onychophorans[1]. The other study[2] provides evidence that the crustacean Ubx contains an additional peptide that modulates the activity of the alanine-rich peptide, and possibly other repression domains, in crustacean Ubx.

Removing the regulatory peptide in the crustacean Ubx protein causes it to repress Dll in fly embryos. Conversely, modifying the fruitfly Ubx protein to include the regulatory peptide abrogates its repression activity. The peptide contains potential casein kinase (CKII) phosphorylation sites, so the crustacean Ubx protein may function as a conditional repressor: it can repress the expression of the Hox gene *Antennapedia (Antp)* in thoracic regions without altering the expression of *Dll* in the same tissues. During the divergence of the crustaceans and insects, Ubx might have evolved into a dedicated — constitutive — repressor of limb development in insects.

A scheme for the evolution of Ubx function is shown in Fig. 1. The onychophoran Ubx protein might function as an activator of appendage development. When the onychophorans and arthropods diverged, Ubx acquired an alanine-rich repression domain near its carboxy terminus. This domain mediates constitutive repression in insects. But in crustaceans the addition of the regulatory peptide causes it to function in a conditional fashion. As a result, Ubx does not suppress limb development in crustaceans. But it eliminates abdominal limbs in insects, greatly reducing the overall number of appendages compared with crustaceans.

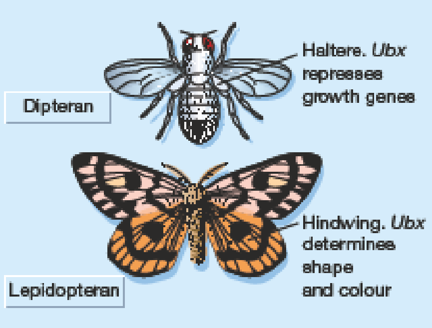

Figure 3 Evolution through changes in Hox target genes. Among the insects, dipterans (such as *Drosophila*, top) have rudimentary wings, called halteres, in place of hindwings. Ubx represses growth in the halteres, suppressing wing development. In contrast, lepidopterans (such as moths, bottom) have well-developed hindwings. Ubx does not suppress growth in lepidopteran hindwings, and it has been proposed that the *cis*-regulatory sequences associated with these genes lack binding sites for the Ubx repressor. In butterflies, Ubx primarily regulates genes that determine characteristics of the hind- and forewings, such as those involved in determining shape and colour.

The work of Galant and Carroll[1], and Ronshaugen *et al.*[2], is a striking demonstration of the importance of protein evolution in the diversification of arthropod limbs. The analysis[2] of the crustacean Ubx protein provides a particularly rigorous standard for future evo–devo studies, in that these authors identified the exact amino-acid substitutions that are responsible for the suppression of insect limbs.

However, there are other sides to the story. For instance, changes in gene expression, rather than changes in protein function, have been implicated in the conversion of swimming limbs into feeding appendages in certain crustaceans[3,4] (Fig. 2). In this example, the shift in the *Ubx* pattern is accompanied by a change in the expression of another Hox gene, *Sex combs reduced* (*Scr*).

Another example comes from the evolutionary conversion of hindwings into rudimentary wings (halteres) in the insect group, the Diptera, that includes *Drosophila*[5,6]. This process centres on '*cis*-regulatory sequences', which are stretches of DNA adjacent to a gene that influence its expression. In *Drosophila*, the production of halteres may have depended on the gradual acquisition of binding sites for Ubx protein in the *cis*-regulatory DNAs of different 'growth genes', such as *wingless* and *decapentaplegic*. As discussed above, Ubx functions as a dedicated repressor in insects. Although it is expressed in the hindwings of butterflies, it does not suppress their growth, possibly because there are no Ubx-binding sites in the *cis*-regulatory DNAs of the butterfly growth genes[5,6].

In summary, evo–devo studies provide evidence for three distinct mechanisms of limb evolution in arthropods. First, there are changes in Hox gene expression patterns (Fig. 2). Second, a given Hox protein can regulate different target genes in different insects, owing to the evolution of Hox-protein-binding sites in the *cis*-regulatory DNAs of the target genes (Fig. 3). Third, as exemplified in the new studies[1,2], Hox proteins can evolve new activities (Fig. 1). Once again we are reminded that evolution is opportunistic and uses every trick in the book to generate "endless forms most beautiful and most wonderful"[7]. ■

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Daedalus

The cliff of stability

Large atomic nuclei, containing many protons and neutrons, tend to be unstable. But stable nuclei do exist, and can be seen as an 'island of stability' on a graph of proton number against neutron number. As the number of protons increases, the number of neutrons required for stability increases too. Daedalus now points out that neutron stars are stable, even though they have no protons but enormous numbers of neutrons. So the graph should have a 'cliff' of stable neutron-rich nuclei along the neutron axis, rising out of the sea of instability. DREADCO physicists are now looking for such a cliff.

X-ray spectroscopy irradiates an atom with an energetic photon that ejects an electron from a low energy level. A higher electron then 'falls' into the vacancy. At some frequency the electron should emit all of its energy and fall not just into a lower orbit, but right into the nucleus. This nuclear transformation would create a new element, with one more neutron and one less proton than the original.

The process would absorb or emit large amounts of energy, and would have to be conducted slowly. But hydrogen and its two isotopes deuterium and tritium — which have one and two neutrons, respectively, in addition to hydrogen's single proton — should become pure neutrons if their electrons drop into the nucleus. A single neutron is unstable; how many must come together for them to be stable?

'Nuclear matter' would be so dense it would be hard to handle. But, says Daedalus, a heavy element such as gold could have most of its electrons dropped into the nucleus, and still keep some in orbit to balance the nuclear protons. The resulting large atomic nucleus would be stabilized by its excess of neutrons, although it might slowly acquire orbiting electrons by beta-capture. These orbiting electrons would make it a low-atomic-number element, such as hydrogen. Their vast orbital space would give it a high but controllable density, around a hundred times that of water. This would be 'superheavy' hydrogen, although you could do the same for helium or lithium, for example.

Daedalus anticipates new chemistry. 'Superheavy hydrogen' should give dense types of water and hydrocarbons, probably incompatible with life. A nucleus of hundreds of neutrons stabilized by a few protons could be taken up the periodic table by a beam of protons until it approached the elusive 'island of stability' from below. And dense anti-tank shells would not need depleted uranium. **David Jones**