With inspiration from Tetris, researchers develop a better radiation detector

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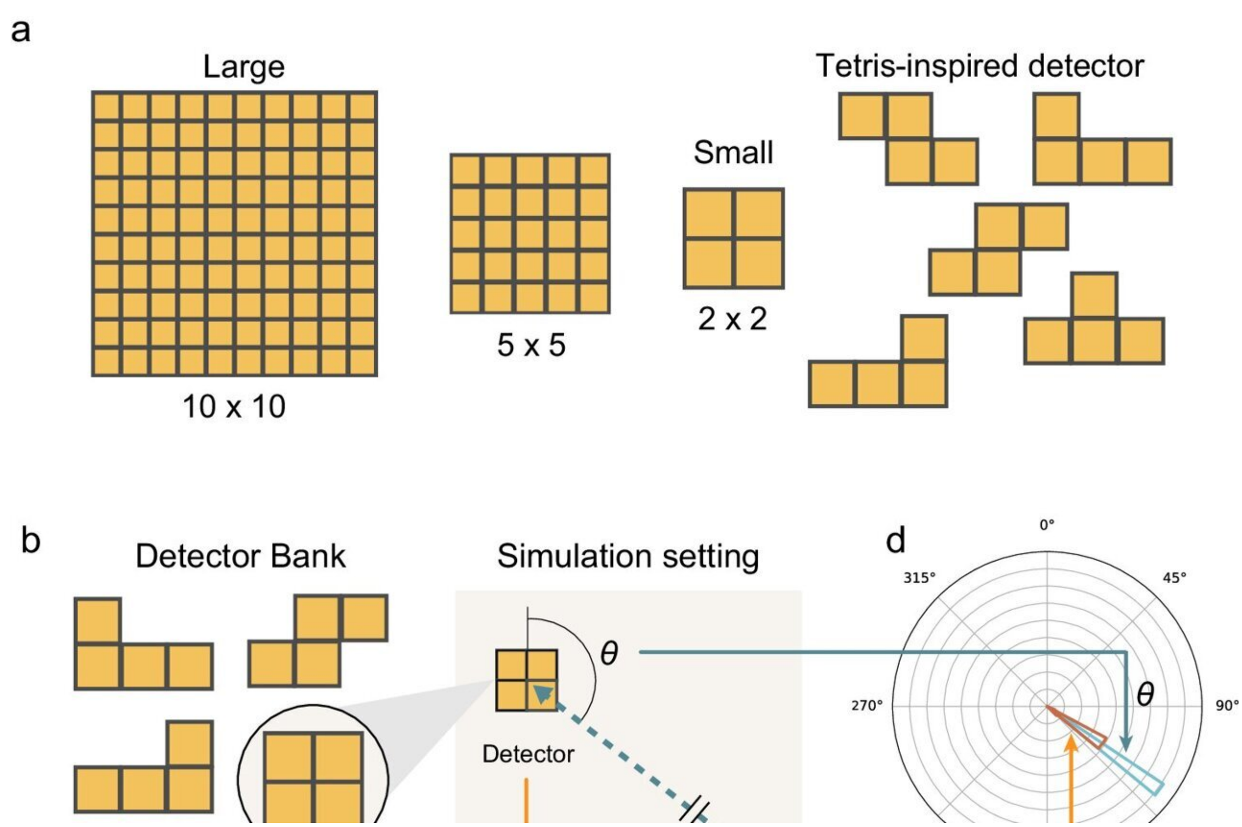

Overview of Tetris-inspired radiation mapping with neural networks. Credit: *Nature Communications* (2024). DOI: 10.1038/s41467-024-47338-w

The spread of radioactive isotopes from the Fukushima Daiichi Nuclear Power Plant in Japan in 2011 and the ongoing threat of a possible release of radiation from the Zaporizhzhia nuclear complex in the Ukrainian war zone have underscored the need for effective and reliable ways of detecting and monitoring radioactive isotopes.

Less dramatically, everyday operations of nuclear reactors, mining and processing of uranium into fuel rods, and the disposal of spent nuclear fuel also require monitoring of radioisotope release.

Now, researchers at MIT and the Lawrence Berkeley National Laboratory (LBNL) have come up with a computational basis for designing very simple, streamlined versions of sensor setups that can pinpoint the direction of a distributed source of radiation. They also demonstrated that by moving that sensor around to get multiple readings, they can pinpoint the physical location of the source. The inspiration for their clever innovation came from a surprising source: the popular computer game "Tetris."

The team's findings, which could likely be generalized to detectors for other kinds of radiation, are described in a paper published in *Nature Communications*, by MIT professors Mingda Li, Lin-Wen Hu, Benoit Forget, and Gordon Kohse; graduate students Ryotaro Okabe and Shangjie Xue; research scientist Jayson Vavrek SM '16, Ph.D. '19 at LBNL; and a number of others at MIT and Lawrence Berkeley.

Radiation is usually detected using semiconductor materials, such as cadmium zinc telluride, that produce an electrical response when struck by high-energy radiation, such as gamma rays. But because radiation penetrates so readily through matter, it's difficult to determine the direction that signal came from with simple counting.

Geiger counters, for example, simply provide a click sound when receiving radiation without resolving the energy or type, so finding a source requires moving around to try to find the maximum sound, similar to how handheld metal detectors work. The process requires the user to move closer to the source of radiation, which can add risk.

To provide directional information from a stationary device without getting too close, researchers use an array of detector grids along with another grid called a mask, which imprints a pattern on the array that differs depending on the direction of the source. An algorithm interprets the different timings and intensities of signals received by each separate detector or pixel. This often leads to a complex design of detectors.

Typical detector arrays for sensing the direction of radiation sources are large and expensive and include at least 100 pixels in a 10 by 10 array. However, the group found that using as few as four pixels arranged in the tetromino shapes of the figures in the "Tetris" game can come close to matching the accuracy of the large, expensive systems.

The key is a proper computerized reconstruction of the angles of arrival of the rays, based on the times each sensor detects the signal and the relative intensity each one detects, as reconstructed through an AI-guided study of simulated systems.

Of the different configurations of four pixels, the researchers tried—square, S-, J- or T-shaped—they found through repeated experiments that the S-shaped array provided the most precise results. This array gave directional readings that were accurate to within about 1 degree, but all three of the irregular shapes performed better than the square. This approach, Li says, "was literally inspired by Tetris."

The key to making the system work is placing an insulating material, such as a lead sheet, between the pixels to increase the contrast between radiation readings coming into the detector from different directions.

The lead between the pixels in these simplified arrays serves the same function as the more elaborate shadow masks used in the larger array systems. Less symmetrical arrangements, the team found, provide more useful information from a small array, explains Okabe, who is the lead author of the work.

"The merit of using a small detector is in terms of engineering costs," he says. Not only are the individual detector elements expensive, typically made of cadmium-zinc-telluride, or CZT, but all of the interconnections carrying information from those pixels also become much more complex. "The smaller and simpler the detector is, the better it is in terms of applications," adds Li.

While there have been other versions of simplified arrays for radiation detection, many are only effective if the radiation is coming from a single localized source. They can be confused by multiple sources or those that are spread out in space, while the "Tetris"-based version can handle these situations well, adds Xue, co-lead author of the work.

In a single-blind field test at the Berkeley Lab with a real cesium radiation source, led by Vavrek, where the researchers at MIT did not know the ground-truth source location, a test device was performed with high accuracy in finding the direction and distance to the source.

"Radiation mapping is of utmost importance to the nuclear industry, as it can help rapidly locate sources of radiation and keep everyone safe," says co-author Forget, an MIT professor of nuclear engineering and head of the Department of Nuclear Science and Engineering.

Vavrek, another co-lead-author, says that while in their study they focused on gamma-ray sources, he believes the computational tools they developed to extract directional information from the limited number of pixels are "much, much more general." It isn't restricted to certain wavelengths, it can also be used for neutrons, or even other forms of light, ultraviolet light, adds Hu, a senior scientist at MIT Nuclear Reactor Lab.

Nick Mann, a scientist with the Defense Systems branch at the Idaho National Laboratory, says, "This work is critical to the U.S. response community and the ever-increasing threat of a radiological incident or accident."

More information: Ryotaro Okabe et al, Tetris-inspired detector with neural network for radiation mapping, *Nature Communications* (2024). DOI: 10.1038/s41467-024-47338-w

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