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Virtual Coronary Cineangiography

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Abstract

The mastering of myocardial infarction diagnosis is traditionally composed of laborious trial and error based examination of canonical coronary cineangiographies. In the following article we suggest a system that enables the instructor to generate student specific cases, thus allowing teaching not only the basic feature searching and stenosis evaluation processes, but also the importance of the correct acquisition viewpoint. With the proposal of the development of the Digital Cardiologist intelligent agent we also envisage the possibility of the student's self tutoring.

Key words: virtual reality, coronary angiography, stenosis diagnosis, stenosis quantification, medical training tool

1 Introduction

According to American Heart Association [1] the cardiovascular disease is the leading cause of mortality in the western world accounting for nearly one third of the total deaths. Of all deaths caused by cardiovascular disease, death by coronary artery disease or ischemic heart disease represents the prevailing cause. The main feature of ischemic heart disease is coronary atherosclerosis. This pathologic process involves deposits of fatty substances, cholesterol, cellular waste products, calcium and other substances in the inner lining of an artery. This build-up is called atherosclerotic plaque. Atherosclerotic plaque in coronary arteries can lead to reduction of blood flow through the coronary arteries and with that a shortage of the heart's oxygen and nutrition supply. This constriction or narrowing of the affected arteries is referred to as stenosis whereas the artery is referred to as stenosed. In case of acute coronary stenosis

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Table 1
American Heart Association classification of stenosis severity.

Classified Value (%)	Severity (%)
100	100
99	91–99
90	76–90
75	51–75
50	26–50
25	–25

the patient evolves an acute coronary event. This can either be an attack of angina pectoris, a myocardial infarction or a sudden cardiac death.

Although researchers are testing different presently available in vivo imaging methods for prediction of angiographically detectable stenosis [2], the tools used in diagnostic procedure of acute coronary syndrome remain the patient's history of chest pain, the specific ECG changes and the elevation of heart enzymes, for example the myoglobin and the troponins [3,4]. The golden standard for the evaluation of the extent of coronary atherosclerosis and the severity of the stenotic lesion is the coronary angiography, which shows the culprit lesion that causes the acute coronary syndrome. This procedure consists of the injection of a radio-opaque substance via an endovascular catheter into the coronary arteries and their filming by means of X-rays.

Medical school students and doctors specialising in cardiology or cardiac surgery are required to distinguish between a person having healthy coronary arteries and a patient with atherosclerotic lesions and an increased risk of acute coronary syndrome, using only simple greyscale images of coronary arteries obtained by coronary angiography. This is why different types of medical images represent a major part in medical education. In anatomy, for example, students use images as surrogates for learning 3D structures, their locations, and their relationships [5]. In cardiology the students have to learn the process of visual inspection of the coronary angiography films for features that allow them to evaluate the patient's coronary arteries and diagnose their risk for acute coronary events.

Traditionally the required skill is mastered through laborious trial and error based visual inspection of canonical case coronary angiographies. In this process the instructor shows to the student the coronary cineangiography and they are to recognise the stenosed artery, the location of the stenotic lesion and its apparent severity, usually grading it by the American Heart Association grading scheme [6] (Tab. 1).

The apparent severity often differs from the true severity, which is mostly due to the non-optimal acquisition viewpoint [7]. Because of this the student is sometimes also requested to tell what would be a better viewpoint. Since stenosis is treated by widening of the stenosed artery or by heart surgery where blood is re-routed or “bypassed” around the clogged arteries to improve the supply of blood and oxygen to the heart the student might even be asked to show the possible bypass location.

2 Computer-based training

The advancement in computing power and especially in graphics processing enabled researchers to delve into the field of merging medicine and computer science. In the process of developing surgical training and assistance tools virtual reality, as a special field of computer graphics, was mainly used. Thus virtual surgical assistance tools became available.

For instance Bartz et. al [8] developed a system where they use a polygonal model constructed from images acquired through 3D angiography to provide the neuroradiologist the ability to explore the extra- and intracranial blood vessels interactively by means of virtual endoscopy.

Gering et. al in [9] present a software package which uniquely integrates several facets of image-guided medicine into a single portable, extendable environment. They present its usability through tree use-cases: pre-operative analysis and planning, surgical guidance, and volumetric analysis and studies of dynamics.

On the other hand, virtual training tools also became available. For instance Montgomery et. al in [10] present an interactive virtual environment for animal dissection in microgravity. The virtual environment is in this case used for astronaut crew training allowing them to train both before launch and during flight. By providing an evaluation mode they enable the possibility of performance review and tracking of progress during the space mission.

Baur et. al in [11] are investigating a variety of virtual reality based methods for simulation of laparoscopic surgery procedures with the goal of developing a virtual reality based endoscopic surgery simulator. In particular they focus on the real time interaction and manipulation between instruments and organs, where they search for trade-offs between the realism to obtain and the real time constraints by discussing with surgeons if the system is realistic enough.

Lately, with the advent of Internet 3D graphics and JAVA researches are considering whether simple web-based solutions can offer a cost-effective alternative to expensive dedicated virtual reality based simulators. Brodlie et. al in [12] present their study of web-based surgical simulators through two applications one in neurosurgery and the other in vascular surgery. They emphasise the accessibility, low-cost, class size, generality, and the possibility of distributed processing of the web-based solutions.

Recent studies of computer-based training also show that this type of education, besides being well accepted by the students, is also superior to conventional methods of education [13].

Regardless to that, currently there is no existing training tool for the fore mentioned cardiology students, since the main emphasis of the current research in cardiology is on computer-assisted localisation and measurement of stenotic lesions through vessel reconstruction [14,15], automatic viewpoint determination [7], and prediction of stenosis through identification of atherosclerosis in an early stage by means of coronary artery diameter variation measurements [16].

3 Use-Case Scenarios

The typical training tool usually supports at least two different modes of use and adapts to multiple user types. This does not allow the development of a single, static user interface [17]. Similar to the work of Brinkly et al. [17] we classified the interface and use-case scenarios by the type of user, for example medical student, clinical specialist as well as lay public. The main emphasis of the project is on the medical student use-case scenario since this is a training tool whereas the clinical specialist and lay public use-case scenarios represent pre-operative use of the system and are reserved for future work.

The learning process as defined by the virtual coronary cineangiography is shown in flow-chart form in Fig. 1. The principal goal of the medical student is to learn the process of visual inspection of angiographic images. This consists of the localisation of features that enable him to evaluate the patient's coronary arteries, generate clinical hypothesis about the possible stenosis and diagnose their risk of acute coronary syndrome.

The instructor's user interface displays a 3D model of coronary arteries with 6 degrees of freedom and the front, top, and right close-up views of the stenotic lesions (Fig. 2). When generating the coronary artery tree special care has to be paid to the realism, in particular the irregularity, and biological constraints. If procedural model generation is used it could be based on the work of Karch et al. [18] with the addition of biological constraints. The latter address the fact that three main coronary arteries — the left anterior descendant artery and the

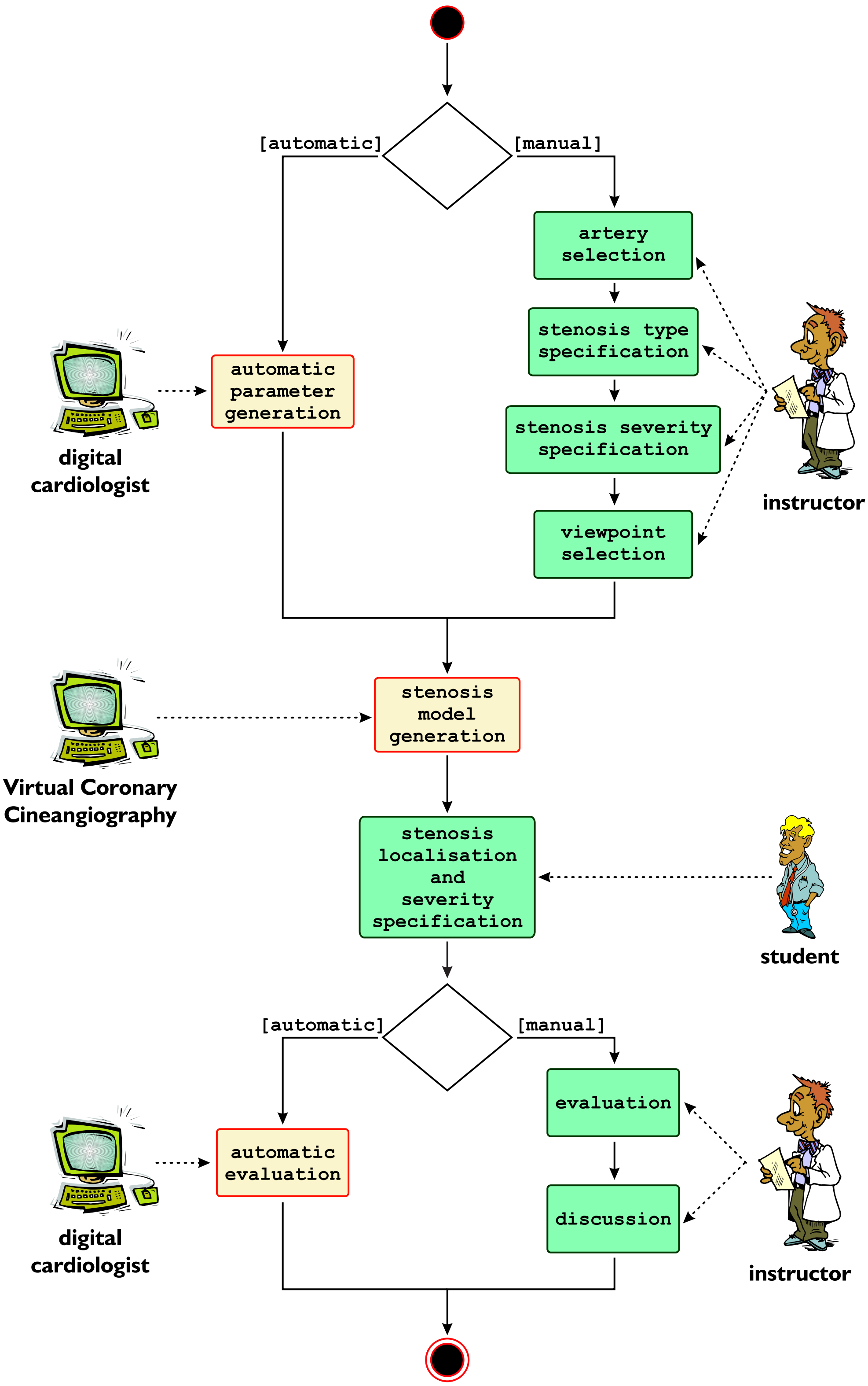

Fig. 1. Flow-chart diagram of the student's learning process.

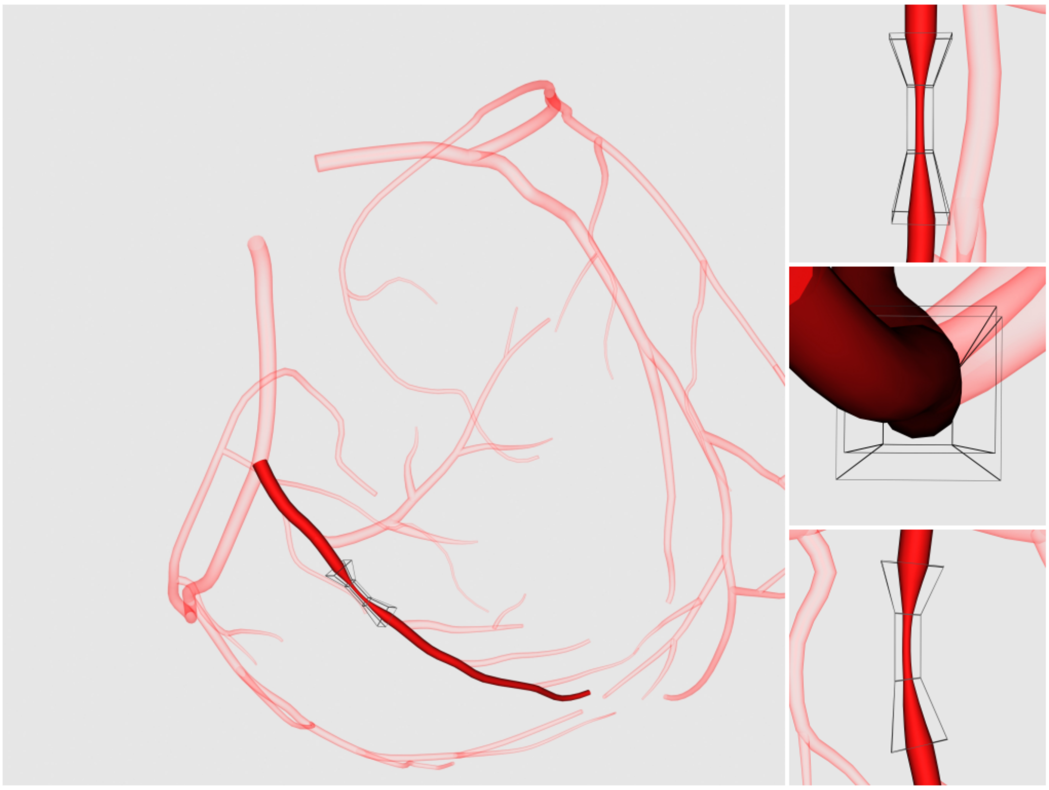

Fig. 2. The instructor's user interface displaying a full three-dimensional coronary arteries tree model and the front, top and right close-up of the virtual stenotic lesion.

left circumflex artery on the left side and the right coronary artery on the right side — supply all regions of the heart. These arteries usually follow one of three major distribution patterns where either the left or the right coronary artery is dominant or the blood flow is equally distributed between them. This is important because when occlusion of the coronary artery occurs, the supplied region of the heart becomes ischemic and later necrotic. The extent of ischemic damage usually correlates with the severity of the symptoms presented by the patient.

The instructor's responsibility is the manual specification of various parameters used for the generation of a user specific case. By means of selection they specify the artery in the coronary arteries tree model that is to be affected by stenosis. The stenosed artery is displayed non-transparently. The exact location of the stenotic lesion is specified through displacement of a wireframe box, while the true stenosis severity is specified by means of two lengths and a factor (Fig. 3). The lengths represent the length of the region affected by stenosis and the effective length of the stenotic lesion, whereas the factor represents the artery diameter reduction. We use diameter reduction since it is directly translatable in %-LENGTH stenosis as defined in [7] and is, as proposed by the American Heart Association scheme, usually estimated by visual analysis

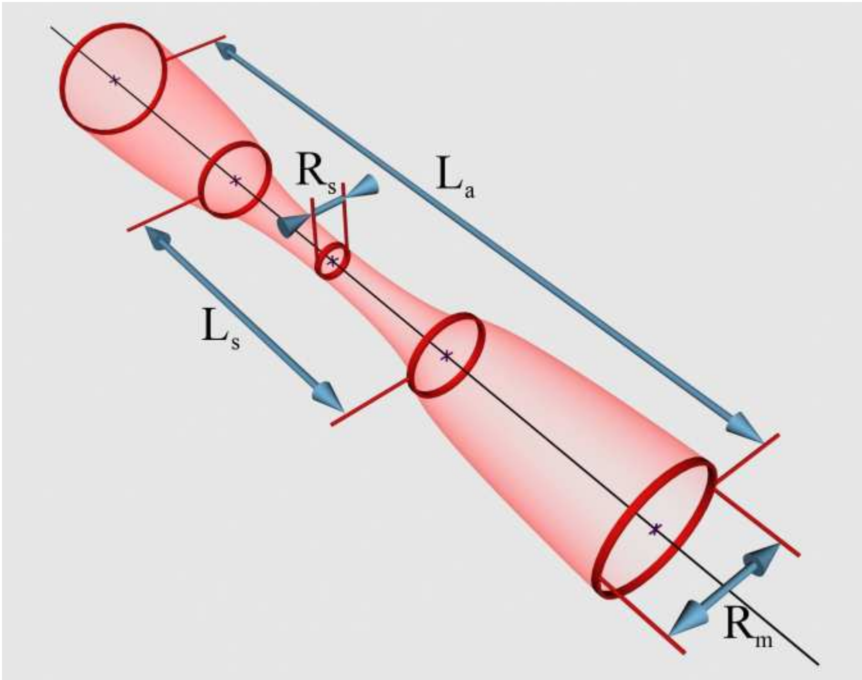

Fig. 3. Stenosis specification, where L_a and L_s specify the total length of the stenotic region and the effective length of the stenotic lesion, respectively. The diameter reduction factor is $f = 1 - R_\mathrm{s}/R_\mathrm{m}$, where R_s and R_m specify the minimal diameter of the stenosis and the mean diameter of the non-stenotic region, respectively.

and classified in one of several categories of severity (Tab. 1). Last but not least, the instructor specifies the acquisition viewpoint by means of rotation of the coronary arteries tree model.

The specified parameters represent the input for the X-ray simulation and visualisation module that produces an X-ray image (Fig. 4). The simulated X-ray image is then presented to the student for visual inspection. They search the presented image for features that give them enough information to answer the given questions. The instructor evaluates their answers and a discussion can follow. During the discussion the instructor and the student examine and together interpret the case by displaying and rotating the full coronary artery tree model. The implementation of the evaluative process gives the instructor the ability of monitoring the student's progress at the process of visual inspection of the coronary cineangiography.

As an alternative to the manual parameter specification the parameters could also be generated automatically by the Digital Cardiologist intelligent agent — analogy to the intelligent agents described in [17]. In this case the answers could be evaluated automatically also, however there would be no follow-up discussion. With automatic parameter generation and evaluation the student's self-tutoring and self monitoring of progress become possible.

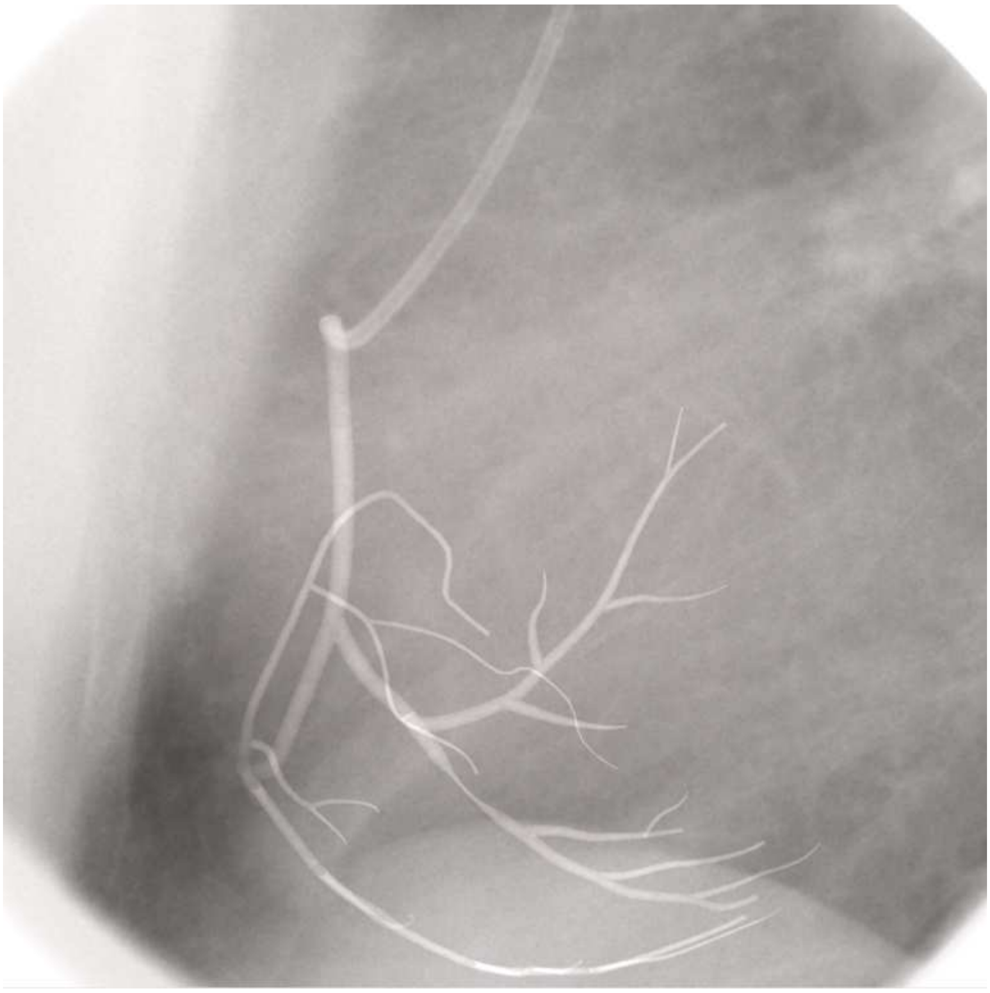

Fig. 4. The simulated coronary angiography that is presented to the student for visual inspection.

With this type of computer-based training the instructor can generate a unique coronary cineangiography for every student. Through that the student is taught not only how to differentiate between the different types of stenosis and the systematic approach to the search for features that impale the stenosis severity, but also the importance of the correct acquisition viewpoint. This is very important since more can be missed by not looking than by not knowing.

4 Current Status and Future Work

Currently our research is focused on the use-case scenario specifications and the development of the different user interfaces, of which the clinical specialist and lay public use-case scenarios still remain the least-researched. Only draft ideas are known. The clinical specialist use-case is intended for pre-operative use as a support tool for the specialist when in need of assistance at the localisation of the regions of the heart that are supplied by the stenosed artery and are thus potentially ischemic. Beside this the use case is also intended as a pre-operative planning tool for optimal bypass localisation and visualisation. The lay public use-case is intended for the clinical specialist also, but with a slight difference of the output image. This must not be too realistic (perhaps in cartoon-like style [19,20]) but still show enough detail for easy explanation to a lay person which arteries suffer of stenotic lesions and accordingly which are the supplied regions of the heart that suffer from potential ischemia. Thus they are in everyday language told why they need the operation, and showed what exactly is going to happen during surgery.

The coronary artery model, its irregularity as well as the X-ray simulation and visualisation module are constantly under development. The future work is focused on the integration of the modules, as well as on the implementation of the Digital Cardiologist intelligent agent.

5 Summary

Medical school students and doctors specialising in cardiology or cardiac surgery are required to distinguish between a person having healthy coronary arteries and a patient with atherosclerotic lesions and an increased risk of acute coronary syndrome, using only simple greyscale images of coronary arteries. These images are usually obtained by means of coronary angiography. The students achieve the required skill mostly through laborious trial and error based visual inspection of existing canonical coronary cineangiographies. In the process the instructor shows the images to the student and the latter is asked to recognise the stenosed artery, the location of the stenotic lesion and its apparent severity. Sometimes the student is also requested to show the possible bypass location.

The advancement in computing power and especially in graphics processing of the modern computers presents a challenging area of research. In the past there was a lot of research done merging medicine and computer sciences. In the process of developing surgical training tools virtual reality, a special field of computer graphics, was mainly used. Such tools brought us to the idea of developing a training tool for the earlier mentioned students. In this article we propose a computer-based training system that allows the instructor efficient teaching and evaluation of the processes of visual inspection of coronary cineangiographies. The primary goal of the proposed system is to enable the instructor to induce a virtual stenosis in a three-dimensional coronary arteries tree model. The computer on the basis of the specified parameters generates a simulated coronary cineangiography, which is presented to the learning student. The latter is requested to recognise the stenosed artery, the location of the stenotic lesion and its apparent severity. The instructor evaluates their answers and a discussion can follow. During the discussion the instructor and the student examine and together interpret the case by displaying and rotating the full coronary artery tree model. Computer-based training allows the instructor to generate a unique coronary cineangiography for every student. Through that the student is taught not only how to differentiate between the different types of stenosis and the systematic approach to searching for features that impale the stenosis severity, but also the importance of the correct acquisition viewpoint. This is very important since more can be missed by not looking than by not knowing. What is more, the implementation of the evaluative process gives the instructor the ability of monitoring the student's progress at the process of visual inspection of the coronary cineangiography.

Currently the research is focused on the different use-case scenario specifications. Future work is aimed at the implementation of a Digital Cardiologist intelligent agent — an alternative to the manual parameter specification and evaluation. With this the student's self-tutoring and self monitoring of progress become possible.

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