Open source bone biology software benefits industry and academia

BBSRC
bioscience for the future

BBSRC-funded research into the relationship between bone structure and animal movement led to the creation of free, open source software BoneJ. BoneJ is now being used for image analysis in fields as diverse as soil science, materials science, volcanology and food science and has been downloaded more than 28,000 times.

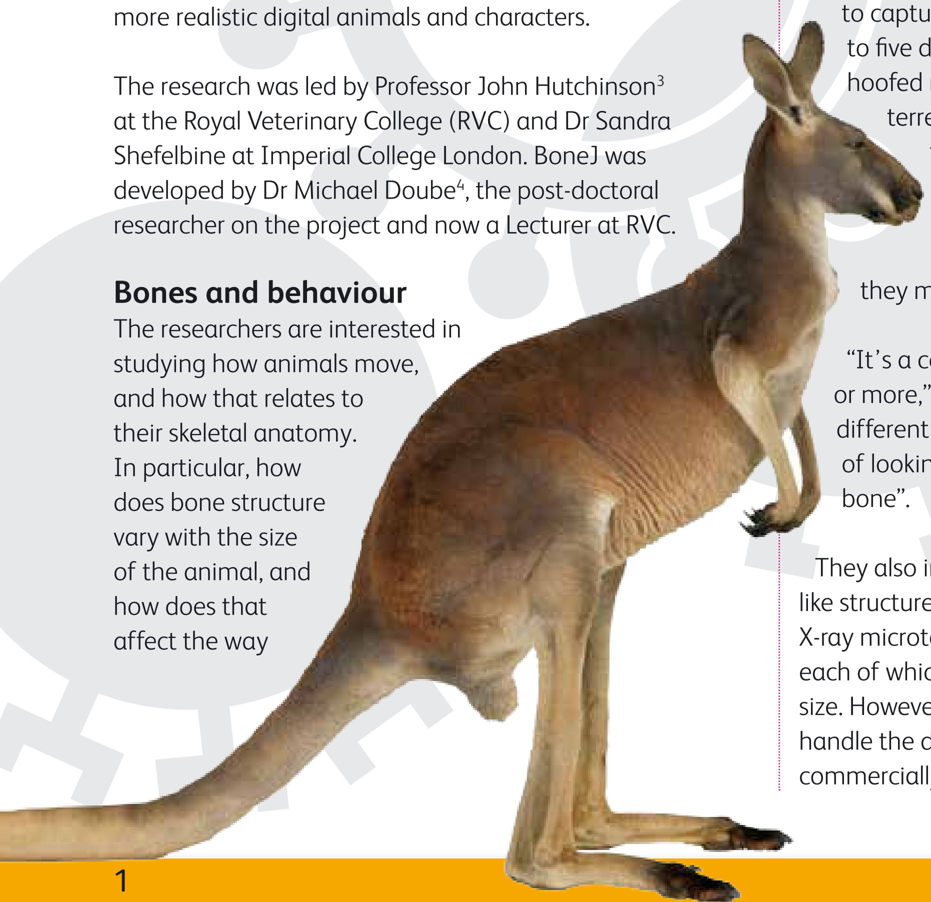
The research, supported by a £336K investment from BBSRC[1], also led to a collaboration with architecture firm Foster + Partners[2], focussed on understanding the self-repairing and structural properties of bone for use in new building materials.

Film-makers and digital artists are also using CT scans of animal skeletons produced by the researchers to create more realistic digital animals and characters.

The research was led by Professor John Hutchinson[3] at the Royal Veterinary College (RVC) and Dr Sandra Shefelbine at Imperial College London. BoneJ was developed by Dr Michael Doube[4], the post-doctoral researcher on the project and now a Lecturer at RVC.

Bones and behaviour

The researchers are interested in studying how animals move, and how that relates to their skeletal anatomy. In particular, how does bone structure vary with the size of the animal, and how does that affect the way in which an animal moves? They also use data on bone and muscle anatomy from living species to explore the behaviour of extinct animals.



BoneJ arose from a BBSRC-funded project led by Hutchinson and Shefelbine to study how bone structure changes between closely-related species of different sizes. They used motion capture video systems and pressure plates to capture behavioural data from animals belonging to five different groups (birds, carnivorous mammals, hoofed mammals, kangaroos and wallabies, and terrestrial primates). The researchers combined that information with detailed computer tomography (CT) scans of bones to provide estimates of the physical forces and loads placed on bones in animal of different sizes as they move.

"It's a common method that's been done for 40 years or more," Hutchinson explains. "What we did that was different was we looked throughout the bone instead of looking at one point as representative of the whole bone".

They also imaged the geometry of bone's internal lattice-like structure, known as trabeculae. The researchers used X-ray microtomography (XMT) to generate 3D images, each of which was hundreds of megabytes to gigabytes in size. However, their image analysis software was unable to handle the data. Doube initially looked for an alternative commercially-available package, as budgeted for in the

IMPACT SUMMARY

Open source image analysis software BoneJ, developed during BBSRC-funded biomechanics research at the Royal Veterinary College, is being used in fields as diverse as volcanology, marine biology, soils science, battery design, and food science. The software has been downloaded more than 28,000 times by users in 56 countries.

The research from which the software arose also led to a collaboration between the researchers and London-based architecture firm Foster + Partners, who are interested in using knowledge about bone structure and its ability to self-repair to develop biologically-inspired building materials.

Scan data from the research has also been used by digital film-makers and animators, including Weta Digital, in the design of CGI characters.

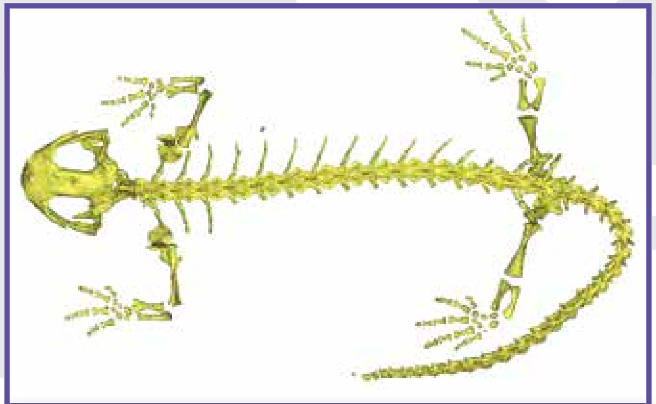
CT scan of a crocodile. Hutchinson and colleagues have made much of this data freely-available online. Image: John Hutchinson, RVC grant, but quickly realised these would not meet his needs. Instead, he took existing plug-ins for open-source imaging software ImageJ and created the first version of BoneJ[5].

Adaptable, flexible, shareable

Doube and colleagues published an early version of BoneJ online in 2010. Since then, it has been downloaded more than 28,000 times by more than 15,000 unique hosts. In 2016 users in 57 countries ran BoneJ modules more than 450,000 times.

Built on an open source platform, BoneJ has several advantages over other imaging software. In particular, users can see how it was made and how it works (unlike many commercial packages), allowing them to adapt it to meet specific needs. The software's flexibility, adaptability and the fact it can be shared easily has also led to the creation of a supportive online community.

"Before this, if you wanted to image bone data, you either had to write your own software, which is laborious, or you had to use expensive, limited commercial software, and that software was often a black box," says Hutchinson.



CT scan of a salamander. Image: John Hutchinson, RVC.

That flexibility has resulted in BoneJ being used in studies of volcanology[6], marine biology[7], and battery design[8], among others[9]. "People started downloading and using it, which was a bit surprising," says Doube. "Even more surprising was that they started using it for stuff like material science[10], and soil science[11] and food science[12], and all these kinds of fields that have similar kinds of questions, or the things they look at have similar geometric properties [to bones]."

For instance, in 2016 Doube was contacted by soil scientist Dr Johannes Koestel from the Swedish University of Agricultural Sciences who has independently developed a derivative version of BoneJ, called SoilJ, for the geosciences community.[13]

BoneJ is also an early example of open research and best practice in research software, as promoted by organisations such as the Software Sustainability Institute[14] (which also supported BoneJ development). Increasingly, funders and academic publishers require researchers to share data and software tools as part of their methods.[15,16] BoneJ has consistently followed these principles as it is fully open and freely available for anyone to use.

Doube has continued to develop BoneJ with support from the Wellcome Trust, which allowed him to hire an engineer to adapt BoneJ to work with ImageJ2. This work will split BoneJ into a set of modules that could be packaged together or used individually, depending on users' needs. In late 2016 Doube received additional funding from BBSRC to develop new capabilities for BoneJ, called ellipsoid factor, which would allow the software to measure rod- or plate- like structures within bone. Researchers can then use that information to look for bone geometry changes during osteoporosis, which affects more than three million people in the UK.[17]

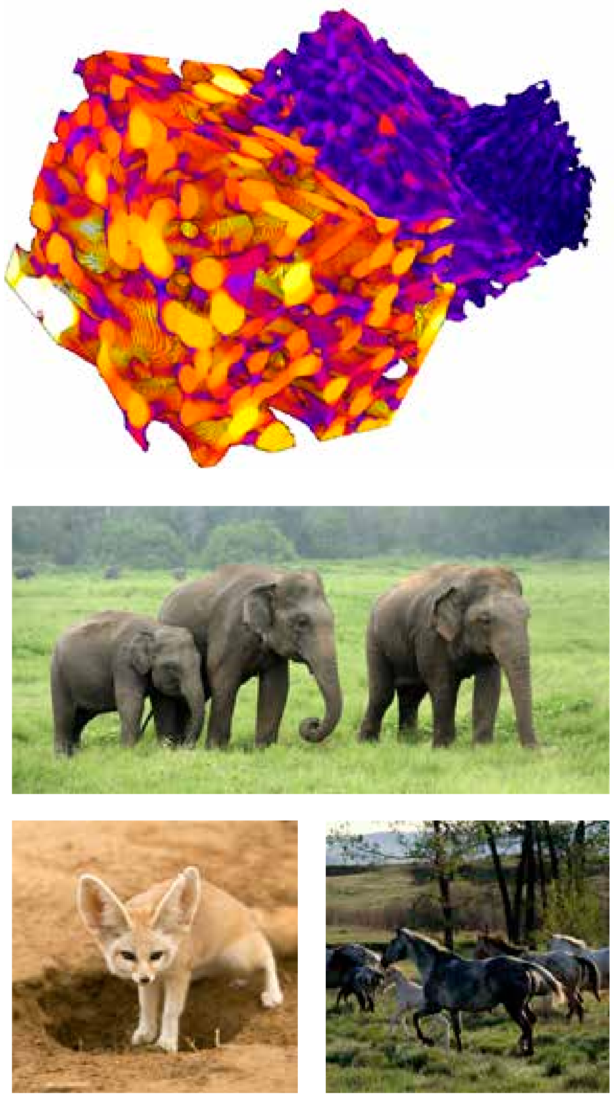
Bones on screen

Hutchinson's research generates large amounts of CT scan data of animal skeletons. In 2011, he was approached by the Creature Department at Weta Digital, and provided them with cat skeleton CT scan data. Hutchinson has also provided data to other film-makers and animators, as such companies are increasingly using CT scan data to ensure digital characters look and move as realistically as possible.

"It's a valuable resource and we've built up a big database which we are gradually putting online as a free resource," says Hutchinson.

Hutchinson is also enthusiastic about public engagement and communicating his science to different audiences via social media and television documentaries, to which he has contributed both in front of the camera and as an off-screen consultant. For instance, drawing on his BBSRC-funded research, Hutchinson contributed to several episodes of BBC4 documentary 'The Secrets of Bones', which aired in 2015.

The group also publish many CT scan videos on Hutchinson's YouTube channel 'What's in John's freezer?'



A composite image showing how the structure of bone changes in different species. Left to right – Asian elephant (Elephas maximus), domestic horse (Equus caballus) and Fennec fox (Vulpes zerda). Larger animals have fewer, thicker 'struts' (yellow is thickest, purple thinnest). But the ratio of struts to spaces does not change with animal size. This data was analysed with BoneJ.
Top image: Michael Doube, RVC.

New insights into architectural design

The BBSRC-funded project has also provided other opportunities for Hutchinson and Doube. "BoneJ has been a great magnet for collaborations," Doube explains. For instance, it led to a collaboration with British architecture firm Foster + Partners through a PhD student co-supervised by Doube and Hutchinson at RVC and by Xavier De Kestelier of F+P's Specialist Modelling Group.[18]

The PhD student is investigating the microscopic structure of bone, looking at how it supports loads, and how it can re-model and repair itself; properties which the architects hope to incorporate into new biologically-inspired building materials. The collaboration began in 2013 when the architects contacted Doube, and the results of the project may potentially be used in a high profile structure.
"The student has been involved in collaborating with Foster + Partners pretty actively, to take the basic science he's doing and to apply that to new insights into architecture design," says Hutchinson.

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