In the field of Petrographic studies a common problem is the analysis of thin sections of rock samples, i.e. the quantification of its mineral components and the percentages of each phase present in it. A technique, called point-counting, is used to achieve this goal. This technique is applied in geological and also in biological, medical, and materials science domains. Point-counting is normally conducted through mechanical or electromechanical devices attached to a microscope; such devices are very expensive, offer limited functionality, and are very time consuming. In this paper we introduce an interactive visualization application called Rock.AR that reduces the amount of time required to apply this technique and simplify its work flow. It provides visual tools, like distortion techniques, overview+detail and statistics to assist the technique. We also show a comparison between this application and a similar tool through users’ experiences. We compare the time it takes to complete a session of point-counting and tools' usability.

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A Software Solution for Petrographic Thin Section Analysis using Point Counting
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Abstract
In the field of Petrographic studies a common problem is the analysis of thin sections of rock samples, i.e. the quantification of its mineral components and the percentages of each phase present in it. A technique, called point-counting, is used to achieve this goal. This technique is applied in geological and also in biological, medical, and materials science domains. Point-counting is normally conducted through mechanical or electromechanical devices attached to a microscope; such devices are very expensive, offer limited functionality, and are very time consuming. In this paper we introduce an interactive visualization application called Rock.AR that reduces the amount of time required to apply this technique and simplify its work flow. It provides visual tools, like distortion techniques, overview+detail and statistics to assist the technique. We also show a comparison between this application and a similar tool through users’ experiences. We compare the time it takes to complete a session of point-counting and tools’ usability.

Keywords: Point-counting, petrographic thin sections, image analysis, visualization.

1. Introduction
Mineral content, chemical composition and texture are, together with shape and size of mineral constituents, the main rock properties considered by petrologists. The determination of the relative abundances of rock sample’s components, i.e. the modal composition, has research, educational and engineering interest. Modal analysis is one of the most common methods for the petrographic classification of rocks, and important for petrologists when establishing evolutionary trends; it provides two types of data series: a) Relative quantity of rock forming minerals, and b) Microscopic grain size distribution of the rocks. The relative proportions of minerals in a rock sample are of utmost importance for the proper classification of a rock.

Point-counting of petrographic thin sections is the standard method for mineral classification of coarse grained igneous, metamorphic and sedimentary rock samples. This requires observations to be made at regular positions on the sample, namely grid intersections. At each position, the domain expert decides to which mineral the respective grid point and its local neighborhood belongs. By counting the number of points found for each mineral it is possible to calculate the percentages that these values represent overall the counted points. These percentages represent the relative proportions of the minerals in the sample. Concerning the statistically correct number of required counts for quantitative examinations, the image to be manipulated must contain between 1500 and 5000 points. This value is established by the domain expert before starting the counting procedure, based on the diameter of the smallest grain of each mineral phase present in the sample.

Although there are automated image processing techniques for counting features on microscope slides in other fields, particularly in biology, these techniques are not easily adapted to petrographic thin sections. Because of the characteristics of the petrographic slide, the color of each conceptual unit is not homogeneous enough to be interpreted as a single component by an automated image processing technique, based on color or grey scale images. Precisely, images obtained from rock thin sections show inhomogeneous colors for each mineral species due to subtle tone changes which are related to inhomogeneous chemical composition and/or deformation due to stress affecting the rock, just to mention two of the most common causes.

In petrographic thin sections, point-counting is normally conducted through an electromechanical or electronic device attached to the petrographic or reflected-light microscope that is capable of moving the sample at regular steps. Due to the complexities involved in point-counting methods executed with these ad-hoc devices, we propose a methodology that replaces the microscope-dependent methods allowing the domain expert to perform the point counting directly on a digitized image of a normal rock thin section also providing visualization techniques for the exploration and analysis of the image data.

We developed a visualization tool called Rock.AR. This is a software application that provides a semi-automatic point counting method. Rock.AR has a user-friendly interface to create an effective point-counting tool that
reduces the user cognitive workload. This tool automates the creation of a grid used to define the point positions. The grid is overlaid on a predetermined image sample, which allows the count of minerals at the intersections of the grid lines. This method significantly reduces the time required to conduct point counting, it doesn’t require an expensive ad-hoc device to perform the job and improves the consistency of counts.

This paper is structured as follows: In the next section, the previous work is detailed. Section 3 begins with a general description of the characteristics of the application including the basic visualization aspects. Based on these characteristics, the interface and the interactions are described in Sections 4 and 5. Section 6 gives the implementations details of Rock.AR and the requirements to execute the application. Section 7 describes the user’s experience from several scientists in the area using Rock.AR. Finally Section 8 summarizes the work providing some closing remarks and directions for future work.

2. Previous Work
The point-counting technique evolved from the work of Delesse (Delesse 1848), Rosiwal (Rosiwal 1898), Shand (Shand 1916), Chayes (Chayes 1949), and others. Point-counting is normally conducted either by hand only or manually through different ad-hoc techniques and devices. In order to improve the effectiveness of this type of work, some applications were developed. In 1993, Gatlin et al. (Gatlin CL 1993) developed a semi-automated method of point-counting. They applied this technique on biological samples, and they pointed out that it could be used on many other types of tissue. This method could only be run on Macintosh computers and it was not publicly accessible. The electromechanical device, mentioned earlier, attached to the petrographic or reflected-light microscope was replaced in 2000 by an electronic device with significantly improved accuracy. Its movement was fully automated, allowing software controlled slide movements in both horizontal and vertical directions. This device was enhanced recently with the addition of a petrographic data analysis system. It is a rather complicated and expensive device, and its software is not intuitive to use. The device must remain in place along the entire process, which would be negative if the microscope is a critical resource. In this case, if someone needs the microscope the device must be detached and the point counting process stopped, forcing the user to restart with the process again.

In 2006 JMicroVision\(^1\) developed a software application available on the Web to analyze high definition images of rock thin sections which can also be used in other domains. Although this application allows point-counting, it is not easy to use. Besides that, the user cannot select, for example, an ad-hoc regular grid to be overlaid on the image. It means that the counting cannot be conducted with the desired step size.

The work presented in this paper addresses the aforementioned problems. The goal of the application is to alleviate the identified problems when performing point-counting, to increase its effectiveness, its navigability and the interaction among the different representations of the data. There are very few published papers on point-counting, much less about the use of computer science related topics to improve this technique. We believe that our contribution to this area is significant and will help geologists in their work.

3. Our Approach
Traditionally, the term visualization has been used to describe the process of graphically conveying or presenting end results (Card et al. 1999). This concept has evolved and revolutionized the way researchers do science. At present it is required to support the analytical reasoning with highly interactive interfaces in order to gain insight from the collected data. Based on these concepts we developed a point-counting visualization application that leads to a natural user-computer interaction and enhances the user’s ability to count. Our primary goal was to achieve the highest level of automatization of the point-counting technique as possible.

Using our application, a typical counting session consists of the sample setup, the counting process and the exploration session. For the sample setup, an image of a petrographic thin section must be loaded into the application. The user is subsequently informed of its dimensions in pixels. Then he has the possibility to input its dimensions in mm and also to adjust its brightness and contrast. At this step, the user is also asked to create the regular grid for optimum point density, and to configure its visual properties i.e., the color of the grid and the color of the grid at the selected point. Then, the grid is superimposed onto the image. After this, the counting process can start, points can be classified and the percentages values of each mineral are calculated and graphically displayed in real time.

\(^1\) http://www.jmicrovision.com/
During the exploration session, intermediate information related with the counted points can be saved and replayed for further analysis. We promote a friendly user-computer interaction, the interface and the interactions are kept simple and intuitive. Our application allows creating the grid, overlying it on a selected image and classifying the minerals at the grid points. The information is organized in multiple tightly coupled views and guides the interactive manipulation of the data (see Section 4).

In order to do a meaningful classification, the image to be manipulated must contain between 1500 and 5000 points. When interacting with large images on the computer display, two goals must be achieved. First, it is important to convey a general overview of all data. Second, it should be possible to view the data at the point in detail. At the classification moment, it is necessary to have a focus on the point and a local context that helps to classify the mineral. At the same time it is important to have an overview of the thin section, without distortion. To meet all these requirements we choose to have a focus + local context + overview display. It must also be pointed out that the local context heavily relies on zoom-in + zoom-out interactions performed by the users. The following sections describe the application in detail, going deeply into the interface and the interactions available to the user.

4. The Interface
Kwan Liu Ma introduced the concept “the user interface of a visualization system is the visualization displayed”\(^2\). Under this premise users are able to concentrate on data exploration and interpretation rather than on user interface artifacts. Our interface follows this premise and presents four views (Figure 1) providing different contents to improve the point-counting process. The interface offers the user the image of the petrographic thin section in the sample view and complementary information views organized in a mosaic fashion. In the following subsections we describe the goal of each view, its interactions and the interface components.

Fig 1 A screenshot of the Rock.AR application. This application is computer platform-independent. Rock.AR provides a semi-automatic point-counting method for petrographic thin sections. The interface offers the user the image of the petrographic thin section in the sample view and complementary information views organized in a mosaic fashion

4.1. The Views
During the data exploration process, the dynamically linked views show quantitative and qualitative information. There are four linked views on Rock.AR: Sample View, Table of Minerals, Chart View and Overview.

4.1.1. Sample View
This is the main view in the application hence the largest one. Through this, the user count, watch, and manipulate the petrographic thin section. The user will see the sample and a grid overlaid on top of it. The grid intersections represent the points to count. The grid is displayed as an overlay on top of the sample image and the user can adjust the distance between vertical and horizontal lines before the count begins, to control the precision of the point counting. The circles in the grid intersections represent the points to count. When the user selects any point, a square is drawn around it; the color of the circle and the grid lines that intersect it is changed to emphasize the selected point.

4.1.2. Table of Minerals
This view represents the list of the minerals the user is looking for in the sample. Each mineral has a key color reference, allowing to easily identifying it in the four views. Different types of minerals correspond to different colors. Each row of the table represents one mineral, for each mineral the following information is displayed: A key value to be referenced, its name, the associated color, the total counted points of that mineral and the percentage they represent considering the total number of counted points on the sample.

4.1.3. Chart View
The most important output of this process is the percentages values of each mineral. These values represent the relative area occupied by each of them. This view shows a graphical representation of those percentages values using the color key references created in the table of minerals.

4.1.4. Overview

\(^2\) http://www.cs.ucdavis.edu/~ma/research.html
Additionally to the sample image, its pixel map is also shown. This map represents each counted point in the thin section with the corresponding mineral color. Pixels are arranged according to the image being counted, offering an intuitive context overview.

5. The Interactions

In this section we discuss various aspects of interacting with the application. User interfaces should become simple and intuitive, so that they can be operated by people with different levels of knowledge and skills. Users should be able to freely choose and interchange their ways of interaction, depending on their skills and the particular situations. That is the reason why applications will especially benefit from simplified and powerful human-computer interfaces that allow users to choose the type of interaction depending on their background and their preferences (Medyckyj-Scott and Hearnshaw 1993).

All interactions in Rock.AR can be done with the mouse or with the keyboard. We consider mouse interactions to be more suitable for novice users, especially those who are learning the technique. Keyboard interaction is better for expert users, because they provide a quick access to the application functionality. The user is free to configure which key will trigger each action.

We identified three interaction tasks: The configuration to begin the procedure, the way the petrographic thin section image will be navigated to do the point counting and the removal and modification of any counted point when necessary. Let us describe each of the three interactions in more detail:

1) The configuration to begin the procedure. When the user select an image to apply the technique, the user can choose to:
   a) Adjust the brightness and contrast of the image.
   b) Set the grid size in order to determine the number of points to count and the step between them.
   c) Set the colors of the grid elements.

2) Navigation of the petrographic thin section image to do the point-counting. We propose a strategy that supports people in this initial stage of interaction with the application and a different one for expert users. Users should be able to freely choose and interchange their ways of interaction, depending on their abilities and the situations at hand. The user can select and navigate the points by mouse movement, for novice users, or keyboard input for expert users. The user then proceeds to classify them by selecting the key mineral value, this can also be done by mouse or keyboard interaction. Once the mineral is selected, if the user press Enter the selected point becomes the next one. Starting from the top left corner, a predefined movement is set: When pressing Enter on the first row, the next selected point will be the next at the right. At the end of the row, the next selected point will be the one below the current one, and then the movement will be from right to left. This pattern continues until the last point is reached. When a mineral is associated with a point, the statistics are updated.

3) Addition, removal and modification of the different counted points in the sample. To modify a counted point the user must select the point, press the Backspace key and enter the new value. If no new value is entered, the associated mineral with the point is undefined and the statistics are updated.

Outside these three tasks, we describe now an additional set of actions categorized according to the view they affect.

5.1. Interactions on the Sample View

- Walk through the points. The user can move through the points by mouse click by pressing the arrows keys. When the user types a mineral key into the mineral key textbox and presses enter, an automatic movement takes place and the next point is selected.
- Import/Export counted information. The user can save the counted point in a file. This file can be used later to resume the work.
- Remove grid components. The visibility of the following grid elements can be toggled by the user at any moment (Figure 2): the entire grid; the circles in the grid intersections; the square and the lines inside it, when a point is selected; the circle in the selected point.
- Zoom in/out. The zoom can be applied to the whole image or just locally to a point in the grid (Figure 3). In the last case, the zoom in allows to view smaller sections inside the square drawn when the point is selected.
- Overview overlap. It is possible to combine the overview information with the sample view (Figure 4) with transparency or full opacity. This will allow the user to see which points have been counted and how they were counted.
5.2. Interactions on the Table of Minerals

- Open/Save table of minerals. Each list created by the user can be saved as a file to be used later.
- Add new mineral. A new mineral can be added to the list, its key value will be automatically assigned, the user will be asked to enter its name and color references.
- Edit mineral. For each mineral, the user can change its name and color references.

5.3. Interactions on the Pie Chart

- Quantitative values. By default only the pie chart is visible in the respective view, if she/he moves the mouse pointer over the graphic, the quantitative values will appear. If the user wants to keep these values visible, she/he must click on the graphic. A second click will make the values invisible again.
- Export data. When the user clicks on the Excel button, a spreadsheet file will be created containing the table of minerals with the number of counted points, its percentages and color references.

Fig 2 All graphics elements inside the main panel can made invisible by user request

Fig 3 Local zoom applied to the selected point, highlighted in blue, on the right

Fig 4 The overview information with the sample using an overlap layer with full opacity. This allows the user to see which points have been counts and how they were counted

6. Implementation

Rock.AR was implemented using Java 1.5. Additionally to the Java libraries, three special purpose libraries were used in Rock.AR: JIU - The Java Imaging Utilities, for image processing, scaling, copying and cutting images; JFreeChart, to create the pie chart; Java Excel API, to create and write an Excel file.

Rock.AR is platform independent, i.e., it runs on all versions of Microsoft Windows (XP and above) and all Linux distribution. The application does require the Java library to be install. For the moment, Rock.AR is not available on the Web because it’s in a beta version, but it can be obtain by contacting the authors. Once a stable version is reached, Rock.AR will be made available as an open source application.

7. User Experience

We conducted a controlled lab study to measure how our application could improve the point-counting technique as compared to other methods. Our general hypothesis was that, with Rock.AR, the users would be able to count faster, more accurately and with greater user satisfaction. Later on this section we will describe how we measured time, accuracy and user satisfaction.

7.1. Participants

Twelve participants were involved in this evaluation, all of them from the Geology Department of our University. We screened participants so that all of them have had some experience with point counting through the use of a microscope but none with any point counting software. They did have experience as PC users. We also screened participants for color blindness. The participants were in the 29-51 age group, with a mean of 38.3.

7.2. Tasks and Samples

We broke down the whole counting process into three tasks:

1) Set up: This task consists of preparing everything to do the point counting. Picking up a sample image, adjusting its size, brightness, contrast, configuring the grid and finally creating the minerals list.
2) Point counting: This is to associate a mineral from the minerals list to each point in the grid.
3) Create the Statistics: This allows creating the sample statistics.

All users were asked to produce a table and a pie chart. To do this evaluation we used three petrographic thin section images, we called S1, S2 and S3. In spite of their differences the three samples had similar complexity. This was checked by a domain expert. The same expert also did the point counting on the three samples. His results were used as the reference set and will be referred as the trusted results.

7.3. Methods

We matched up the Rock.AR against two other point counting methods, JMicroVision and the manual method using a microscope with a microstepper. We took into account these two methods because they are clearly different approaches to the same technique. The microscope based one is the most common manual method and the JMicroVision is a computer approach to improve the technique. Despite that the goal of Rock.AR is very
close to that of JMicroVision we will show that its design with different interactions and new features will improve time, accuracy and user satisfaction.

7.4. Study Design and Procedures
Originally, we proposed fifteen participants, distributed into three groups. Each group was going to work with the three tools. Because our Geology Department doesn’t have a microstepper it was impossible to include it. Fortunately we were able to use a Cameca SX100 electron microprobe at another Department in another country. So, in order to improve the results of these tests, ten of the twelve participants were in our country and two overseas. Because the microscope test is very time consuming only two participants carried out this test.

The ten participants were divided into two groups. To identify each group we gave them a call name based on a color: RED and GREEN group, we got a random distribution on each group by assigning the members to each group following their arrival order. The experiment consisted of two sessions, one per day. In each session, each group worked with one tool over one sample. The user’s goal was to perform a point count on a given sample using the given method. Each user had to go through the three tasks that we described earlier.

It was very important to ensure the validity of the experiment. Validity is mainly concerned with the question of whether the experiment measure what it is supposed to measure. We considered two types of validity: Internal validity and external validity. Internal validity is the extent to which the differences in values of the dependent variables, i.e. the outcome variables, are currently caused by the independent variable, i.e. the variable that is manipulated by the experiment, and not by any other source of variation. The external validity of an experiment is concerned with the following question: how well do the results of the experiment generalize beyond the sample of subjects in the experiment? We ensured internal validity by assigning subjects to the test groups randomly. Also, to avoid the effects of external variables on the final results we use a within-subject design for the experiment. In this design all subjects are used two times, once with Rock.AR and another with JMicroVision, not necessarily in this order. By doing this we are canceling any possible carryover effect.

7.5. Results
The times the users took to complete the three tasks on each method are summarized in tables 1, 2 and 3. It is important to remark that the second task is the most important one as it is the most time consuming one. At the end of each task, for both the JMicroVision and Rock.AR, participants had to answer the following questions, providing a number between 1 and 5, we based these questions on the work done by (Shneiderman and Plaisant 2004).

For the Set Up, task one, the question was:
- **How do you rate the interface? Give a number between 1 and 5, where 1 is intuitive and 5 is artificial.**
  For JMicroVision the average answer was 4, and for Rock.AR it was 2.

For the counting process, task two, the questions were:
- **How do you rate the interface? Give a number between 1 and 5, where 1 is intuitive and 5 is artificial.**
  For JMicroVision the average answer was 5, and for Rock.AR it was 2.
- **How do you rate the interactions? Give a number between 1 and 5, where 1 is intuitive and 5 is artificial.**
  For JMicroVision the average answer was 4, and for Rock.AR it was 1.

For the statistics, task three, the questions were:
- **Which is your overall reaction to this method? Give a number between 1 and 5, where 1 is frustrating and 5 is satisfying.**
  For JMicroVision the average answer was 2, and for Rock.AR it was 4.
- **How do you rate the amount of information on screen? Give a number between 1 and 5, where 1 is inadequate and 5 is adequate.**
  For JMicroVision the average answer was 4, and for Rock.AR it was 4.

<table>
<thead>
<tr>
<th>Group</th>
<th>User</th>
<th>Rock.AR</th>
<th>JMicroVision</th>
<th>Microscope</th>
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In this set of questions Rock.AR got better results than JMicroVision. An important aspect against JMicroVision was its complex interface. For Rock.AR the users commented that the language used in the menus was not appropriate for the geology domain. After the sessions were concluded, we compared the counted points from the users with our trusted results, in order to calculate the errors made by the users. Using Rock.AR fewer than 3% of the counted points were wrong for all the users, while for JMicroVision the wrongly counted points were above 9%. In a discussion after the sessions, all users agreed that been able to locally zoom in a point while keeping the context help them. We believe that the low number of wrongly counted points is because of this feature and an easy and intuitive set of interactions. All participants were able to finish all the tasks. With

### Task 2: The Counting Process

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Table 2 Time result from the second task. The second task is the most important one as it is the most time consuming one. As with task one, users working with Rock.AR completed this task in a shorter time.

### Task 3: The Statistics

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Table 3 Time results from the third task. Users completed this task in less time with Rock.AR.
JMicroVision and Rock.AR users were able to complete the task two in less time than using the microscope. With regard to user satisfaction, participants consistently rated the Rock.AR software higher than JMicroVision.

8. Conclusions and Future Work
Rock.AR is a visualization tool mainly designed to do point-counting on images obtained from petrographic thin sections. It is implemented in the Java programming language, has a user-friendly graphical interface, uses information visualization techniques and is computer platform-independent. These attributes qualify it to be used as a research, and educational tool for various users and especially to provide geologists with a valuable educational, and research tool. The software will be freely available for download.

Because the point-counting task is a very tedious and time consuming task; we are exploring alternate methods to provide a more automatic way to do it. Our goal is to provide the application with an automatic count of the points. We assume that on the basis of a number of points classified from the user, the application can learn how to classify most of the sample points with a minimal error rate and much less commitment of time.

9. Acknowledgements
This research is partially supported by the PGI 24/N020, 24/H108 and PIP 112-200801-02306. We would like to acknowledge the support from Secretaría General de Ciencia y Tecnología, Universidad Nacional del Sur and CONICET, Argentina.

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Figure 2