

Addressing Future Challenges of Telemedicine Applications

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Abstract

The Dagstuhl Seminar “*Addressing Future Challenges of Telemedicine Applications*” brought together interdisciplinary researchers to chart a forward-looking vision for remote healthcare delivery. With the rapid evolution of telemedicine technologies, driven by global health crises and enabled by advances in extended reality (XR), artificial intelligence (AI), gaze-based interaction, and embodied conversational agents, this seminar explored the critical intersections of innovation, usability, ethics, and equity. Participants engaged in structured discussions on how immersive and intelligent systems can expand access to care, enhance diagnostic accuracy, and foster human-centered experiences in remote contexts. Key themes included building trust in AI, ensuring inclusive design for diverse populations, leveraging eye-tracking and avatars for personalized interaction, and balancing automation with human expertise. The seminar emphasized that addressing technical, cultural, and regulatory challenges is essential to responsibly shaping the future of telemedicine. Through collaborative dialogue, the seminar laid the groundwork for next-generation healthcare technologies that are explainable, adaptive, and empathetic.

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1 Executive Summary

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This seminar gathered experts from *XR Technologies*, *Avatars Assistants*, *UX: Gaze Control and Visual Attention*, and *Data Privacy and Security* fields with the objective of identifying the strengths and weaknesses for delivering healthcare assistance remotely, safely, and efficiently. Experts from these different fields described the state-of-the-art of their area of expertise

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and addressed future directions that these technologies should focus on for creating the next generation of healthcare telemedicine systems. The outcomes of the proposed seminar will hopefully be highly relevant to researchers in academia and healthcare as well as to the field of Human-Computer Interaction.

A four-day Dagstuhl Seminar was organized to bring together experts from the fields of extended reality (XR) technologies, artificial intelligence (AI), embodied conversational agents, and eye tracking. The seminar followed a structured daily format designed to foster interdisciplinary exchange and collaborative discussion.

Each day commenced with a series of interdisciplinary presentations in which designated experts provided focused overviews on key developments and challenges within their respective domains – namely, XR technologies, AI, and embodied conversational agents. These sessions aimed to establish a common knowledge base and to contextualize ongoing research efforts. Following the morning presentations, participants were divided into interdisciplinary working groups.

Each group engaged in facilitated discussions on predefined topics, chosen to encourage integration across disciplines and to address open research questions relevant to the seminar's overarching themes. In the final session of each day, all participants reconvened in a plenary meeting. During this session, each working group reported the outcomes of their discussions, highlighting key insights, areas of consensus, and proposed directions for future investigation.

This reporting session served to synthesize the day's activities and to promote cross-group dialogue. This daily structure was maintained consistently throughout the seminar to ensure coherence and cumulative progress across the four days.

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3 Talks Overviews

The following section provides a detailed overview of the organizers' activities across the duration of the seminar. Each day's responsibilities and tasks are outlined to highlight the structure, coordination, and facilitation efforts undertaken by the organizing team. These summaries offer insight into the planning and execution process that supported participant engagement, interdisciplinary exchange, and the overall success of the seminar.

3.1 Telemedicine

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The presentation examined how Virtual and Augmented Reality (VR/AR) transformed healthcare and rehabilitation. It highlighted practical applications such as enhancing radiology diagnostics, enabling interactive rehabilitation, and advancing surgical planning and navigation. Challenges were addressed, including high implementation costs, hardware limitations, accessibility issues, and data privacy concerns. Solutions showcased included real-time feedback systems and immersive education tools to improve patient outcomes and professional training. The session also explored how VR/AR was integrated into clinical workflows and examined its convergence with AI to enable precision medicine and personalized care. Telemedicine and remote diagnostics were discussed as transformative areas, demonstrating how these technologies bridged gaps in healthcare delivery. The presentation concluded by emphasizing the need for collaboration, innovation, and rigorous validation to ensure that VR/AR achieves its potential to enhance patient outcomes, engage users and expand accessibility in medical science.

3.2 Intersection of AI with VR

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The presentation explored how Artificial Intelligence (AI) and Extended Reality (XR) are reshaping healthcare, focusing on radiology as a key domain for these advancements. Highlighting applications like improving diagnostic precision, immersive training for radiologists, and expanding global access to healthcare, it also emphasized the role of explainability and trust as foundational elements for AI adoption in healthcare systems.

A key aspect was the innovative use of knowledge graphs and large language models (LLMs) to achieve explainability in medical imaging. These technologies bridge the gap between complex radiological data and actionable insights, making medical findings more interpretable for both clinicians and patients. Knowledge graphs organize relationships between radiological findings, anatomical structures, and clinical conditions, providing a clear, structured representation of the reasoning behind diagnoses. For example, slides demonstrated how knowledge graphs can connect concepts such as cardiothoracic ratios, pleural effusions, and associated opacities, offering an intuitive, visual explanation of why a heart may appear enlarged on an X-ray.

Large language models, like GPT-4o, were shown to complement knowledge graphs by transforming radiology reports into interactive and understandable interfaces. In projects such as ReXplain, LLMs summarize key findings, link them to annotated images, and use avatar-based interfaces to deliver patient-friendly explanations. For instance, a radiology report describing a pneumothorax or atelectasis is paired with annotated medical images, 3D organ renderings, and video-based explanations. This approach ensures that both medical professionals and patients can better understand diagnostic outcomes, fostering trust in AI-driven systems.

The presentation also emphasized interactive explainable interfaces powered by these technologies. Through visualization tools, radiologists can explore layered explanations, starting with a high-level summary and diving deeper into the relationships between clinical variables. This interactive experience allows for real-time query answering, enhancing confidence in diagnostic conclusions while enabling clinicians to communicate findings effectively to patients.

Another core innovation was the use of digital twins, virtual replicas of organs or systems, generated through AI segmentation models. These models reconstruct 3D visualizations from medical imaging, such as CT scans, providing an immersive and detailed view of patient-specific anatomy. For example, a 3D colon reconstruction created from AI-predicted segmentations was showcased as a tool for enhanced diagnostic and procedural planning.

The session further explored how AI and XR bridge global healthcare disparities by extending radiological expertise to underserved areas. Portable XR systems allow practitioners in remote regions to collaborate with urban radiologists using 3D medical models. This approach empowers non-experts with decision support, fostering global health equity.

In conclusion, the presentation highlighted the transformative potential of AI and XR in healthcare. By integrating innovative technologies like knowledge graphs, LLMs, and interactive explainable interfaces, it demonstrated how these tools enhance diagnostic precision, improve medical training, and build trust in AI-driven healthcare systems. The future of medicine, as depicted, is one of collaboration, transparency, and accessibility, driven by the synergy of cutting-edge technologies.

3.3 Gaze Interaction in XR

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Andrew Duchowski's presentation on "Gaze Interaction in XR" reviewed gaze-based interaction, distinguishing eye movement analysis from synthesis in virtual reality, games, and other applications. His focus was on five forms of gaze-based interaction: diagnostic (off-line measurement), active (selection, look to shoot), passive (foveated rendering, a.k.a. gaze-contingent displays), expressive (gaze synthesis), and assistive (subtitling). Diagnostic interaction is the bread and butter of serious applications such as training or assessment of expertise. Active interaction is rooted in the desire to use the eyes to point and click, with gaze gestures recently growing in popularity. Passive interaction is the manipulation of scene elements in response to gaze direction, with an example goal of improvement of frame rate. Expressive eye movement centers on synthesis, which involves the development of a procedural (stochastic) model of microsaccadic jitter, embedded within a directed gaze

model, given goal-oriented tasks such as reading. Assistive technologies are used to expand inclusive experiences, ranging from assisting the Deaf and Hard-of-Hearing with subtitles, or the Blind and Visually Impaired with Audio Description driven by gaze scanpaths. In discussing each form of interaction, Duchowski briefly reviewed classic works and recent advancements and highlighted outstanding research problems.

3.4 Virtual Humans for Telemedicine: Embodied Conversational Agents and Avatars Assistants

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This seminar presentation was structured into two distinct yet interconnected topics: Embodied conversational Agents and Avatars for medicine. In the first segment, the discussion focused on the dual role of Embodied Conversational Agents (ECAs) as both barriers and facilitators in the delivery of telemedicine services. Specific attention was given to how attributes such as verbal and non-verbal communication, cultural alignment, and user-agent rapport can either enhance or hinder the accessibility, efficacy, and inclusivity of telemedicine platforms. Case studies and empirical data from clinical trials involving ECAs were highlighted, illustrating their diverse applications in healthcare, from patient education to therapeutic interventions and chronic disease management.

The presentation expanded the scope by exploring cutting-edge technologies that can augment the capabilities of ECAs to create more seamless and intuitive interactions. Eye-tracking technology was examined as a tool to deepen understanding of user behavior and engagement, providing real-time feedback for tailoring agent responses. The potential of extended reality (XR) systems, including virtual and augmented reality, was discussed in the context of creating immersive environments that facilitate trust and enhance patient-provider communication. Additionally, the talk emphasized the importance of robust cybersecurity measures to safeguard sensitive patient data and ensure trust in ECA-mediated interactions. Together, these topics underscored the interdisciplinary challenges and opportunities in designing ECAs for telemedicine, offering a forward-looking perspective on their role in shaping the future of healthcare delivery.

The second part of this talk covered how avatars that represent the user can be used to either perform training or to meet patients remotely. For the case of training, the expert can show step-by-step instructions with the use of animated self-avatar that can accurately follow the user movements. In the case of remote telemedicine, the doctor could visit patients by being embodied in an avatar that can communicate not only with speech but also using nonverbal communication through gesturing. This multimodal communication allows one to build trust with the patient, and thus the presentation also covered several aspects that affect ethics and trust, such as the level of rendering quality needed, or the need to match gender or race with the patient to improve trust.

4 Day 1: Extended reality (XR) for Telemedicine

4.1 Overall description

The discussion explored the effectiveness of extended reality (XR) for training and discussed key considerations for measuring its impact, such as performance metrics and other evaluative factors. The discussion revolved around learning how medical staff in training learned intubation procedures. In the discussion it was examined how to ensure that training in virtual environments translates to real-world performance and highlights the advantages of technology-mediated training. Challenges like latency and communication issues in remote training are also addressed.

4.2 Key Points from Immersive Training Discussion

- **Immersive Education:** Education is framed in terms of two primary goals – the acquisition of knowledge and the development of procedural skills.
- **Main Challenges in Training:** Traditional training methods face several obstacles, including the high cost of equipment and limited availability of resources such as manikins. For instance, observing and practicing procedures like intubation often depends on whether resources are accessible.
- **Challenges with Immersive Technology:** Fidelity in virtual training environments is critical to ensure that procedural skills learned in XR are transferable to real-world scenarios. Intubation was discussed as a key example requiring high fidelity for effective skill transfer.
- **Alternatives to Virtual Training:** Augmented reality (AR) can be used to enhance physical manikins, allowing learners to visualize internal anatomical structures during procedures, thereby improving comprehension and effectiveness.
- **Simulators:** Simulators are valuable tools for procedural training. Laparoscopy was presented as a well-established example where simulation has had measurable educational benefits.
- **Serious Issues:** The talk also addressed risks associated with procedural errors, especially in critical interventions such as intubation, where mistakes can have fatal consequences.
- **Potential Projects:** Future project ideas include developing virtual monitors to assist in diagnostics and real-time information visualization. Such tools could be particularly useful for anesthesiologists and might employ gaze and gesture-based control mechanisms.

4.3 Challenges and Opportunities

The lack of locally available specialists is presented as a significant challenge, which could be mitigated through telemedicine. Additionally, tools such as video or AR-based systems are proposed to facilitate the transfer of procedural knowledge during surgeries.

Once an XR technology is adopted in a certain learning context, there is the possibility of knowledge transfer to other communities and environments. That transfer should take into account all the stakeholders involved: the initial developers, the targeted physicians, the targeted patients and their communities. The success of a solution in a particular context not necessarily guarantees the success in other environments, due to differences in practices,

cultural beliefs, and resources, just to mention some factors. Critical to the success of any technological solution is working with stakeholders to understand needs and co-developing the solution through participatory design or co-design methods.

For telemedicine in particular, stakeholders include doctors/physicians/nurses and other formally trained medical professionals, informally trained care providers such as family members and hospice staff, technologists and the patients themselves. Communicating across differences in training and background knowledge when modulated by gender, racial, and cultural/ethnic differences is challenging. When the doctor-patient dynamic is added to these differences, there is an exacerbation of the communication challenge.

An example from Colombia comes from a training environment developed for pediatricians in a Hospital in Bogota. The system was well received and it is used by both pediatricians and students to learn and reinforce best practices related to 12 different situations while delivering a newborn. Pediatricians want now to start a dialogue with midwives in a rural area of our country to explore possibilities to adapt this system to their own situations delivering babies while at the same time incorporating some of their best accepted practices.

Additionally, it was noted that while the technologist wants to address these challenges, when this technologist belongs to the mainstream socioeconomic demographic in a WEIRD country, the formally trained physician belongs to the same population, and the patients/informally trained caregivers do not, this creates additional communication challenges in the design process, making it harder to identify where the technology can benefit.

The technologist typically wants to improve/address these challenges. When this technologist belongs to the WEIRD population, and the doctor belongs to the WEIRD population and the patients/caregivers do not, this is its own communication challenge in the design process. This can make it harder to identify where the technology can benefit.

An example from Colombia comes from a training environment developed for pediatricians in a Hospital in Bogota. The system was well received and it is used by both pediatricians and students to learn and reinforce best practices related to 12 different situations while delivering a newborn. Pediatricians want now to start a dialogue with midwives in a rural area of our country to explore possibilities to adapt this system to their own situations delivering babies while at the same time incorporating some of their best accepted practices.

4.4 Applications for Telemedicine

In the case of medicine, one scenario is a surgical procedure performed by a local team whose surgeon lacks the required expertise. A remote expert surgeon oversees the procedure through a remote AR interface that allows them to send guidance through virtual annotations. The local team can communicate with the remote through a voice channel and observe the annotations through an AR interface with 3D registration of the operated organ. Meanwhile, a cohort of students passively observes the procedure from the vantage point of the remote expert. Gaze data from the remote expert is rendered to the local team and also to the student group, while gaze data from the local surgeon is relayed to the remote expert.

An asynchronous example could be a virtual space for mental health awareness. Both patients and physicians could use the space at their own convenience. Patients could relate to the actions and situations of other patients. Physicians could get data from the system about the mental state of the patients and find ways through the system to aid them. There could be differences in the information that each participant sees from others, due to privacy issues or due to interests or focus. VR is beneficial in this scenario because it allows people in different regions to be together, thus helping people in isolated areas.

Other practical examples could include:

- Psychology therapy / phobias treatment: This has been widely explored in the past and has been proven to be a very efficient and successful way of treating psychological disorder, taking advantage of the fine tuning of the scenarios that we can achieve with VR
- Collaboration in Rural Areas: providing access to expert knowledge through VR for areas that are isolated. This could be used for training, for real-time medical advice, and also for remote visits to patients
- VR – mediated collaboration between doctor(s) and patient(s) via XR: several doctors could be working together, alternatively the patient and the doctor could be virtually together in the virtual room. In this way, patients could communicate by gestures (pointing at where it hurts for example) in a more natural way than videoconference alternatives
- Remote Expert Surgery Guidance: Issues include trust between the local surgery team and the remote expert. Many questions arise, such as: is it important to have an AR avatar representation of the remote expert in the local surgery room?
- Rehabilitation with self-avatars: Self-avatars can be used to provide the Sense of Embodiment (SoE), which leads users to experience the virtual body as if it were their own. This can have a very strong impact on the participant, which can be used for rehabilitation to trigger effects such as the virtual mirror to trigger the mirror neurons that improve mobility (by observing the virtual representation capable of correctly moving and arm or leg for which the user has mobility problems). Embodiment can also be employed to trigger the proprioceptive drift of body parts (the feeling that our virtual hand/arm/feet is in a different location), which can be used to overcome pain thresholds by making the patient believe he/she still has a pain-free range of motion.

4.4.1 Categories / Dimensions

There are many aspects that need to be taken into account when discussing the concept of virtual togetherness. This working group discussed the following taxonomy for the use of avatars in telemedicine to achieve the feeling of copresence (being in the virtual environment with other people). The group proposed the following taxonomy:

- **Synchronous vs. asynchronous:** most situations that require collaboration will need to be synchronous. However there can be situation such as training applications, where the expert could have recorded the entire session and then others can re-play it asynchronously. In this case there will not be able to perform Q&A directly with the expert, but it could be helpful for training situation that require repetition.
- **Embodied vs. non-embodied:** embodied implies that a real user is driving the avatar in terms of movement, decisions, audio, etc. However we could have training scenarios with an LLM autonomous agent which would not be embodied by a real participant.
- **Virtual environment vs. telepresence augmented reality:** XR involves both situation, fully immersive VR applications, or else augmented reality situations, where the patient is in the comfort of his/her home, and the virtual doctor is overlaid with the real environment.
- **anonymity vs. non-anonymous:** this refers to whether anonymity matters or is needed. It could have an impact on several aspects of the avatar, such as the appearance, or voice.

- **Therapist-guided vs discussion groups:** If there is a therapist or doctor driving the session or medical visit, or we have a discussion group where several patients share their experience.
- **dyad vs. group:** whether we have only two users, or whether we have a larger group.
- **training vs. part of a procedure:** we could either have an expert explain how to perform a specific surgery or perform the procedure on a patient while other doctors are virtually attending.

4.5 Challenges and barriers

There are many challenges related to this topic. The main issues that were discussed in this working group were:

- What is the **impact of technology** barriers such as latency and registration errors? As with any other technology that requires remote assistance or collaboration, it is necessary to take into consideration the impact that latency due to low bandwidth could have on VR applications. Unfortunately, this is still a problem in many rural areas or third world countries, so when exploring the use of VR applications in telemedicine, we should take this into consideration. The design should recognize that there will always be technical issues and go around it. This is not a new problem, similar issues appear in fields such as aerospace or videogames. Therefore, the first step should be to examine existing solutions in those fields to explore their applicability in telemedicine.
- **Current software limitations:** The lack of standard tools and generalizability of tools for re-purposing, imposes a huge impact when it comes to the quick development of new applications. There is a need for tools that can be reused and easily imported from previous applications.
- **Collaboration / shared virtual spaces:** what are the best solutions for collaboration in VR. For example, the continuum from having multiple VR avatars adhering to social proxemic conventions, over having multiple semi-transparent self-overlapping avatars, to multiple users fully overlapping to the extent of embodying the same avatar (co-embodiment). Many aspects need to be considered when having several avatars sharing the same virtual space, such as proxemics or social rules. When sharing the virtual space, what is convenient or good for the patient may not be the same for the doctor, so it is necessary to find a good balance between the needs of each type of user (e.g. data recording, gaze tracking, body motion tracking. etc.)
- **Trust and correct understanding:** In the real world, we know that appearance and movements have an impact on building trust and achieving a good understanding by having non-verbal communication supporting the audio information. These aspects need to be correctly incorporated in VR when having self-avatars to ensure trust and mutual understanding from the medical expert to the patient.
- **Change established procedures to the ones with new technology:** the medical field has very strict protocols for all procedures that must be followed. Some of them may not be easily adapted to new technology, so alternatives would have to be explored for the purpose of implementing solutions based on VR.
- **Deal with large amounts of data:** new solutions for large data storage would need to be evaluated, taken special care about data protection, privacy, ethics and other legal considerations. It is also necessary to develop robust solutions for deleting persistent data/recording when necessary.

- **How to maintain equipment and systems:** Doctors should not have to learn how to configure systems. VR solutions need to be plug-and-play, meaning very easy to learn and use. There should not be an assumption of any computing competence for the doctors, instead hospitals would need to hire technology experts to rapidly handle any issue with VR. This should not imply a big barrier, given that most hospitals already have complex computer systems that need full time employers to manage and solve problems.
- **research prototypes vs. real applications:** Moving from research prototypes to more complex, flexible yet robust solutions that can work for real applications. Many issues are not considered in prototypes, for example the variety of scenarios and medical cases that need to be taken into account. The final users (i.e. the doctors) should participate in the design process and authoring of scenarios without the need of having advanced computer science skills.
- **dealing with interruptions:** when being in an in-person meeting we are less likely to allow interruptions from our environment or personal life. When in online meetings, this is not the case specially when people are working from home.

4.6 Opportunities

Despite all the barriers and challenges previously mentioned, VR offer a great ammount of opotunities in the field of telemedicine. Some of the main opportunities that were discussed by the group are:

- **Enhanced point of view:** in VR training, we could avoid occlusions of the instructor by seeing only semitransparent hands. This would provide an enhanced learning experience with respect to the real world, by allowing the practitioner to see the procedure from the point of view of the expert, instead of looking over the shoulder or having the point of interest occluded by the experts' hands.
- **Virtual perspective taking:** in the context of a shared virtual space with users having different roles within a procedure (e.g. patient, nurse, doctor, admin, etc.), VR offers a perfect platform for understanding each other perspectives. For example, a surgeon understanding the perspective of the nurse, putting the doctor in the shoes of the patient when receiving difficult news, etc. This aspect of perspective taking has been successfully applied to other application areas, such as understanding racial problems, or domestic violence.
- **Variety of visualizations for each collaborator:** VR offers the oportunity to completely customize the visualization to the preferences, needs of each type of collaborator.
- **Leaning opportunities:** VR offers a platform to learn what happened (if everything is recorded). A challenge that arises here involves privacy and how to ensure that persistent data will protect vulnerable populations, such as patients, etc...

5 Day 2: AI and XR for Telemedicine: Addressing Challenges in Trust, Personalization, and Adoption

The session titled “XAVIER: Explainable AI and Virtual Reality for Enhanced Radiology” set the foundation for the seminar’s discussions. This talk explored the transformative potential of combining AI-driven explainability techniques and XR interfaces to enhance radiological workflows and patient outcomes. Key topics included:

- **Knowledge Graphs for Explainability:** Demonstrating how knowledge graphs structure relationships between radiological findings, anatomical structures, and clinical conditions, making diagnostic reasoning interpretable for clinicians.
- **Large Language Models (LLMs) for User Interfaces:** Highlighting how LLMs like GPT-4o can summarize radiology reports, link findings to annotated images, and provide interactive, patient-friendly explanations.
- **Digital Twins and Immersive Visualizations:** Showcasing AI-driven segmentation models that reconstruct 3D anatomical structures for detailed diagnostic and procedural planning.
- **Global Health Equity:** Discussing how portable XR systems and collaborative platforms can extend radiological expertise to underserved regions, empowering non-experts with decision support.

The session aimed to demonstrate how these tools build trust, improve diagnostic precision, and enhance communication between clinicians and patients.

5.1 Breakout Groups and Facilitation

To encourage focused discussions, the participants were divided into breakout groups centered on five pre-identified topics. These topics emerged through interactive polling facilitated by *Wooclap*, where participants voted on priorities and proposed additional themes. LLMs were used to analyze and synthesize participant input, ensuring the breakout topics captured the most pressing challenges and opportunities in telemedicine.

Each breakout group was structured as follows:

- **Topic Briefing:** An initial overview of the topic was provided to establish a common understanding and align goals.
- **Guided Discussion:** Moderators guided discussions using prompts derived from the poll results, encouraging participants to share insights, propose solutions, and debate challenges.
- **Documentation:** Designated note-takers recorded key points and synthesized actionable outcomes.
- **Plenary Reporting:** Each group presented their findings to the broader seminar, sparking cross-group dialogue.

5.2 Relevance of the Breakout Topics

The five breakout topics were carefully chosen to address critical areas where AI and XR could significantly impact telemedicine:

- **Trust, Transparency, and Explainability:** Building trust in AI-driven XR systems is fundamental for adoption. The discussion focused on effective methods for explaining AI outputs, such as provenance tracking and accuracy metrics, to foster confidence among clinicians and patients.
- **Balancing Automation and Human Expertise:** As automation becomes more prevalent, participants debated the boundaries of AI autonomy and the role of clinicians in ensuring patient safety while leveraging AI's capabilities.

- **Personalization and Context Awareness:** Personalized care is a cornerstone of effective telemedicine. This group explored how XR interfaces can adapt to cognitive, physical, and emotional needs, addressing barriers to delivering tailored healthcare at scale.
- **Ethics, Data Protection, and Policy:** Ethical concerns and regulatory compliance are critical to ensuring safe and equitable telemedicine adoption. Discussions focused on frameworks for privacy protection, data ownership, and guidelines for ethical AI use.
- **Usability, Training, and Change Management:** The group tackled practical barriers to adoption, such as usability challenges, training requirements, and organizational resistance, proposing strategies to equip healthcare professionals with the necessary skills.

5.3 Trust, Transparency, and Explainability

This discussion group highlighted the complex interplay between technological design, user perceptions, and ethical considerations in fostering confidence in AI-driven XR tools for telemedicine. The participants examined the dynamics of trust-building, methods for achieving explainability, and the critical role of human oversight in medical decision-making.

5.4 Proposed Methods for Fostering Trust

Participants identified several strategies for cultivating trust among patients and clinicians. *Provenance tracking* emerged as a priority, emphasizing the importance of providing clear, verifiable pathways for generating diagnoses or recommendations. For instance, an AI tool could display the series of inferences leading to its conclusions, akin to an annotated flowchart of reasoning. As one participant noted, this approach helps “reduce uncertainty by revealing the decision-making process.” Similarly, accuracy metrics – such as confidence intervals or comparisons with known benchmarks – can offer tangible evidence of reliability.

Another suggestion involved designing interfaces that enable real-time interaction with the AI system. Participants discussed layered explanations, where users can start with a summary and drill down into deeper levels of reasoning as needed. This functionality allows users to engage with AI outputs at a level that matches their expertise, fostering a sense of control and understanding.

5.5 Exploring Broader Scenarios: Trust Beyond AI Systems

To extend the discussion beyond AI-specific tools, participants conducted a thought experiment on trust and transparency in telemedicine more broadly. One scenario considered the integration of 360-degree cameras in virtual consultations. By enabling clinicians to observe a patient’s living environment, such systems could provide contextually rich data to support diagnoses. For example, clinicians managing stroke rehabilitation might assess whether a patient’s home environment is conducive to recovery, identifying hazards or necessary modifications.

However, participants acknowledged that increased observational capabilities raise critical privacy concerns. The concept of shared spaces was a recurring theme, with one participant remarking, “The patient may not fully understand what is visible to the clinician, and that

asymmetry can undermine trust.” The group agreed that transparency about what data is being captured and how it will be used is essential for maintaining both patient autonomy and confidence.

5.6 Challenges Identified: Privacy, Proximity, and Perceptions

The discussion underscored the nuanced relationship between proximity and trust. Remote consultations, while convenient, can sometimes lead to misunderstandings or assumptions that may not arise in face-to-face interactions. For example, a clinician observing a disorganized home environment through a camera might make assumptions about a patient’s adherence to treatment without understanding their circumstances fully. Participants highlighted the risk of such misjudgments, stressing the importance of empathetic design that accounts for these social and cultural dynamics.

Privacy was another dominant concern. Participants debated the trade-offs between providing clinicians with more comprehensive data and protecting the patient’s right to privacy. One suggestion was to develop systems that allow patients to control what the clinician can observe, providing a sense of agency while still enabling effective care.

5.7 Role of Human Oversight

The concept of a “human in the loop” emerged as a critical point of discussion. Participants agreed that in high-stakes medical contexts, human oversight must remain central to decision-making. However, they also explored how AI systems could enhance this oversight by providing traceable, contextualized explanations. For example, a collaborative AI system might present a suggested diagnosis with a rationale that includes supporting data and references to medical literature, allowing the clinician to make an informed judgment.

Participants debated whether human oversight should always involve the capacity to override AI outputs or whether trust in the system could sometimes allow for autonomous actions. Some argued that enabling clinicians to question and modify AI recommendations is essential for maintaining trust, while others suggested that in certain low-risk scenarios, automation might be more efficient without undermining confidence.

5.8 Insights and Reflections

The group’s discussions revealed a shared understanding that trust is not simply about technological robustness but also about transparency, empathy, and respect for user autonomy. By designing systems that are both explainable and interactive, AI-driven XR tools can bridge the gap between complex algorithms and human decision-making. At the same time, addressing challenges such as privacy concerns and asymmetries in information requires ongoing attention to ethical design principles and user-centered approaches.

5.9 Balancing Automation and Human Expertise

This group examined the integration of AI into clinical workflows, emphasizing how automation can enhance human capabilities rather than diminish them. Discussions revolved around delineating the roles of AI in healthcare, addressing cultural and ethical implications, and exploring the limitations and opportunities of automation in a field rooted in trust, empathy, and accountability.

5.10 Defining Roles for AI in Healthcare

Participants categorized the potential roles of AI into three broad categories, reflecting varying degrees of autonomy and complexity:

- **AI Task Facilitator:** This role involves automating repetitive and routine tasks such as collecting patient data, scheduling appointments, or triaging cases based on urgency. Participants agreed that this role poses minimal ethical concerns and is widely accepted by clinicians. However, ensuring transparency about the data collection process and how the triaging criteria are determined remains critical.
- **AI Medical Advisor:** In this role, AI systems assist clinicians by synthesizing patient data, generating diagnostic insights, and summarizing relevant medical literature. The group discussed how this role requires a high degree of reliability and traceability, as clinicians depend on these insights to make informed decisions. A participant highlighted, “The AI must not only analyze data but also explain its rationale in a way that aligns with the clinician’s thought process.”
- **AI Decision-Maker:** This role envisions AI systems operating autonomously in well-defined, low-risk scenarios, such as prescribing standard treatments for minor conditions. While participants acknowledged the efficiency of such systems, they also raised concerns about over-reliance and the potential erosion of clinicians’ expertise in routine medical decision-making.

5.11 Framing and Cultural Implications

The framing of AI’s role emerged as a critical factor in shaping user expectations and acceptance. Participants debated the implications of referring to AI systems as “AI doctors” versus “AI assistants.” While the term “doctor” conveys a sense of authority and expertise, it also implies accountability and autonomy that many felt was inappropriate for AI. One participant remarked, “*Calling it a doctor implies it can be trusted the same way a human doctor is, which is misleading and could distort the patient-clinician relationship.*”

This discussion highlighted the importance of cultural and societal contexts in defining the roles of AI. In some cultures, patients may prefer clear delineations between human and machine expertise, whereas in others, AI might be more readily trusted if framed as an equal contributor to medical care. The group concluded that consistent and context-aware communication about AI capabilities is vital for managing expectations and building trust.

5.12 Empathy and the Limitations of AI

The group also examined the potential for AI to address issues such as stigma in healthcare. Participants noted that AI systems, by their nature, lack the biases and judgments often associated with human interactions. This neutrality could make AI particularly effective in sensitive areas like mental health, where patients might hesitate to disclose information to a human clinician. However, this advantage is tempered by AI's inability to convey genuine empathy or respond to nuanced emotional cues. A participant emphasized, “*While AI can reduce stigma, it cannot replicate the reassurance of a compassionate human presence, which remains crucial in many clinical contexts.*”

5.13 Regulatory and Ethical Considerations

The group explored the ethical and regulatory implications of increasing automation in healthcare. A recurring concern was the question of liability: if an autonomous AI system prescribes a medication that leads to adverse effects, who should be held accountable – the AI's developers, the healthcare institution, or the clinician overseeing the process? To address this, participants proposed several regulatory measures:

- Confidence Disclosure: AI systems should clearly indicate their confidence levels in specific decisions, enabling clinicians to weigh the AI's recommendations appropriately.
- Traceability: The rationale behind AI decisions should be fully documented, allowing for post hoc analysis in case of errors or disputes.
- Certification Standards: AI systems should undergo rigorous testing and certification processes before being deployed in clinical settings, with standards tailored to the level of autonomy the system is expected to have.

Participants emphasized that while regulatory frameworks can help mitigate risks, they should not stifle innovation. Balancing accountability with adaptability will be key to fostering safe and effective integration of AI in healthcare.

5.14 Broader Insights on Human-AI Collaboration

The discussions highlighted the importance of maintaining the clinician's central role in healthcare decision-making, even as automation becomes more prevalent. Participants expressed concerns about over-reliance on AI, which could lead to a decline in clinical expertise and a loss of critical thinking skills. Drawing an analogy to aviation, one participant suggested, “*Just as pilots are regularly trained to fly without autopilot systems, clinicians should be periodically tested to ensure they can operate without AI support.*”

At the same time, the group acknowledged the potential for AI to act as a safety net, reducing the cognitive burden on clinicians and improving diagnostic accuracy. For instance, AI systems could serve as a second opinion, flagging potential oversights or errors in human judgment. This collaborative dynamic, rather than a hierarchical one, was seen as the most promising path forward.

5.15 Concluding Reflections

The group concluded that the integration of AI into clinical workflows must prioritize complementing human expertise rather than attempting to replace it. By clearly defining roles, addressing cultural and ethical concerns, and implementing robust regulatory measures, AI systems can enhance healthcare delivery while preserving the trust and empathy that are essential to patient care. The discussions underscored the need for ongoing dialogue among stakeholders to navigate the evolving relationship between automation and human expertise in medicine.

6 Day 3: Eye Tracking Technologies

The Dagstuhl Seminar brought together experts to explore the use of eye tracking and gaze-sharing technologies in remote clinical practice, with a focus on improving communication, accessibility, and inclusivity. Discussions highlighted both the potential benefits and the technical and ethical challenges associated with implementing these tools across diverse user populations. The following sections detail the key themes, observations, and recommendations that emerged from these conversations.

6.1 Shared Eye Gaze in Remote Clinical Practice

Eye gaze offers an implicit communication channel that can bridge the physical gap in remote collaboration. In telemedicine, where nonverbal cues are often absent, gaze data can enhance mutual understanding between expert and novice users. One major insight from the seminar was that shared gaze facilitates grounding by confirming that both parties are focused on the same detail. Features like real-time gaze overlays and gaze-based attention indicators were seen as instrumental for improving diagnostic accuracy and collaborative decision-making.

6.2 Perspective Alignment and Virtual Proxemics

Ensuring alignment between the expert's and the local user's viewpoints is critical. This is particularly important in immersive or augmented reality environments, where mismatched perspectives can lead to confusion. Similarly, designers must account for proxemics – the sense of personal space in virtual settings. Poorly managed virtual proximity can lead to discomfort or reduced engagement, especially in high-stakes medical consultations.

6.3 Expert-Novice Communication Gap

Experts may unintentionally omit details they consider obvious, creating challenges for novice users. To address this, the integration of visual overlays, contextual cues, or AI support can help novices interpret the scene more effectively. A feedback loop where gaze cues, speech, and gestures confirm mutual understanding can bridge this expert-novice divide.

6.4 Multimodal Interaction Channels

While gaze is a powerful cue, it becomes even more effective when combined with other modalities such as facial expressions, hand gestures, and speech. The seminar emphasized the importance of designing multimodal interfaces that support naturalistic interactions and mutual understanding in remote healthcare scenarios.

6.5 Challenges and Ethical Considerations

Participants highlighted multiple challenges related to privacy, training, and technical feasibility. Gaze and attention data can be sensitive and reveal underlying health conditions, necessitating strict data security protocols and informed consent. Moreover, real-time systems must function reliably across devices and bandwidth conditions. Clinicians also require training to interpret gaze data accurately, and clear liability structures must be established in the case of miscommunication or diagnostic errors.

6.6 Recommendations for Implementation

The group proposed a set of actionable next steps:

- Develop user interfaces that reflect expert perspectives without overwhelming novices.
- Conduct pilot studies comparing gaze-enhanced sessions with traditional video calls.
- Define ethical frameworks for data use, including consent and anonymization.
- Leverage AI to detect interaction breakdowns or mismatches in shared attention.

6.7 Inclusive and Assistive Eye Tracking for Users at the Edge

The seminar also addressed issues in applying eye tracking to users at the margins – such as neurodivergent individuals, users with cognitive or motor disabilities, and infants. Current systems often fail to account for variability in eye behavior, head shape, pupil distance, or compliance with calibration protocols. Devices may not fit properly, or may not accommodate different gaze patterns and motor behaviors (e.g., in ASD populations).

6.8 Hardware, Software, and Calibration Issues

Poor physical fit, discomfort, and calibration failures were repeatedly identified as barriers to inclusion. Existing eye tracking algorithms and systems are often designed around normative assumptions, failing to generalize across diverse users. The seminar emphasized the need for adaptable calibration protocols, robust hardware, and data-driven models that account for individual variability.

6.9 Data Gaps and the Need for Infrastructure

A major bottleneck for research is the lack of publicly available datasets representing non-normative users. No large-scale repositories currently exist for these populations, and much of the data collected by companies is proprietary. The lack of standardized terminology and absence of de-identification practices further limit the ability to share data responsibly.

6.10 Toward Inclusive Design and Industry Collaboration

To advance the field, participants advocated for:

- Establishing open, crowdsourced databases that capture diverse eye behavior.
- Creating industry standards for inclusive eye tracker design.
- Pushing for business models and incentives that support accessible technologies.
- Encouraging collaborative data collection practices that protect privacy and support reproducibility.

6.11 Unique Challenges in Specific Populations

Special attention was given to young children and users with unique impairments. These groups are often excluded due to head movement, lack of compliance, or outlier biometric features. Customized protocols and adaptable systems will be necessary to ensure that these populations are included in future studies and systems.

7 Day 4: Embodied Conversational Agents and Avatars Assistants

7.1 Introduction

On Day 4, the seminar presentation was structured into two distinct yet interconnected topics, each addressing critical aspects of leveraging embodied conversational agents (ECAs) and Avatars assistants in telemedicine. In the first segment, the discussion focused on the dual role of ECAs as both barriers and facilitators in the delivery of telemedicine services. Specific attention was given to how attributes such as verbal and non-verbal communication, cultural alignment, and user-agent rapport can either enhance or hinder the accessibility, efficacy, and inclusivity of telemedicine platforms. Case studies and empirical data from clinical trials involving ECAs were highlighted, illustrating their diverse applications in healthcare, from patient education to therapeutic interventions and chronic disease management. During this part, eye-tracking technology was examined as a tool to deepen understanding of user behavior and engagement, providing real-time feedback for tailoring agent responses. The potential of extended reality (XR) systems, including virtual and augmented reality, was discussed in the context of creating immersive environments that facilitate trust and enhance patient-provider communication. Additionally, the talk emphasized the importance of robust cybersecurity measures to safeguard sensitive patient data and ensure trust in ECA-mediated interactions.

7.2 Presentation Summary: ECAs and Avatars in Telemedicine

Embodied Conversational Agents (ECAs) are synthetic characters designed to replicate human conversational behaviors. These agents recognize and respond to verbal and nonverbal cues such as gestures, facial expressions, and eye gaze, enabling them to engage in naturalistic interactions. ECAs hold promise in healthcare for delivering personalized, interactive experiences, addressing critical challenges in patient education, mental health support, elderly care, and medication adherence.

Telemedicine witnessed unprecedented growth during the COVID-19 pandemic, with ECAs offering a transformative potential to improve engagement, accessibility, and personalization compared to traditional video conferencing. By leveraging technologies like natural language processing, sentiment analysis, and gaze tracking, ECAs can foster trust, empathy, and social presence, particularly in populations with low healthcare literacy or language barriers.

The presentation highlights key applications of ECAs in telehealth, including their role in therapy for veterans with chronic pain and post-hospital discharge education. It also emphasizes their ability to promote equity in healthcare through culturally sensitive communication and accessibility features, such as voice input for users with low literacy.

Challenges discussed include the “uncanny valley” effect, behavioral imperfections, and the need for cybersecurity measures to protect sensitive patient data. To mitigate these barriers, future advancements in adaptive ECAs are proposed, focusing on multimodal interactions that integrate gaze, body language, and speech to dynamically respond to patient needs.

The presentation concludes with a vision for ECAs to revolutionize telemedicine, overcoming existing barriers and creating more engaging, empathetic, and effective remote healthcare experiences. Future directions include exploring adaptive behaviors, enhancing patient compliance, and improving user experience through innovative technologies.

Avatars were discussed as highly customizable virtual representations, allowing users to modify their appearance or adopt culturally relevant traits. This customization can significantly improve patient comfort and trust, but it also raises ethical concerns regarding identity, representation, and potential misuse. These aspects served as the foundation for the group discussions that followed.

7.3 Group Discussions

After the presentation on the role of Embodied Conversational Agents and Avatar Assistants in telemedicine, the seminar next transitioned into group discussions to explore specific themes in greater depth. Each group focused on a distinct aspect of the topic, fostering diverse perspectives and generating valuable insights. The discussions were structured into four groups, each addressing critical areas: accessibility and equity in telemedicine, trust and ethical considerations in telehealth, technical innovations and challenges in XR technologies, and the use of XR for training and education in healthcare.

Telemedicine presents unique opportunities to bridge gaps in healthcare access, particularly for individuals with disabilities or those in remote areas. Participants in this group highlighted the importance of enabling equitable participation by leveraging avatars and digital agents. For example, avatars that mirror users’ real or aspirational appearances can help reduce stigma, allowing users to feel more comfortable and included during medical interactions. Features like text-to-voice systems and subtitles were also identified as critical tools for improving accessibility.

The discussion on Accessibility and Equity in Telemedicine with Avatars explored how avatar representation can promote inclusivity and equity in telemedicine. Key points included: **Representation and Inclusivity:** Avatars can allow users to control how they present themselves, addressing needs across genders, disabilities, and cultural backgrounds. However, current avatars lack representation, especially for little people, individuals missing limbs, and gender-neutral options. Attempts at creating gender-neutral avatars often lead to unintended gender perceptions, highlighting challenges in design and cultural biases.

Equity in Interaction: Personalized avatars could help users with disabilities, those facing bandwidth constraints, or individuals with motor or social challenges participate effectively in telemedicine. For example, avatars can bridge gaps in conversational ability or create relatable representations for diverse patients and doctors.

Cultural and Social Impacts: Avatars can challenge stereotypes, such as representing doctors in non-traditional roles (e.g., a child seeing a doctor in a wheelchair). This might also foster social change by addressing biases in patient-provider dynamics.

Personalization in Telemedicine: Stroke rehabilitation agents demonstrated the importance of personalization in conversational style, voice, and memory of patient history. A failure to adapt or remember interactions can harm user trust and satisfaction, emphasizing the need for tailored AI-driven agents.

Continuity for Vulnerable Populations: For patients with memory disorders or high caregiver turnover, digital agents could provide continuity in care. This could be critical in rural areas or communities skeptical of telemedicine due to cultural differences.

Ethical and Emotional Considerations: Avatars that resemble deceased loved ones or culturally insensitive portrayals can cause distress, underlining the need for thoughtful design and deployment.

Insights: Cultural and social diversity must be incorporated into avatar design, ensuring both patients and healthcare providers feel represented. Digital agents capable of maintaining memory and continuity can provide consistent care for patients with chronic conditions, such as Alzheimer's. Personalization in ECAs and avatars should extend beyond appearance to include factors like ethnicity, language, and health literacy, enabling tailored interactions that meet users' unique needs. The group concluded that designing equitable and accessible avatars for telemedicine requires balancing representation, personalization, and cultural sensitivity while addressing technical and ethical challenges.

7.4 Trust, Privacy, and Ethical Considerations in Telehealth

Trust and privacy are foundational elements of telemedicine, especially when sensitive personal and medical data are involved. This group explored how trust can be cultivated through transparency, empathy, and user control over data. Participants emphasized the importance of addressing privacy concerns and ethical dilemmas related to the use of avatars and ECAs in healthcare.

Trust Building. Trust in telemedicine systems is built through empathetic interactions, clear communication about data usage, and involving human oversight in data management. Participants noted that patients often worry about how their data is stored and shared, particularly if it is handled by companies with questionable reputations.

Ethical Concerns. Behavioral data, such as gaze patterns and facial expressions, are valuable for improving telemedicine services but also pose significant risks if misused. For example, poorly anonymized data could lead to breaches of patient privacy or stigmatization. Educating users about what data is collected and how it is used is critical to addressing these concerns.

User's demographics. There is ongoing debate about whether avatars should closely match users' demographic traits, such as age, gender, or culture, to foster trust. While this alignment may boost trust, it also risks reinforcing harmful stereotypes or feeling inauthentic. Participants discussed the balance between personalization and authenticity. Some argued that even if avatars appear artificial, they are acceptable if they improve healthcare outcomes.

Data Protocol procedure. A speaker mentioned that it would be important to develop clear and accessible de-identification protocols for handling sensitive data. Empower patients by providing them with simple tools to manage data sharing and privacy settings.

7.5 Technical Innovations and Challenges in XR for Telemedicine

Participants highlighted the potential of conversational agents to create meaningful interactions by combining high-fidelity facial animations, natural language processing, and adaptive gaze models. Generative models offer a promising avenue for developing realistic avatars that can respond dynamically to user behavior.

Current gaze recognition systems lack robustness in unconstrained environments, making it difficult to maintain realistic interactions. Memory and adaptation capabilities in avatars require significant improvement to enable long-term, personalized interactions. The computational requirements for real-time avatar rendering remain a bottleneck, especially in resource-constrained environments.

Recommendations. Leverage generative AI to improve real-time avatar representation and interaction quality. Conduct longitudinal studies to evaluate the long-term impact of ECAs and avatars on patient engagement, trust, and healthcare outcomes. Explore the use of multimodal inputs – including gaze, body language, and speech – to create more immersive and adaptive telemedicine systems.

Applications. Training healthcare providers in communication and emergency response skills. Providing mental health support and rehabilitation services for patients in remote areas. Offering virtual coaching for managing chronic conditions, tailored to individual patient needs.

The integration of XR technologies, embodied conversational agents, and telemedicine platforms presents several cross-cutting challenges and opportunities that must be addressed to ensure equitable and effective healthcare delivery. Key areas of focus include promoting ethical and cultural sensitivity to represent diverse populations, safeguarding data privacy and security to build user trust, overcoming technological limitations to enable scalability and usability, and adopting user-centered design approaches to create practical and inclusive solutions. These considerations are critical for advancing telemedicine into a future that aligns with the needs and expectations of diverse global communities.

7.6 Summary of Key Perspectives and Discussions

■ Accessibility and Equity:

- ECAs and avatars can address barriers faced by individuals with disabilities, low health literacy, or language differences.
- Features such as text-to-voice systems, subtitles, and culturally tailored interactions enhance inclusivity.
- Designing inclusive avatars that represent diverse demographics, including gender-neutral and disability-representative options, remains a challenge.

■ Trust and Privacy:

- Building trust requires empathetic and transparent interactions, particularly in data handling.

- Privacy concerns around behavioral data (e.g., gaze patterns, facial expressions) pose ethical challenges.
- Developing clear de-identification protocols and empowering users with control over data sharing are critical.
- **Ethical Considerations in Representation:**
 - Avatars' customization options improve comfort and trust but raise ethical concerns regarding deceptive representations.
 - Balancing personalization and authenticity is necessary to foster trust without reinforcing harmful stereotypes.
- **Technical Innovations and Barriers:**
 - Advances in conversational agents, high-fidelity animations, and adaptive gaze models enhance telemedicine capabilities.
 - Challenges include computational demands for real-time rendering and improving the robustness of gaze tracking.
 - Long-term personalization and memory capabilities in avatars require further development.
- **Training and Education:**
 - XR environments provide immersive simulations with high-quality anatomical models and haptic feedback.
 - These technologies improve healthcare training and preparedness but demand significant resources and user acceptance.
- **Cybersecurity:**
 - ECAs handle sensitive patient data, necessitating robust cybersecurity measures to mitigate risks like identity spoofing and data interception.
 - Advanced solutions are required to ensure data privacy and maintain user confidence.

7.7 Insights and Forward-Looking Perspectives

- XR technologies, ECAs, and avatars have the potential to enhance engagement, accessibility, and personalization in telemedicine, addressing gaps in traditional healthcare delivery.
- Future research should focus on adaptive ECAs that dynamically respond to user behavior using multimodal inputs like gaze, speech, and body language.
- Longitudinal studies are needed to evaluate the long-term effects of ECAs and avatars on patient trust, compliance, and outcomes.
- Integrating cultural and social diversity into ECA and avatar design is essential for promoting equity and inclusivity.
- Innovations in cybersecurity and de-identification protocols must safeguard sensitive data and foster trust in telemedicine systems.
- XR environments for healthcare training and rehabilitation should be further explored to revolutionize skill acquisition and therapeutic interventions.
- By addressing these challenges, XR technologies and ECAs can drive equitable healthcare delivery for diverse populations.

7.8 Avatars: Diversity in Representing Remote Users

Members emphasized that being represented by an avatar in remote environments provides an opportunity to be fully included and treated as equals, based on the design and capabilities of the avatar that links them to that space. The avatars could even augment their communicative abilities, possibly overcoming limitations, for instance caused by disability. However, there is a need to offer flexibility and choice in avatar representations – some people may prefer a realistic likeness, while others might benefit from different or less stereotypical representations. Concerns were raised about current avatar designs and choices, which often lack diversity (e.g. limited options for avatars that show disabilities or non-typical body types like little people or amputees). It should not be assumed that people with disabilities wish to hide those traits, as that would be a form of ableism. There is also a lack of gender-neutral avatars, which often default to feminine traits. Others noted how avatars could help people express themselves, especially for those from marginalized communities, like transgender individuals, who may use avatars before coming out. Avatars should not only represent patients but also healthcare providers, who are often portrayed in ways that may be intimidating (e.g., as middle-aged, male, healthy individuals). It was suggested that allowing doctors to use avatars that reflect diverse identities could be an intervention for social change, though it's complex and could have unintended consequences.

7.9 Virtual Agents or Characters: Continuity in Patient Care

A member shared his work on developing virtual agents for stroke rehabilitation and stressed the importance of personalization. Patients – especially seniors – want agents with a personality that motivates them. They also expect the agents to remember past interactions, which could reduce frustration for patients. Concerns were also raised about continuity of care for patients with memory disorders (e.g., Alzheimer's), where caregivers' faces change frequently. Virtual agents could provide consistent, comforting interactions, especially in rural areas or for underserved populations. This could lead to the potential for “tele-kits” with virtual agents that could provide continuity of care, even if a patient is admitted to the hospital. This would allow personalized virtual agents to travel with the patient, helping to ensure consistency.

7.10 Hybrid Avatar-Agent: A Unified Face for Remote Service

A unique opportunity presents itself when Virtual Agents could seamlessly become avatars for remote healthcare professionals. As in the previous example of a consistent personalized virtual agent for patients with memory disorders, that same virtual body could become an avatar for a remote physician or other healthcare professional who wishes to interact with the patient remotely. That way, the patient gets remote care delivered through a familiar face, even if the remote professional is not always the same person. Indeed, Entire teams could be represented as the same persona entire teams could be represented as the same persona to patients at home, or even at hospitals. It was also discussed how such an avatar-agent hybrid could gently introduce new people to the patient, for instance before they arrive at the patient's door at home.

7.11 Hybrid Avatar-Agent: Mixed Expertise and Emotional Support

Hybrid avatar-agents could also respond autonomously to patients to address immediate needs that can easily be handled by AI, but would have the capability to bring in experts as needed – all through the unified visual representation. Such hybrid avatar-agents could also maintain positive and emotionally supportive visual behavior towards the patient, regardless of the current emotion or energy level of the professional providing the expertise. Furthermore, the hybrid avatar-agents could even help with or fully autonomously deal with difficult emotional patient interactions, shielding the professionals from some of the “emotional labor” that often places unnecessary and unwanted strain on the professionals.

7.12 Tele-Robotic Avatars: Extending the Work Force

A member shared his experience in Japan with tele-robotics, where remote workers with disabilities control robots that interact with customers at a cafe. Some of them waited on the tables, while others joined guests at the tables to provide social company. This provides unique opportunities for people who otherwise might become isolated at home to integrate with society as valuable members. The particular robotic representation chosen in Japan (e.g. a penguin), or even the idea of such a tele-robotics cafe, may not necessarily be something other cultures might accept. We may need to look into what is possible and culturally acceptable in different countries. The idea was raised that such tele-robotic avatars could be brought into the medical field where they could allow disabled medical professionals to enter hospitals or other places where they could interact with both patients and medical staff, providing consultation or even just emotional or social support.

7.13 Ethical and Practical Considerations for AI in Healthcare

In the working group session on “Balancing Automation and Human Expertise”, participants explored the roles AI could take in medical advising, the metaphors that match the respective role, the challenge in balancing out AI and human competencies and the opportunities of using AI in therapeutic and medical contexts.

While the fields of application for AI in medicine and therapy may be wide spread – from its usage in medical institution management over advising medical staff to direct patient contact as an AI companion, advocate or “doctor”, the role of AI currently lacks a systematic classification. The working group proposed three potential roles of AI in future telehealth systems along the dimension of responsibility, tightly knit to system complexity: AI as a task facilitator, AI as a medical adviser, and AI as a medical decision maker. AI as a task facilitator might include using it to perform motivational interviews in psychotherapy, to gather information about patients and their background, or to create reports. These tasks demand a relatively low complexity, leaving the main expertise and responsibility with the human operator. The working group expected this level of AI usage as a realistic first step regarding user trust and acceptance. Using AI as a medical adviser increases its complexity, its involvement and also the responsibility gathered towards it. As such, the AI system might summarize information, suggest approaches based on conditions and to proactively inquire with the human expert to ensure they retrace its rationales and agrees with them. One challenge within that role would be implementing the detection of false information or lies by patients instead of assuming truthfulness in all statements. As a solution, the group suggested following existing strict decision diagrams for standard routines.

7.14 Bias in Diagnoses and Advice: Ensuring AI Operational Neutrality

There is a growing concern about bias in AI-driven medical diagnoses and prescription advice. For example, if an AI model is perceived as being developed or owned by a pharmaceutical company, such as a “Pfizer AI Doctor”, trust in its prescription recommendations may be compromised. To address this, AI systems must provide traceable rationales for specific ingredient choices or treatment paths. Furthermore, rigorous certification procedures must be implemented and continuously maintained to ensure impartiality, especially as AI capabilities rapidly evolve in an arms race of technological development.

7.15 Responsibility and Power: Monitoring Between AI and Human Experts

A critical question arises around responsibility: should AI systems monitor human experts, or should human experts monitor AI systems? The answer has deep implications for accountability and legal liability. If an AI advises a course of action that leads to harm, determining who is legally responsible becomes complex. Clear governance structures are required to define authority, establish protocols for dispute resolution, and manage the legal consequences of AI-assisted medical decisions.

7.16 Declining Human Expertise: Mandatory Autonomy Testing for Healthcare Professionals

As AI tools become more integrated into medical practice, there is a risk that human expertise may atrophy. To counteract this, a “Healthcare Autonomy Test” may need to be developed, akin to flight simulator tests in aviation. These tests would ensure that medical professionals retain the ability to operate independently of AI systems, maintaining core diagnostic and decision-making skills even in high-tech environments.

7.17 Changes in Acceptance After Incidents: Design and Communication Considerations

Public acceptance of AI in healthcare can change significantly following incidents or adverse events. These shifts – akin to changes in the Overton window – must be anticipated in the design and marketing of AI systems. It is essential to document moments of public impact meticulously and to communicate AI capabilities in clear, metaphorically appropriate ways. This includes avoiding misleading analogies or exaggerated claims in commercials and ensuring users understand the AI’s true role and limitations.

7.18 Matching Hardware Capability to Therapeutic Requirements

The effectiveness of AI in healthcare is also constrained by the quality of supporting hardware. In domains such as radiology or surgical robotics, improved hardware can enhance the AI’s analytical, interpretive, reporting, and decision-making capabilities. However, in other

fields like psychology, where interventions are more conversational or cognitive, the demand for high-end hardware may be less critical. Identifying the appropriate level of hardware sophistication for each specialty is necessary for optimizing clinical integration.

8 Day 1-4: Data Privacy and Security

Data privacy and security emerged as a recurring theme throughout the seminar, woven into discussions across all four days. Given the sensitive nature of healthcare data and the increasing reliance on connected, intelligent systems in telemedicine, participants consistently emphasized the importance of ethical data handling, robust security protocols, and user trust. Whether examining gaze-based interfaces, AI-driven diagnostics, or avatar-mediated communication, conversations regularly circled back to the need for secure, transparent, and equitable data practices.

■ **Table 1** Summary of Trust, Privacy, and Ethical Considerations in Telehealth.

Category	Details
Trust, Privacy, and Ethical Considerations in Telehealth	■ Self-avatars: high fidelity/cartoonish ■ Deceptive appearance (age/gender/...) good or bad? ■ Gaze (synthetic)
Trust in Telehealth	■ Trust builds through empathy, transparent data use, and involving humans in data management. ■ People worry about privacy – how data is stored, shared, or even mishandled by companies with questionable reputations. ■ A big question: how do we balance user control over data with the need for enough data to provide accurate care?
Privacy and Ethical Concerns	■ Behavioral data (like gaze tracking) and health records raise risks, especially if they're misused or poorly anonymized. ■ Not everyone understands what data collection means, and lower health literacy could worsen this. ■ Socioeconomic factors play a role: affluent users might demand more privacy, while others don't have the same options.
Avatars in Telehealth	■ Should avatars match a user's age, gender, or culture? It might boost trust, but there's a risk of reinforcing stereotypes. ■ Some argue fake personalization could feel inauthentic, while others say it's fine if it improves outcomes. ■ Participatory design – creating avatars with community input – can help avoid ethical pitfalls.
Emerging Data Types	■ Gaze, behavior, and other new data types offer insights but come with risks of misuse or over-collection. ■ De-identification techniques could help, but protocols for how this data is handled are still unclear.

8.1 Privacy in Healthcare Data

The discussion covered the multifaceted issues surrounding privacy in healthcare, AI, XR, ECA, data collection through wearable sensors, applications, usage and regulatory processes. A key focus was the intricacies of data collection in healthcare, particularly how personally identifiable information (PII), such as demographic profile of the user combined with interaction history and other information from doctor summaries, is handled in a secure way to ensure users' privacy and minimize potential risks. The discussions underscored the ethical need for strict protocols and regulations to safeguard sensitive data and protect users. Topics such as the use of biosensors, audio, and video recordings revealed both the potential benefits for health outcomes along with the privacy risks inherent in modern healthcare technology. De-identifying data to minimize privacy risks was emphasized, particularly while exploring behavioral data and ignoring potential implication and the consequences of its misuse. The sources of data as well as its representation when developing content and interaction in telemedicine contexts – if not done in a critical way– can further exacerbate stigma and mental health challenges.

8.2 Trust, Ownership, and Patient Autonomy

Ensuring trust in the healthcare delivery through virtual agents remains as an open challenge to be addressed, along with safe processes to handle the medical records in a telemedicine context. While we acknowledge that patients should have freedom of choice, there is a complexity and added burden inherent to control choices. Surely patients must have the ability to opt in or out of data usage processes, seeking to respect their autonomy. Yet there are aspects of privacy literacy to be considered too. Concerns about power dynamics were raised, particularly in telehealth contexts where patients may feel coerced into sharing data with de facto platforms (ECA, avatars) or organizations without room for negotiation (like health insurance companies). Other issues raised involved the bias on how information is perceived depending on the characteristics of the embodied agents (demographic profile, voice, speech, accent). Companies were urged to prioritize privacy literacy and offer clear terms and conditions, or other applicable measures that are intuitive and accessible to the patient, empowering patients to make informed decisions about their data in a flexible, negotiable way. Building trust with users requires transparency, strong reputations, and good company values. Critical reflection is necessarily to go beyond retroactive strategies that

8.3 Risks and Consequences of Data Usage

The discussion raised also the risks associated with the PII and sharing of healthcare data, opening risks such as misuse for marketing purposes, health insurance premium changes, denial of care, or biased decision-making by health practitioners, insurance companies, or other stakeholders involved. Participants reflected on the growing role and threats involved with the usage of deceptive appearances (e.g. through deep fakes), such as changeable avatars or personalized agents, which can manipulate user trust and introduce cultural biases. Discussions also touched on the burden of privacy risks, especially for marginalized communities or those suffering from mental health conditions, where loss of privacy can deepen social stigma and worsen health outcomes. The cost of free access to healthcare platforms was a recurring theme, as it often comes at the expense of personal data and it may reinforce inequalities in treatment.

8.4 Organizational Responsibilities and Regulatory Needs

Even though nowadays organizations handling healthcare data are required to adopt strict regulations and clearly defined purposes for data usage, privacy risks in a telemedicine contexts are unknown and to minimize errors in handling sensitive information more efforts are needed [1]. Critical reflection on the implications of data sharing and aggregation highlighted the need for a balanced dynamic between organizational interests and user privacy. The role of health insurance companies and their influence on reimbursement and data usage policies has to be scrutinized to prevent harmful processes. Attendees stressed the importance of building a robust regulatory framework to address evolving privacy risks in the context of modern telemedicine operations and maintain trust in the doctor-patient relationship.

8.5 The Role of Personalization and Trust in Healthcare

Finally, the discussions addressed the vast potential of personalization in healthcare, such as tailoring personas in an embodied agent or avatar, and consideration about the intersectionality of individual patients to ensure that the delivery of healthcare meets individual needs without relying on stereotypical and reductionist approaches that not only limit the patient to a single attribute (like nationality) but also exacerbate bias in treatment. While this personalization approach offers promising benefits for enhancing health outcomes, it also poses challenges related to power dynamics and bias. For example patients are more likely to trust an ECA with certain traits, but adopting “preferred” traits will reinforce bias and prejudices even further. Overall, the trust in the medical system remains a cornerstone of patient confidence, but doing so is achievable through community-based approaches relying on a deep understanding of users, as well as an energetic, transparent communication. Organizations must integrate seamlessly innovation with ethical considerations of fairness and trustworthiness, ensuring that personalization does not lead to manipulative practices in the field or prejudice. By fostering trust and prioritizing patient choice, healthcare systems can achieve both technological advancement and equitable care that meets the needs of marginalized populations.

References

- 1 Vivian Genaro Motti and Shlomo Berkovsky. Healthcare privacy. In *Modern Socio-Technical Perspectives on Privacy*, pages 203–231. Springer International Publishing Cham, 2022.

9 Discussion

The Dagstuhl Seminar “*Addressing Future Challenges of Telemedicine Applications*” served as a multidisciplinary forum that brought together researchers and practitioners to reflect on the current and future challenges of telemedicine technologies. The central themes discussed throughout the seminar revolved around the integration of XR technologies, AI, eye tracking, and embodied conversational agents, with a strong emphasis on accessibility, trust, inclusivity, and clinical relevance.

A recurring thread across all sessions was the necessity for building trust and transparency in AI-driven telemedicine systems. This includes the importance of explainable interfaces that help clinicians and patients understand the reasoning behind AI outputs. Provenance

tracking, confidence scores, and layered explanations were discussed as viable strategies to increase interpretability and foster confidence. These methods aim not only to justify clinical decisions but also to support accountability and ensure ethical standards in remote healthcare delivery.

Another key area of discussion was the role of immersive and extended reality in transforming medical training and remote collaboration. Through virtual environments and avatar-based interactions, clinicians can train or deliver care in shared virtual spaces. These systems provide new ways to represent co-presence and embodiment in therapeutic and educational contexts. However, participants emphasized that such tools must be critically examined for accessibility, particularly among users with cognitive, motor, or perceptual differences. Topics such as gaze calibration issues, hardware fit, and lack of representative datasets were identified as technical and infrastructural challenges that continue to marginalize certain populations.

Ethical dimensions also featured prominently in the seminar discussions. From the need to clearly define the role of AI in healthcare workflows to managing data privacy concerns and regulatory standards, the participants explored the balance between innovation and responsible design. Cultural framing and communication around AI capabilities – particularly in how we label and market AI systems – was also seen as having a direct effect on user expectations and trust.

Participants recognized that current research prototypes often fall short of real-world deployment, particularly in underserved regions where infrastructure may not support high-bandwidth XR applications. Emphasis was placed on ensuring usability, creating inclusive design pipelines, and adopting participatory design methods that empower patients and practitioners alike.

In sum, the discussions illuminated a shared vision: future telemedicine tools must not only be technologically advanced but also ethically grounded, inclusive by design, and tailored to the diverse needs of patients, clinicians, and care ecosystems.

10 Conclusion

The Dagstuhl Seminar “*Addressing Future Challenges of Telemedicine Applications*” successfully convened a diverse community of experts to address the interdisciplinary challenges at the intersection of telemedicine, extended reality, artificial intelligence, and embodied interaction. The four-day seminar fostered meaningful discussions that revealed both the tremendous promise and the complex hurdles that lie ahead in the evolution of remote healthcare systems.

Key takeaways from the seminar underscore the need for solutions that are not only technologically robust but also ethically sound and accessible to all users. Trust-building mechanisms such as explainable AI and transparency in data usage were identified as essential features for widespread adoption. Additionally, participants emphasized the importance of designing for inclusivity – from hardware and software that accommodates non-normative users, to interface designs that support multimodal and culturally sensitive interactions.

Future directions call for collaborative efforts across disciplines. The challenges discussed – from enabling shared gaze in remote diagnostics, to developing empathetic and personalized virtual agents, to establishing regulatory frameworks for AI in medicine – cannot be addressed in isolation. Researchers, developers, clinicians, and policy-makers must work together to ensure that telemedicine technologies evolve with a balance of innovation, responsibility, and empathy.

Ultimately, the seminar provided not just a space for dialogue, but a foundation for ongoing collaboration and actionable research. It laid the groundwork for future initiatives that aim to advance telemedicine as a core pillar of equitable and patient-centered healthcare in the digital age.

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