Using Actor-Network Theory to Make a Case for Human-Robot Triage for Disaster Management

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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One of the deadliest terrorist attacks in US history were the Septemper 11, 2001 attacks on the World Trade Center. As a direct result of the attacks, 2,753 citizens and 413 first responders lost their lives; however, the death toll for first responders continues to rise years after the event. (Smith, 2019, p. 625). In the days following the attack, 90,000 responders rushed to New York City to aid in the search for victims and removal of wreckage (Smith, 2019, p.626). Unbeknownst to responders, the debris of the World Trade Center was toxic to breathe. As of 2023, the 9/11 death toll matches those lost from 9/11 related illness is equal (Halpert, 2023). These deaths were caused by respiratory illnesses and cancers born from inhalation of the toxic fumes from the debris of the World Trade Center.

Poor advisory from leadership led to the high quantity of first responder deaths. A week after 9/11, head of the Environmental Protection Agency Christine Whitman made an announcement to the public: “I am glad to reassure the people of New York and Washington, DC, that their air is safe to breath” (Bendix, 2015). The EPA had no basis behind their claim, and it gave the first responders a false sense of security (Walters, 2016). After hearing Whitman’s statement, half of the first responders did not wear respiratory protection equipment (RPE) while working at the World Trade Center site; for those that did wear RPE, one-third of responders did not have RPE training (Antao, 2011, p. 900). First responders often juggle their own safety with that of the victims. A difference of minutes could cost a victim their life. Although there are protocols in place to protect first responders, such as wearing RPE, these protocols can be overlooked during scenarios with limited time, or when people in positions of power claim that conditions are safe.

One potential solution for limited first responder exposure to disaster areas is the novel idea of a human-robot triage, which utilizes a team of autonomous robots with a singular human

medic. The robots are responsible for exploration and basic triage; when a victim in need of immediate medical attention is located, the robot enlists in the help of a human medic. Currently, the use of robotics in disaster response is limited to semi-autonomous systems; the human-robot triage aims to use a fully autonomous system. Using 9/11 as a case study, this paper aims to analyze human-robot triage as a safer method for triage. By analyzing what went wrong at the World Trade Center site, this paper determines characteristics of current triage that are important for future disasters, as well as the characteristics of current triage that are harmful. The paper begins by explaining relevant information about current triage processes, providing context to the 9/11 case study. The next section introduces Actor-Network Theory, which focuses on the different actors within a system, and applies it to the disaster response that occurred during 9/11. Lastly, this paper explains why triage is inherently utilitarian in nature; based on this observation, it suggests a novel approach that utilizes a team of heterogeneous robots working in tandem with a human medic. The use of a human-robot triage in disaster response allows for objective exploration of environments and triage of victims in disaster scenarios.

Background on Disaster Triage

In instances of disaster, EMT priorities are listed as follows: personal safety, then safety of colleagues, and lastly safety of the patient (Klein, 2023). Regardless of the protocols put in place, there will always be an element of risk for first responders. Depending on severity of injuries, victims have a limited amount of time for survival. The time pressure and safety are two competing ideals for first responders; there is a tradeoff between taking the time to make sure safety protocols are met and saving as many victims as possible. There is no mathematical equation for this tradeoff; in an experiment focused on how first responders respond to disaster scenarios, researches found that first responders relied on their "power of intuition" based on

their previous experience as a first responder (Hintze, 2008, p. 1). Each scenario is unique and requires first responders to react with limited time. Under time pressure, first responders may make unsafe decisions.

Another aspect of disaster triage affected by time pressure is ranking patients based on severity of injuries. One of the most common methods for ranking victims is the SALT method (Bhalla, 2015, pg. 1), where SALT is an acronym that stands for Sort, Assess, Life-Saving Interventions, and Treatment. For the purpose of this paper, I will focus on the Sort and Assess phases, since these are the phases completed by the robots during a human-robot triage. During the Sort phase, the victim is sorted into four levels. The first level is Minimal, where the victim has the physical ability to walk; these victims are assessed last. The next level is Delayed, where the victim is conscious and able to wave or conduct purposeful movement; these victims are

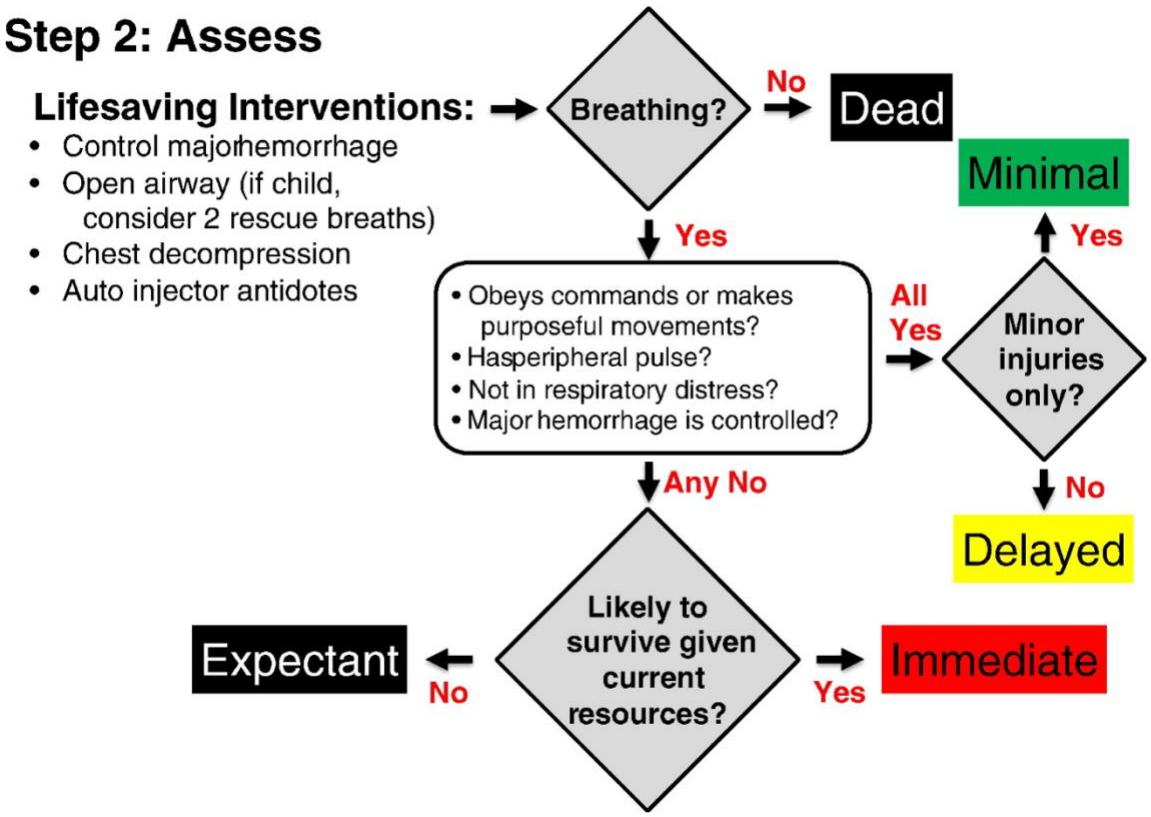

Figure 1: Diagram of Assess Phase in the SALT Triage Classification Method

assessed second. Next is Immediate, where the victim is unconscious or has an obvious life-threatening injury; these victims are assessed first. The last stage is Dead/Expectant, where the victim is not attended to. This will be explained in more depth during the Assess phase, shown in the diagram above. The Assess phase begins by observing if the victim is breathing. If they are not, the patient is declared dead, and the first responder continues exploring to find the next victim. If they are, the set of conditions shown in the diagram above are assessed. If all conditions are met, victims are examined for severity of injuries and sorted into Minimal or Delayed. If any of the conditions are not met, the medic has to make a decision on whether they think the victim will survive given the resources. This is another area where the first responder uses their "power of intuition", since there is no set formula to decide if a patient with critical injuries is likely to survive. However, first responders have limited time to make this decision, and if they decide to aid the victim, there is limited time to perform life-saving intervention. This is time that could be spent locating more victims with higher chances of survival; or, first responders risk leaving a victim and continuing to explore when there are no other victims. The invention of a human-robot triage, where a first responder is paired with a system of autonomous robots, eliminates potential miscalculations due to human error in the triage process. It reduces decisions about continued exploration and patient aid into algorithmic outputs.

Background on Disaster Robotics

Currently, there is no real-world implementation of a human-robot triage with an autonomous robot system. However, there are studies related to human-robot triage. These include studies on human-robot interaction, the use of robots in rescue robotics, and the use of robots for triage. In a study conducted at Vanderbilt University, researchers compared the workload of a human-human and a human-robot team (Harriott, 2011). The scenario for the

study is that there is a CBRNE incident, which means first responders are not allowed to enter the site. Because of this, a victim inside the site has to perform triage while receiving instruction from either a human medic or a robot; for the human-human team, the medic was located outside of the site, and for the human-robot team, the robot was put inside the disaster site with the human. Another study focuses on the current application of rescue robots in urban search and rescue (Murphy, 2004, p. 151-152). While this study looks at real-world applications of robots in search and rescue, it focuses on fields where robots are performing tasks that humans are unable to perform; for example, at the World Trade Center site, robots were not used to search the surface, which could be done by humans. Robots would be used to search hollow areas in the pile of the rubble that humans could not safely climb into. Additionally, there are multiple studies purely focused on robot triage. One of the studies focuses on the use of robots in instances where medics can not perform triage, due to large numbers of victims, dangerous environments, or non-accessible places (Chang, 2007, p. 267-271). Although this is similar to the human-robot triage, it is missing two key aspects: the human-robot interaction, and autonomous robot systems. The robots in this study were teleoperated, which means there were controlled remotely by human operators. The other study uses a singular autonomous robot to find and triage victims (Senthikumaran, 2024). In their future research section, this study mentions the use of multiple robots in a autonomous robot system, similar to that of the human-robot triage; however, it fails to mention a human-robot interaction.

Although there are pre-existing studies on human-robot interaction and robot triage, there are limited studies on the combined capabilities of a human-robot triage. Each of these studies have pieces that are relevant to the final method, but none capture the complete scope of human-robot triage. It is not enough to have an autonomous robot system without looking into the

human-robot interaction aspect; similarly, it is not enough to have a human-robot interaction study without the autonomous robot aspect. The proposed final solution aims to combine pre-existing elements from current uses of robots in disaster response, such as various sensors and cameras, but it aims to utilize an autonomous system to provide strict algorithms for the triage process to follow. Additionally, the use of human medics is important to the system. There are some medical functions that a robot is unable to perform. By incorporating a combined human-robot triage, the robotic system is responsible for exploration and basic triage via the SALT method, allowing first responders to focus on medical intervention.

Actor Network Theory

ANT is a sociotechnical framework within Science and Technology field that studies associations between human and non-human actors in a technical or scientific system. Cressman defines ANT as follows: "everything – people, organizations, technologies, nature, politices, social order(s) – are the result, or effect, of heterogeneous networks (2009, pg. 4). Simply put, systems are the result of differenct actors coming together to influence each other, forming a network. Another aspect of ANT is a network builder; a network builder is responsible for setting a common goal for actors to work towards. Although there may be "rogue actors", whose goals are different from that of the network builder, the network builder is the primary actor responsible for bringing together the various actors to form a network.

ANT provides a lense to understand how interactions between different actors lead to the success, or failure, of a technology or science. For 9/11, ANT is used to evaluate the current method for triage. Additionally, ANT can also be used to look forward towards future technologies. Cressman describes what this would look like with ANT, saying, "The social study of technology should not be limited to rejecting technological determinism or social

reductionism (although this is invaluable) – it should also attempt to point out alternative trajectories to technological modernity" (2009, pg 10). In addition to focusing on what went wrong with the methods of triage at the World Trade Center site, the paper looks to improve on future disastster exploration through the use of an autonomous human-robot system to better protect first responders. For the sake of this paper, only the actors relevant to disaster response are included in the network.

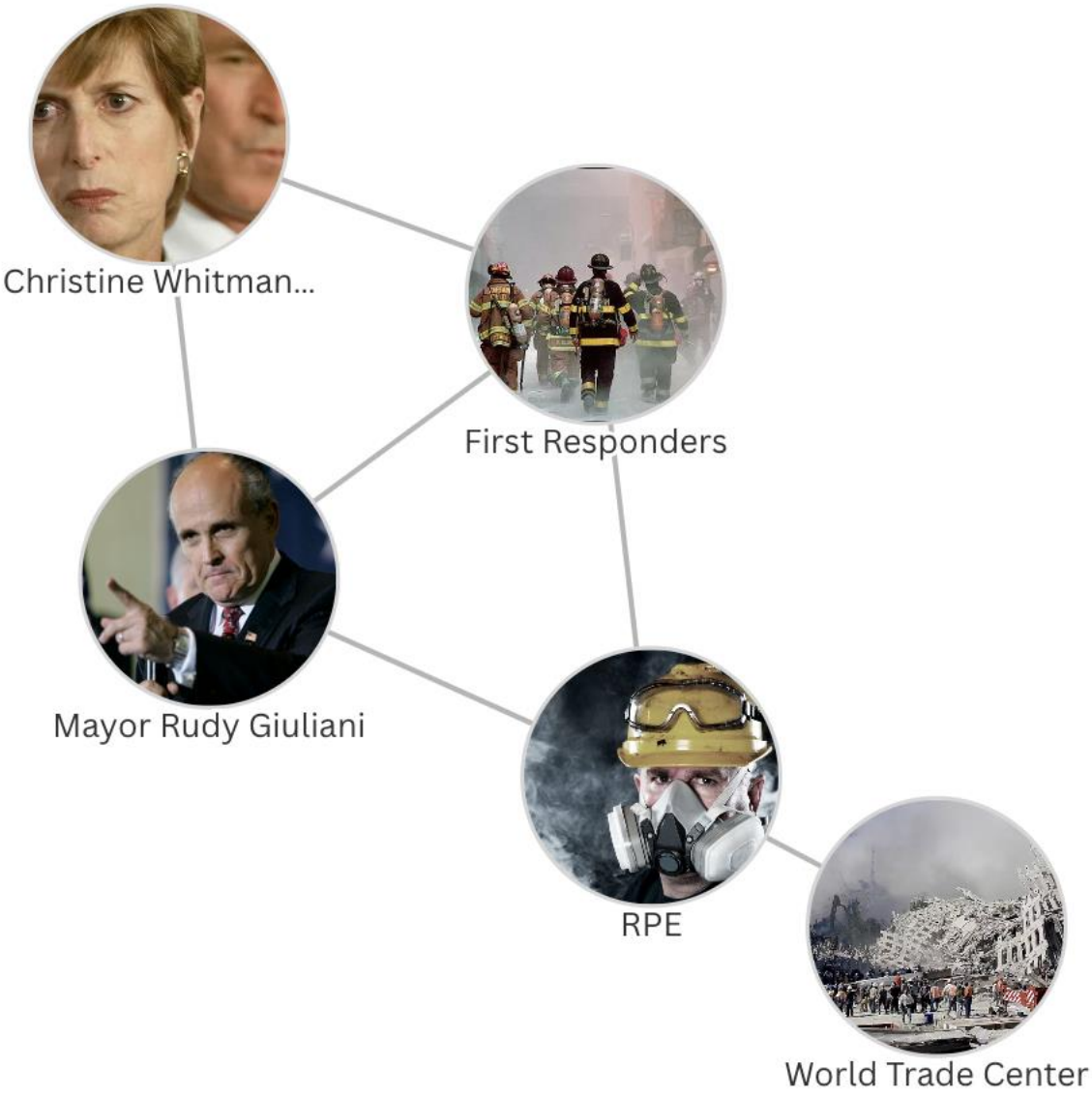

Figure 2: Actor-Network Theory Diagram

The diagram above shows the different major actors involved in the decisions that led to the lack of safety at the World Trade Center Site. Although most of the actors had a negative impact on the health of the first responders, the respiratory protective equipment (RPE) was one factor that had a positive impact on the health of the first responders. As for the rest of the actors, they ultimately contributed to the hazardous conditions for first responders during 9/11.

Christine Whitman and the EPA

Whitman, as head of the EPA, claimed that the air around the wreckage of the World Trade Center was safe to breathe; in actuality, the EPA had no basis behind the claim that the air quality was safe to breath (Walters, 2016). Whitman herself claimed that she was passing on what government scientists claimed, even though the surrounding environment was covered in ash and dust (Walters, 2016). Whitman was the network builder of this actor network; regardless of whether there was actual science backing the claim of safe air quality, Whitman was the public face of the statement, so she was responsible for the false statement of safety.

Respiratory Protective Equipment (RPE)

RPE was the only rogue actor going against the negative actors led by the EPA and Christine Whitman. Firefighters are required to wear RPE to prevent direct exposure to disaster areas. At a disaster site, there is a wide range of airborn particlates, gases, and fumes, all with the potential to be harmful when inhaled (LeMasters, 2006). The Ocupational Safety and Health Administration states that firefighters are required to wear a self-contained breathing apparatus (SCBA) when entering an immediately dangerous to life or health atmosphere (US Department of Labor). An SCBA is a type of RPE that supplies breathing air to the wearer. When a site is not deemed to be an immediately dangerous to life or health atmosphere, it is the responsibility of

the employer to have a plan in place for using RPE. However, many of the first responders on the site had no RPE training, so even if they were wearing RPE, they were still exposed to the toxic air surrounding the World Trade Center (Antao, 2011, p. 900).

Mayor Rudy Giuliani

The 9/11 attacks on the World Trade Center were unprecedented circumstances; there was nothing for Fire Chiefs to refer to in order to make sure their firefighters were protected. In this instance, the responsibility fell to the person in charge of searching the debris of the World Trade Center, which was New York City Mayor Rudy Giuliani. Giuliani, following the advice of the EPA head Christine Todd Whitman, did not enforce RPE among first responders.

First Responders

Although the first responders had less responsibility for the overall circumstances, they still should have taken accountability for their own safety. Although Whitman said that respiratory equipment wasn't mandatory, first responders with previous experience using RPE, such as firefighters, should have recognized the unsafe scenarios based on similar pre-existing firefighter protocols: this is refered to as their "power of intuition", which is built in their experience as a first responder (Hintze, 2008, p. 1)

World Trade Center

The materials used to construct the World Trade Center were toxic to breathe. If the World Trade Center used less toxic materials, first responder deaths could have been prevented. The particles in the air were a mix of carcinogenic particles and chemicals like asbestos, fiberglass, mercury, and benzene; the Natural Resources Defense council estimates between 300-400 tons of asbestos used in the construction of the World Trade Center (Bendix, 2015, pg. 1).

ANT Synthesis

As a result of the poor leadership from Christine Whitman and the EPA, over 800 first responders have died from illness related to exposure to the toxic debris at the World Trade Center site (Smith, 2019, pg. 626). Whitman has since apoligised for her statements regarding the quality of the air at the World Trade Center site, claiming that she never lied, but was unaware of the dangerous pollutants in the air (Reilly, 2016, pg. 1). Regardless of whether Whitman's statement is true, the EPA failed their obligation to protect the first responders and citizens of New York after 9/11. It was their job to determine the safety of the air quality, and by making a false claim, they endangered hundreds of first responders. Another problem was the blind faith in Whitman and the EPA from first responders and Mayor Giuliani. Considering there were visible pollutants in the air surrounding the World Trade Center site, Giuliani could have ordered the first responders at the site to wear RPE, regardless of Whitman's statements. Similarly, the first responders could have taken safety into their own hands; less than 20% of first responders decided to still wear RPE on their own. To prevent future loss of life in disaster scenarios, one principle from this case study is important to future applications of disaster response: disaster response is utilitarian in nature.

Disaster response is utilitarian because when disaster occurs, the goal of first responders is to save as many people as possible. Disaster triage decisions aim to do the most for the greatest number of victims with their limited resources, such as time and manpower (Sztajnkrycer, 2006, p. 749). This can be shown in the SALT methodology for disaster response. For example, when first responders decide to leave Expectant victims, they do this with the assumption that they can save more victims, and the time it would take to save an expectant victim wastes resources. Based on available manpower and limited time, it is not always possible

for first responders to save all victims; however, by taking a utilitarian approach to the triage process, the greatest number of victims survive.

One way to implement utilitarianism in disaster response is by implementing a novel human-robot triage. The human-triage robot system works by utilizing an autonomous, heterogeneous robot system with a singular human medic. The robot system consists of Unmanned Ground Vehicles (UGVs) paired with an Unmanned Arial Vehicle (UAV). The UGVs are tasked with exploring the area and triaging victims. The victims are triaged into 4 levels using the Sort, Asses, Lifesaving Intervention, Treatment/Transport (SALT) method: 1 is Minimal, 2 is Delayed, 3 is Immediate, and 4 is Dead. One change to this method is the removal of the Expectant category. When writing the code for the UGVs to follow, we determined that the robots should not be responsible for determining if a victim is expectant; this should be left to the human medic to determine. Otherwise, the levels are identical to those in the SALT method. When a UGV finds a level 1 or level 2 victim incapable of walking, it continues exploring. When a UGV finds a level 3 victim, they report the triage level and the coordinates of the victim to the UAV. The purpose for this is to save the greatest number of lives; although this prevents level 1 and 2 victims from receiving immediate aid, the victims with the highest probability of death are saved first. This follows the utilitarian idea of saving the greatest number of victims, and therefore doing the greatest good. Although this may lead to longer wait times for level 1 or level 2 priority victims, it preserves the ultimate goal of the first responder, which is performing life-saving intervention. The UAV is responsible for hovering in the center of all of the UGVs. The number of UGVs is variable, so the UAV is responsible for adjusting its position based on the number of UGVS. When the UGVs deliver the message to the UAV, they deliver the full list of victims found, including those that are lower priority. The UAV then takes this to the human

medic, who calculates an optimized path to go to victims. The order utilizes a Traveling Salesmen Problem (TSP) that accounts for priority first, followed by location. The TSP first splits the given tasks into separate lists based on priority. The path with the shortest distance is selected for the priority level 3 tasks, then the same is done for priority level 2 tasks, and lastly, this is done for priority level 1. After calculating this optimized path, the medic goes to the coordinates to perform the necessary treatments to the victim. If new tasks are added, a new optimized path is generated. After reporting the victim to the UAV, the UGV continues exploration. If the UGV has tasks in its task list after exploring its entire area, it reports them to the UAV.

Although there was no physical implementation of the human-robot triage, various trials with different behaviors were analyzed to create the above triage methods. Different aspects of the disaster response were altered, such as when the UGV returns to report victims and variables used in the TSP, to determine the method that resulted in the greatest number of lives saved. By only reporting when a priority level 3 patient is found, the UGVs are able to explore the entirety of the environment faster, so first responders don't have to worry about the tradeoff between continued exploration to locate victims with potentially higher risks and tending to higher priority patients. This relates to the utilitarian principle of saving the greatest number of lives. Another decision directly related to utilitarian principles is the use of a prioritized TSP. A traditional TSP only accounts for distance between tasks; the priority TSP accounts for the priority level of the victim before considering the distance between victims. All decisions made are objective based on their algorithmic nature. Although human input was required for the design of the code, the decisions were made based on which methods performed in a way that aided the most high priority victims the fastest. While testing different methods, there were some

methods that completed exploration and triage faster than the chosen method; however, this method aided all of the high-priority victims the fastest, focusing on the utilitarian nature of disaster response.

Conclusion

Through human-robot triage, decisions regarding triage are utilitarian in nature. The algorithms selected for robot and human behavior are chosen to aid the highest number of high-priority victims with the goal of saving the greatest number of lives; because of this, the triage and exploration methods are utilitarian in nature. By looking at 9/11 as a case study, we can observe how triage without a strict set of ethical rules can lead to lack of safety. While 9/11 is not the best case study to examine unethical triaging patterns, it shows how the desire to aid potential victims led to over 800 first responder deaths (Smith, 2019, pg. 626). By putting first responder deaths at risk, this failed to follow the utilitarian principle of saving the greatest number of lives, instead putting more lives at risk unnecessarily. Human-robot triage provides a solution for future disaster response to better protect first responders, providing less exposure to a smaller number of first responders by pairing them with a team of autonomous robots. Although the technology necessary is still in development, it has the ability to change disaster response for the better.

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