

An Interactive Visual Analysis Tool for Cellular Behavior Studies Using Large Collections of Microscopy Videos

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Abstract—This paper presents an interactive visual analysis tool created for studying collections of video data. Our driving application is cellular behavior studies that use microscopy imaging methods. The studies routinely generate large amounts of videos with various experimental conditions. It is very time-consuming for the scientists to watch each video and manually extract features-of-interest for further comparative and quantitative studies. We show that with our visualization tool, scientists are now able to conveniently observe, select and isolate, and compare and analyze the cellular behaviors from different perspectives within one framework. The tremendous time and effort saved allow scientist to focus on deriving the actual meaning behind certain observed behaviors.

I. INTRODUCTION

In many fields of life and physical sciences, studying cell dynamics and function using microscopes is an essential task. As the microscope technology continues to advance, over a study images can be generated at increasing resolution and rate, resulting in vast amounts of data to be processed and analyzed. The previous manual way of processing and examining the image data is no longer feasible. A new set of tools is needed.

This paper presents such a tool, which we call “*CellVis*”, whose design is driven by the need of analyzing large collections of video data generated from controlled experiments conducted by biochemical scientists for studying time-evolving patterns of cellular behaviors. Such experiments are usually conducted under different stimuli and experimental conditions for comparative studies, and recorded optically in the form of videos with different types of microscopies. Using a collection of such videos, scientists try to understand cellular behaviors against particular types of stimuli. They can observe and quantify the changing geometric properties of the cell, such as size and shape, as a function of time. In addition, they want to compare the behaviors under different stimuli captured by different videos. However, playing back and visually comparing a series of videos is a very time-consuming task as scientists often need to compare the experiment results frame by frame and also switch back and forth between different videos. Furthermore, human memory is not designed to remember observed behaviors in a long video sequence especially after watching several videos. Figure 1 shows three diverse example images that are sampled and cropped from the videos used in this study.

Although some microscope image analysis tools, like imageJ [1], have been widely used because of their rich functionalities, the tasks of quantifying desired features and facilitating comparative studies cannot be directly and efficiently accomplished with those individual tools/libraries. For example, due to the low contrast of images from bright field microscope, these tools often fail to accurately detect cell contours, and certainly do not offer functions for handling features specific to a particular domain of study. While a fully automatic video processing system is desired, from time to time, domain experts need to assist in the process of validating, tuning, and analysis, which suggests the need of an interactive user interface. Without our tool, scientists may have to manually direct and verify the feature detection process for each individual video including the corresponding quantitative analysis tasks. This is neither scalable nor reliable.

The premise of our design is the ability to generate a visual summarization of cell behaviors from a large collection of videos under study. Through an interactive visual interface, the user may select a cell of interest from a video, in which such a cell is detected and tracked over the whole time sequence. The extracted cell’s behaviors in terms of geometric properties of interest are quantified and recorded. After all videos are processed, the user can examine a visual summarization of the recorded cell behaviors for all videos and watch individual videos for validation as needed through the same interactive interface.

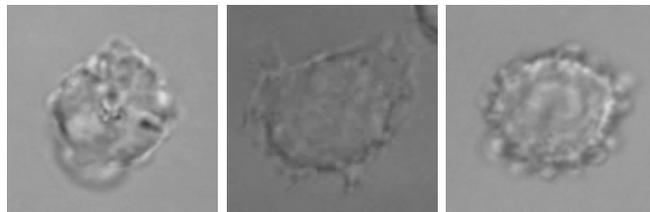


Fig. 1: Examples of subregions from input videos.

Since cell behaviors are characterized by multiple features, it is impossible for the scientists to manually look over these time-evolving features individually and mentally correlate them. Information visualization can become helpful here by visually summarizing the multidimensional information not only for each video but also for all the videos in a study. The visualization presents selected aspects of each tracked cell into

a visual thumbnail, and all visual thumbnails are organized in a spreadsheet-like layout to provide an overview of the whole set of experimental results. The interface allows scientists to perform operations such as filtering by feature parameters, time, and videos, as well as sorting by parameter values.

In summary, we have made tangible contributions to scientific studies involving large collections of video data by creating:

- A visualization design that effectively summarizes multi-dimensional information extracted from a large collection of videos to enable scientists to conveniently study dynamics of cellular features change over time.
- An interactive visualization system that allows scientists to quickly review and verify their hypotheses in cell studies by comparing cell behaviors both qualitatively and quantitatively.
- A set of case studies that we conducted together with domain scientists from biochemistry to demonstrate the effectiveness of our design.

While in this paper we have only demonstrated our design and the resulting tool on microscopy data for the study of cell dynamics, by adding domain-specific feature detection functions, such an interactive visualization system is applicable to *Big* video data in general.

II. RELATED WORK

We reviewed two areas related to our work as follows.

A. Cell Video Analysis

There has been intensive research effort dedicated to cellular behavior studies using microscopy videos. Meijering et al. [2] and Held et al. [3] discussed cellular feature analysis algorithms based on fluorescence microscopy images, while Ali et al. [4], Selinummi et al. [5], and Buggenthin et al. [6] studied bright-field microscopy images. Previous studies show that correlating fluorescence staining and bright-field images [5], or leveraging both in-focus and de-focus images [4] may help address the low contrast problem when analyzing cell images. Research effort has also been made to leverage machine learning techniques for recognizing cells [7]. For example, Kanade et al. [8] and Mualla et al. [9] utilized local image features descriptor to track the overall migration patterns of multiple cells over time. Most of the methods mentioned above have certain limitations that either cell images have to be specially produced or require a large number of pre-labeled datasets. There has been no universal solution for cell recognition/tracking. More importantly, the presentation of their analysis results are mostly annotations on the cell images or the visual summarization of single features. When analyzing a large amounts of video data is required, providing a global summarization for all cellular features will greatly facilitate the analytical process.

B. Video Summarization/Visualization

One goal of video visualization is to assist users to intelligently reason with their data without having to repeatedly

inspect the video. Video visualizations can be seen in various forms, it could be another video, an animation, a collection of images, or even a single composited image [10]. Here we categorize previous video visualization approaches into keyframe-based techniques and abstraction-based techniques and review the literatures respectively.

Keyframe-based techniques detect keyframes from videos and arrange those frames in order. The Stained-Glass Visualization [11] lays out critical regions and blend them together into a condensed visual summary. Kang et al. [12] presented a space-time montage where multiple portions of the video are blended in the same frame. Goldman et al. [13] summarized videos by rearranging selected frames and annotate them with outlines, arrows and text in a storyboard. Bartoli et al. [14] and Correa et al. [15] created panorama-style summaries that naturally blends the foreground motion to a stitched background. Schoeffmann et al. [16] presented a video navigation technique that interactively provides abstract visualization of video contents.

These techniques trim the content of videos and emphasize more on the presentation of featuring frames. As a result, they are less often used in scientific studies, such as in cellular behavior visualization, where scientists usually would expect to see the continuously changing pattern of cell feature(s) to be visualized and analyzed.

Abstraction-based techniques, on the other hand, summarize attributes from video streams. Study subjects are not explicitly depicted from videos. Instead, featuring information are summarized and visualized. For general video visualization, Daniel et al. [17] and Chen et al. [18] extracted features from video streams and visualized them as volumes. Similarly, Sun et al. [19] extracted the trajectory of cells and visualized them as time-vary volumes. Hoferlin et al. [20] and Parry et al. [21] presented hierarchical event visualizations that depict shots and notates scoring in snooker videos.

Nonetheless, comparing videos with videos in a quantitative illustration can be difficult. Duffy et al. [22] developed a glyph-based microscopy video summarization technique that conveys both spatial and temporal contexts in one single graph. However, the method described in [22] cannot be used to convey continuous measurements of multiple features simultaneously, as one of the main objectives in this work is to visualize the change of multi-dimensional data over time.

III. CELLVIS

In this section, we first introduce the design goals of the CellVis system. Then, a brief overview of CellVis is described. After that, we present the visualizations for representing each of the time-evolving cellular features. Finally, the supported data manipulations in CellVis are explained in detail.

A. Design Goals

We have interviewed domain scientists to understand what data they wish to explore within each cellular experiment video as well as how they would compare the data across all videos.

Based on their feedbacks we derived the following design goals (DG) for designing CellVis.

- DG1 CellVis should provide a highly expressive visual summary of cellular features evolve over time.** As each experimental video records the subsequent behavior of a cell, it can be time-consuming for the scientists to observe the cellular behavior by inspecting the video frames one at a time, let alone there could be multiple features of interest that the scientists may want to compare together. The goal is to provide a visualization that summarizes the whole cellular evolution process into one single view so that scientists can quickly identify the correlation and trend of features within a video.
- DG2 CellVis should allow easy comparison of the visual summaries across a collection of videos.** As mentioned in DG1, scientists may have multiple features of interest. Besides, they may also want to compare those features of interest across multiple videos. Frequently, scientists conduct experiments by setting up different parameters and study how the cellular features would change accordingly. Therefore, it is important for the system to allow users to make such comparison.
- DG3 CellVis should provide the interactivity and flexibility for data manipulation.** Given the variety of cellular features as well as the experimental parameters, scientists usually need to arrange or organize the data in a certain way to verify their hypothesis. Sometimes, they may also want to explore more possibility to discover new patterns from a different aspect. For achieving such goal, it is crucial to support interactive operations for data manipulation in the system, e.g. sorting and filtering.

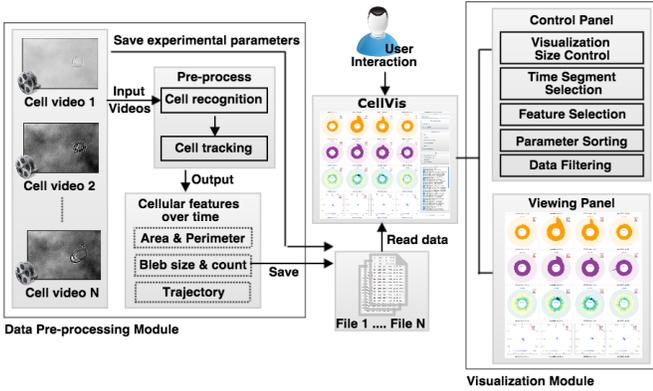


Fig. 2: The system flow chart of CellVis.

B. System Overview

Figure 2 shows the system flow chart of CellVis, which contains two modules: data pre-processing module and visualization module. In the data pre-processing module, the parameters scientists used while conducting the experiments are first saved into files. Since some findings of the cellular behavior study described in this paper have not yet been published, we have chosen to use a generic term, i.e. *stimulus*,

for replacing those sensitive experimental parameters hereafter. Then, we applied computer vision techniques for the purpose of cell recognition and tracking. Note that the cell recognition and tracking are done automatically. However, sometimes there may be multiple cells recorded in one video while not all of them are of interest. By default, we assign the cell of interest (COI) according to its location, shape, and size. Furthermore, we also provide a post-verification interface so that the users have the option to choose another COI for each video. After deciding the COIs of the videos, we can derive the time-evolving cellular features of the COIs, such as area, perimeter, bleb count/size. Finally, the derived features along with the saved experimental parameters are fed into the visualization module.

Figure 3 shows the user interface of the visualization module, which consists of two panels, a control panel (right, marked A through E) and a viewing panel (left, marked F). The viewing panel displays the visualizations with a spreadsheet-like layout while providing the flexibility to interactively explore/arrange the data/visualizations in different aspects by configuring in the control panel, for example: changing layout or filter out unwanted data. We will explain more details about the two modules of CellVis in the following sections.

C. Data Pre-processing (DG1)

In order to provide an expressive visual summary of cellular features from each cell video, we first pre-process the cell video and transform the cellular features to quantitative values. There have been abundant existing studies dedicated to automate the process of cell shape segmentation and cell tracking, machine learning-based approaches [23] [24] [25] [26] and image-based methods [27] [28] are usually adopted. We apply similar algorithms such as texture filtering and random walker to implement the function. The focus of this paper is not to invent new algorithm to improve the accuracy of the detection, we therefore will not discuss such topic further in this paper. Once the cell in the video can be detected and tracked, we can easily derive several features of interest easily, such as area and perimeter of the cell, cell bleb count and size, cell shape, cell migration trajectory. To confirm the validity of the derived features, we sampled a few dozen frames from videos under different experimental parameters and asked the domain experts to undergo a visual inspection to verify if the detected results match with the real case. The domain experts have approved that the detection accuracy to be acceptable for further analysis.

D. Visualization of Cellular Features (DG1 and DG2)

In this section, we discuss how we summarize the time-evolving cellular features as visualizations and how the visualizations created from a collection of videos can be compared with each other.

1) *Area and Perimeter:* For visualizing numerical time-series data such as cell area and cell perimeter, it is straightforward to present such type of data using bar charts with one axis representing time while another axis indicating the numerical

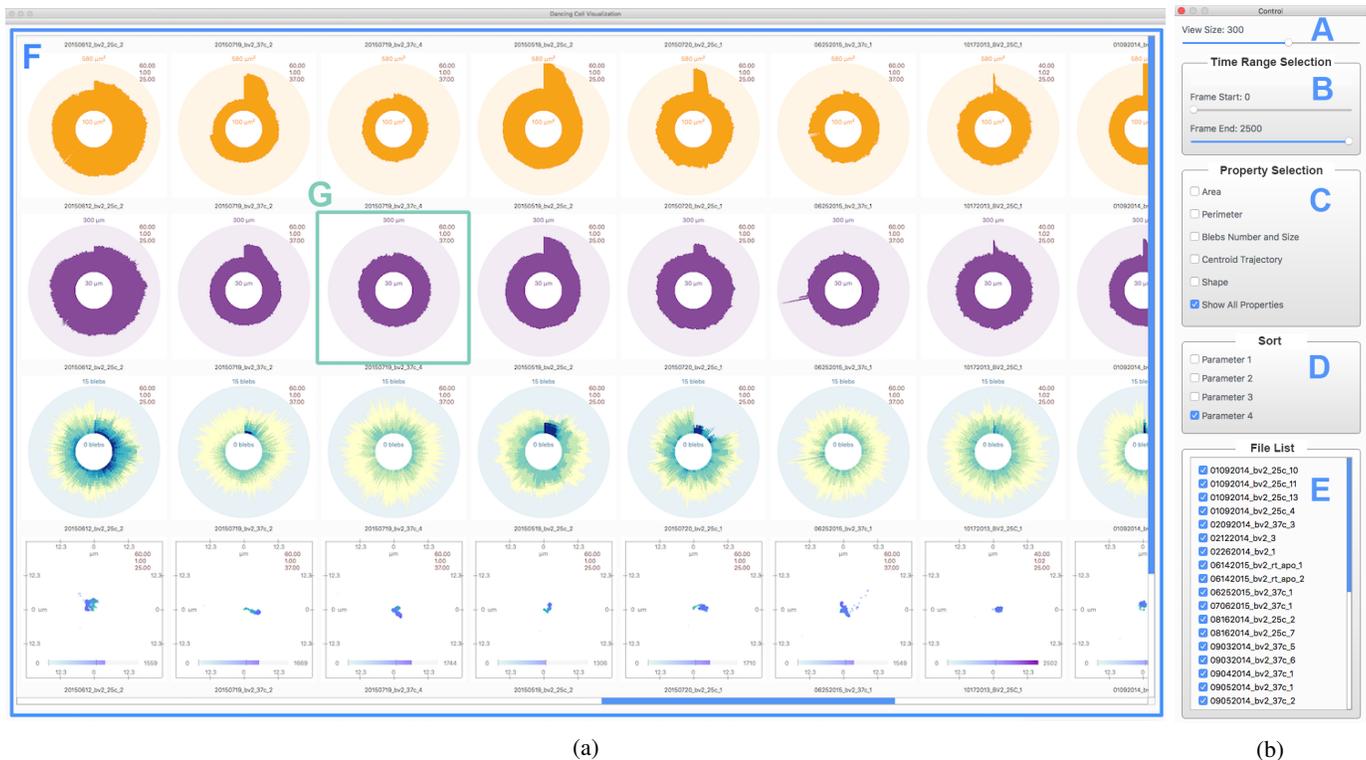


Fig. 3: The user interface of visualization module of CellVis. It consists of two panels: control panel (right, marked A through E) and viewing panel (left, marked F). In the viewing panel, visualizations of cellular features from multiple videos are displayed with a spreadsheet-like layout. Five data manipulations are provided in the control panel that allows users to interactively explore the data in different aspects.

value. Although the concept of time is usually presented horizontally (for example: from left to right represents from the beginning to the end), in CellVis we choose to arrange the timeline in a radial fashion. The reasons of making such decision are two-fold. First, it is easier to control the size of the resulting visualizations to be the same if we normalize the timeline by setting the longest video to form a full circle. Second, the radial layout is more compact, which saves us more screen space when we want to put multiple visualizations side by side for comparison.

Figure 4a shows the visual summary of the perimeter of a cell evolve over time. Each perimeter value in one time step is represented by the height of a bar. The bars are arranged in clock-wise order starting from 12 o'clock. Cellular perimeters from all cells are normalized to the possible range, i.e. from $10 \mu\text{m}$ to $80 \mu\text{m}$, which are provided by domain scientists. As can be seen in Figure 4a, the perimeter value drops severely at the beginning, which means the cell has encountered a sudden shape change. After that, the perimeter of the cell then became more stabilized.

The time-evolving area of a cell is also visualized in a same fashion. As displayed in Figure 4b, we can see that the cell size decreases significantly at the beginning. After a certain period of time, another significant size shrinking of the cell occurs again.

2) *Bleb*: As cell bleb may be a domain-specific feature in cell studies, here we give a brief introduction: Cell blebbing is

one of the most dynamic cellular process characterized by continuously expanding and retracting spherical membrane blebs. Blebbing is part of many different and fundamental cellular processes such as cell division, migration and programmed cell death. Cell blebbing is driven by the continuous polymerization and powered by Myosin motor proteins which together cause continuous rearrangement of the cortical actin cytoskeleton.

To summarize the blebbing behavior of a cell, we also adopt the radial bar chart visualization as for area and perimeter. However, the domain scientists would want to compare two attributes of cell blebs, which are number of blebs and bleb size, together at the same time. A minor adjustment can be made so that the two attributes can be fitted into the same type of visualization. We use the height of a bar to represent the number of blebs that a cell has at a certain time point, while the size of each bleb is presented by color. To be more specific, each bar is segmented into equally sized sticks while each stick represents a bleb. The color of the stick then encodes the size of the bleb where darker color is used to refer to a bigger bleb size. As the example shown in Figure 4c, at the beginning there are fewer but bigger blebs. As time proceeds, there are many smaller blebs emerge while bigger blebs are retracting and expanding periodically but never expand to as big as they are at the beginning.

3) *Trajectory*: The trajectory of a cell’s migration can be described as the movement of the cell centroid over time. As the trajectory contains spatial information, instead of using the radial bar chart visualization, we plot the trajectory of a cell on to a 2D Cartesian coordinate system. We start by setting the cell centroid extracted from the first video frame to be the origin point of the coordinate system. Then for every time point after, the derived cell centroid is drawn as a dot located at its relative position to the first centroid. The color of the dots encodes time information where light blue refers to the beginning of the video, and as time of the video proceeds, the color of the dot will become darker and darker. Figure 4d demonstrates an example that the cell stays around the original location for a little while, and it starts to migrate towards it left after a certain point of time.

4) *Spreadsheet Layout*: As one of the design goals of CellVis is to support easy comparison between visualizations and across multiple videos. We adopt a spreadsheet layout for displaying visualizations of different features and of multiple videos. The visualization spreadsheet layout has been demonstrated to not only allow users to view large collections of visualizations simultaneously but also enable them to easily conduction visual exploration and comparison through multiple representations of different data sets [29] [30]. The viewing panel of CellVis, marked F in in Figure 3a, shows an example of our spreadsheet layout, where each individual visualization (for example, the one marked in G) is scaled to have the same size as the others to support direct and side-by-side comparison. In addition, each video’s corresponding experimental parameters are annotated on the top-right corner in red. Note that by default the visualizations of one video is arranged vertically in the order of *Perimeter*, *Bleb*, and *Trajectory*. Users are given the flexibility to change the order or even apply other data manipulations to view the visualizations in different aspects. The supported data manipulations will be explained in more detail in the next section.

E. Data Manipulation (DG3)

To allow scientists explore their video data in different perspectives, CellVis provides several data manipulations that would re-arrange or re-organize the layout in the viewing panel instantly and accordingly. As can be seen in Figure 3b, the control panel supports the following operations: A) Visualization Size Control, B) Time Segment Selection, C) Feature Selection, D) Parameter Sorting, and E) Data Filtering.

1) *Visualization Size Control*: The slider bar marked A in Figure 3b control the universal size of visualizations displayed in the viewing panel. The layout of the visualizations will be changed simultaneously when the user scrolls the slider bar. When the visualizations are set to a smaller size, users are able to compare more videos at the same time, trends or anomalies of data may be identified at a glance. On the other hand, if the size of the visualizations is set to be bigger, then the users can see the detail of each individual visualization more clearly.

2) *Time Segment Selection*: The slider bars shown in region B of Figure 3b provide users the functionality to select and

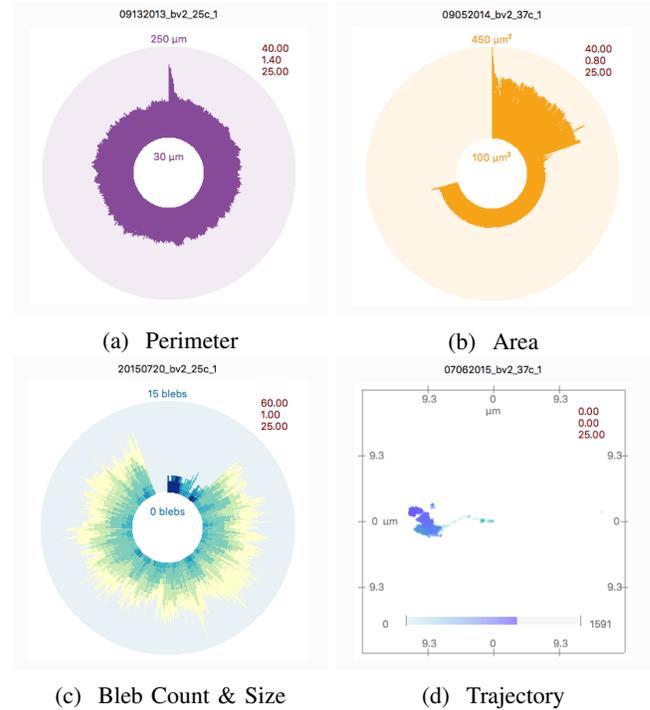


Fig. 4: Visualizations of time-evolving cellular features.

visualize only a specific time period of the videos. Sometimes, scientists would want to focus on the cellular features change during a specific time range. For example, scientists may give the cell a certain stimulus at a certain time point and want to observe the cell behavior afterwards. After a new time segment is selected, the visualizations will update at the same time by only considering the data derived from the assigned time period. Note that the starting frame number can only be set to be smaller than the ending frame number.

3) *Feature Selection*: Region C in Figure 3b lets to user decide which cellular features to be displayed in the viewing panel. By default, the viewing panel displays all visualizations so users can compare all features comprehensively. However, in some cases not all features are of interest, keeping unnecessary visualizations in the viewing panel may result in unwanted distraction. The feature selection panel allows scientist to focus on only one or a subset of features and help them find trends or patterns with respect to those selected features.

4) *Parameter Sorting*: To help scientists discover the effect of setting certain experimental parameters, a sorting panel, as marked D in Figure 3b, provides the functionality to sort the visualizations according to their corresponding experimental parameters. In this way, scientists are able to identify if it would make the cells behave differently when applying different levels of stimulus to the cells. Or, they might find some trend of cellular feature change under certain environmental condition.

5) *Data Filtering*: The last data manipulation provided in CellVis is data filtering. As can be seen in region E of Figure 3b, all video file names are listed as the same displaying order in the viewing panel (from left to right, from top to

bottom). By selecting/deselecting the check-box in front of a file name, user can show/hide the corresponding visualizations of the video in the viewing panel. This functionality is especially helpful when scientists find the parameter setup for some videos incorrect or when some cells behave so awkwardly and can be identified as outliers. Excluding the visualizations of those videos from the viewing panel would allow scientist stay focused only on those valid/interested videos.

IV. CASE STUDIES

In this section, we demonstrate several real use cases of CellVis. The domain scientists we collaborate with have specifically indicated that the following case studies indeed show the powerfulness of CellVis as it helped them perform the tasks that cannot be done in the past. In the following case studies, we paraphrase the remarks made by scientists after using the CellVis system.

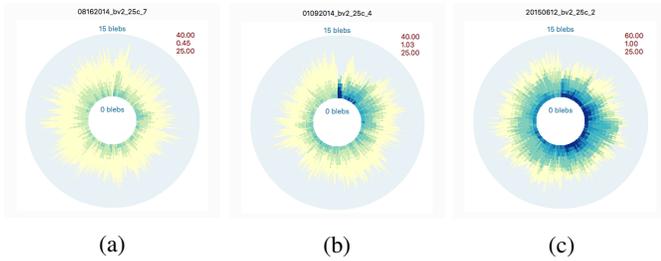


Fig. 5: Visualizations of different cell blebbing behaviors. (a) Visualization of a cell’s blebbing behavior when a lower magnitude of certain stimulus is applied. (b) Visualization of a cell’s blebbing behavior when a higher magnitude of certain stimulus is applied. (c) Visualization of a cell’s blebbing behavior when increasing the efficiency of a certain stimulus applied to the cell.

A. Case study 1

First case study shows that scientists can quickly identify several cells that different blebbing behavior of cells can be identified by only looking at the bleb visualization charts. Figure 5 shows visualizations of blebbing of three cells which exhibit the most visually different behavior among more than 30 cells. The visualized data suggest that the magnitude of applied stimulus directly correlates with the blebbing behavior. It was found that larger magnitude of stimulus trigger more intense continuous bleb formation (Figure 5b) than smaller stimuli (Figure 5a). Figure 5a shows that the largest blebs appears predominantly in a short period after the trigger but this cell exhibit larger and higher number of blebs along the entire blebbing process compared to cells which was triggered with 2.2 times lower stimulus (Figure 5b).

B. Case study 2

Continued from case study 1, it was found that increasing the efficiency of the stimulus the blebbing behavior can be significantly altered. Figure 5c shows that the different stimulus triggers larger blebs compared to the previous ones (Figure 5a

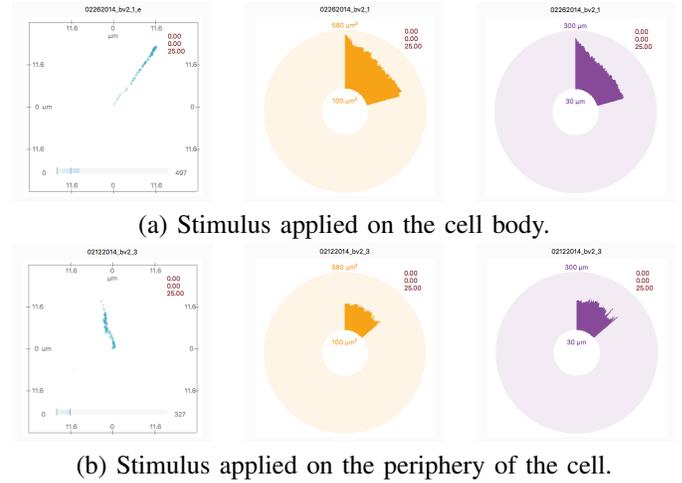


Fig. 6: Visualizations of cell trajectory (first column), cell area (second column), and cell perimeter (third column) when a certain stimulus is applied on (a) the cell body, or (b) the periphery of the cell.

and Figure 5b). The chart also give an insight to the dynamics of blebbing behavior showing that while the bleb size significantly increased the number of the blebs remained unchanged.

The scientists found the bleb visualization useful as it gives them a clear summary of the dynamic blebbing of individual cells. It allows for comparison of cell behavior and reveals trends and patterns among cells which were subject to different magnitude of stimuli. In the presented case study, the visualization data suggest that the extent of the damage to the cortical actin cytoskeleton of cells, which correlates with the magnitude of the stimulus, can be the factor what determines the blebbing behavior.

C. Case study 3

In this case study, scientists investigated if the location of stimuli applied to a cell can result in different cellular responses. The hypothesis was that imposing stimulus on the cell body or the periphery of elongated cells can result in different cellular responses.

By comparing the visualizations of cell perimeter and cell area, two different behaviors can be clearly distinguished. Stimulus applied to the cell body cause significant morphological change which involves a rapid decrease of the length of cell perimeter and cell area as the elongated cell shrinks and its flat morphology change to spherical shape (Figure 6a). In contrast, a cell with a stimulus applied on the periphery shows increased cell motility without any significant change in cell shape or size (Figure 6b).

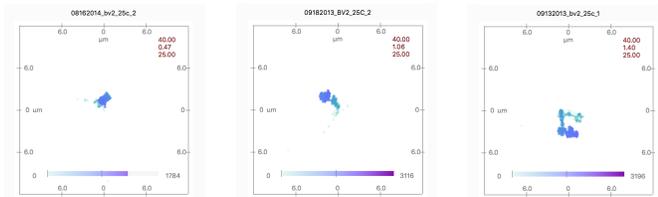
The scientists agreed that the plots of cell trajectory give them a straightforward visual summary of the activated motility of the cells, which depicts the direction and extent of a cells locomotion. Moreover, they concluded that arranging the visualizations of the three parameters together (cell perimeter, cell area, and trajectory) allows them to describe and summarize all of the captured dynamic events.

D. Case study 4

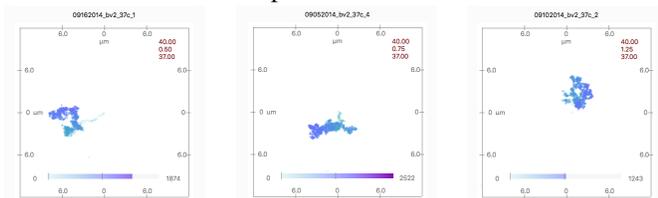
Visualization of cell trajectories can give an insight to the dynamics of cellular motility. The plots can reveal the speed, direction and overall intensity of motility and can help to find trends among cells which were subjects of different experimental conditions. Figure 7 provides a comparison of the cell trajectories where experiments were conducted under two different temperature conditions: room temperature, shown in Figure 7(a), and 37 degree Celcius, shown in Figure 7(b). The cell trajectory visualization revealed suggesting that a gradually increasing stimulus can activate the cellular motility in room temperature experiments (Figure 7a). In contrast with this finding, the same experiments carried out in a 37 degree Celcius environment shows that the cells exhibit a higher degree of the cell motility compared to room temperature regardless of the magnitude of the stimul (Figure 7b) and this motility cannot be increased further.

The current results suggest that the cells have a more pronounced response to the applied stimulus at room temperature compared to 37 degree Celcius. The initial very slow motility at room temperature is caused by the lower enzymatic activity of Myosin motor proteins. The increasing motility upon increasing stimulus is likely due to the higher number of activated of Myosin. This observation suggest that the stimulus can activate cell signaling cascades which regulates Myosin activity and therefore cellular motility. The data collected at 37 degree Celcius suggest that either minimum level stimulus cause maximal activation of cellular motility or the signaling cascades are already activated at physiological conditions and their activity cannot be further increased.

The visualized data pointed out that further control experiments has to be done in order to find out the relationship between the temperature and activation of cell motility by the stimulus.



(a) Visualizations of cell trajectory under room temperature environment.



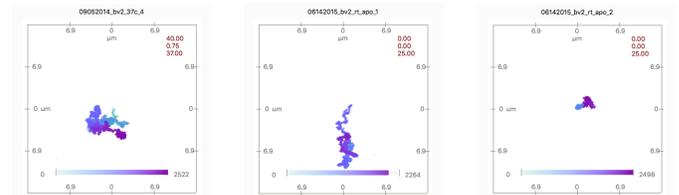
(a) Visualizations of cell trajectory under 37 degree Celcius environment.

Fig. 7: Comparing the cell trajectories under different environmental conditions: (a) room temperature, and (b) 37 degree Celcius.

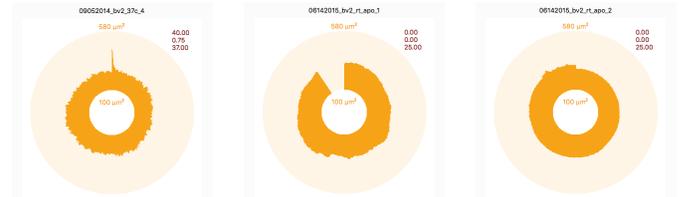
E. Case study 5

In this case study, we show how CellVis can help scientists promptly identify if a cell is alive or dead. To differentiate between live and dead cells with bright field microscope without using any specific viability test requires longer observation of suspicious cells. Apoptotic cells can be in different stages of programmed cell death (apoptosis) and they often have similar morphology to dead cells. However, apoptotic cells still have function and can recover from apoptosis, therefore identifying them and distinguishing them from dead cells can be important.

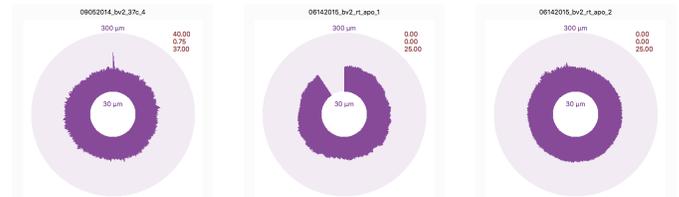
By looking at the visualizations of cell trajectory, perimeter, and area together enables scientists to identify dead cells at a glance. As it can be seen in Figure 8, the dead cell features negligible changes in cell perimeter, area and motility compared to healthy or dying apoptotic cells. The scientists also noted that the visualizations can potentially be used to track the viability of cells if specific viability tests cannot be carried out.



Visualizations of cell trajectory.



Visualizations of cell area.



Visualizations of cell perimeter.

(a) Healthy cell (b) Apoptotic cell (c) Dead cell

Fig. 8: Comparison of cell trajectory (first row), cell area (second row) and cell perimeter (third row) between healthy cell (first column), dying apoptotic cell (second column), and dead (third column) cell.

V. SUPPLEMENTAL MATERIALS

We provide one of the cell videos that we used in this study for the reviewers to see what the video and cellular features are like. Please refer to the following link: <http://nauhc.github.io/CellGUI/>. We should also note that the length of each video used in our study is usually more than 30 minutes, and some

may last for a few hours. Therefore, a video file size may be in the range of gigabytes. We have chosen to upload a shorter video and also made the video play 30 times faster to keep its size small.

VI. CONCLUSION

With CellVis, we have demonstrated the value of using information visualization to organize and present multidimensional, quantitative information extracted from large video data. Through an interactive user interface, users can effectively browse the information and perform comparative studies. In the case studies on microscope video data, CellVis helped the domain scientists not only gain quick insights about cell dynamics in response to external stimuli but also study their data much more comprehensively with reduced time and effort. As biomedical imaging capabilities continue to improve, their studies are expected to routinely produce larger volumes of higher resolution images. A tool like CellVis, designed to address big data analytics challenges, will allow the scientists to work more efficiently and more quickly accomplish their research goals.

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