

Computational Medical XR: Spatial, Neural and Wearable Computing Converging to Transform Healthcare

SIGGRAPH 2023 Frontiers Talk

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Dr. Walter Greenleaf, Stanford University



Celebrating 50 Years of Conferences

1974



2023



Computational Medical XR

Intro



***Computational medical XR** is a new interdisciplinary field, bridging life sciences, with mathematics, engineering and computer science.*

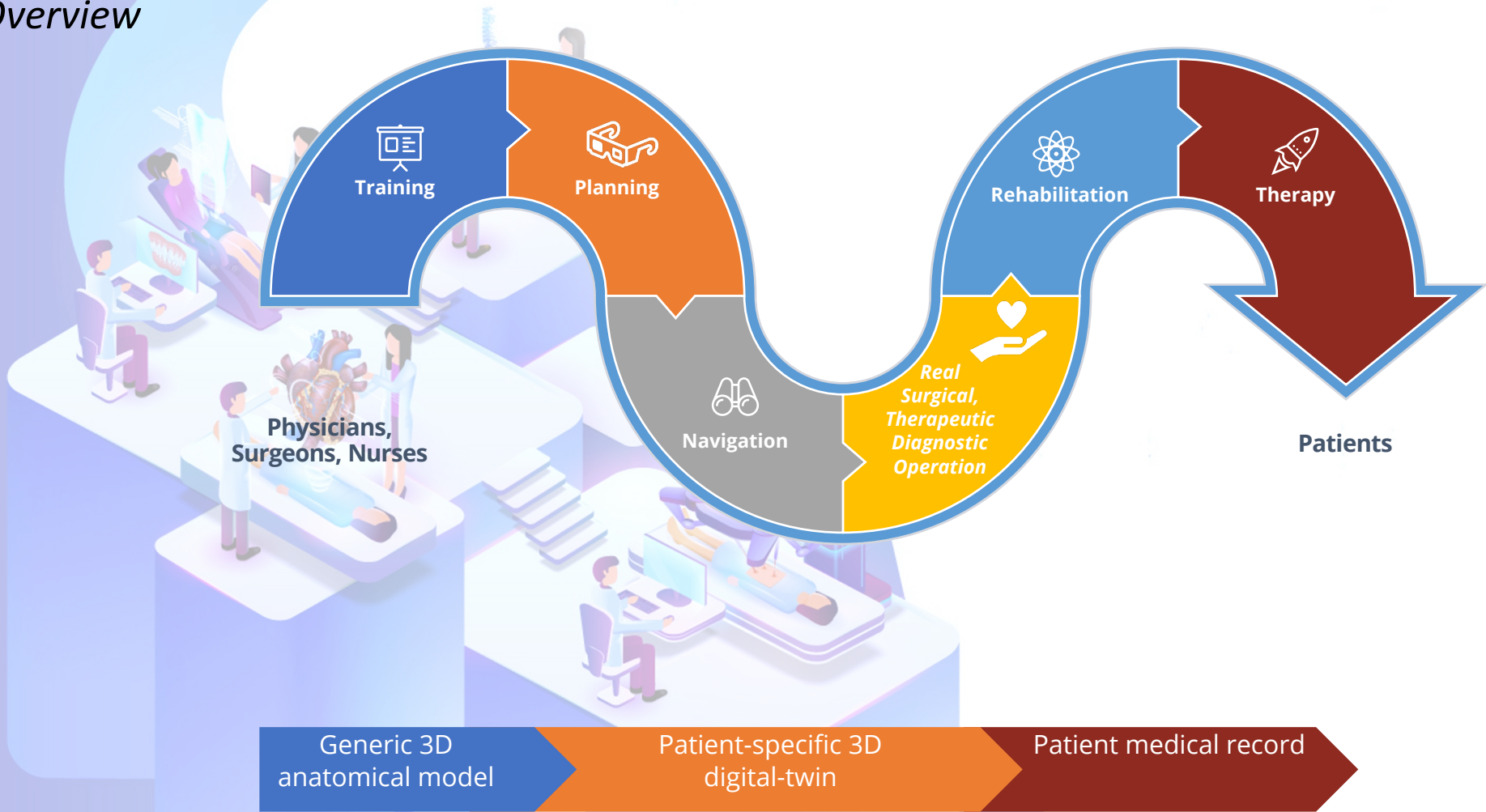
*It unifies **computational** science (scientific computing) with intelligent **extended reality** and **spatial computing** for the **medical** field.*

It integrates **computational** methods from computer **graphics**, computational **geometry**, **vision** and **deep learning** to solve hard problems in medicine and neuroscience:

- low-code/no-code **authoring** XR platforms
- XR surgical **planning**
- XR operative **navigation**
- Computational systems for **rehabilitation** and **therapeutics**

Computational Medical XR

Overview



Why now for computational medical XR?



Stable Diffusion prompt:
"doctors and nurses with 3D VR and AR glasses in digital and real objects and environments integrated and communicating between each other based on immersive experiences"

"After **years** of **validation** and **use** by early adopters – VR medical technology is poised to move to the **mainstream**; recent changes in **cost** and **access** make VR quite **affordable**"

*Dr. Walter Greenleaf,
Stanford Health Care & Virtual Human Interaction Lab*

"The biggest **challenges** in **healthcare** are (1) **access**—there aren't enough enough good doctors to provide timely care to all who need it (and clinicians are leaving the field in droves due to burn out), and (2) **cost**—the cost of healthcare has skyrocketed, largely because of increasing labor costs.

AI will solve both of these issues."

*Daisy Wolf and Vijay Pande,
<https://a16z.com/2023/08/02/where-will-ai-have-the-biggest-impact-healthcare/>*

Spatial and neural computing authoring challenges for computational medical XR



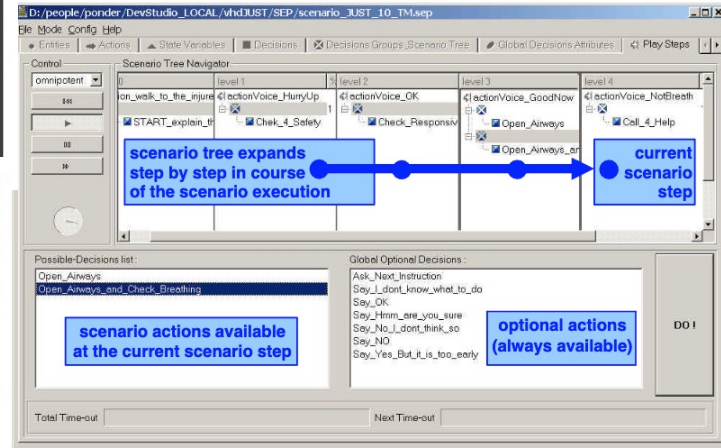
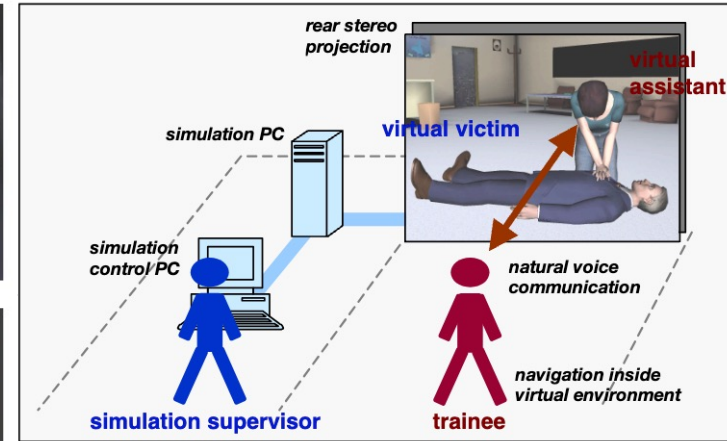
Dr. George Papagiannakis
ORamaVR co-founder, CEO
george@oramavr.com

&

Prof. University of Crete,
Affiliated Researcher at FORTH
Visiting Prof. University of Geneva

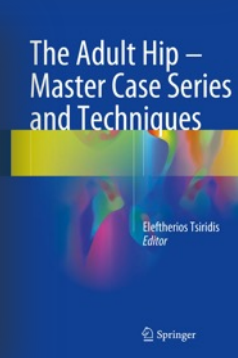
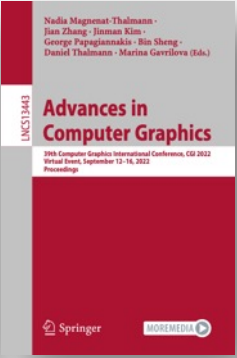
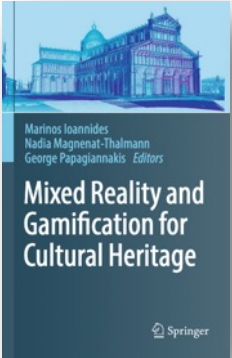


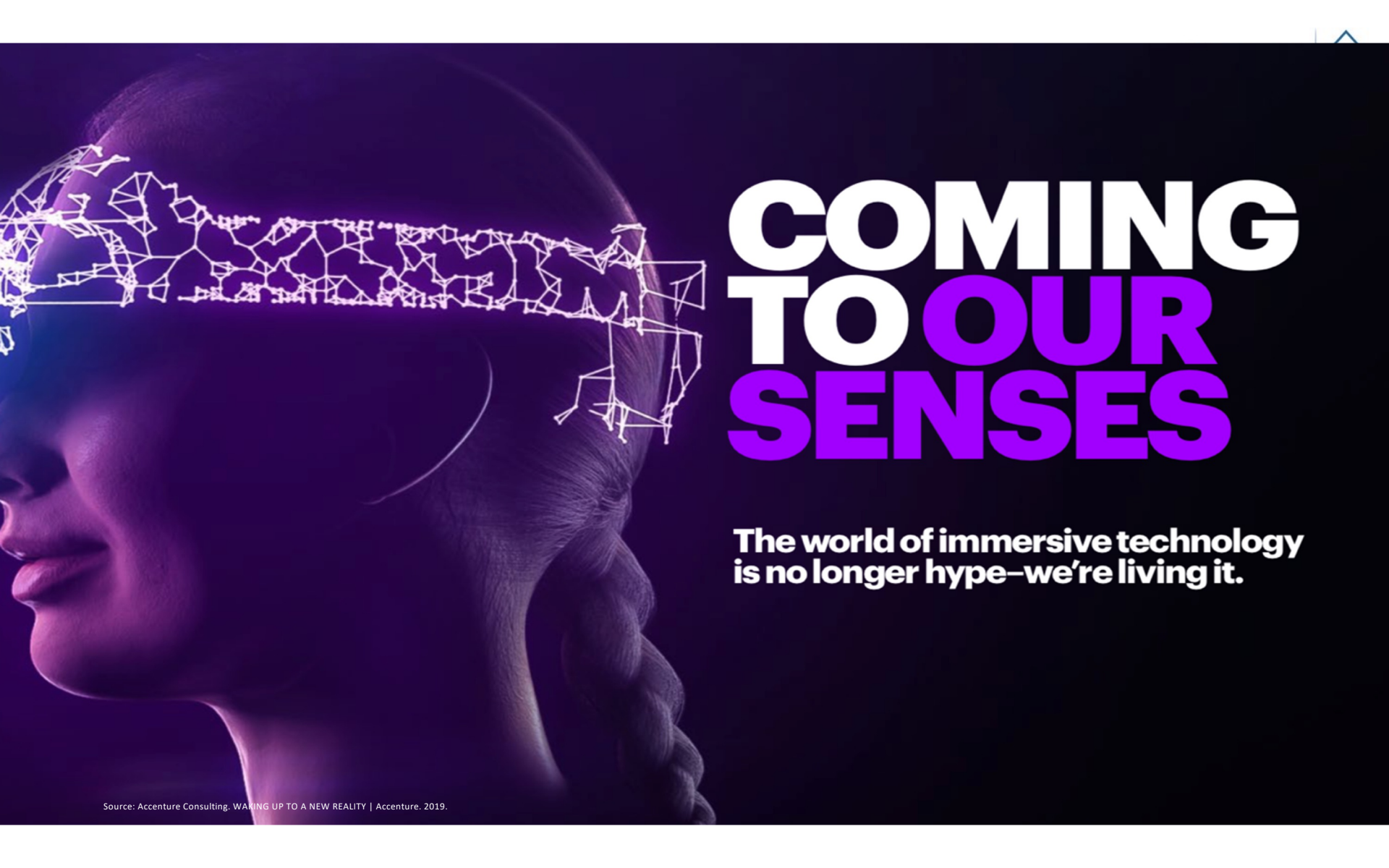
Spatial computing for medical training?



- M Ponder, B Herbelin, T Molet, S Schertenleib, B Ulicny, G Papagiannakis, N Magnenat-Thalmann, and D Thalmann. 2002. Interactive Scenario Immersion:Health Emergency Decision Training in JUST Project. Proc. Of 1st International Workshop on Virtual Reality Rehabilitation, VRMR2002, Lausanne, (November 2002), 87–101.
- Michal Ponder, Bruno Herbelin, Tom Molet, Sebastien Schertenlieb, Branislav Ulicny, George Papagiannakis, Nadia Magnenat-Thalmann, and Daniel Thalmann. 2003. Immersive VR decision training: telling interactive stories featuring advanced virtual human simulation technologies. DOI:<https://doi.org/10.1145/769953.769965>

My Career arcs





COMING TO OUR SENSES

**The world of immersive technology
is no longer hype—we're living it.**



Metaverse* = Internet(3D)^{AI} ↔ XR

The Rules

**

Rule #1: There is only one Metaverse.

Rule #2: The Metaverse is for everyone.

Rule #3: Nobody controls the Metaverse.

Rule #4: The Metaverse is open.

Rule #5: The Metaverse is hardware-independent.

Rule #6: The Metaverse is a Network.

Rule #7: The Metaverse is the Internet.

* Source: A. Graylin, HarvardXR, April 2023

** <https://medium.com/meta-verses/the-seven-rules-of-the-metaverse-7d4e06fa864c>

Stable Diffusion prompt:

"a girl in VR glasses experiencing metaverse worlds"

**AN EU INITIATIVE ON WEB
4.0 AND VIRTUAL WORLDS:****A head start in the next
technological transition**11 July 2023
#DigitalEU
#VirtualWorldsEU

The Commission has adopted a strategy on Web 4.0 and virtual worlds to steer the next technological transition and ensure an open, secure, trustworthy, fair and inclusive digital environment for EU citizens and businesses and public administrations.

4 PILLARS

1

Empowering people and reinforcing skills
to foster awareness, access to trustworthy information and build a talent pool of virtual world specialists.

2

Business: supporting a European Web 4.0 industrial ecosystem to scale up excellence and address fragmentation.

3

Government: supporting societal progress and virtual public services to leverage the opportunities virtual worlds can offer.

4

Governance: to set up the structures for the EU to steer the openness of virtual worlds.

23 RECOMMENDATIONS

The Commission hosted a *European Citizens' Panel on Virtual Worlds*. A representative group of citizens made 23 recommendations on citizens' expectations for the future, principles and actions to ensure that virtual worlds in the EU are fair and citizen-friendly.

***Virtual worlds:** persistent, immersive environments based on 3D and extended reality (XR) technologies.
***Web 4.0:** digital and real objects and environments integrated and communicating between each other, enabling immersive experiences.

Virtual Worlds and Web 4.0 *

Virtual Worlds:

Persistent, immersive environments based on 3D and extended reality (XR) technologies

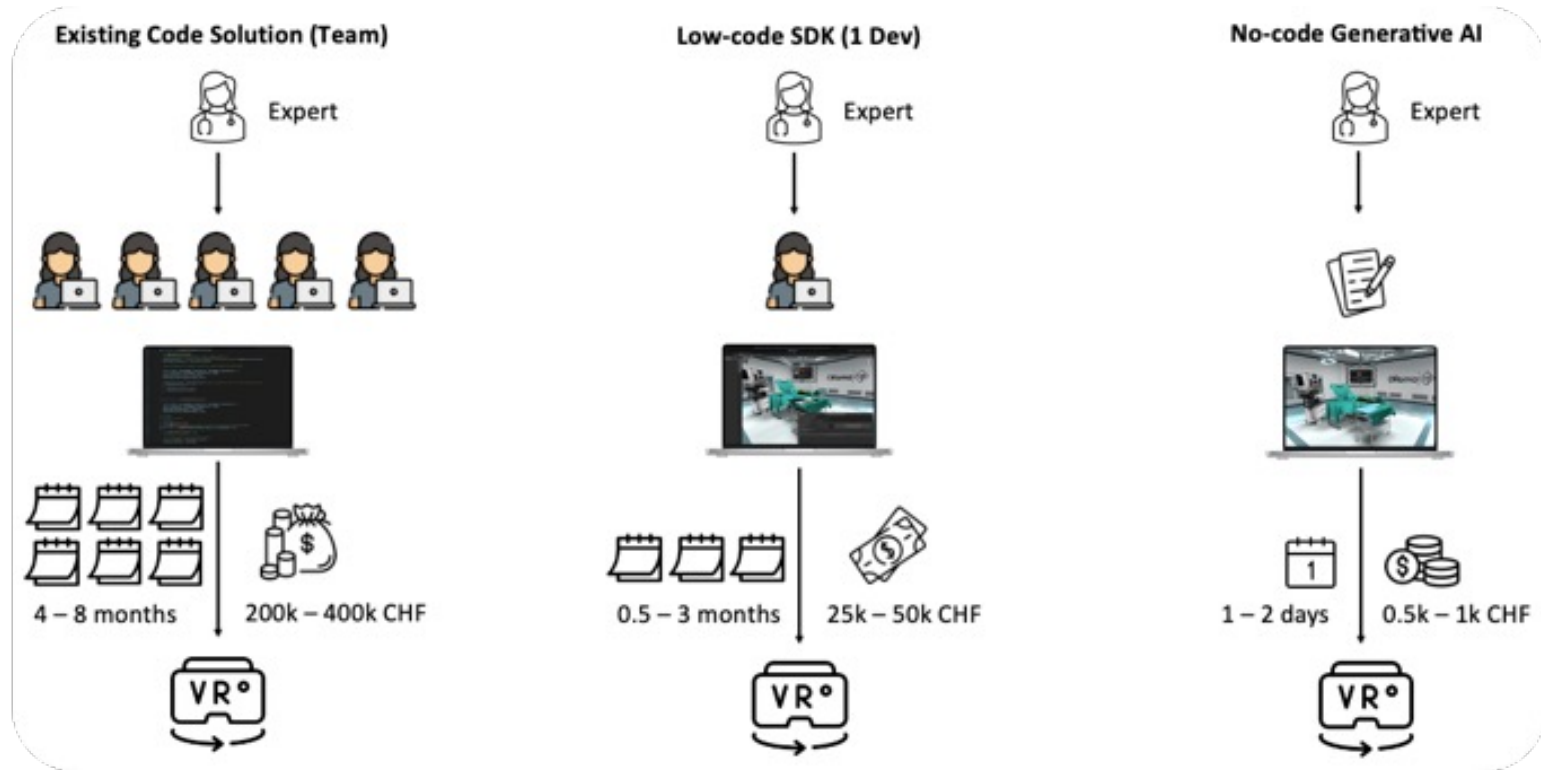
Web 4.0:

Digital and real objects and environments integrated and communicating between each other, enabling immersive experiences

* Source:

<https://digital-strategy.ec.europa.eu/en/library/virtual-worlds-and-web-40-factsheet>

METaverse GENERATED REALMS (VIRTUAL WORLDS): CODE -> LOW-CODE -> NO-CODE (GENERATIVE AI)





AI's greatest impact? healthcare

“**Healthcare** as an industry has been slow to **adopt** technology, reluctant to burden **overwhelmed** IT teams, and **train** burned-out staff on **new** systems.

We believe that any new technology has to be **10 times better** to successfully **displace** the last one—marginal improvements aren't worth the effort. Enterprise software struggled to clear that 10x bar in healthcare; **AI clears** it easily.

With AI, healthtech companies no longer need to fight the uphill battle of **training people** on **software**. Instead, they can sell AI that **acts** like a **person** and takes more and more of the work off healthcare professionals' plates, **enabling them** to **work** on more **interesting** problems and **practice** at the **top** of their **licenses**.”

Daisy Wolf and Vijay Pande, <https://a16z.com/2023/08/02/where-will-ai-have-the-biggest-impact-healthcare/>

Stable Diffusion prompt:

“doctors and nurses with 3D VR and AR glasses in digital and real objects and environments integrated and communicating between each other based on immersive experiences”

XR draws on AI

“In order to get to **ultrarealistic** and **useful** 3D, there’s a need to **step beyond** hardware and incorporate AI.

Even the most powerful GPU wouldn’t be able to **generate** high-quality **ray-traced** 3D models in real time.

Just when Moore’s Law is **expiring** and graphics as usual has run into a roadblock, AI has appeared as a **valuable** tool.

It provides us with new and powerful methods to **push** graphics forward, by being smarter about the rendering process.

We are at the **cusp** of **enormous innovation** in the 3D rendering space”

Samuel Greengard. 2023. 3D Modeling Draws on AI. Commun. ACM 66, 8 (August 2023), 15–16.
<https://doi.org/10.1145/3603748>



Stable Diffusion prompt:
“interacting in extended reality with a photorealistic environment of a hospital”

Deep learning and generative AI

“Deep learning takes **data points** and turns them into a **query-able structure** that enables **retrieval** and **interpolation** between the points.

You could think of it as a continuous **generalization of database technology.**”

“It is categorically **different** from even the simplest of **embodied biological agents**. As in, it's an entirely different category, with no shared characteristics.

Analogies to the brain are just as misleading as when people used the same analogies to describe computers in the 1950s.”

F. Chollet, Google AI

Stable Diffusion prompt:
“*an explosion of colorful powder*”



THE PROBLEM

XR training improves learning outcomes¹,
XR content creation cannot keep up with demand:



LENGTHY CREATION TIMES: 4 – 8 MONTHS



**HIGH AUTHORING COSTS²:
MIN \$20K PER MINUTE**



**INFINITE NUMBER OF TRAINING EXPERIENCES
TO BE SIMULATED AS DIGITAL TWINS**

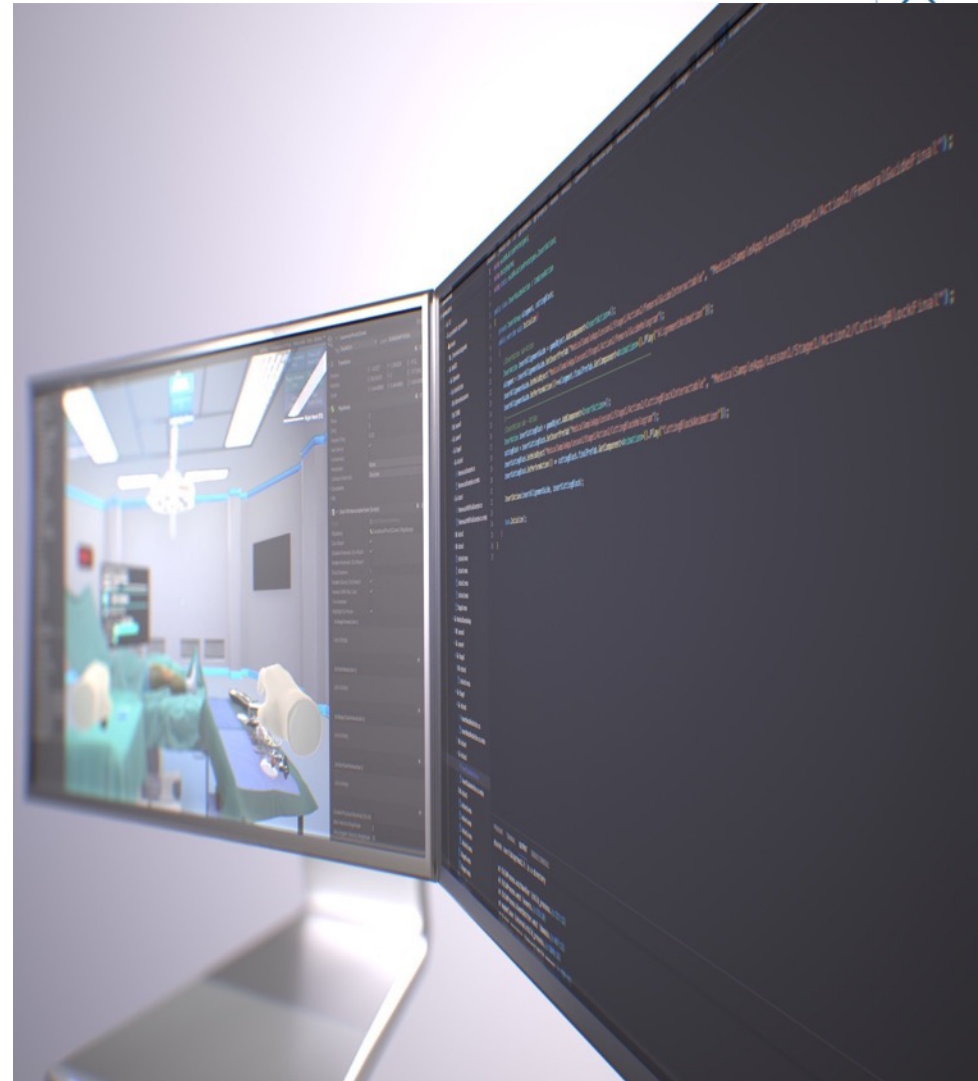


LACK OF LOW/NO-CODE, CONTENT AUTHORING TOOLS

¹ <https://www.sciencedirect.com/science/article/pii/S0883540319303341>

and more than 55 published clinical trials since 2020 verify this fact

² <https://roundtablelearning.com/cost-of-virtual-reality-training-full-vr-2020/>



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>

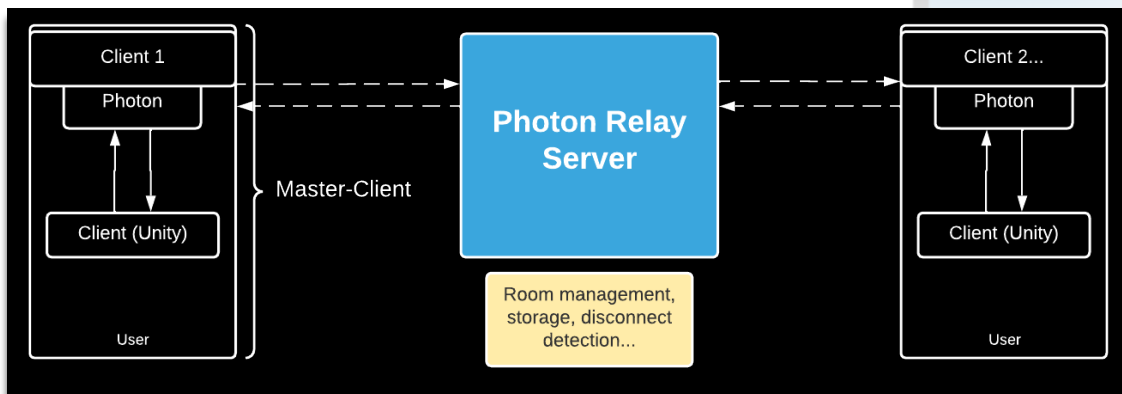
MULTIPLAYER WITH GA INTERPOLATION

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



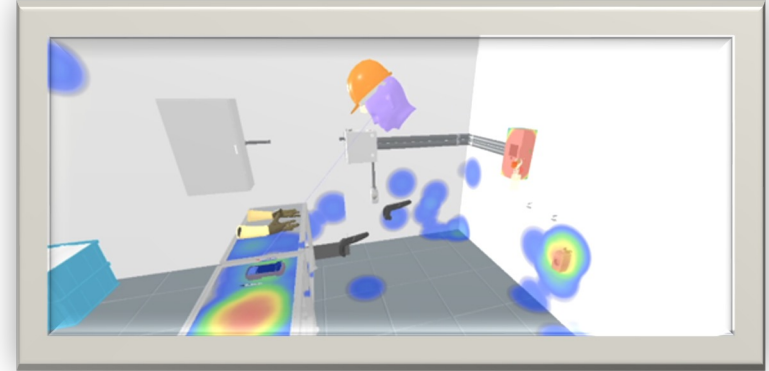
*Kamarianakis, M., Chrysovergis, I., Lydatakis, N. et al. Less is More: Efficient Networked VR Transformation Handling Using Geometric Algebra. Adv. Appl. Clifford Algebras 33, 6 (2023). <https://doi.org/10.1007/s00006-022-01253-9>

ANALYTICS – DL BASED GAME ENGINE

State of the Art



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

- 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



<https://doi.org/10.1145/3532719.3543253>

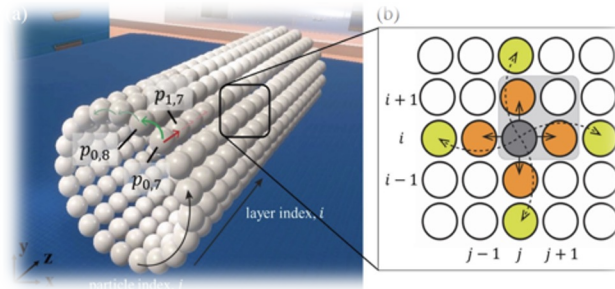
GA DEFORMABLE ANIMATION, CUTTING, AND TEARING

State of the Art

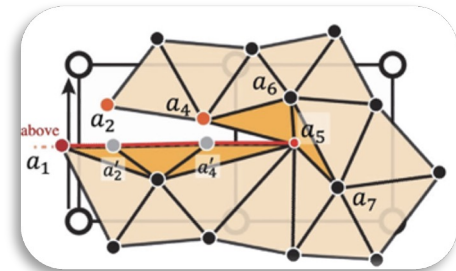
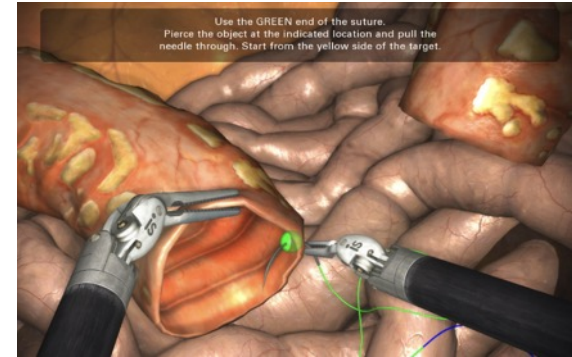
- Predefined, **animated** cuts in restricted areas
- Custom solvers for **heavy** particle-based deformations
- Use of **matrices** for transformations



[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



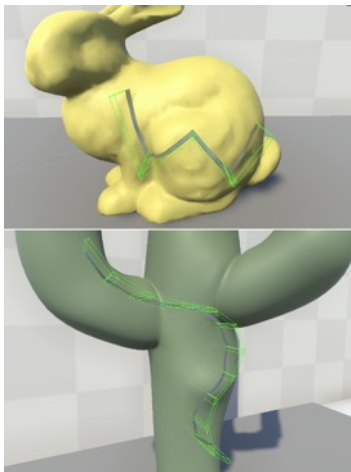
[1] P. Korzeniowski, S. Plotka, R. Brawura-Biskupski-Samaha and A. Sitek, "Virtual Reality Simulator for Fetoscopic Spina Bifida Repair Surgery," 2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Kyoto, Japan, 2022, pp. 401-406, doi:10.1109/IROS47612.2022.9981920.

[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>

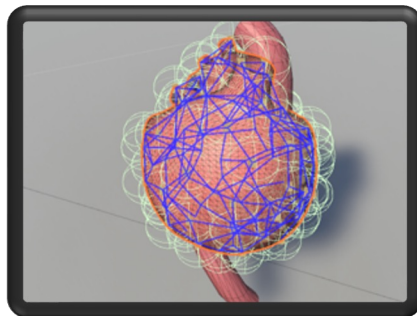
GA DEFORMABLE ANIMATION, CUTTING, AND TEARING

Our Contribution

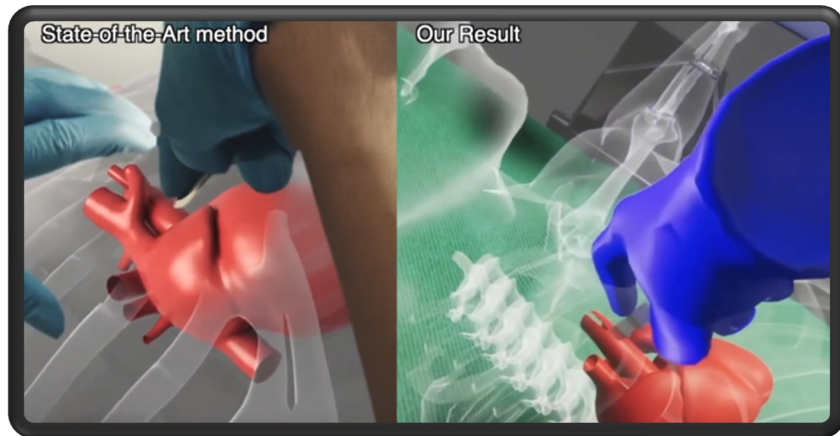
- Real-time **cutting, tearing** and **drilling** of deformable surfaces
- Hand manipulation of skinned deformable meshes
- Particle based simulation
- Proprietary **GA interpolation** engine



We are not limited from the scalpel's movement



Our cutting algorithms are real-time

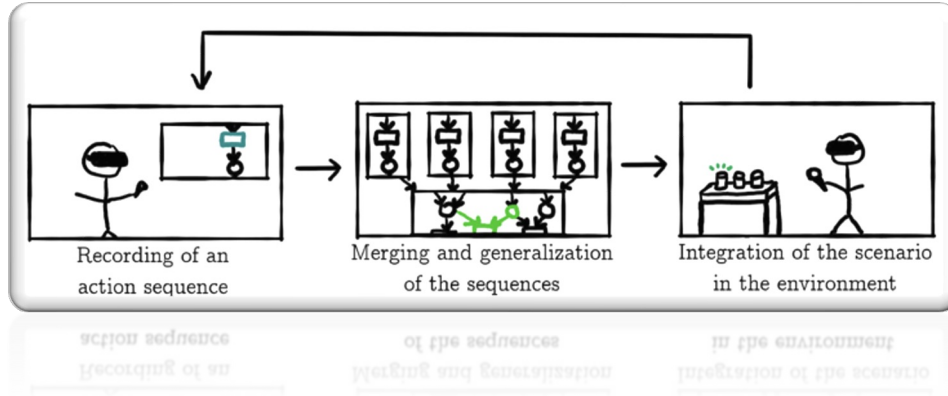


Model	Faces	Running Time
Horse	4266	10.14 ms
Bunny (OUR)	4968	11.19 ms
Cuboid	18128	52.77 ms
Heart (OUR)	18336	18.65 ms

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., Lamergerie, 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

8X faster & 8X cheaper

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

Insert Action

Use Action

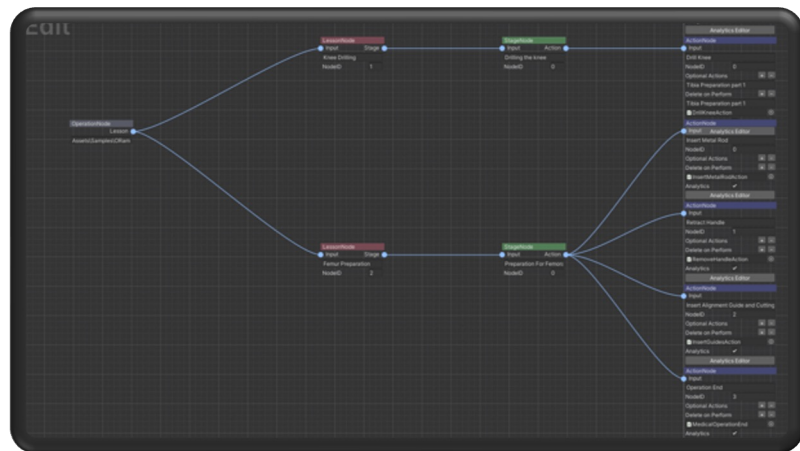
Remove Action

Animation Action

Cut/tear Action

Tool Action

Q&A Action



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

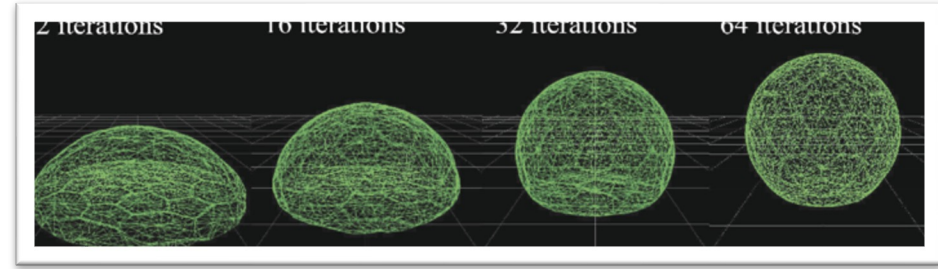
- Each node is a step/Action in VR

*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

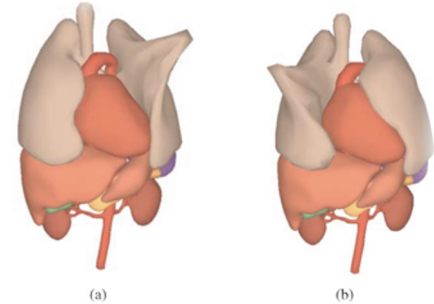
State of the Art

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



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



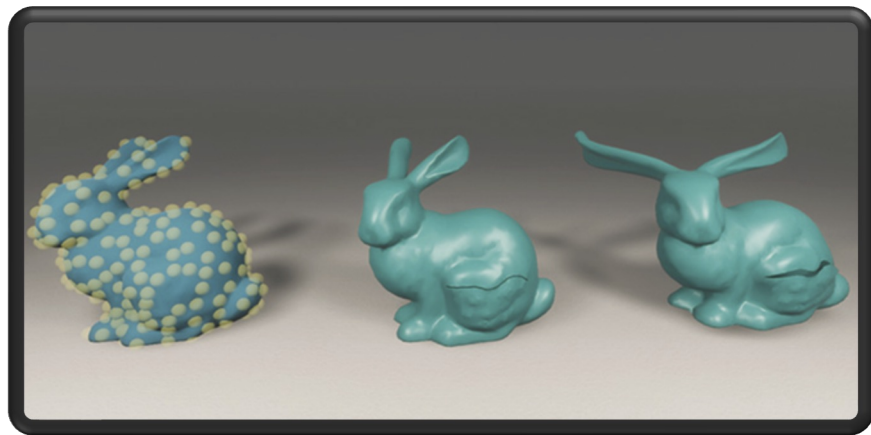
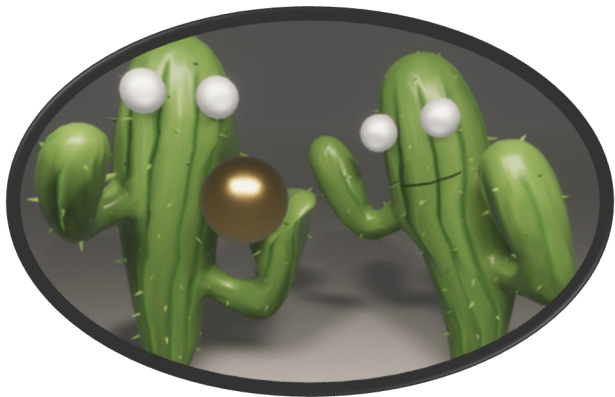
[1] Wang, M, Ma, Y, Liu, F. A novel virtual cutting method for deformable objects using high-order elements combined with mesh optimisation. *Int J Med Robot.* 2022; 18(5):e2423. <https://doi.org/10.1002/rcs.2423>

[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

SOLUTION: METAVERSE AUTHORIZING FRAMEWORKS

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

Main characteristics of virtual reality authoring tools: [1]

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

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

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



Our work among others is cited in the following publications:

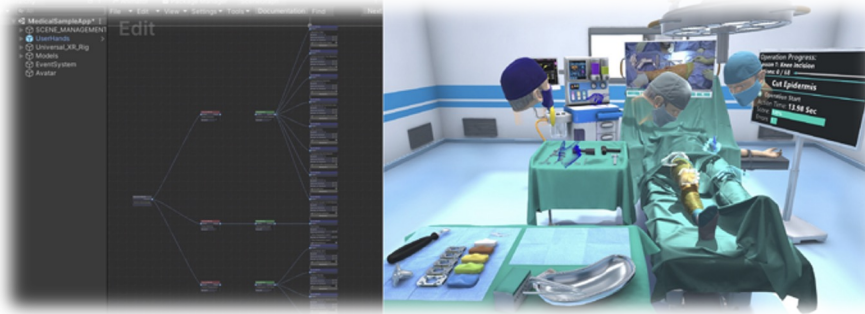
[1] Chamusca, I. L., Ferreira, C. V., Murari, T. B., Apolinario, A. L. & Winkler, I. Towards Sustainable Virtual Reality: Gathering Design Guidelines for Intuitive Authoring Tools. *Sustainability-basel* **15**, 2924 (2023)

[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 AUTHORIZING FRAMEWORKS: OUR 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.

MAGES 4.0

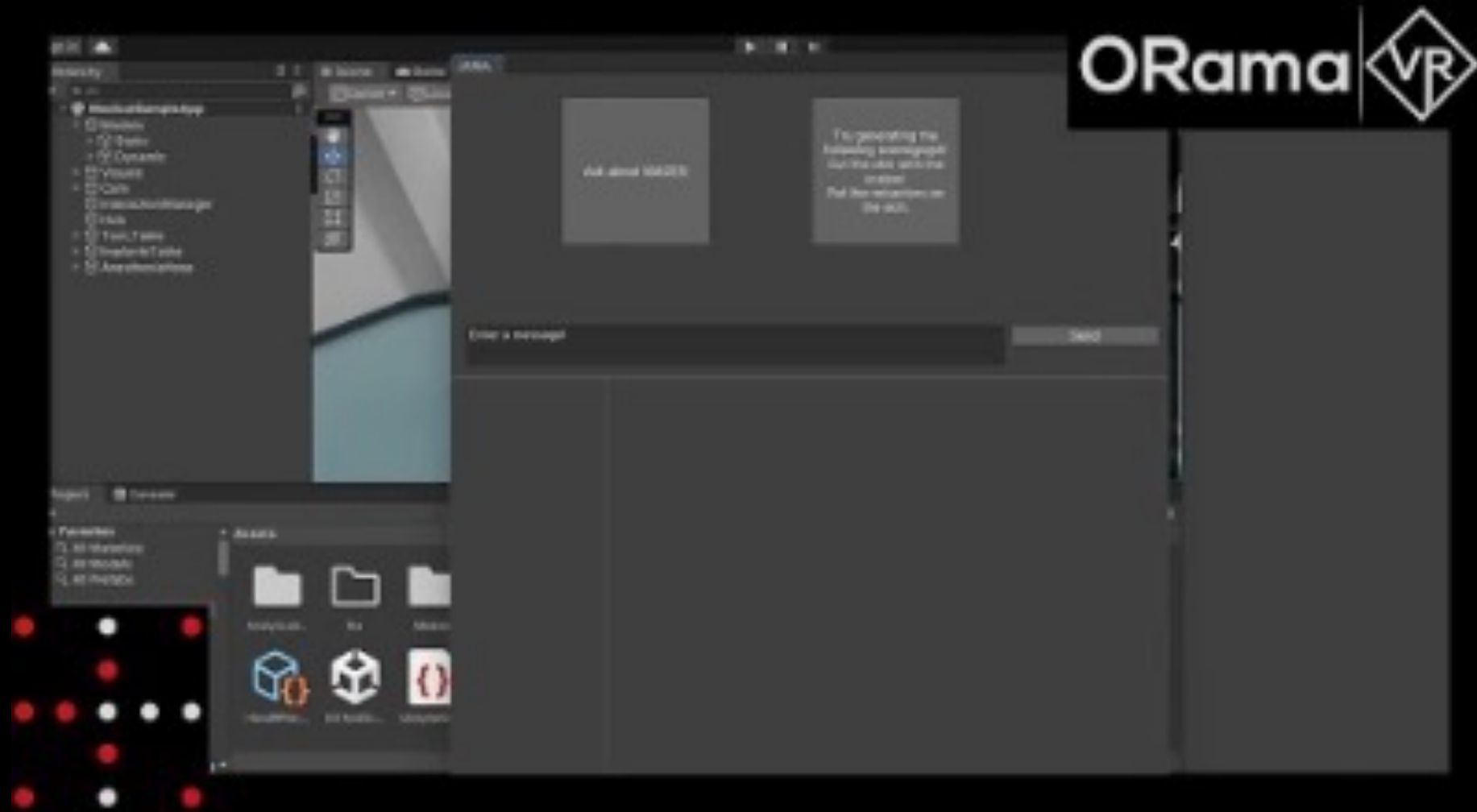


One more thing

What about no-code?

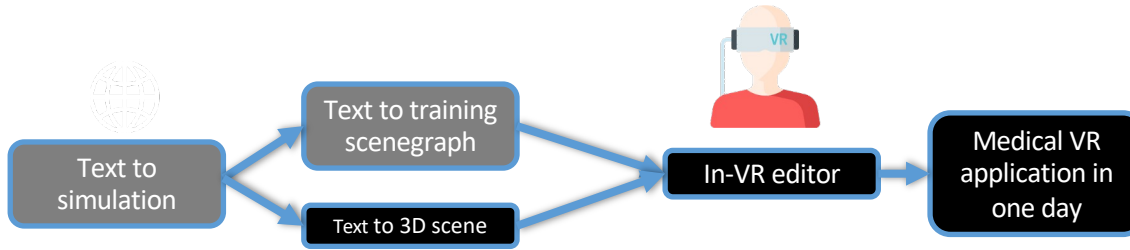


JARIA – MAGES SDK



OMEN-E: Open MEDical Neural metaversE

MAGES OMEN-E No-code platform
(JARIA Generative-AI, no developer needed)

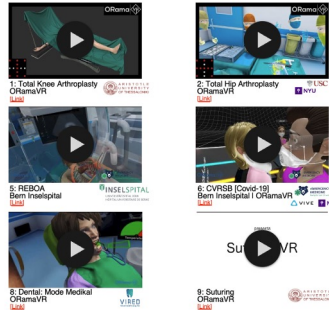


MAGES NXT SDK Low-code platform
(support all VR/AR/mobile h/w devices, 1 developer needed)

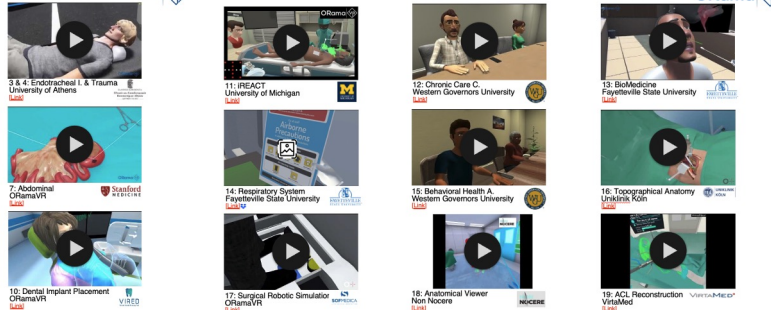


MAGES SIM template Library (reach 100 sims as medical VR app)

Made with MAGES SDK - Pt. 1



Made with MAGES SDK - Pt. 2



```
response = openai.ChatCompletion.create(  
    model = "gpt-3.5-turbo",  
    messages=[  
        {"role":"system", "content": "You are a helpful assistant."},  
        {"role":"user", "content": "Can you say something to inspire the audience of ACM SIGGRAPH 2023 about computational medical extended reality?"},  
    ]  
)  
print(response["choices"][0]["message"]["content"])
```

... Welcome to ACM SIGGRAPH 2023!

Computational medical extended reality merges technology and healthcare, transforming the way we diagnose, treat, and educate.

With XR, doctors visualize complex data in immersive environments, enhancing precision and patient outcomes.

Surgeons practice intricate procedures in virtual spaces, reducing risk.

Patients experience immersive therapies for pain management and rehabilitation.

Researchers collaborate globally, pushing boundaries in medical innovation.

Let us embrace the power of computational medical XR, empowering healthcare professionals, revolutionizing patient care, and opening doors to a future where technology merges seamlessly with humanity's quest for well-being.

Together, we can redefine medicine and shape a healthier world.



Swiss Accelerator innovation project supported by



Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Innosuisse – Swiss Innovation Agency



Funded by the
European Union
NextGenerationEU

Greece 2.0
NATIONAL RECOVERY AND RESILIENCE PLAN

fidal
field trials
beyond 5G.



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



*Let's accelerate world's transition to
computational medical XR!*