

Simula School of Research and Innovation

**CURRENT RESEARCH ACTIVITY 2010**

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The Simula School of Research and Innovation, often referred to as SSRI, was founded in 2007 in order to improve and boost the research education at Simula Research Laboratory. To establish close industrial collaboration with real impact on the shaping of a new educational unit, SSRI was founded as a private company partly owned by industrial partners.

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# CURRENT RESEARCH ACTIVITY 2010

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## TIM DORSCHIEDT

**Position:** PhD Student

**Research Group:** Center for Biomedical Computing

**Project title:** Evolutionary Mechanisms of Sympatric Speciation

“ A new Take on the Origin of Species;  
Using Computers to Understand Life ”

Evolution is the driving force behind all life we see around us. Humans are a product of millions of years of small adaptations, as are sharks, snails and even spinach. Studying how forms of life come about is at the core of biological research. Evolution is, however, difficult to study in nature, because it is too slow to observe. New research using computers can simulate millions of years in a day, making it an ideal tool to better understand how new species originate.

### Theories on how new species originate

Before Darwin's theory of evolution, many thought species changed because there was a need to: a bunny is born with bigger teeth, for its mother needed to eat bigger seeds. Evolution, however, is blind, and works through random mutations over many generations. Some mutations advantageous: bigger teeth, but often the opposite: no teeth at all.

This explains how a species slowly adapts to its surroundings, because bunnies with better teeth have more children. However, how does one species split up into two species? The most common theory states that new species arise by literally splitting up, e.g.: a newly formed mountain range divides the group. The two isolated groups will experience separate evolutionary adaptations and eventually become different species.

Recently, an additional theory has gained popularity: a population does not need to split up for new species to

arise. This theory is however not without its problems, which the following example shows. If one bunny in a population has a mutation for smaller teeth, and another bunny has bigger teeth, each is adapted to different sized seeds, and this might sound like the start of two new species. However, over the next generations, bunnies with smaller teeth will unavoidably mate with big-teethed ones, averaging their offspring's teeth size, and preventing speciation to even get off the ground.

### Tackling the problem using a new approach

This theoretical problem has yet to be overcome by mathematical studies that model speciation. We work on a new approach for studying this process, by incorporating more detail into the model and simulating each individual separately. Additionally, each individual has its own DNA-string, giving evolution the tools to work on the level of single genes.



Lake Malawi in Africa has seen many Cichlid fish species arise in recent evolutionary history.

Our model and its additional level of detail is capable of showing that a single population can indeed give rise to separate adaptations that do not average out over time. Evolution does this by rearranging genes in a specific order, allowing a child to become identical to only one

of its parents and not becoming the average of both. The questions that now remain are how robust this process is and how one gets from the difference between big and small teeth to the difference between a bunny and a hare.

## TOR GILLBERG

**Position:** PhD Student

**Research Group:** Computational Geoscience

**Project title:** Fast Marching and Level Set Methods in Geological Modeling

“ Going Below the Surface  
to Understand the Inner Earth ”



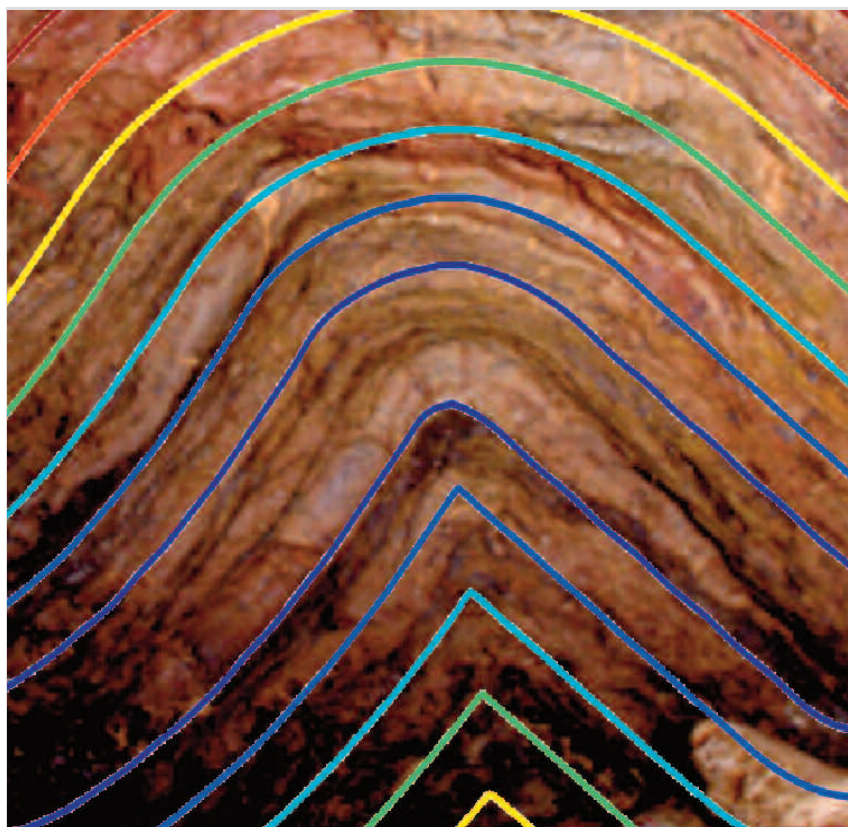
### We need petroleum

The traditional oil and gas resources are diminishing, but the demand for energy is increasing with the world population. Fortunately, during the last decade, several new petroleum sources have been found on previous unexploited places. Often these oil reservoirs are in remote places and are hard to extract. To benefit from these sources, expensive exploration tools and technology are needed. One example is the deepwater resources outside of the Norwegian coast, where the cost of drilling one well is at the order of 100 million US dollar.

### Maps of the inner earth

It is not possible to know for sure whether there is any oil or not before drilling a well. To help decide where to drill, one creates maps of the inner earth. These maps are based on models that describe layers of rock types, and geological formations. Several properties that are important for the existence of oil depend on distances and other relations between geological structures. Such distances and relations are found using numerical methods, primarily Fast Marching and Level Set Methods. By using advanced models to create maps, the number of holes where no oil is found is decreased by several orders of magnitude. But, if we can further refine the models there is a lot of money to save.

earth, and must therefore make many assumptions regarding structures and types of rock. To gain a better understanding one create many maps of the same volume of earth, preferably in an interactive way. This puts a high demand on speed and quality of the numerical methods used to create the maps. My research is towards making the Fast Marching and Level Set methods faster and more accurate, and also to investigate other methods to replace the used ones.



An illustration of how layers of rocks can be modelled using Fast Marching methods.

### Improving algorithms

One issue with geological modelling lies in the uncertainty of the data. We do not know much about the inner



## ARON WAHLBERG

**Position:** PhD Student

**Research Group:** Automated and Distributed Computing

**Project title:** Simulation of biomedical flows in complex geometries

“ Breathing Ones and Zeros –  
Towards a Virtual Lung ”

Every year more than five million people die in lung related diseases and hundreds of millions more are affected. Common in both industrialized and development countries, lung diseases are global problems. Why do people get lung cancer? Can COPD, one of the world's deadliest illnesses, be better understood? Why do some people get breathing problems from the smell of a perfume? What particle size is optimal for medicines that people with those problems inhale? These are questions that I want to help answer.

### A virtual lung as a medical tool

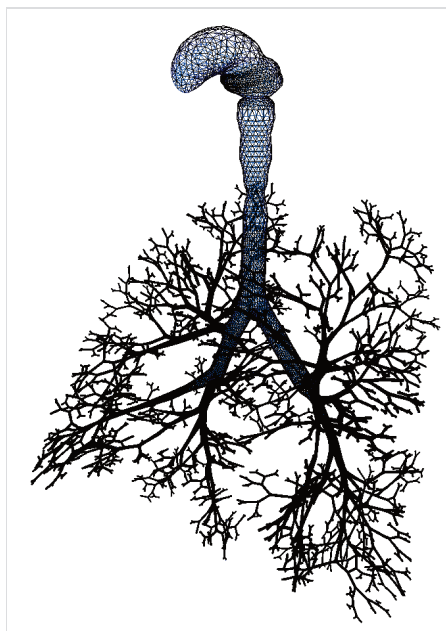
Since it is impossible to get a detailed look at a living human's lung in motion, medical doctors need another tool: a virtual lung. What if a physician can scan your lung and then press a button to let a virtual model of your lung breath in some ones and zeros? The physician could then see where in the lung you need your medicine. It might not be the same spot as where I need mine. With the right information, medicine can be individually targeted!

Relying on simplified geometries, previous attempts towards a virtual lung are ill-founded. To make my results trustworthy, I have built a geometry for a virtual lung based on best available real human lung data. You see the result in the picture. The lung is truly a very complex geometry!

### New methods allow for a complete model

Many physical effects are going on inside the lung. For instance, the lung moves as you breathe, both due to muscles and the airflow itself. Also, the inner walls have hairs and a wet surface that we need to account for. In addition, the airflow might be turbulent. Furthermore, chemical reactions occur in the gas exchange process, and so on.

With all these effects unified in one virtual lung model, computations in the complex lung geometry becomes hard and time consuming. If at all realizable, computations might take months or even years to run on a supercomputer. This is why it is important to come up with faster and more effective computational methods.



A geometry for a virtual lung based on best available real human lung data.

In my research group, we are primarily working on two such computational methods for the virtual lung. With an adaptive method, we try to focus the computational power where interesting phenomena occur. For example, an eddy in the airflow of the lung might be a more interesting place to focus on than a flow that goes straight ahead. Another technique that we are working on is to split the lung up into smaller parts, compute the flow in each part and then put them back together again. Combining these methods might realize our goals, and in the long run help physicians in their everyday work!

## KAREN-HELENE STØVERUD

**Position:** PhD Student

**Research Group:** Biomedical Flows and Structures

**Project title:** CSF hydrodynamics in patients with Syringomyelia and Chiari I malformation

“ Using Computer Simulations to help  
People with a Chiari Malformation ”



Even though it is unknown to most people, about 0.1% of the population in the US have a Chiari malformation. Chiari is characterized by displacement of a part of the brain into the spinal canal. Refer to the figure to see the difference between a normal person and a patient with a Chiari malformation.

### Triggers and Symptoms

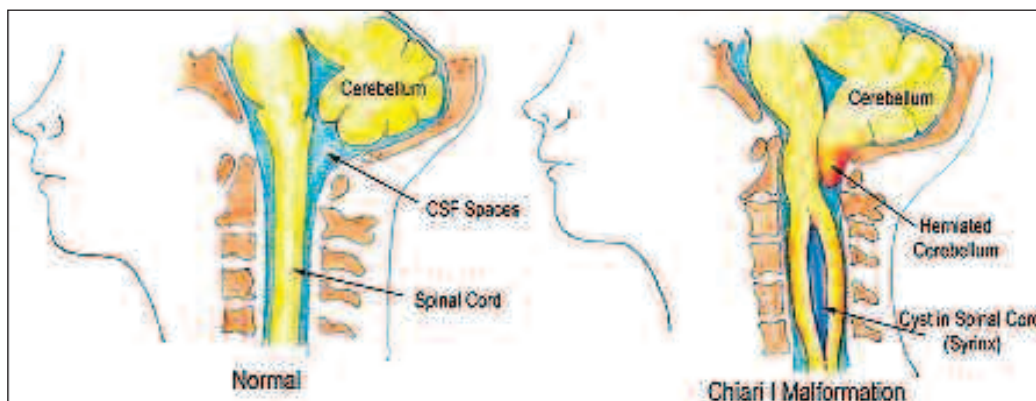
The malformation causes various symptoms in the patients. The most common symptom is having acute headaches induced by activities such as coughing, laughing or changing body posture. Additionally, many patients have trouble swallowing and suffer from muscle weakness, some patients even become paralysed. Secondary to a Chiari malformation, a fluid filled cyst may develop in the spinal cord, leading to yet other symptoms. In this study we focus on patients with both a Chiari malformation and a cyst.

The most common treatment is decompression surgeries where parts of the uppermost vertebrae and the skull are removed to create more space for the brain. About 80% benefit substantially from this treatment and the cyst disappears, while the remaining patients do not respond or even have the condition become worse. However, it remains unclear why the surgery is successful in some cases and not in others. To offer each patient optimal treatment, we need to understand the mechanisms causing cyst formation such that the cause can be removed. Appropriate treatment can be chosen.

### Simulations

The brain and spinal cord is bathed in a water-like fluid called Cerebrospinal Fluid (CSF). CSF flows up and down the spinal cord, from high to low pressure, following the heart beat. In patients with a Chiari malformation this flow pattern is altered due to the narrowed CSF space, and may even lead to cyst formation. However, the exact cause remains unclear.

Hypothetically, cysts in the spinal cord develop because of the altered CSF flow. In response, several simulations and mathematical models have been developed to study the CSF flow and pressure environment. However, few studies have addressed the effects that the abnormal flow and pressure have on the spinal cord. The cyst develops



The Chiari malformation is characterized by displacement of a part of the brain into the spinal canal and is often associated with a cyst in the spinal cord.

within the spinal cord we believe that this is important. In this study we will develop a computational model to investigate the forces acting on the spinal cord in Chiari patients. This model can be used to test different hypotheses and gain insight into an unsolved problem.



## RAINER NERLICH

**Position:** Research Trainee

**Research Group:** Computational Geosciences

**Project title:** The motor of plate tectonics: quantifying the forces that drive plate tectonic motions

“ Studying our Anxious Earth ”

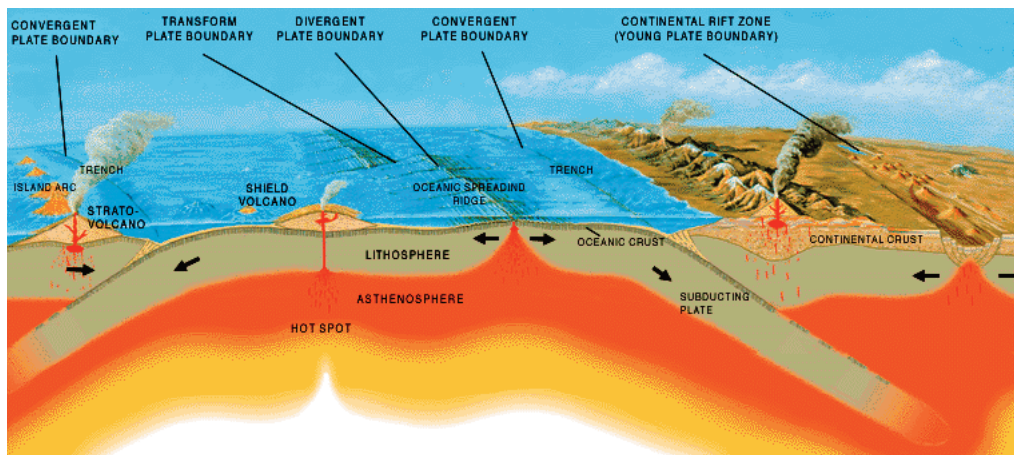
Motions of tectonic plates are responsible for volcano eruptions and devastating earthquakes – every few weeks, the Earth reminds us on its overwhelming power.

Unfortunately, reliable earthquake or volcano explosion predictions are not yet possible. Many people would clearly benefit from a better understanding of the forces involved in these processes – the first step on a long way to be able to predict natural hazards. Millions of U.S. citizens for example risk their lives by simply living in the state of California where the “big one”, that is a major earthquake of magnitude greater than 7 on the Richter scale, has long been predicted. Another recent example is the eruption of Iceland's Eyjafjalajökul volcano that forced most countries in northern Europe to shut their airspace for a few days in April because of circulating volcanic ash. This event occurred totally out of the blue and had a huge negative impact on world's economy. Knowing the exact occurrence time of such events beforehand would help people to prepare appropriately.

### What is known?

Since Alfred Wegner persuaded the scientific community about his “theory of plate tectonics” in the late 1960's, much progress in this research field (known as geodynamics) has already been made. For instance scientists have been able to come up with concepts for the driving mechanisms for tectonic plate motions, but these concepts

continue to be highly under debate. The main question remains whether mantle convection (frictional forces), or surface boundary processes and plate forces (gravitational forces) are the most relevant force contributors to tectonic plate motions. In other words, are the plates passively moving – just like on a conveyer belt – on top of mantle convection cells, or are the plates themselves the main drivers that pull along the mantle below (see figure)? Without an understanding of these fundamental forces,



The figure illustrates the plate tectonic concept. After initial creation of new crust along oceanic spreading ridges, the crust cools, becomes denser, and eventually is pushed away from the spreading center (known as slab push force). Once the plate reaches a subduction zone, the old, cold and very dense crust is pulled downwards (the so-called slab pull force) and gets destroyed by subduction. Last but not least, mantle convection underneath the crust is a major contributing force in the plate tectonic system.

how should we be able to predict natural hazards which arise from even more complicated systems?

### What is our approach?

Simulations provide insight into the processes behind plate tectonics that involve continent-sized landmasses and act over millions of years. Computational models in particular provide a promising way to simulate such processes efficiently. In our work, we will test different computer model setups and hope to be able to identify the most relevant forces involved in this complex dynamic system known as the “Earth”.

## ANDRE MASSING

**Position:** PhD Student

**Research Group:** Automated and Distributed Computing

**Project title:** Nitsche's method for Fluid-Structure-Interactions problems

“ Let the Computer Pump - Using Simulations to Understand Blood flow Through Heart Valves ”



Approximately 280.000 heart valves are transplanted worldwide each year. More than 170.000 mechanical heart valves are used since they are more robust and last longer than their biological counterparts. However, they alter the flow substantially, causing blood clots. To avoid blood vessel blocks the patient has to take blood-thinning medicine. Therefore, it is essential to improve the design of artificial heart valves to preserve the normal blood flow pattern as much as possible.

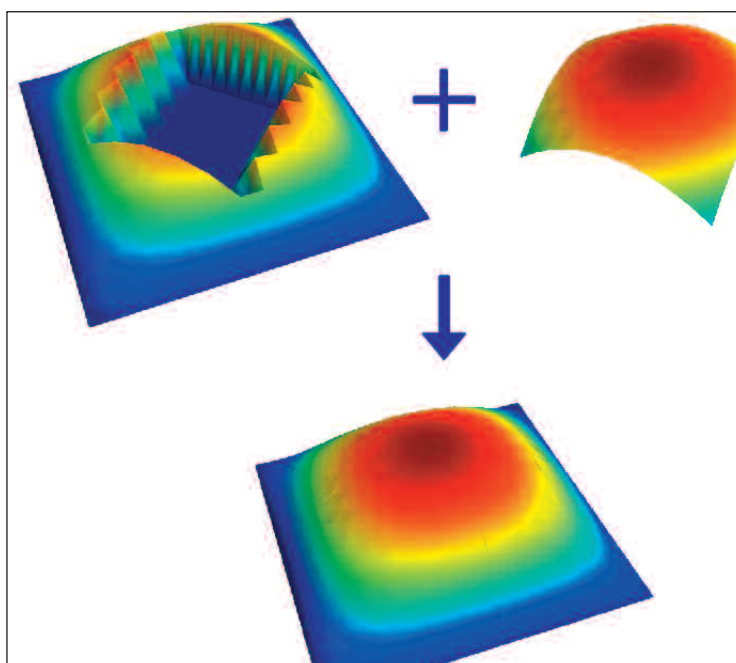
### Simulations for better design choices

Since experiments are not practical either for ethical or cost reasons, computer simulations have to be used. Simulations could enable the manufacturer to quickly estimate the impact of various design choices in a reasonable amount of time. In addition, assuming efficient methods are available, shape designs could be automatically optimized. A first step is an efficient and reliable simulation method of a given setting, that means how the blood interacts with a given mechanical heart valve.

### Heart valves and blood flows – hard to compute

Several factors make heart flow computation a challenging topic: Simulation of fluids and elastic structures, interaction between those, turbulent flows and contact between the heart leaflets. Ideally, a complete simulation environment would also include a model of the electrical physiology of the heart. Each of these building blocks is challenging on its own and far from being usable as black box component. It is the large deformation of the heart during a contraction cycle I am dealing with in my Ph.D. project.

merical methods. Therefore an approach is being developed which is much less sensitive with respect to the large geometry changes. The basic idea is to decompose the simulation domain into several pieces according to their physics (fluid or tissue). Later on a solution on the whole domain will be patched together as the figure illustrates. The research topic combines different fields as fluid-structure interactions and computational ways to solve the physical equations and the geometric related issues. Such a method could provide an essential building block in a virtual laboratory for heart simulations.



The computation of flows in combination with large deformations pushes current simulation tools beyond their limits. Roughly speaking, the strong changes of the underlying geometry require a constant adaptation of the nu-



## RAZIEH BEHJATI

**Position:** PhD Student

**Research Group:** Software Engineering

**Project title:** Model-driven software engineering for the maritime and energy sectors

“ Mexican Gulf Disaster  
– it Could have been Avoided ”

An explosion happened recently on an oilrig in the Mexican gulf. Several lives were lost, and news sources report that people are still missing. Environmental and economic damages are the major consequences of such incidents. Severe environmental damage occurred with the leakage of oil to the water, polluting and threatening the lives of many species living under the sea. Economic damages can also be enormous. The source of this disaster has been oil leak from a well, which could have been avoided if higher quality devices and controllers had been used.

### Software is brain of the system

Systems in oil and gas industry are typically composed of mechanical and electrical devices deep under the sea that are controlled by software systems. The devices are either sensors that detect temperature and pressure, or valves that are attached to pipes and control the flow of oil. In such systems, software is the brain that makes decisions according to different situations. For example, the controller software shall keep the pressure in the pipes in a specific range. This is done by gathering pressure and temperature information from sensors, and then sending the appropriate commands to open or close the valves attached to the pipes. If the software fails to send the correct commands, or if a device fails to carry out a command, a possible consequence would be an increase of the pressure inside the pipe. In the worst case, an explosion can result. Therefore, the controlling software needs to be of the highest quality.

Controllers used in this context are large-scale complicated software systems. These systems can be seen as

networks of components, each controlling a special device while communicating with others. Putting these components together and making them function properly is not trivial. Many problems show up between interacting components, preventing them from fulfilling their functions. Many other problems happen under exceptional situations that were not considered during the development of the system.

### Models can help predict and prevent problems

Complexity of the software system is known to be the main cause of the problems mentioned above. To avoid these problems, we need to devise techniques that help us manage complexities, and avoid the problems they cause. Model-based software development techniques

are promising approaches here, since they help us provide abstract, precise, and analyzable models of the system before developing the expensive controllers. The main questions therefore concern finding out the types of models that are suitable in this context, the information that they represent, and the level of details that they capture. An-

swers to these questions enable us to devise a methodology that can predict and prevent such problems with a lower cost.



## AMIR REZA YAZDANSHENAS

**Position:** PhD Student

**Research Group:** InspectIT

**Project title:** Software model reconstruction and analysis

“ Software Archeology:  
Finding Forgotten Design Decisions ”



Software systems are everywhere now. From your portable music player, to monstrous oil tankers, or even the recycling machines in your nearest grocery store. One might hope that these software systems are flawless, or at the very least, created using the most reliable and advanced engineering methods of the time. In general, you would expect that the company selling the product have a reasonably clear idea about the software behind their product. Unfortunately that is much too often not the case.

### Dated and stable, but unpredictable

You might have already experienced one of these products if you have ever recycled your empty bottles. The product line of one of the main producers of these reverse vending machines was created about 15 years ago, at a time when some software engineers did not cherish crystal-clear designs. This product is a prime example of using hacking methods instead of straightforward engineering methods, creating a nightmare for the maintainers of the machine.

What do you think will happen if the original creators of such systems leave the company with no document behind and no traces of their footprint? Manual code inspection could help in here, however, it will not scale up, it will cost a lot, it is not reproducible, and it will be prone to human error.

### Digging into software

Understanding the structure and behavior of an existing system is the cornerstone of any maintenance task. Therefore, the need for better and simpler understanding of software systems and their original design intentions is not recent and dates back to 70s.

However, most of the reported research has been carried out on mock example systems and with a focus on the structure and static organization of software components.

In our research we are relying on proven methods of investigating software artifacts as much as possible. For instance, We are using both dynamic and static analysis techniques to help us gather enough information about the system. Static analysis deals with static structure of the system in design time and dynamic analysis considers executions of a running system. However, we intend to adapt the suggested approaches to the requirements of the particular case.

Our overall approach to the problem can be described in three steps:

1. Extract: gather as much information as possible about the software using automated tools.
2. Abstract: as we are working on industrial systems we need to hide the unnecessary details and make higher-level abstractions of the extracted information chunks.
3. Present: the digested information needs to be presented to the users of the models in simple, and yet informative models.

We will adapt each of the steps to each case study accordingly.



Recycling machine

