ImPatho - an Image Processing Based Pathological Decision Support System for Disease Identification and a Novel Tool for Overall Health Governance

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***Abstract*—Governance of healthcare has been one of most challenging and complex issues of the government of any developing country. Many of the life threatening diseases, such as Sickle Cell Anemia, can be prevented properly if these can be diagnosed on time. In many cases, diagnosis demands a simple blood test to find out deformation in the shape of blood cells. We investigated in this paper, if such tests can be carried out at the doorstep of the likely patient wherein the intervention of a skilled person from the pathology lab is suitably replaced by a technology developed in form of an app. The app and the hardware combo which we propose, called ImPatho, uses image processing algorithm to judge if blood cells are indicative of some disease. Our solution then follows a decision support system through data analyses which can be reported to doctors, district health officers, state health department for proper treatment and monitoring, via our app. It is shown that the developed system, ImPatho, is a complete end-to-end solution for the challenges faced by the government of developing countries particularly where people from remote, tough or even rural terrain cannot come to a nearby pathology lab to get themselves investigated for a likely disease. Our solution ImPatho empathizes this Catch 22 situation and makes an attempt to bring the pathology lab at the doorstep of such helpless people. This is how our system helps ensure proactive, responsive healthcare governance. ImPatho has a huge potential, if scaled to higher levels of governing echelon, to provide an alternative solution for governments who are sensitive towards healthcare of poor people.**

***Index Terms*—Health, Data Analysis, Survey, NGO, Software, Health Care Organization, Microscope, Sickle Cell Anemia, Health Information System, Image Processing, Disease.**

I. INTRODUCTION

Basic education, healthcare, sanitation, drinking water, electricity etc. are some of the fundamental needs of people living in any continent, country or terrain. These are much more serious challenges than computer literacy, Internet of Things (IoT) and "One Laptop Per Child" mission. Each of these problem is so petty and yearned for that it has become too difficult to be solved.

In this paper basic healthcare system and governance is addressed. Healthcare sector is one of the biggest and fastest growing sectors in the world, with several thousand billion dollars being spent every year in this field. As per the WHO statistics 2013 [1], total global expenditure on health as % of gross domestic product (GDP) was 9.2 in 2010. In developed countries like America, this total expenditure in health is 14.3% of GDP while it is only 6.2% in African region and 3.6% in South-East Asia. Poverty, illiteracy and unawareness of healthcare solutions are some of the key reasons for such an imbalance. This shows that in developing countries of the world, it is indispensable to find a cheap, efficient and reliable healthcare solution.

According to the health policy report of The New England Journal of Medicine [2], an *"interoperable"* and *"connectivity"* based Health Information Technology (HIT) can promise to transform healthcare services with improved quality and reduced cost. On the basis of their personal experience, physicians make subjective clinical decisions for patients with similar problems, who may end up receiving different clinical guidelines depending on their geographical location, physician or clinics etc. [3]. One of the reasons for this difference in treatment is lack of past medical history of patients; past history can highly influence the current medical treatment [4].

Many of the healthcare issues may be prevented, had the patients come to a pathology lab for routine check-ups. This is not possible in many of the developing countries because of other pressing problems like non-proximity of these pathology labs or clinics. Very often in many parts of such countries, people used to travel tens of kilometers simply to fetch drinking water. Therefore it is unthinkable that people would visit pathology lab for their basic tests to know about their health condition. Hence, despite of the provision of Community Health Centers, their trained, semi-skilled health workers and a watchful support from WHO, outreach of health support and governance system has not been satisfactory in developing countries. The solution, which we propose, can ensure that these pathology labs reach the population whenever and wherever they need them. Our solution, ImPatho, is an attempt in this direction which is explained in this paper.

Healthcare industry today generates large amount of complex data about patients, hospitals resources, diseases, diagnosis methods, electronic patients records, etc. [5]. These data go to a health care organization. A health care organization is a body which collects, maintains and analyzes the data information regarding the health of people thereby providing a cure for a problem, tangible or intangible, which is by any means related to health. The increasing number of branches of a single health care organization encumbers them from establishing inferences of the collected data, most of the time data being unstructured. Even today, most of the health care organizations use traditional paper based survey method to collect health data which is highly inefficient and costly [3]. Human errors can be introduced while entering paper data into analytical tools which make this method inefficient. Attempts have been made to digitize this system of surveying healthcare data [3], [6] but they have some constraints like internet connectivity requirement for web apps, absence of proper graphical analysis for the collected structured data etc. Our solution, ImPatho, takes care of this part by digitization of data, analysis and dissemination for proper end-to-end monitoring and governance of healthcare mechanism.

II. OUR SOLUTION - IMPATHO

ImPatho is an image processing based pathological decision support system for disease identification. A device to get magnified image of stained blood sample is designed and developed. Its detailed working is explained in section III. The system architecture is briefly mentioned in section IV whereas the key element of our solution, the image processing algorithm, is discussed in section V. This gives all data digitally available for further use, such as storage, analysis and dissemination to appropriate authorities. In section VI the user interface of our solution is elaborated. It also gives information about the database system that we have used to ensure healthcare governance.

In our engineering problem of healthcare governance, we have selected Sickle Cell Anemia, a haemoglobin disorder, as one representative life threatening disease since the most prevalent disease in African countries is Sickle Cell Anemia [7]. The executive summary of WHO states that in several countries, $10\% - 40\%$ of the population carries sickle-cell anemia, a haemoglobin disorder, resulting in estimated Sickle-cell disease (SCD) prevalence of at least 2% [8]. The summary concludes that sickle-cell disease, along with its serious health and socioeconomic impacts, is largely neglected. SCD ultimately results in multiple organ failure and premature death, occurring mostly in children under five years of age, adolescents and pregnant women. It is demonstrated in this paper that SCD can easily be diagnosed by analysing morphological change in RBCs, when infected.

Unlike what is generally perceieved, there are easy and accurate ways to expedite the process of diagnosing RBC disorders like Sickle Cell Anemia, Macrocytes, Microcytes etc., without any human intervention [9]. Visual inspection of microscopic images is the most widely used technique for detection of such disorders despite the fact that this method needs skilled physicians in pathology lab which is time consuming and costly. We try to overcome this disadvantage by analysing morphological changes in RBCs structure. In our paper we used non-combursing image processing technique for this purpose.

The tool which we developed makes an attempt to overcome some of the existing loopholes, thereby providing a simple, lucid, aesthetic and robust solution to the problem of collecting and analysing healthcare data. Also, it tries to provide a cost effective solution to detect Sickle Cell Anemia using image processing of stained blood slides thereby making it easier and cheaper to detect it.

III. SYSTEM DESIGN

According to exploratory case study in South Africa by [10], most *Community Health Workers* who worked as volunteers, provided primary healthcare services in the community despite the fact that they lacked absolute skills required for disease diagnosis. In case of doubt regarding diagnosis, Health Workers refer patients to nearby center of health care organization. The study also discovered that most Community Health Workers are familiar with the basic use of a mobile phone - this creates an opportunity for simple technological tool that will assist these Community Health Workers in their daily activities, help them to access past record of patient and record new one. In this section, we will describe hardware and software design of our idea in subsections A and B respectively.

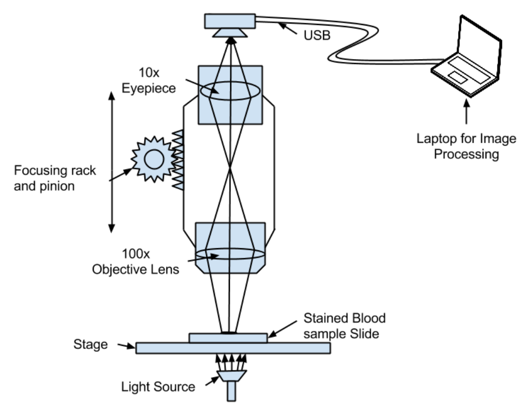


Fig. 1: Hardware design

A. HARDWARE DESIGN

Our hardware has been designed to mitigate human intervention as much as possible. Figure 5 manifests the abstract view of how a magnified image is clicked and processed in the PC or laptop to detect SCD, using image processing techniques. Hardware includes a microscope loaded with an eyepiece of $10X$, objective of $100X$ and mounted a USB webcam.

B. SOFTWARE DESIGN

Our App "ImPatho" has been designed in such a way that it is intuitive to use. The first feature of application provides an aid to the Community Health Workers, who have limited knowledge about common diseases and first aids, by providing some basic information about them. This information can prove to be useful for providing them atleast temporary clinical guidelines. The second part replaces the traditional paper based

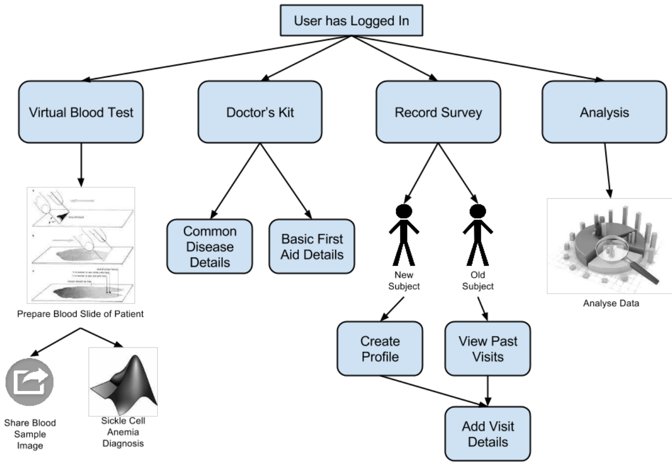


Fig. 2: Impatho: System Design

survey with an electronic survey, which is marginally easier to use and sometimes more enjoyable than paper surveys [11]. Organisations usually hire employees to feed the survey data into computers, present at center. This increases the chances of human error in data. These chances of error and increased salary overhead are reduced by this feature, since Community Health Workers can carry our system to the field and store medical details of patients directly into electronic database. The data collected by different Community Health Workers of different regions, working for same organisation will be synchronized into the cloud whenever internet service is available to the device. The third part provides the user with graphical as well as statistical analysis of the medical data of a particular organisation, provided that organization has registered. Such analysis is very useful for authorities at higher level of echelon in government or health care organizations to making crucial decisions regarding health. Fourth part of application is automatization of SCD diagnosis using microscope with mounted camera whose design is already shown in figure. The workflow of the software design and it's integration with hardware is also shown in figure 2.

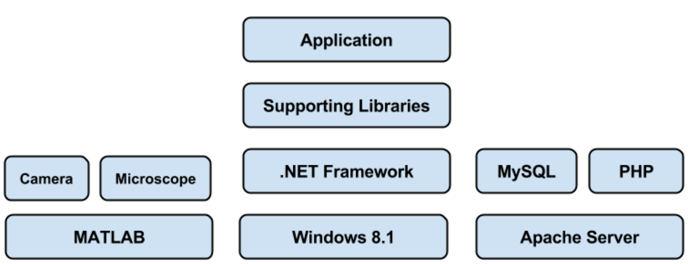


Fig. 3: ImPatho: System Architecture

IV. SYSTEM ARCHITECTURE

Various technologies have been used to implement the software and its features. ImPatho is an Windows 8.1 Store App contrived using .NET framework, SQLite, MySQL, Windows UI Metro ChartModern UI Charts for Windows 8[12], MATLAB and supporting libraries. The software part has been coded in C# and PHP. The system architecture for the application has been shown in the figure 3.

V. ALGORITHM FOR DETECTION OF SICKLE CELL ANEMIA

The key element of our system ImPatho is an image processing algorithm for making a preliminary judgement about Sickle Cell Anemia. The idea that normal RBC has circular shape while SCD affected RBC has elliptical shape as shown in figure 4. If an RBC has eccentricity near 1 then it's an indication of infected cell while if it is near 0 then it's an indication of healthy cell. We have used MATLAB 7.10 to implement this image processing techniques of algorithm, pseudocode for the same has been shown as algorithm 1.

Fig. 4: The above image shows contains normal RBCs and Sickle Cell Anemia affected RBC

As shown in part a of figure 6, first of all the we convert the magnified image obtained from microscope to grayscale image. Then, this grayscale image is converted to part b of figure 6 since we are interested in identifying the number of complete objects who have mutation in their shape. Next, we fill the borders, as shown in part a of figure 7, since this step will only fill those objects which are enclosed or complete. This is done by edge detection of all objects in the frame of the image captured by the mounted camera. The method used for edge detection is Canny Edge Detection, which is one of the best known edge detection algorithm [13]. Remaining objects which were not enclosed are noise in our image processing so they can be removed by border removal step as shown in part b of figure 7. This resulting image we get will have only complete objects either circular or elliptical, prior ones indicate normal RBC's while the later ones are indicative of Sickle Cell Anemia.

Remark 1. *(For * in Algorithm 1) aThreshold - Range of areas (in pixels) within which a RBC falls. If the area of an object doesn't fall in this range then it is an overlapped version of cells or an impurity in image.*

Algorithm 1 Algorithm for detecting Sickle Cell Anemia

Require: Magnified Images of stained blood slide using 10x eyepiece and 100x objective
Ensure: Percentage of elongated RBC's in blood sample
  for each image in the specified directory **do**
    Convert RGB image to Grayscale image
    Find the edge of all the cells in the image
    Fill the cells with boundary color, whose edges are enclosed
    Remove the unenclosed cell edges from the image
    Remove cells located at the border of the image
    Remove cells whose area is outside aThreshold*
    for each cell in image **do**
      Calculate the eccentricity of the cell
      Store the calculated eccentricity in the eArray
    end for
    for each eccentricity in eArray **do**
      if eccentricity >= eThreshold** **then**
        Count the number of affected cells
      end if
    end for
    if number of affected cells >= nThreshold*** **then**
      This image sample indicates presence of Sickle Cell Anemia
    end if
  end for
  print Percentage of image samples indicating presence of Sickle Cell Anemia.

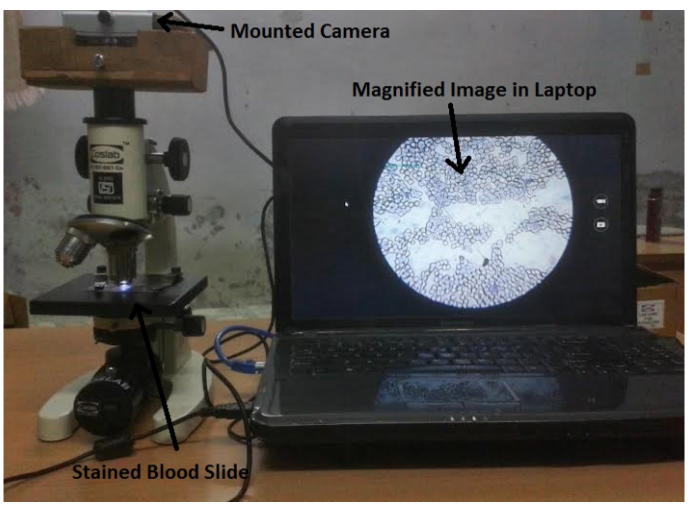
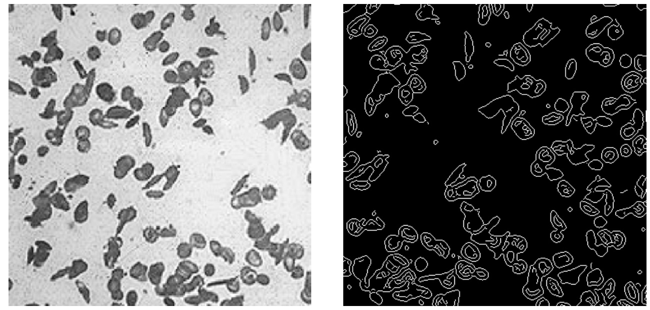


Fig. 5: This is how we the camera sees the image.

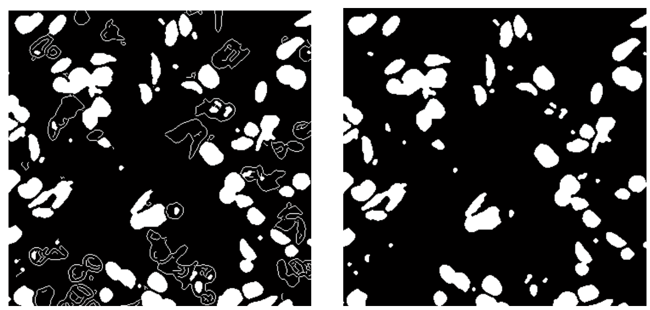
Remark 2. *(For ** in Algorithm 1) eThreshold - This is the limit of eccentricity value, an unaffected call can have. So, if any cell's eccentricity value in the eArray is out of this threshold, it's a positive sign for Sickle Cell Anemia.*

Remark 3. *(For *** in Algorithm 1) nThreshold - This is the minimum number of affected cells in a sample, to conclude the sample as if it is affected by Sickle Cell Anemia.*



(a) Grayscale Image (b) Border Detection Image

Fig. 6: This figure shows the first two steps which inculde converting an image to grayscale and then detected the edges of the cells.



(a) Filled Border Image (b) Border Removed Image

Fig. 7: This figure shows the later two steps which inculde converting an image with detected border to filled border image and then after removing the border from it.

VI. GRAPHICAL USER INTERFACE (GUI) OVERVIEW

"ImPatho" has been primarily developed to facilitate an easy way to collect, manage and analyse healthcare data collected by Community Health Worker. Other important feature coved by the App is Virtual Blood Test where in we detect haemoglobin disorder - Sickle Cell Anemia - by image processing of stained blood slide. So, there are four basic modules of the App as discussed in the sections A, B, C and D. Any Health Care Organization, which wants to use our App, first needs to signup and then after logging into the App, they will see the homepage of the App as shown in figure 8.

A. VIRTUAL BLOOD TEST

In this section, we used algorithm 1 to detect Sickle Cell Anemia. We made a MATLAB script to do the same, which is invoked from our App. After setting up the respective hardware, the user will have to take the snapshots of the magnified blood sample from the App. Once this is done, he needs to press TEST button which will start MATLAB GUI

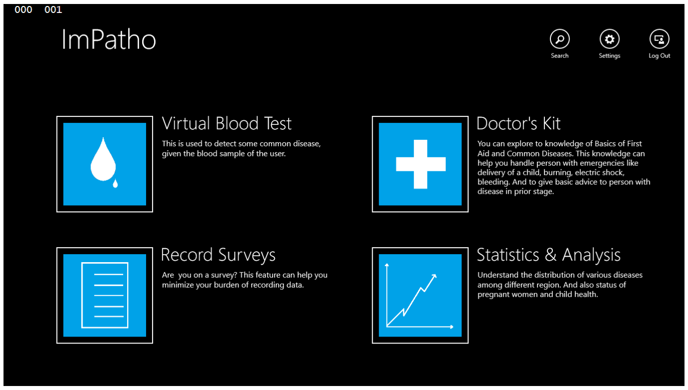


Fig. 8: ImPatho: Main Menu Page

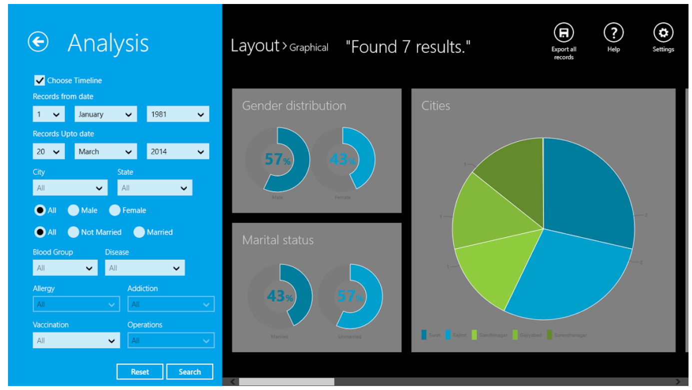


Fig. 10: ImPatho: Statistical Analysis Page

where in user needs to select threshold and then go for the test.

B. DOCTOR'S KIT

This section is an add-on to the App, which can be proved useful in case health volunteer would like to refer to the information for basic diseases or basic first aids. The App is preloaded with some common kinds for both of them but, in case the Health Care Organization would like to avail it's health volunteers with the information about some other diseases or first aids, which they believe are common in their region of operation, then they can add them later. Also, existing information can be edited and deleted, if required.

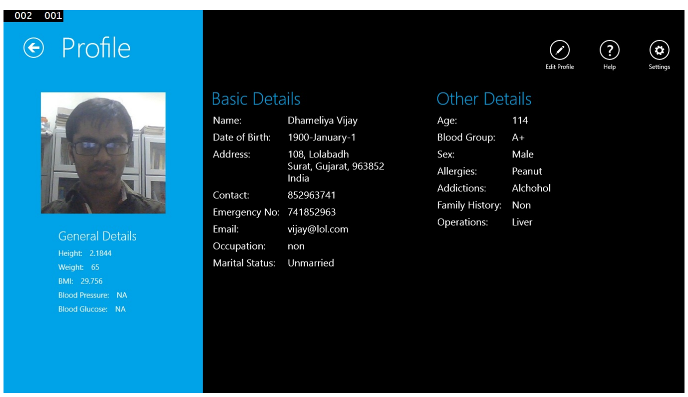


Fig. 9: ImPatho: Medical Visit Page

C. RECORD SURVEYS

This page displays few patient records classified according to their towns. User can select any one town, in case he would like to see all the patient's records for that town. These records can be edited and deleted, also new can be added. When the user clicks on any record, a new page will be opened showing all his records sorted according to his date of visit as shown in figure 9. Every visit contains patient's medical details like date of visit, symptoms, disease diagnosed, medicines given, height, weight, blood pressure, blood sugar etc. Also, View Profile button can be clicked, incase user would like to view or edit patient's profile.

D. STATISTICAL ANALYSIS

Using this module of ImPatho, a Health Care Organization can do detailed analysis of the surveyed data. If the organization wants all the patients in an area X, of age Y, with disease Z, who are married/unmarried, then the user can select the respective parameters in the search box and he will get graphs for the data as shown in figure 10 in the resulting dashboard. This kind of analysis may be useful at various levels of monitoring and governance. If a big health care organization wants to know how many doctors, of particular speciality should they send to a specific village or city, in which season, then it can be estimated using this analysis module of our App. On the other hand, data about particular age groups can also be collected. However, a lot of other possibilities do exist.

CONCLUSION AND FUTURE WORK

We have shown here how ImPatho tells about blood cell disorders pertaining to sickle cell disease. The cost of this device is low and affordable. It costed us less than 7000 INR (USD 110), which is much less as compared to any of the existing digital microscopes with mounted camera. Apart from this, ImPatho requires a laptop of minimal configuration that can run MATLAB in it. Usability of this device has been kept lucid. It requires almost zero maintenance costs unlike the machines used in pathology labs. Also, our App does not require internet connection unless the App is expected to synchronize the data over cloud.

The data collected over time in this App can be used by a health care organization to estimate number of specialized doctors required in an area, how common is any indigenous disease in an area, which season do they occur in, which age-group or sex has it affected the most etc. and many more queries. Also, this data collected can be shared, after approval of the patient, to other health care organization thereby helping physicians of that organization to provide proper clinical guidelines.

For showing scalability of ImPatho, we also attempted to code algorithm for detecting other RBC disorders like Macrocytes, Microcytes etc. on the basis of same concept of identifying morphological change in RBC. However, this technology is limited as of now only to the diseases where a change in RBC's morphology is observed. However, we hope that ultimately the ImPatho facility would enable testing for HIV, malaria and numerous other life-threatening diseases. The challenge for inclusion of any new disease for identification is to develop the Matlab code for the unique confirmatory test advised for that disease.

The data analyses given by ImPatho can be accessed by Doctors, District Health Officers, State Health Secretaries, National Health Mission Directors and other policy makers for proper treatment, monitoring, and governance of healthcare. It is shown that ImPatho is a complete end-to-end solution for the challenges faced by the government of developing countries particularly where people from remote, tough or even rural terrain cannot come to a nearby pathology lab to get themselves investigated for a likely disease. In this way, our system helps ensure proactive, responsive healthcare governance. ImPatho has a huge potential, if scaled to higher levels of governing echelon, to provide an alternative support for governments who are sensitive towards healthcare of poor people.

We are also hopeful that ImPatho has great potential to address global healthcare crisis faced by low-income population. We see the future of ImPatho to be integrated with the recently launched concept of solar powered mobile clinic [14]. Solar powered mobile clinics are in use these days in many parts of Africa [15] and even in England [16]. These provide ENT, dental, maternity related quality medical treatment [17]. This system will enhance the scalability of ImPatho for the diseases, wherein we need the blood sample slides to be prepared under controlled temperature and pressure conditions. These solar powered mobile clinics are equipped with refrigerators running on the secondary power unit which will preserve those chemicals safely and thereby enabling ImPathos reach to any tough terrain land or in any area where electricity is scarce.

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