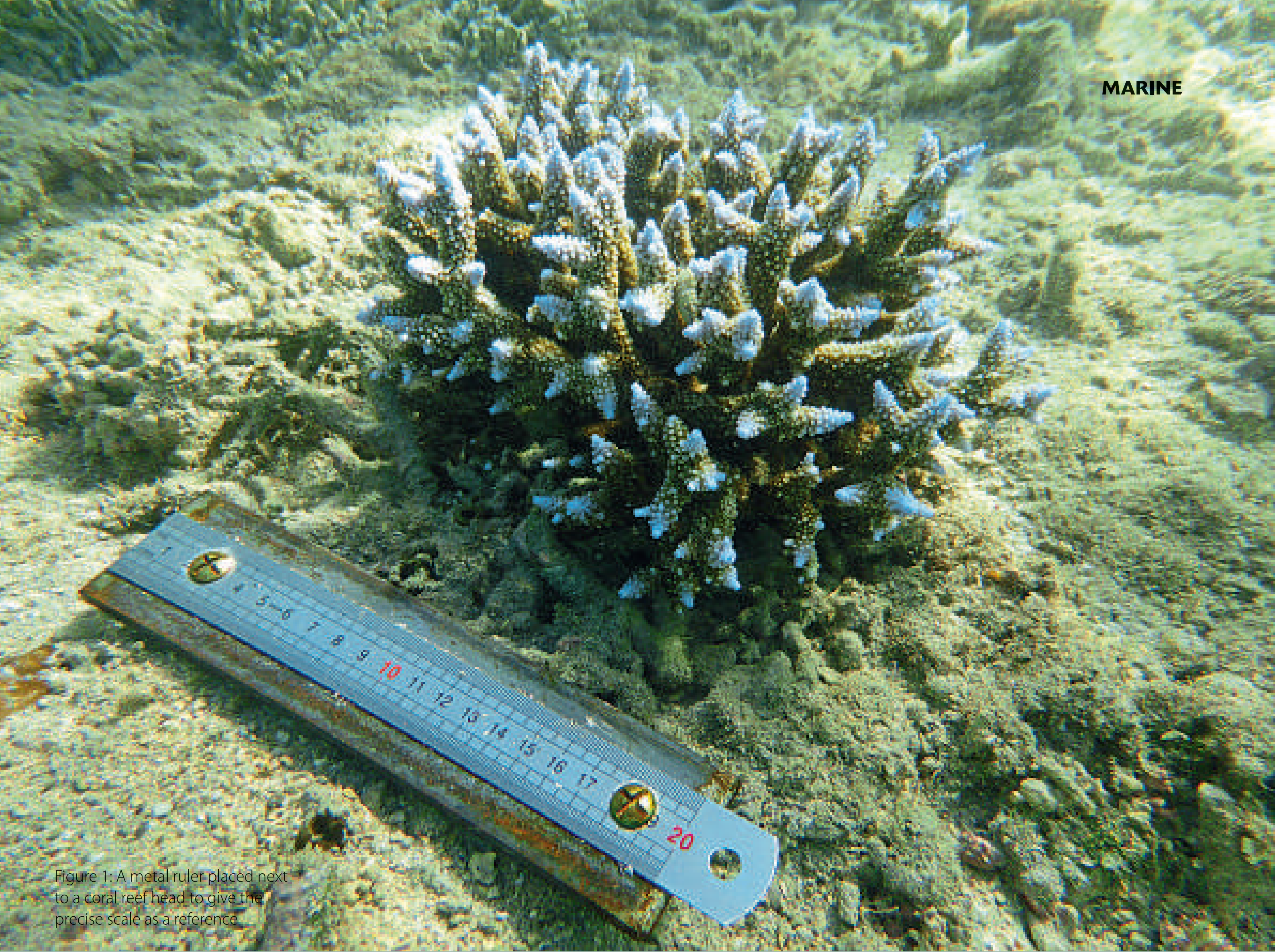

Figure 1: A metal ruler placed next to a coral reef head to give the precise scale as a reference

DIVING INTO UNDERWATER PHOTOGRAMMETRY

UNDERWATER PHOTOGRAMMETRY PRESENTS ITS OWN UNIQUE CHALLENGES. LISA CHEN AND ROMAIN PINEL DISCUSS A NEW APPROACH THAT'S ALREADY PRODUCING GOOD RESULTS IN THE INDIAN OCEAN

In recent years, photogrammetry has extended from aerial to terrestrial and now to underwater. Using photogrammetry under water is still in an exploratory phase, but the need already exists for industries, such as environmental monitoring, archaeology, forensics, and infrastructure inspection. With a measureable 3D model or 2D map that covers a large area, ship or plane wrecks can be documented for scene reconstruction; bridge piers can be inspected for maintenance and repair; ancient cultural heritage can be mapped and archived for further research; focused regions can be repetitively monitored for detecting environmental change; and more.

Ocean dynamics have a great impact on the entire globe: the bleaching of coral reefs, for example, is an important index of the impact of El Niño. Last year, Pix4D began work with Pierre-Antoine Poncet and French oceanic conservation organisation, Reef Check, on a protocol for mapping the coral reefs of Saint-Leu near the French island of Réunion in the Indian Ocean. The project has successfully aroused a lot of attention and attracted more people to participate in as well as improve mapping techniques.

Coincidentally, following a preliminary test of a few underwater images that gave promising results, GIS and surveying company Geolab, also based on Reunion Island, decided to develop its own mapping protocol. Based on its experience in aerial mapping and with the support of subsea works company Seanergy Océan Indien, Geolab created a method of acquiring images for photogrammetry that could be processed with Pix4D's mapping software, Pix4Dmapper Pro.

Camera calibration

The immersion of a camera in water results in distortions to any captured images, as the water refracts light. Geolab's first step was to assess whether Pix4Dmapper Pro could accurately calibrate and undistort the images captured underwater with the company's mirrorless camera.

It performed a special calibration project using a calibration target (see Figure 2), then compared the adjusted internal camera parameters computed by the software to the theoretical values from the law of refraction. The software calibration was in line with the theory. Both results were equivalent, indicating an increase of focal length in the same proportion.

Experience from further projects tended to show that Pix4Dmapper Pro is generally capable of automatically calibrating the camera correctly for sets of good quality images with sufficient overlap, without this pre-calibration procedure of the camera.

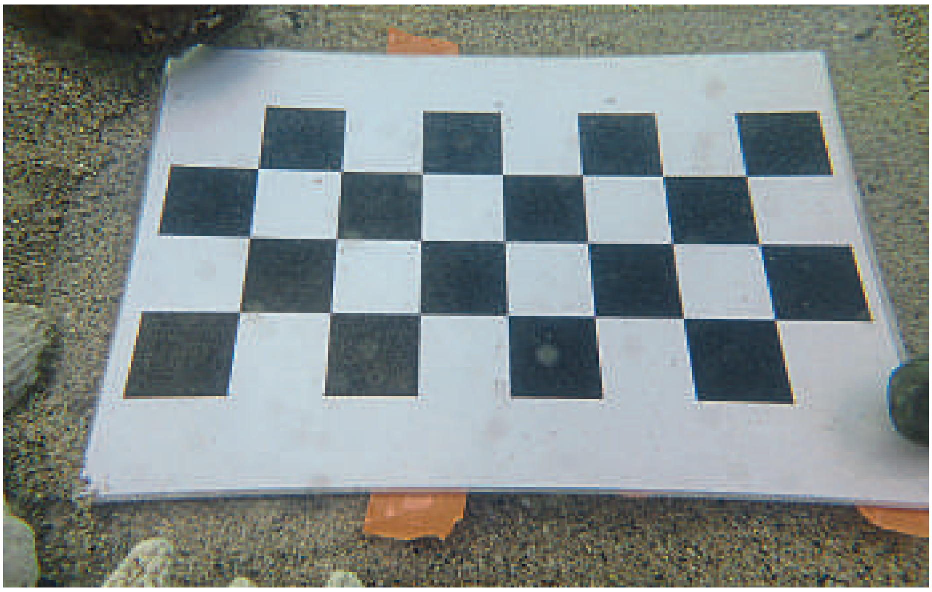

Figure 2. One of the original images used for the calibration project showing important distortions

Distance-based image acquisition

As in most underwater projects, time-lapse images were taken by a camera moving above or around the object of interest. However, this creates many problems for post-processing images. Unlike above-ground, the speed underwater cannot be known or estimated precisely and divers will take many useless images while swimming against the current and not enough images when swimming with it. This inconsistent image overlap either requires considerable manual work to pick out the unnecessary images or risks messing up the calibration, due to short baselines or disconnection of the content of adjacent images.

The method Geolab developed and applied requires a team of at least four professional divers, including one boat operator and one or two photographers, along with a project coordinator. Instead of taking images randomly based on time-lapse, it enables the divers to know exactly where each image must be taken, the divers manually triggering the camera at specific positions based on the distance to the object and to the previous and adjacent images. This results in a much more regular distribution of images, easier calibration and better 3D reconstruction, while optimising the precious time spent underwater by the surveying team (see Figure 2).

However, mapping underwater is still far trickier than on land: as well as differences caused by refraction of light by the water, small particles suspended in the water can strongly affect visibility. The divers therefore need to know the basics of photogrammetry and to adapt the procedure depending on the visibility that they experience on-site.

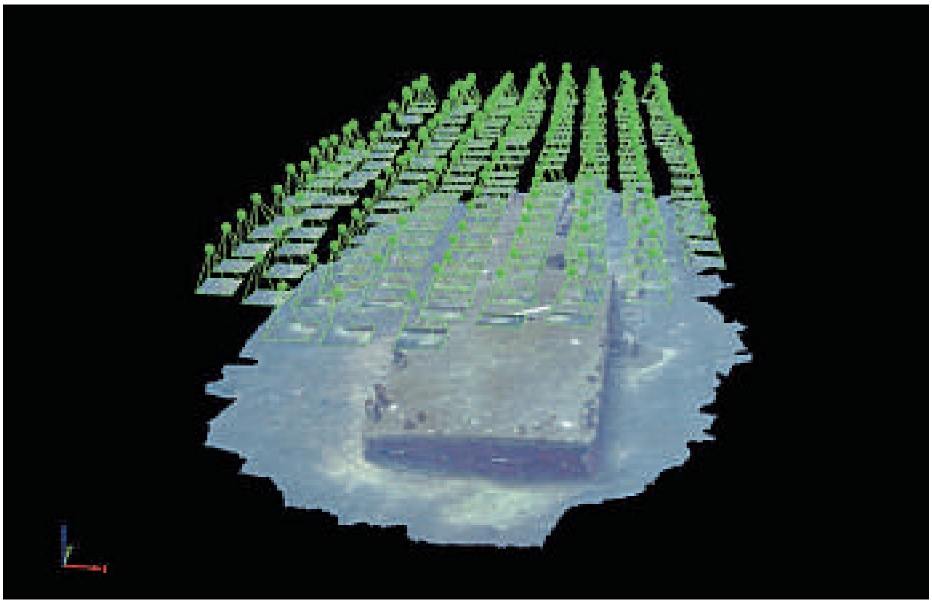

Figure 3. An image acquisition plan that ensures consistent image overlap

Figure 4. Metal scale bar and tags placed in the mapped area to be used in Pix4Dmapper Pro as a scaling tool and as GCPs

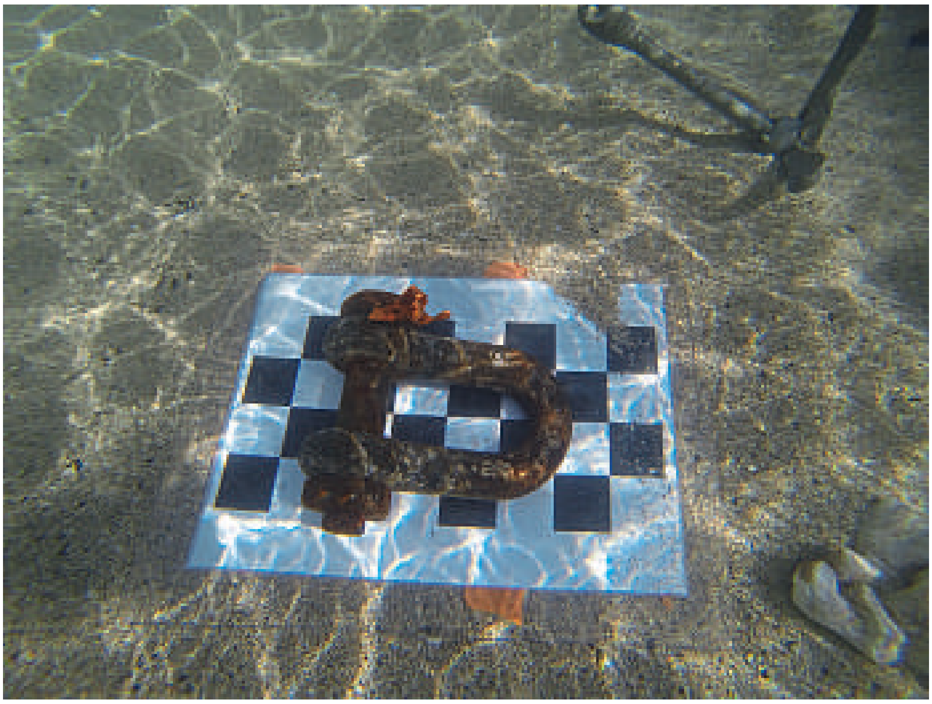

Figure 5. Light patterns change due to the water surface waves

Accuracy

For mapping professionals and surveyors, accuracy is a requirement. Currently, most of the underwater mapping projects are still in the experimental phase, trying to reconstruct 3D images from the acquired photographs.

Having figured out a way to capture images in the optimal plans for mapping, Geolab's team needed to go a step further to ensure the 3D reconstruction was accurate and to be able to geolocate their projects referenced to a global coordinate system.

Scales and measurements

Based on a common scaling method used in archaeological photogrammetry, the team placed either rulers or customized scale bars in the mapped area and then indicated their actual dimensions in Pix4Dmapper to scale the entire projects. These scaling tools should preferably be as long as possible and placed perpendicular to each other to decrease the relative length error and the possible error in one direction (see Figure 1).

To verify the 3D reconstruction is precise, extra scale bars can be placed on site to check that the measurements computed in the software after the scaling step match their actual dimensions. This ensures any 2D or 3D measurement in the projects are accurate, which is essential for any mapping work.

Tags, GCPs and geolocation

As in some aerial mapping practices, metal tags are also distributed over the surveyed area. While not obligatory, they help the software to find and match identical keypoints between images (the software operator confirms them as manual tie points) and can be used as ground control points (GCPs) for georeferencing the project (see Figure 4).

Limits and visual aspects

Lighting conditions

In water shallower than about 3m, the light patterns illuminating the mapped area between images often change – when sunlight hits the surface of water, waves create numerous concave and convex lenses that reflect and refract the light in a very complex and unpredictable way. As a result, images that depict the same object can still be very different from one another, resulting in difficult photogrammetry processing. Therefore, underwater mapping projects in shallow water can be extremely difficult (see Figure 5).

However, going deeper does not necessarily mean getting away from light problems. When light travels in water, it is absorbed, refracted or reflected, each wavelength behaving differently, leading to different travelling distances.

Figure 6 shows the theoretical distance light penetrates underwater according to its wavelengths and the resulting loss of colour. You can see that the underwater environment gets darker proportional to the distance from the surface. Even though the short wavelengths possess larger energy and penetrate longer, they are still refracted and absorbed. At depths greater than 40m, only blue light is visible and the loss of light is rapid.

Geolab's projects were mainly conducted between 5m to 25m underwater. By setting higher camera ISO values and increasing the exposure times when needed, the divers could capture sufficient light, although this resulted in poorer images. This is unfortunately very common for underwater mapping and to mitigate this, particularly at depths greater than 30m to 40m, artificial lighting is needed. However, ensuring uniform lighting over the mapped area would be another challenge.

Underwater colours

As all the wavelengths of light do not penetrate equally in water, the visual impact to the captured images is large. At medium depths, filters can be placed in front of the camera to help capture specific wavelengths, but at higher depths, some colours are no longer present and the only way to bring them back is to use artificial light.

The captured images can be colour-corrected in an image editing program before conducting photogrammetry. This can help to restore more natural colours while keeping the continuity of colour intensity (see Figure 7). Although this step is not a mandatory, since the original images can also give accurate results, it certainly creates a more visually-pleasant outcome, which can be very useful for some applications such as coral reef monitoring (see Figure 8).

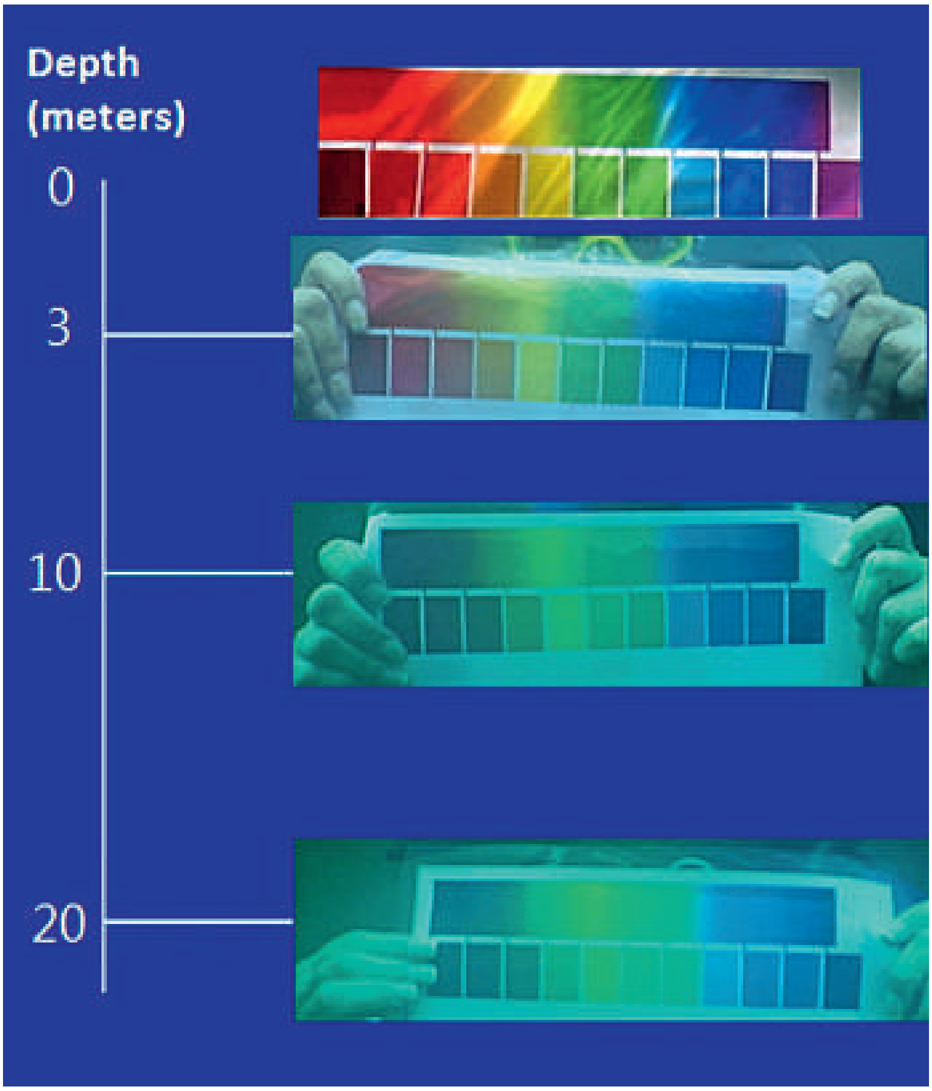

Figure 6. Loss of red when diving deeper

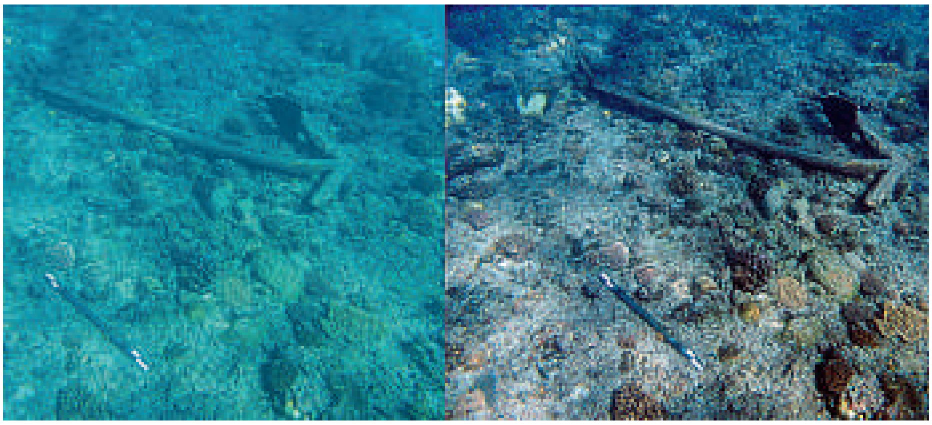

Figure 7. The same underwater image in its original state (left) and after colour-correction (right)

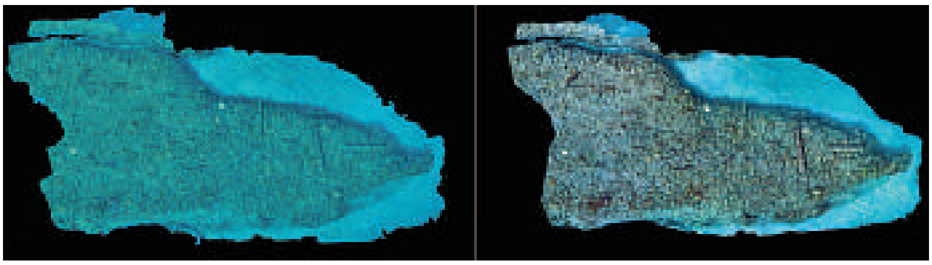

Figure 8. Comparison of a 3D model generated with a set of original images (left) and with colour-corrected ones (right)

Conclusion

Thanks to recent developments of Pix4D's photogrammetry software and Geolab's data acquisition techniques, accurate underwater mapping is now possible, although both companies are still developing their solutions. Geolab plans to upgrade its camera setup and ultimately adapt its acquisition method to remotely operated vehicles, while Pix4D will improve its workflow for processing underwater images. With Pix4D's pre-calibrated camera database, Pix4Dmapper Pro is capable of reconstructing 3D images in a very short time. However, since focal length changes significantly underwater, more adaptable processing options will be needed. Pix4D and Geolab will collaborate on future projects and assist each other's progress, extending this advancement beneath the water surface.

MAPPING UNDERWATER IS STILL FAR TRICKIER THAN ON LAND

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