Building an **atlas** for pig **breeding**

Moving from general body composition measurements toward partitioning pig carcasses into different segments, would add information not only from the whole animals, but also from parts such as primal cuts or internal organs.

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With the advancement of large-scale computed tomography (CT) in the Topigs Norsvin breeding system, there has been a huge increase in genetic progress in body composition and lameness detection. The focus has been on lean meat percentage and yield (carcass to live animal), which treats the animal as a pool of digital pixels from CT images. This may be similar to putting the whole animal in a grinder and measuring the amount of fat, lean meat, and bone.

Moving ahead, atlas-based segmentation is a framework for performing dissection or cutting in a database of images of live pigs. The construction of a pig atlas, or map for breeding, can be seen as the phenotypic analogue to mapping the genome in genomics.

Understanding anatomy

Anatomy atlases have been used throughout history as templates to understand the anatomy of living things, both humans and animals. Before the advent of non-invasive imaging techniques such as CT, ultrasound, and magnetic resonance imaging (MRI), anatomy involved the invasive post-mortem dissection of the object. By use of non-invasive imaging techniques, the living object can be studied in vivo. Obtaining information from such non-invasive imaging techniques as CT requires relationships between the images and the physical reference to be studied. This relationship can be represented as an atlas by labeling different objects in the CT images based on density (fat, lean meat, bone), anatomy (liver, lungs,muscles) or different cuts of meat (belly, loin, ham, shoulder, etc.). The atlas will allow us to make further advances in the use of the database of CT images and its application in phenotypes that can be used in the Topigs Norsvin breeding system.

Atlas version 1.0. Start with a simple atlas - build a framework

An atlas can have many layers of information. In order to build a framework, a simple atlas may be a good way to start. Separating the pig into segments such as carcass/non-carcass and primal cuts such as ham, belly, loin, shoulder, and head could serve as a basis for building a framework around the atlas . We would then need to build an atlas based on expert knowledge of how we separate the non-carcass (internal organs, etc.) from the carcass part of the live animal, and then on how to segment the carcass part into primal cuts. The labeling of segments is done in 2D, stacking them up into 3D over time. Building the first atlas is laborious and time-consuming, but we would only need one atlas, so time spent here may save time on all the other animals. The key is to sample animals which may represent the whole population in terms of variation in anatomy; we may therefore need one animal or an average of a sampled group. Images from new animals are then registered and aligned to match the atlas template. This registration may be a simple alignment of two images or a more complex alignment of a 3D volume of a segment.

When we have a running pipeline for atlas-based segmentation, we can then add more layers to our atlas, bringing in more details which may be samples. The CT images are stored, which means that new and more detailed atlases can be used retrospectively, adding more data to our existing pool of CT images and animals.

The pig skeleton is used to produce landmarks for the construction of the pig atlas

The skeleton of a pig contains structures which can easily be utilized as landmarks in an atlas (Figure 1). Recognizing structures such as the spine, pelvis, ribs, scapula, femur, and skull, will aid in the construction of a pig atlas, especially with respect to different cuts of meat (i.e. belly vs. ham). Butchers use the skeleton as a reference when producing primal cuts from a pig carcass, and we aim to reproduce this procedure in the virtual carcass produced from the CT images.

More complex atlases require more expert knowledge and labeling of segments. More layers to the atlas require more information. Separating different muscles and internal organs may be examples of more complex features. Labeling different types of bones may also be obtained through expert knowledge.

More complex atlases require more expert knowledge and labeling of segments

An atlas of internal organs can be represented in two dimensions (2D) in the coronal direction. This atlas is a representation of the body cavity containing internal organs in purebred pigs, and this may be adjusted to fit and label the internal organs in future pigs.

The atlas can contain many layers of information, from skeleton to carcass, from carcass to different muscles, and from body cavity to small organs within the pig's body. More complex atlases require more expert knowledge and labeling of segments. This labeling may be done in different ways, either by fully automatic procedures based on pixel values or density (fat, lean meat, and bone segments), or by manual labeling by experts of, for instance, cuts of meat, internal organs, or specific bone studies, such as measuring the level of osteochondrosis in joints. The framework presented in this article, and the retrospective nature of CT images from 2008 until this day, will allow us to build further on the pig atlas, producing new and improved phenotypes which can be applied in our pig breeding program.

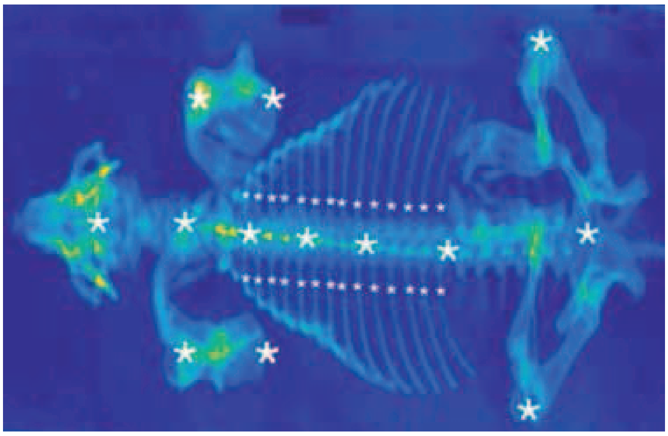
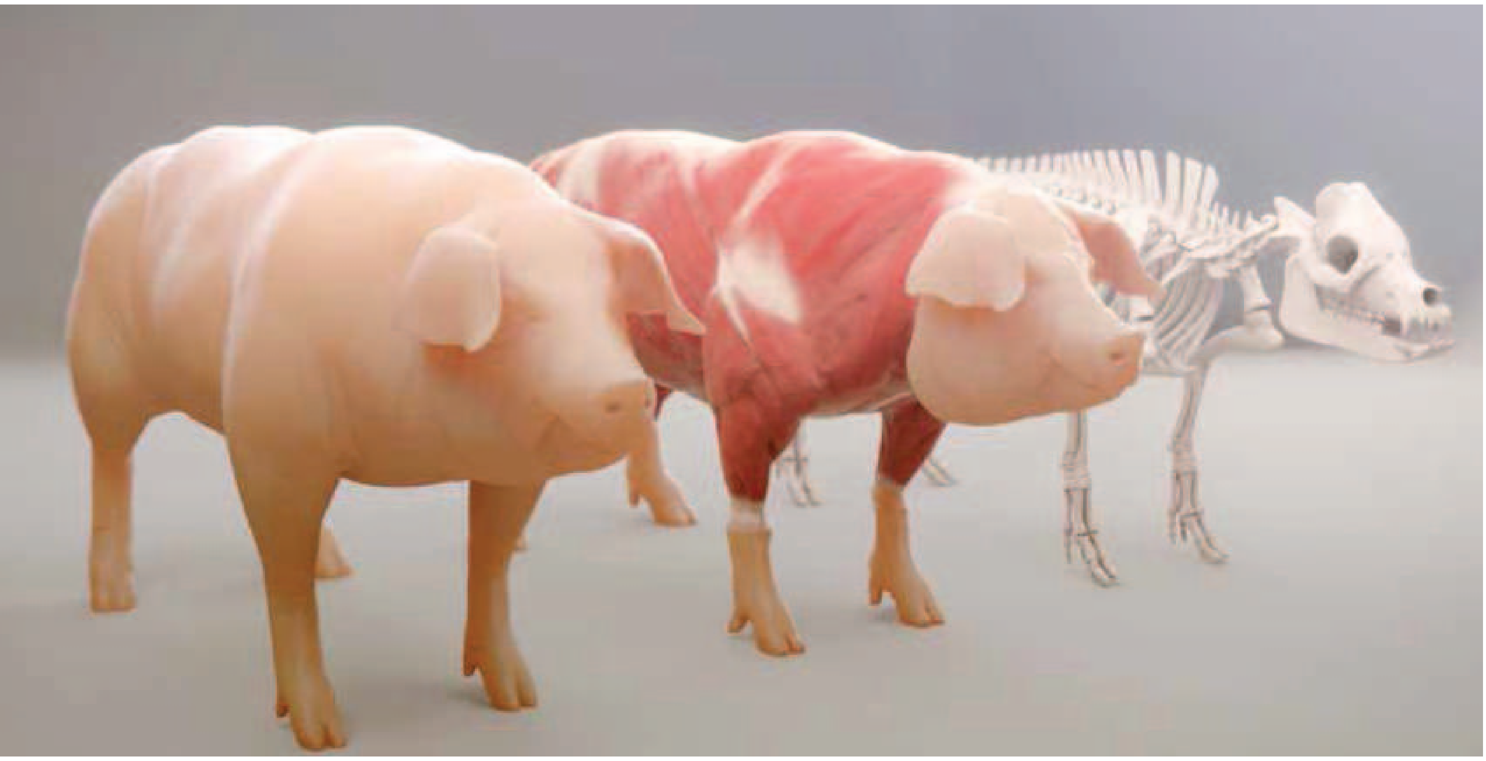
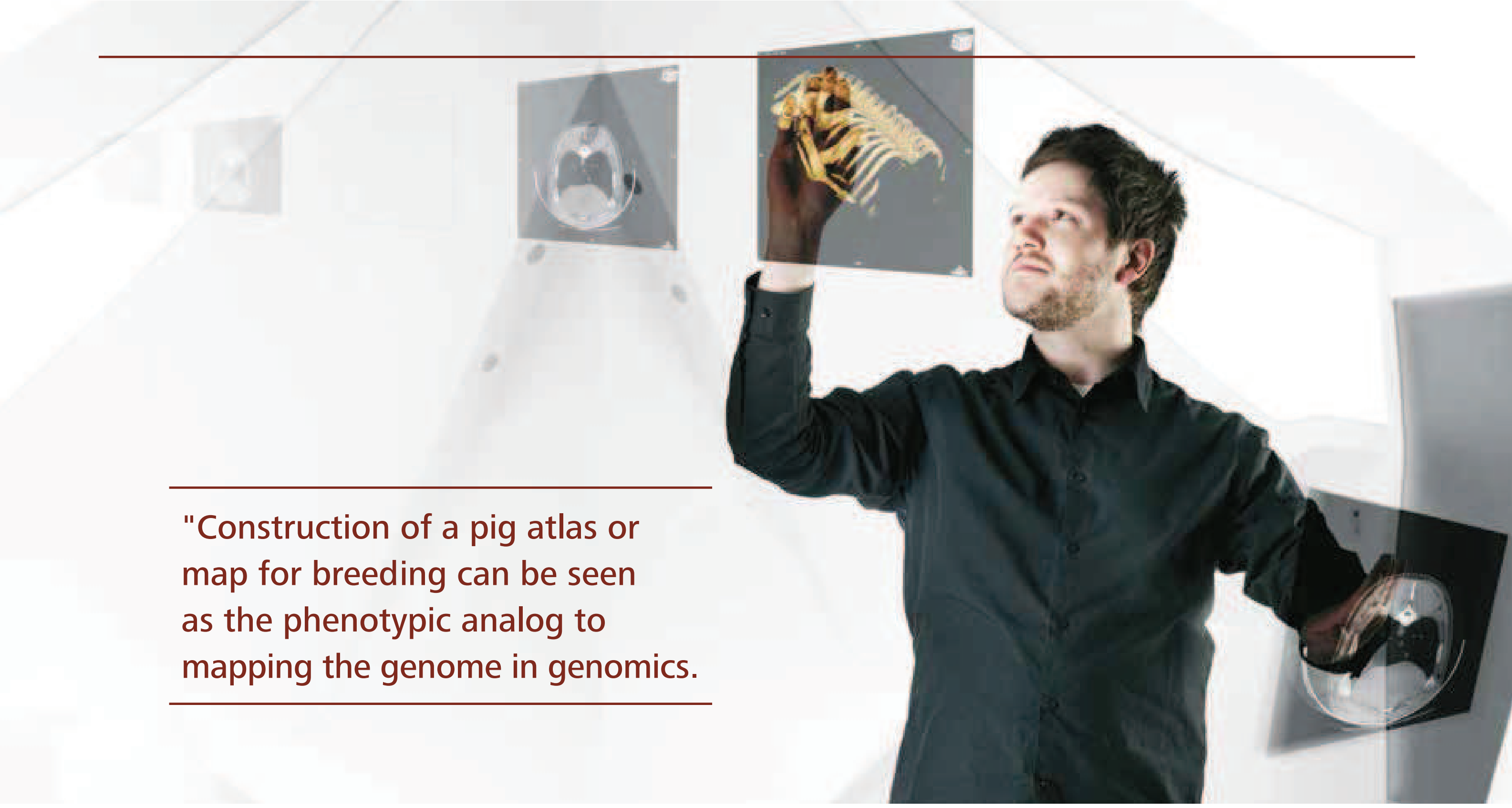


Figure 1 - Anatomical landmarks in a pig skeleton





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Bringing the pig atlas into multi-dimensional space

The atlas of the pig is by default three-dimensional (3D). We observe the anatomy of the pig in 3D, and the images from CT reproduce this anatomy as a digital volume. By adding more information, not only from CT, the atlas can be seen in dimensions beyond 3D. For example, we might add to our 3D CT atlas information from other modalities, such as information on growth (studies over time), meat quality from near-infrared spectroscopy (NIR), ultrasound scans on back fat, loin thickness, and intramuscular fat. In the future MRI, PET scans and images/videos of behavior can be included. All of this together will add to the atlas, making it more multi-dimensional. The aim is to create an atlas which will serve as a framework for the phenotypic data collected from our breeding animals, making data more accessible, detailed, and accurate, and bringing progress to Topigs Norsvin genetics.

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ATLAS FOR PIG BREEDING

An atlas for pig breeding is an anatomy map of the live pig from a set of annotations of a reference representation of the anatomy (Fogtmann Hansen, 2010). In our case, the anatomy map is sampled from a volume CT scan of the entire pig.

New pigs are registered to the atlas, and the atlas is adapted or adjusted for the new pig. This adjustment of the atlas will allow the automatic labeling of different structures and the ability to measure the variation between animals.