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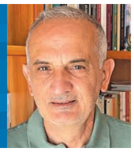

Urgent Computing for Protecting People From Natural Disasters

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Urgent computing systems have become increasingly useful in supporting rapid alerting and forecasting frameworks associated with monitoring and management of natural hazards. High-performance computing systems offer effective computing environments for providing accurate prediction of disaster scenarios.

Natural disasters often threaten people in many regions and cities with disruption to civil infrastructures, damage to buildings and roads, and loss of human life. Advanced information technologies, such as artificial intelligence and high-performance computing (HPC), are proving to be increasingly useful for preventing and managing natural disasters by limiting damage to the environment and saving lives. When a disaster occurs, time is a very important factor. For this reason, urgent computing systems in the last decade have become increasingly useful in supporting rapid alerting and forecasting frameworks associated with monitoring and management of natural hazards. HPC systems, with their ability to process large datasets in a very limited time, offer effective computing environments for providing accurate prediction of disaster scenarios.

ORIGINS OF URGENT COMPUTING

Urgent computing is a set of technologies that exploit HPC methods and resources to support computations whose results are necessary for decision making under a strict deadline, after which the computation results may be useless for decision-making purposes. If the time constraints of an urgent computation are not met, unrecoverable human losses and/or extensive material damages may arise. Typical urgent computing scenarios involve

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high-performance modeling and simulations from large amounts of data for time-critical applications such as flood modeling, severe weather prediction, and infectious diseases modeling. The term gained popularity in 2006 after the Special PRiority and Urgent Computing Environment (SPRUCE), a system developed at the Mathematics and Computer Science Division of Argonne National Laboratory to support urgent or event-driven computing on both traditional supercomputers and distributed grids.[1] SPRUCE employed a token-based model in which tokens can have various levels of priority and different sets of resources applicable to them. This approach was inspired by existing emergency response systems, such as the priority telephone access system supported by the U.S. Government Emergency Telecommunications Service.

Typical urgent computing scenarios involve high-performance modeling and simulations from large amounts of data for time-critical applications.

Urgent computing solutions have been successfully adopted over the years by scientists and government agencies to prevent or mitigate the effects of natural disasters. According to the U.S. Federal Emergency Management Agency (FEMA) (https://hazards.fema.gov/nri/natural-hazards), a natural disaster is "the negative impact following an actual occurrence of *natural hazard* in the event that it significantly harms a community," while natural hazards are "environmental phenomena that have the potential to impact societies and the human environment." A comprehensive list of natural hazards can be found in the National Risk Index dataset maintained by FEMA. Some examples are avalanche, coastal flooding, earthquake, hurricane, ice storm, landslide, lightning, strong wind, tornado, tsunami, volcanic activity, and wildfire. These natural hazards can also cause secondary hazard events. For instance, volcanic activity can create other hazards, such as ash and lava spread, which are not in the aforementioned main list, but can be targets of urgent computing applications.

SIGNIFICANT PROJECTS

The European Union (EU) has supported significant scientific initiatives aimed at exploiting urgent computing for protecting people from natural disasters. For example, the Center of Excellence for Exascale in Solid Earth (ChEESE) project, based at the Barcelona Supercomputing Center (BSC), was funded by the EU to exploit the power of supercomputers for hazard assessments and early warning forecasts for earthquakes, tsunamis, and volcanoes (https://ec.europa.eu/research-and-innovation/en/projects/success-stories/all/supercomputers-help-save-lives-during-natural-disasters). Thanks to HPC systems, ChEESE allows scientists to model thousands of scenarios very quickly, ensuring that the results are made available to decision makers under the strict time constraints required during emergency situations. Significant examples of urgent computing applications developed at ChEESE using supercomputers include the creation of probabilistic tsunami forecasts combining many physics-based scenarios to predict impacts well before the wave hits the coast, and the production of high-resolution volcanic ash cloud forecasts to help civil aviation authorities plan accordingly.

In 2021, the ChEESE volcanic ash pilot demonstrator helped the Spanish authorities manage the emergency generated by the eruption of the Cumbre Vieja volcano on San Miguel de La Palma island in the Canary Islands. The intense volcanic activity, lasting almost three months, caused devastating lava flows with thousands of people evacuated and emitted substantial amounts of ash into the air, generating pollution and disrupting air traffic. During the whole eruption, ChEESE ran computations at several resolutions covering a number of possible eruption scenarios, providing local authorities with daily operational forecasts. A dedicated urgent computing system, based on a supercomputer located at BSC, allowed the ChEESE volcanic ash pilot demonstrator to run its simulations every morning from 6 to 7 a.m., delivering its forecast no later than 7:30 a.m. Local authorities used these forecasts to predict the impact of upcoming volcanic activity to civil aviation and to reroute traffic accordingly. They also used forecasts to predict air quality problems and issue confinement orders for those living within critical zones.

Another EU-funded project that focuses on urgent computing for natural hazards is eFlows4HPC (https://eflows4hpc.eu/urgent-computing/). The main goal of eFlows4HPC is to deliver a workflow software stack and an additional set of services that enable the integration of HPC simulations and modeling with high-performance data analytics in scientific and industrial applications, with urgent computing workflows as relevant use cases.[2] Developing urgent computing workflows for natural hazards such as tsunamis and earthquakes involves deploying advanced tools and complex tasks to ultimately bring them to an operational level. Urgent computing workflows take advantage of the eFlows4HPC software stack to improve technology and provide fast solutions for mitigating the effects of potentially catastrophic tsunamis and earthquakes.

The key role of HPC in urgent computing for natural hazards is further demonstrated by several use cases developed at the Texas Advanced Computing Center (TACC) (https://texascale.org/2020/feature-stories/urgent-computing/). An example is represented by hurricane storm surges, which are among the most destructive and difficult parts of a hurricane to forecast. Hurricane Katrina in 2005 serves as a stark reminder of the destructive power of storm surge. The event resulted in the deaths of at least 1,500 people, many of whom died directly or indirectly due to the surge (https://www.nhc.noaa.gov/surge/). To prevent such disasters, emergency managers need to have real-time information on the maximum water level over the coast throughout the duration of a hurricane. Thanks to storm surge forecasts run at TACC, scientists were able to predict, days in advance, several feet of water flooding Lake Charles from Hurricane Laura in 2020. Urgent computing facilities at TACC are also used to provide real-time storm simulations to the National Oceanic and Atmospheric Administration (NOAA) National Severe Storms Laboratory every spring. These simulations are delivered by 4 a.m. each day and used to help predict severe weather events.

Tsunami forecasting and warning systems are among the most important urgent computing applications. Two major tsunami events in the last 20 years, the 2004 Indian Ocean and 2011 Tohoku seismic tsunamis, serve as dramatic examples of how tsunamis may strike a large coastal population within a short amount of time after an earthquake. Several tsunami warning systems are currently operated by government agencies all over the world. One of the major challenges of warning centers is to rapidly forecast tsunami threats immediately after an earthquake, when there is high uncertainty due to data deficiency. A solution to this problem, called *probabilistic tsunami forecasting* (*PTF*), has been proposed by Selva et al.[3] PTF treats data and forecast uncertainties, enabling alert-level definitions according to any predefined level of conservatism, which is connected to the average balance of missed-versus-false alarms. Impact forecasts and their resulting recommendations become progressively less uncertain as new data become available.

ROLE OF SOCIAL MEDIA IN DETECTING HAZARDS

In the context of natural disasters, the use of social media has enabled eyewitnesses and other disaster-affected people to share information about their damages, risks, and emergencies in real time. The widespread use of social media allows people who are victims of disasters (for instance, earthquakes and landslides) to share real-time information about damages, problems, and subevents that can take place at different locations after a disaster (for example, collapsed bridges and broken gas pipes). The analysis of social media posts is very useful to identify and extract small-scale events that affect small communities. In fact, each disaster creates a series of small-scale emergencies (subevents), such as family members stranded, power outage, damage to buildings, school closure, or damage to bridges. Normally, these subevents affect only a small portion of the population in the disaster area and thus receive less attention and a delayed response. Among other causes, the lack of information about these events causes a slow response from the authorities, especially during an ongoing disaster. Valuable information is known only to people located where the events occurred, and it can be shared through social media platforms with rescue teams and authorities that are far away from the area. As an example, during Hurricane Harvey in 2017, when 911, the U.S. emergency telephone number, was overwhelmed by thousands of calls from those in need of immediate aid, people turned to social media to ask for help.[4] Research studies show the importance and usefulness of the information shared during disasters, both through traditional infrastructures[5] and social media.[6]

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For handling these kind of occurrences, we and our colleagues proposed a system called *Sub-Events Detection on sOcial Media During Disasters* (*SEDOM-DD*), for detecting and signaling subevents during disasters.[7] Specifically, the designed system addresses two important issues: understanding whether a post is relevant about a disaster, and discovering the subevents that occurred in the disaster area. SEDOM-DD performs these tasks in four main steps: 1) collecting posts that are potentially related to the disaster, 2) filtering posts to keep only the relevant ones, 3) enrichment data by using information contained in posts to increase the number of posts for which it is possible to estimate their geolocalization, and 4) using clustering techniques on geotagged relevant posts for detecting subevents. Using 80% of relevant posts and 15% of geotagged posts, the system correctly detects the subevents and their location areas with an accuracy of approximately 85%. In all the other configurations that were considered, SEDOM-DD was able to detect subevents with high accuracy, revealing its effectiveness even when dealing with noisy data.

Other studies on the use of social media data for signaling natural disasters have recently been carried out. For example, Avvenuti et al.[8] developed the Earthquake Alert and Report System (EARS), which analyzes streaming data from Twitter for detecting seismic events. Such a system exploits a burst-detection algorithm to identify earthquakes from tweets, and processes the corpus of each message for determining the impact of the seismic events on people and infrastructure. LastQuake[9] is a system that was developed in collaboration with the European Mediterranean Seismological Center that provides eyewitnesses with visual information on felt earthquakes and, at the same time, allows for the collection of user feedback on the main seismic shock and its subsequent aftershocks. Finally, Sangameswar et al.[10] proposed a sentiment analysis approach for identifying the places of natural disasters (for example, earthquakes), which could be a region, country, or continent.

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The use of urgent computing technologies can increase the safety of residents when a disaster occurs and reduce the burdens of government offices and workers involved in disaster management. The real-world examples we discussed show how urgent computing systems used in disaster prevention, detection, and management are novel and very useful means for improving natural disasters assessment, speeding up interventions, and minimizing damages to people and infrastructures. By harnessing HPC systems, big data, and machine learning techniques to create powerful urgent computing solutions, researchers are making natural hazard prediction more accurate and effective in limiting damage, improving rescue services, and saving lives. C

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