Medical Spatial Computing:

Unraveling the Future of Medical VR Training through challenges, opportunities, and insights

Dr. George Papagiannakis

ORamaVR co-founder, CEO

george@oramavr.com

&

Prof. University of Crete,

Affiliated Researcher at FORTH

Visiting Prof. University of Geneva

Augmenting Human intellect?

Let us consider an "augmented" architect at work. He sits at a working station that has a visual display screen some three feet on a side; this is his working surface, and is controlled by a computer (his "clerk") with which he can communicate by means of a small keyboard and various other devices.

He is designing a building. He has already dreamed up several basic layouts and structural forms, and is trying them out on the screen. The surveying data for the layout he is working on now have already been entered, and he has just coaxed the "clerk" to show him a perspective view of the steep hillside building site with the roadway above, symbolic representations of the various trees that are to remain on the lot, and the service tie points for the different utilities. The view occupies the left two-thirds of the screen. With a "pointer," he indicates two points of interest, moves his left hand rapidly over the keyboard, and the distance and elevation between the points indicated appear on the right-hand third of the screen.

STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIFORNIA

SRI

Republished in abridged form in ***Vistas in Information Handling***, Howerton and Weeks [Editors], Spartan Books, Washington, D.C., 1963, pp. 1-29, titled "A Conceptual Framework for the Augmentation of Man's Intellect."

October 1962

AFOSR-3223

Summary Report

AUGMENTING HUMAN INTELLECT: A CONCEPTUAL FRAMEWORK

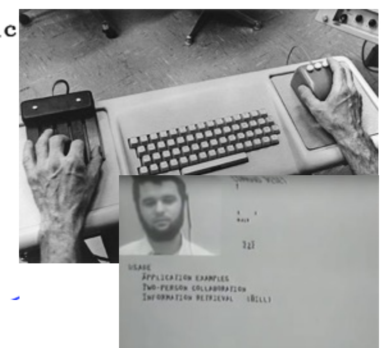
Prepared for:

DIRECTOR OF INFORMATION SCIENCES
AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
WASHINGTON 25, D.C.

CONTRACT AF 49(638)-1024

By: D. C. Engelbart

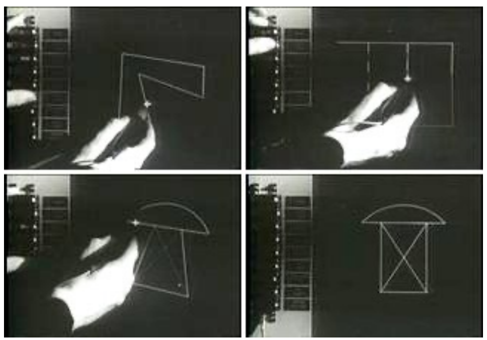
SRI Project No. 3578

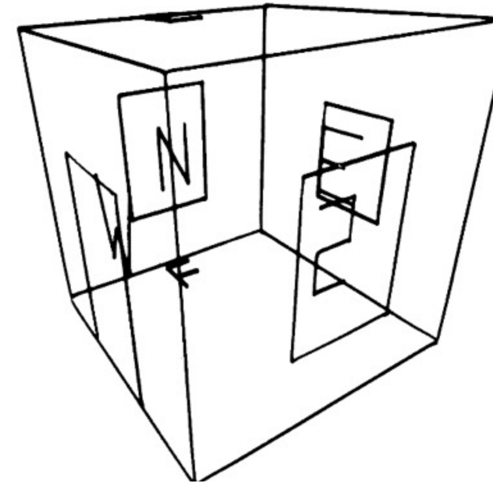


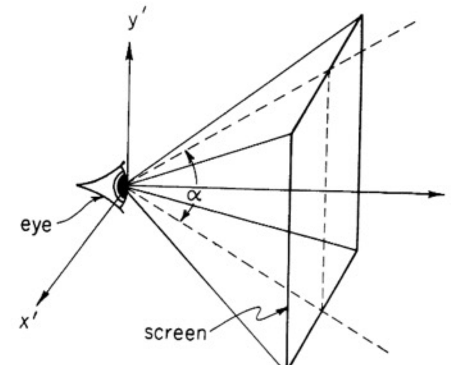
Engelbart, Douglas. "Augmenting human intellect: A conceptual framework. Summary report." *Stanford Research Institute, on Contract AF* 49, no. 638 (1962): 1024.

[“Mother of all demos”: https://youtu.be/B6rKUf9DWRI](https://youtu.be/B6rKUf9DWRI) , 1968

Head Mounted Displays and natural user interaction?





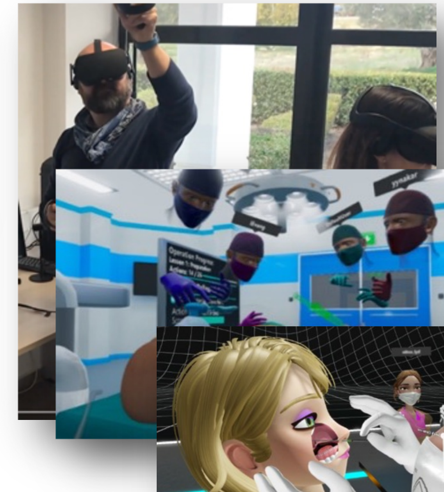


The sketchpad demo: https://youtu.be/6orsmFndx_o,1963
Sutherland, I. E. A head-mounted three dimensional display. *AFIPS Fall Joint Computing Conference* 757–764 (1968)
doi:10.1145/1476589.1476686. https://youtu.be/eVUgfUvP4uk

My Career arcs


TECHNOLOGIE Réalité et images de synthèse mêlées

LE TOURISME EN 3D EST NÉ




VHD++ Development Framework:
Towards Extendible, Component Based VR/AR Simulation Engine
Featuring Advanced Virtual Character Technologies

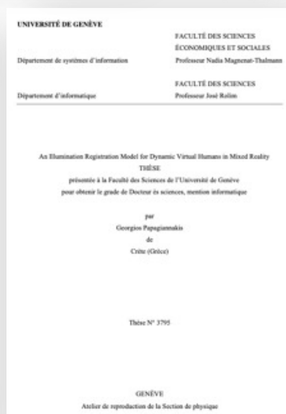
Michal Ponder, George Papagiannakis, Tom Molet, Nadia Magnenat-Thalmann, Daniel Thalmann

Abstract

1. Introduction: The Demand

2. Motivation: Curbing Complexity

2.1. Common Experience: Facing Complexity


UNIVERSITÉ DE GENÈVE

FACULTÉ DES SCIENCES ÉCONOMIQUES ET SOCIALES

Département de systèmes d'information

Professeur Nadia Magnenat-Thalmann

FACULTÉ DES SCIENCES

Département d'informatique

Professeur José Rolim

An Illumination Registration Model for Dynamic Virtual Humans in Mixed Reality

THÈSE

présentée à la Faculté des Sciences de l'Université de Genève

pour obtenir le grade de Docteur ès sciences, mention informatique

par

Georgios Papagiannakis

de

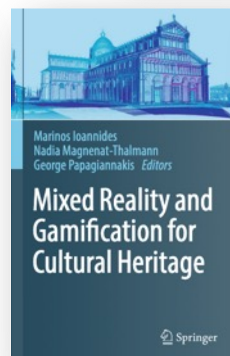
Crète (Grèce)

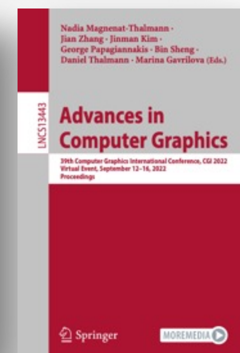
Thèse N° 3795

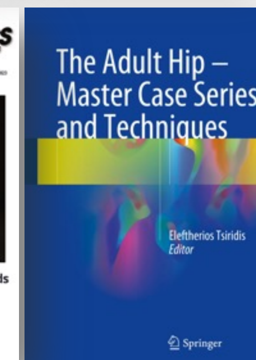
GENÈVE

Atelier de reproduction de la Section de physique

2006







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ORama VR

Overview of Medical Spatial Computing

- Applications
- Advantages
- Current status
- Examples
- Outcomes
- Medverse
  - Review of Spatial Reality technologies enabling the medverse
  - Our approach
- Challenges & Lessons learned

State-of-the-art in medVR training: Applications*

- Surgical/ Diagnostic/ Therapeutic training
- Anatomy education
- Disaster Preparedness
- Patient Education
- Patient Counselling

* Bashir, A. K. *et al.* A Survey on Federated Learning for the Healthcare Metaverse: Concepts, Applications, Challenges, and Future Directions. *Arxiv* (2023).

Medical Metaverse[1] and Digital Twins are revolutionizing healthcare

81%[2]

Of healthcare executives say the metaverse will have a positive impact on their organizations

5B$[3]

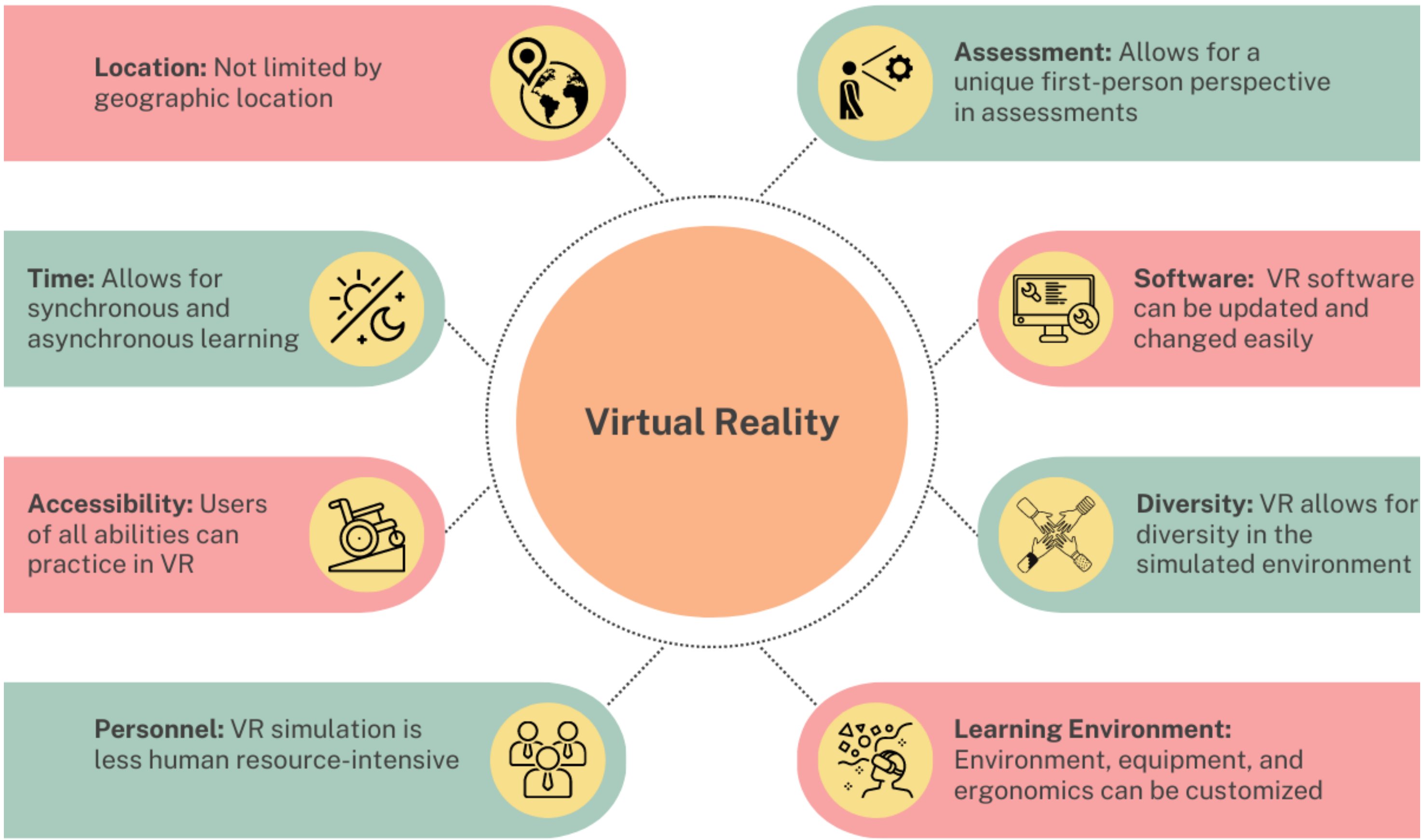
By 2030, the healthcare metaverse market will grow by 48.3% CAGR and be worth $5.37 billion

570%[4]

Reduction in learning time by using immersive medical VR training

1. https://ieeexplore.ieee.org/document/9940237
2. https://www.accenture.com/us-en/insights/health/digital-health-technology-vision
3. https://finance.yahoo.com/news/healthcare-metaverse-market-projected-worth-122100949.html
4. Lohre, R., Bois, A. J., Athwal, G. S. & Goel, D. P. Improved Complex Skill Acquisition by Immersive Virtual Reality Training. *J Bone Joint Surg Am* **Latest Articles**, 1–10 (2020).

Medical Virtual Reality[1] simulation-based training advantages



1. Gupta S, Wilcocks K, Matava C,Wiegelmann J, Kaustov L, Alam F., Creating a Successful Virtual Reality–Based Medical Simulation Environment: Tutorial JMIR Med Educ 2023;9:e41090, doi: 10.2196/41090

Med VR simulation-based training: where we are today

- Initial search identified 1,394 articles,
- of which 61 were included in the final qualitative synthesis.
- The majority (54%) were published in 2019– 2021, 49% in Europe.
- The commonest VR simulator was ArthroS (23%) and the commonest simulated skill was knee arthroscopy (33%).
- The majority of studies (70%) focused on simulator validation.
- Twenty-three studies described an educational module or curriculum, and of the 21 (34%) educational modules, 43% were one-off events.

Review | Published: 22 March 2023

Current status of virtual reality simulation education for orthopedic residents: the need for a change in focus

Graham Cate, Jack Barnes, Steven Cherney, Jeffrey Stambough, David Bumpass, C. Lowry Barnes & Karen J. Dickinson

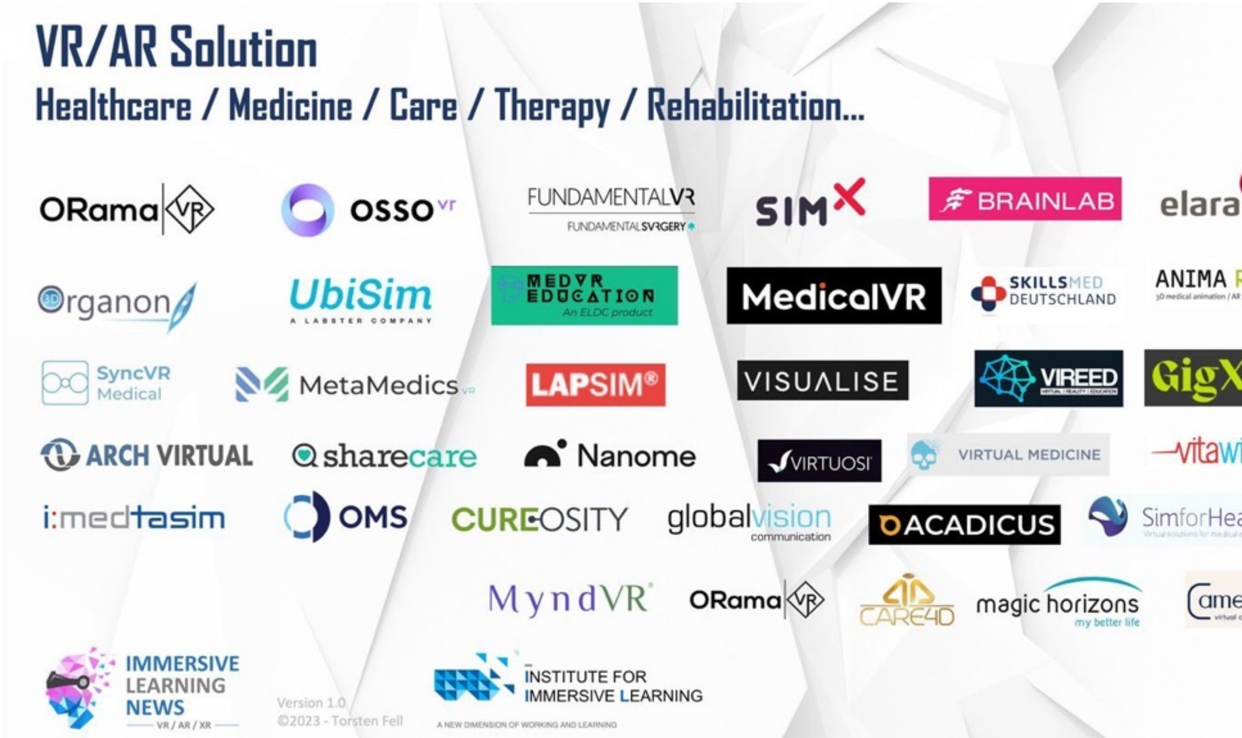
Global Surgical Education - Journal of the Association for Surgical Education **2**, Article number: 46 (2023) | Cite this article

Current literature pertaining to **VR training** for orthopaedic residents is **focused on establishing validity and rarely forms part of a curriculum**. Where the focus is education, the majority are discrete educational modules and do not teach a comprehensive amalgam of orthopedic skills. This suggests **focus is needed to embed VR simulation training within formal curricula.**

- Cate, G., Barnes, J., Cherney, S. *et al.* Current status of virtual reality simulation education for orthopedic residents: the need for a change in focus. *Global Surg Educ* **2**, 46 (2023). https://doi.org/10.1007/s44186-023-00120-w

Med VR simulation-based training: examples of current programs*

ORama VR



VirtaMed: Arthroscopy simulators

OssoVR: Orthopedic Surgery training

FundamentalVR: Haptics-based VR training

UbiSim: Nursing, scenario-based VR training

SimX: Emergency VR training

* https://www.linkedin.com/posts/torstenfell_vr-ar-medical-activity-7028626299917099009-ZUGo?utm_source=share&utm_medium=member_desktop

Med VR simulation-based training: real-world outcomes

Improved Skills

- **Studies** have shown that medical virtual reality training leads to improved surgical skills and reduced errors.

Better **Patient Outcomes**

- Virtual reality training can improve patient outcomes by **reducing complications** and improving patient satisfaction.

Financial **Savings**

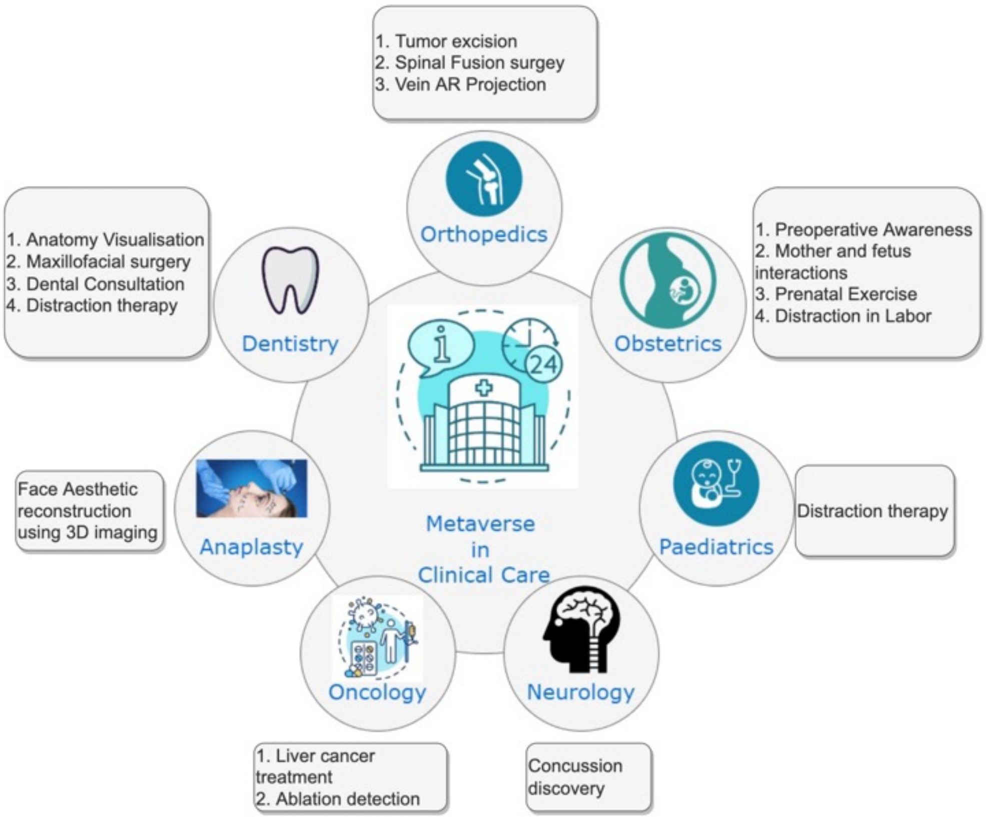
- Medical virtual reality training can **reduce costs** associated with traditional training methods by minimizing the need for materials and equipment.

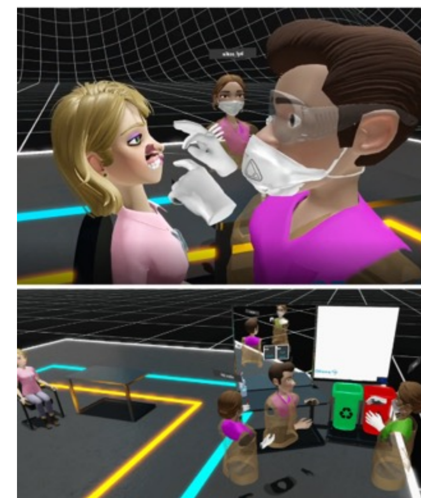
Increased **Accessibility**

- Virtual reality training can be accessed from **anywhere**, allowing medical professionals to learn and train at their **own pace**, and reducing the need for travel.

Medverse*: state-of-the-art

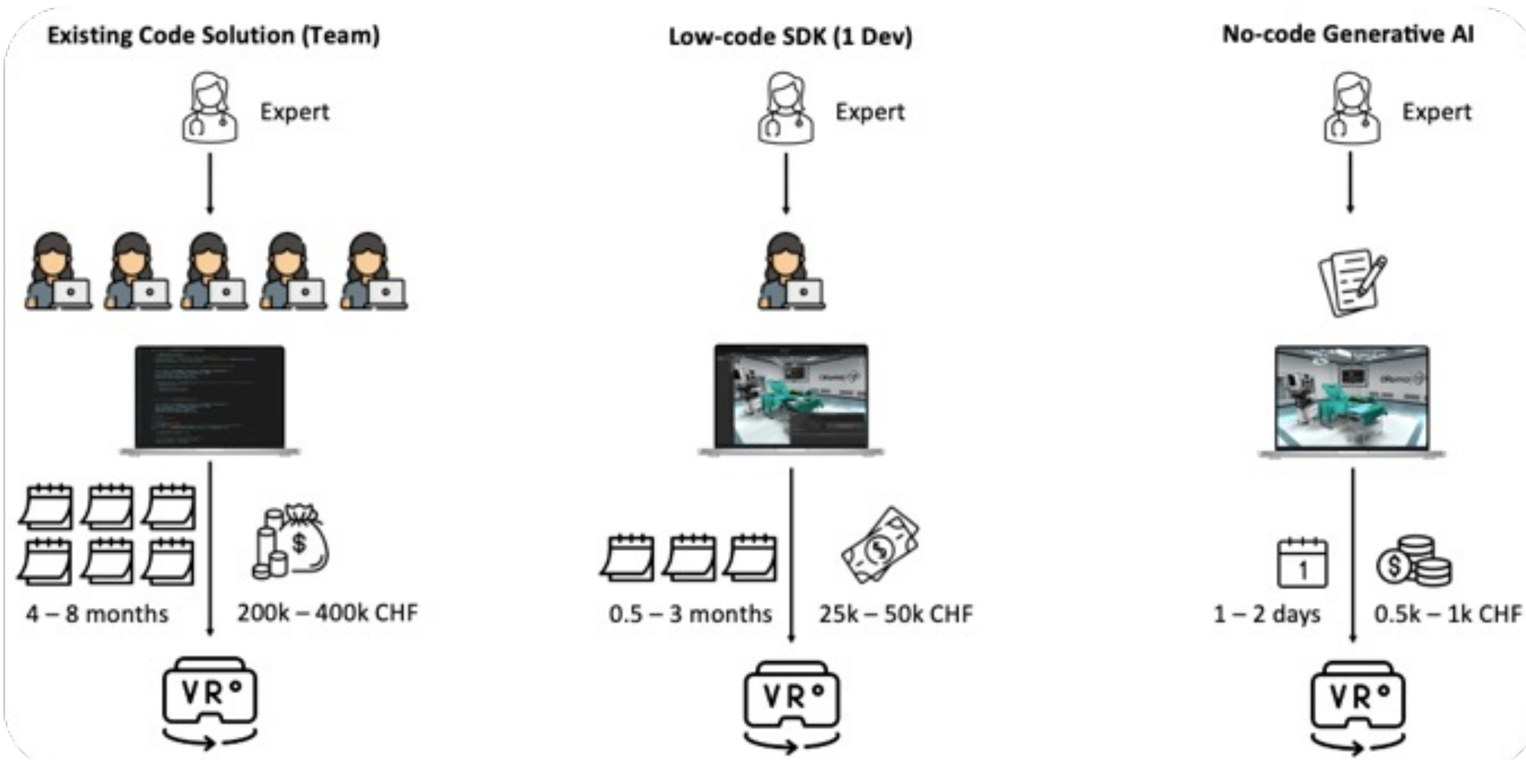
*With the term “MEDverse”, we can define the entry of the metaverse into a medical context**





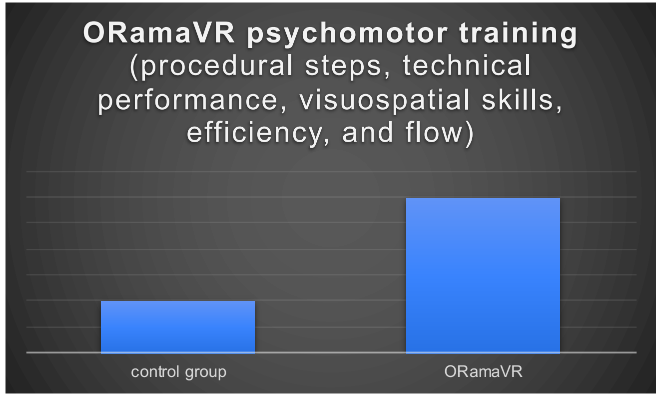
- *Cerasa, A., Gaggioli, A., Marino, F., Riva, G. & Pioggia, G. The promise of the metaverse in mental health: the new era of MEDverse. Heliyon e11762 (2022) doi:10.1016/j.heliyon.2022.e11762
- Bansal, G., Rajgopal, K., Chamola, V., Xiong, Z. & Niyato, D. Healthcare in Metaverse: A Survey On Current Metaverse Applications in Healthcare. IEEE Access PP, 1–1 (2022)

MEDVERSE AUTHORING:
CODE -> LOW-CODE -> NO-CODE

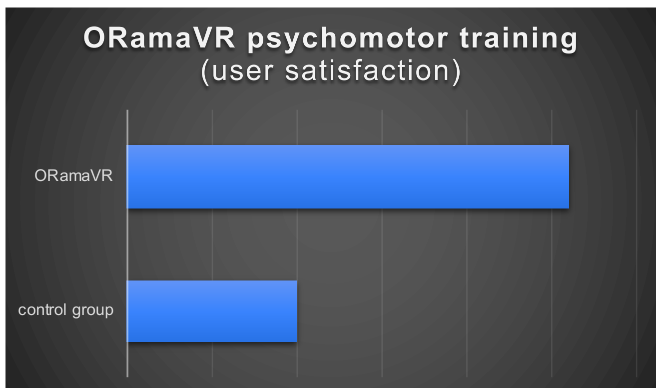


Medverse: our MAGES approach

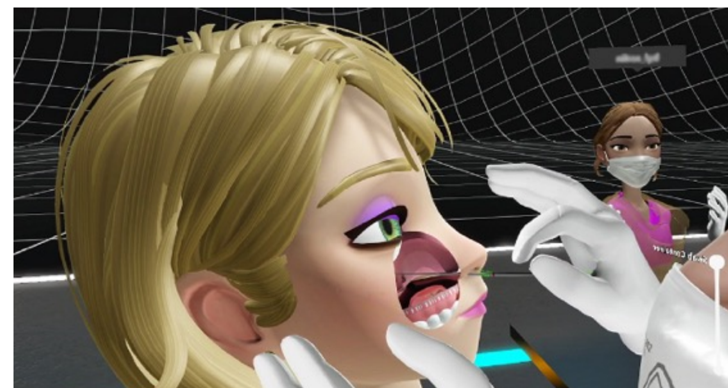
We have proven that medical VR training facilitates skills transfer from the virtual world to the real



Hooper et al 2019, NYU, USA (N=14), Journal of Arthroplasty*



Birrenbach et al 2021, Inselspital, Switzerland (N=29), Journal of Medical Internet Research**



*https://www.sciencedirect.com/science/article/pii/S0883540319303341
**https://games.jmir.org/2021/4/e29586/

MULTIPLAYER SUPPORT

State of the Art

"The 80 player limit is based on the current performance of VRChat and the limits of CPUs"

"For groups up to 50 users where the speakers are represented as avatars and about half of the participants view from the lobby"

"The app offers virtual meeting rooms, whiteboards and video call integration for up to 50 people"

[1] Limited number of concurrent users. Usually for simple cognitive tasks (e.g. questions)

[2] Use of standard networking frameworks (PUN) without any optimization

[1] Brown, K.E., Heise, N., Eitel, C.M. *et al.* A Large-Scale, Multiplayer Virtual Reality Deployment: A Novel Approach to Distance Education in Human Anatomy. *Med.Sci.Educ.* (2023). https://doi.org/10.1007/s40670-023-01751-w

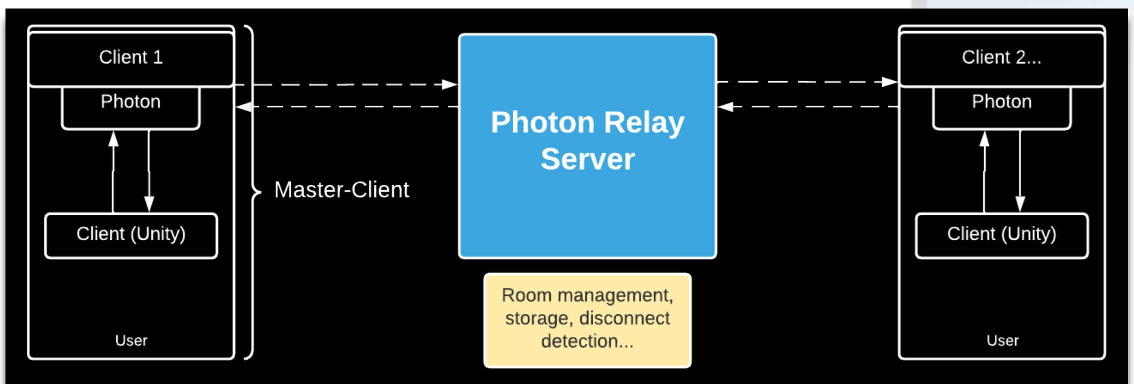
[2] Tea, S., Panuwatwanich, K., Ruthankoon, R. and Kaewmoracharoen, M. (2022), "Multiuser immersive virtual reality application for real-time remote collaboration to enhance design review process in the social distancing era", *Journal of Engineering, Design and Technology*, Vol. 20 No. 1, pp. 281-298. https://doi.org/10.1108/JEDT-12-2020-0500

MULTIPLAYER WITH GA INTERPOLATION

Our Contribution

- Up to 300 concurrent users in the same virtual room
- Trainees can join with any VR/AR headset or mobile phone/tablet even desktop
- Collaboration between VR and AR
- Powerful GA interpolation engine* to reduce network traffic (33% reduced)
- Automated co-op configuration

Our networking is based on the server – client model



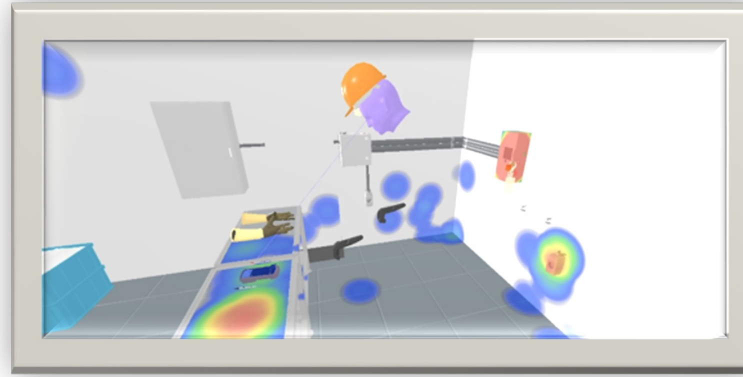
*Kamarianakis, M., Chrysovergis, I., Lydatakis, N. et al. Less is More: Efficient Networked VR Transformation Handling Using Geometric Algebra. Adv. Appl. Clifford Algebras 33, 6 (2023). https://doi.org/10.1007/s00006-022-01253-9

ANALYTICS – DL BASED GAME ENGINE

State of the Art

(VadR)

Easy to use platforms but track **limited events**



- Provide mostly linear storytelling **functionality**
- Do not support collaborative analytics (multiplayer) for large number of concurrent users

[1] Proposes a low-code tool to gather various user data but it is only for AR platforms
[2] Deep learning analytics are used for user assessment

[1] P. Fleck, A. Sousa Calepso, S. Hubenschmid, M. Sedlmair and D. Schmalstieg, "RagRug: A Toolkit for Situated Analytics," in *IEEE Transactions on Visualization and Computer Graphics*, doi: 10.1109/TVCG.2022.3157058.

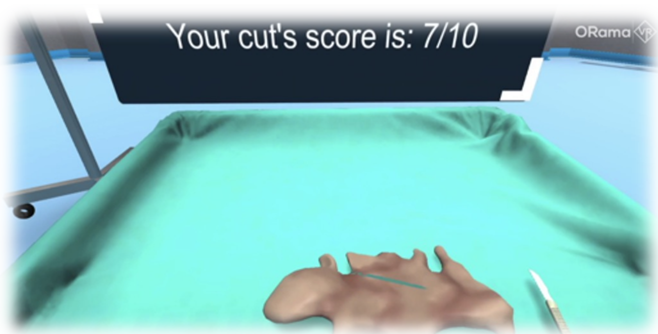
[2] Mark Hawkins "Virtual Employee Training and Skill Development, Workplace Technologies, and Deep Learning Computer Vision Algorithms in the Immersive Metaverse Environment", Addleton Academic Publishers, 2022

ANALYTICS – DL BASED GAME ENGINE

Our Contribution

- No-code configuration of analytics
- Deep Learning tools to analyze and assess trainees
- We capture **hundreds of events** per second
- Can be extended to user's needs

- Our VR Recorder* enables **recording** and **replaying** VR training sessions



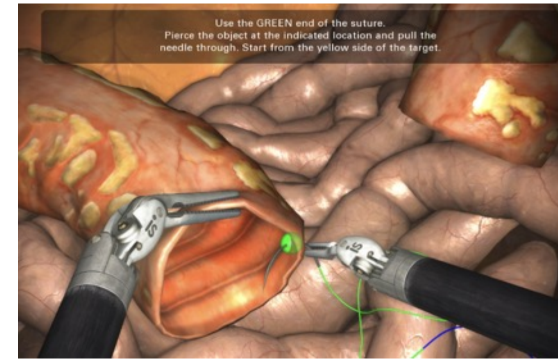
*Manos Kamarianakis, Ilias Chrysovergis, Mike Kentros, and George Papagiannakis. 2022. Recording and replaying psychomotor user actions in VR. In ACM SIGGRAPH 2022 Posters (SIGGRAPH '22). Association for Computing Machinery, New York, NY, USA, Article 30, 1–2. https://doi.org/10.1145/3532719.3543253

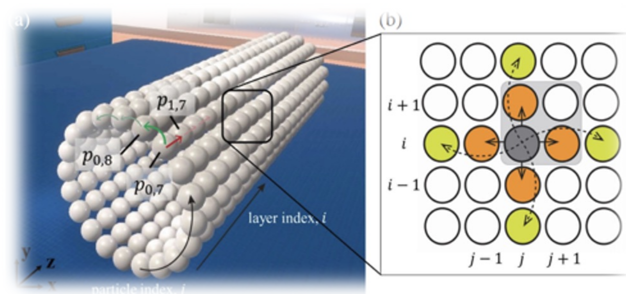
GA DEFORMABLE ANIMATION, CUTTING, AND TEARING

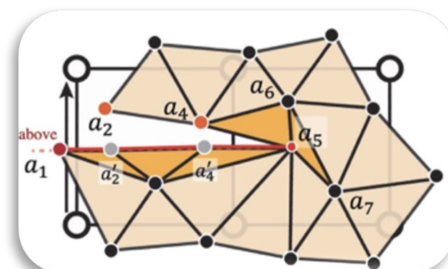
State of the Art

- Predefined, **animated** cuts in restricted areas
- Custom solvers for **heavy** particle-based deformations

- Use of **matrices** for transformations







[1] Other approaches use **volumetric meshes** which are very **expensive** to use with VR

[2] **Particle based** simulations are also used. In this case for bowel anastomosis

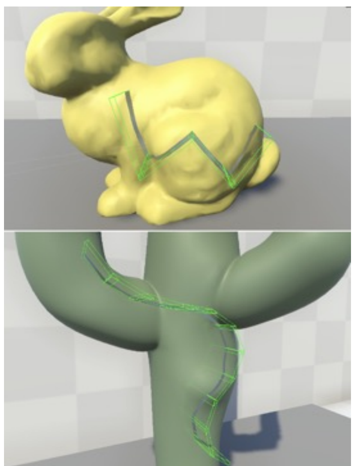
[1] P. Korzeniowski, S. Płotka, R. Brawura-Biskupski-Samaha and A. Sitek, "Virtual Reality Simulator for Fetoscopic Spina Bifida Repair Surgery," *2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, Kyoto, Japan, 2022, pp. 401-406, doi:10.1109/IROS47612.2022.9981920.

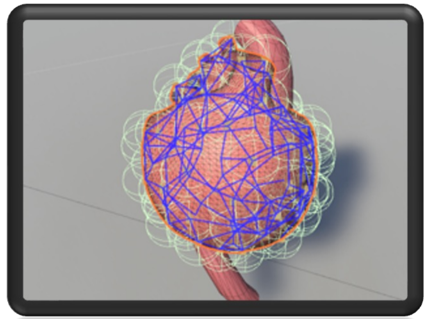
[2] Qi, D, De, S. Split and join: An efficient approach for simulating stapled intestinal anastomosis in virtual reality. *Comput Anim Virtual Worlds*. 2023;e2151. https://doi.org/10.1002/cav.2151

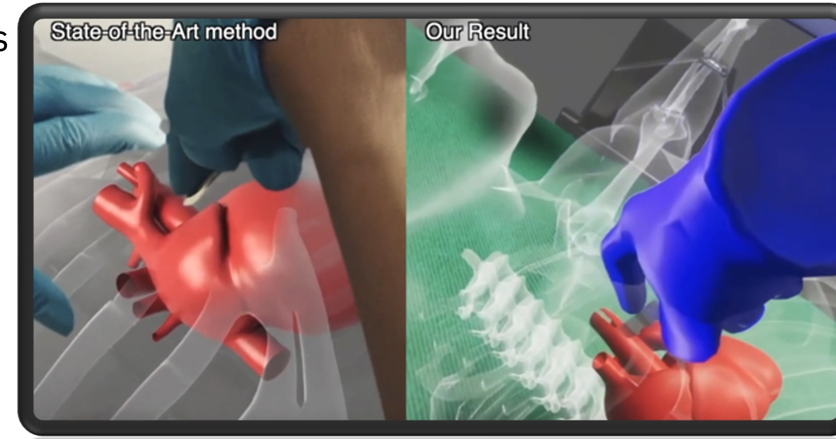
GA DEFORMABLE ANIMATION, CUTTING, AND TEARING

Our Contribution

- Real-time **cutting, tearing** and **drilling** of deformable surfaces
- Hand manipulation of skinned deformable meshes
- Particle based simulation
- Proprietary **GA interpolation** engine







We are not limited from the scalpel's movement

Our cutting algorithms are real-time

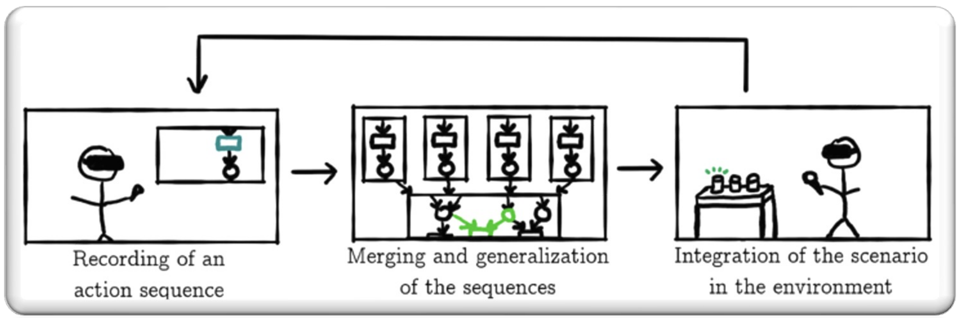
Model	Faces	Running Time
Horse	4266	10.14 ms
Bunny (OUR)	4968	11.19 ms
Cuboid	18128	52.77 ms
Heart (OUR)	18336	18.65 ms

Manos Kamarianakis, Antonis Protopsaltis, Dimitris Angelis, Michail Tamiolakis and George Papagiannakis. 2022. P. CAT-EGVE 2022 - International Conference on Artificial Reality and Telexistence and Eurographics Symposium on Virtual Environments https://doi.org/10.2312/egve.20221275

EDITOR WITH ACTION PROTOTYPES

State of the Art

- Similar platforms provide editors with **limited customization** (e.g immersive.io)
- There are no dedicated **software design patterns** for VR behaviors (steps/actions)
- More companies pivot towards creating **platforms** for training simulations (i3Simulations)



[1] Content creation through **recording of steps** or storyboarding is widely used

Scenegraph data structure can represent a training scenario

[2] Authoring tools and visual scripting editors have emerged for rapid creation of training simulations

[1] Lécuyer, F., Gouranton, V., Lamercerie, A. *et al.* Unveiling the implicit knowledge, one scenario at a time. *Vis Comput* **36**, 1951–1963 (2020). https://doi.org/10.1007/s00371-020-01904-7

[2] Blattgerste, J.; Behrends, J.; Pfeiffer, T. TrainAR: An Open-Source Visual Scripting-Based Authoring Tool for Procedural Mobile Augmented Reality Trainings. *Information* **2023**, *14*, 219. https://doi.org/10.3390/info14040219

EDITOR WITH ACTION PROTOTYPES

Our Contribution

- Low-code editor to create/modify training Actions
- Automatic **script generation**
- Action prototypes* for rapid creation of training simulations

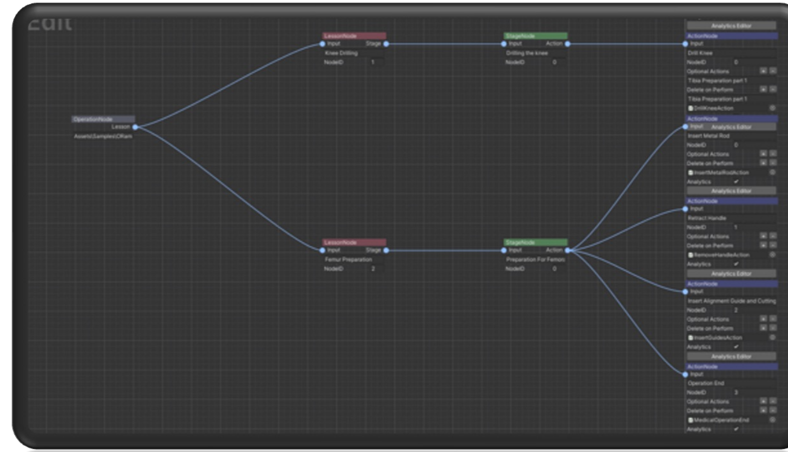
- We are moving towards a **no-code** solution

<u>**8X faster & 8X cheaper**</u>

We abstract training scene interaction-design with 7 VR Action Prototypes*:

Insert Action **Use Action** **Remove Action**

Animation Action **Cut/tear Action** **Tool Action** **Q&A Action**



The training scenegraph editor, a low-code solution to create VR experiences

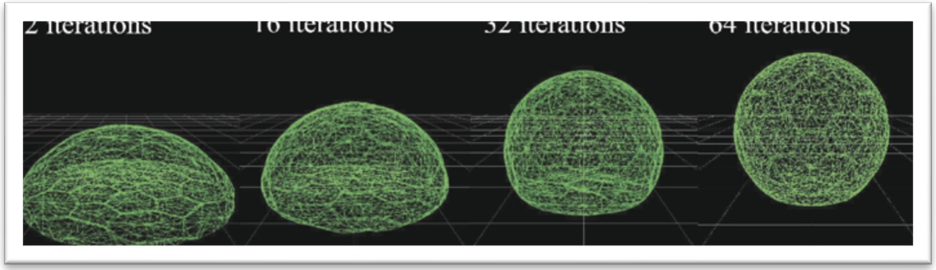
- Each node is a step/Action in VR

*Zikas, P., Papagiannakis, G., Lydatakis, N. *et al.* Immersive visual scripting based on VR software design patterns for experiential training. *Vis Comput* **36**, 1965–1977 (2020). https://doi.org/10.1007/s00371-020-01919-0

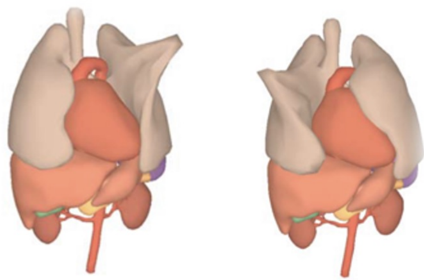
SEMANTICALLY ANNOTATED DEFORMABLE, SOFT, AND RIGID BODIES

State of the Art

- Expensive algorithms for **PBD** with **custom solvers**
- Not compatible solutions with modern game engines (Unity, Unreal)
- Not scalable nor real-time



- [1] There are similar approaches, but it is difficult to simulate them in VR due to the **algorithmic complexity**



(a) (b)

- [2] Most of the state of the art methods are not suitable for VR, since the specific calculations must be performed in a real-time manner within a few ms to preserve user immersion.

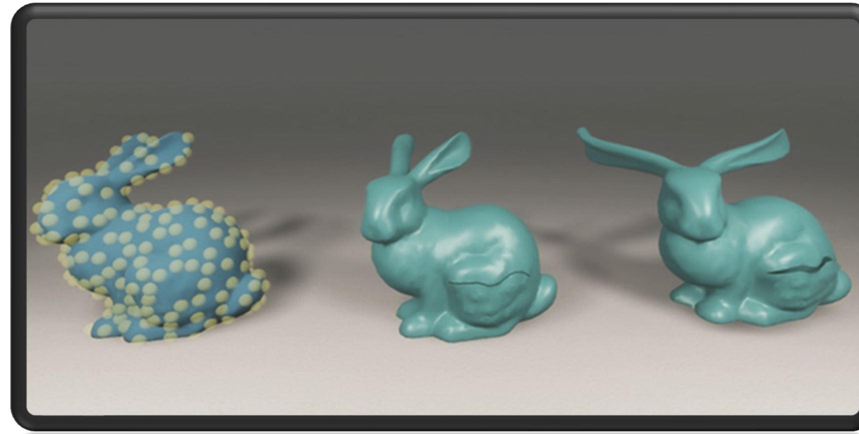
[1] Wang, M, Ma, Y, Liu, F. A novel virtual cutting method for deformable objects using high-order elements combined with mesh optimisation. *Int J Med Robot*. 2022; 18(5):e2423. https://doi.org/10.1002/rcs.2423

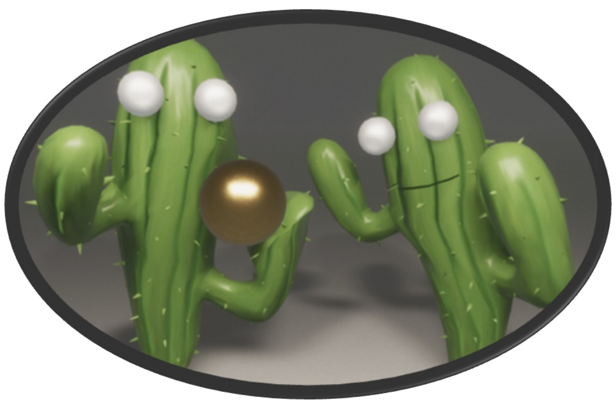
[2] W. Xu, Y. Wang, W. Huang and Y. Duan, "An Efficient Nonlinear Mass-Spring Model for Anatomical Virtual Reality," in *IEEE Transactions on Instrumentation and Measurement*, vol. 71, pp. 1-10, 2022, Art no. 9700110, doi: 10.1109/TIM.2022.3164132.

SEMANTICALLY ANNOTATED DEFORMABLE, SOFT, AND RIGID BODIES

Our Contribution

- Particle system for **real-time elasticity** simulations
- Simulate tissues and organs
- Under **10m/s** rendering
- Easy **configuration**
- Handling of tissue and organs with hands





- We can simulate various **physical material** properties
- Our algorithm is applied to **skinned meshes** as well

Manos Kamarianakis and Antonis Protopsaltis and Michail Tamiolakis and George Papagiannakis. 2022. Realistic soft-body tearing under 10ms in VR. arXiv 2205.00914

METAVERSE AUTHORING FRAMEWORKS: STATE OF THE ART

Numerous **authoring frameworks** have emerged to sustain the creation of VR/AR applications

Main characteristics of the virtual reality authoring tools: [1]

- Virtual environment **creation**
- Manipulating and importing **3D** objects
- Interactive **human characters** development
- Artificial intelligence **automation**

"The most evaluated metrics were **usability**, **effectiveness**, **efficiency**, and **satisfaction**." [2]

"Our virtual-worlds **(or digital twins)** will seem fundamentally different in the future due to the incorporation of developing technology" [3]

Our work among others is cited in the following publications:

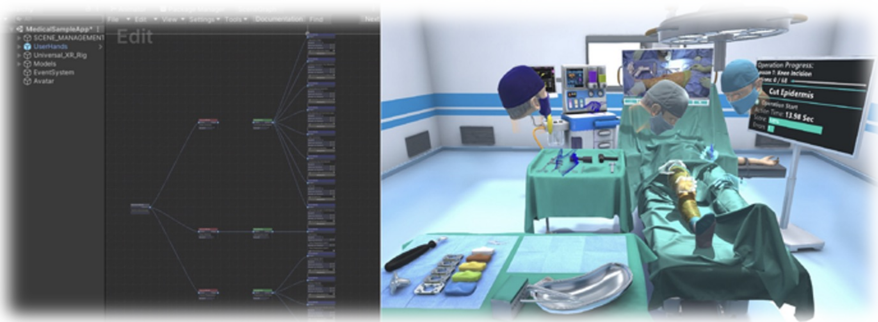
[1] Chamusca, I. L., Ferreira, C. V., Murari, T. B., Apolinario, A. L. & Winkler, I. Towards Sustainable Virtual Reality: Gathering Design Guidelines for Intuitive Authoring Tools. *Sustainability-basel* **15**, 2924 (2023)

[2] Coelho, H., Monteiro, P., Gonçalves, G., Melo, M. & Bessa, M. Authoring tools for virtual reality experiences: a systematic review. *Multimed Tools Appl* 1–24 (2022) doi:10.1007/s11042-022-12829-9

[3] Bansal, G., Rajgopal, K., Chamola, V., Xiong, Z. & Niyato, D. Healthcare in Metaverse: A Survey On Current Metaverse Applications in Healthcare. *Ieee Access* **PP**, 1–1 (2022)

METAVERSE AUTHORING FRAMEWORKS: MAGES 4.0

Our latest advancements were published in **IEEE Computer Graphics and applications** journal



MAGES 4.0 introduces

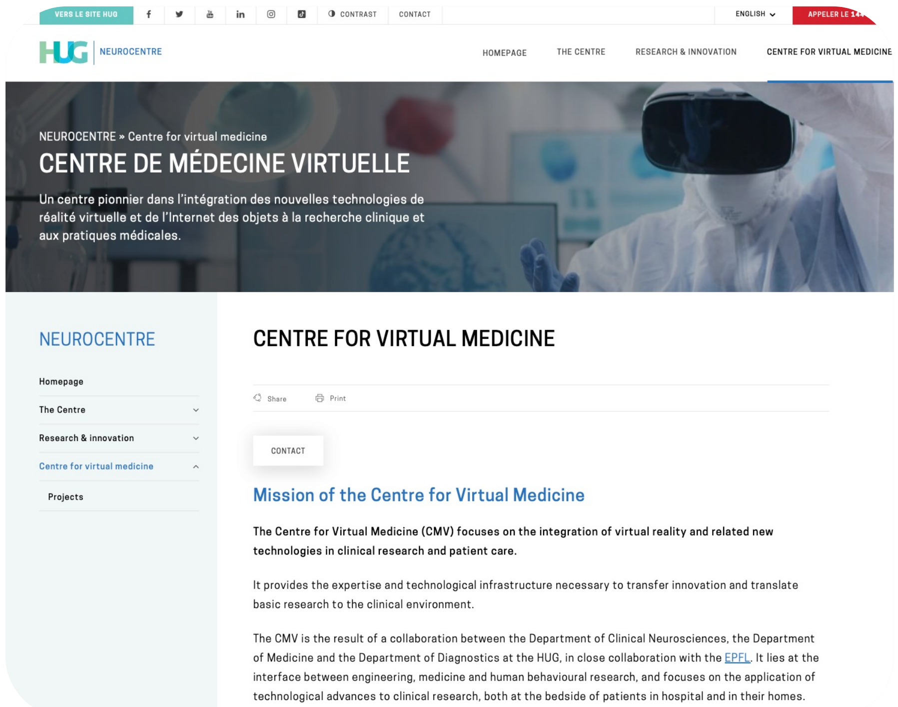
- Automations in VR design-patterns for interaction-design **Actions development**
- VR recorder to capture and replay VR sessions
- Realistic real-time **cut, tear and drill** algorithms
- AR and mobile (ios) support
- Dissected edge physics engine
- Edge-cloud **remote** visual **rendering**
- Optimized networking layer with collaboration of **AR/VR** devices
- Convolutional **neural network** automatic assessment
- New template applications (open source)

P. Zikas *et al.*, "**MAGES 4.0: Accelerating the World's Transition to VR Training and Democratizing the Authoring of the Medical Metaverse**," in *IEEE Computer Graphics and Applications*, vol. 43, no. 2, pp. 43-56, 1 March-April 2023, doi: 10.1109/MCG.2023.3242686.

ORama VR

MAGES simulation-based training: a transformation underway*

- Hospitals creating in-house medical VR training simulations
- Not just for training but exams too!



* https://www.hug.ch/en/neurocentre/centre-virtual-medicine , VMC at HUG, Geneva
https://visl.ch Virtual Insel Simulation Lab at Inselspital, Bern

MAGES technology adoption so far

7,500+

CLIENT CLOUD TRAINING SESSIONS REGISTERED

20

B2B CLIENTS WORLDWIDE
6 B2B subscribers on SDK
10 medical schools/institutes
2 medical device companies
1 surgical training center
European Commission

Med VR simulation-based training: Challenges and Lessons Learned

- **Cost**
  - Can be expensive to purchase and maintain
- **Technical Challenges**
  - Can be complicated to set up and use
- **Learning objectives**
  - Depends greatly on each subject-matter-expert – scope creep
- **Evaluation and Validation**
  - Need for standardization in the development and evaluation
- **Lack of high fidelity?**
  - "functional correspondence" instead of fidelity*

*Hamstra, S. J., Brydges, R., Hatala, R., Zendejas, B. & Cook, D. A. Reconsidering Fidelity in Simulation-Based Training. *Acad Med* **89**, 387–392 (2014).

Med VR training with Spatial Computing technologies: Future paths

> **The scene is set for massive change**

Improved Immersion, Embodiment and Presence

- Spatial Reality advances can lead to even more immersive and engaging training experiences

Expanded Scope

- Can be used to train medical professionals for a wider range of scenarios and procedures

Increased Accessibility

- As VR technology becomes more widespread and affordable, medical virtual reality training will become more accessible to institutions around the world

Source: Accenture Consulting. WAKING UP TO A NEW REALITY | Accenture. 2019.

Let's accelerate world's transition to VR training with Medical Spatial Reality!

Prof. George Papagiannakis
Prof. University of Crete,
Affiliated Researcher at FORTH
Visiting Prof. University of Geneva
&
ORamaVR co-founder, CEO
george@oramavr.com

UNIVERSITY OF CRETE
FORTH
Foundation for Research & Technology - Hellas
ORama VR
UNIVERSITÉ DE GENÈVE