

Avatar

- Avatars denote the digital representation of users in virtual spaces.

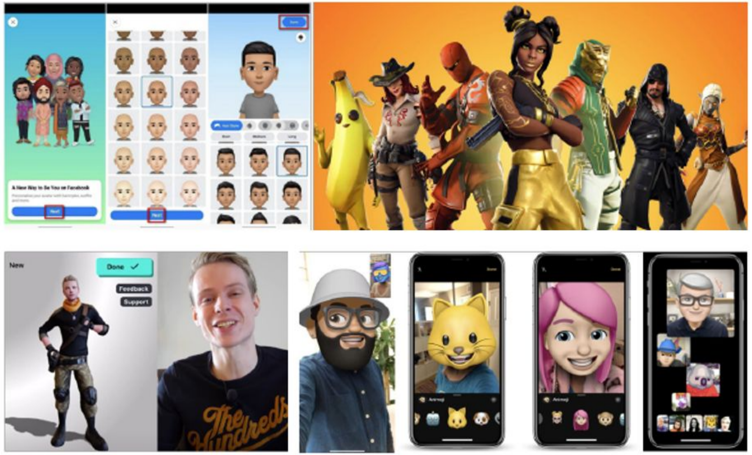
- The digital representation of a human user aims to serve as a mirrored self to represent their behavioursand interaction with other users in the metaverse.



Avatar: Real-life Examples

Several real-life examples of avatars, as a ‘second-identity’ on a wide spectrum of virtual worlds:

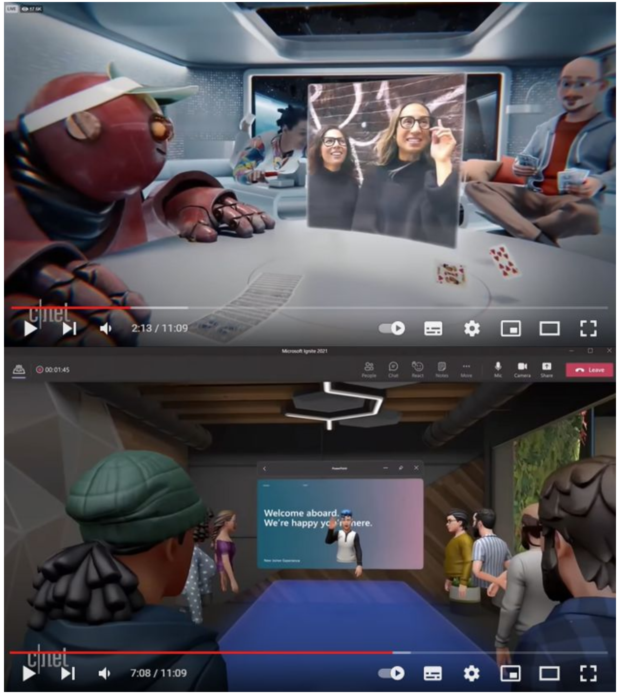
- ***Facebook Avatar*** – users can edit their own avatars in social media;
- ***Fortnite*** – a multiplayer game that allows game players to create and edit their own worlds;
- ***VR Chat*** – a VR game;
- ***Memoji*** – virtual meetings with cartoonised faces during FaceTime on Apple iOS devices, regarded as an example of AR.



Avatar

The design and appearance of avatars could impact the user perceptions (e.g., realism), which are subject to a bundle of factors:

- the details of the avatar’s face,
- the related micro-expression,
- the avatar styles, representation, colour, and positions.



Avatar

Avatars have the key role of shaping how the virtual social interaction performs in the multi-user scenarios inside the metaverse.

Six under-explored issues related to the user interaction through avatars with virtual environments:

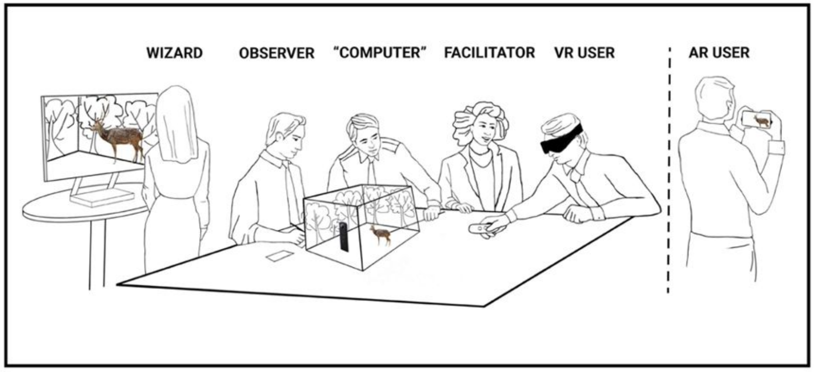
1. in-the-wild user behaviours,
2. the avatar and their contexts of virtual environments,
3. avatar-induced user behaviours,
4. user privacy (leakage from the avatar),
5. fairness,
6. connections with physical worlds.

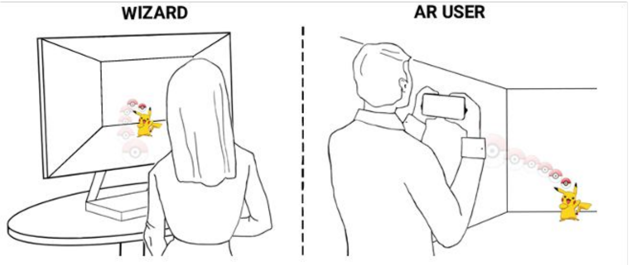
Metaverse ecosystem: Content Creation

Content Creation: User Collaborations

In virtual environments, authoring tools enable users with various roles to create new digital objects in intuitive and creative manners.

The peer users can act in different roles and work collaboratively in virtual environments, such as *wizards*, *observers*, *facilitators*, *AR and VR users as content creators*, and so on.





Designers, the Stage Is Yours! Medium-Fidelity Prototyping of Augmented Virtual Reality Interfaces with 360theater. EICS, Article 205 (June 2021), 25 pages. DOI:https://doi.org/10.1145/3461727

Content Creation: Freedom of Information, Ideas and Behaviours

Analogue to the censorship employed on the Internet, we conjecture that similar governing approaches will be exerted in the metaverse, especially when the virtual worlds in the metaverse grow exponentially, for instance, blocking the access of certain virtual objects and virtual environments in the metaverse.

- hurt the interoperability between virtual worlds

Will the users' logs and their interaction traces be eradicated in one censored virtual environment?

As such, do we have any way of preserving the ruined records?

Alternatively, can we have any instruments temporarily served as a haven for sensitive and restricted information?

Also, other new scenarios will appear in the virtual 3D spaces. For example, such governing scheme can be applied to restrict certain avatar behaviours, e.g., removal of some keywords in their avatars' speeches, forbidding avatars' body gestures, and other non-verbal communication means.

Content Creation: Creator Cultures

As every participant in the metaverse would engage in creating virtual entities and co-contribute to the new assets in the metaverse, we expect that the authoring systems should remove barriers for such co-creation and co-contribution.

In other words, the digital content creation will probably let all avatars collaboratively participate in the processes, instead of a small number of professional designers.

- Investigating the design space of authoring journeys and incentive schemes designated for amateur and novice creators to actively participate in the co-creation process.
- AI-human collaborative co-creation?

Content Creation: Digital Heritage

The virtual living space containing numerous avatars (and content creators) may add new and unique contents into their virtual environments in iterative manners.

In virtual environments, the creator creation can be further enhanced by establishing potential measurements for the preservation of outdated contents, for instance, a virtual museum to record the footprint of digital contents.

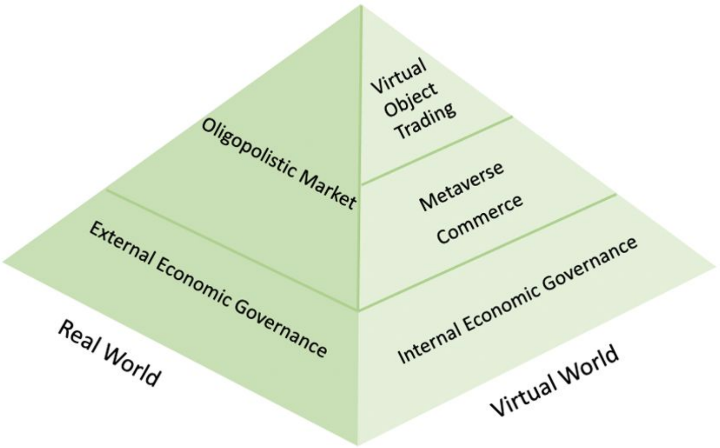
The next issue is how the preserved or contemporaneous digital contents should appear in real-world environments.

Metaverse ecosystem: Virtual Economy

The Dual-World Pyramid of Metaverse Economy

Collectively, the **external economic governance** in our real world and the **internal economic governance** in the virtual world form the basis for a functioning metaverse economy.

On the top, we have the anticipated **market structure** of the metaverse industry, aswell as **metaverse commerce** & **virtual object trading**.



Economic Governance (Internal)

1. To form a sustainable and trust-worthy currency system within the virtual world that is robust to deflationary pressure.

2. To safeguard the virtual economy by annihilating illegal economic activities.

3. To enshrine virtual property ownership.

https://financialeconomyblog.com/inflation-disinflation-deflation-what-is-the-best-scenario-for-investment/

Economic Governance (External)

"If we create it without principles, overall harm will be done to everybody"

by Tim Sweeney, CEO of Epic Games*

1. Major tech firms (e.g., Meta, Microsoft), who have an edge in the game, are already investing for a metaverse future.

2. To regulate major players in the metaverse business from collusion.

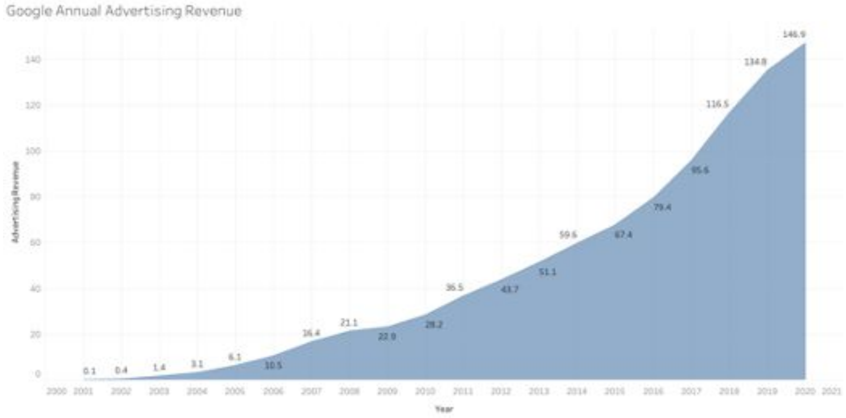
https://www.saic.edu/150/man-behind-monopoly-man.html

Economic Governance (External)

Why is a metaverse world with malevolent oligopolies alarming?

1. Firms do not even need to live on charging fees on players for using their metaverse service.

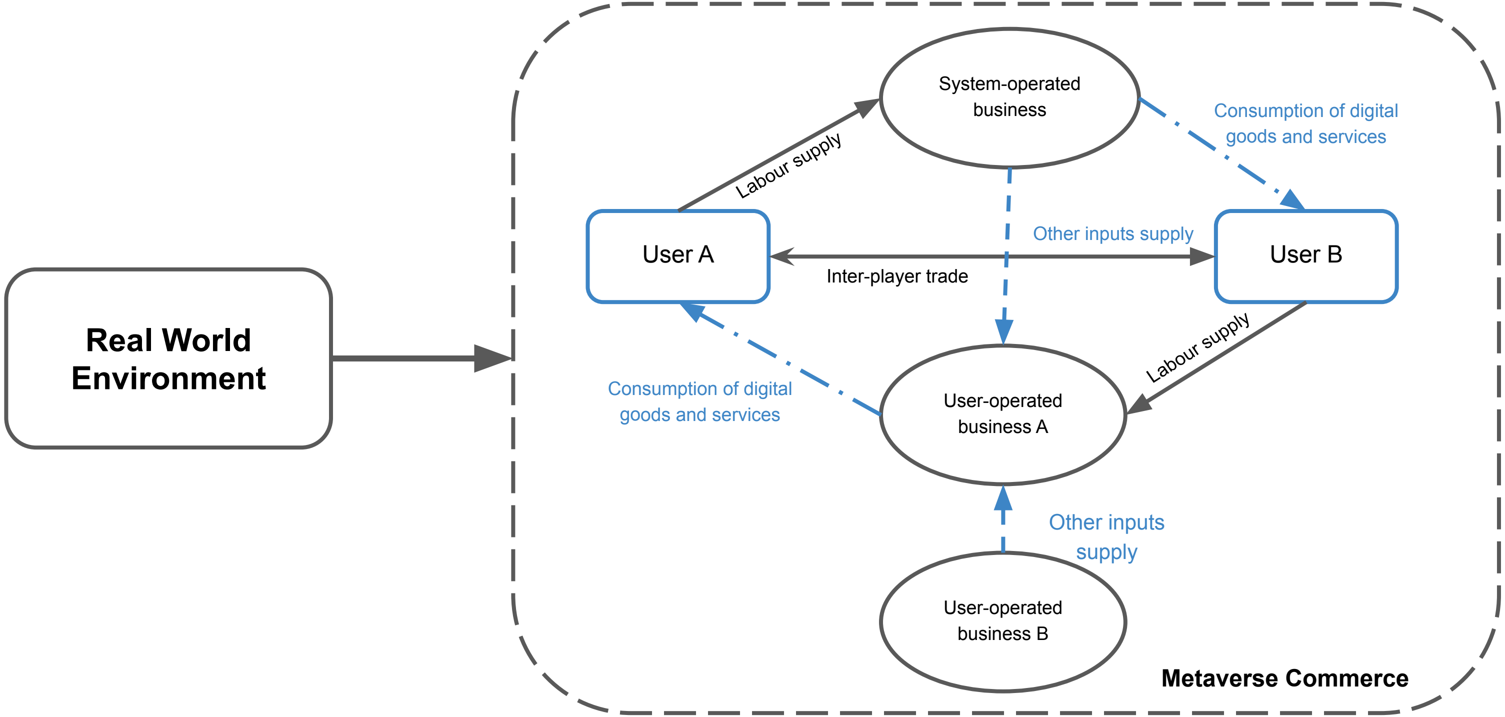
2. Their power to project advertisement in our alternative world arising is more than suffice to promise lucrative profit.



Data from: https://bit.ly/3o2wGeM

Our conjecture of pervasive advertisement in a metaverse world with the company being the sole decision maker on where, when and what products wesee.

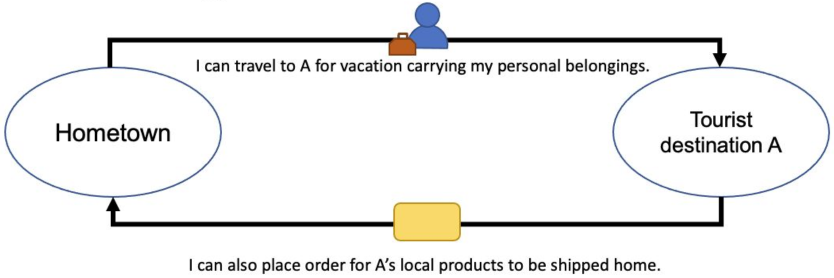
Metaverse Commerce



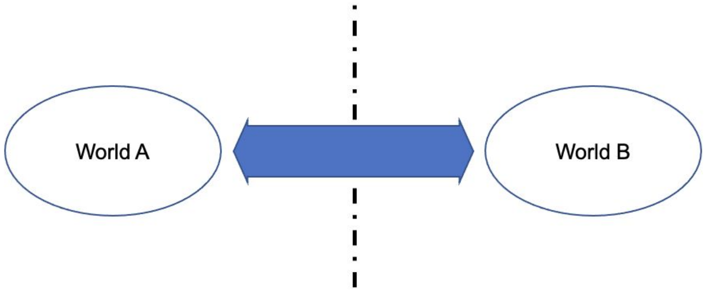
Metaverse Commerce

Interoperability: The ability to carry/trade an object from virtual world A tovirtual world B frictionlessly.

Real world analogy:



Permeable barrier between virtual worlds:



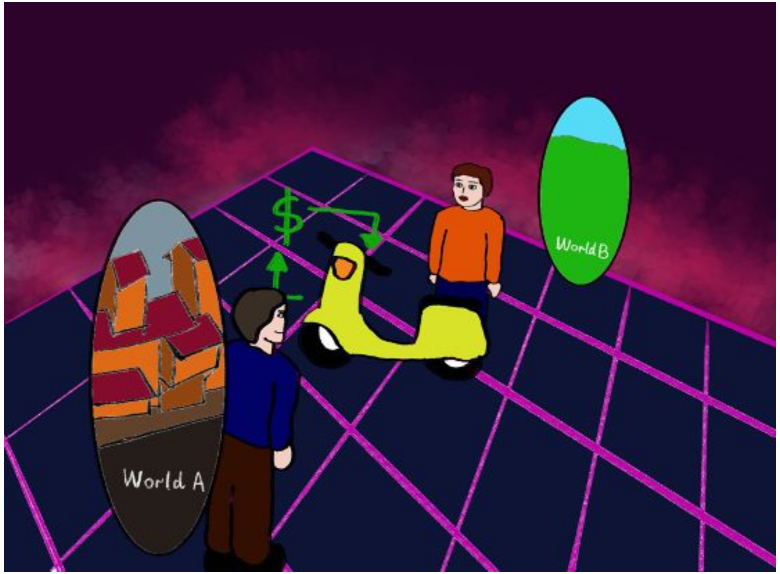
Metaverse Commerce

Interoperability: Our conjecture of how trades may take place between two worlds.

Digital objects are often easily **reproducible** (e.g., piracy of a popular movie).

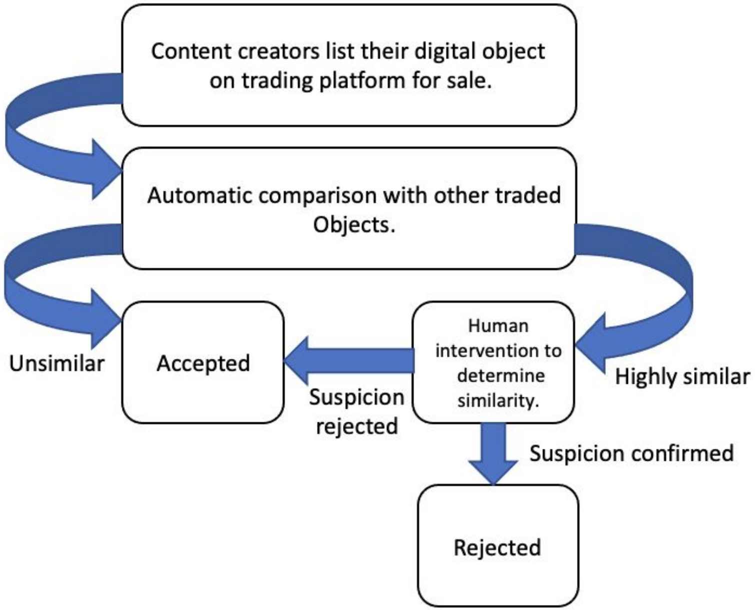
In a digital native stage, individuals residing in a metaverse world may work as virtual content producers. Piracy and forgery will directly impact their personal welfare.

How should one enshrine digital ownership in a metaverse world?

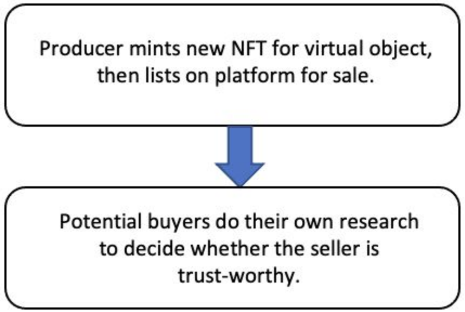


Metaverse Commerce

One potential active screening mechanism:



Passive approach:



Metaverse ecosystem: Social Acceptability

Social Acceptability: Privacy Threats

Some early signs of how society might react to the ubiquitous presence of technologies that would enable the metaverse from the public outcry against the Google Glass, when their concerns (or perceptions) are not taken into account.

Coming up with a verifiable privacy mechanism would be one of the foremost problems to be solved in order to receive social acceptability.


Google Glass users fight privacy fears

By Heather Kelly, CNN

Updated 1948 GMT (0348 HKT) December 12, 2013

Anti-Google Glass icons from StopTheCyborgs.org, a group raising awareness about Google Glass privacy concerns.

https://edition.cnn.com/2013/12/10/tech/mobile/negative-google-glass-reactions/index.html

Privacy Threats

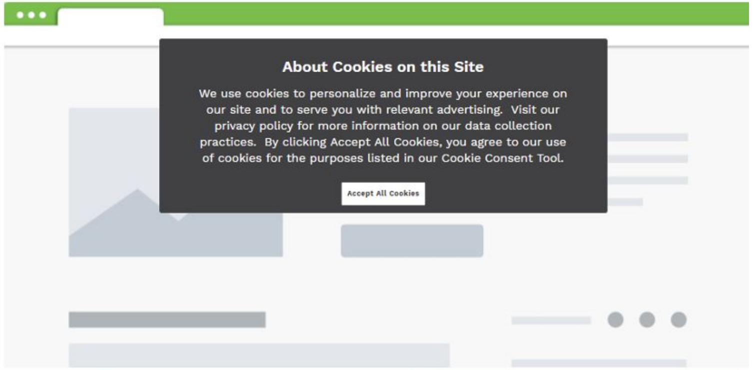
Facebook and Cambridge Analytica Data Scandal triggered a public outcry.

- Facebook was summoned by the U.S. Congress and the U.K. Parliament to hearings.
- Cambridge Analytica went bankrupt soon after.

One solution would be not to collect any user's data at all.

- Feasible?
- Have the consent form in every new service session?

Social Acceptability



Another solution which has also been advocated by world leaders like the *German chancellor Angela Merkel*, is to enable user-consented privacy trading.

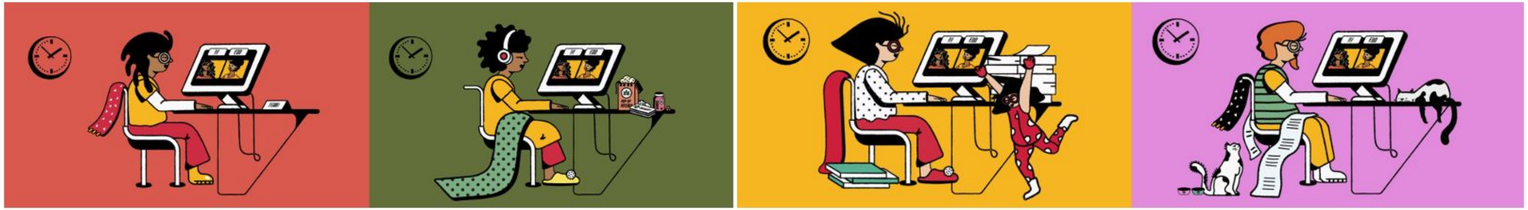
User-consent privacy trading will enable the flow of data necessary for potential innovations, and at the same time, it will also compensate users fairly for their data, thereby paving the path for broader social acceptability.

Social Acceptability: User Diversity

The metaverse should be inclusive to everyone in the community, regardless of race, gender, age and religion, such as children, elderly, disabled individuals, etc.

It is important to consider personalised content display in front of users, and promote the fairness of the recommendation systems, in order to minimise the biased contents and thus impact the user behaviours and decision making. So important question

'How to design the contents to maximise the acceptance level under the consideration of user diversity'



Social Acceptability: Fairness

Autonomous agents will engage in the role of governance in virtual worlds, to alleviate the demands of manual workload.

The autonomous agents in virtual worlds rely on machine learning algorithms to react to the dynamic yet constant changes of virtual objects and avatars.

- unfair or biased model could systematically harm the user experiences in the metaverse.
- The biased services could put certain user groups in disadvantageous positions.

Metaverse designers should open channels to collect the voices of diversified community groups and collaboratively design solutions that lead to fairness in the metaverse environments.

Social Acceptability: User Addiction

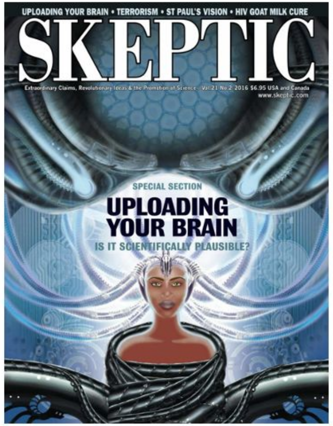
Excessive use with digital environments (i.e., user addictions) would be an important issue when the metaverse becomes the most prevalent venue for people to spend their time in the virtual worlds.

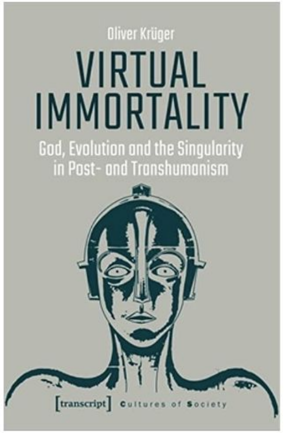
In the worst scenario, users may leverage the metaverse to help them ‘escaping’ from the real world, i.e., escapism.

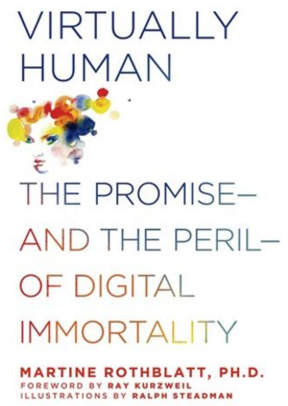
Social Acceptability:
Other factors

A variety of design factors influencing the social acceptability of the metaverse:

- Virtual immortality,
- Digital humanity,
- Digital legacy,
- Device acceptability,
- Cross-generational design,
- Acceptability of users' digital copies (i.e., avatars),
- Eco-friendliness and environmental responsibility, etc.







Metaverse ecosystem: Privacy and Security

Privacy at sensor level

Internet connected devices such smart devices allow monitoring and collect users' information:

- Personal information (e.g., physical, cultural, economic)
- Users' behaviour (e.g., habits, choices)
- Communications (e.g., metadata related to personal communications)

Users accept the benefits in comparison with the privacy risks.

Users are unaware of the continuous recording of these devices.

Privacy at sensor level

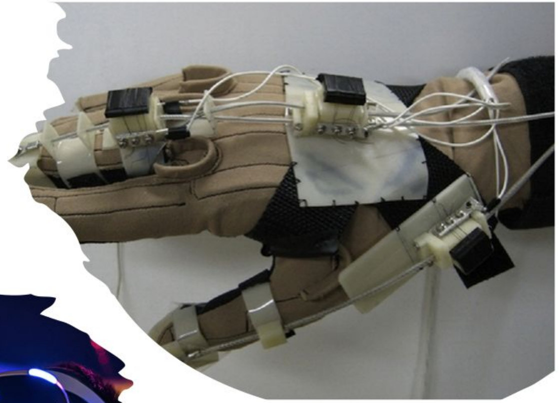
In the metaverse, the primary devices used includes:

- Head mounted displays such as VR headsets
- Wearables and haptic devices to track and give feedback to users

These devices suffer from similar privacy risks as the previous mentioned but in the metaverse, the digital and immersive experience raises more privacy threats.

The metaverse can be a digital copy of our reality:

- Social microcosmos where users exhibit real social behaviour
- Including privacy behaviour



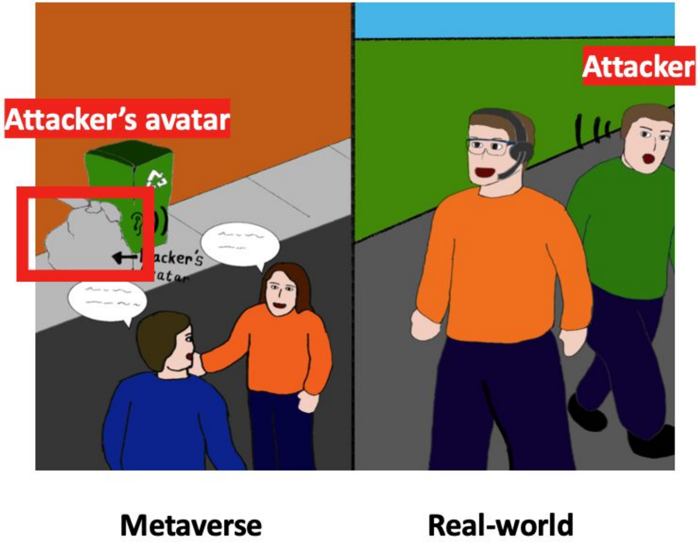
Privacy behaviours in the metaverse

In the metaverse individuals can create virtual avatars:

- Realistic following the real individual characteristics (e.g., age, gender)
- Fictional, an animal or other person:
  - Or use deep-fakes to generate a similar person to confuse other avatars
    - Collect more information about other users
- Attackers can use such avatars to blend in the virtual world, as the example on the right, where the attacker is a trash bag eavesdropping other avatars' conversations

Users can use also other avatars simultaneously to confuse attackers:

- For example, when shopping in the metaverse, several copies of the users' avatars can be placed in different locations, so the attacker does not know the real user's



Ethical designs: Digital twins

Governance: who is going to regulate the metaverse?

- Jurisdictions and restrictions
- Federated model
  - Tools to control members
  - Specific virtual spaces for groups of member with same affinities
- Blockchain and democratic techniques to control illegal behaviour

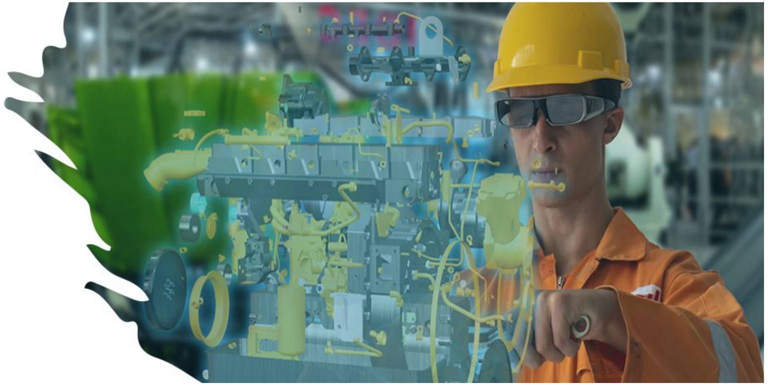
Ethical designs: Governance

Digital twins are virtual objects created to reflect physical objects.

- Resemble not only appearance but physical behaviourof real-world assets

How can we be sure a digital twin is original?

- Use a digital ledger such as Blockchain to protect original twins
- Non-fungible tokens (NFTs) provides a good example



Ethical designs: Biometric data

Metaverse uses data collected from real-world to provide immersive experiences.

- Sensors attached to users (e.g., gyroscope to track users' head movements) can control their avatar more realistically

Integration of such biometric information to provide mixed modality (input-output) to build holistic experiences

How can we protect the collected information?

- Privacy-enhancing technologies
  - Differential privacy to protect the users' information
  - Federate learning to use pre-trained models in users' devices and not share the data with third parties

Metaverse ecosystem: Trust, Informed Consent, Accountability

Trust and Information

How to establish a verifiable trust mechanism?

- The age of online gossips, deepfakes.

Can metaverse solve the problem of loneliness?

- COVID-19 pandemic forced many elders into lonely life!
- Elderly folks are also most vulnerable to online scams.

How to use “plausible presence” to make users realize events occurring in virtual environment are actually occurring?

- Users’ actions in immersiave state may leake information more than users would like to share in real world.

Could virtual reality be a solution for loneliness among elderly? https://inside.arcada.fi/healthpromotion/could-virtual-reality-be-a-solution-for-loneliness-among-elderly/

Theories of Presence in Virtual Reality http://www.vi-mm.eu/2017/09/12/theories-of-presence-in-virtual-reality/

Trust and Information

How to build trust by providing situational awareness to user in unobtrusive manner?

- Providing awareness about physical world while user in immersive state may improve trust, but could also degrade immersiveness.

Flip side: The issues of over-trust?

- Users often tend to overtrust the big brand.
- Many big brands engage in practices aimed to collect as much user's data as possible.

GOOGLE ADMITS GIVING HUNDREDS OF FIRMS ACCESS TO YOUR GMAIL INBOX

Facebook admits tracking users and non-users off-site

Google admits giving hundreds of firms access to your email inbox https://www.independent.co.uk/life-style/gadgets-and-tech/news/google-gmail-data-sharing-email-inbox-privacy-scandal-a8548941.html

Facebook admits tracking users and non-users off-site https://www.theguardian.com/technology/2018/apr/17/facebook-admits-tracking-users-and-non-users-off-site

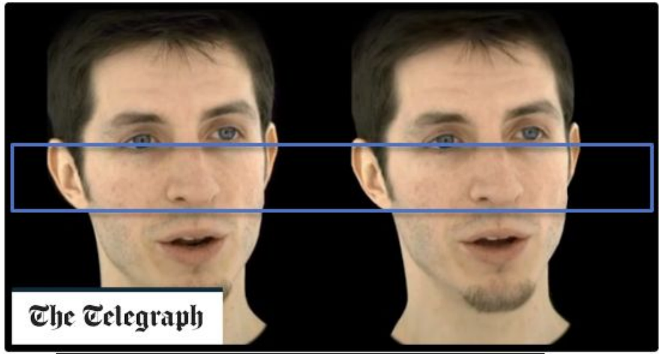
Informed Consent

How to design informed consent mechanism which will allow avatars, i.e., the virtual embodiment of users, to place their trust?

- Give/Refuse Consent in the light of new information
- Avatars may not capture the dynamics of a user's facial expression

How to handle sensitive information of the minors?

- Sophisticated and tech-savvy XR users, but traditionally less aware of privacy risks
- How to ascertain whether a user is a child and, for instance, valid parental consent has been given.



Which one is really an Avatar?

https://www.telegraph.co.uk/technology/2018/09/26/facebook-reveals-deepfake-avatars-bear-uncanny-resemblance-humans/

Informed Consent

How to design consent mechanism for users from vulnerable populations?

- E.g. Pregnant women should not be forced to give martial information to get health benefits if disclosure of such information could harm the women

How to ensure that informed consent mechanism always leads to informed choice?

- Often users do not read privacy policies!

Accountability

Accountability relates to the responsibilities, incentives, and means for recourse regarding those building, deploying, managing, and using XR systems and services.

- Often handled by Content Moderation.

How can metaverse content moderation ensure that whether a given avatar embodies a human user or an auto-troll?

- Freedom of expression could be extended to a human user, while an auto-troll may not enjoy such right .

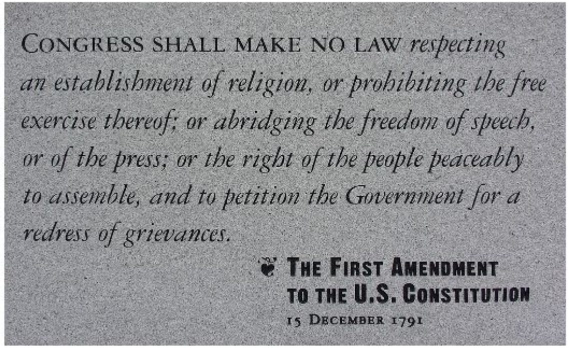
Accountability

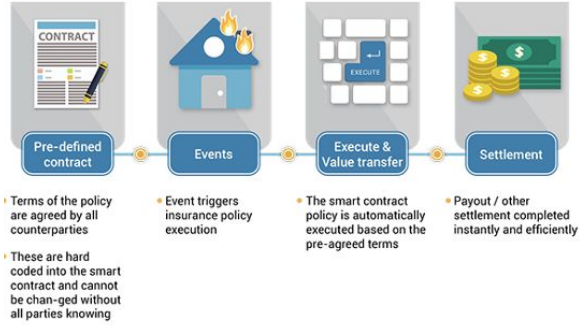
Can constitutional directives serve as yardstick to design content moderation for given audience?

- Using First Amendment as yardstick for the U.S. based audience.

Can smart contract be used as a foundation in metaverse to ensure accountability?

- Using smart contract to operationalize data collection pipeline with always follows fixed set of consented policies, and subsquentlly delete the data once the primary purpose of the data has been served.





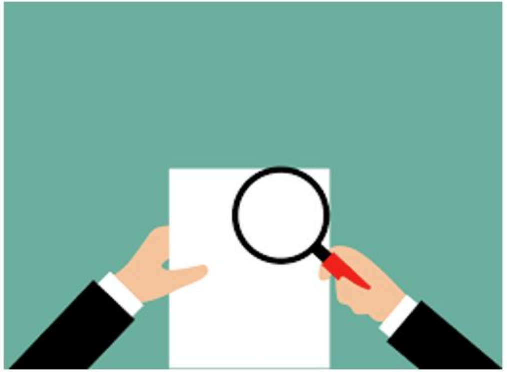
Accountability

How to audit the secondary data which has been created from user's data

- Difficult to establish the relationship between a given secondary data and the exact primary data.
- Who really owns the secondary data? GDPR explicitly focuses on PII!

How to determine liability in Metaverse?

- Projection of digital overlays by the user's XR mobile headsets may contain criticalinformation, such as manholes -threatening accidents.
- 2020 Uber Self-Driving –Pedestrian Accident. No judiciary precedent/legislation yet!



Safety driver in fatal Arizona Uber self-driving car crash charged with homicide
https://www.reuters.com/article/uber-selfdriving-idUSKBN26708P

Three Grand Challanges

How to design a principled framework that can define personal data while keeping up with potential innovations?

- The metaverse expands the definition of personal data, including biometrically-inferred data, which is prevalent in XR data pipelines.
- Privacy regulations alone can not be the basis of the definition of personal data, since they can not cope up with the pace of innovation.

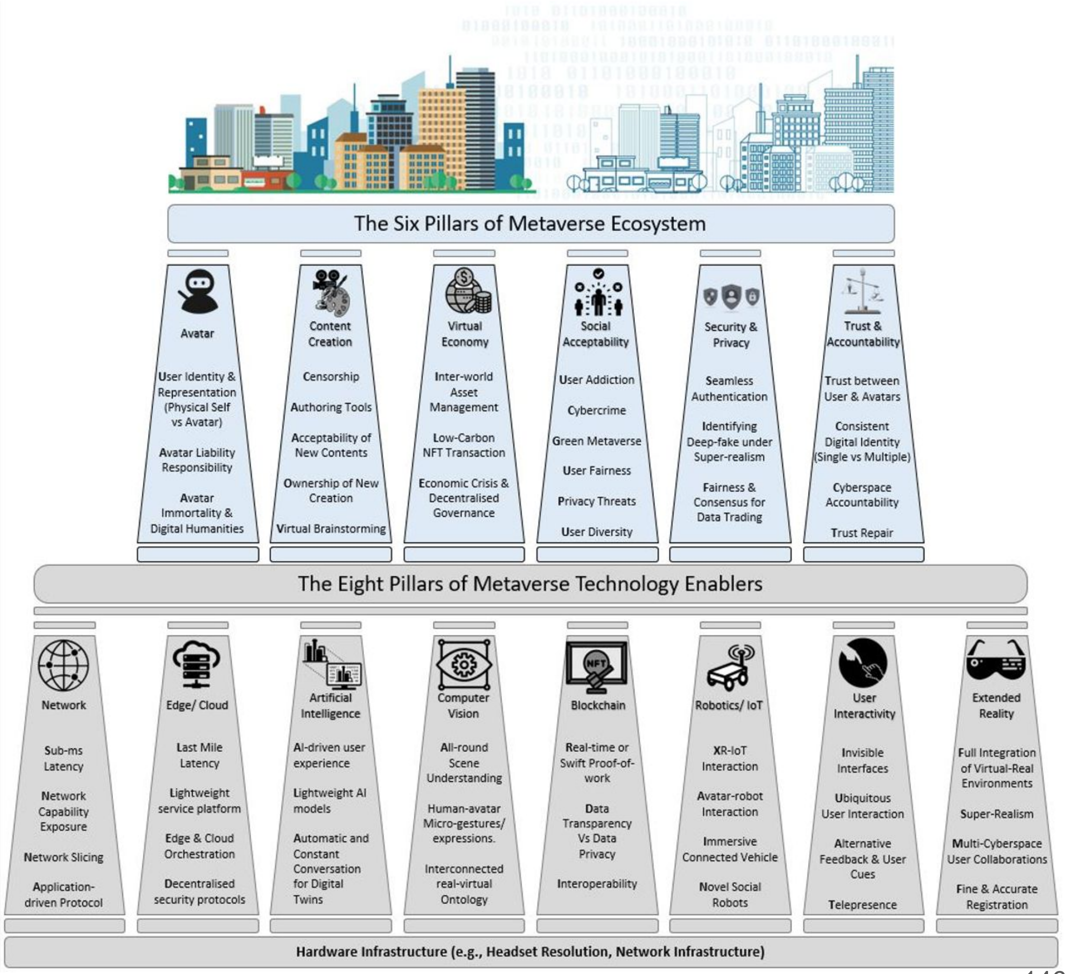
How to develop user-consented privacy trading mechanism in metaverse ecosystem?

- If user can not have either due to their own fault, i.e. privacy paradox, or large-scale surveillance, can user be compensated?

How to accommodate rights of minorities and vulnerable communities into Metaverse ecosystem from the beginning?

- Majority of the current online socio-technical systems are based on normative principles.
- Unlike in traditional socio-technical systems, potential mistreatment in metaverse would have far more disastrous consequences.

Future issues



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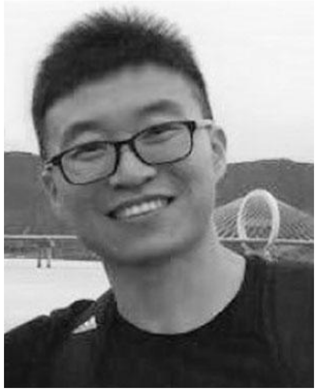

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The Hitchhiker's Guide to the Metaverse

The content of the slides are extracted from the following technical report:

All One Needs to Know about Metaverse:
A Complete Survey on Technological Singularity, Virtual Ecosystem, and Research Agenda

Scan the QR code
to read the original article
and start exploring the
metaverse!

The Hitchhiker's Guide to the Metaverse

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Xian Wang

Yiming Zhu