3D Reconstruction of Insects in Amber

A PhD plan explanation

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Global context

- This PhD is part of a research project entitled "Phylorama - Expanding the Tree of Life through a digital view of museum collections" between the Department of Computer Science (DIKU) and the Natural History Museum of Denmark (NHMD) at the University of Copenhagen.
- The tree of life (phylogeny) is a fundamental concept in biology for understanding the biodiversity of our planet. Species are represented as "leaves" and their evolutionary relationships as tree branches. However, the position of more than a million insect species remains ill-defined.
- By combining computer vision with entomology, we will explore the possibility of a high-throughput "phylogenetic" pipeline, capable of rapidly acquiring and managing images of millions of specimens, recent and fossil, in museum collections.

PhD Subject

- Many natural history museums have collections of insects in transparent medium like amber. Those prehistoric insects, that no longer exist, were trapped in amber during ancient geological areas a long time ago (between 40 to 90 million years ago).

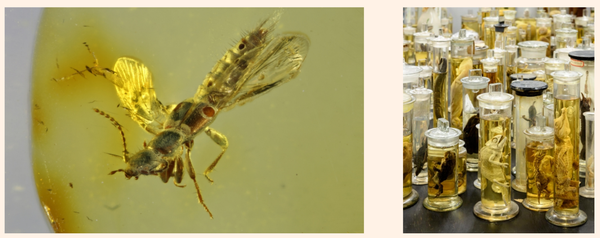


Figure 1: Prehistoric beetle trapped in amber (seen under a microscope), and reptiles specimens in jars, from the Natural History Museum in Copenhagen.

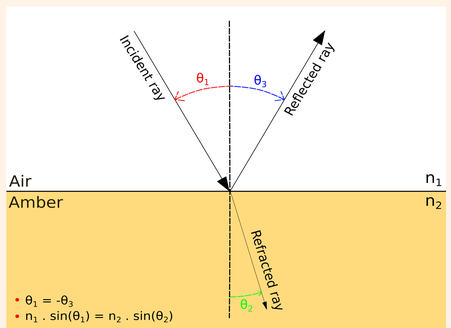
- Those insects are an invaluable source of information to evolutionary scientists. Because it is impossible to extract the insect from its amber, one solution is to do a 3D reconstruction of the insect in the amber block.
- The first idea, to do a robust and accurate 3D reconstruction would be to use a medical scanner to obtain a 3D model of the insect, but this would be time-consuming and expensive. To give an idea, the Natural History Museum in Copenhagen, for which this feasibility study was conducted, has a collection of about 50,000 prehistoric insects preserved in amber. It therefore seems more reasonable to opt for photogrammetric scanning, which only requires a photogrammetric camera and 3D reconstruction algorithms.

Data

- The data will be selected from an existing collection of about 50,000 prehistoric insects preserved in amber containing small fossils (around a few millimeters) of various shapes. We will use specialized cameras together with microscopes.
- In order to test and implement our solutions, we will build prototypes and 3D software to simplify some of the parameters (synthetic models, software phantoms, insects in box shaped medium or in water with a plane surface, ...).

How should we adapt 3D reconstruction techniques to take into account a refractive medium ?

- In current 3D reconstruction methods, rays of light are always following a straight line because they are only diffusing in the air. Now, each time they are in contact with the interface between the air and the refractive medium, some of the rays are refracted, and some are reflected. So, each time we are doing projection or back-projection (with epipolar lines for example), it changes the equations because we have to take into account the Snell-Descartes laws.



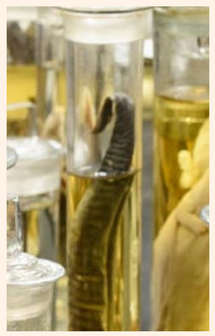


Figure 2. Left: Schema explaining the influence of Snell-Descartes laws on a ray at the interface between two different mediums. Right: an example.

- To take into account those laws, it is really important to have an accurate knowledge of the shape of the refractive medium. Indeed, these laws are effective on a plane surface. So we need to discretize the surface of the medium as accurately as possible in order to increase the precision of the final 3D model.

Methodology

- How to get the shape of the medium ?
  - **A large piece of amber :** if we can cut the shape of the medium in order to create a parallelepiped or another basic form, then, with the help of some calibration tests patterns we can figure out the amber shape
  - **A small piece of amber :** we can use the Shape-From-Silhouette technique, by taking care to place the block in front of a colored background, this technique allows one to estimate the volume of any convex object, provided a sufficient number of images are used.
- How to get pictures of the insects ?
  - **A large or normal piece of amber :**
    - Use a good quality standard camera.
    - Use a macro objective, better local precision, but blur will appear
  - **A small piece of amber :**
    - Use a microscope (macro objectives might not be accurate enough)
- When we have the data, we can implement algorithms :
  - **Geometric 3D-reconstruction**
    - Refractive Structure-From-Motion (RSFM) + Refractive Multi-View Stereo (RMSV)

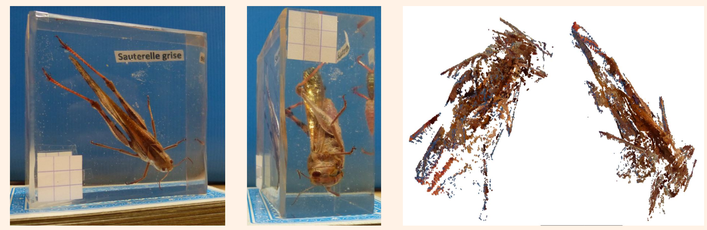


Figure 3: Two real images of a grasshopper cast in a box-shaped block of resin, and a 3D-reconstruction of the grasshoper by RMVS (five images through the same face, plus one side shot)

  - **Photometric stereo 3D-reconstruction**

To implement this technique, it needs to take into account some aspects of the amber :

- A model of the phenomenon of attenuation of the light (Beer-Lambert law)
- A knowledge of the color of the amber (the attenuation depends on the wavelength)
- The dispersion of the light