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CROWDSOURCING

Educational Games for Malaria Diagnosis

CROWDSOURCING OF COMPLEX TASKS TO EXPERT AND NONEXPERT POPULATIONS has emerged as a powerful tool to solve intricate or time-consuming problems by merging individual human responses through statistical analysis. This "wisdom of the crowd" has already been used for various exciting applications, such as to predict a protein folding process or for digital recognition of characters scanned from old books or newspapers (*1*, *2*). Recently, we introduced a gaming-based crowdsourcing platform—BioGames (http://biogames.ee.ucla.edu)—for distributed biomedical image analysis and diagnosis (*3*, *4*). Online gamers collectively assist us in the diagnosis of malaria-infected red blood cells by inspecting microscopic images of cells—a task that requires a trained diagnostician, often leading to incorrect diagnoses especially in resource limited settings (*5*).

GREATER THAN THE SUM OF ITS PARTS

The general concept of crowdsourcing biomedical image analysis and related diagnoses to a group of diagnosticians is compelling for several reasons. First, the process of statistically combining the decisions of individuals improves the accuracy and specificity of the diagnosis, which can surpass results provided by even the best expert in a group of diagnosticians (*4*). This crowdsourced analysis can be especially powerful if we have the history of each expert's error rates. In other words, we can build a community of experts and then track their performances through the use of control images carefully embedded in the collection of test images. With this information, we can reach an accurate diagnosis, even with a limited number of relatively poorly trained diagnosticians, by statistically giving less weight to the answers from those who responded inaccurately to the control images (*3*, *4*).

A second, important use of crowdsourced biomedical image analysis is telepathology, in which specimens that are imaged at, for example, a local point-of-care office with inadequate expertise can be inspected remotely by a group of experts. Considering the large false-positive rates in malaria diagnosis in some developing countries (*5*), crowdsourced telepathology could be especially helpful in reducing the overuse and misuse of medicines, thus minimizing drug resistance and side effects and improving the management of other diseases that have similar symptoms.

A third noteworthy outcome of crowdsourcing biomedical image analysis to a network of diagnosticians is the creation of gold-standard image libraries that can be used for education and training as well as for the development of machine-learning algorithms that facilitate automated classification or tagging of biomedical images.

PLAYING DOCTOR

The BioGames malaria-diagnosis gaming platform has been available online for almost 2 years now, and a few thousand gamers from more than 80 countries have participated in our online experiments to test whether nonexpert gamers can collectively come close (within, for example, ~1 to 2%) to the accuracy of an expert diagnostician (*3*, *6*). (They do.) The same BioGames platform also has been played by a group of expert diagnosticians to create gold-standard labels for individual red blood cell images. For this case, in which the gamers were all well-trained experts, they were given three choices for each cell image: positive (malaria infected), negative (uninfected), and questionable (the image does not contain sufficient information to make a reliable diagnosis); questionable cells might contribute a source of images that yield false diagnoses. On the basis of responses from these expert gamers, we mathematically converged on a gold-standard label for each cell image using an expectation maximization algorithm (*4*). This multiuser cell-analysis system allowed us to create a malaria image library composed of more than 2850 distinct red blood cell images, of which ~4 and ~5% are labeled as positive and questionable, respectively, and the rest as negative.

On 25 April 2014, World Malaria Day, we will release this BioGames image library to the public as an educational training module and expert scoring system. Each online gamer will be shown and asked to rate ~500 cell images per game, and through their responses,

we can assess their level of training in identifying malaria-infected cells. At the end of each game—which can be played on personal computers or mobile phones—the gamer is given a quantified score that is based on their false-positive and false-negative rates. Each deck of images per game is created randomly from a subset of our malaria image library [characterized through BioGames (*4*)] in which each selected cell image also undergoes random rotations; this process gives the gamers many opportunities to play the training module with new sets of images every time they start a new game. At the end of each game, a player is given not only a BioGames score, but also training feedback in the form of a list of images that they miscategorized.

We plan to expand our image database as the BioGames platform continues to create gold labels for new microscopic images of thin or thick blood smears. We hope that this continued enrichment promotes widespread use of the educational module, eventually making it a standard digital tool in malaria diagnostic training. With large databases connected to user-friendly games and Web interfaces, this platform can be used not only for efficient and robust training of medical personnel toward accurate reading of microscopic slides, but also for the development of algorithms for automated digital diagnosis of a variety of diseases. Considering the relatively poor training of some health care workers in developing countries, BioGames could be especially valuable for improving the accuracy of malaria diagnoses and of measurements of parasitemia (which is typically much less than 1%) in infected patients who are undergoing treatment.

As the great basketball player Michael Jordan counsels, "Always turn a negative situation into a positive situation." Best of luck with your BioGames scores!

– Aydogan Ozcan

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