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

FORTH
ORama
Université de Genève
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.

"Mother of all demos": https://youtu.be/B6rKUf9DWRI , 1968
Head Mounted Displays and natural user interaction?

The sketchpad demo: [https://youtu.be/6orsmFndx_o](https://youtu.be/6orsmFndx_o), 1963
Sutherland, I. E. A head-mounted three dimensional display. AFIPS Fall Joint Computing Conference 757–764 (1968)
My Career arcs
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*

The increase of virtual hospitals  The gamification of healthcare  AR/VR-powered surgeries

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

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.

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Medical Virtual Reality simulation-based training advantages

- **Location:** Not limited by geographic location
- **Assessment:** Allows for a unique first-person perspective in assessments
- **Time:** Allows for synchronous and asynchronous learning
- **Software:** VR software can be updated and changed easily
- **Accessibility:** Users of all abilities can practice in VR
- **Diversity:** VR allows for diversity in the simulated environment
- **Personnel:** VR simulation is less human resource-intensive
- **Learning Environment:** Environment, equipment, and ergonomics can be customized

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.

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.

Med VR simulation-based training: examples of current programs

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


- **VirtaMed**: Arthroscopy simulators
- **OssoVR**: Orthopedic Surgery training
- **FundamentalVR**: Haptics-based VR training
- **UbiSim**: Nursing, scenario-based VR training
- **SimX**: Emergency VR training
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*

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

Existing Code Solution (Team)

- Expert
- 4 – 8 months
- 200k – 400k CHF
- VR°

Low-code SDK (1 Dev)

- Expert
- 0.5 – 3 months
- 25k – 50k CHF
- VR°

No-code Generative AI

- Expert
- 1 – 2 days
- 0.5k – 1k CHF
- VR°
Medverse: our MAGES approach

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

- ORamaVR psychomotor training (procedural steps, technical performance, visuospatial skills, efficiency, and flow)

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

- ORamaVR psychomotor training (user satisfaction)

  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


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

ANALYTICS – DL BASED GAME ENGINE

State of the Art

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

[VadR]

[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
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

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


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

<table>
<thead>
<tr>
<th>Model</th>
<th>Faces</th>
<th>Running Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horse</td>
<td>4266</td>
<td>10.14 ms</td>
</tr>
<tr>
<td>Bunny (OUR)</td>
<td>4968</td>
<td>11.19 ms</td>
</tr>
<tr>
<td>Cuboid</td>
<td>18128</td>
<td>52.77 ms</td>
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<tr>
<td>Heart (OUR)</td>
<td>18336</td>
<td>18.65 ms</td>
</tr>
</tbody>
</table>

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

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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

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**

- [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.

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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
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

"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:


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)

MAGES simulation-based training: a transformation underway*

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

[https://visl.ch](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

NYU Langone Health
INSE Ls PITAL
University of Bern
University of Michigan
University of Cologne
Wake Forest School of Medicine
globalvision communication
SOFMEDICA
European Commission

Hôpitaux Universitaires Genève
NON NOCERE
VirtAmed®
VIRED
FORTH
Institute for Medical Education
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*

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
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