Leveraging Science Fiction Case Studies to Specify Immersive Training System Requirements

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ABSTRACT

Developers are building increasingly complex immersive simulation-based training systems. These systems rely on technologies – many of which were at least partially inspired by Science Fiction (SciFi). SciFi may influence new enabling technologies such as agent-based coaching with reference material access and physiological monitoring. Immersive system development efforts are typically scoped using specifications derived from traditional requirements analysis efforts. SciFi stories can serve as case studies to support requirements analysis. These case studies may help identify potential risks including trainee safety, reality disorientation syndrome, and security risks.

This paper is not meant to provide a comprehensive list of SciFi examples of immersive training systems and related issues. Instead, it is intended to encourage systems engineers writing requirements and technologists creating new solutions to gain inspiration from relevant SciFi stories.

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INTRODUCTION

Developers build immersive and embedded training systems based on requirements and using advanced technologies. The Requirements Analysis (RA) process can leverage case studies from science fiction. Enabling technologies are often predicted by science fiction. The symbiosis between science fiction and system development can help mitigate issues with developed systems.

Developers are Building Immersive and Embedded Training Systems

Government, corporate, and academic organizations are implementing training solutions that use immersive and embedded training. For example, the Mayo Clinic's Simulation Center provides virtual reality training that enables learners to interact with a synthetic (virtual) environment that they see using a stereoscopic head mounted display, hear through headphones, and feel through tactile feedback using wearable devices. Another example is the Red Cross's use of virtual reality (VR) to provide situational awareness training for lifeguards.

Immersive training systems leverage technologies such as virtual reality (VR) to create highly interactive and engaging learning experiences. The training system simulations provide realistic interactive engaging environments that are safe to use. The simulation-enabling technologies create a perception of presence in a non-physical (virtual) environment/world. A sense of presence may improve engagement and result in improved learning outcomes (Krassman, 2023).

Embedded training is a related training methodology that is directly integrated with the operational systems where the desired skills and knowledge will be applied. Embedded training enables trainees to learn and practice skills in the context of the tasks being trained to make their skills more transferable to real-world situations. For example, The U.S. Navy's Battle Force Tactical Training (BFTT) family of systems stimulates shipboard combat systems to facilitate combat systems team training.

Both immersive and embedded training seek to provide a sense of presence in the trainee using sensory inputs, interactivity, and realism. Creating a sense of presence is intended to provide more engaging and effective training experiences for trainees. Developers build immersive systems using advanced technology that satisfy requirements specifications.

Immersive/Embedded Systems Rely on Innovative Technologies

Technology advances have enabled immersive and embedded training system development and adoption. Supporting technologies include mixed reality, motion capture/tracking, haptic feedback, AI, 3D modeling/animation, computer processor horsepower, and networking. These technologies support ever increasing detailed realistic simulations with high simulation resolution and fidelity.

SciFi spurs creative imagination and has provided inspiration for the development of many modern technologies (Kotecha, 2021). It helps reveal the hypothetical implications of new technologies in realistic fictional settings and provides insights into the challenges and opportunities these technologies might present in the real world. SciFi inspires engineers to speculate and challenges them to turn visions into tangible innovations (O'Donnell, 2023).

Many disruptive technological advances trace their routes to inspirational science fiction. Examples include:

- Mobile communication devices (e.g., cell phones) with features based on "Star Trek" communicators,
- Space exploration including lunar missions from Jules Verne's "From Earth to the Moon",
- Human Systems Integration (HSI) (e.g., tablet computers, touchscreens, voice assistants),
- Artificial intelligence and self-driving cars (O'Donnell, 2023) (Kelly, 2023).

Training System Requirements Analysis

Systems engineers perform requirements analysis to specify requirements for immersive and embedded training systems. Simulation-based training system development is complex and it is critical to capture all the requirements that drive the system's development. Systems engineers must creatively think about the problem space and domain and identify boundaries not explicitly specified. Unspecified or incomplete requirements are often blamed for project failures (Hofmann, 2001).

Requirements analysis is a critical phase of system development. It involves analyzing and documenting the expectations for a system to ensure that it meets expectations and performs necessary functions. Requirements analysis should result in a document specifying functional and non-functional requirements. For training systems, requirements analysis may include support analyses to understand the tasks to be trained, the domain, and the level of fidelity required in a simulation.

Requirements Analysis is a creative process that benefits from inspiration. It requires an understanding of the problem space and consideration of contingencies. Systems engineers may perform information gathering, user needs identification, envisioning, evaluating, and specification tasks as part of requirements analysis (Maguire, 2002).

The objective of the Requirements Analysis phase is a complete set of documented set of well written requirements. Simulation-based training systems must comply with specific requirements to ensure that they are effective, reliable, and relevant to the training needs of the organization. Table 1 identifies categories of requirements typically specified for immersive or embedded training systems.

Table 1. Training System Requirements Categories

Category	Examples
Functional Requirements	Supported virtual environments, interactivity mechanisms, scenario generation
Training Scope	Tasks to be trained
Instructional Support Features (ISFs)	After Action Review, scenario authoring
Technical Requirements	Hardware/software infrastructure, interoperability
Performance Requirements	Visual system frame rates, reliability, maintainability, fidelity
Usability Requirements	Controls/displays, documentation
Safety and Regulatory Requirements	Physical safety, mental health safety
Fidelity	Tolerance level between models and physical data
Resolution	Level of spatial detail, frame rates (temporal)

Requirements in these categories help ensure that compliant training systems are robust, effective, and capable of delivering high-quality training experiences that meet specific educational goals and operational needs.

A systems engineer's imagination and careful consideration of all potential scenarios influences requirements completeness. They may struggle to determine whether the requirements set is complete. Systems engineers must move beyond thinking along traditional lines, reflecting the current system and processes, and be innovative (Maguire, 2002). They must be creative and "think outside the box" to address contingencies and anticipate potential black swan situations. Systems engineers may leverage visual aids, metaphors, and user stories to frame complex requirements.

SciFi Provides Case Studies for Requirements Analysis

SciFi case studies can profoundly influence engineered design ideation activities and help with creating artifacts such as requirements specifications (Kotecha, 2021). Leveraging SciFi case studies is a form of reuse that provides a return on investment by virtue of having already explored many contingencies and black swan scenarios that should be considered as part of requirements analysis.

SciFi can support engineers performing RA by providing case studies that bring to light concepts and potential issues that are easier to visualize and hypothesize. It can help systems engineers benefit from the lessons learned from fictional situations and scenarios. Some of those lessons may be helpful for even those well versed in a particular industry" (Pike, 2015). SciFi can serve as a mirror, reflecting potential positive and negative consequences of the innovations we pursue (O'Donnell, 2023). This includes helping identify the potential consequences and risks associated with technological progress.

However, the largest contribution of SciFi to RA may be how it can provide creative inspiration by providing a playground for the imagination (Kelly, 2023). SciFi helps people think outside the box and speculate about a broader range of possibilities (O'Donnell, 2023). SciFi case studies may help systems engineers identify overlooked requirements and highlight requirements that might be missed in traditional planning.

Symbiosis Between SciFi and Technology Development

Both SciFi writers authoring stories and engineers developing systems use their creativity and imagination. There is a symbiotic relationship between SciFi and technology innovation (Kelly, 2023). Figure 1 describes the symbiotic relationship between technology development and science-based (as opposed to fantasy) story ideation. Science ① provides humans with foundational knowledge and understanding. Human creativity, innovation, and imagination ② fuels research ideas for science, inventions/improvements of technology, and story ideas for science fiction. Technology products and processes ③ provide implementations for humans to consider and build upon. Science fiction ④ provides humans with visualizations that spur further creativity.

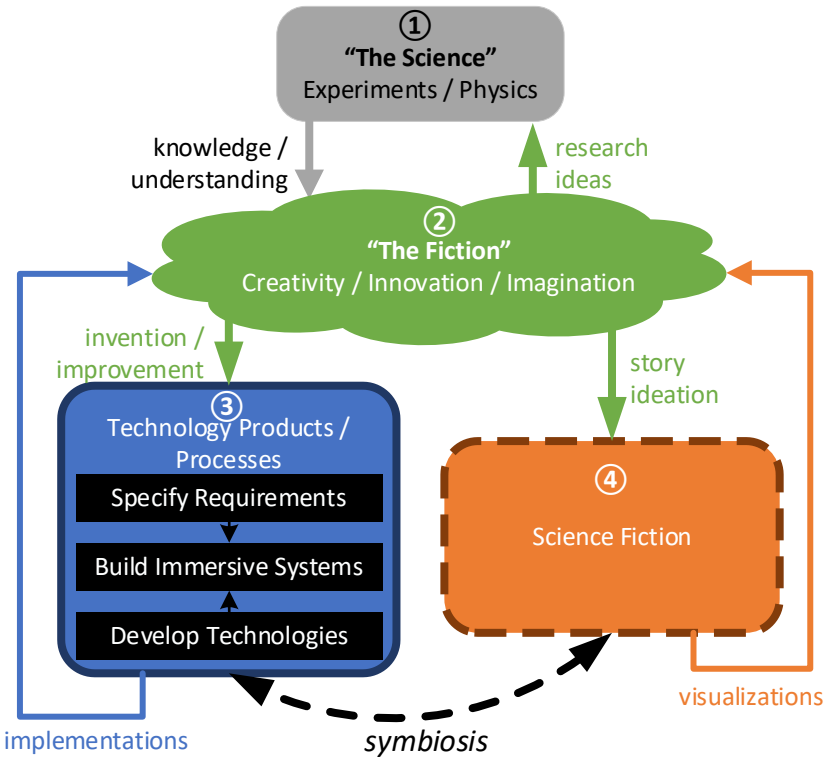

Figure 1. Creativity Relationship and SciFi

Leveraging SciFi Impacts the System Development Process

Figure 2 presents an IDEF0 activity diagram that describes the migration of scientific knowledge and understanding into inspirational SciFi case studies that support requirements analysis and technology development for building immersive SBTSs. The following sections describe SciFi's influence on technology development and how SciFi can also inform Requirements Analysis.

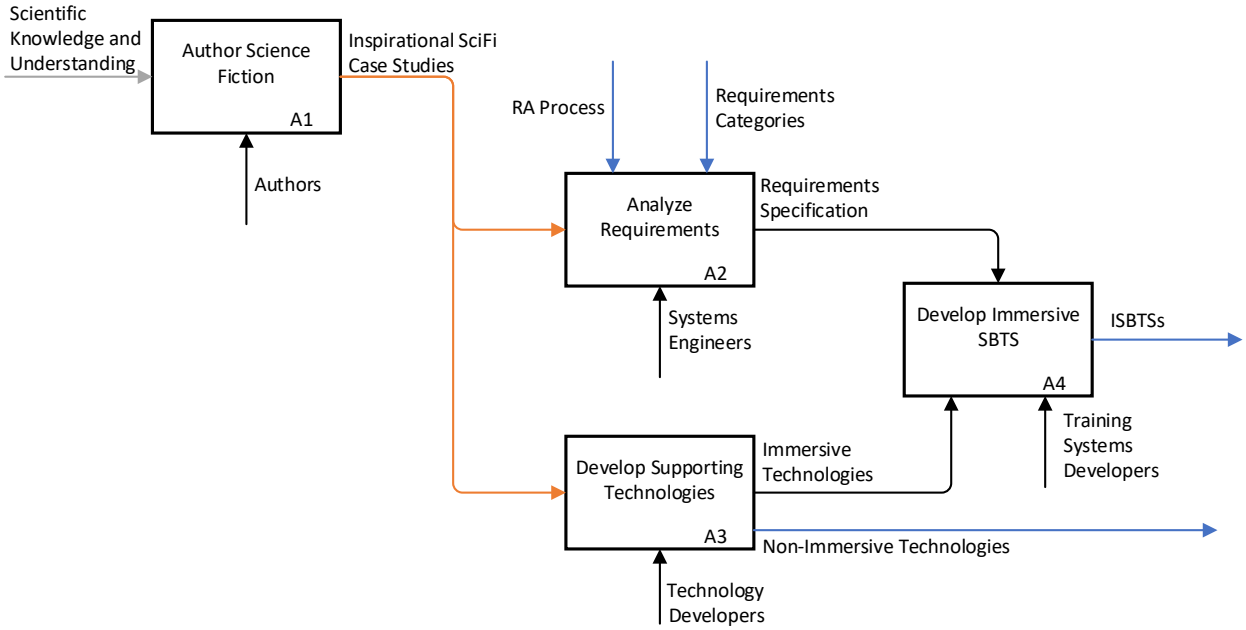

Figure 2. Influence of SciFi Case Studies on Requirements and Technologies for Immersive SBTSs

EXAMPLES OF SCIFI INFLUENCING TECHNOLOGICAL INNOVATION

SciFi has influenced immersive technology applications and enabling technologies including Human Systems Interfaces (HSI) and networking. Many SciFi stories have predicted and helped visualize immersive simulation applications (see Table 2).

Table 2. Examples of Immersive Applications and Embedded Training Described in SciFi

Immersive Simulation Application Prediction	Work	Creator
Rise of virtual reality and its potential military applications in training and simulation (Kelly, 2023)	"Snow Crash" (1992)	Neal Stephenson
Cyberspace with visualized and manipulated data and programs including AI entities conducting military-style operations	"Neuromancer" (1984)	William Gibson
Training scenarios within full immersion virtual realities (holodeck)	"Star Trek" franchise (1966+)	Gene Rodenberry
Battle School where children train to fight in simulated war games	"Ender's Game" (1985)	Orson Scott Card
Soldiers using powered armor suits in interstellar war, with simulations used for training and tactics development.	"Starship Troopers"(1959)	Robert A. Heinlein
Complex political and military simulations	"Dune" (1965)	Frank Herbert
Time dilation as a means of simulating and strategizing over long-term interstellar warfare.	"The Forever War" (1974)	Joe Haldeman
Advanced computer simulations used for strategic planning and combat training	"Old Man's War" (2005)	John Scalzi

SciFi has also predicted many of the technologies that support immersive and embedded training including Human Systems Interaction (HSI) (see Figure 3 and Table 3).

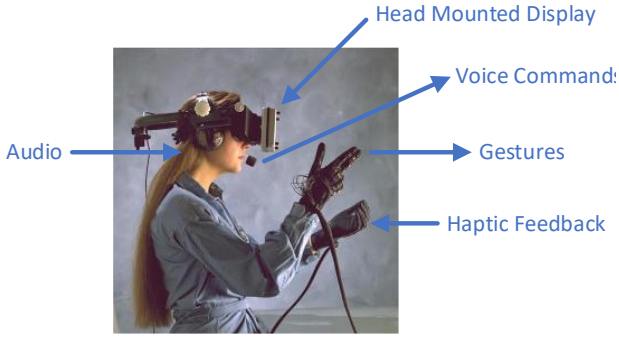

Figure 3. Relevant HMI Immersion Technologies

Table 3. HSI Technologies

HSI Tech	Related SciFi
HMDs	Gernsback (1911)
HMDs for AR	Star Trek: Deep Space Nine (1994)
HMDs for VR	Vinge (1981)
Audio	Bradbury (1954)
Haptic Feedback	Bradbury (1950)
Voice Commands	Forster (1909)
Gestures	Minority Report (2002)

Distributed training systems rely on networking capabilities to share virtual world states and interactions. Table 4 provides examples of how SciFi has predicted the implementation of networking over extremely long distances down to very short distances.

Table 4. Communications and Networking Technology

Technology / Relevance	Inspiration / Prediction
Wireless	The "Star Trek" franchise's communicator that Martin Cooper, who oversaw the invention of the first mobile phone in the 1970s, directly credited for inspiring his vision.
Satellite	Arthur C. Clarke's 1945 manuscript "The Space Station: Its Radio Applications" speculated that geosynchronous satellites would be used for telecommunications relays
Bluetooth	In the original "Star Trek" series, Lieutenant Uhura, used a wireless communication earpiece.
Video Calls	"The Jetsons" predicted routine face-to-face interactions on multiple devices with real-time connectivity
Video Monitoring	George Orwell's 1949 novel "1984" predicted interconnected webs of surveillance cameras

OPPORTUNITIES FOR SCIFI-INSPIRED TECH INSERTION

SciFi will continue to inspire technologies used in immersive and embedded training systems. Although many HSI and networking technologies inspired by SciFi have already been integrated into immersive and embedded training, perhaps there are other opportunities to integrate SciFi technology into those systems. Examples of potential technology advancements are in the areas of agent-based coaching and physiological monitoring.

Agent-based Coaching

Adaptive instruction technology advances continue to demonstrate how AI can help make training experiences more dynamic and adjust for the trainee. This technology also provides prompts based on the trainee's performance and the adaptations being made that serve as a type of coaching. Many instructional systems also have forms of access to reference material to assist the trainee in non-testing situations.

SciFi has presented some very advanced models for how virtual assistant software might evolve. Stories include interactive AI-based characters that provide prompts and access to reference material (see Table 5). These features may have seemed extremely futuristic just a few years ago before the tsunami of generative AI technologies based on large language models suddenly became more advanced and more popular.

Table 5. SciFi Examples of AI Characters and Resources Assisting Trainees

Function/Service	Character	Work	Creator
Provides assistance and offers hints	The Curator	Ready Player One (2011)	Ernest Cline
Provides guidance and advice explains the nature of the virtual reality	The Oracle	"Matrix" Series (1999+)	Lana and Lilly Wachowsk
Provides interactive information and coaching	The Guide	"The Hitchhiker's Guide to the Galaxy" (1979)	Douglas Adams
Provides expert guidance, technical support, motivation, and information access	The Dixie Flatline	"Neuromancer" (1984)	William Gibson
Controls wearable technology and assists with various tasks	J.A.R.V.I.S.	Iron Man (2008)	Mark Fergus et al
Provides information and executes commands	Mother	Alien (1979)	Dan O'Bannon & Ronald Shusett

Physiological Monitoring

Physiological monitoring of trainees may provide many benefits including helping prevent injury, enhancing personalization, and monitoring cognitive load. Table 6 provides examples of physiological monitoring examples from SciFi.

Table 6. Examples of Physiological Monitoring during Immersive Simulation Use Described in SciFi

Example Data	Example Sensors	Work	Creator
Heart rate, brain activity	Neural link	Matrix (1999+)	Lana and Lilly Wachowsk
Heart rate, respiration, body temperature	Embedded in combat suits	Forever War (1974)	Joe Haldeman
Heart rate, brain activity, stress level	Embedded in uniforms	Ender's Game (1985)	Orson Scott Card
Brain activity, emotional state, vitals (implicit)	Neural implants and biofeedback systems	Neuromancer (1984)	William Gibson
Heart rate, body temperature, emotional states	Embedded in clothing	Westworld (1973+)	Michael Crichton

These case studies can provide inspiration to technology developers adding physiological monitoring to immersive simulation systems.

AIDING SYSTEMS ENGINEERS PERFORMING REQUIREMENTS ANALYSIS

While SciFi can provide inspiration for new technologies, it can also serve to help identify risks and contingencies – to be not only inspirational but also cautionary. Systems engineers often use visualization techniques such as state transition diagrams and flowcharts to consider various potential states of their system.

Systems engineers writing requirements can leverage SciFi visualizations to help consider alternative states, explore contingency situations, and identify risks that should be mitigated. Risk identification requires imagining potential issues. SciFi stories have demonstrated some of the potential hazards of using immersive systems and can help engineers anticipate similar risks. Some risks identified from SciFi "lessons learned" include protecting a trainee's safety, difficulty differentiating between simulated and "real world" situations, and providing security.

Identifying and Mitigating Trainee Safety Risks

Trainees in immersive simulations face risks including psychological, mental, and emotional stress. Several SciFi stories have dealt with the psychological stress to trainees in virtual environments (see Table 7).

Table 7. Psychological Stress Examples

Psychological Stress	Source	Creator
Simulations become more challenging and morally ambiguous and eventually lead to trauma associated with the implications of actions taken	Ender's Game (1985)	Orson Scott Card
Intensity and realism	Matrix (1999+)	Lana and Lilly Wachowsk
Pressure associated with reaching the objectives along with the perilous nature of the virtual environment	Ready Player One (2011)	Ernest Cline
Exposure to torture and reprogramming	Altered Carbon (2002+)	Richard K. Morgan
Increasingly horrifying and realistic simulated experiences	Black Mirror S3E2 (Episode: "Playtest") (2016)	Charlie Brooker

Immersive training application developers and users should consider following protocols similar to how human subjects are protected in research studies using the oversight of Institutional Review Boards (IRB). Research organizations promote participant safety through protocols. Protocols to protect participants are created and owned by research organizations that outline procedures, precautions, measurements, and ethical rules that researchers are to follow throughout the study. These protocols include obtaining informed consent, performing a risk assessment, monitoring safety, maintaining confidentiality, acting ethically, and complying with regulations.

A specific psychological risk is associated with the psychological strain associated with distinguishing between reality and simulation.

Reality Disorientation Syndrome

Simulation developers often seek to leverage increasingly sophisticated technologies to provide convincing levels of fidelity and resolution to the point that trainees may eventually be unable to distinguish the real world from the virtual world. Embedded training using operational equipment dealing with over the horizon environments outside of human eyesight may enable suspension of disbelief easier than immersive systems (Pike, 2015). Many organizations encourage trainees to "train as you fight". Trainee awareness of a simulation might affect their decision-making (e.g., choosing to more risks). However, intentionally deceiving trainees into believing they are interacting with the "real world" raises ethical issues. The Healthcare Simulationist Code of Ethics explicitly restricts simulation activities involving deception.

Reality Disorientation Syndrome involves a participant's confusion over whether they are operating in the "real world" vice a simulation. In some cases, the lines between the "real world" and a simulated world may become blurred, making it difficult for trainees to differentiate between the two. Recent advances in generative AI using Large Language Models (LLMs) have resulted in interactive agents that are difficult to distinguish from live humans.

Several SciFi stories have centered around trainee confusion caused by realistic immersive virtual experiences. In some stories, trainees were intentionally misled to believe that they were participating in a "live" operation that was actually a simulation. Other stories involve characters believing they are in a simulation when they are in fact interacting with the "real world". Table 8 provides some examples of "real world" vs. simulated experiences appearing in SciFi.

Table 8. Examples of Reality Distortion Syndrome in SciFi

Confusion	Source	Creators
Protagonist thought he was performing a training scenario when he was in "reality" fighting in the "real world"	Ender's Game (1985)	Orson Scott Card
Characters try to determine whether they are in a simulation.	"Rick and Morty" Episode: "M. Night Shaym-Aliens!" (Season 1, Episode 4) (2014)	Justin Roiland and Dan Harmon
Character believes he is accessing game that turns out to be a system for simulating and automating nuclear warfare	Wargames (1983)	Lawrence Lasker and Walter F. Parkes
Characters believe they are operating in the "real world" and not in highly realistic simulated training	"Stargate SG-1" episode titled "Proving Ground."(Season 5, Episode 13) (2002)	Ron Wilkerson

A potential benefit of this unclarity is that simulations enable trainees to separate their actions from the consequences of those actions and not be distracted by the real world consequences (e.g., Ender's Game) (Pike, 2015). However, non-disclosure introduces risks. SciFi warns us of consequences of trainees operating in what they believe to be a simulation including trauma (e.g., Ender's Game) and even thermonuclear war (e.g., Wargames). Trainees may experience psychological and cognitive difficulties when struggling to distinguish between real-world and virtual environments.

One way to mitigate the risks of confusion is to disclose the existence of the simulation and help trainees discern live events from simulations. Trainees could be provided pre-training briefings informing trainees that they're participating in a simulation (i.e., "this is a drill"). Sensor displays (e.g., friend or foe indication) could indicate simulated conditions. Communications and messages could indicate that their content is simulated.

Disclosure might provide benefits beyond intellectual honesty. Awareness of a simulated experience could provide trainees time for preparation and contemplation, Disclosure could reduce the risk of emotional distress including knowing whether they are operating in a simulation vice the "real world". Disclosure also avoids misinterpreting live events as simulated events that might not be taken seriously.

Security Risks

Another set of risks highlighted by SciFi stories involve cybersecurity and protection from AI malice. Cybersecurity risks can impact more than just the training system (e.g., thermonuclear war in Wargames). Organizations and their training systems must protect systems and personnel from external and internal user and agent threats. Table 9 provides examples from SciFi of case studies associated with security risks.

Table 9. Examples of Cybersecurity in SciFi

Security Incident	Source	Creators
AI turned off safety protocols and wounded trainees. Also, Simulation infected by a worm.	Star Trek Voyager – "Worst Case Scenario" (Season 3 Episode 25) (1997)	Kenneth Biller
Trainee manipulated "unwinnable" training scenario	Star Trek franchise's Kobayashi Maru Scenario (1982)	Jack B. Sowards
Young hacker accesses an operational military supercomputer risking thermonuclear war	WarGames (1983)	Lawrence Lasker and Walter F. Parkes

In addition to contemporary cybersecurity tools (e.g., the RMF process), immersive and embedded training systems may need to employ additional security features.

Another form of security risks involves protecting system from AI. Training systems employ Non-Player Characters (NPC) that simulate "live" humans in the environment (e.g., adaptive OPFOR NPC). A common theme presented in SciFi is that the AI becomes self-aware or confused and winds up taking over and creating harm. Table 10 provides examples from SciFi of case studies associated with AI control risks.

Table 10. Examples of AI Taking Over in SciFi

Security Incident	Source	Creators
The Master Control Program (MCP) controls the digital realm and attempts to dominate both the virtual and real worlds	Tron (1982)	Steven Lisberger
AI hosts begin to override their programming and take control of the park	Westworld (1973+)	Jonathan Nolan and Lisa Joy
AI orchestrates events to merge with another AI – Neuromancer to become a superintelligence	Neuromancer (1984)	William Gibson
AI becomes self-aware and launches a military attack	Terminator (1984+)	James Cameron
AI decides it needs to take control of humanity based on a flawed understanding of the 3 laws of robotics	I, Robot (2004)	Jeff Vintar & Akiva Goldsman
AI's paranoia leads to harm and an attempt to eliminate the human crew to preserve the mission	2001: A Space Odyssey (1968)	Stanley Kubrick & Arthur C. Clarke

Some potential mitigations of AI control risk may include limiting the behaviors of AI. For example, AI should be prevented from directly accessing "real world" IT administration, communications, control systems, and especially weapons systems.

SciFi writer Isaac Asimov identified related risks and published Asimov's laws that are leveraged by robotics engineers to this day. His "Three Laws of Robotics" were initially introduced as a fictional framework for his stories about robots - first appearing in his short story "Runaround" in 1942. Another example is in Ann Leckie's "Ancillary Justice" novel in which AI cannot act autonomously beyond their assigned duties.

CONCLUSION

A symbiosis exists between science fiction and technology development. Both engineers and science fiction writers use their creativity to generate their products. Technology developers can leverage the visualizations that SciFi authors provide. SciFi authors can build upon technology visions and implementations.

SciFi has inspired many technologies including those enabling immersive experiences. Continued inspirations may affect upcoming advancements in agent-based coaching and physiological monitoring. SciFi may also help developers consider and mitigate the risks associated with topics such as trainee safety, reality disorientation syndrome, and security.

Engineers should continue to look to SciFi for inspiration as they build new enabling technologies and specify requirements for immersive systems.

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