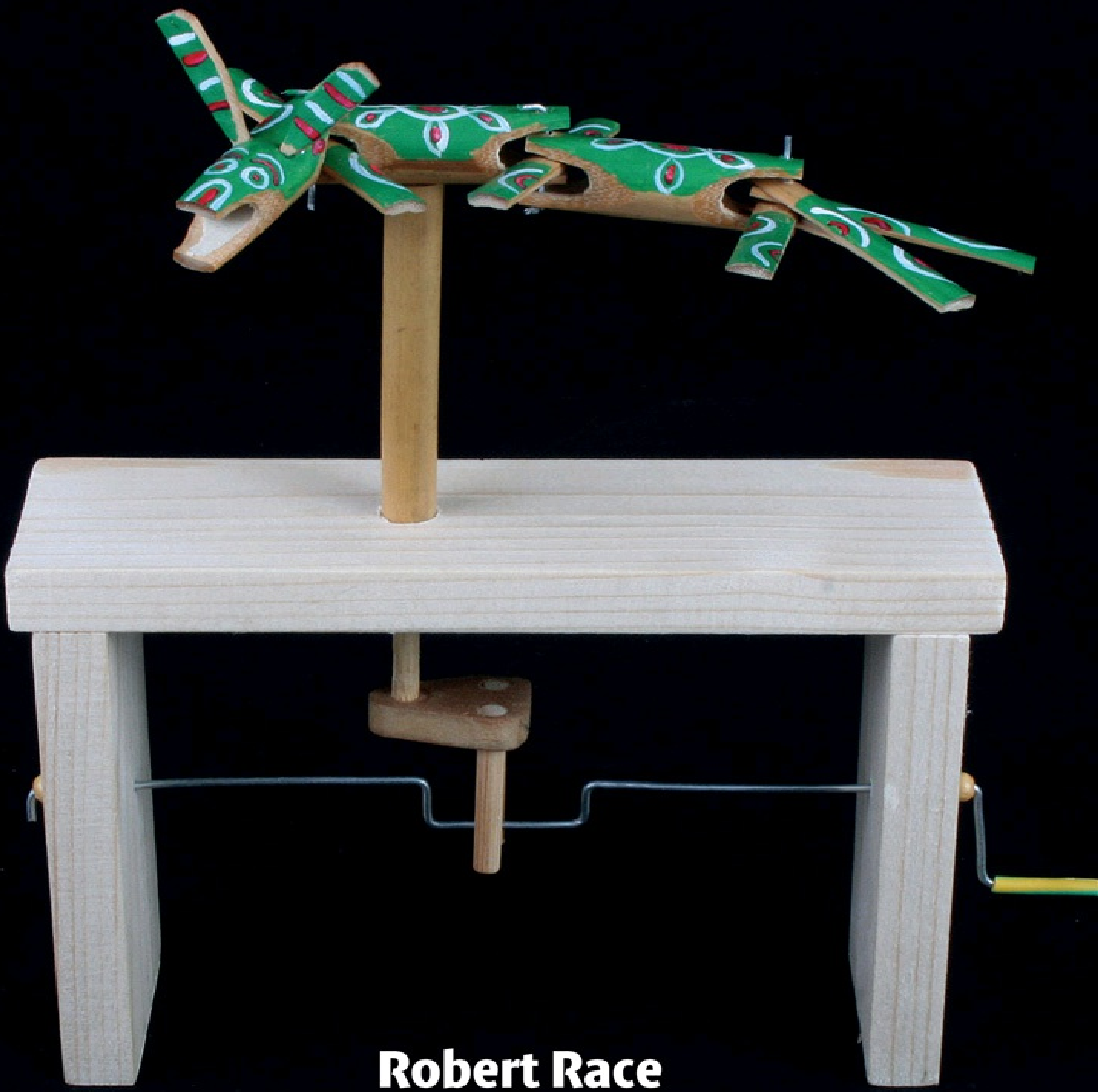
Making
MOVING TOYS AND AUTOMATA



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THE CROWOOD PRESS

First published in 2018 by
The Crowood Press Ltd
Ramsbury, Marlborough
Wiltshire SN8 2HR

www.crowood.com

This e-book first published in 2018

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library.

ISBN 978 1 78500 492 6

All photographs are by the author unless stated otherwise.

Frontispiece
Cat and Spider.

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INTRODUCTION

This book is about designing and making small-scale automata. The emphasis is on using readily available materials, such as scraps of wood and wire, card and paper, bamboo, skewers, string, tinplate, and feathers. Of course, using the phrase ‘readily available’ does rather evade the issue; what *is* readily available will vary greatly according to circumstances. Many of the materials I use in my moving toys and automata are recycled or re-used, such as redundant packaging, off-cuts and driftwood.

A jumping jack made by the author from a sardine can and a used paintbrush. Pulling the string makes the wooden limbs dance about.

In the course of the book a number of simple mechanisms are explored, such as levers, linkages, cranks and cams. Also considered are ways of moving those mechanisms directly by hand, by springs or falling weights, and by the wind.

In many places around the world there is a long tradition of using readily available materials and simple mechanisms to make moving toys. They may be made by parents for their children, or by the children themselves;

they may be made by hand, using minimal resources, to sell on the street or at fairs and festivals; they may be the product of small-scale manufacture. Much of my own inspiration for making automata comes from a collection of such toys gathered over more than thirty years.

Three paper windmills mounted with wires on a bamboo frame, from Dhaka, Bangladesh.

The pattern I have followed in each chapter is to start simple, and to move, with occasional meanderings and diversions, to the design for an automaton. Thus each of the seven chapters begins by looking at some

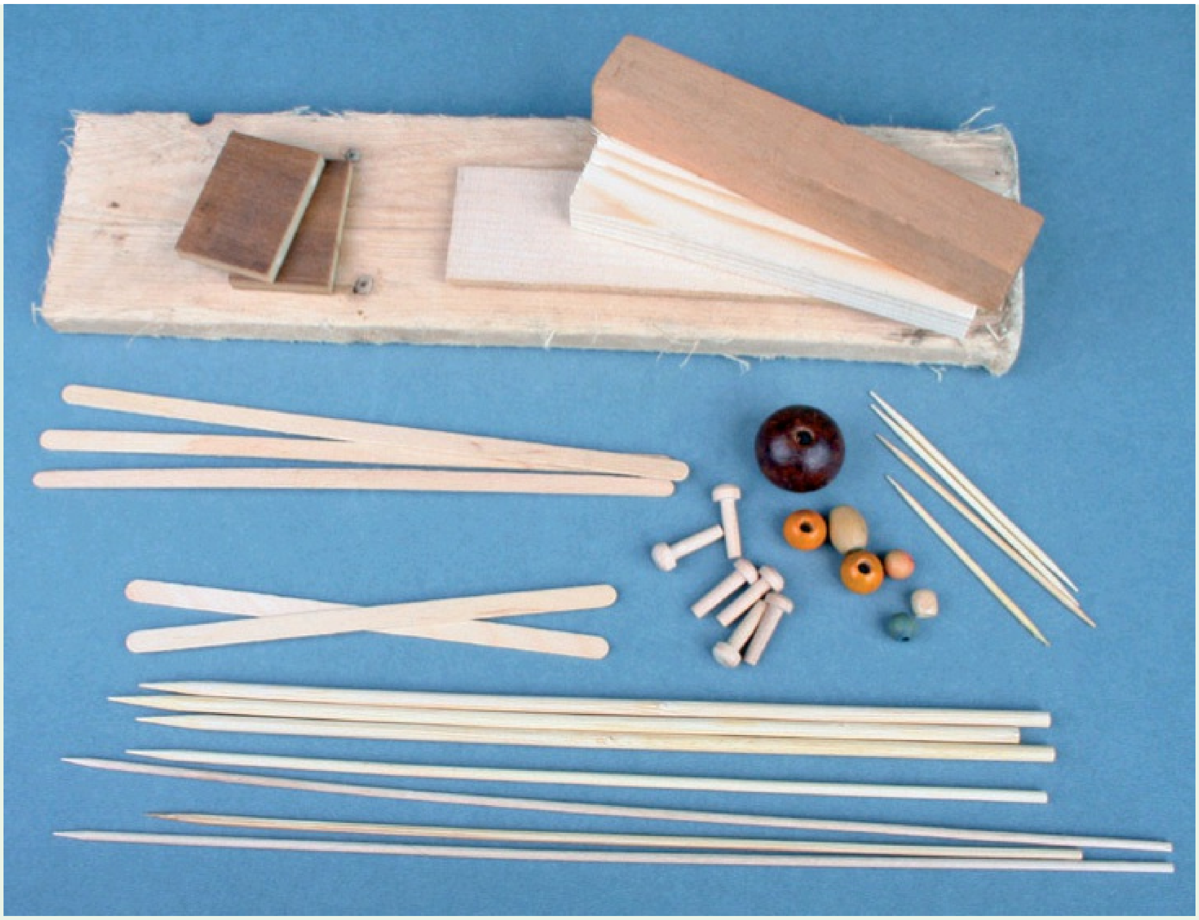
traditional moving toys, describing and evaluating the mechanisms and the materials used. It goes on to consider some possible variations and describes how to make a related moving toy. Finally, from this basis, a design is developed for a simple automaton, sometimes arising more or less directly from the mechanisms and imagery of the moving toy, sometimes adding further mechanisms, and sometimes wandering off on a bit of a tangent. Basic instructions are given for making it, but I have tried not to be too prescriptive, and I look to encourage an experimental and problem-solving approach with regard to materials and construction techniques. The message is that designing and making these simple, useless, but hopefully satisfying mechanical devices is fun, and that good results can be achieved in many different ways, depending on the materials, the tools and equipment, and the various skills that are brought to bear.

A spinning figure with loose-jointed arms in turned and painted wood, from India.

An advantage of starting with traditional moving toys is that many of them have been made using limited resources both in respect of tools and materials. Some are really simple to make. Others, despite the limited resources deployed, involve considerable patience and skill.

MATERIALS

The wood that I use is mainly scraps and off-cuts, pieces of fruit box and pallet, driftwood, and sticks from the hedgerow.



Scraps and off-cuts of wood, cocktail sticks, skewers of various diameters in birch wood and split bamboo, wooden hot drink stirrers, beads and turned axle pegs.

A range of wooden dowels is often available from DIY stores, but on a smaller scale a whole variety of sizes of cocktail sticks and skewers, made of wood or of split bamboo may be found in supermarkets, pound shops or hardware stores, as can flat wooden hot drink stirrers.

The turned wooden axle pegs that I use for various purposes are available in the USA from Woodworks Ltd (www.craftparts.com) and can be obtained in the UK from various suppliers on eBay. I find the smallest, with a 4mm (5⁄32in) shaft particularly useful.

Wooden beads are also useful – necklaces from charity shops are a good source of these.

Bamboo canes can be found at garden centres, which also often stock some small diameter galvanized steel wire.

Galvanized steel wire, bicycle spokes, scraps of electrical wiring and paperclips.

Paperclips provide short pieces of wire and for slightly longer and stouter wires the spokes from broken bicycle wheels can be used.

Small screw eyes are widely available in a range of sizes.

Tools

For cutting wood, a fine-toothed saw is needed, and for cutting shapes a fret saw, or a coping saw, is useful.

Some useful tools: a fine toothed Japanese saw, a fretsaw, a craft knife, scissors, long-nose pliers, pin vices with small drill bits, a square-bladed awl, sandpaper.

For making holes, a really useful tool is a square-sided awl, sometimes known as a birdcage awl; this can be used for marking where to drill, and for making small holes. For making more precise small holes, in the absence of a power tool, a small bit can be held in a pin vice and twisted by hand. Larger holes can be made with a hand drill, although an electric drill – better still, a bench-mounted one – will make things easier.

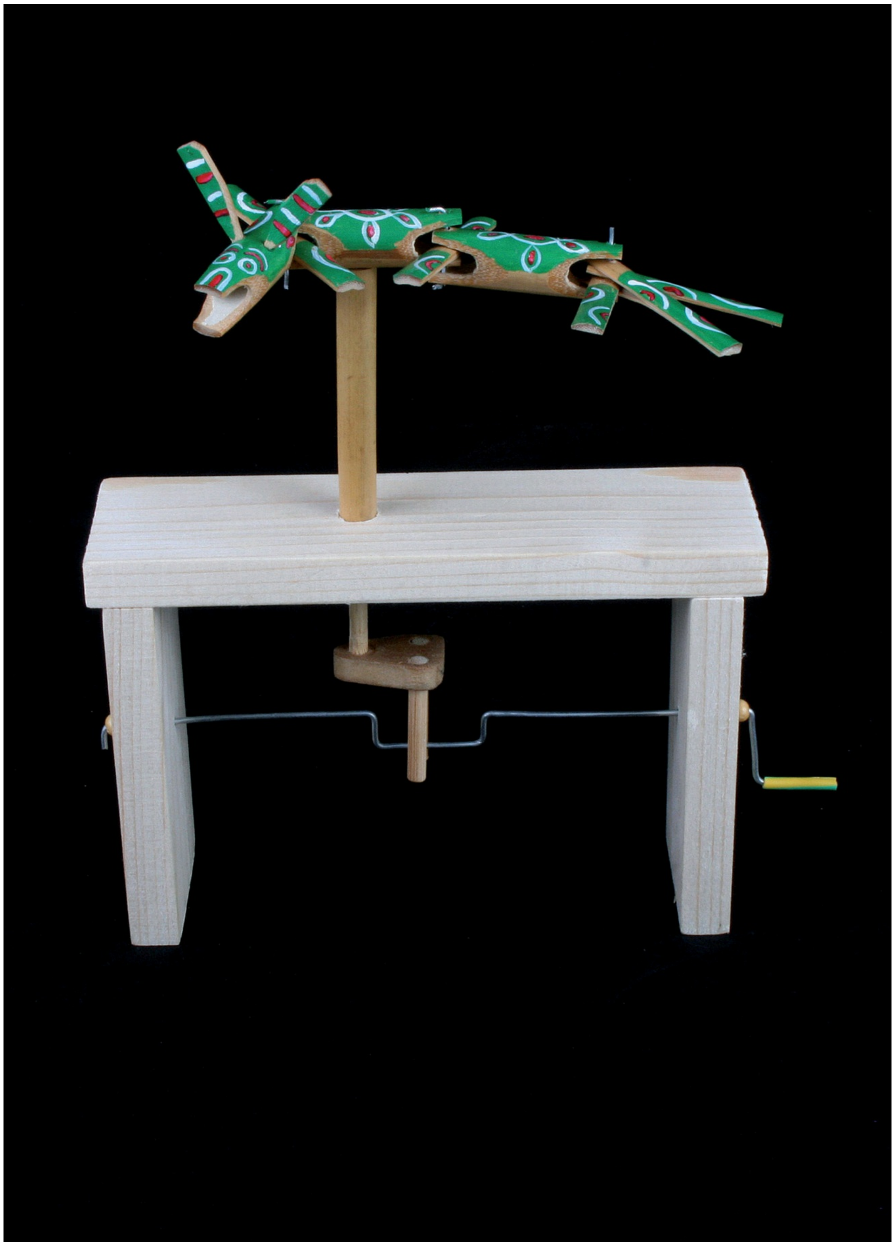
For working with wire a pair of long-nose pliers is needed. They often incorporate a cutter – if not a pair of snips is needed as well.

There is an endless variety of modern glues. You may have your own favourites. I use a white PVA wood glue, and, only where necessary (for sticking metal to wood, for example) a rapid setting, 5-minute, two part epoxy.

CHAPTER ONE

BACK AND FORTH – Oscillating shafts

An element very frequently found in moving folk toys and in simple automata is a turning shaft. Such a shaft will need one or more bearings: supports that hold it in place but allow it to rotate. Also required are a source of power, and a means of transmitting that power. The rotation may be in one direction, at constant or variable speed, or it may be reciprocal, turning one way and then the other. To take a very simple example, a thin stick, such as a wooden dowel, or a split bamboo skewer, held upright and rolled back and forth between finger and thumb, becomes a vertical oscillating shaft. In this case the finger and thumb do two jobs: they provide the bearing that holds the shaft in position, but allows it to turn; and they also transmit the muscle power that provides the movement. Anything attached rigidly to this shaft will oscillate with it, and if extra pieces are added, using flexible joints or hinges, then the movement starts to get more interesting – for example, a drum rattle, which consists of a two-sided drum on a stick, with two beads or clay pellets mounted on strings attached at either side. Oscillating the stick between finger and thumb makes the beads fly out and swing round to strike the drumheads.



Dragon automaton.

A drum rattle, made with a stretched paper drumhead on a clay drum. Ahmedabad, India, 1994.

Noisemakers such as this have been used all over the world, with the drumheads being made from all sorts of materials, producing very different sounds, and including animal skin, wood, paper, tinplate and plastic.

A sturdy African drum rattle with animal skin drumhead and wooden strikers.

***Percussionist*, a drum rattle made by the author in painted wood, with a hollow body and wooden beads as strikers.**

In a version that I made the drummer becomes the drum: the head and legs are solid wood, but the body is hollow, with wood veneer glued on back and front, to make it more resonant. Beads on strings form the arms.

A batch of drum rattles ready for their paper drumheads. Ahmedabad, 1994. *(Photo: Thalia Race)*

An Indian puppet toy made from dyed and painted palm leaf. Twisting the stick between finger and thumb produces animated movement of the limbs. 1980s.

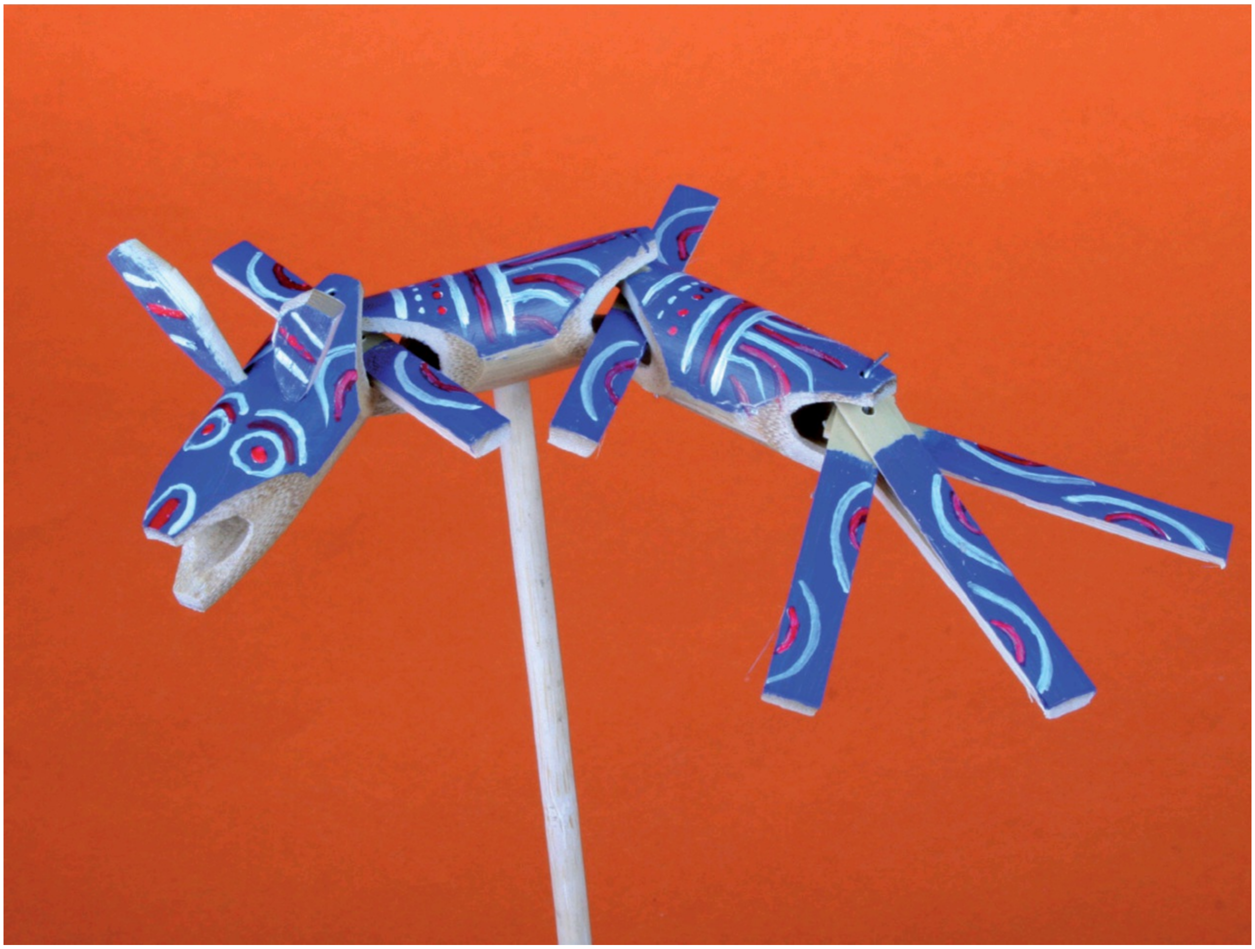
An Indian puppet toy, consisting of a looselimbed figure cut from scraps of card, or of palm leaf, and mounted on a stick, illustrates a quite different use of this centrifugal effect: when the stick is held upright and twisted between finger and thumb, the limbs are sent flying up and out in expressive gestures.

The effectiveness of this toy depends on some interesting design features: firstly, the body is in two flat layers, with the tops of the legs and

the upper arms slipped in between them. The lower arms are again double, and the hands are a single layer. This means that each of the joints, at the shoulders, elbows, thighs and wrists, forms a sandwich. These joints are made with a piece of string, threaded through holes, and knotted close up on each side. They will move very freely, but only in the same plane as the flat body. Thus, when the stick is twisted between finger and thumb, the limbs of the figure are thrown up and out; they do not swing round behind or in front of the figure like the strings and beads on a drum rattle.

Secondly, the figure is painted with a face on both sides. There is a good reason for this: if the stick is held up between forefinger and thumb, and twisted back and forth through 180 degrees, the limbs are seen to fly about in a crazy dance, but the rapid reversal of the body is not so obvious to a spectator. The illusion is that the figure remains facing forwards and is moving its own limbs in an animated dance.

Thirdly, the arms, jointed at shoulder, elbow and wrist, are very long in proportion to the rest of the body. Their unnatural length helps to emphasize the wild movement. The movement of the legs, jointed only at the hips, is less important in the overall effect. Indeed, in other examples of this toy the figure wears a long dhoti, and the legs are not represented at all.



Bamboo dragon on a stick. Made by the author from a drawing of Chinese toys by Kawasaki Muizumi (1877– 1942).

In the Indian puppet toy the body is held upright, and the limbs move only in the vertical plane. In contrast, a Chinese dragon toy shows movement only in the horizontal plane. The head and body of the dragon are made from three short sections of a bamboo tube, shaped, and joined with thin wire hinges. Strips of split bamboo are used for the limbs and for a three-pronged tail. These are threaded onto the wire hinges so that they are securely attached, but free to move. Slivers of bamboo are added as ears, and the body is firmly mounted on a split bamboo skewer.

When this stick is rolled between finger and thumb the dragon wriggles about from side to side, and the legs and tail also move.

The form of the head and body sections, and the way that they are overlapped and joined with vertical wire hinges that pass through the full depth of the bamboo tubes, ensure that the dragon maintains its shape without drooping, but allow the head, body, limbs and tail to move quite

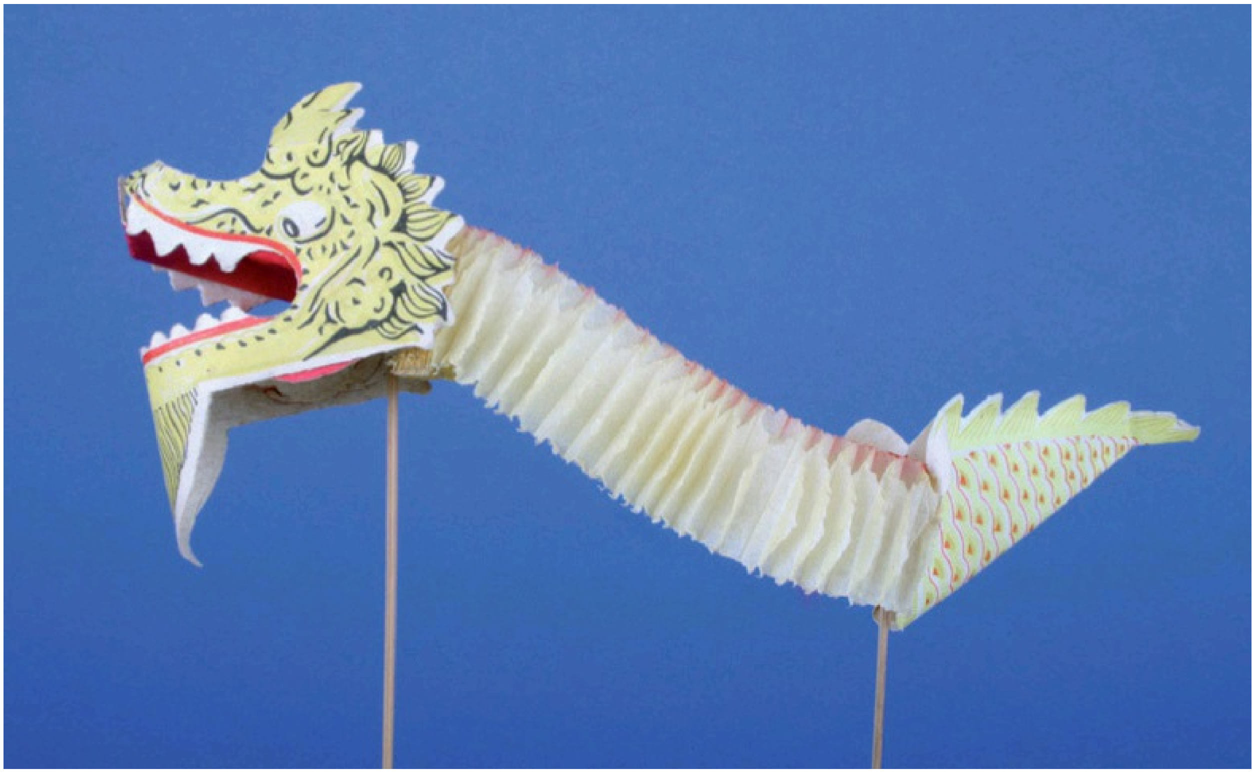
freely in the horizontal plane. The design for the dragon is taken from a watercolour in a large and amazing collection of illustrations of traditional toys, mostly Japanese, drawn and painted in a series of sketchbooks, by Kawasaki Muizumi (1877–1942). These extraordinary and beautiful pictures are now housed in the Osaka Prefectural Library, and are available as a database to view online:

http://www.library.pref.osaka.jp/site/oec/ningyodou-index.html

A bamboo snake of unknown origin.

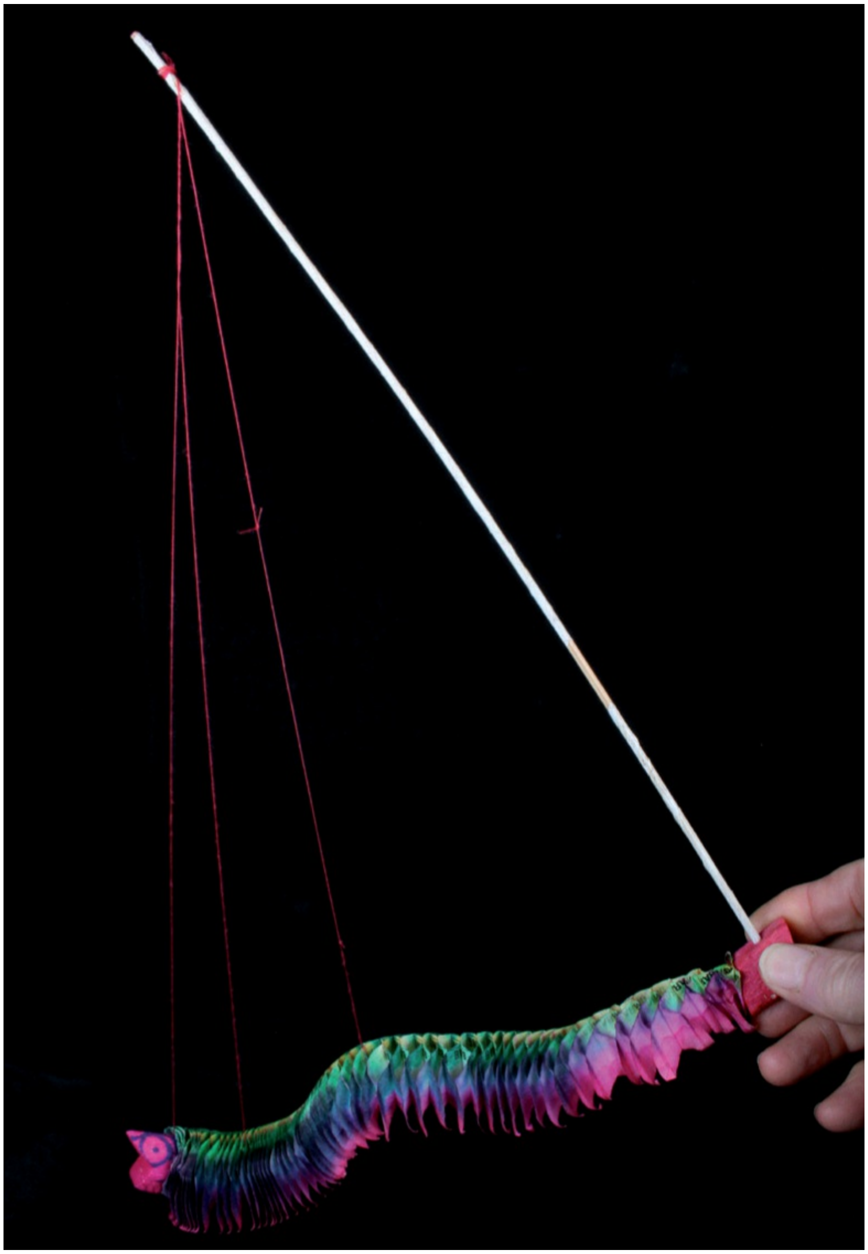
Kawasaki Muizumi shows several similar versions of the dragon on a stick: some have the supporting stick attached to the head rather than to the central body section; some have more body sections; some have no supporting stick. He also shows toy snakes, using the same construction, without the stick, the ears and the limbs, but with multiple body sections. I have a similar bamboo snake, with a head, eight body sections and a tail. If the tail, or one of the body sections, is held horizontally between finger and thumb, a slight rolling produces convincingly snaky movements, with

the head swaying from side to side and the body writhing about.



Chinese honeycomb paper dragon, operated with two sticks.

Another Chinese dragon toy in my collection has a ‘honeycomb’ tissue paper body that will extend, and flex in any direction. Unlike the hinged bamboo construction, it would flop down if only supported on one stick, but with another stick to support the back end it can, using two hands, be given sinuous movement up and down as well as from side to side.



An Indonesian dragon or snake with a similar paper body, suspended from a stick by several threads.

A similarly constructed paper body is used for an Indonesian toy (snake, or dragon?), in which the tail end is fixed to the bottom of a stick, and the wooden head is supported by a string, which is tied to the other end of the stick. A couple more strings help to hold up the body. This can be operated with one hand; moving the stick around swings the head to and fro, and the lighter, flexible body twists to follow it.

A Chinese toy snake, with a clay head and a lightweight, crimped paper, body. As the head is swung about on a thread the body twists and darts to follow, giving a very life-like effect.

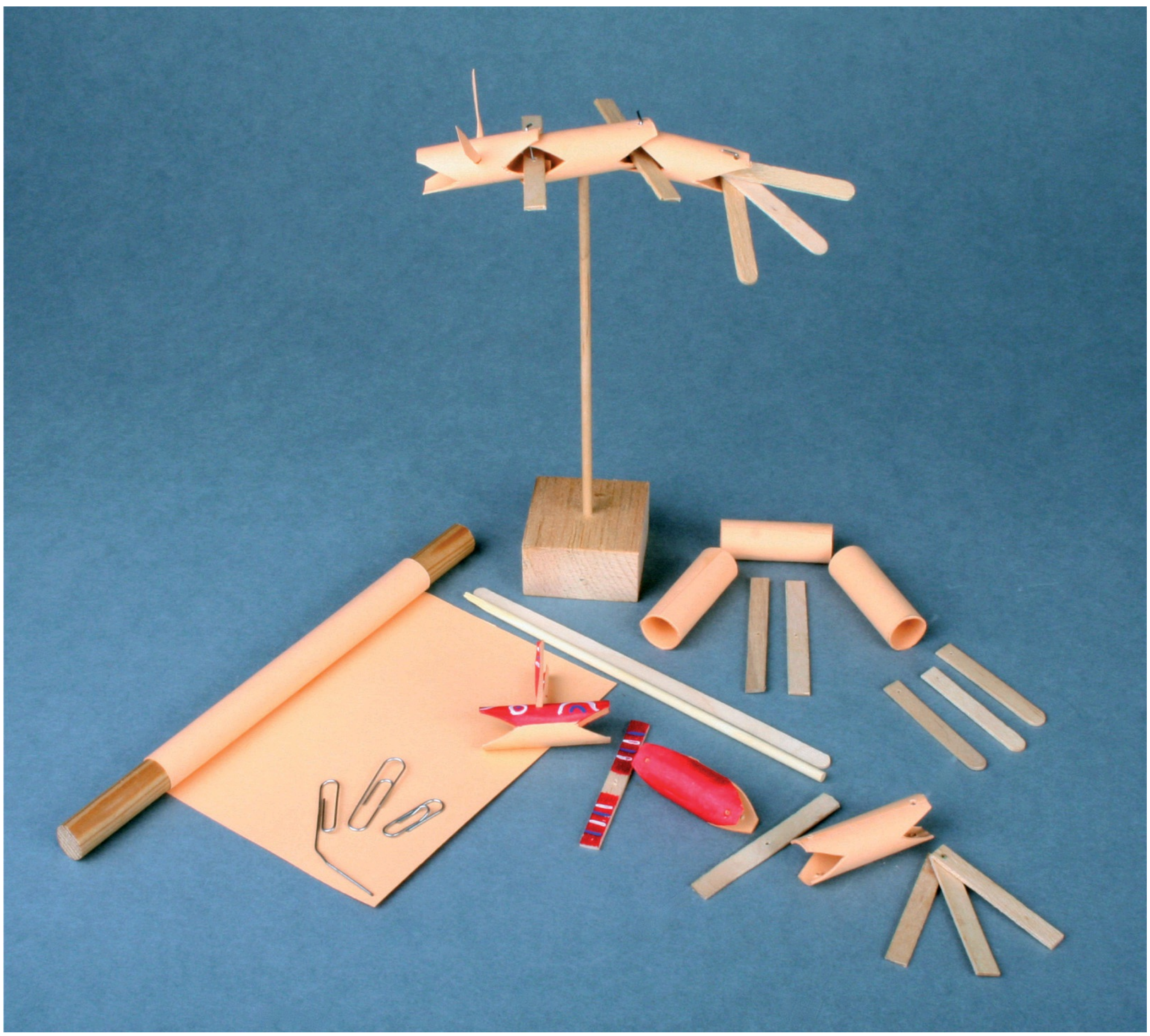
Operated in the same way, and more convincingly life-like in its movement, is a traditional Chinese toy snake with a crimped paper body, a painted clay head and a forked tongue made from a dyed feather.

Making a dragon on a stick

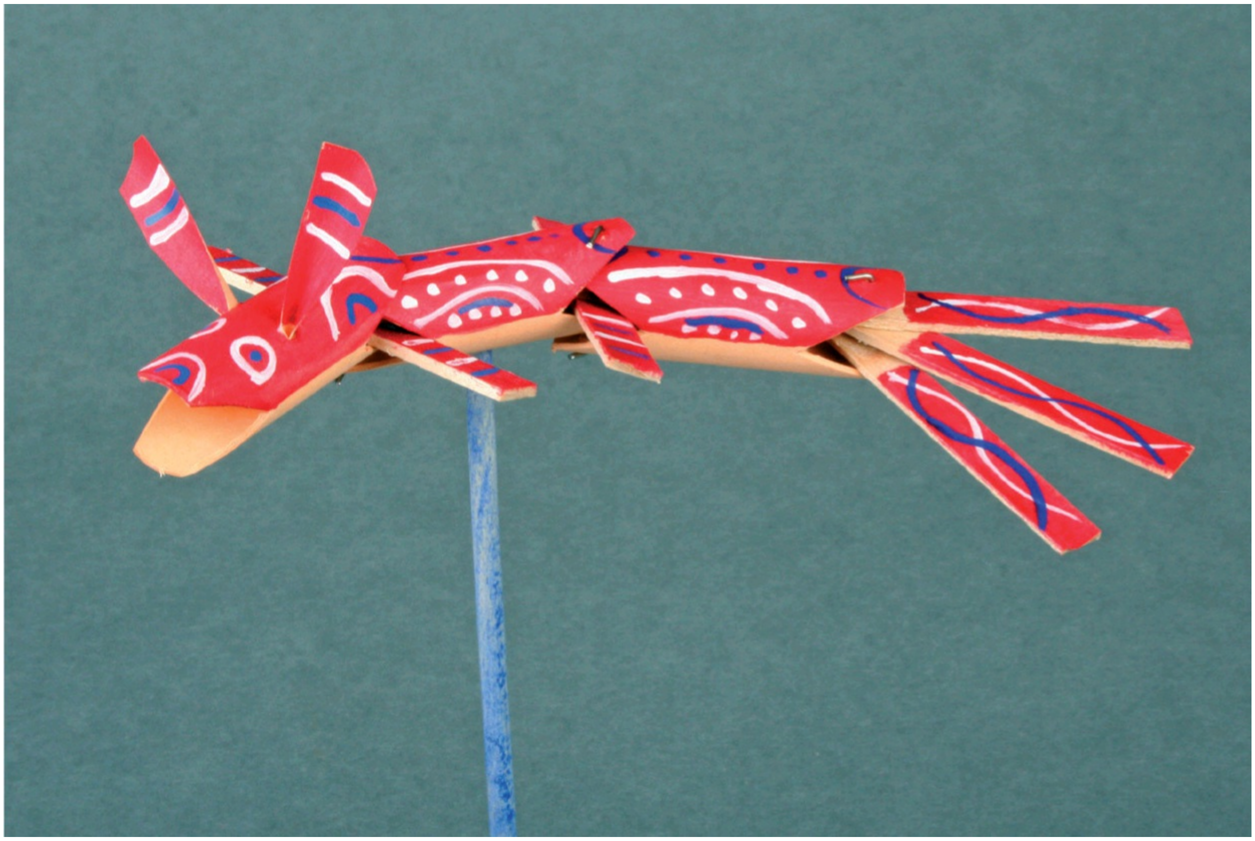
In the absence of bamboo of a suitable diameter, or the tools to work it, an effective lightweight version of Kawasaki Muizumi's dragon on a stick can be made using paper or very thin card, rolled and glued into tubes of a suitable diameter.

Materials

A piece of paper or very thin card; PVA glue; a couple of strips of thicker card (or some wooden hot drink stirrers); a skewer (or a thin dowel); three small paperclips, straightened out; paint, or decorative paper.



Materials for making a dragon on a stick using rolled paper tubes in place of bamboo.



The paper tube version of a dragon on a stick.

Tools

A pair of scissors and/or a craft knife; a square bladed (birdcage) bradawl for making holes, or a very fine drill bit, mounted in a pin vice; something to use as a cylindrical former, such as a dowel around 12–15mm (½–⅝in) diameter; a ruler for measuring, and a pair of long-nose pliers to bend and cut the wire paperclips.

Method

The paper should be long enough to cut into three to make the head and two body sections, and wide enough to give about four layers when wound round the former you are using. Roll the paper into a tube on the cylindrical former, applying enough glue as you roll it to make a reasonably sturdy tube. The aim is to make a tube that is robust enough to keep its shape,

but not too thick to cut easily. Be careful not to glue the paper to the former; you need to be able to slide the tube off easily when the glue is dry.

While the glue is drying, cut and shape two ears from a scrap of paper or card, and cut the legs and tail from strips of card (alternatively you could use wooden hot drink stirrers). Each pair of limbs is a single straight strip, long enough to stick out suitably on either side of the body. Three slightly shorter pieces make up the three-pronged tail.

When the glue has dried, measure the tube, and cut it into three equal lengths: it is best to use a craft knife while the tube is still on the former, or you can slide it off and cut with sharp scissors. Each of these three sections then needs shaping by cutting out a triangular piece from each side, at the front and at the back.

Using an awl, a large needle, or a small drill bit in a pin vice, make holes for the wire hinges: you need a hole top and bottom at the back end of the head piece, and holes top and bottom at both ends of the two body pieces; the holes should be only just big enough for the wire to thread through easily. Make similar holes at the centre of each pair of limbs, and at one end of each of the three tail pieces.

Make two slightly larger holes in the top of the head for attaching the ears, and another underneath the middle body section to attach the stick (skewer or thin dowel).

Glue the ears into their holes in the head section, and also glue the three tail pieces together in a fan shape (feed the three tail pieces onto a piece of wire while the glue sets to ensure that the holes line up). At this stage the pieces may be painted, but the way that the dragons illustrated by Kawasaki Muizumi are painted, only on the upper surfaces, suggests that they could have been decorated after assembly and this may be more convenient.

Once the glue is dry, assemble the pieces. Using the long-nose pliers, bend over the end of one of the wires at right angles. Feed the other end through the small hole in the top of the head, and then successively through the top hole at the front of a body piece, through the central hole in a pair of limbs, through the bottom hole in the head piece, and finally through the bottom hole in the body piece (this is a bit of a fiddle). Bend the wire over at right angles, and trim if necessary.

The head is now attached to the front part of the body, and should move

freely from side to side. Use the second wire to attach the second part of the body, and the other pair of limbs, in a similar way. Now use the third wire to attach the three-pronged tail at the back of the second body part. Finally, glue the stick (skewer or thin dowel) firmly into the hole in the bottom of the body.

Hold the stick vertically and twist back and forth between finger and thumb. Twisting the stick like this should make the dragon move in a lively way.

Developing the design for an automaton

The next stage might be to introduce a mechanism to oscillate the vertical shaft, with the dragon on it, indirectly. Many mechanical devices with serious purposes, as well as many automata, incorporate a driveshaft, which is made to turn with a motor, with a falling weight, or with a cranked handle. The continuous rotation of this shaft in one direction is then converted by various mechanisms into other kinds of movement. A widely used way of achieving this is through a cam and a cam follower. A cam is simply a projection from the rotating driveshaft that pushes against and displaces a cam follower. This follower may be another shaft, or a lever.

The initial requirement is a supporting framework on which to mount: firstly the dragon on its shaft, in a bearing that holds it upright, but free to turn, and secondly a horizontal driveshaft, with a crank handle at one end.

There are many possibilities for the supporting framework. I shall describe two relatively simple alternatives. Making two versions will allow me to explore further possibilities of the hinged tube construction by replacing the dragon with a fish, which makes use of the fact that bamboo tube is available in a wide range of diameters. For the first version the paper tube dragon described above can be used, or it can be replaced with a similar dragon made in bamboo tube.

Making a bamboo dragon

The head and body of the dragon use three short tubes of the same diameter cut from a bamboo cane. Except at the nodes bamboo stems are

hollow (or filled with easily removed pith), but the wall thickness varies and here it is best if possible to use relatively thin walled canes. I have used three 40mm (1½in) sections of a bamboo about 12mm (½in) in diameter, but the scale can be adapted to the materials available: it gets a bit fiddly with bamboo tubes of a smaller diameter, but the simple robust structure of the dragon means that it will work well with rather larger diameters. Bamboo canes for garden use are widely available in a range of small diameters, and larger diameters are available from specialist suppliers. Each section of tube has to be tapered on each side, and at both ends, as in the paper tube version described above: this can be done with a sharp knife, or with a fine-toothed saw. Use a craft knife to carve out the tapered ends enough to make them free to move when overlapped to form the body of the dragon. The thicker the wall of the bamboo tube the more needs to be removed this way. The strips needed for the limbs and tail can be split from another piece of the cane used for the head and body. Bamboo splits easily along its length: care is need because the material is very hard and is likely to be resistant at first and then suddenly split. It helps to carefully work a knife into the end of a length of bamboo and then slightly twist the blade to open up a split. The knife can then be worked along, slightly twisting it as necessary to continue opening the split.

Making the bamboo dragon. The head, body, ears, limbs and tail are all cut from bamboo.

Method

Drill holes, and assemble the pieces as described above for the paper tube version. To make the small holes for the wire joints, use a fine drill bit in a pin vice, or (very carefully so as not to split the bamboo) a sharp, square sided awl twisted continuously rather than pushed straight in quickly. The head piece needs two slightly larger holes to glue in the ears, and the middle tube has a hole drilled underneath to fit the dowel, or bamboo skewer, that will form the vertical shaft (about 100mm (4in) long and 5–6mm (¼in) in diameter). As with the paper tube version, the pieces can be painted before or after assembly.

The framework

The framework is made up of three pieces of timber. I have used a softwood strip 42mm (1½in) wide and 12mm (½in) thick. The top is

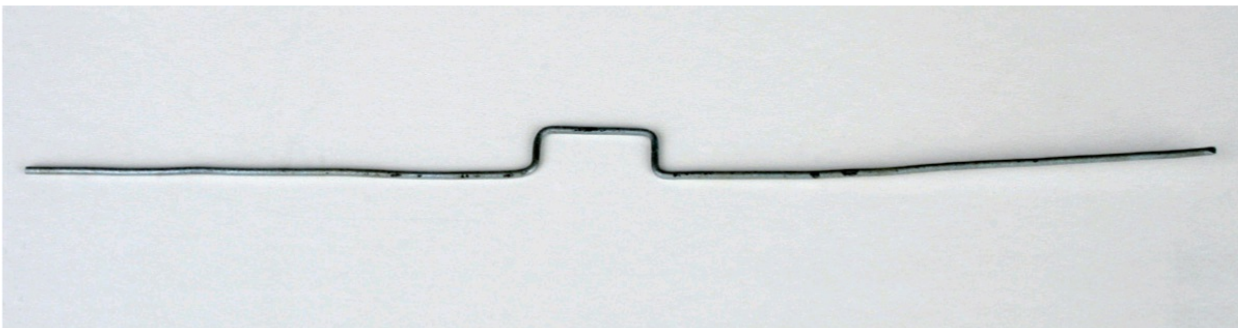
150mm (6in) long (the same length as, or just longer than the dragon), and is supported on two end pieces 90mm (3½in) high, attached with dowelled joints. At this scale this makes a reasonably sturdy structure, but a base could be added for additional strength.

Parts for the base and the shafts.

The horizontal shaft

Galvanized steel wire is used for the horizontal camshaft: I have used 2mm

(5⁄64in) wire, thin enough to bend neatly with a pair of pliers to shape the cam and the crank handle, but thick enough, at this scale, to make a reasonably rigid shaft. The cam here takes the form of a cranked portion of the shaft about 25mm (1in) wide, and with 10mm (3⁄8in) arms. It is formed by using the pliers to make four right angle bends roughly in the centre of a straightened piece of wire around 250mm (10in) long.



The wire shaft, showing the cranked section which will act as a cam and move the vertical shaft with the dragon on it.

After it has been installed in the frame, two further bends will be made in the shaft to form the crank handle. To mount this shaft, drill a 2.5–3mm (3⁄32–1⁄8in) hole in each of the two end pieces of the framework, equidistant from front to back and 50mm (2in) from the bottom.

The vertical shaft and cam follower

The vertical shaft, with the dragon mounted on it, is supported in a tube sticking up from the top of the framework. This tube is a length of bamboo cane around 75mm (3in) long, and about 9–10mm (3⁄8in) in external diameter. The internal diameter must be wide enough for the vertical shaft to move freely within it. Mount the tube by drilling a hole that matches its external diameter through the top of the framework 60mm (2 3⁄8in) from the left hand end, and equidistant front to back. Glue the tube in place, with about 10mm (3⁄8in) projecting below the top. The cam follower is formed using a triangular piece cut from a strip of wood about 6mm (¼in) thick. Before cutting the triangle, drill three holes, right through the strip, which are a tight fit on the dowel used for the vertical shaft. One hole at the apex of the triangle, to attach it to the shaft, and two others, about 15mm (5⁄8in) away and 10mm (3⁄8in) apart, to mount two short pieces of the same

dowel (about 35mm (1⅜in) long) that will project down on either side of the wire camshaft. Cut out the triangular piece, and glue in these two short pieces. The vertical shaft should not be glued into it at this stage, because the length may need adjusting during assembly.

Assembly and adjustment

With the wire camshaft in position, glue the two side pieces to the top of the framework. Check that the dragon sits squarely on the vertical shaft and glue it in place. When the glue is set, slide the vertical shaft into its bamboo tube support. Underneath the top of the framework, fit the triangular piece onto the end of the vertical shaft, with the two short dowels projecting down, one each side of the wire shaft. Position the wire so that the cranked portion is directly underneath them and check that when the wire shaft turns it does so without lifting the wooden triangle or coming below the ends of the short dowels. If it does lift the wooden triangle, take the vertical shaft out, cut a bit off and reassemble. If on the other hand the cam comes below the ends of the short dowels then cut a little off the bamboo tube that supports the dragon.

Glue the wooden triangle in position at the bottom of the vertical shaft, so that it is aligned with the body of the dragon. With the cam in the correct position below the wooden triangle, feed a small bead onto the right-hand end of the wire shaft, bend the wire at right angles and then back, to form a crank handle. A piece of plastic insulation of suitable diameter from an electrical wire can be slid onto the wire to make a neat handle. Feed another small bead onto the left-hand end of the wire, bend the wire over as close as possible, and trim off any excess.

Turn the handle to make the dragon wriggle.

Bamboo fish

Considering the further possibilities of an articulated body of bamboo led me to experiment with nesting tubes of different diameters, resulting in a tapering bamboo fish: the body consists of four short lengths of bamboo of decreasing diameter, from 32mm (1¼in) at the head to 8mm (5⁄16in) at the tail. In the absence of a suitable selection of bamboo a series of rolled and glued paper tubes (as described above) could be used. I added a tail and

fins, cut from 3mm (1⁄8in) plywood, and cocktail stick teeth. Vertical wire hinges, similar to those in the dragon, are used to articulate the body, but the shape of the sections is rather different from that used in the stepped structure of the dragon: each body section is left square at the front, but cut in on each side at the back sufficiently to allow for the necessary side-toside movement.

Atapering bamboo fish, with a similar mechanism, mounted on a bamboo and oak frame.

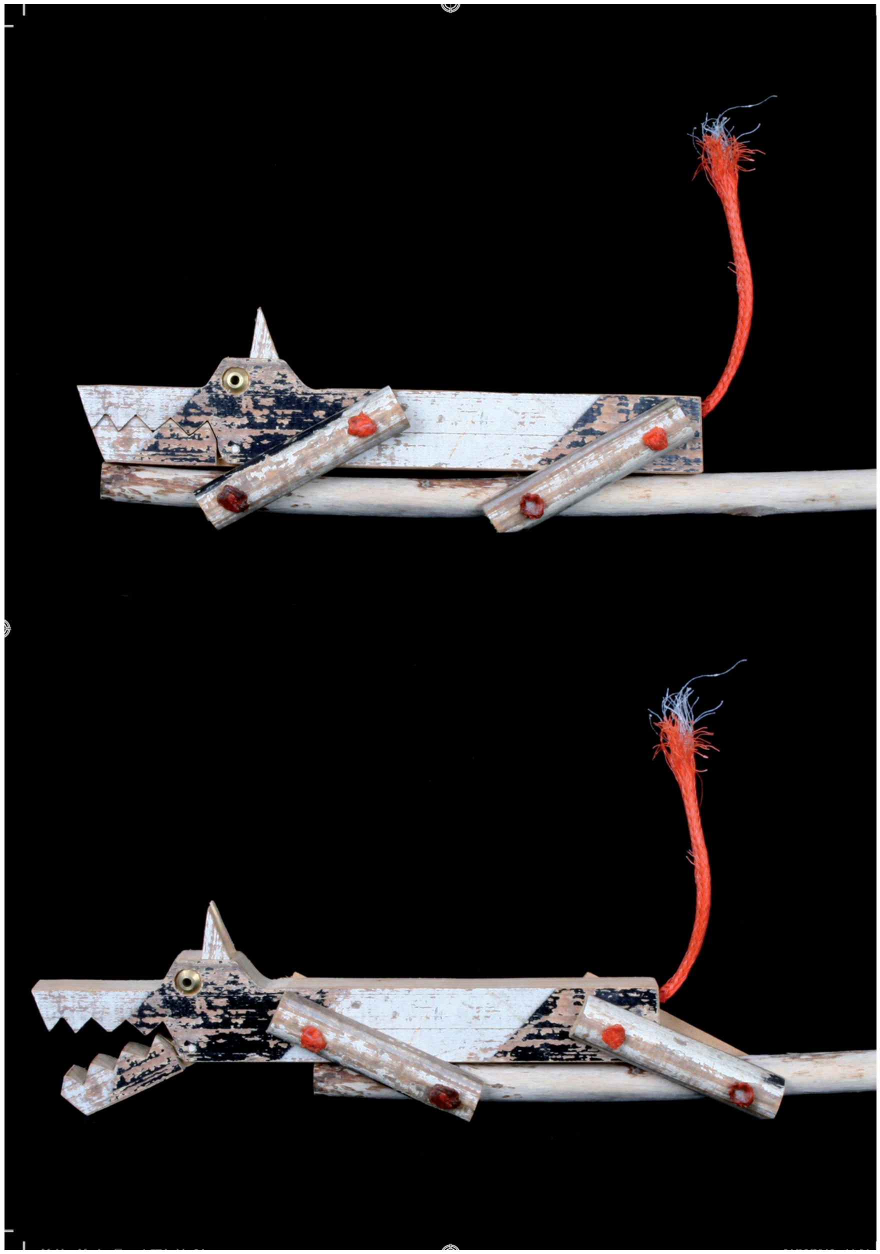
For the supporting framework, two uprights of 10mm (3⁄8in) bamboo are

mounted firmly in a solid base. A section from an old oak barrel stave has been used for the base here. The bamboo uprights are drilled with holes to support the wire driveshaft and topped with a thicker bamboo crosspiece. In that crosspiece is mounted the vertical bamboo tube, about 10mm ($^3\!/\!_8$in) diameter, which supports the fish on its vertical shaft. The cam and follower are similar to those used for the dragon.

CHAPTER TWO

MAKING LINKS – Links and linkages

The bamboo fish, snakes and dragons described in Chapter 1 are made up of a number of rigid links attached together with moveable joints to form a flexible linkage. In all of them the links form simple open chains. What if the links are looped round and joined into a closed chain? If three links are joined in a closed chain the resulting triangular linkage will be rigid: movement will only be possible if a link bends or breaks. With four links, of various lengths, there are all sorts of possibilities for different movements, and many mechanical devices make use of them. James Watt was particularly proud of the linkage that gave the approximate straight-line motion required in his double action steam engine in connecting the piston, moving straight up and down, to the beam, moving in an arc. Moving toys and automata also often incorporate such linkages, for example *Small Ship*, where, as in the Watt's linkage, there are three links that move, with the supporting framework providing the fourth. In this case the rotary motion of a crankshaft is converted to the pitching and surging of the ship.

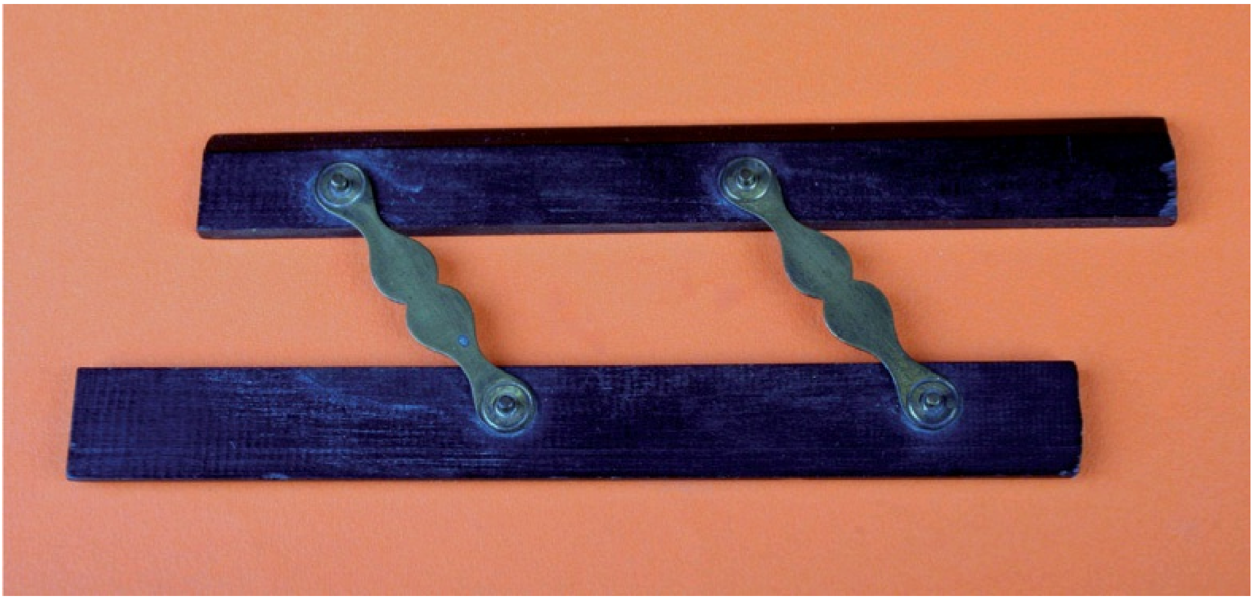


Dog with opening jaw. Aparallelogram linkage toy.

***Small Ship*, showing the four 'bars' which make up a linkage that converts the rotation of a crank into the pitching and surging of the ship. The three solid red lines indicate the moving bars, while the dotted line represents the fourth bar that completes the linkage through the fixed base.**

Parallelogram linkages

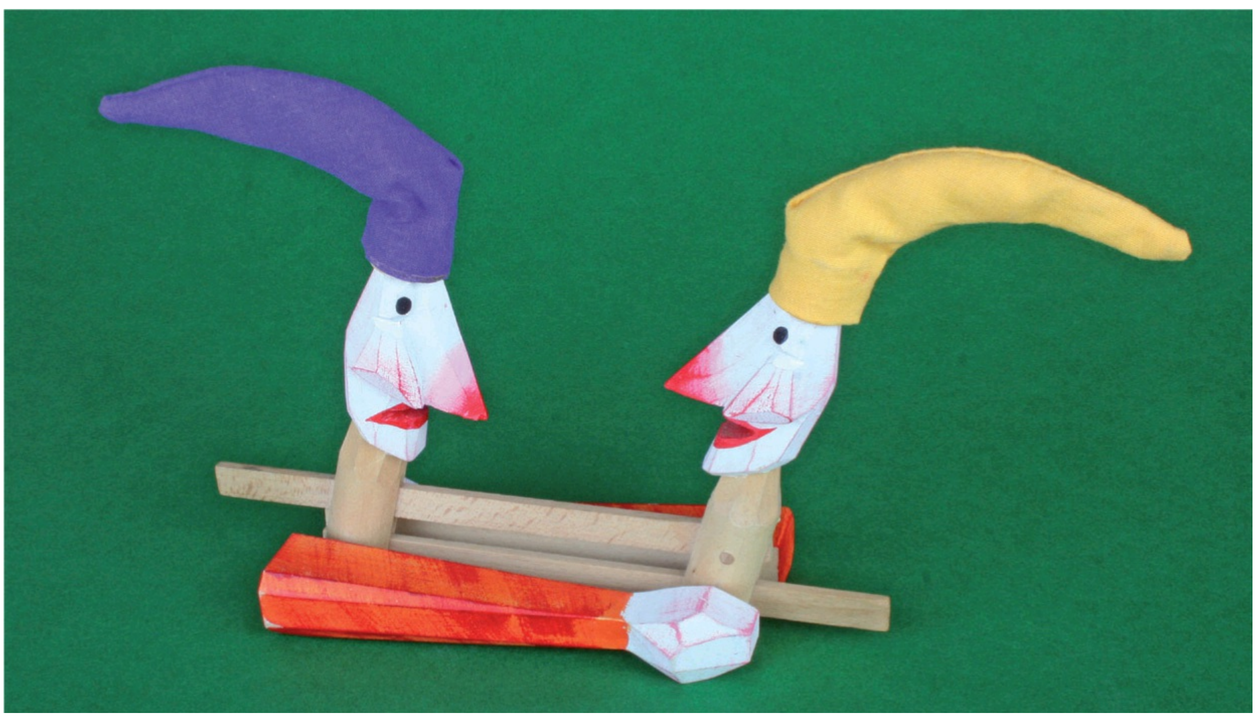
The 'parallel motion' in James Watt's 1784 patent combined the Watt's linkage with another four bar linkage in the form of a parallelogram.



A parallel rule from a set of old drawing instruments.

If each corner of a parallelogram is a rotating joint, it can be moved freely over to lie flat on one side or the other without jamming at any point. At the centre point it will form a rectangle. The opposite sides remain parallel, and extensions to those sides also remain parallel. A clear and simple example is the parallel rule, generally included in a traditional set of drawing or navigational instruments, and comprising a pair of straight edges joined by two equal arms.

The blacksmith and the bear. A traditional toy in carved lime wood, from Bogorodskoye in Russia, which takes the form of a parallelogram linkage.



A witty use of the parallelogram linkage by the master puppeteer and toy designer Miroslav Trejtnar. Prague, 1990s.

The blacksmith and the bear is a carved wooden toy traditionally made in Bogorodskoye in Russia, where a range of moving toys are still produced, typically with unpainted figures carved in lime wood. The legs of the blacksmith and the bear are mounted on straight wooden cross pieces with joints that are free to rotate in the plane. The joints in each of the figures' legs are the same distance apart, and two crosspieces are the same length between the joints. This structure then is also a four-bar linkage in the form of a parallelogram. The proportions are arranged so that as the horizontal bars are moved back and forth, the blacksmith and the bear take turns to raise and bring down their hammers on the central anvil.

Astrange creature in painted wood that jumps forward when you tap the stick behind it. Chiapas, Mexico, 1990.

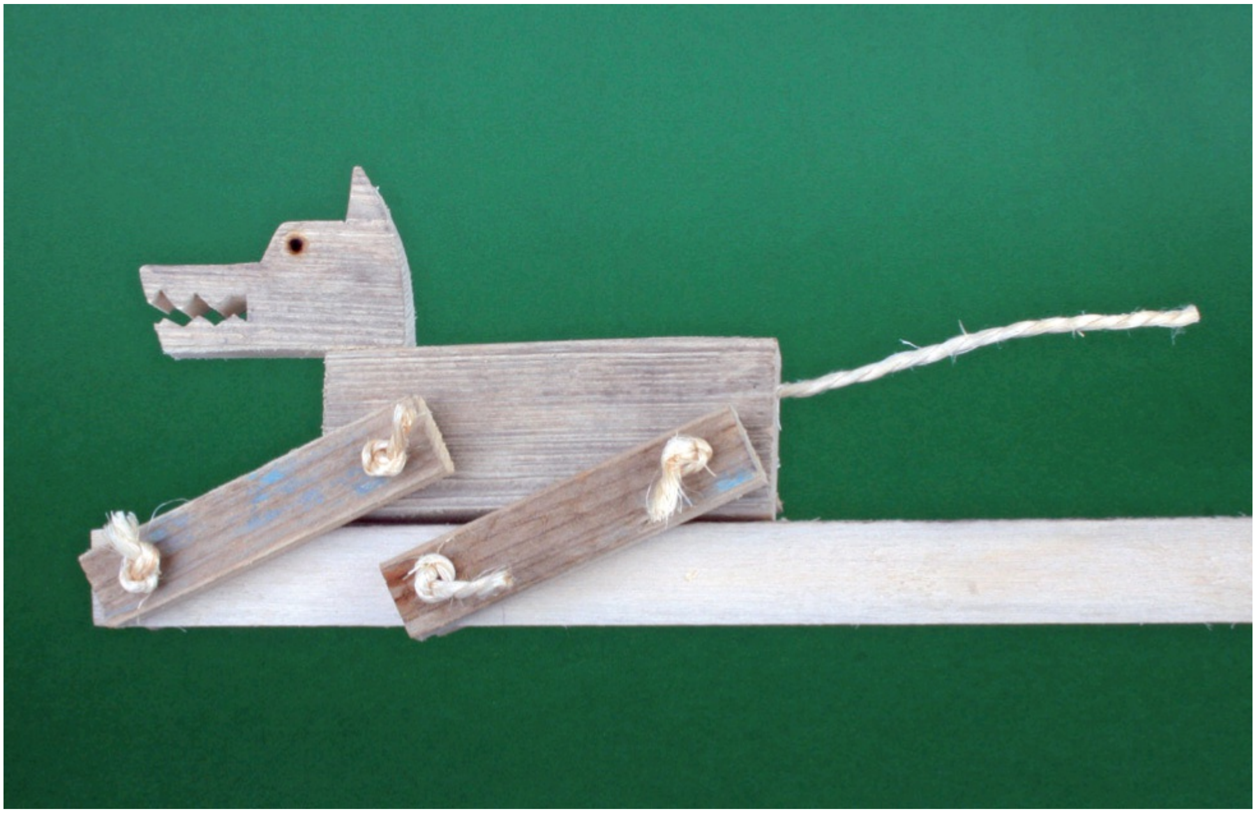
Toys that move in a similar way, with two cross bars and two upright figures that move from side to side, are to be found all over the world with varied imagery and using a wide range of materials.

A different use of this linkage is seen in a toy from Chiapas in Mexico: a curious four-legged creature is mounted on a stick, using knotted string joints, in such a way that the body, the legs and the stick form a parallelogram linkage. The joints are loose enough for the body to move freely right forward or right back to rest on the stick. If the stick is held horizontal in one hand, with the creature on top and legs leaning right back, then a sharp tap, with the forefinger of the other hand, on the stick behind

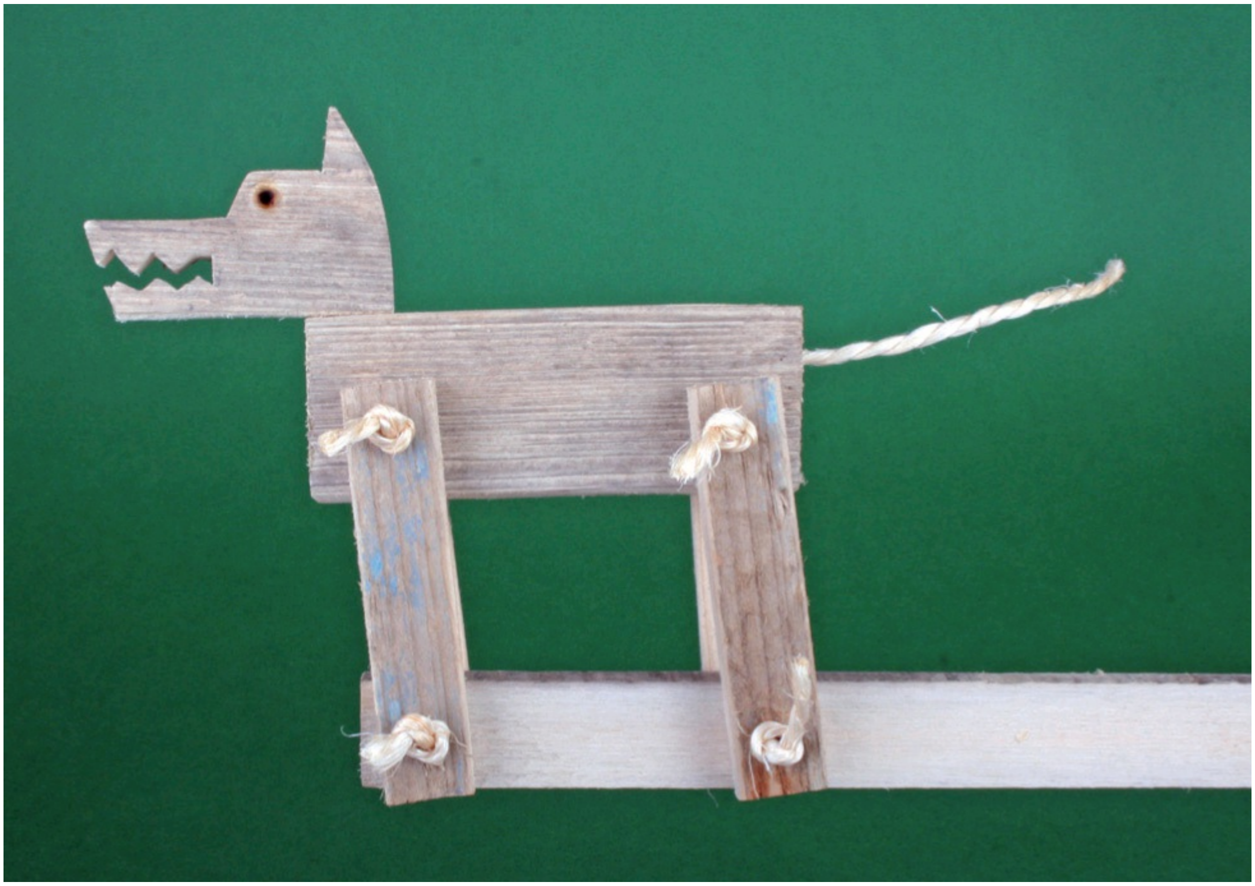
the creature will make it jump up and over into the forward position. Another tap and the creature will jump back. The explanation for this is that there are only two stable positions: right forward, and right back. At any point in between, the body of the animal, constrained by the legs, will tend to fall towards one of the two stable positions. The tap on the stick transfers movement to the body of the animal. If the tap is firm enough the momentum of the moving body will carry it past the central point and it will then fall to the other stable position.

Making an excitable dog

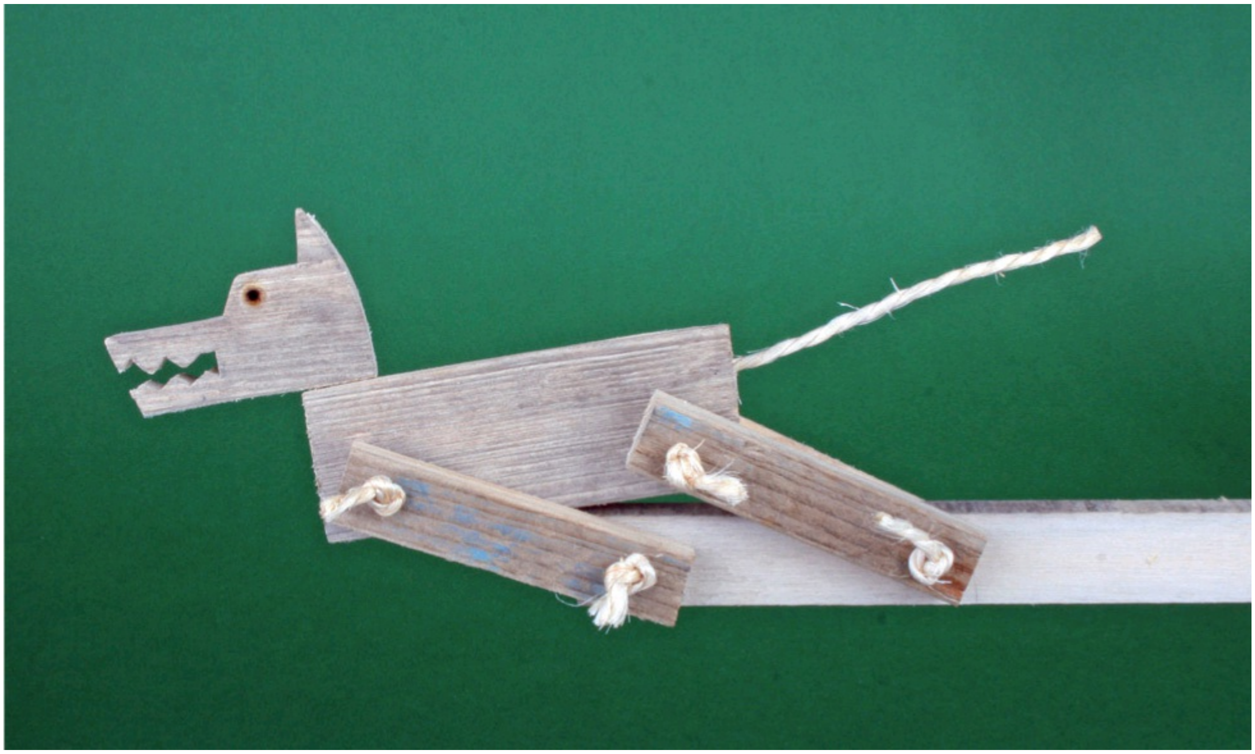
I have used this mechanism in a number of ways, frequently choosing to represent small dogs. The bouncy action seems appropriate to their excitable nature.



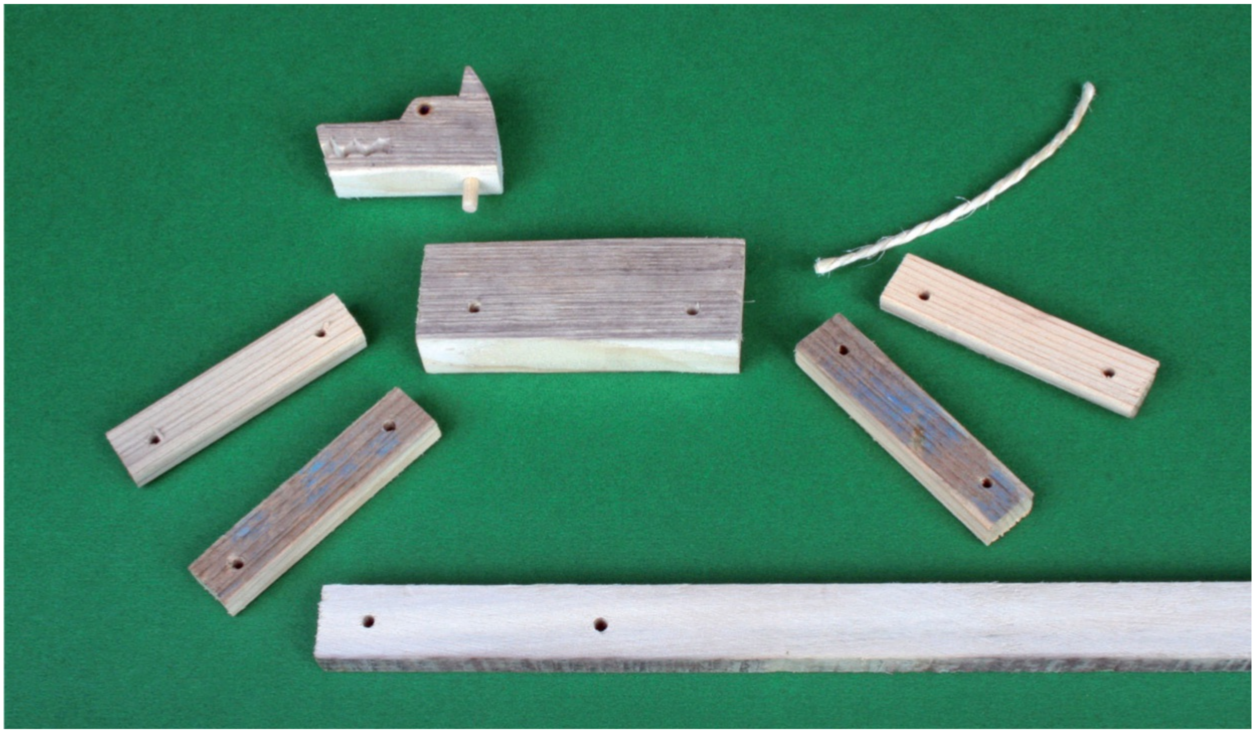
The excitable dog crouches back ready to leap. The limbs are attached with knotted string.



The excitable dog mid-leap.



The excitable dog leaps forward.



The parts for the excitable dog.

Materials

A stick, dowel or strip of wood long enough to mount the dog at one end and provide a hand grip at the other end, leaving enough space in between to tap the stick with a finger; scraps of wood or plywood for the legs, body and head of the dog (the wood for the body should be as thick, or slightly thicker than the stick); string for the knotted string joints, and to make a tail.

Tools

Saw; scissors; sandpaper; drill and drill bits.

Method

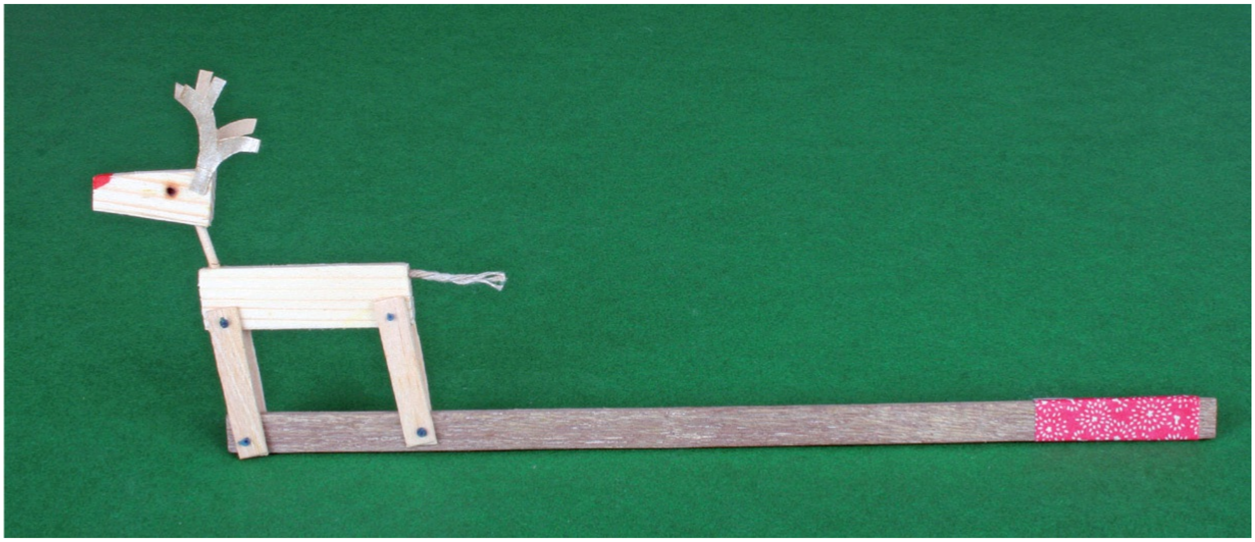
Cut four identical rectangular strips of wood for the legs and drill holes near each end. It is important that the holes in each leg are precisely the same distance apart. The holes should be just big enough to thread the string through to make the joints. Cut and shape a body and head. It could be cut from one piece or built up. Drill two holes through the body to attach the tops of the legs. Near one end of the long stick or strip of wood drill two holes right through, exactly the same distance apart as the holes in the body. You could also drill a blind hole at the back of the body to glue in a string tail. Now make four knotted string joints to attach the tops of the legs to the body and the bottoms of the legs to the stick.

Knotted string joints, which are often found in folk toys, work well for movable joints in lightweight materials such as paper, card and wood; they are simple in structure, but a certain knack is needed to make them well. It is important that the holes are not too large for the string used. Ideally the string fits through the hole without too much of a fiddle, but a single thumb knot is large enough not to pull back through the hole. If it does, then a larger knot is needed: a figure-of-eight knot might do it, or another thumb knot can be made on top of the first to bulk it up. It is easier if the string or thread is not too fine. For each joint tie a knot in the end of a piece of string that is long enough to work with comfortably. Feed the unknotted end

through one leg, then the body (or the stick), and then the other leg. Now tie the second knot. This is the tricky bit (especially if you need to make a double knot). The aim is to make a joint that is easily movable, but not too loose. You need to pull the string through tight, form the second thumb knot and work it along the string until it is close up against the wooden leg (or the stick). Then cut off the excess string. When all four joints have been made the dog should be mounted on the stick, easily movable backwards and forwards, but not flopping to either side.

Holding the stick and tapping as described above should make the dog jump forwards and backwards.

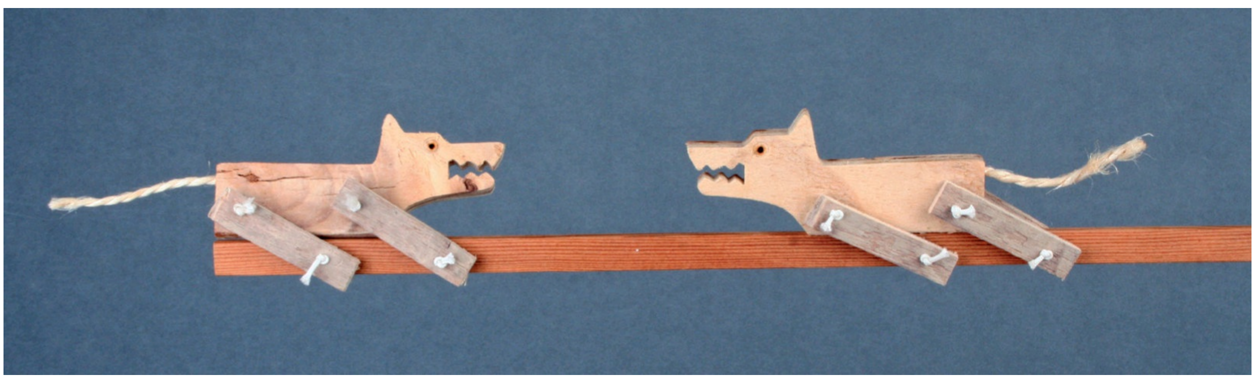
Knotted string joints are quickly made (once you have the knack), cheap and effective, but other materials will work well: for example, thin wire with the ends bent over, as used for the Chinese dragon in Chapter 1. Alternatively dowels can be glued into the holes in the limbs. In this case the holes in the body and the stick need to be a little larger so that these dowels can move freely in them. On a very small scale a neat way to make the joints is to use a thick monofilament fishing line and, instead of making knots, melt the ends into a flattened blob, using a soldering iron (or an old knife blade heated in a flame). This method was used for a little jumping reindeer, with a body less than 50mm (2in) long, and legs made from bits of wooden hot drink stirrers.



Aminiature jumping reindeer, with hot drink stirrer legs. The joints are made from monofilament fishing line, melted at the ends rather than knotted.

Dog fight

Another possibility is to mount two animals facing each other on the same stick, so that they both jump when the stick is tapped. This makes for an unpredictable encounter; there are different possible starting positions, with both animals either in the forward or backward position, or with one back and one forward, and as a result they may both jump forward and back together, or one may jump forward when the other goes back. Moreover, one of these patterns can flip to the other, because at any single tap one or the other animal may not complete the jump, but fall back to its starting position. I do not have such a toy in my collection, but in *The World of Toys* by Josef Kandert (Hamlyn, 1992), there is a drawing of a nineteenth-century Chinese version representing (rather grotesquely) a tiger and a monkey, with ceramic bodies and wooden legs. This double version is most effective if the animals nearly, but not quite, touch when both are in the forward position.



Two dogs facing each other on the same stick; both jump when it is tapped.

The illustration at the head of this chapter shows another version I tried in which the mouth opens as the dog jumps forwards, and closes when it jumps back. To achieve this, the lower jaw is loosely hinged with a tenon, and, crucially, the head has become simply a straight continuation of the body, so that in the backward position the lower jaw is held shut because it rests on the stick; when the dog jumps forward, because of a tap on the stick, the head moves beyond the end of the stick, and the jaw drops open.

***Woman and Goose*: another way to use the parallelogram linkage.**

Yet another way to use the parallelogram linkage is to lay it down horizontally and attach figures vertically so that they turn together on their axes when the cross bars are moved. An example, in painted softwood, is *Woman and Goose*, a wooden toy from the USA. The figures are mounted on wooden discs which act as two bars of the four-bar linkage. The woman shoos the goose with her broom, but when she turns away the goose returns to the attack, and actually moves slightly nearer to her because it is mounted towards one side of its disc, whereas the woman is centrally placed on hers.

Developing the design for an automaton

In *The Three Watchers* I took this form of the mechanism, and extended it with an extra link making two parallelograms side by side, and so accommodating a third figure. The three figures consist of six sea-worn bricks, found on the beach. They had been sitting on my windowsill for some time, waiting for their moment. Moving an extension of the central

lever from side to side causes the figures to shift their gaze in unison, one way and then the other (just the heads move). Usually a bit of variation in the movement of the different elements helps to animate an automaton, but here the strictly coordinated swivel of the three heads does make their unblinking gaze slightly disturbing. What are they staring at?

Making *The Three Watchers*

The mechanism of *The Three Watchers* is pretty basic, but careful measurement is needed in making the parallelogram linkage if it is to move smoothly. Sea-worn bricks are likely to be only very locally available, and are more difficult to work with, so, in accordance with my exhortation to experiment, I have developed three smaller versions, taking the opportunity to vary both the imagery of the figures, and the materials used.

***The Three Watchers*: the original used old bricks, smoothed and rounded by the sea.**

In the first version, staying true to the seasmoothed quality of the bricks in *The Three Watchers*, I have used pieces of driftwood, already rounded by the sea, and further shaped as necessary. Holes are drilled right

through the heads to represent the simple staring eyes that were a feature of the brick version.

***The Three Watchers*: the first version, using driftwood.**

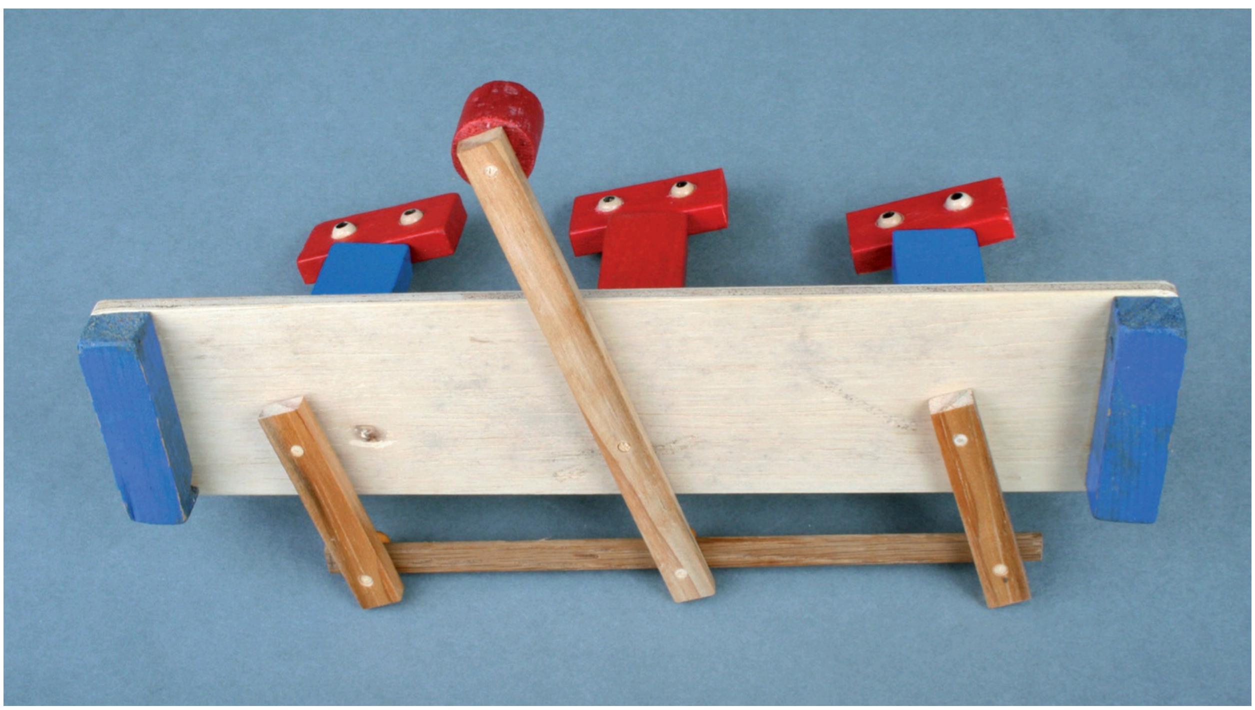
Method

Making the figures

The tops of the bodies and the bottoms of the heads need to be smooth curves so that the moving heads can turn freely on the fixed bodies without snagging. Holes are drilled in the bottoms of the heads so that they can be firmly mounted on dowels, long enough to pass through the body and the base. The bodies are flat at the bottom, where they will be glued onto the base, and each has a hole drilled right through vertically, in which these dowels can rotate freely. The height of the bodies, and the diameter of the holes, may be limited by the drill bits available. It will be easier if the drill bit is long enough to pass right through the body. If the body is taller than the drill bit you will need to drill from each end to meet in the middle. If only for

this reason, it may be easiest to start with the holes through the bodies, and to select dowels to mount the heads on that are a good fit in those holes. They need to be loose enough to turn freely, but not so loose that they rattle around.

The base (with the bodies attached) acts as the front side of the parallelogram linkage. A wooden bar forms the rear side. The base and the bar at the back are linked with three more wooden bars, running front to back, the central one extending at the front to form the operating lever. The wooden base needs to be deep enough and wide enough to accommodate the three figures with an allowance at each side for supporting blocks which lift it up and allow room for the linkage underneath. Three holes are drilled in it to take the dowels that are fixed into the heads and run through the vertical holes in the bodies (they must be able to turn freely). In this version the base is cut from a recycled wooden board, and a similar piece of board has been added (after assembling the mechanism) below the supporting blocks. This under-base is not essential, but I thought in this piece it looked better. The other two versions do not have it.



***The Three Watchers*: the second version, using wooden toy building bricks, seen from below and showing the arrangement of the bars.**

The bar at the back has three holes exactly the same distance apart as

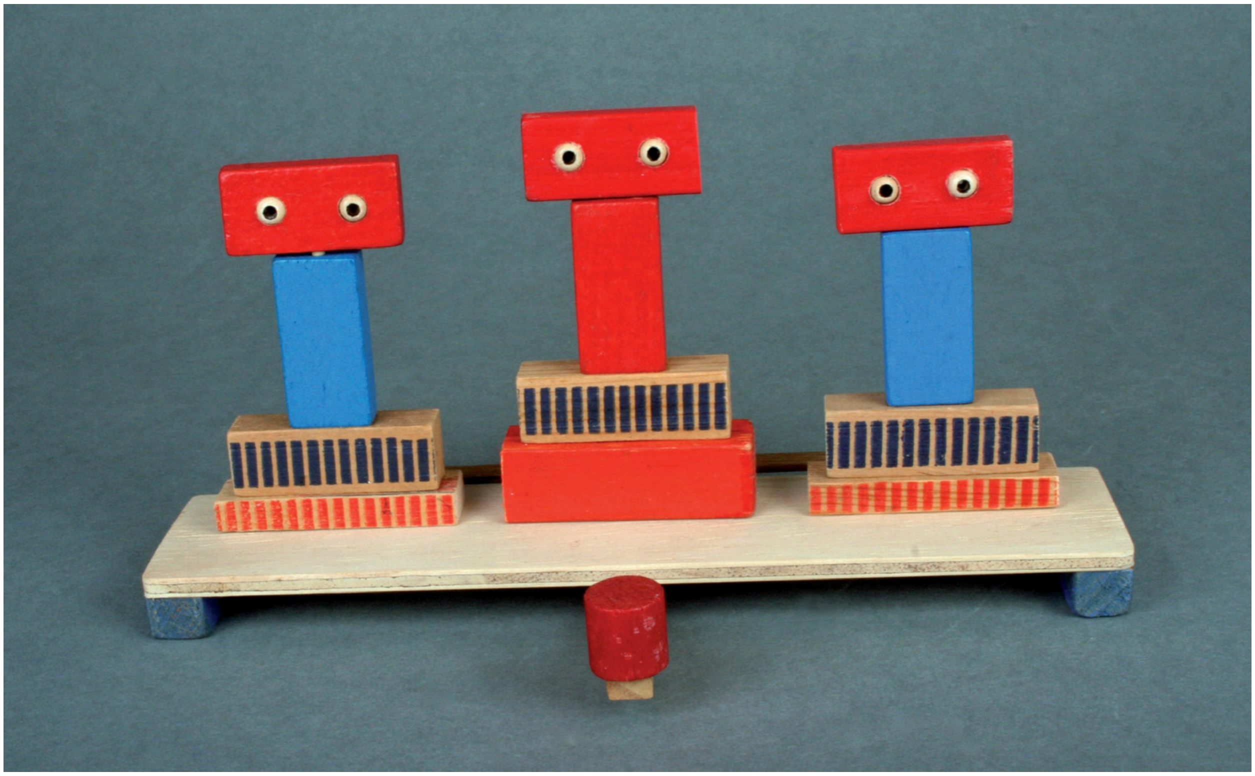
the three holes in the base. The three bars running from front to back are long enough to stick out behind the base to accommodate the bar at the back. Each has two holes, the same distance apart. The central bar is longer so that it sticks out at the front to form the operating handle. The positioning of the holes in the base, the back bar and the three linking bars is important for the smooth movement of the parallelogram mechanism. The holes in the bottom of the heads and in the three bars running front to back should be a tight fit on the dowels, which will be glued into them during assembly. The holes in the back bar, like those in the bodies and in the base, should be a loose fit on the dowel.

Assembly

Glue the three bodies to the base, taking care that the holes in the bodies are aligned exactly with the holes in the base. Glue the two spacing blocks on under the base at either end.

Glue three short dowels into the holes at the back of the three linking bars. These dowels need to be long enough to accommodate the thickness of the back bar, with a bit extra so that a bead can be glued on as a stopper. Insert the dowels attached to the heads into the bodies and locate them in the holes in the three linking bars (with the short dowels at the back sticking up, not down). Adjust the linking bars to stick out behind at right angles to the body, with the heads facing forwards. It is best not to glue them in place yet.

Now the back bar can be positioned onto the three short dowels at the back. Move the handle from side to side and check that the heads are aligned correctly and turn freely. Finally glue the dowels from the heads into the linking bars, making sure that the bars are still at right angles, and glue the three beads onto the short dowels at the back. Do not push the beads down too far – the cross bar must be able to move freely. A neat alternative to using a short dowel with a bead glued on as a stopper is to use a turned wooden axle peg (see the section on materials in the Introduction). A final touch is a knob on the handle. I used a short length of twig, attaching it with a dowelled joint. A dowel, an axle peg or a bead would do just as well.



***The Three Watchers*: the second version, watching you.**

In the second version, following the brick-like nature of *The Three Watchers*, I have built the figures up from some old wooden toy building blocks. Holes were drilled, and beads glued in for the eyes. The bodies are built up of three bricks, which could be drilled individually before assembly, avoiding any need for a long drill bit. The base is a single layer of plywood, supported at each side on another toy building block, and a cylindrical block is used as a handle.

In the third version I have picked up on something owl-like in the large prominent eyes and the mobile necks of *The Three Watchers*. Here the bodies and heads are cut from a driftwood branch. The beaks are cut from thin board, and for the eyes I have used slices from a spalted sycamore branch. The spalting, caused by a fungus, gives the striking patterns of black lines in the pale wood. The base is a piece of wood cut from an old athletics hurdle (hence the black and white painted stripes). It is raised, to allow space for the linkage underneath, on four short legs cut from a driftwood branch.

***The Three Owls*: the final version, using recycled wood, dead branches and feathers.**

CHAPTER THREE

PULLING STRINGS – Levers and fulcrums

Jumping jacks and pantins

Toy figures with movable limbs, operated by pulling a string, are found all over the world, and have a long history, being found in Egyptian tombs and described in classical Greek texts. A bizarre episode in that long history was a sudden intense craze amongst fashionable Parisians that reached its height in 1747. Everyone who was anyone had to be seen with a 'pantin' – a cardboard figure with jointed limbs that could be made to dance by pulling a string. You could spend a lot of money: even eminent painters such as François Boucher were engaged to produce designs. The height of this strange fever that gripped the top of French society did not last long, but printed paper sheets of pantins, to stick on card, cut out, and string up, remained widely popular, as did more substantial painted wooden jumping jacks. The 'puppet on a string' aspect was irresistible to satirists: for more than two hundred years many of the great and not-so-good – unpopular politicians, heads of state and generals – have been lampooned as jumping jacks.

***Canoe with Bird*. When you turn the crank handle the canoe rocks and the canoeist paddles.**

In Mexico wooden and cardboard jumping jacks feature amongst the many skeleton toys made traditionally for the Day of the Dead celebrations.

Pantins. A printed paper sheet with pierrot and columbine to stick on card or thin wood, cut out, and string up .

The essential mechanical element in these jumping jack toys is a class 1 lever. Levers are rigid links pivoted at a fixed fulcrum somewhere along their length. A force (the effort) applied at another point, moves a resistance (load) at a third point. In class 1 levers the fulcrum is between the effort and the load. Usually the limb of a jumping jack has a string attached at one end, with the fulcrum quite close to the same end, so that pulling the string down a little way (the effort) raises the other end of the limb (the load) through a much greater distance. On releasing the string the raised weight of the limb becomes the effort and it falls back, so that the short end, with the attached string, now the load, is raised to its original position. For a jumping jack like this to work it has to be held upright so that the limbs do fall back after being raised by a pull on the string. If the string is replaced with a rigid link, such as a stiff wire, then the lever can be moved with a push as well as with a pull and it is no longer necessary to rely on the force of gravity for the return movement.

Skeleton guitarists in wood and thin card made for the day of the dead festivities in Mexico.

Snowman. A tiny jumping jack mounted on a miniature peg.

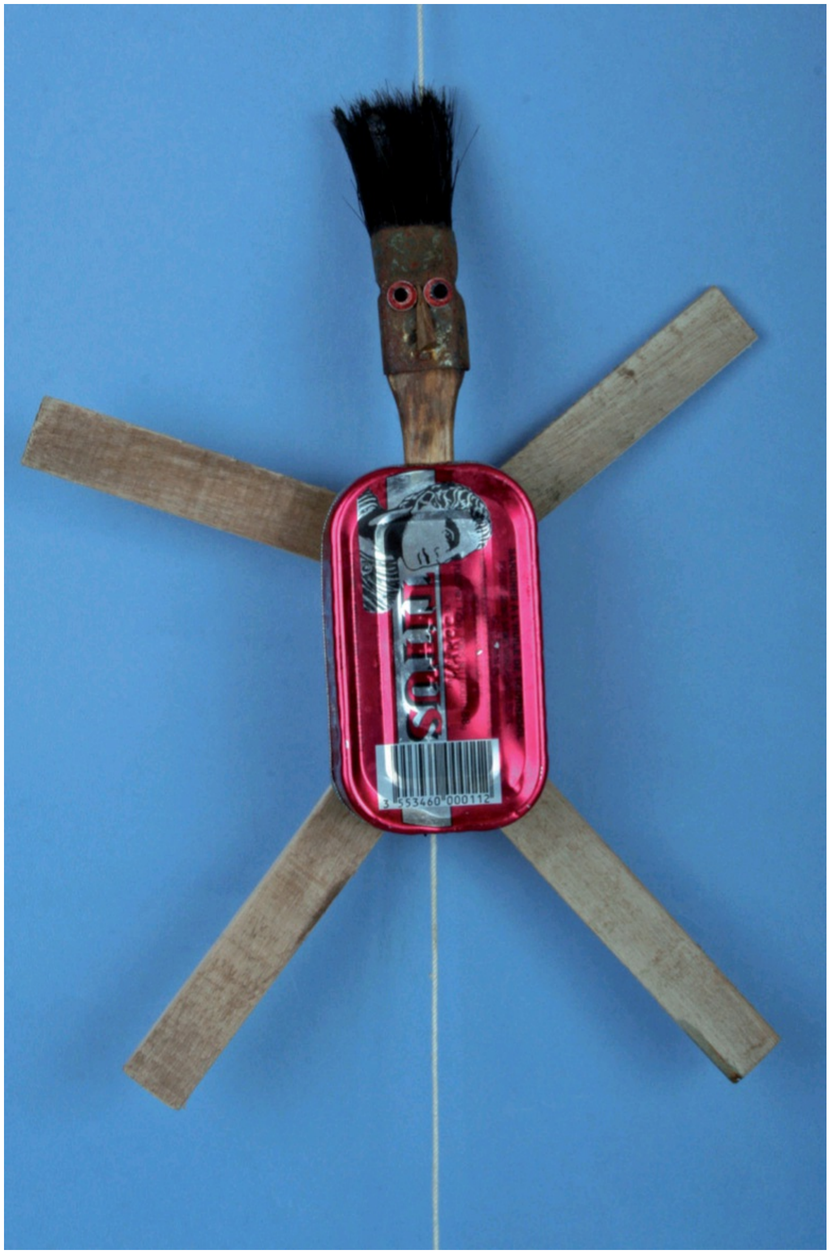
Squeezing the peg pulls on a thread and raises the arms.

This is illustrated in a pair of miniature peg toys: the snowman mini-peg toy has moveable arms, but like most snowmen no legs. It operates like a traditional jumping jack: the body is mounted on the top part of the peg. The arms are pivoted behind on small brass pins and attached by a thread to the bottom part of the peg. When the peg is squeezed the thread is pulled and the arms are raised. When the peg spring is released the arms fall back.

Father Christmas holds his hat on his head.

Squeezing the peg pulls on a wire and he removes his hat.

In the Father Christmas mini-peg toy, the body is similarly mounted on top of the peg. The two arms are a single piece, pivoted behind the body, and shaped so that one arm holds his hat on his head while the other is down by his side. A wire runs from near the shoulder to the lower part of the peg. When the peg is squeezed the wire pulls down the arm holding the hat, raising the other arm. When the peg is released the wire pushes the arms into the original position, and the hat is returned to his head.



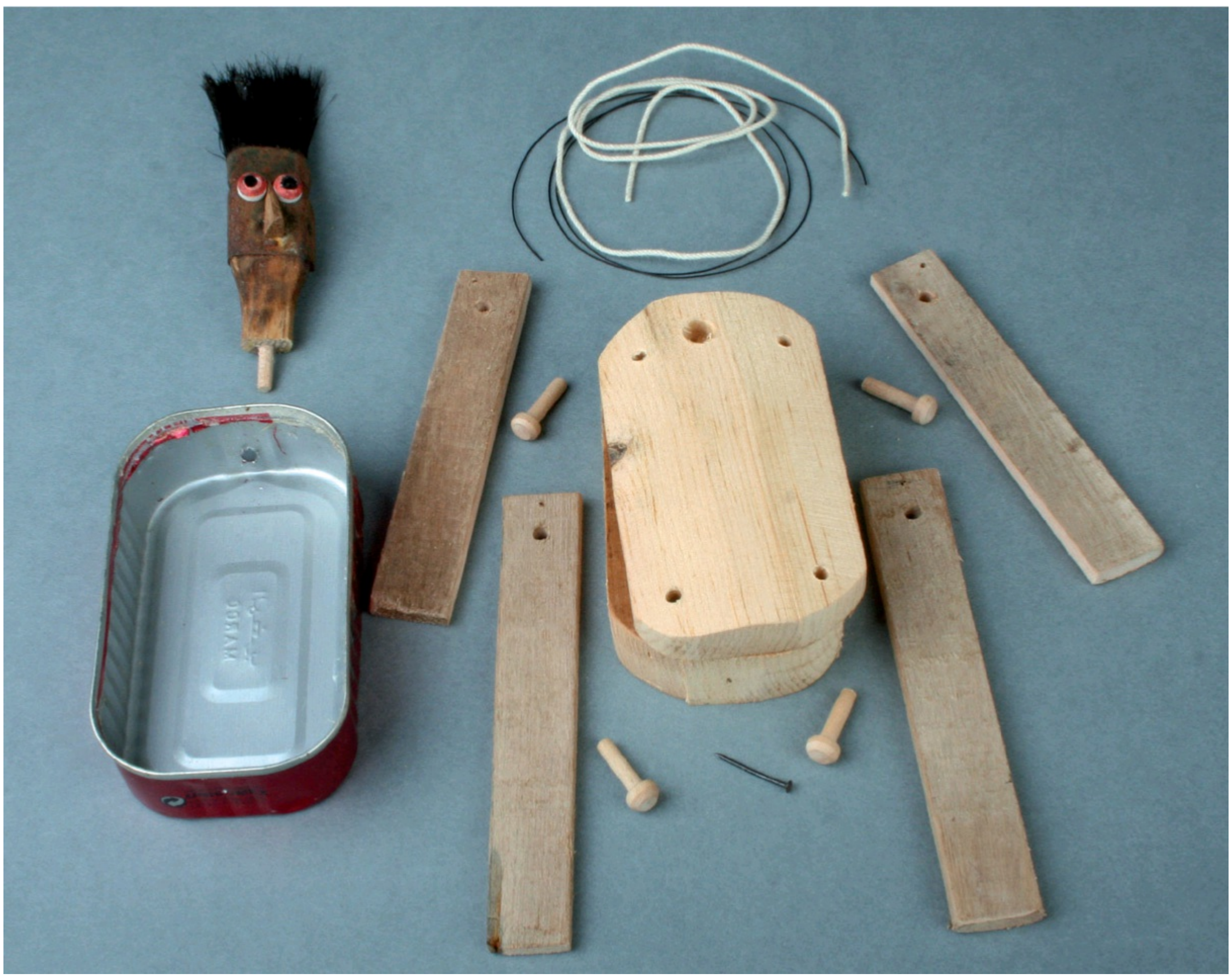
A jumping jack with wooden limbs, a sardine can body, and a paintbrush head.

There are many different ways of joining the limbs to the body of a jumping jack. The Mexican examples illustrated show two possibilities: the wooden version uses a thin wire, bent into a small loop on each side, while the cardboard version uses knotted string joints as described in Chapter 2. Pantins, with the printed paper mounted on card or thin wood, are usually jointed this way too. Other traditional European jumping jacks are often more substantial: the wooden body is thicker, and has a separate front and back joined with four short dowels. The (thinner) arms and legs are

mounted on the dowels, in the gap between the front and back of the body. This makes a robust structure, and hides the strings attached to the limbs. But if a string breaks or comes loose after assembly it can be difficult to mend.

I made a number of very basic jumping jacks with sardine can bodies and paintbrush heads, with simple wooden strips for the limbs. The core of the body is a piece of wood, shaped to fill the sardine can, with the limbs mounted at the back on small wooden axle pegs. Small round-headed screws (brass, or black japanned) can be used in place of these wooden pegs.

Making a sardine can jumping jack



Parts for making the sardine can jumping jack.

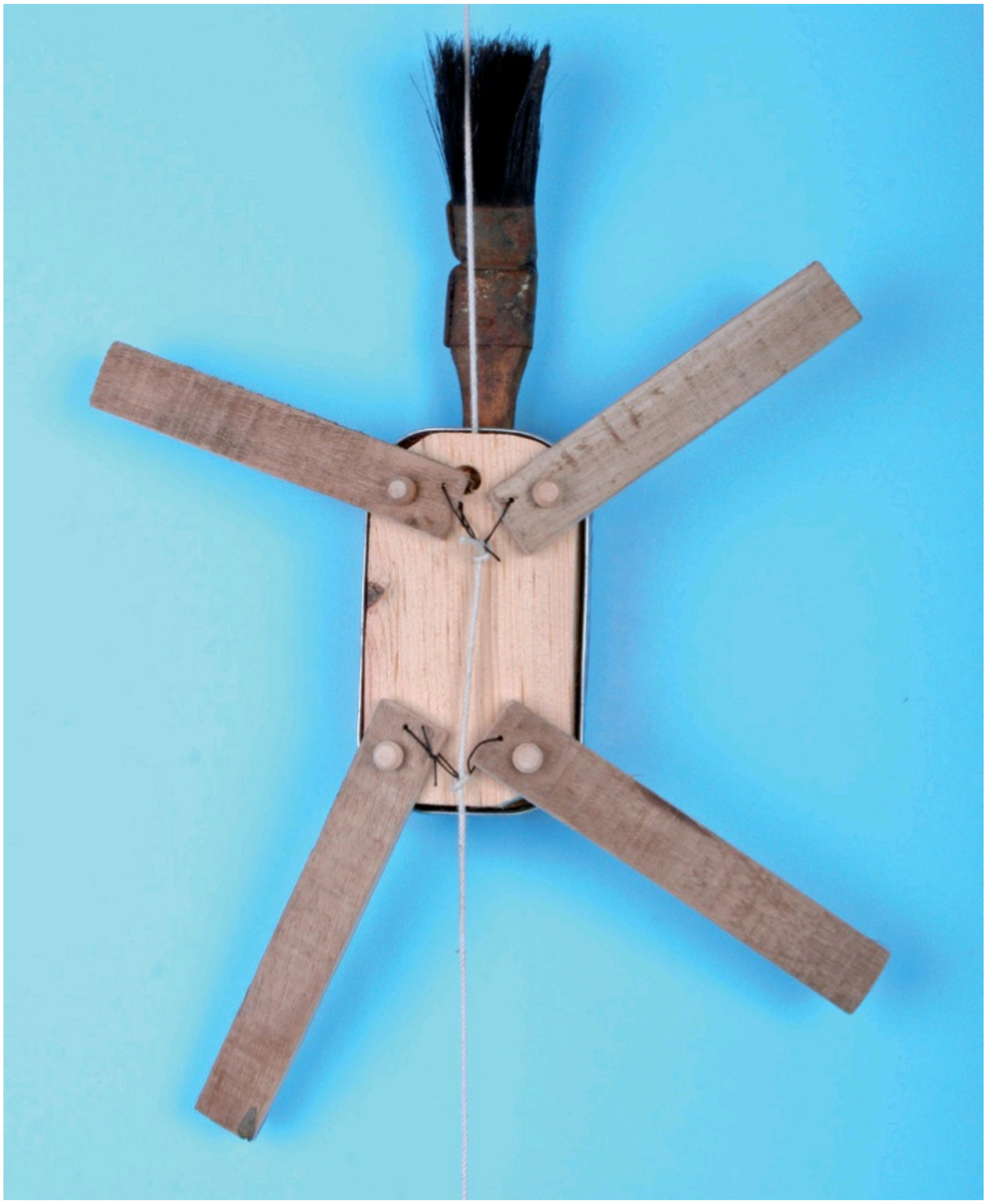
Method

Head and body

The jumping jack head and body could be made from any old scraps of wood, but I do like the combination of the slightly rounded form and bright incongruous graphics of a sardine can for the body, with a dead paintbrush for the head. This is not quite as easy to achieve now as it was with the old-fashioned cans, supplied with a key for rolling back the lid. They could be opened by leaving the roll-back top in place and using a conventional rotary can opener on the seam underneath, thus preserving the shiny pictures and graphics on the front. Modern ring pull cans of fish only have one seam, often on the top. In many of these the underside of the can is disappointing – unprinted or uninteresting – but some do have similar pictures back and front. Such cans are best opened at the front with a can opener. Otherwise use the ring pull. In the latter case a flange will be left which must be bent back inside the can to allow for the insertion of the wooden block.

I use a piece of wood that is rather thicker than the depth of the tin can (you could build up that thickness by sandwiching two thinner bits of wood together). Cut it to size and round off the corners so that it will fit snugly inside the tin can. As shown, the extra depth at the back is planed, chiselled or sanded at a slight angle on each side so that when the limbs are attached they will project forward a bit. This will stop the limbs scraping if the figure is hung against a wall.

The paintbrush handle is cut off, leaving a neck. Two of the small wooden axle pegs have been used for the eyes, and a sliver of wood glued on as a nose. The neck is attached with a dowelled joint, which passes through a hole in the tin into the wooden body. This, together with a nail at the bottom, is enough to keep the tin can in place.



The back of the jumping jack, showing the arrangement of the strings. The limbs have been attached using wooden axle pegs (see section on materials in the Introduction). These could be replaced with round-headed screws.

The Mexican skeleton jumping jacks were mounted on a stick, to be held in one hand while the string is pulled with the other. This one is hung from a stout string attached to the top of the body behind the paintbrush head. A neat way of attaching it is to drill a hole, just big enough to thread the string through, vertically down into the top of the wooden body where it sticks out from the tin can (behind the neck and head). Then drill a second, larger

diameter, hole in horizontally from the back about 15mm (⅝in) below the top, deep enough to meet the first hole. Feed the string into the top hole and hook it out of the larger hole. A thumb knot can then be tied, and pulled back into the large hole.

Limbs

The limbs are simply strips of wood, around 20–25mm (¾ –1in) wide, 5–6mm (¼in) thick and long enough to look right with the size of body used. In this example the legs are 125mm (5in), and the arms a little shorter.

Each limb has two holes drilled through near the top end: a smaller one about 6mm (¼in) from the end for attaching the string or thread, and a larger one that is a loose fit on the axle peg or screw that will be used to attach it to the body.

The exact position of the holes for attaching the strings at the top end of the limbs will affect the amount of movement of the limbs: as a rule I make the holes for the leg strings central, directly above the holes for the axle pegs, and the holes for the arm strings 6mm (¼in) from the outside edge of the arms. The typical traditional jumping jack has a string attached to each of the four limbs, but is operated by pulling a single string that hangs down below the figure. There are various alternative ways of combining the strings. The method that I use works best with the string holes at the top of the limbs placed as described above.

Attaching the limbs and stringing up

Position the limbs and mark where the axle pegs, or screws should be, at shoulders and hips. Drill holes to fit the axle pegs, or guide holes for the screws.

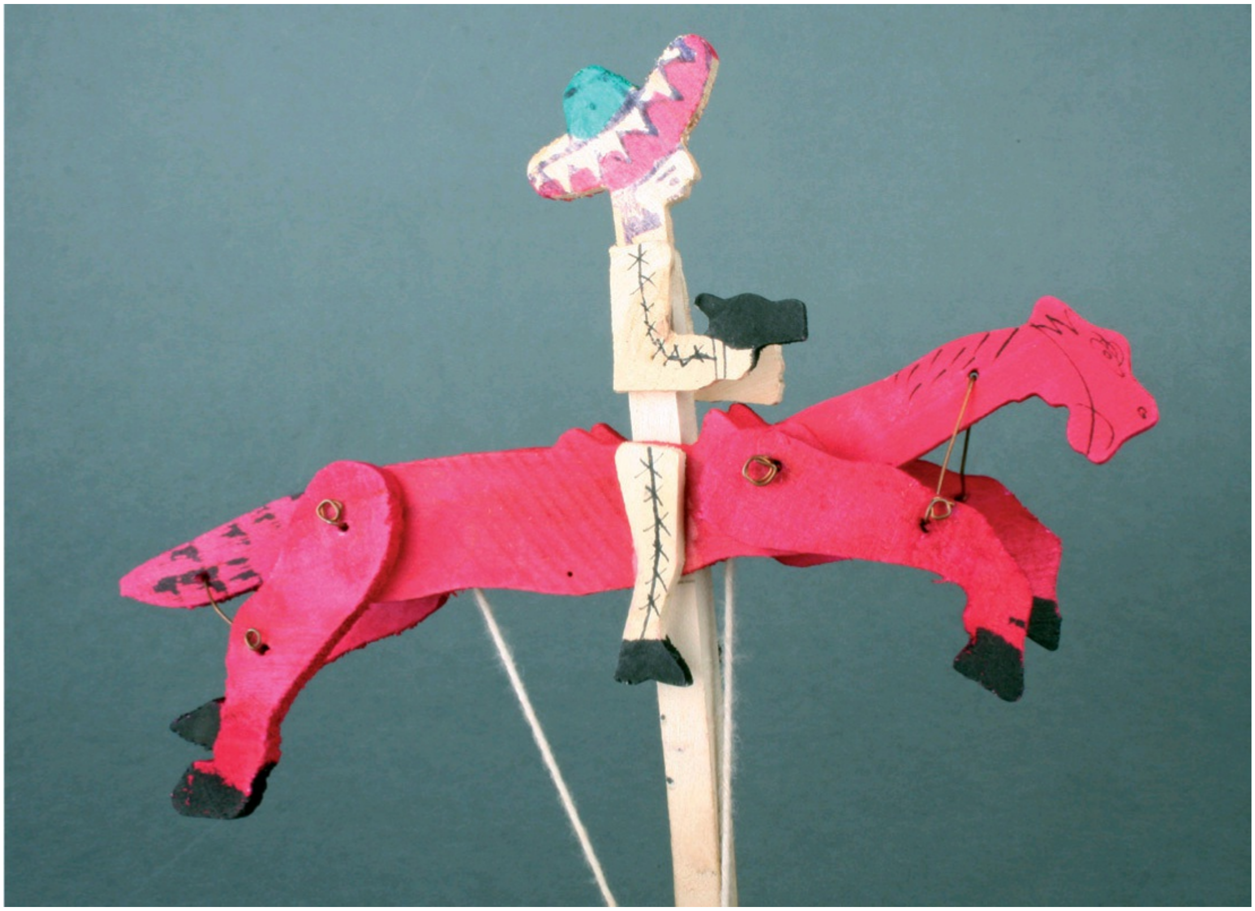
I find it effective to use a relatively thin, strong thread to connect arm to arm and leg to leg, and a thicker cord or string to join them together and hang down to form the pull.

From the back pass the strong thread down through the hole at the top of one arm then up through the hole in the other arm. Do the same for the legs with another piece of thread. Now attach the arms and legs to the body with the wooden pegs, or the round-headed screws. With the arms down, tie the two ends of the thread together into a loop. Do the same with the leg thread. Take a piece of the thicker cord or string and tie the

end to the loop of thread between the arms. Then, with all the limbs still down, tie it to the loop of thread between the legs, letting the remainder hang down. Hold up the jumping jack and pull the cord to check the movement: you may need to adjust the strings a little to get the best action.

Developing the design for an automaton

The jumping jack mechanism is used in another traditional Mexican wooden toy, a gun-toting horseman seen in profile. I have two slightly different versions of this toy: the first comprises a static rider on a rather strange red horse. The four legs, the head and the tail of the horse are loosely attached to the body with wires. Pulling the string at the bottom makes it gallop: one branch of the string is attached to the neck of the horse, the other to the base of the tail. The front legs are connected by a wire to the neck, and the rear legs are similarly connected to the tail. The result is that when the string at the bottom is pulled, the head, the tail and all four limbs are pulled up, and the horse appears to gallop.



The jumping jack mechanism used for a galloping horse. Mexico, 1990s.

A similar galloping horse jumping jack, with an extra string to raise and lower the rider's arm.

The second version is similar in action. A minor difference is that the links between the head and tail and the limbs are strings, rather than wires, so that the head and tail droop down between the legs when the string at the bottom is released. There is another string, attached to the strings from the head and tail, which raises the gun arm of the rider, pivoted on a small nail at the shoulder.

***Canoe with Fish*.**

In *Canoe with Fish* the canoeist is also essentially a jumping jack, with a lever, consisting of the arms plus the paddle, being raised by pulling on a string, and falling back under gravity. The two arms are mounted securely on a thin dowel that passes through a hole at the shoulder and is free to rotate. The arms move together as one, raising and lowering the paddle, also rigidly attached.

The canoe itself is another lever, which is both pushed and pulled by a wire link. The canoe is pivoted at the top of an upright support stand.

Lower down a hole is drilled through the stand. This hole acts as a bearing for a wire crankshaft, which has a crank handle at the front, and a short crank behind. The short crank forms one bar of a four-bar linkage (see Chapter 2). The other three bars in this linkage are the support stand, the canoe, and a wire link that connects the short crank to the canoe. Turning the crank handle makes the canoe rock: the rotary motion of the wire crankshaft is converted to oscillatory motion of the canoe through the four-bar linkage. The canoe is pivoted roughly in the middle, with the canoeist positioned at the back. The rocking motion of the canoe is used to produce a pull on the string attached to the arms and paddle of the canoeist. This is achieved by running a string from the back of the uppermost arm, just behind the point where it is pivoted at the shoulder, through a guide – a small brass screw eye in the side of the canoe – and down to a fixing point on the support stand. The distance between the guide on the canoe and the fixing point changes as the canoe rocks. The length of the string can be fixed so that as the canoe rocks the arms and paddle are alternately raised and allowed to fall back, creating the illusion of a paddling motion.

Making *Canoe with Bird*

Method

The canoe

In *Canoe with Fish* the canoe is a section of a driftwood branch, cut to shape at the bow and with a flat to mount the canoeist on. In *Canoe with Bird*, illustrated at the beginning of the chapter, the boat is a very basic shape, cut from a thin board, as are the canoeist and the bird. A 30mm (1¼in) length of 4 or 5mm (3⁄16) diameter dowel, to act as the pivot, is glued into a hole drilled at right angles into the side of the canoe, slightly behind the halfway point between bow and stern. It is best to position it here because the canoeist adds weight to the stern end. This dowel will be mounted in a hole through the top of the support stand to make the fulcrum about which the canoe rocks.

Parts for *Canoe with Bird*.

The stand

The stand has two components: firstly a base, which is a flat piece of wood, large enough to be stable (in *Canoe with Fish* it is longer and thinner; here it is shorter but fatter, heavy enough in both cases not to slide about when the handle is turned); secondly an upright support, which is long enough to support the rocking canoe, leaving enough space below to mount the operating crank. Here the upright support is a piece of dowel

about 12mm (½in) diameter. Drill a hole of the same diameter in the base to mount it. Before gluing it in, drill two holes in the support: firstly a hole about 10mm (⅜in) or so from the top; this hole should be a loose fit for the 4 or 5mm (3⁄16) pivot on the canoe; secondly a hole about halfway along the support, to take the wire crankshaft; this hole should be a loose fit on the wire used for the crankshaft.

The crankshaft

I have used some steel wire with a black finish, which was a spoke cut from a broken bicycle wheel. The diameter is not critical, but the wire does have to be thin enough to bend easily, and thick enough to hold its shape. It will depend also on the hardness of the wire used. The wire spoke is a little harder than galvanized steel wire, but can be bent easily enough without heating it. Galvanized wire around 2mm (5⁄64in) diameter would also be good. Take a piece of wire about 90mm (3½in) long. Using a pair of pliers, make a right-angled bend about 20mm (¾in) from the end. Then bend the wire back again at right angles, forming a small crank. A link that connects to this crank will push the canoe up and down: it does not need to be a very big movement, so the length of the crank arm has to be quite small. It is important to remember that, as a crank rotates right round, the throw – that is, the up and down movement – will be twice the length of the crank arm. It is easy to make too large a crank that will produce an exaggerated rocking of the boat. When the small crank has been formed feed the wire through the hole in the upright support and check that it can rotate freely. Holding the wire as close as possible to the support with the pointed jaws of the pliers, bend the wire to form another slightly longer crank, which will act as the operating handle. Cut off any excess wire. A neat handle can be made by pushing onto the wire a piece of the insulation from a scrap of electrical wiring of a suitable diameter.

The wire link

The wire link is galvanized steel wire, around 1mm (1⁄32in) diameter, with a cylindrical coil formed at the lower end that will fit neatly on the crank. This is a technique that I first came across in African wire push-along toys. A simple wire loop on a wire crank will tend to slip round the elbow of the crank and jam. There are various other ways to prevent this, but this one

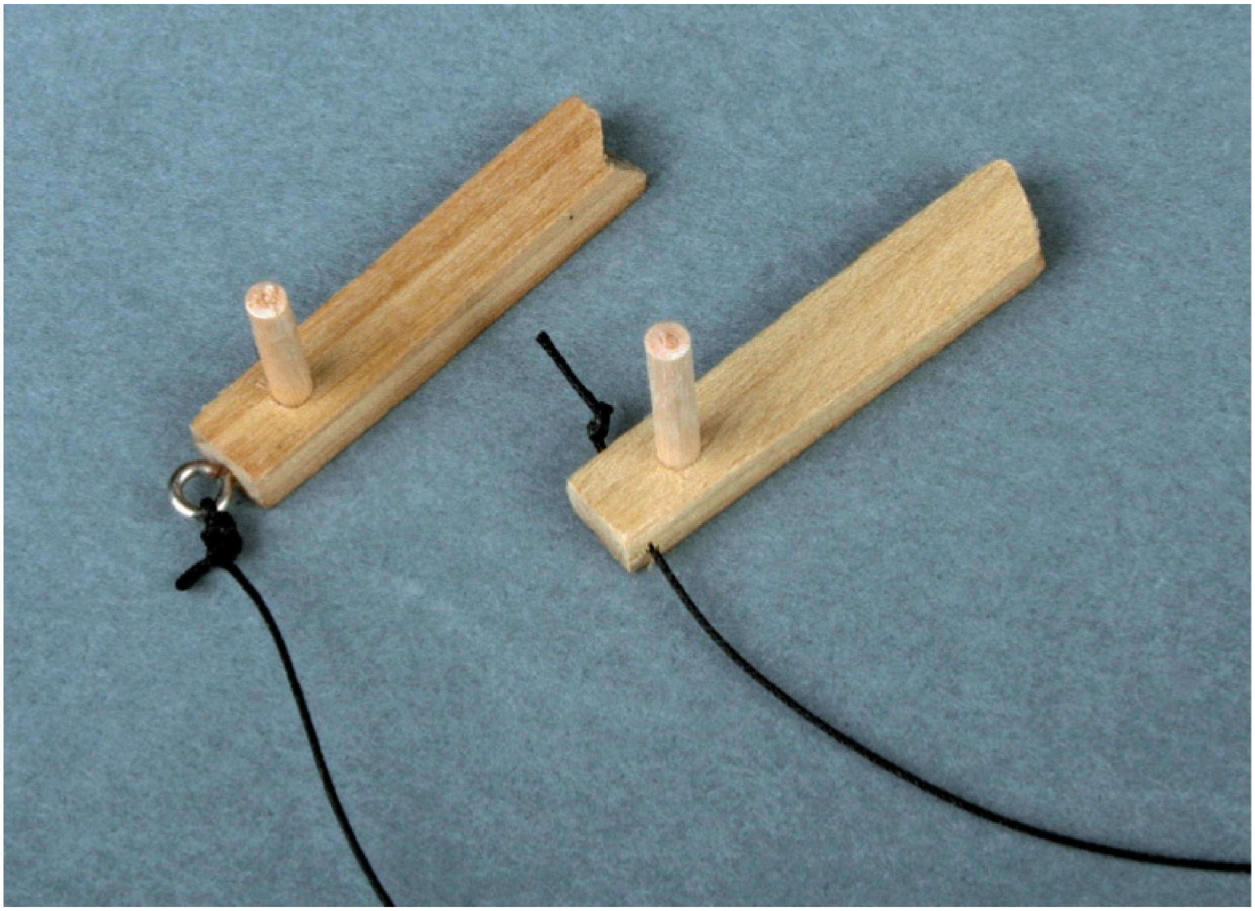
works well and looks good. The easiest way to form the coil is on a piece of wire slightly stouter than the wire used for the crankshaft. This will ensure that the link will move freely when slipped onto the crankshaft. The end of a piece of the thinner wire, about 200mm (8in) long, is held against this thicker wire former and it is wrapped round half a dozen times or so, trying to keep each loop tight against the last. The long end of the wire is bent back towards the middle of the coil, and then out at right angles, while the short end is similarly bent towards the middle, and trimmed off (if this is not done the projecting end of the wire may catch on the crank). The exact length of this wire link will be determined during the final assembly.

Canoeist, arms, paddle

The profile of the canoeist can be cut from a thin wooden board, around 6mm (¼in) thick. I have further shaped it a little by whittling with a knife and sanding. The arms are straight pieces cut from a thin strip of wood. Ideally they will be a bit thinner than the body, so as not to look too chunky, but it is good if they are thick enough to drill a blind hole about 8mm (5⁄16in) from the top end of each to take a thin dowel, 2.5 or 3mm (3⁄32in or 1⁄8in) diameter. This dowel will form a shaft linking the two arms. A slightly larger hole, 3.5 or 4mm (5⁄32in), is drilled through the shoulder of the body to take the shaft.

Before mounting the arms and paddle on the body, an attachment for the operating thread should be made on the arm that will hold the top of the paddle handle. The illustration shows two possible alternatives: a small screw eye (the smaller the better) can be screwed into the shoulder end of the arm; or, using a very fine drill bit, a hole can be drilled through from above, close to the end of the arm.

In the latter case the string or thread is knotted at the end and then is fed down through the hole (checking that the knot will not pull through). In the former case the string is tied securely to the eye.



Fixing the thread to the arms. Two alternative solutions.

Attachment of the arms and paddle

In *Canoe with Fish*, holes have been drilled through the arms at an angle to take the handle of the paddle. After adjustment of the angles and checking that the arms and paddle move freely as a unit, the dowel was glued into the tops of the arms, and the paddle was also glued in place. This does work well but is a little tricky to do and requires a very thin paddle handle. In *Canoe with Bird*, rather than drilling at an angle through the arms, the ends of the arms have been trimmed at an appropriate angle, and a slightly stouter paddle handle glued on. It helps to cut or file a slight groove at each 'hand' for the paddle handle to sit in.

The cargo

The cargo in *Canoe with Fish* is a plastic fish-shaped soy sauce container saved from a takeaway sushi set and painted. In *Canoe with Bird*, scraps

of the same thin board used for the canoeist have been used to represent a little bird, which stands on a thin dowel leg.

Final assembly

Glue the canoeist in position near the back of the canoe. I use a single dowel joint: drill a small hole in the bottom of the canoeist and glue in a short piece of cocktail stick or very thin skewer. Then mark the position and drill a corresponding hole in the canoe.

The canoe is mounted on the support stand by sliding the short dowel through the hole in the top of the stand. A bead, or a short length of thicker dowel with a hole drilled through it, is then glued onto the dowel to hold the canoe in place. The canoe should rock freely.

The canoe mounted on the stand, and joined to the crank with the wire link, seen from the back.

Now slide the cylindrical coil bearing at the bottom of the wire link onto the crank. To stop it slipping off the crank a short piece of the insulation from a scrap of electrical wiring of a suitable diameter can be pushed on, as described above for the crank handle. Otherwise a bead, or a short piece of dowel with a hole drilled in it, can be pushed onto the end of the crank, and glued if necessary. The link must be able to turn freely on the crank. I find it best at this point to put a slight double bend in the wire link,

so that it clears the support, and can be lightly held against the side of the canoe about halfway between the pivot point and the bow. Now, if the crank handle is turned, the position of the canoe and the wire link can be adjusted so that the rocking motion looks right – with the canoe about level at the mid-point, and not rocking too extremely. The extent of the rocking can be reduced by moving the point at which the wire link meets the canoe further from the pivot, or increased by moving it nearer. When the movement looks about right mark the position, and screw a small eye into the side of the canoe. Now the wire link can be held against the side of the canoe, and slid up or down to find the length necessary to hold the canoe more or less level. Bend the wire at this point, and feed it through the screw eye. Turn the crank to check that the length is right. Cut the wire off and make a small loop at the end to attach it more permanently to the screw eye. The canoe should now rock when the handle on the crankshaft is turned. If the canoe is tipping too much one way, forward or back, then the double bend which was made in the wire link, to bring it close to the canoe, may be useful now: by slightly changing the angle of the bends the wire link can be lengthened or shortened a little bit to adjust the angle of the canoe.

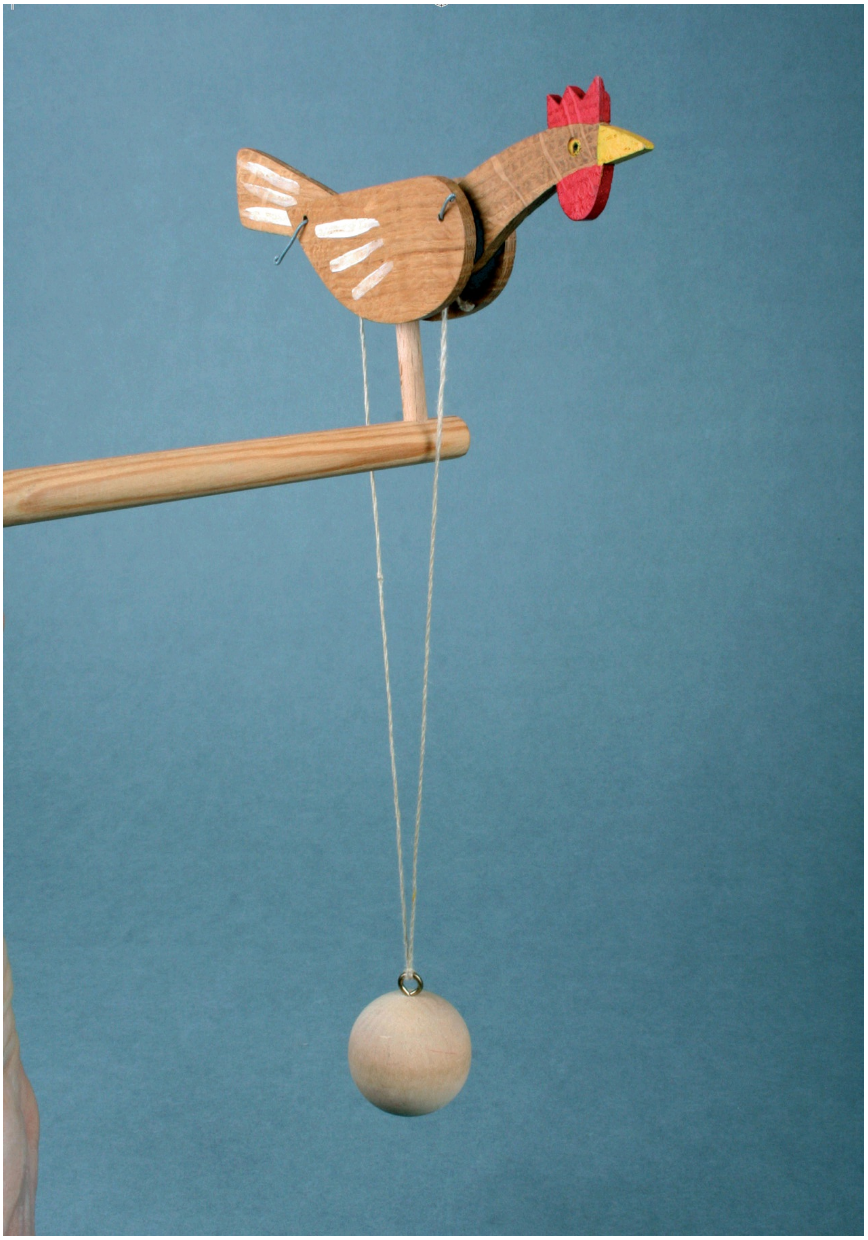
Attaching the thread from the arms

Pulling down on the thread attached to the arms raises the paddle. This thread must now be run through a guide on the canoe and attached to the support: screw another small metal eye into the side of the canoe, immediately below the shoulder of the canoeist (where the thread has been attached). Feed the thread through this eye from the stern side and check that pulling on the thread raises the arms and paddle. The thread must now be tied off to another screw eye in the upright support. To decide on the best position for this screw eye, hold the thread against the upright support, and pull taut enough to raise and lower the arms when the crank handle is turned. Experiment by trying different positions further up or down the upright. The aim is to find a point that gives a full movement up and down of the arms and paddle, without the thread going too slack when the arms are lowered. Screw the eye in at that point, and tie the thread securely to it. I find it best not to cut the excess off too short in case the length needs adjusting. A bead or shell can be threaded on as a neat finish.

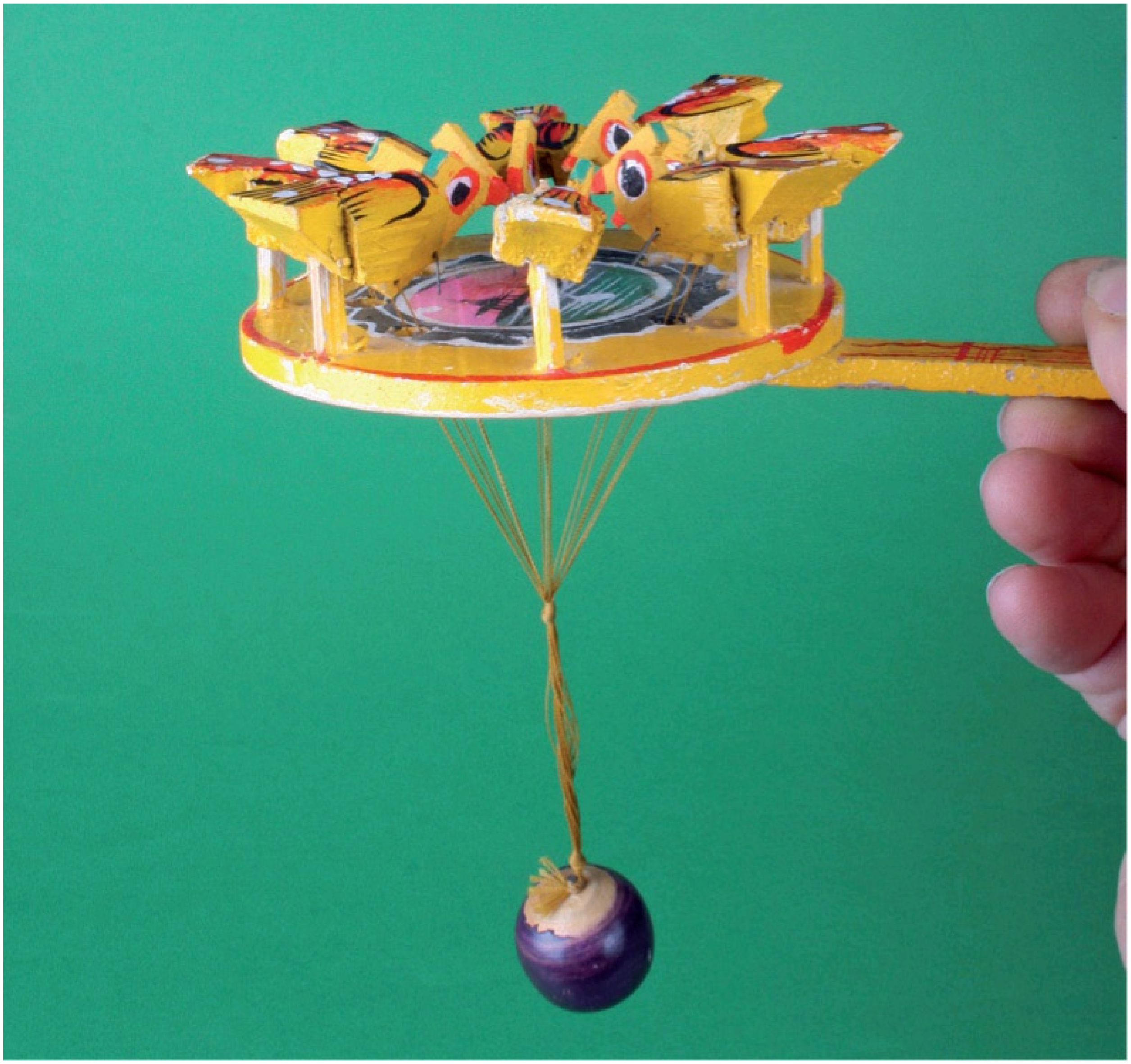
CHAPTER FOUR

SWINGING WEIGHTS – Balance and movement

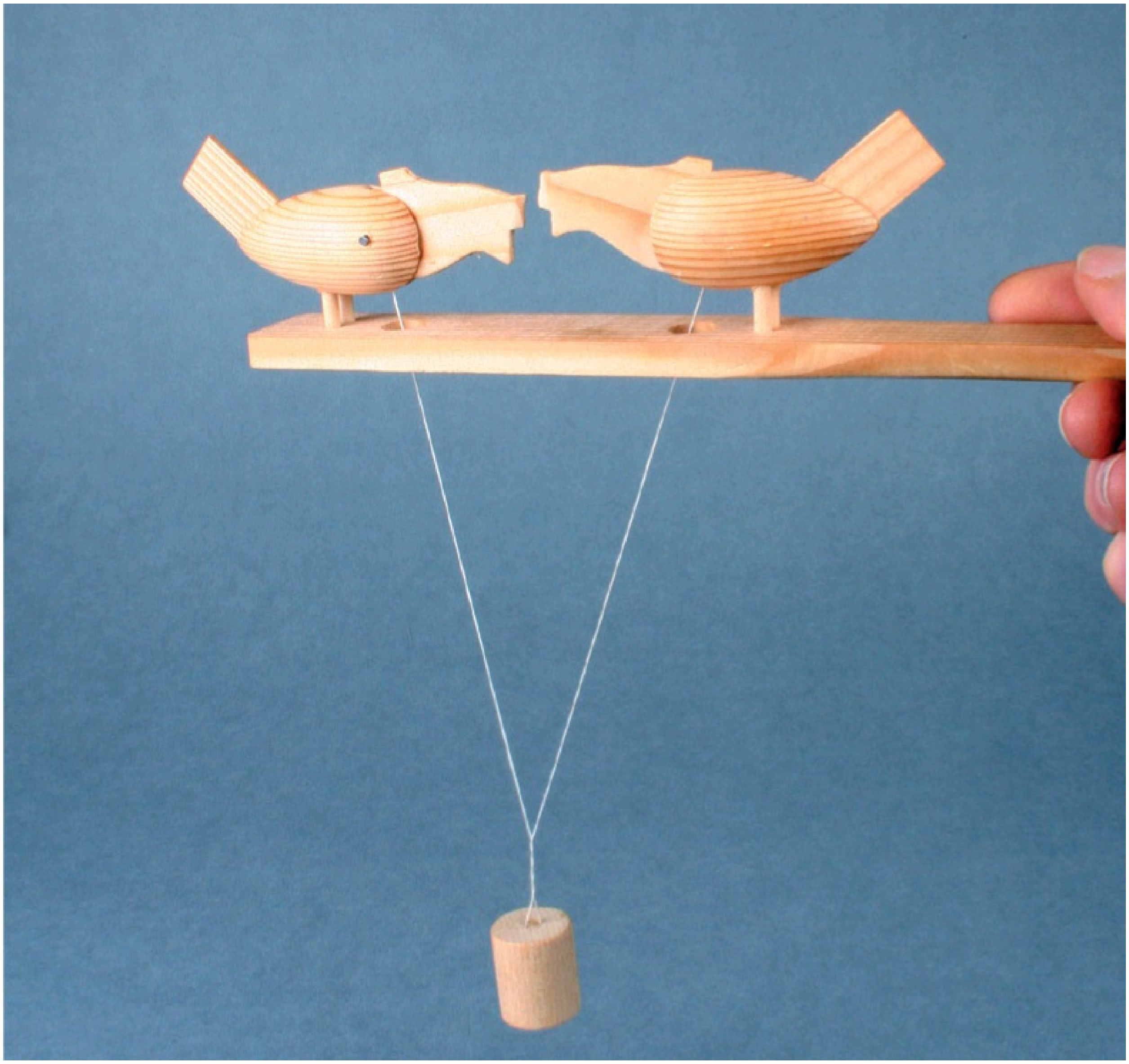
The limbs of a jumping jack or a pantin are moved with a direct pull on a string. Usually the two or more limbs are set in motion together, but slight variations in friction at the joints and in the distribution of forces through the moving parts can make the action more irregular and unpredictable, which adds to the illusion of animation. There is another related class of moving toys, equally widespread and variable, in which the irregular movement of levers is produced by attaching strings to a swinging weight. A familiar type consists of a table tennis bat-like platform with a number of birds in a circle, facing towards the middle. Each bird has a moving head that is pivoted at the neck. A string attached just behind the pivot runs down through holes in the bat. The strings are gathered together and attached to a weight. When the bat is moved around, the weight swings about, putting more or less tension on the various strings, so that the birds move their heads up and down as if pecking. This can give a pleasantly rhythmic clicking noise.



Pecking chicken. The head and the tail move when the weight is swung about.



A traditional pecking bird toy operated with a swinging weight. An Indian example with a circle of eight brightly painted wooden birds.



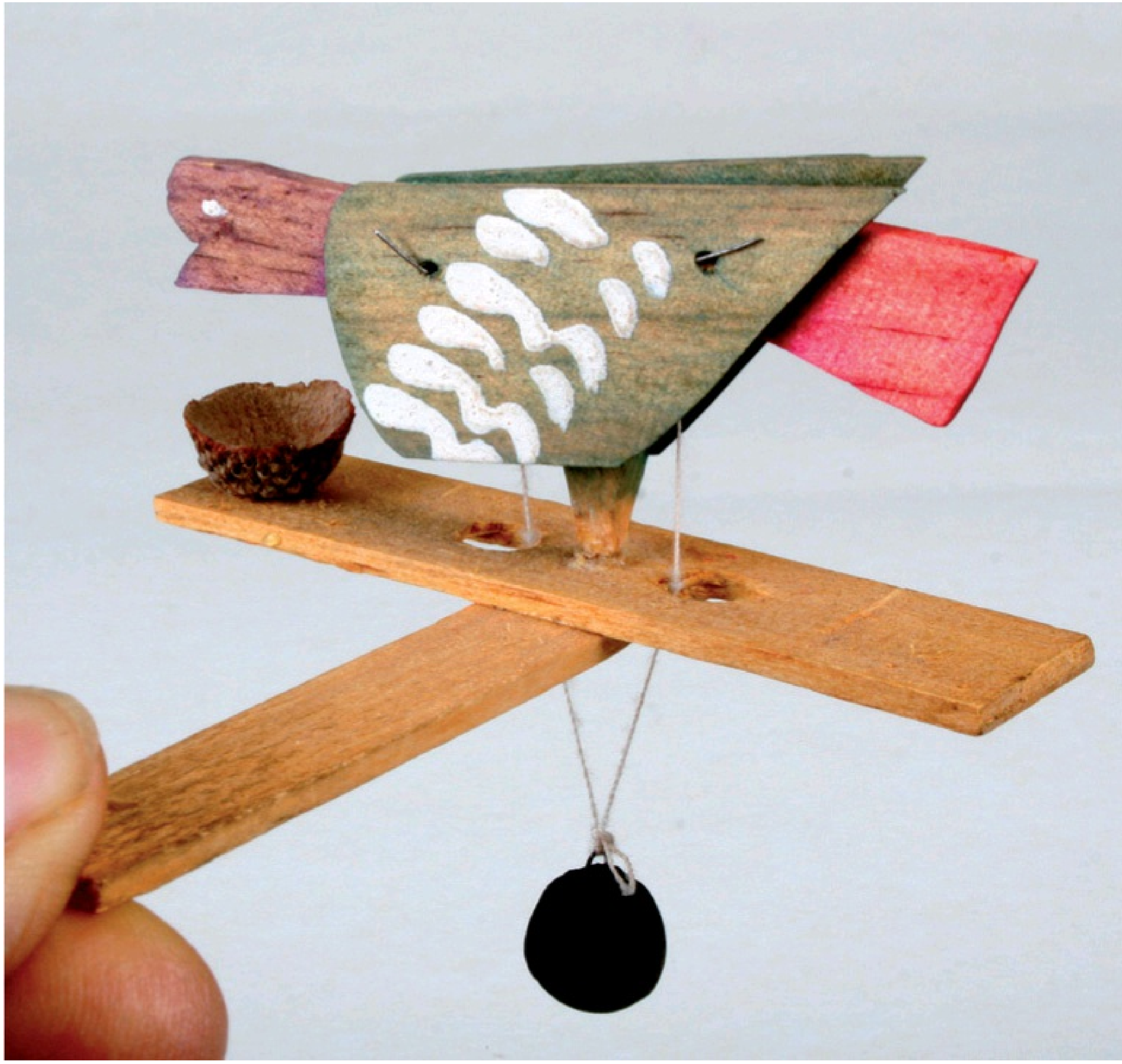
Two pecking chickens. A stylized design in plain wood from the Czech Republic.

Other examples have only two birds, or there may be just one, with a string to a moving tail as well as to the neck.

One example in my collection is a Chinese bird in carved and painted wood, with the legs ingeniously made from naturally bent twigs, and a clay fish as the weight. I bought it more than forty years ago, and it is a little battered, but still elegant. The long tail, like the limb of a jumping jack, has the pivot very close to the end where the string is attached, so that it wags through a wide arc in a convincingly lifelike manner. It is mounted crosswise on a stick, so that the strings to the swinging weight are

unimpeded.

A Chinese bird in painted wood, with moving head and tail and a clay weight. The long tail wags in a very life-like manner. 1970s.

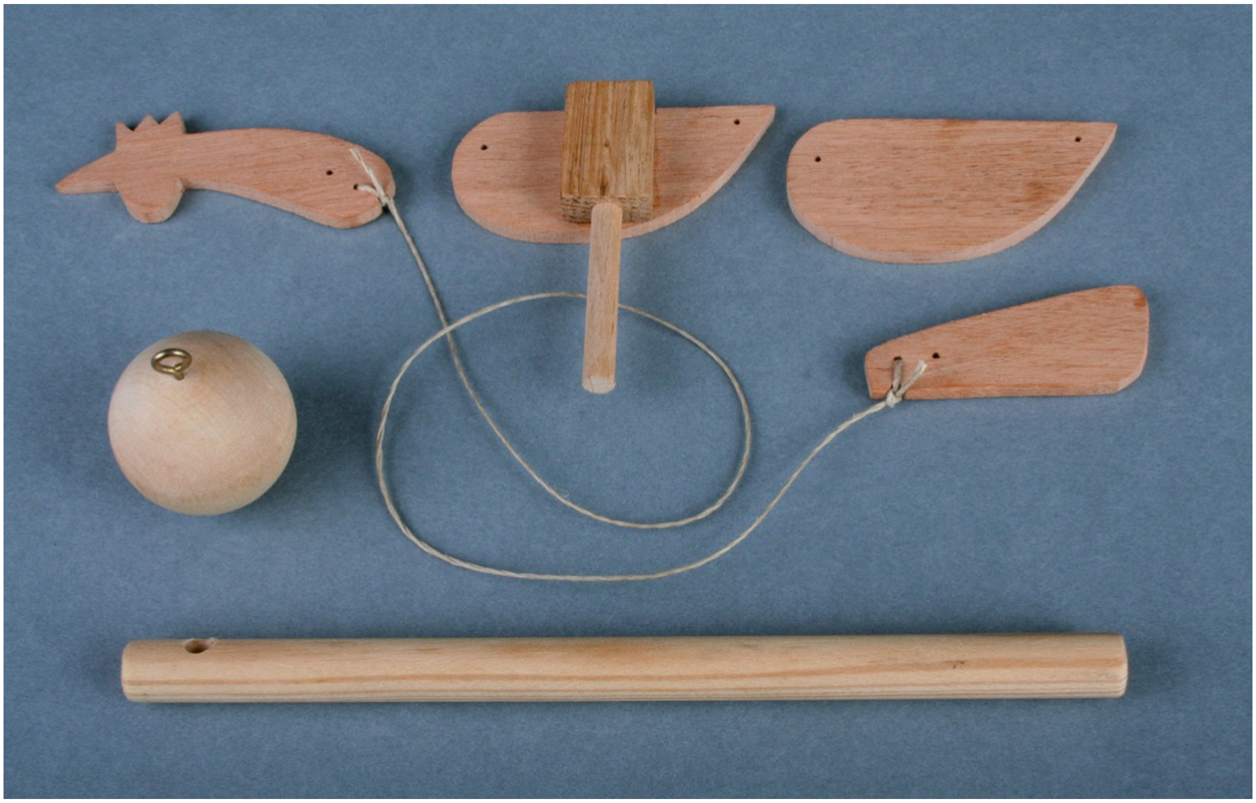


A tiny bird in dyed and painted wood, drinking from an acorn cup. Mexico, 1990s.

A traditional Mexican version is a little bird mounted on a flat strip of wood, with two holes drilled in it for the strings to pass through. The structure of the bird is simpler and more stylized than the Chinese bird, and its movement is less naturalistic, but it tips its head towards an acorn cup bowl, which is a pleasing feature.

Making a pecking chicken

The pecking chicken illustrated at the head of the chapter combines the simple sandwich structure of the Mexican toy with the stick mounting of the Chinese bird.



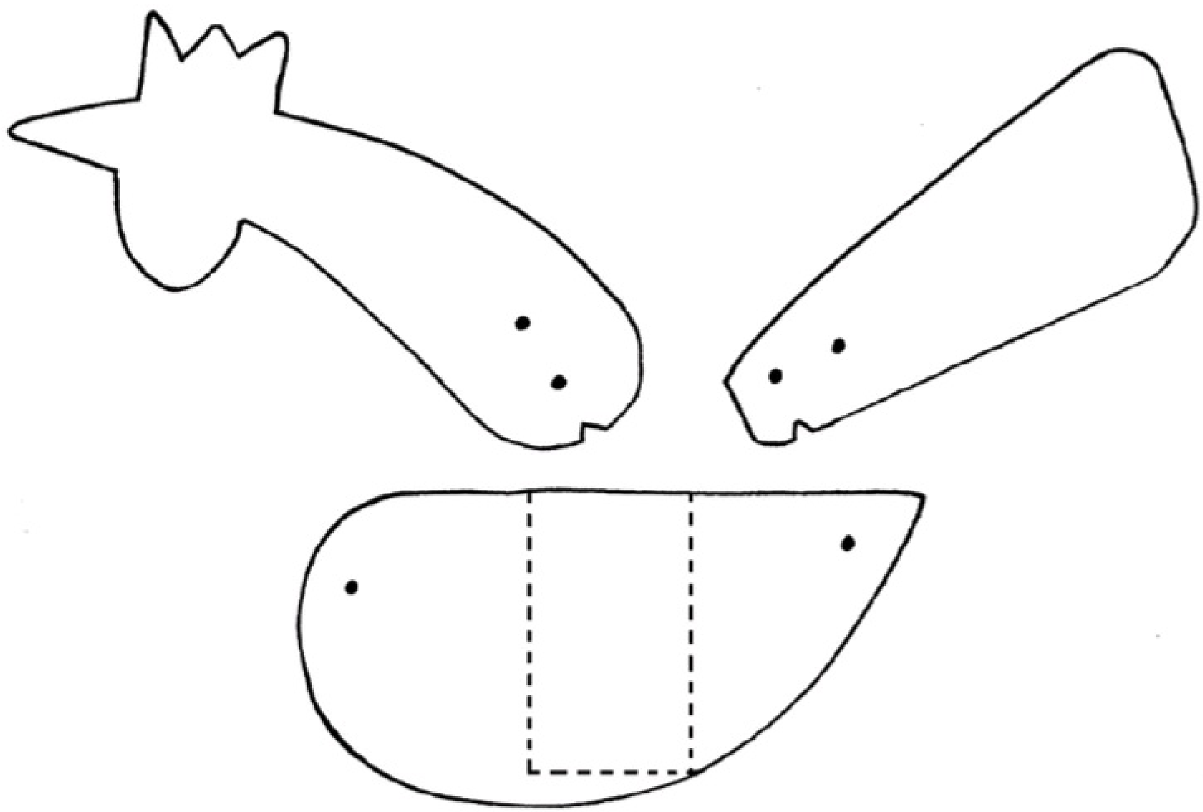
Parts for the pecking chicken.

Materials

A strip of wood about 4 or 5mm (3⁄16in) thick, enough to cut two body sides and the head and tail; a block of wood 30 × 18 × 9mm (1¼ × ¾ × 5⁄16in), to make the centre of the body; 50mm (2in) of 5 or 6mm (¼in) diameter dowel for the leg; about 180mm (7in) of 12mm (½in) diameter dowel for the handle; a wooden block or ball, with a small screw eye mounted in it, for the weight (some experiment may be needed to get the weight right, I have used a wooden ball about 35mm (1⅜in) diameter); around 500mm (20in) of string or strong thread; thin wire for the joints; paint.

Tools

A fret saw (scroll saw) or coping saw to cut the head, tail and body side shapes; sandpaper; clamps to hold the pieces together while gluing (large clothes pegs would do); a drill with a small drill bit to make the holes for the wire joints, and a bit the same size as the leg dowel; long-nose pliers to cut and bend the wire; paintbrushes.



Pecking chicken. Shapes for the head, body, and tail. Two body sides are needed. The dotted line shows the position of the slightly thicker centre block.

Method

Mark out, cut and sand the head, tail and body sides. Drill the holes for the wire joints. Note the position of the nicks in the lower edges of the head and tail pieces. These will ensure that the string is secured in the right place to give a good balanced position of head and tail. Drill a hole, about 6mm (¼in) deep, in the bottom of the 30 × 18 × 9mm (1¼ × ¾ × $^5/_{16}$in)

block, to fit the leg dowel. Drill a similar hole in the 12mm (½in) dowel, about 15mm (⅝in) from one end. Glue the body block between the two body sides. Make sure that it is in the right position, with the top of the block flush with the tops of the sides, and the holes for the wire joints lined up. Clamp, and allow the glue to set.

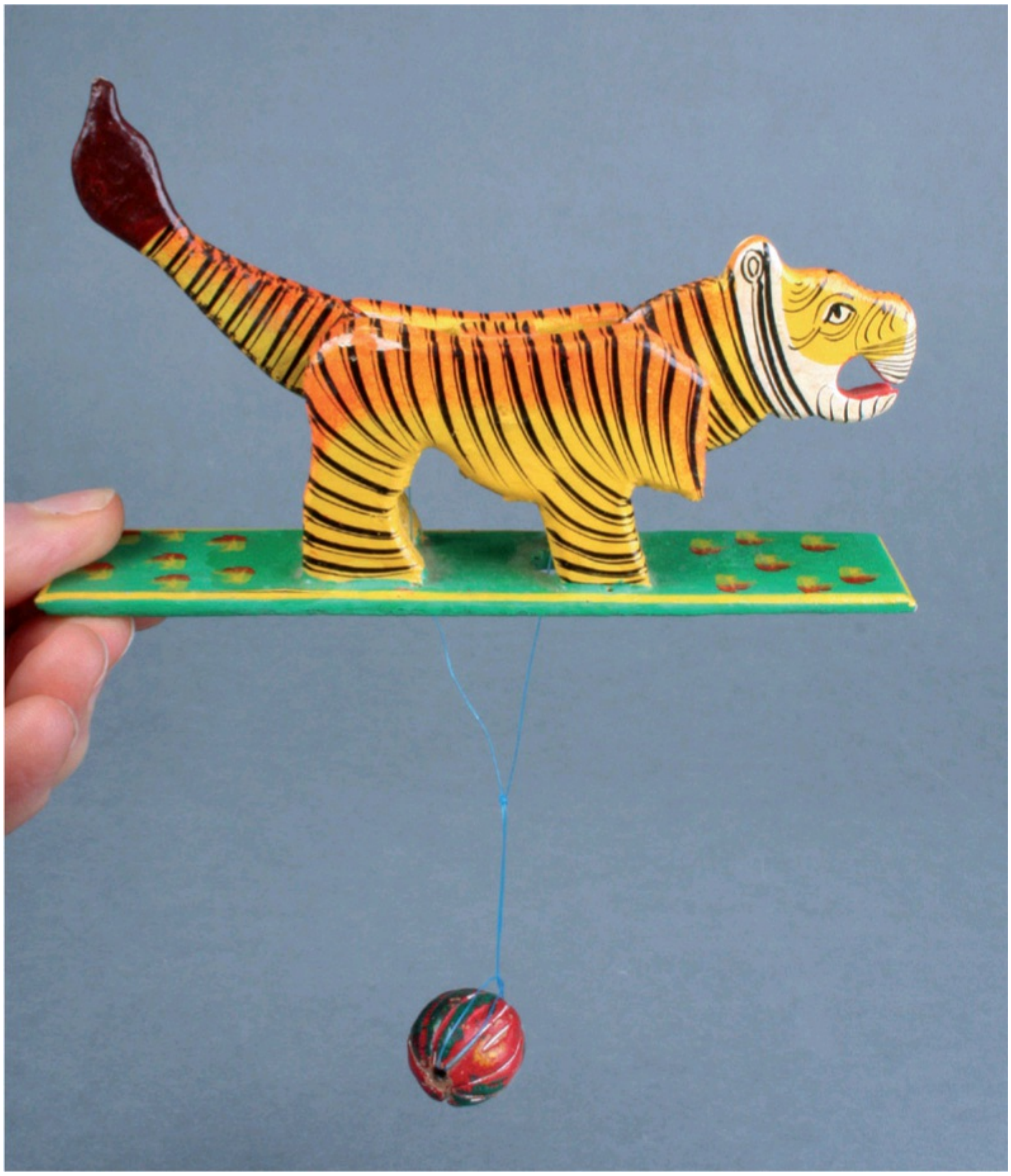
Glue the leg dowel into the holes in the body and the handle, with the body at right angles across the handle. Feed one end of the string through the hole in the head piece, and tie it round the edge, using the small nick to locate the knot. Attach the tail to the other end of the string in the same way. Mount the head and the tail in the body using two short lengths of thin wire, bent over on either side. Find the approximate centre of the string loop and feed it through the metal eye in the weight. Now pass the loop right around the weight and pull the loop tight on the eye so that the head and tail strings are roughly equal.

Hold the handle up horizontally, with the body upright, and swing the weight: if the head hangs too low loosen the loop on the metal screw eye and pull the string or thread through to make it a *little* shorter on the head side (and vice versa). If *both* the head and tail are a little droopy, then you will need to try a rather heavier weight. For the best effect, when the toy is held still the head and tail should be slightly raised, and when the weight is swung they should both move up and down.

Developing the design for an automaton

Not only birds can be animated with this swinging weight mechanism: the carved lime-wood toys from Bogorodskoye in Russia (see the blacksmith and the bear in Chapter 2) include some ingenious applications, such as a bear knitting a sock, or washing her cub in a tub.

Another use for the swinging weight mechanism. A bear washing her cub. A carved wooden toy from Bogorodskoye, Russia.



A painted tiger with moving head and tail, from India.

I also have a blue cat from Mexico and a tiger from India. Very similar in construction to each other, the two sides of the body are joined with a central block, leaving a slot for the head and the tail, as in the pecking chicken. They stand on a strip of wood, with the strings from head and tail passing through two holes (for the tiger) or a slot (for the blue cat). As their heads move up and down they appear to be looking at something.

A lacquered blue cat with a very similar construction, from Mexico.

This gave me the idea for an automaton which comprises a cat, with a moving head and tail, observing a spider hanging from a tree (see frontispiece). The stand is raised on a framework which supports a driveshaft with a cam that knocks against the hanging weight, moving the cat's head and tail, and also a crank to raise and lower the spider on a thread.

Making Cat and Spider

***Cat and Spider*: a trial assembly before painting.**

Materials

Two pieces of wood about 200 × 75 × 15mm (8 × 3 × ⅝in) for the top and bottom of the base; thick dowel, 18–20mm (¾in) diameter, for the uprights; dowel about 8mm (5⁄16in) diameter for the driveshaft and the handle; wooden discs, or slices of a branch, about 40mm (1½in) diameter and 10mm (⅜in) thick for the cranks; 2 or 3mm (3⁄32in) diameter dowel for

the cam; bamboo tube or metal washers for spacers on the shaft; strips of wood about 6mm (¼in) thick to make up the body sides and head of the cat; a piece of wood about 30 × 25 × 8mm (1¼ × 1 × 5⁄16in) for the middle of the cat; willow twigs, or dowel, for the cat's legs; a twig, about 6mm (¼in) diameter for the tail; a branching twig for the tree; beads, copper wire and a cocktail stick for the spider; thin wire for the joints; thread; a wooden block, bead or stone for the weight; small screw eyes; glue and paint.

Tools

Saw; craft knife; long-nose pliers; sandpaper; a drill with a range of bits.

Method

The base

The top of the base needs a slot for the strings from the cat's head and tail to pass through. Mark the centre line along the length and drill a 6mm (¼in) hole right through, 35mm (1⅜in) from the right-hand end, and a second hole 40mm (1½in) from the first. Drill a series of holes between these two and use a knife or chisel to join up the holes and form a slot.

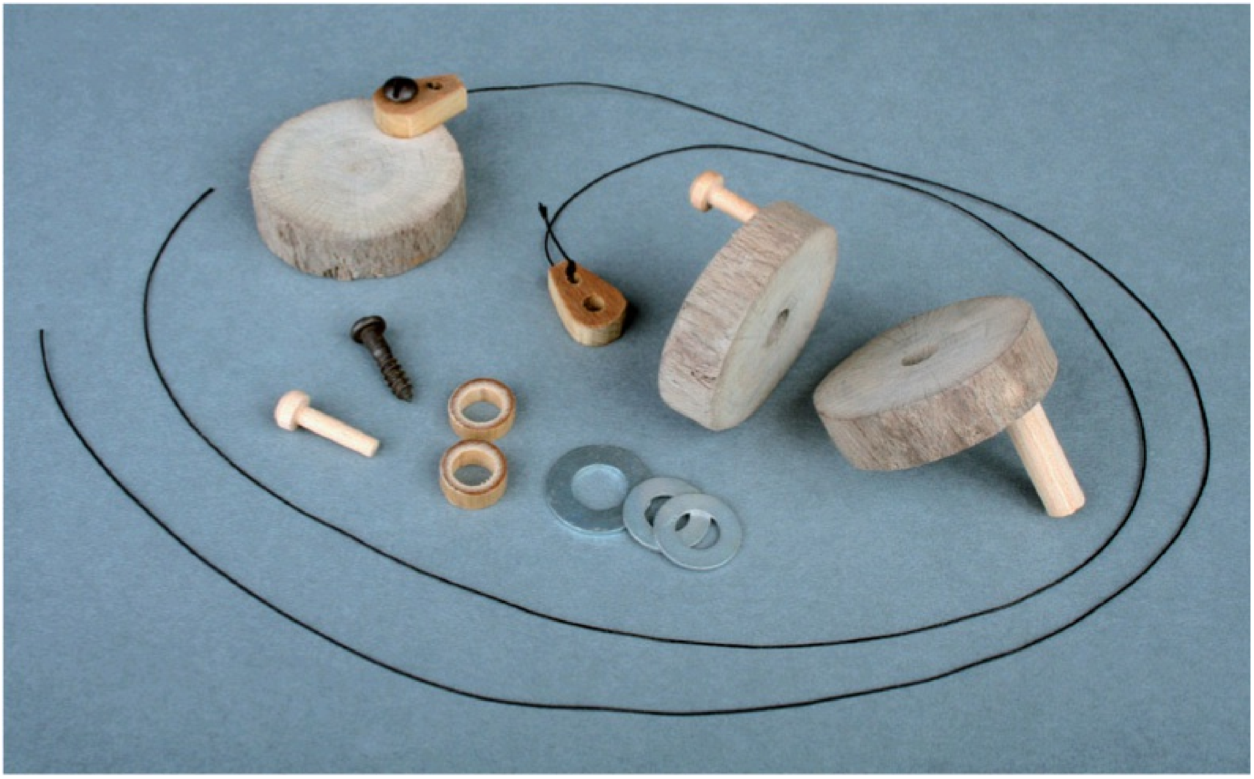
Cut two uprights from the thick dowel, about 120mm (4¾in) long. Drill right through each upright, 35mm (1⅜in) from one end. These holes should be a loose fit on the dowel used for the driveshaft.

To assemble the base, fix the two thick dowel uprights into 10mm (⅜in) deep holes drilled underneath the top piece, and on top of the bottom piece. Using a drill bit that matches the diameter of the uprights, drill these holes on the centre line, and 15mm (⅝in) from each end. I only had a drill bit that was slightly smaller than the dowel, so I had to thin down the ends of the dowel a little to fit. Insert the thinner dowel to be used for the driveshaft into the holes in the uprights to ensure that they are correctly aligned, and glue the uprights into the holes in the top and bottom of the base, checking that all is square.

The driveshaft, cam, crank and handle

Drill a hole to fit the dowel used for the shaft centrally in each of the wooden discs (or slices of a branch). To make the handle drill another hole of the same size, near the edge of one of these discs, and glue in a short length of the same dowel. To make the crank that operates the spider on its thread I have used a small axle peg (see section on materials in the Introduction); a small round-headed screw is a good alternative. As the shaft rotates this crank will pull the thread down and then slacken it, raising and lowering the spider.

The base, the driveshaft and the tree.



Parts for the handle, spacers, the crank, and the thread attached to a little wooden block that will rotate on the crank.

To attach the thread to the crank, tying a loop and hooking it on will work, but not very well because as the thread slides on the crank the friction tends to fray it, and it also quite easily catches, or comes off. This can be avoided by using an off-cut of the wood used for the cat to make a little wooden block to rotate on the axle peg or screw, and attaching the thread to that: drill a hole in the block that is a loose fit on the axle peg or screw (it must be able to turn freely). Above that drill a rather smaller hole to accommodate a knot at the end of the thread, and into the top of the block a hole just big enough for the thread. Feed the thread into the hole in the top, hook it out from the second hole and tie a knot to stop it pulling out.

Mount the driveshaft dowel in the holes in the upright supports, and cut it to length, leaving enough outside the upright on either side to fit on the discs, plus a little extra for a spacer to stop the discs from rubbing against the uprights. I have used small slices of bamboo as spacers. Metal

washers will do the same job.

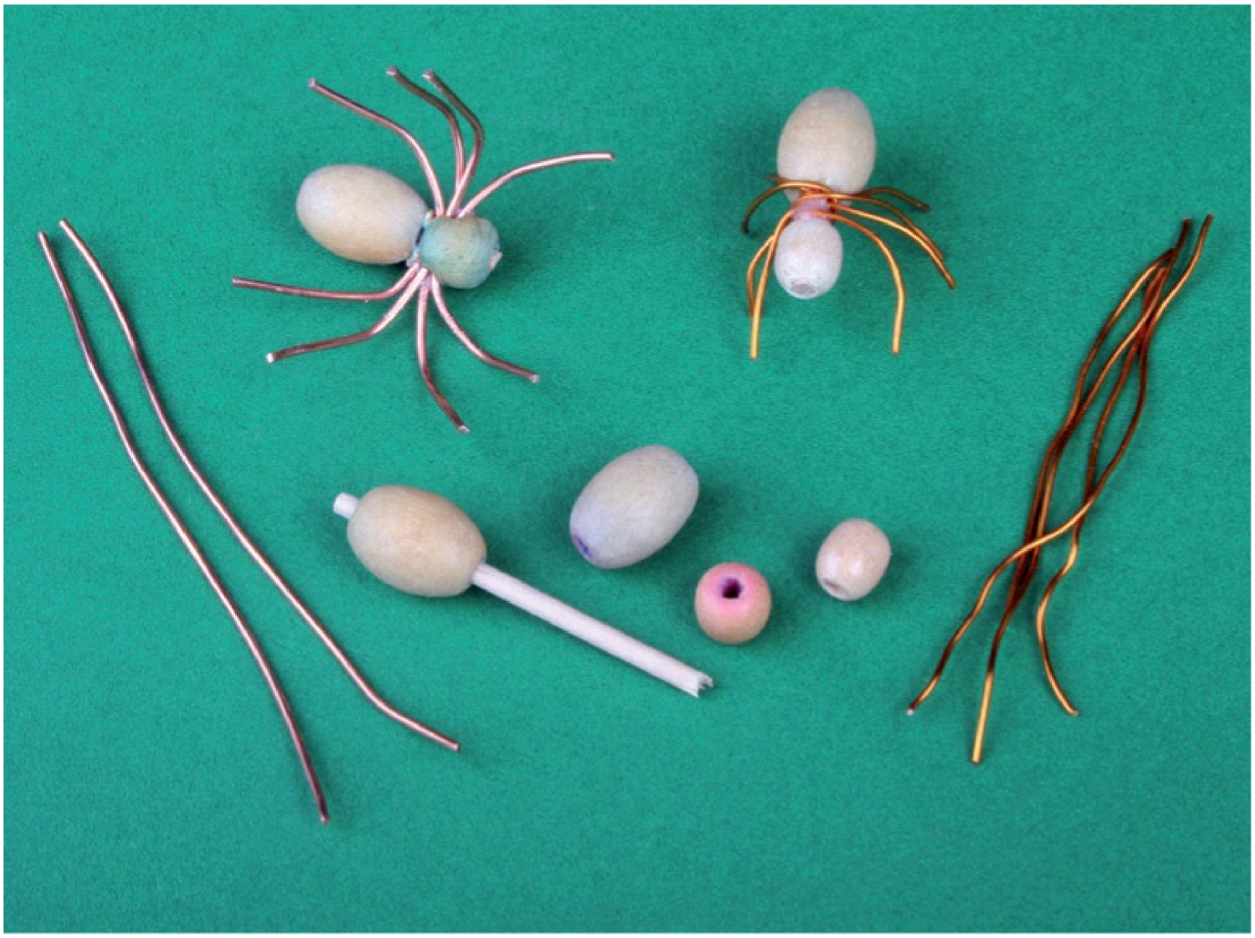
With the driveshaft trimmed to length, the position of the cam that will knock against the hanging weight and move the head and the tail of the cat can be determined. This cam simply consists of two little dowels (from a cocktail stick or a thin skewer) mounted in holes drilled into the shaft, at a slight angle, one each side and positioned directly below the slot in the top of the base. The exact length of the little dowels can be adjusted during the final assembly, so that they knock effectively against the hanging weight.

The tree

For the tree, look for a slender twig, with at least two branches. It should be long enough to suspend the spider from a point about 150mm (6in) from the base, and the thread must have a clear run down to the crank. A couple of screw eyes, judiciously placed on the branches, serve to guide the thread. The end of the twig is fixed into a hole drilled in the top of the base. The exact position for this hole is best decided when the cat has been mounted on the base.

The spider

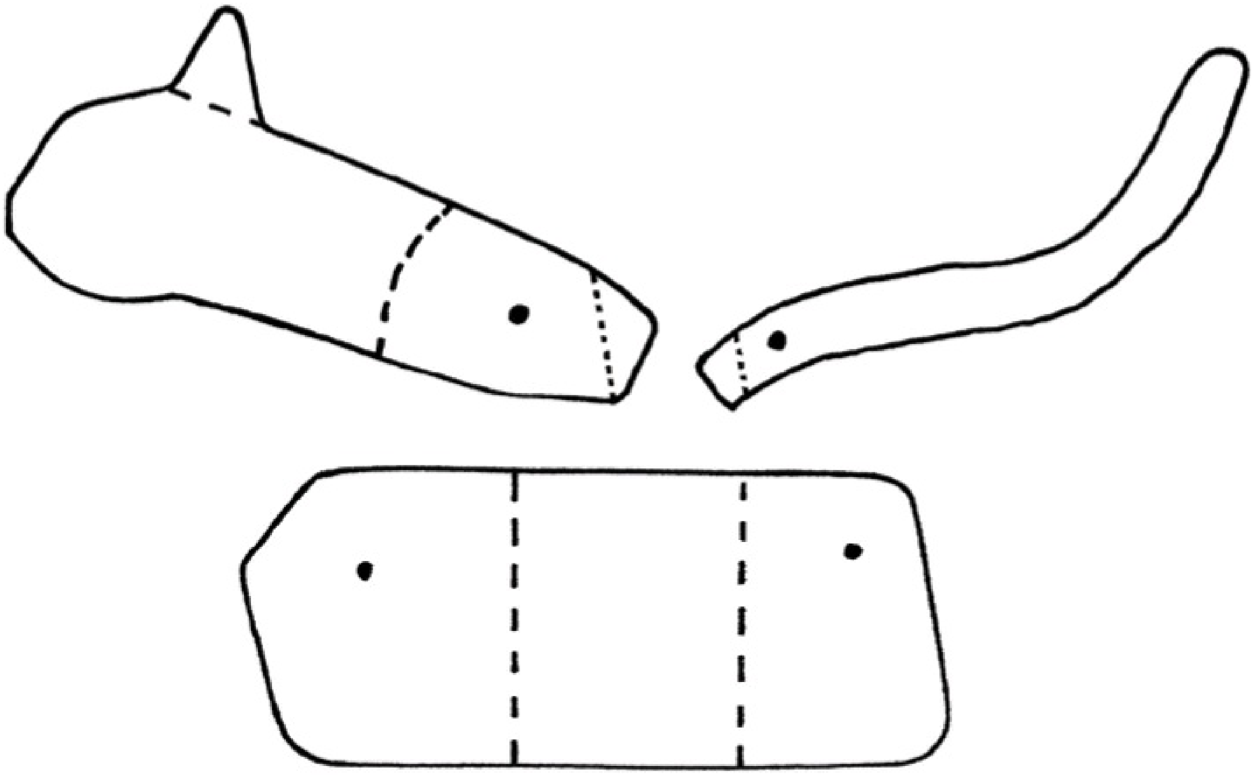
The spider needs to be heavy enough to drop down smoothly when the crank at the end of the driveshaft slackens the thread. I went for gluing a couple of beads on a cocktail stick and either drilling a hole and gluing in four pieces of soft copper wire, or simply wrapping the wire around between two beads and gluing it in place with epoxy. The copper wire is easily bent to form the eight legs, and the whole can be painted black.



The spider: alternative constructions using a cocktail stick, wooden beads and copper wire.

The cat

The cat’s body is made up of two roughly rectangular side pieces (see the diagram), and a central block which must be slightly thicker so that the head and tail can move freely in the slots in the body. Sand the side pieces and drill the holes as marked for the joints. Glue the two side pieces to the central block, being careful to position it correctly, with the holes for the wire joints aligned, and leaving room for the head and the tail.



Shapes for the cat's head, body and tail. Two body sides are needed. The dotted line shows the position of the slightly thicker centre block. The head requires two shorter outer pieces, complete with ears, and a longer central piece, without an ear, but including the neck that will project back into the slot in the body.

The cat's head could be carved from a single piece of wood, but I have gone for using the same wood as for the body sides, and again making up a sandwich of three pieces: cut two shorter outer pieces, complete with ears, and a longer central piece (without ear), including the neck that projects back into the slot in the body. Glue them together and shape the head by whittling with a knife and sanding. Drill a hole as marked for the wire joint. Also drill a small hole through from the top, at the back of the neck, for attaching the string.

The tail can be a piece of twig, or it can be cut from the same wood as the head and body sides. Drill a hole for the wire joint and, from the top, for attaching the string.

For the legs cut four 50mm (2in) pieces of willow twig or dowel, about 6mm (¼in) diameter. Glue the legs to the flat sides of the body: to do this, use a craft knife to shave the top 15mm (⅝in) of each leg back to form a flat gluing surface. It is a good idea to fix them on with one of the front legs slightly raised, so that the cat stands on three legs: firstly this will make

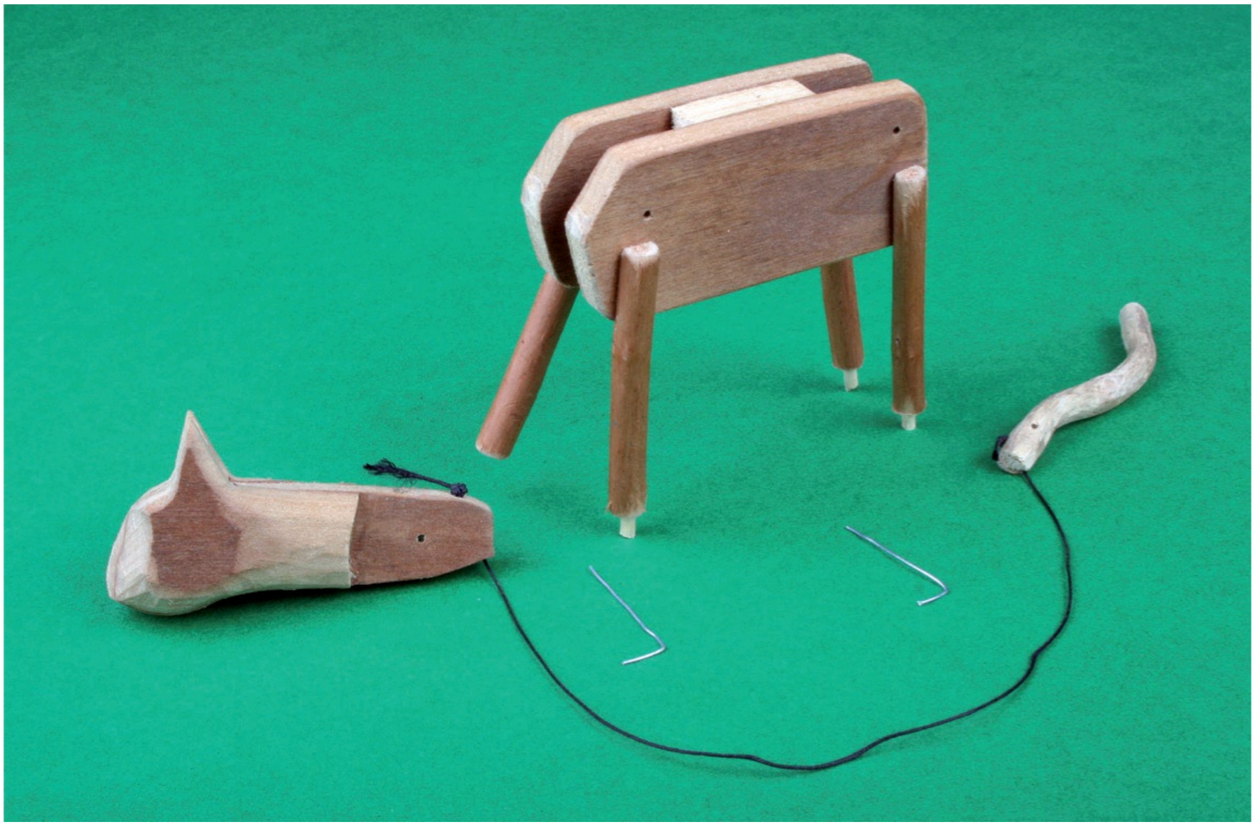
mounting the cat on the base easier, and secondly it will look more animated. Even with only three legs to fix down it is tricky to get the bottoms of the legs flat enough to simply glue onto the top of the base. It is best to drill small holes into the bottom of the three legs to take little dowels (cut from cocktail sticks or thin skewers), which during the final assembly can be glued into holes in the base. Position the cat carefully above the slot in the base so that the string joining the head and tail will be able to hang down through it. Mark the positions of the three legs on top of the base, and drill holes to take the cocktail stick dowels. Paint the head, tail and body at this stage.

The parts for the head and the body. The back legs have a section cut flat ready to glue to the body sides. This tail has been cut out from the same wood as the head and body. An alternative is to use a suitable piece of twig.

Cut two short lengths of thin wire for the joints. Position the head and the tail in the slots in the body, and feed the wires through the prepared holes. Bend the ends of the wire over and trim off any excess. Check that both head and tail can move up and down freely.

Before finally fixing the cat on the base it is necessary to choose a

suitable weight to counterbalance the head and the tail. The head and tail must be joined with a length of thread or string, as in the pecking chicken, but it will not be possible to decide the exact length needed until the cat is mounted on the base. At this stage use a thread or string about 400mm (16in) long: feed it through the holes in the head and tail and tie a knot each end. If the knot looks as though it might slip through, wedge the end of a cocktail stick into the hole to prevent it. Now you can try out some weights. What is needed is a weight that is small enough to fit comfortably in the space below the top of the base and above the camshaft, but heavy enough to counterbalance the head and tail of the cat so that they are held level, or slightly up, at rest. I have used a red brick ‘pebble’ which weighs just over 30grams (1oz), with a screw eye glued into it. You could try a wooden block with a screw eye, a heavy bead, metal washers or a small stone with a hole in it: as with the pecking chicken, feed a loop from about the middle of the thread or string through the ring eye, or the hole, and pass it right over the weight. As with the pecking chicken, you will probably have to loosen the loop and pull the string through one way or the other get the right balance between head and tail. Holding the body of the cat level, check that the weight roughly balances the head and tail. If both are drooping the weight is too light. If both are held right up high then the weight is too heavy. With a suitable weight chosen you can start the assembly.



The body with the four legs glued in place. One of the front legs is slightly raised. The head and tail are joined with the thread, ready to mount in the body with wire joints.

Assembly and adjustment

The tricky bit is to get the cat mounted on top of the base, with the weight from head and tail in place underneath. Since the weight will not fit through the slot in the base, it is necessary to remove the wire joints that are attaching the head and tail to the body, and remove the weight from the string by passing the loop back around it. Now lay the head and tail on top of the base, push the string loop down through the slot, and reattach the weight as before, by feeding a loop through the eye, or hole, and passing it right over.

Reattach the head and tail to the body with the wire joints and glue the cat in place on the top of the base. The length of the thread, and the position of the loop, will probably need adjusting: the weight should hang just above the driveshaft and, as described above, you may need to loosen the loop and pull the string through one way or the other get the right balance between head and tail. Turn the handle and check on the movement. The length of the little dowels that form the cam may also need

adjusting.

Find the best position for the tree: mark, and drill a hole in the top of the base to glue it into. Position two small screw eyes so that the spider can be hung in front of the cat, with the thread guided up, over and down to the crank at the end of the driveshaft. With the little wooden block at the end of the thread in position on the crank, feed the thread through the screw eyes on the tree and tie the spider on so that it is at the right level to taunt the cat.

Turn the handle and check that the spider moves smoothly up and down, while the cat moves its head and tail somewhat unpredictably.

CHAPTER FIVE

TWISTING AND TURNING – Springs, shafts and cams

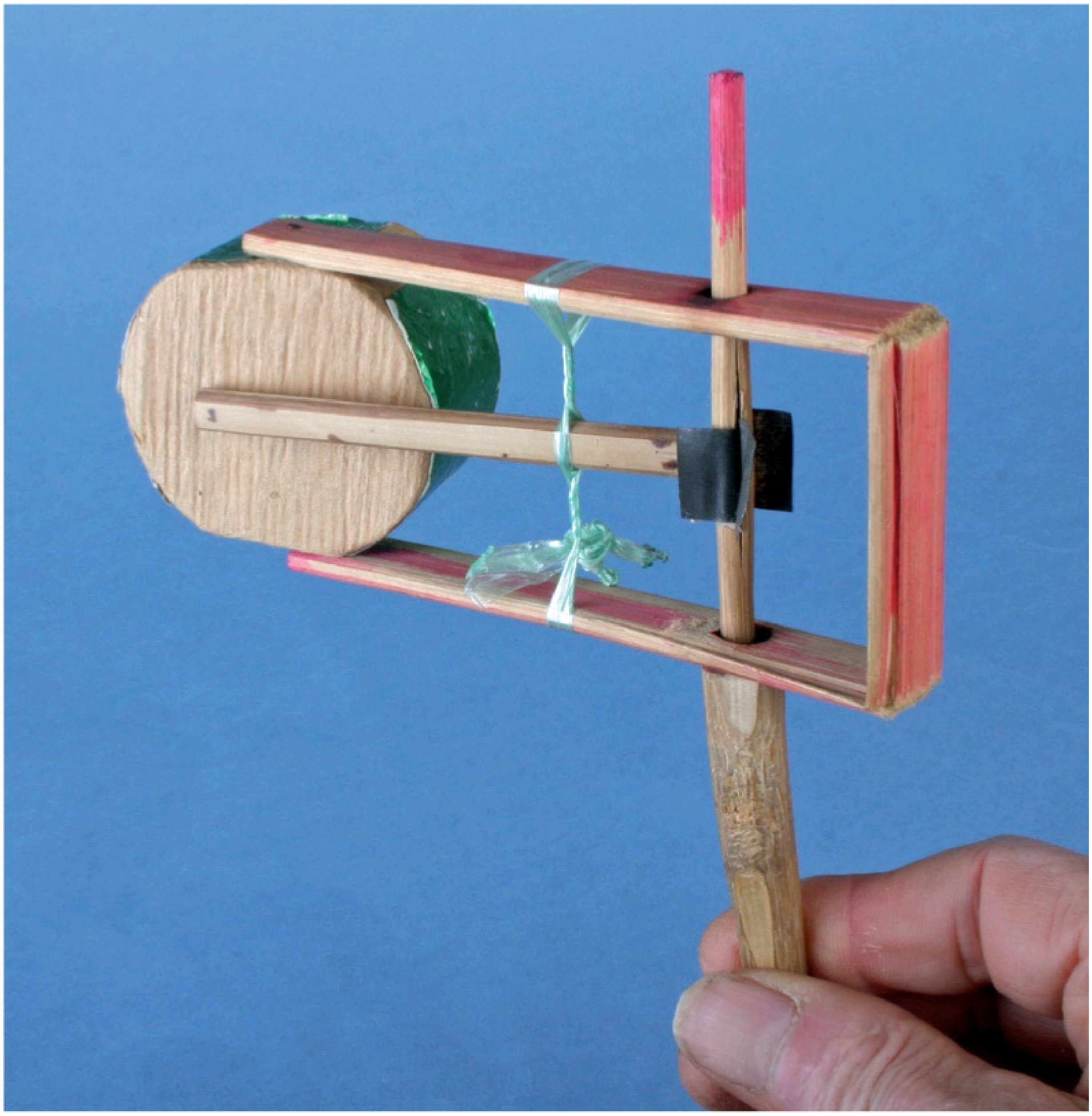
Many traditional moving toys are noisy. In some the noise is an accidental product of their movement, and not important; in some it adds to the overall effect, as in the pecking birds on a ‘table tennis bat’ described in Chapter 4; in others it is the main purpose. One of my favourites amongst the latter is an Indonesian drum rattle. I like the ingenious use of the distinctive properties of bamboo in a strong and spare design. The drum is a short length of a substantial bamboo tube, about 50mm (2in) diameter, shaved flat on two sides where it fits against the framework. The drumhead is a thin veneer split from the wall of a similar bamboo tube. To make the frame of the rattle a length of split bamboo, about 25mm (1in) wide and 6mm (¼in) thick is half cut through in two places, and bent to form three sides of a rectangle, which is completed with the drum. This rough and ready technique makes a surprisingly strong frame. The drum is held in position partly by a single small nail through the upper arm of the frame, and partly by a twisted string that pulls the rectangular frame together and also holds and tensions the beater. A similar strip of split bamboo forms the handle, which is broad at the base, but narrowed for the top half to make a shaft, which is inserted through two holes in the rectangular frame. When the handle is held upright the frame sits on the square shoulders where the handle narrows to become a shaft. A single split is carefully made near the middle of the shaft section, and, with the shaft in place in the frame, two rectangular pieces of tinplate, cut from a can, are slipped into it, and bent out at each side to form a cross. The bends hold the tinplate pieces quite firmly in place. This tin cross acts as a

cam to raise the beater. The beater is a piece of split bamboo. It is held in place by a string tied in a loop round the frame and then twisted by inserting the beater into the loop and turning it round a couple of times, sliding the beater along as necessary. As mentioned above, this twisted string does two jobs: it holds the framework tightly together and also acts as a spring forcing one end of the beater against the drumhead. The drum is set at a slight angle to the frame so that the end of the beater rests on the centre of the drumhead. The other end of the beater lies between two arms of the tin cross. Now if the handle is held upright, and the framework, with the drum, is swung firmly round, the arms of the tin cross each in turn push against the beater; the other end of the beater is raised from the drumhead, and then springs back, giving four drumbeats for every complete turn of the frame around the handle.

***Jumping Puffins*.**

A smaller and more delicate version from India uses a clay ring, covered with paper on both sides, to form the drum. Two wires are set into the clay to stick out one side, parallel. The cam is a cross, made with two rectangular pieces of stiff cardboard, half cut through and slotted together. Two slits, at right angles, are made in the split bamboo shaft that serves as the handle: the cardboard cross is slid into these slits, and thread is bound round the shaft above and below to hold it in place. Now the wires are bent round the shaft above and below the cardboard cam. In the gap

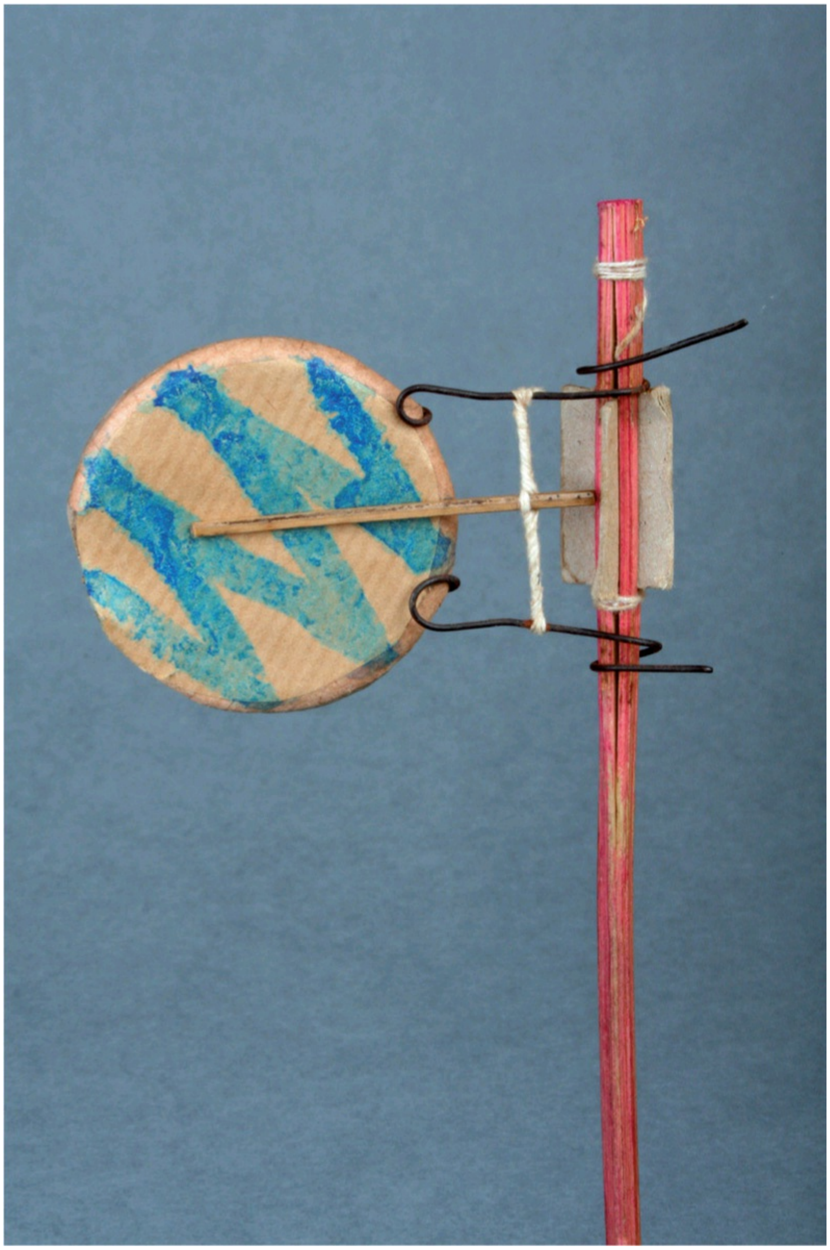
between the drum and the shaft, a string is tied in a loop around the wires; the beater, a sliver of bamboo, is inserted into the loop and twisted round several times (it is necessary to slide it through one way then the other to achieve this). The wires hold the drum at slight angle so that only the end of the beater rests on the drumhead.



A drum rattle robustly constructed from bamboo. When the frame is swung round the shaft the tinplate cam lifts and releases the beater to strike the drum. Indonesia, 1990s.

Drum rattles of this kind, made from a variety of materials, are found all

over Asia in many different guises; some are figurative, which gave me the idea for a miniature version of the Indian drum rattle, with a head on top of the shaft, and a beater shaped to represent an arm and hand. The construction is similar, but the drum is a ring cut from a thick cardboard tube, with a wood veneer drumhead, and the cam is formed by drilling two small holes through the shaft at right angles and gluing in thin strips of split bamboo. In the Indian drum rattle the cam follower (the split bamboo beater) is narrow and the cam (the cardboard cross) is wide. Here the cam follower (the wooden arm) is broad, and the cam is a thin stick. In the Indian drum rattle the cardboard cross keeps the drum at the right place on the shaft. Here, as in the Indonesian drum rattle, it is necessary for the shaft to be wider at the bottom, with a shoulder that the wire frame rests on, holding the drum up and ensuring that the cam lines up with the cam follower.



A drum rattle with a clay and paper drum on a wire frame. The cam is cardboard. India, 1990s.

A miniature drum rattle. The framework becomes the drummer.

In *Percussionist Two* a wooden figure, with a hollow body, becomes the drum, and its arms and legs serve as the rotating framework. In this case the drum is in line with the shaft, not angled, and consequently the beater needs to be curved so that it will strike the drumhead cleanly in the centre. Here the cam is a wooden cross with a hole drilled through it so that it can be slid onto the wooden dowel shaft, and secured with a small nail.

A painted wooden drum rattle. The drum becomes the drummer.

Push-along toys with a drum rattle

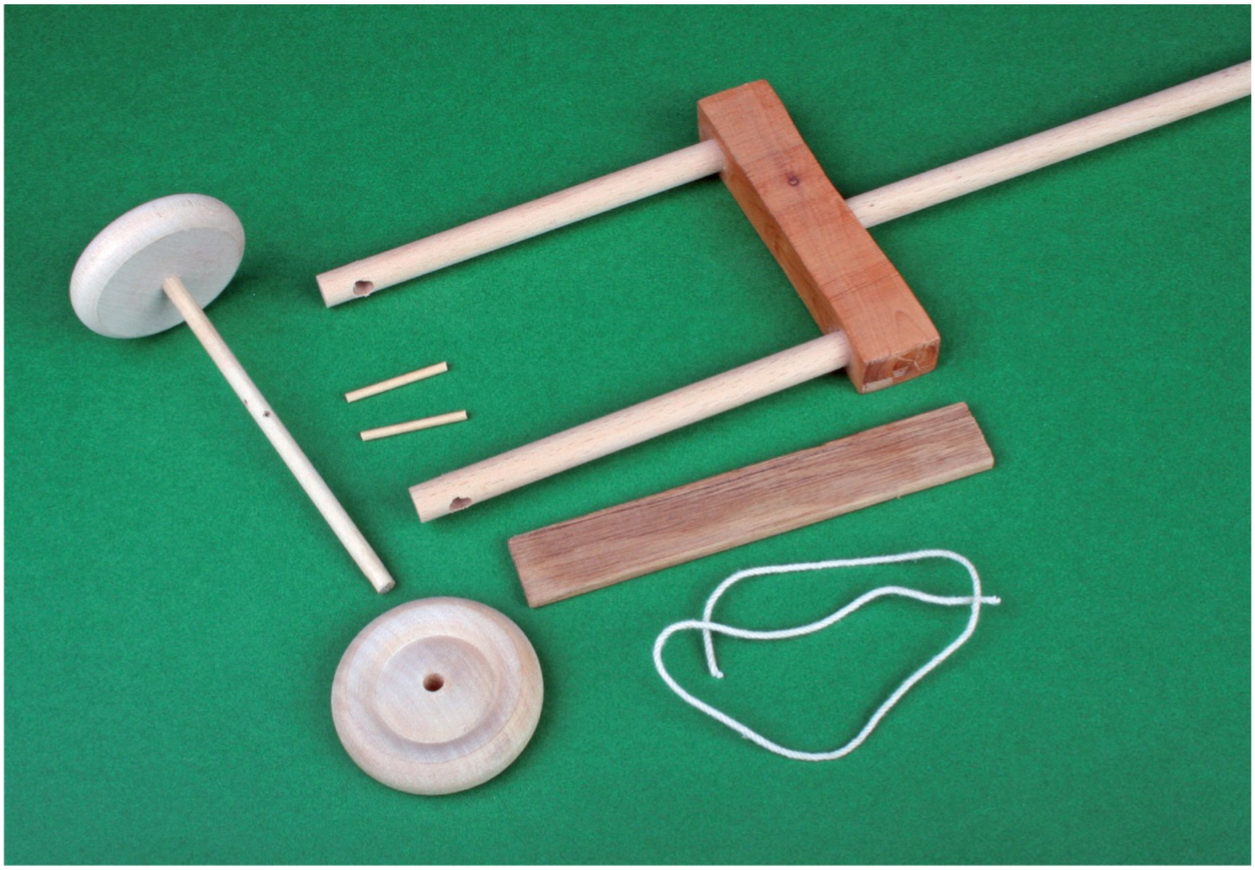
In all these the examples the camshaft is held steady, and the drum is swung round it. The cam raises the beater, which springs back to strike the drum. An alternative would be to hold the drum steady, and rotate the camshaft. This is achieved in a variety of push-along toys: here the camshaft is an axle fixed to two wheels and free to turn in a framework which has a long handle so that the wheels can be pushed along the ground. The drum and the beater are attached to the framework. Three examples from Indonesia show the possibilities.

Two push-along toys from indonesia: a wooden aeroplane with a large tin can drum, and a painted tinplate bird with flapping wings. In both, the handle and framework are a partly split strip of bamboo.

Another indonesian push-along drum rattle. Here the legs of the wooden cockerel form the framework for the mechanism.

Making a push-along rattle

This version uses a wood block in place of a drum.



Parts for a push-along rattle, using a solid wood block in place of a drum.

Materials

A piece of wood, preferably giving a good resonant sound when struck, at least 20 × 15mm (¾ × ⅝in) and about 100mm (4in) long, I have used an off-cut of yew wood; wooden dowel, around 10mm (⅜in) diameter: one piece around 450mm (18in) for the handle, and two pieces around 130mm (5in) for the framework; about 120mm (4¾in) of thinner wooden dowel or skewer, 4 or 5mm (3⁄16in) in diameter, for the axle/cam shaft; two thin dowels, 2–2.5mm (3⁄32in) diameter and 30mm (1¼in) long (from cocktail sticks or very thin skewers) for the cams; two wooden discs, 40 or 50mm (1½ or 2in) in diameter for the wheels: I have here used ready-made turned wooden wheels; a thin strip of hardwood 125mm × 20mm (5in × ¾in), and about 3mm (⅛in) thick, to make the beater; string to make the spring; glue.

Tools

A measuring rule; a fine-toothed saw; a drill with a selection of bits to match the diameters of the various thicknesses of dowel.

Method

Using a drill bit a little larger than the diameter of the axle, drill a hole right through about 10mm (⅜in) from one end of each of the 130mm (5in) long thick dowels. Check that the axle dowel can turn freely in these holes. Using a bit the size of the thick dowel, drill two holes in the piece of wood about 10mm (⅜in) deep, and 80mm (3in) apart, to mount the two dowels that make up the sides of the frame. Drill a similar hole centrally on the other side of the piece of wood to mount the handle. The three thicker dowels can now be glued into the piece of wood to form the framework. It is best temporarily to slide the axle into the two holes in the shorter dowels while gluing them into the wooden block. This will ensure that the holes are correctly lined up, and that the axle is square to the frame and able to turn freely. Find the centre point on the axle and drill two holes to fit the thin dowels to be used for the cams.

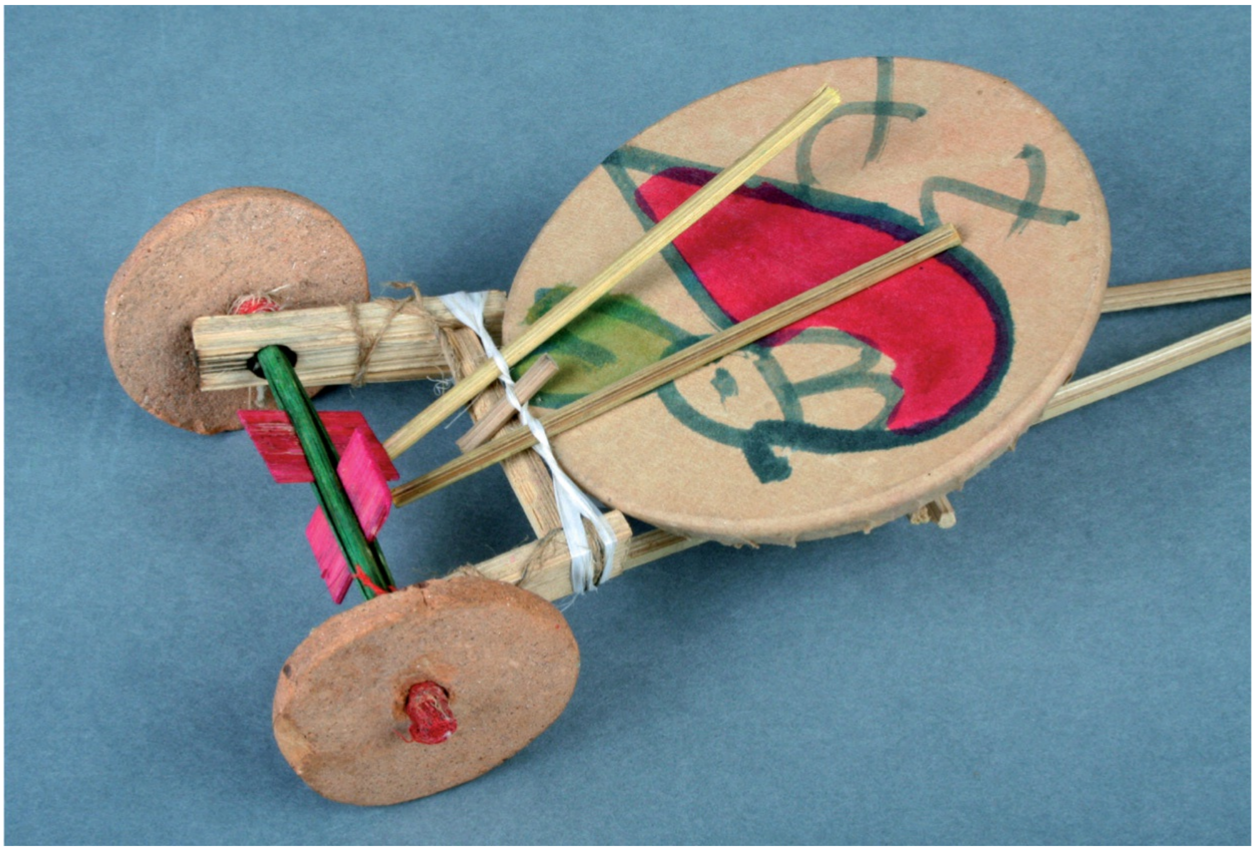
Drill these holes right through, a few millimetres apart, one at right angles to the other. With the axle inserted back into the frame glue the thin dowels in so that they form an equal armed cross. Drill holes in the centres of the wheels, to fit the axle dowel, and glue them on.

Finally, fix and adjust the beater: tie the string in a loop round the two sides of the frame; put the strip of hardwood through the loop and turn it several times, twisting the string. As you turn it you will need to slide it backwards and forwards to clear the axle and the wood block. The number of turns will depend on the tightness of the initial loop, and the nature of the string used. Some kinds of string or cord make a more elastic spring, so it is worth experimenting. Cheap polypropylene twine seems to work well. Slide the beater so that the lower end lies between the arms of the cross, nearly touching the axle, but not quite. The other end should overlap the wooden block, so that, as the axle turns, the cams raise the beater and allow it to spring back and strike the block firmly.

The completed wooden push-along, with two other possibilities: one with a similar construction in bamboo, with cams cut from a metal can, and inserted into a split in the axle, as in the indonesian examples, and one made from a partially split hazel twig, using plastic bottle tops for the wheels and the drum.

All these toys need to be pushed along, rather than pulled, because the wheels must rotate in the direction that causes the cam to lift the beater off the drum, tensioning the twisted string spring. Rotation the other way is prevented by the cam pushing the beater onto the drumhead rather than moving it away. However, if the push-along is turned upside down, so that

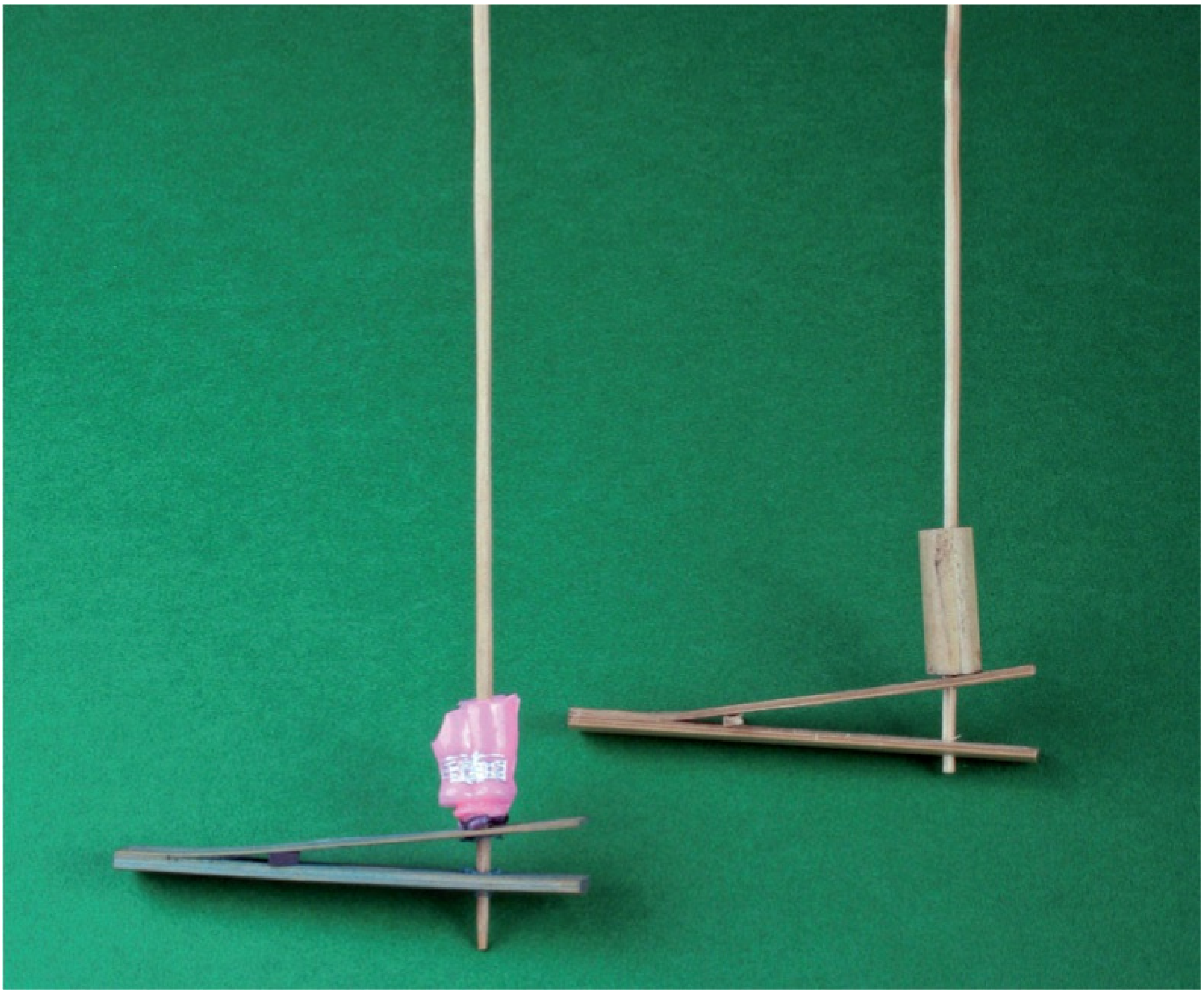
the beater is on top, then the reverse is true, and the toy must be pulled along. A version specifically designed to be pulled along with a string, rather than a wooden handle, is a beautiful and noisy drum cart toy from Bangladesh, with a split bamboo framework, clay wheels, and a clay drum with a paper drumhead. It has two beaters mounted on a single loop of twisted string. This is tensioned with a short lever between the two beaters.



An elegant and ingenious pull-along drum rattle in bamboo, with clay wheels and a clay pot for a drum, with a paper drumhead and two beaters. Bangladesh, 2000s.

In all these examples twisted string makes an effective spring. Another possibility, also widely used in moving toys, is a spring made from split bamboo. One of my favourite examples, a delightfully simple structure that makes clever use of the properties of bamboo, consists of a spring made from a section split from a large bamboo cane: the section is trimmed square and a split is made across the width for part of the length. A small sliver of bamboo is pushed into this split as a wedge to hold it open. This constitutes the spring. A hole is made in its upper part, and a smaller hole

immediately below in the lower part. A long thin shaft of split bamboo is inserted through the upper hole and fixed firmly into the smaller hole in the lower part. If a little bamboo tube is threaded onto the shaft so that it rests at the bottom, then flicking the spring, by pushing it down and sliding the finger off, will make the tube jump up.



The remains of a 'jumping girl' toy. The pink plastic girl has disintegrated, but the simple spring, a slice of bamboo with a partial split held open with a wedge, is intact. The spring is operated by pushing it down and sliding the finger off. The copy behind has a short bamboo tube to represent the jumping figure.

Twenty-five years ago, In India, I bought a bundle of these toys in which the jumping bamboo tube was replaced, rather bizarrely, with a hollow plastic girl, pink, green or blue, with a silver dress and socks. Unfortunately, I left all but one of them on a bus. The one that survives has

lost all the cut paper decorations that it originally sported at the top of the stick, and the plastic girl has mostly disintegrated – only her feet are left. The bamboo spring, however, remains fully operational.

A woman with a bundle of 'jumping girls' for sale. India, 1994. *(Photo: Thalia Race)*

Developing the design for an automaton

I have made a number of automata in which a hand-cranked camshaft

operates similar bamboo springs to make a number of bamboo tubes jump up and down. The tubes are painted to represent various birds, with beaks added, and also thin wooden wings set at an angle, which makes them spin slightly as they jump. I thought that it would be interesting to try replacing the bamboo springs with the twisted string springs discussed earlier in this chapter. I particularly like the twin beater mechanism in the Bangladeshi pull-along drum rattle, and it might lend itself well to operating a pair of jumping birds. The axle in that toy would become the camshaft, mounted on a fixed frame and turned with a crank handle. The beaters would become the levers that propel the bamboo tubes up the shafts. They would need to be wide enough to make a slot in, to accommodate the shafts.

Making Jumping Puffins

Materials

A piece of wood for the base around 20mm (¾in) thick and 130mm (5in) deep by 130mm (5in) wide; wood strip about 6mm (¼in) thick and 50mm (2in) wide for the end supports; two strips of wood 110mm (4¼in) long, about 4mm (5⁄32in) thick and 18mm (¾in) wide, for the levers; a piece of wood 30mm (1¼in) × 10mm (3⁄8in) × about 8mm (5⁄16in) thick for the arm of the crank handle; 15 or 16mm (5⁄8in) diameter dowel for the camshaft; 6mm (¼in) diameter dowel for the cams and the supports for the twisted string; 5mm (3⁄16in) diameter dowel or skewer for the upright shafts, the ends of the camshaft, the handle and the central lever for tightening the cord (these exact diameters can be varied, but the size of the holes for mounting them in the base and the camshaft must be altered correspondingly); bamboo cane to make the bodies of the birds, plus wood veneer or stiff card for the wings and beaks; small screws to attach the end supports to the base; beads for the tops of the upright shafts; glue; paint; a suitable cord to make the twisted spring – for example a shoelace of the flat woven type.

Parts for *Jumping Puffins*.

Tools

Measuring rule; a fine-toothed saw, to shape the wood and cut the bamboo and dowels; a craft knife to notch the levers and cut the veneer or card; sandpaper; a drill and drill bits to match the dowels used; paintbrushes.

Method

The base

Drill two 6mm (¼in) diameter holes, about 10mm (3⁄8in) deep, 25mm (1in) from the front, and 10mm (3⁄8in) from the sides, to mount the dowels that will support the twisted cord. Drill two 5mm (3⁄16in) diameter holes, also

about 10mm (3⁄8in) deep, 60mm (23⁄8in) from the back and 30mm (1¼in) from each side, to mount the upright shafts that the puffins will jump up.

Cut the two side pieces to shape, 65mm (2½in) high by 50mm (2in) wide at the bottom, with one side sloped back to 25mm (1in) wide at the top. Drill a 6mm hole in each, 10mm (3⁄8in) from the square side, and 10mm (3⁄8in) from the top. Also drill two holes in each, 10mm (3⁄8in) from the bottom to take the small screws. Screw the end supports onto the sides of the base with the square edges level with the back.

Mount the upright shafts in the 5mm (3⁄16in) diameter holes in the base. They need to be 250–300mm (10–12in) long for a good jump. Cut two pieces of 6mm (¼in) dowel about 40mm (1½in) long for the twisted cord supports, and glue them firmly into the 6mm (¼in) diameter holes.

The camshaft and crank handle

Cut a piece of 15 or 16mm (½in) dowel 125mm (5in) long and drill a 5mm (3⁄16in) diameter hole centrally in each end as straight as possible. Mount it between the two end supports by pushing a short length of the 5mm (3⁄16in) diameter dowel through the holes in the supports, and into the ends of the camshaft. Check that it rotates freely. Now the cams must be mounted on this shaft: take it off and drill two 6mm (¼in) diameter holes, about 6mm (¼in) deep and 30mm (1¼in) from each the end. These holes should be on opposite sides of the camshaft, at 180 degrees to each other. Cut two pieces of the 6mm (¼in) diameter dowel about 25mm (1in) long, and mount them in these holes. Remount the camshaft between the end supports and check that the shaft will turn. The cams might need trimming if they are too long, and touch the base. To make the crank handle, take the piece of wood 30mm (1¼in) × 10mm (3⁄8in) × about 8mm (5⁄16in) thick and drill a 5mm (3⁄16in) diameter hole 5 or 6mm (¼in) deep, 8mm (5⁄16in) from each end, on opposite sides. Glue a 20mm (¾in) length of 5mm (3⁄16in) dowel into one hole, and use the other hole to mount it onto the dowel at the end of the camshaft.

The levers

The two levers should be 110mm (4¼) by 18mm (¾in) and about 4mm (5⁄32in) thick. In order to position them on the upright shafts a slot must be

cut in each: drill a 6mm (¼in) diameter hole centrally 20mm (¾in) from one end, and a second hole, 10mm (3⁄8in) on from the first. Use a craft knife to join the holes into a slot. These slots will allow the levers to move up and down without being checked by touching the upright shaft. Cut a small notch into the edges of the levers between 20 and 25mm (¾–1in) from the ends furthest from the slots – this will help keep them in the right position in the twisted cord.

The puffins. The beaks and wings can be cut from thin card or wood veneer, and glued into slots made with a fine-toothed saw.

The birds

The birds could be made from a glued paper tube, as described for the Chinese dragon toy in Chapter 1, with the wings and beak in thin card. I have used short lengths of bamboo cane and some scraps of wood veneer.

Painting the puffins.

The veneer is very thin, so the wings and beak are mounted by gluing them into slots cut with a fine toothed saw: for each bird, cut about 35mm (1⅜in) of bamboo tube, 10 or 12mm (⅜ or ½in) in diameter. To mount the beak, cut a slot on one side at the end, running lengthwise. To mount the wings cut a slot at a slight angle across the tube, about in the middle. Cut the slot for the other wing on the other side of the tube, and angled the other way. Having the wings set at an angle like this will cause the birds to twist round a bit as they jump up and down. Cut the shapes for the beak and wings from wood veneer or from thin card and glue them into the slots. Paint the birds: I have gone for puffins.

Assembly and adjustment

With the camshaft and crank handle, the two upright shafts and the dowel

supports in place on the base you are ready to attach the twisted cord and the levers. I tried various different strings and cords. Cheap polypropylene twine is good, but I settled on a length of shoelace, of the flat, woven type, which seems to work particularly well.

Getting it strung up is a bit of a fiddle: tie the shoelace in a just slightly loose loop around the two dowel posts, with a firm reef knot. Slide each lever onto its upright shaft, and place the ends with the notches within this loop.

The next stage is to form a twist between each post and the nearest lever: slide the loop up off one of the posts, turn it over, crossing the lace, and replace it on the post. The top of the loop must be turned away from the camshaft, so that the strand on top of the twist runs round the post on the side furthest from the camshaft. Now slide the loop off the other post and repeat this process, again turning the top of the loop away from the camshaft. Take 40mm (1½in) of 5mm (3⁄16in) diameter dowel and slip it into the loop in the middle, between the two flat levers. Turn it right over away from the camshaft, forming twists on either side. Slide it through so that the longer part, nearer the camshaft, rests on the base, holding the twisted lace in place. Slide the laces down on the posts, until the levers are held with the ends near the camshaft just below its centre line, and the other ends resting on the base. If the levers are held in the right place, and spring back well when depressed, then slide the birds onto the upright shafts, turn the camshaft and see how they jump (fix the beads on top of the shafts to stop them flying off). If the tension in the twisted lace is not enough to make the birds jump right up, then try putting another twist in the lace by rotating the dowel tensioner another half turn or two. If you are still not getting a good spring then you may need to remove the tensioning lever, undo the twists and retie the lace a little tighter before trying again.

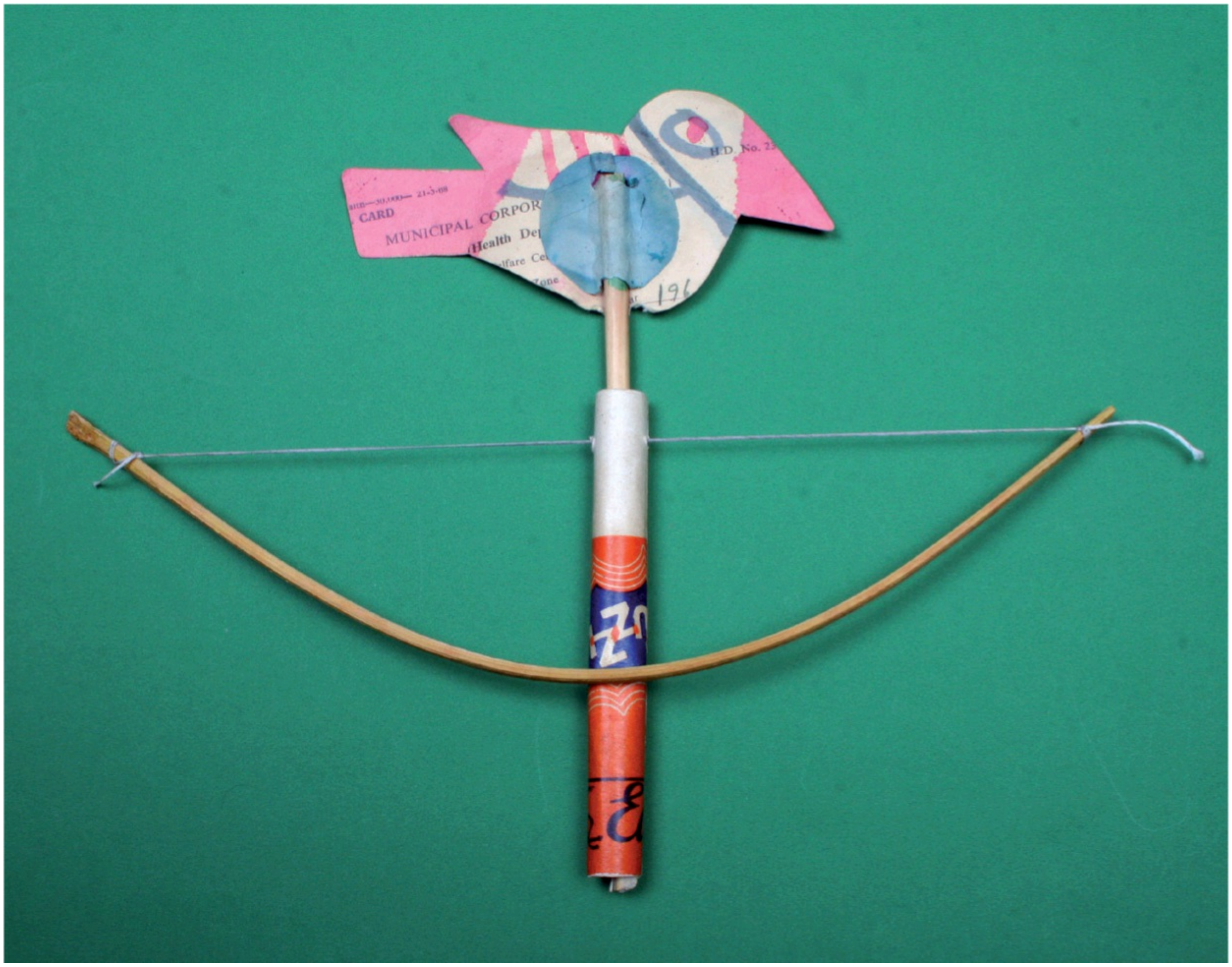
The base assembled, showing the tensioned spring.

CHAPTER SIX

ROUND AND ABOUT – Momentum and control

We started in Chapter 1 with a vertical stick simply held between finger and thumb and twisted back and forth. Another possibility for turning such a vertical shaft is seen in a simple spinning bird toy from India.

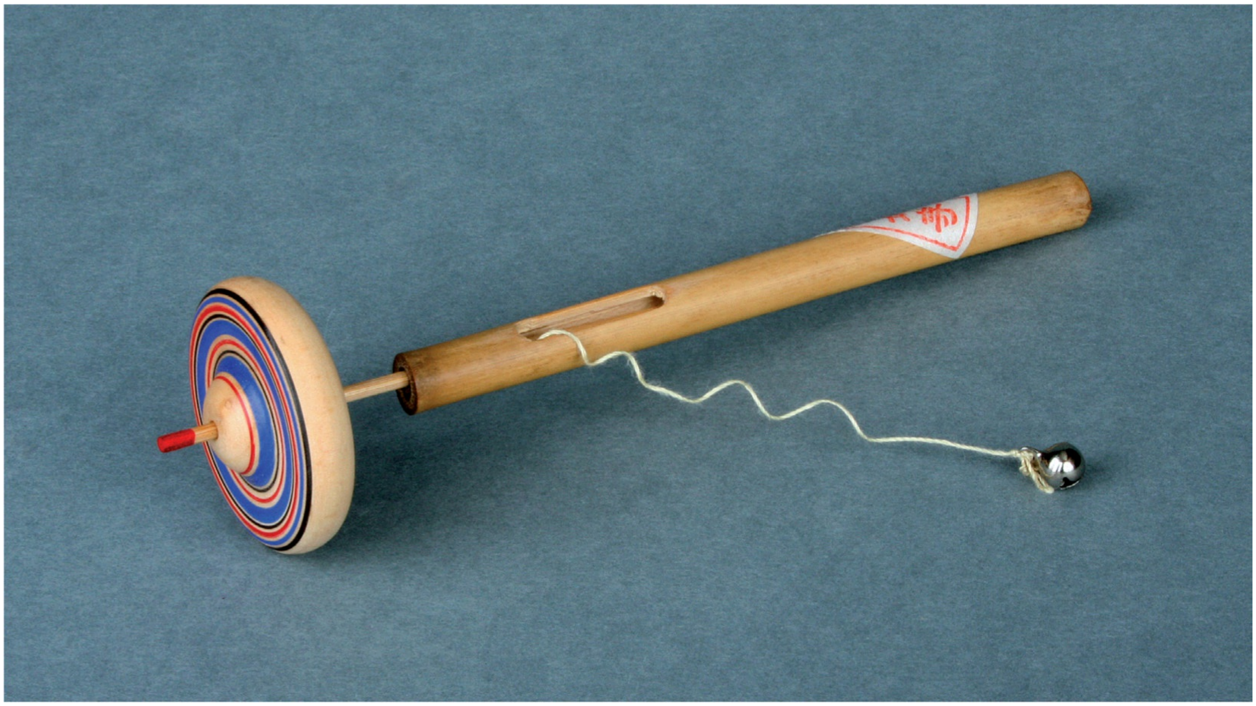
***Man and Insect*.**



Spinning bird. The string passes once around the shaft inside the tube, and is held taut by the split bamboo bow. Moving the bow back and forth causes the bird to turn. India, 1990s.

Here the stick is supported in a rolled paper tube and rotated one way and then the other by moving backwards and forwards a string that passes once around the stick, and is tied at each end to a bow made from a bent strip of split bamboo. The string emerges from two holes in the support tube, so that the loop around the stick cannot be seen, adding a touch of mystery. This arrangement does pose a small problem in assembly: how do you get the string loop around the stick inside the tube? It can be done by tying the string to one end of the bow, feeding it straight through both holes in the tube, and then, using a piece of thin wire bent into a hook, pulling a loop of the string out of the top of the tube, twisting it into a single loop, and feeding the stick through that loop and down into the tube. The string can now be pulled taut and tied off at the other end of the bow. The bow is a spring, of course, but unlike the split bamboo and the twisted

strings in Chapter 5, it does not provide the motive power. It just serves to hold the string tight against the shaft so that it does not slip when the bow is moved backwards and forwards by hand. An alternative way of providing the necessary friction is to replace the bow with a weight (maybe a heavy bead) at each end of the string. Pulling on one bead then the other will rotate the shaft in a similar way to moving the bow.



A Japanese version of the nut mill, with a bamboo tube as the supporting container and a turned and painted wooden top piece. 2005.

Nut mills and fan machines

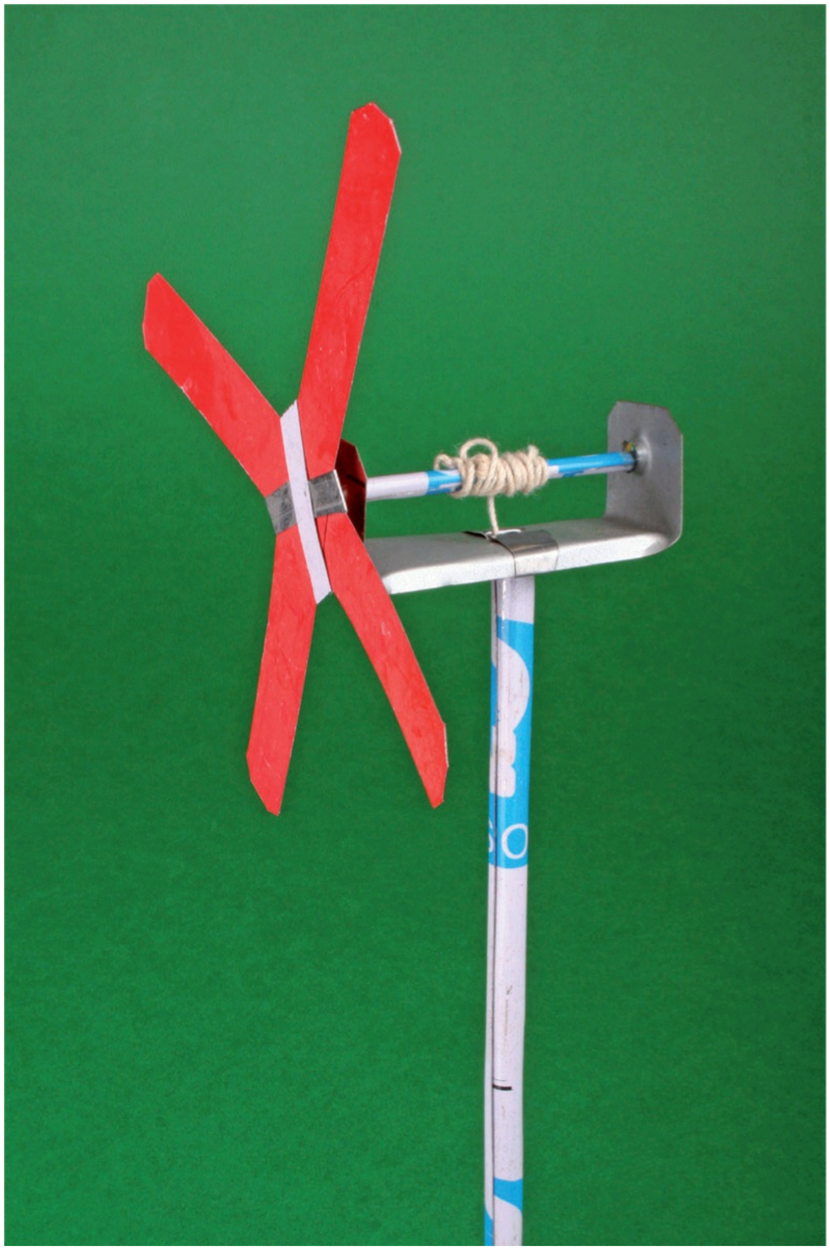
Another toy with a shaft that rotates one way and then the other is the nut mill, or fan machine. This toy can take many different forms, consisting of a supported shaft with something symmetrical, and relatively massive, fixed onto it. A string is securely attached to the shaft, and wrapped round it several times. If the support is held in one hand and the string is given a short pull with the other, the shaft is set spinning as the string unwinds. When the short pull is relaxed, the momentum of the moving shaft, with its top piece, keeps it spinning in the same direction until the string is rewound the other way on the shaft. Another pull will now rotate it the other way.

Repeatedly pulling and releasing the string judiciously will keep the mill spinning, one way then the other. These toys are found all over the world: all manner of hollow or hollowed out structures, such as gourds, rubber plant seeds, mango stones and bamboo tubes, may be used as the support for the shaft, and often a similar thing is used to form the end piece on the rotating shaft.

In Europe a typical version used a walnut shell as the support, and crossed straws, sticks or strips of wood as the top piece on the shaft. This toy was quite frequently illustrated in medieval paintings and illuminated manuscripts, and later in prints and on Dutch tiles.

A modern copy of a seventeenth-century dutch tile showing a girl playing with a nut mill.

A 'fan machine' made with two mango seeds, as described by sudarshan Khanna, in *Joy of Making Indian Toys*, national Book trust, india, 1992.



Another 'fan machine' toy. A more realistic model, in reused tin plate, with the rotating shaft held horizontal rather than vertical, and in an open bracket rather than inside a hollow container. India, 2000s.

It was known as a *moulin à noix*, *nootmolentje*, or nut mill. This can be slightly confusing since these terms are also used for mechanical devices for grinding nuts. The reason for the name is that firstly the toy was, typically, made from a large nut, and secondly the usual top piece, with four blades forming a cross, resembled a windmill in form and movement. It may look like a windmill, but of course the blades turn because pulling

the string rotates the shaft that they are fixed to, not because the wind moves them; indeed, and particularly if the blades are slightly twisted, it will act as a fan. That is, the rotating blades will move the air, creating a draught. In India, where cooling fans are ubiquitous, a ‘nut mill’ is known as a ‘fan machine’. The same mechanism is used to operate the turned and painted wooden figure illustrated in the Introduction.

Making a nut mill

Materials

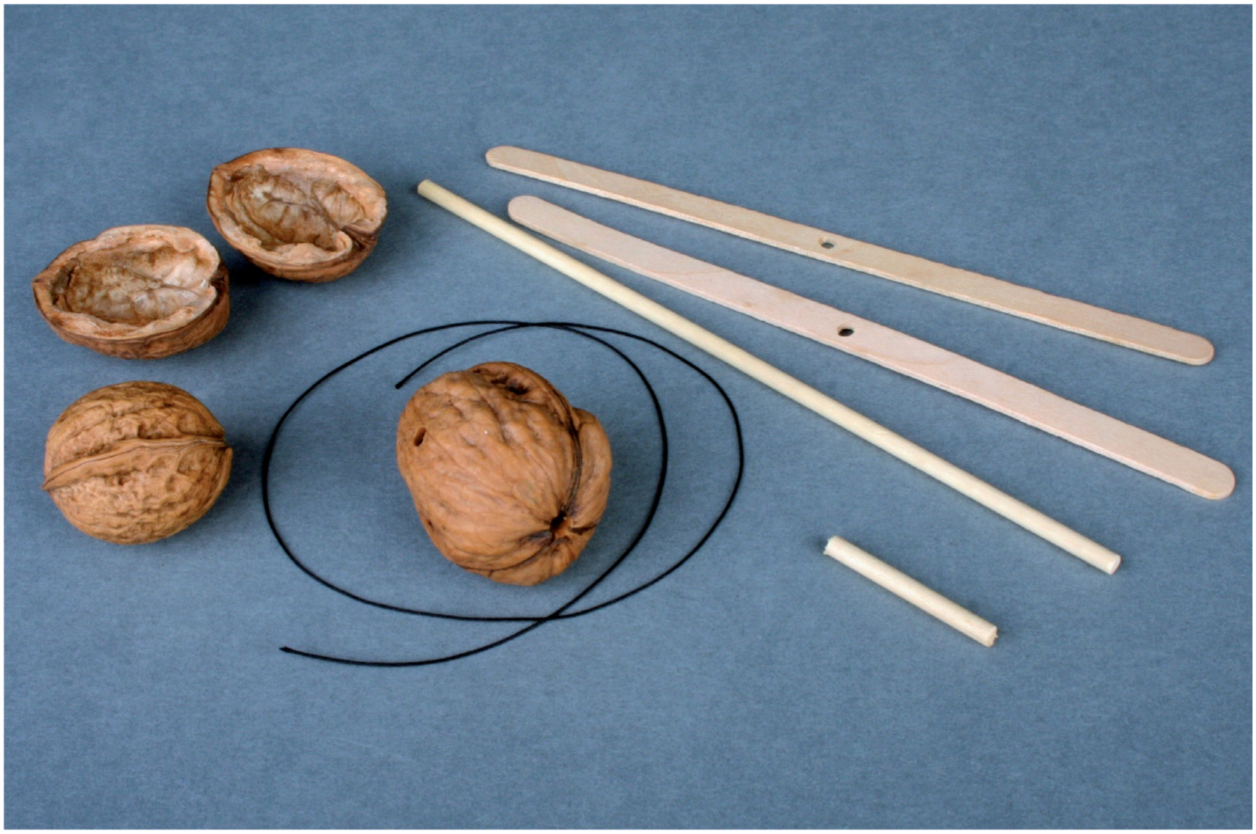
Walnut(s); a thin skewer or dowel; string or thread; two hot drink stirrers; glue.

Tools

A drill and a choice of bits; a piece of wire to make a hook; a pair of long-nose pliers to cut and bend the wire; possibly nutcrackers, or a knife, to lever the nutshell apart.

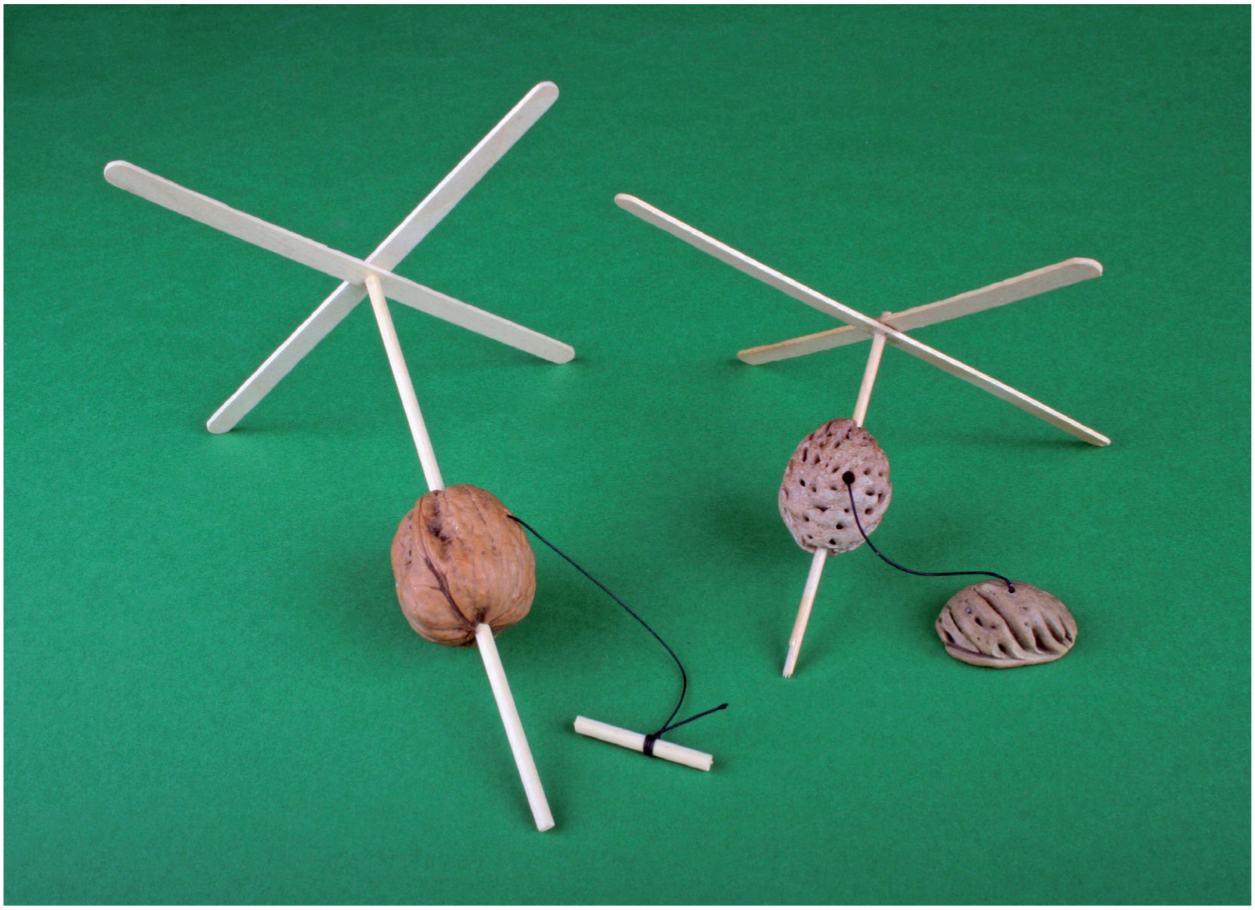
Method

Choose a sound nut. If the two halves of the shell seem to be really firmly attached, then drill a hole, a bit larger than the diameter of the skewer or dowel, in the bottom of the nut, and then drill straight through, emerging at the pointy top (or, if easier, drill a second hole in from the top). This has to be done with care to avoid cracking the nutshell. These two holes provide the bearings for the rotating shaft; check that the skewer or dowel will fit through the two holes easily. Now drill a hole centrally into one side of the nut, for the string. Next remove the remaining contents through these holes, using a hook made from a bent piece of wire.



Parts for a nut mill.

Picking the contents of the nutshell out through a small hole using a wire hook is easy enough, but it takes a while and is a rather tedious task. In *Joy of Making Indian Toys* (National Book Trust, India, 1992), Sudarshan Khanna describes an ingenious dodge employed by children in Kerala when making a ‘fan machine’ from a rubber plant seed: a small hole is made in the seed and it is left on an anthill for a few days, by which time the ants have cleaned out the contents, leaving an empty shell ready for the construction of the toy.

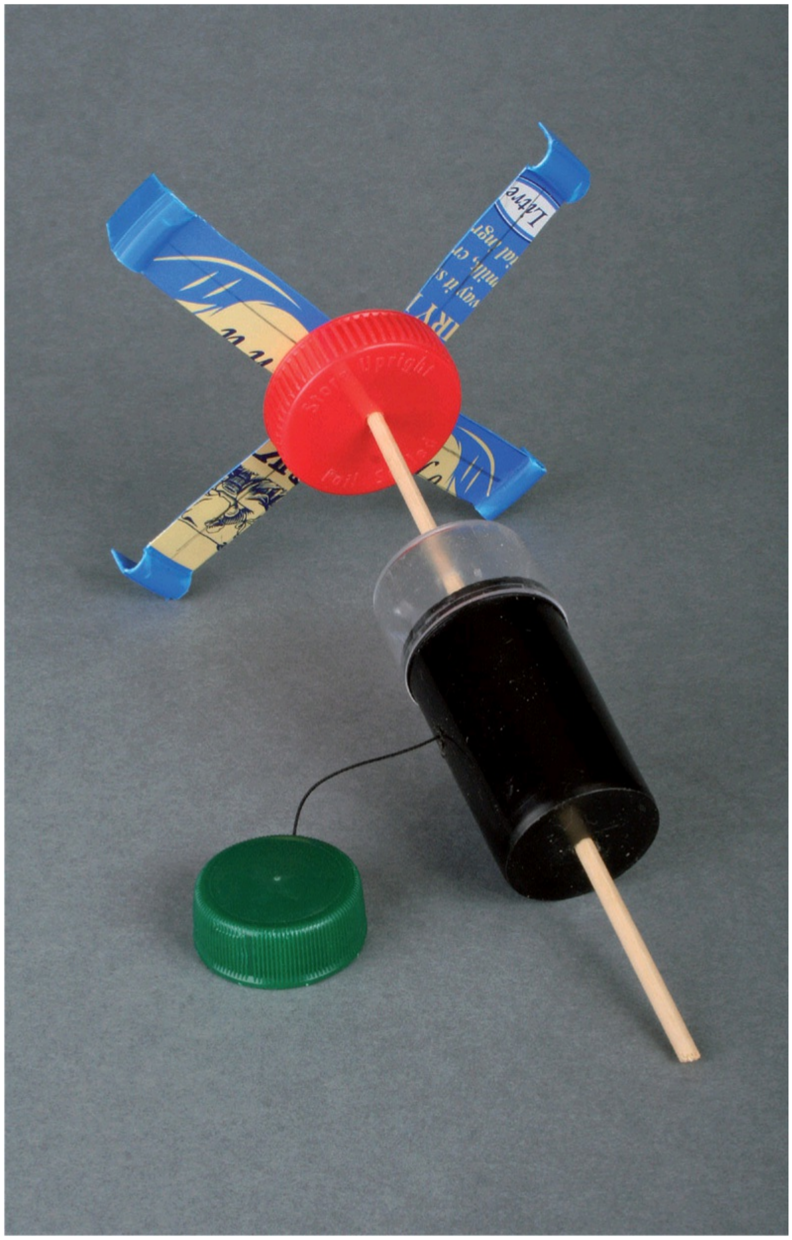


The completed nut mill, and another using a peach stone in place of a walnut.

Some walnuts will crack open easily enough into two half shells, without otherwise breaking. In that case the contents can easily be removed (and eaten), and the two halves of the shell glued firmly back together before drilling the holes.

Mount the two hot drink stirrers in the form of a cross on the end of the skewer or dowel by drilling a hole at the middle of each stirrer that is a tight fit on the stick and gluing them firmly onto it.

Take 300–400mm (12–16in) of strong thread, or thin string, and feed one end into the hole at the top of the nut, then try to hook it out with a bent wire through the hole in the side. When you succeed, tie the emerging thread securely to a short piece of dowel, to act as a handle. The other end must then be tied very firmly onto the skewer at about the middle. Gradually pull the thread through towards the handle and feed the stick down through the hole in the top of the nut, and out through the hole in the bottom. The knot is now inside the nut.



A nut mill made from a recycled plastic container and lids.

Operating the nut mill requires a certain knack: hold the nut in one hand and rotate the cross with the other to wind the thread round the shaft inside. Now, holding the nut upright with one hand, pull the handle on the end of the thread out steadily with the other. This will spin the shaft one way. Before the thread is pulled out to its full extent, keep hold of the handle, but let the thread go slack by moving your hand back towards the nut. The momentum of the moving shaft will keep it rotating in the same direction and when the thread is fully unwound it will rewind onto the shaft

the other way. Another pull on the handle, at the judicious moment, will now rotate the shaft in the opposite direction to the first pull. With a little practice this can be repeated indefinitely, keeping the mill spinning rapidly one way and then the other, often with a satisfying whizzing noise.

Developing the design for an automaton

In these examples a shaft is turned by pulling, by hand, on a string that is wound around it. Another possibility is to hang a weight on the string. A further refinement would be to introduce some control to regulate the fall of the weight. In *Making Simple Automata*, The Crowood Press, 2014, I discussed a wrapping escapement, used occasionally in weight-driven clocks and in some spring-driven ‘clockwork’ toys.

I have experimented with another weight-driven version: the first problem is to mount a vertical shaft so that it will turn freely without too much friction when a thread wound around it is pulled at right angles to the shaft. Taking inspiration from the Indian toy illustrated in the introduction, I started with a light figure, simply represented with a piece of dowel for the body, and a smaller one for the head, mounted on a vertical shaft made from a piece of good quality split bamboo skewer, which is quite uniformly round, and with a hard, smooth surface. I mounted it on a wooden frame, holding it upright in two bearings: the first, a blind hole in the wooden base, was lined with a short length of plastic drinking straw, and a small spherical steel ball bearing (re-used from a dead bicycle wheel) was dropped into it for the bottom of the shaft to rest on; the second bearing, raised on a platform a little above the base, was another hole lined with plastic drinking straw. The string was firmly attached to the shaft in the gap between the two bearings. If the shaft is rotated to wind the string onto it, then a sideways pull on the string will rotate the shaft back the other way as the string is unwound.

The unwinding is controlled by the wrapping escapement: this comprises two posts, fixed the same distance from the central shaft, and a wire firmly attached into the head of the figure on the shaft, with a bead on a thread hanging from it. The wire is shaped so that the end, with the bead on a thread hanging from it, nearly touches the fixed posts as the figure rotates on its shaft. As the shaft rotates the bead on the thread will swing out and

wrap around one of the fixed posts. This halts the rotation for a moment, but the bead on the thread then unwraps itself, and the rotation resumes. It then swings out again, and the same process is repeated when it reaches the other fixed post.

In the initial experiments the base, with a bent wire cradle mounted on it to guide the string clear of the base and down, was placed at the edge of a table, and a weight was tied to the string. The figure on the shaft was rotated, winding the string up around the shaft until the weight was at the top. When the weight was released, then the string unwound and operated the escapement well, with the hanging bead on a thread wrapping and unwrapping from each post in turn, so that the rotation of the shaft, with the figure on it, was halted twice in every complete revolution. The snag was that each time the string was completely unwound, the weight had to be rewound back to the top by turning the figure on its shaft by hand, and this had to be done very slowly, so as not to swing the hanging bead on its thread out to wrap round the posts, checking the turning of the central shaft, as happened when the weight was falling.

A better option seems to be to pass the string round the shaft, without tying it on. An additional wire cradle allows the two ends of the string to hang over the edge of the table a little way apart. Attaching it to a large bead at either end keeps the string taut on the shaft and an additional weight can be hooked onto one side. The advantage is that when this weight gets to the bottom rewinding by hand is not necessary, because the weight can be unhooked and hung below the bead on the other end of the string, now at the top. The wrapping escapement then operates in the reverse direction. There is, however, still a snag: in order for the string not to slip it is best to pass it once right around the shaft, making one complete loop. When the string is pulled this loop tends to travel a little up or down the shaft, depending on which end is pulled. This is not a problem most of the time, but, because the strings are guided over the wire cradles at a set height, occasionally the upward or downward movement causes the string to cross over itself and jam. This problem can be cured by fixing the wire cradles at slightly different heights, and making sure that the string from the top of the loop round the shaft runs to the higher guide. The loop still tends to travel up or down the shaft a bit, depending on which way it is turning, but it no longer seems to jam.

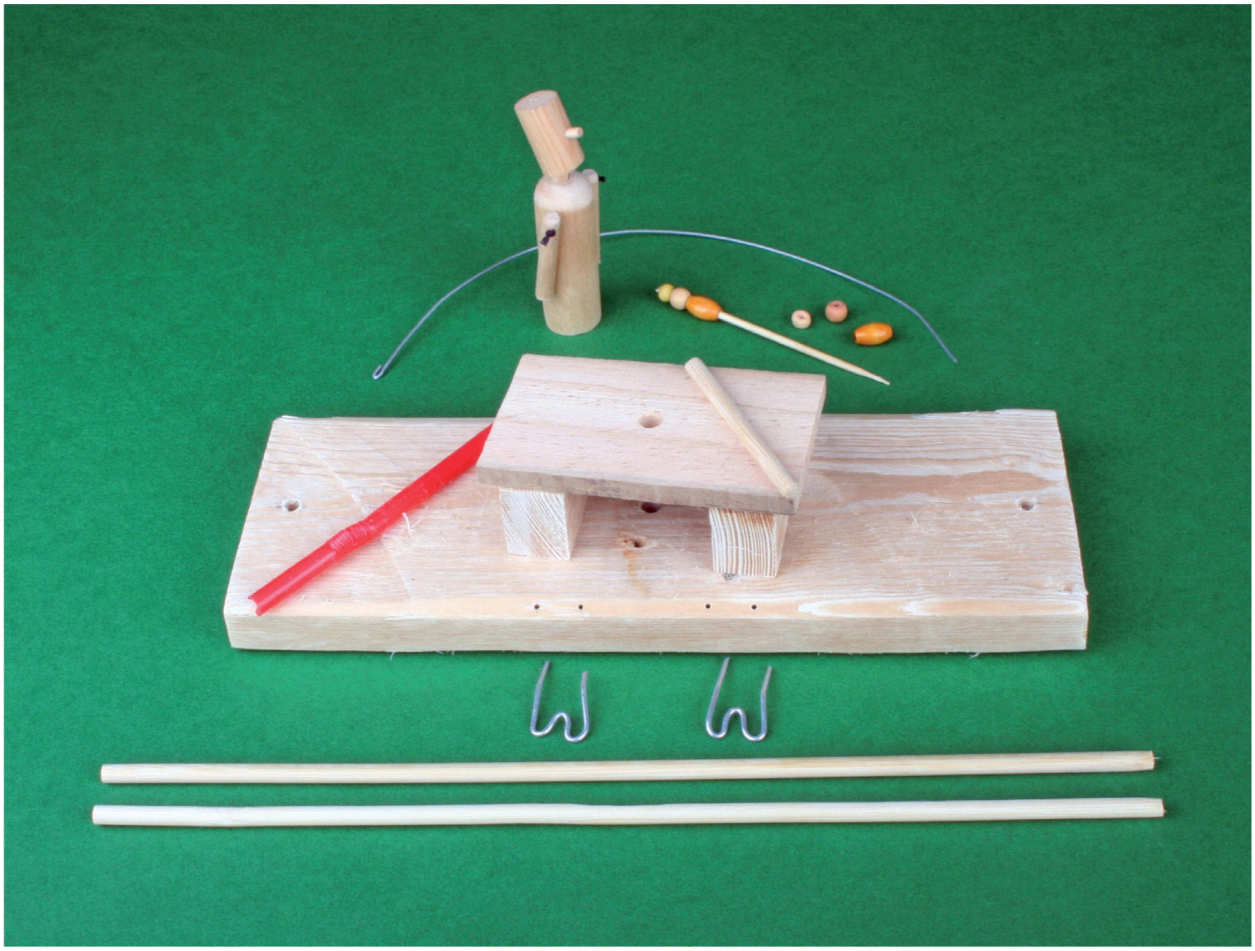
Placing the framework at the edge of a table, and guiding the string to

run over the edge, works well, allowing for a good long drop for the weight, and therefore a long running time for the automaton. But, for a self-contained version that does not need an unobstructed table edge to set it up, the framework can be mounted on a raised stand.

Making Man and Insect

Materials

Wood for the base and framework, and the stand, if required; smooth dowel or split bamboo skewers, about 5 or 6mm (¼in) diameter for the two posts (about 200mm (8in) long) and for the central shaft (50mm (2in) long); thicker dowel or scraps of wood to make the figure; a small steel ball bearing; a plastic drinking straw that is a good (loose) fit on the dowel or skewer; beads; a selection of possible weights, such as blocks of wood, stones with holes, metal washers or heavy beads; wire; string or thread; glue.



Parts for *Man and Insect*.

Tools

Saw; craft knife; sandpaper; a drill with a range of drill bits; long-nose pliers to cut and bend the wire.

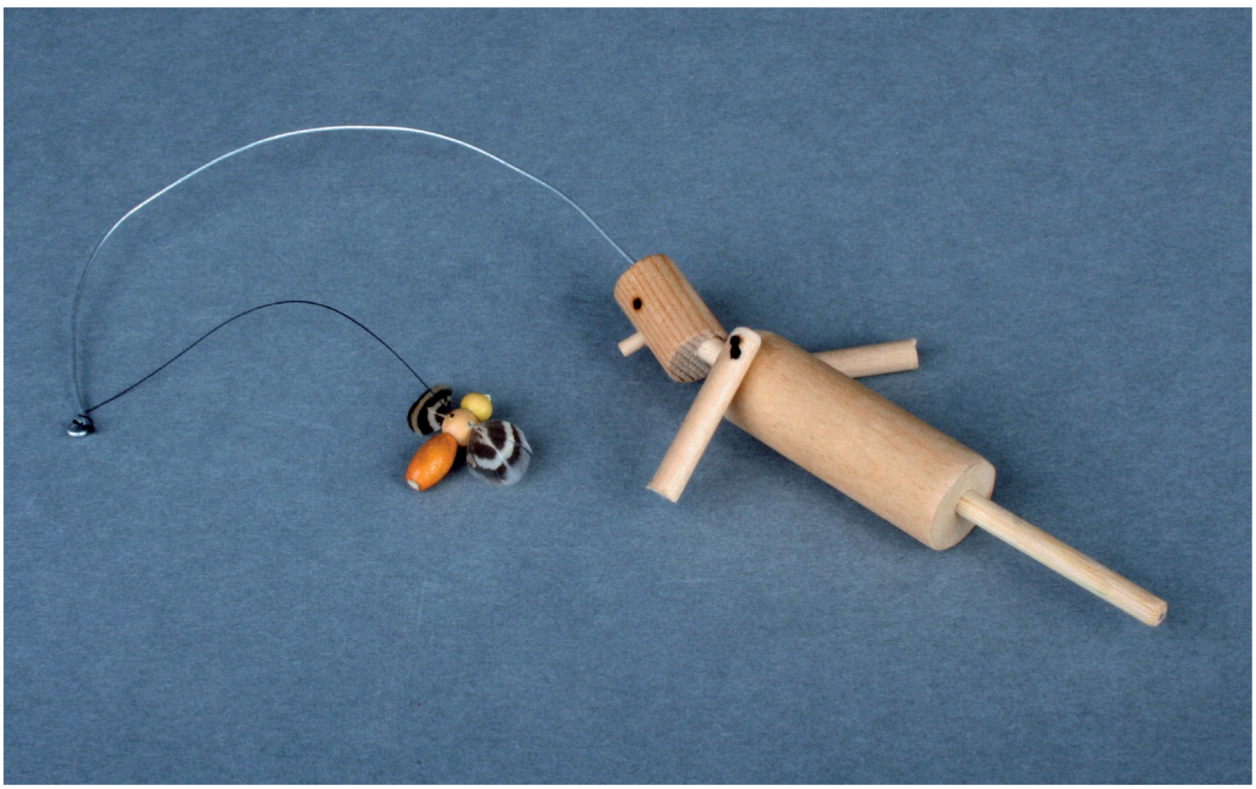
Method

The man and insect

The figure could be turned, or whittled from a scrap of wood. I have made it up using a variety of thicknesses of dowel for the body, neck, head, nose and arms. The body is 50mm (2in) of 15mm (5⁄8in) diameter dowel, rounded at the top, and with a hole in the bottom to mount it on the central

shaft and a hole at the top to glue in the neck. The head is from 12mm (½in) dowel. Drill a small hole through the shoulders and through the top of the arms to attach them using a knotted thread. This will allow the arms to waggle a bit as the figure rotates.

The bead on a thread has become an insect: it could be turned, or whittled and sanded from a piece of dowel, but I have used three small beads glued onto a cocktail stick core, with small feathers added as wings. Tie on the supporting thread between two beads, and glue the feathers in the same place. Alternatively, and better, if you have a very small drill bit, drill a hole through the middle bead to attach the thread, and a hole each side to glue in the feathers.



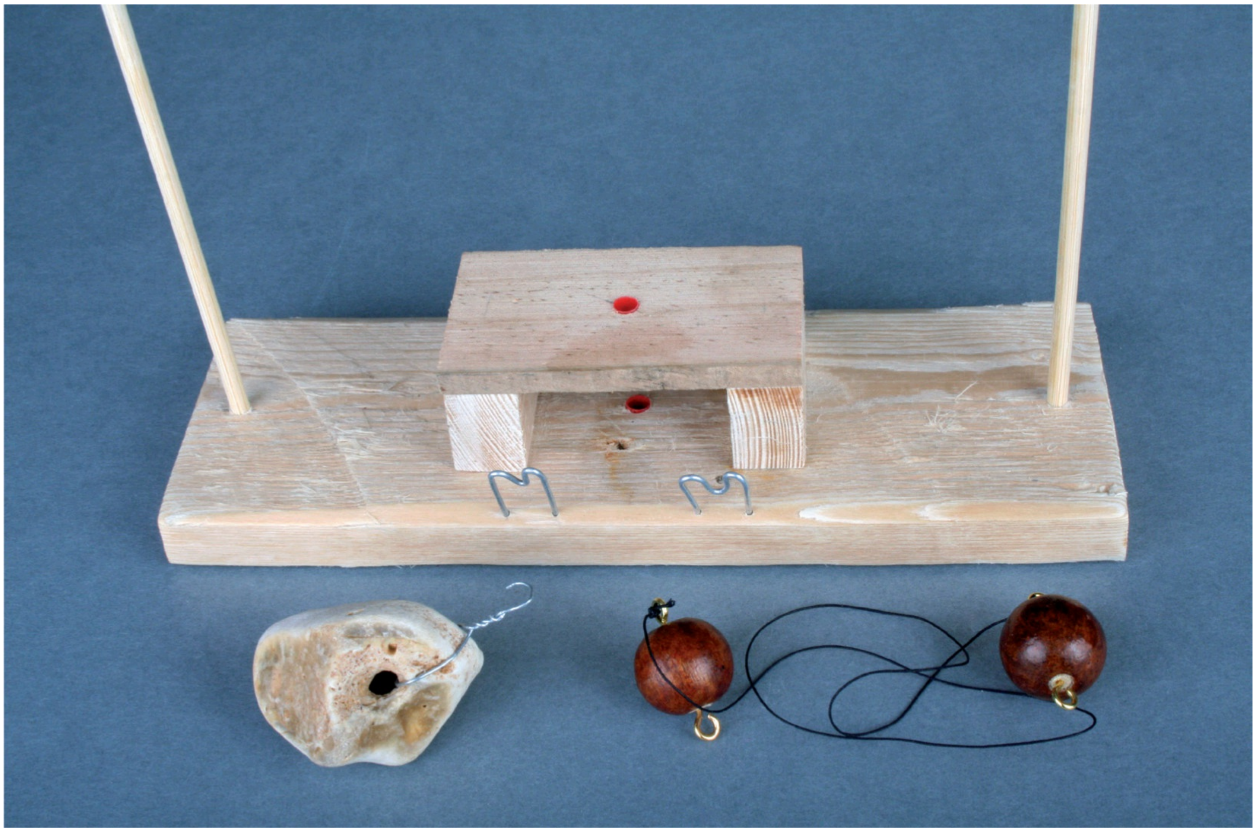
The insect on a thread attached to a curved wire mounted into the top of the head.

The insect on its thread will be supported on a curved wire attached to the figure's head. You will need a thin wire that can be readily bent to shape, but is rigid enough not to lose that shape too easily. I have used about 200mm (8in) of 0.9mm (1⁄32in) diameter galvanized steel wire. To fix the wire to the head firmly it is better to bend the end back on itself in a tight U, and glue that into a hole in the top of the head with a two-part

epoxy glue. Shaping the wire, trimming to length, forming an eye at the end and tying on the thread with the insect is best done when the figure is in position on the framework in its bearings.

The framework

The base is a piece of wood about 200 × 70 × 15mm (8 × 2¾ × ⅝in), with a central platform 75 × 40 × 6mm (2¾ × 1½ × ¼in), raised on wooden blocks 40 × 15 × 20mm high (1½ × ⅝ × ¾in). First drill holes for the bearings: a blind hole about 10mm (⅜in) deep at the centre of the base and a hole right through at the centre of the platform; these holes must be a good fit for the plastic straw used to line them. Also, at each side of the base drill a blind hole to fit the upright post, level with the central hole and 90mm (3½in) from it. Before gluing the platform in place, drop a steel ball bearing into the central hole in the base, and then push in a piece of plastic straw, cutting it off flush. Line the hole in the platform with a piece of plastic straw in the same way. To assemble, first glue the platform onto the two wooden blocks and let the glue set. Then carefully glue this unit in place on the base: it is important that the bearings are lined up so that the central shaft will be held vertical and be free to move easily. It is best to check this by inserting the shaft, or a similar dowel, into the bearings while gluing. Next the two upright posts can be fixed in place, and the two wire cradles to guide the string: I used galvanized steel wire about 1.25mm (3⁄64in) diameter bent into an M, about 12mm (½in) wide and with elongated legs. The legs should be long enough to fix into the base and hold the middle of the M at a level above the base and below the platform. As discussed above, one of the wire cradles needs to be slightly taller than the other, and so one of the Ms should have longer legs than the other. The two cradles are fixed centrally at the edge of the base, about 50mm (2in) apart: drill guide holes for the legs of the Ms, and tap them in with a light hammer. They need to project out slightly from the base. If necessary the legs of the Ms can be bent a little to a suitable angle. It does not matter which side the taller cradle is fixed, but to prevent jamming, care must be taken when the string is wound round the shaft that the higher side of the resulting loop is on the side with the taller wire cradle.



The assembled base, the thread with two large beads, fitted with screw eyes top and bottom, and the weight with a wire hook

The raised stand

The framework can be used by positioning it at the edge of a table, with the weight travelling down to the floor, or it can be fixed on a raised stand. A simple stand can be made from a length of broomstick, or stout dowel. It needs to be about 250–300mm (10–12in) high to give a reasonable drop. Take two flat pieces of wood, one large enough to make a stable base, and the other a little smaller than the base of the framework of the *Man and Insect*, and drill a hole in the centre of both of them that is a good fit on the broomstick or dowel. Also drill two holes in the smaller piece to accommodate screws to attach it to the underside of the framework. Glue the broomstick or dowel into the base and the smaller piece, checking that it stands up square, and screw the framework in place on top of the smaller piece.

The stand.

The drive

The drive requires a weight, fitted with a wire hook; a length of thread or string; two blocks of wood, or large beads, each fitted with a screw eye at the top, so that they can be tied onto the ends of the string, and another screw eye at the bottom to hook the weight onto.

The weight

The weight needed to operate the automaton will depend on a number of factors, such as the efficiency of the bearings and the weight of the insect. I have used a stone with a hole in it, with a piece of wire attached to make a hook. It weighs just over 40 grams (1½oz). You may need to experiment with a range of possible weights. They need to have a wire hook attached so that they can be hung from the screw eyes on the blocks or beads at the ends of the string.

Assembly and adjustment

First mount the figure on the central shaft and place it in its bearings. The bottom of the figure should be just clear of the platform. Trim the shaft if there is too big a gap. The shaft should turn freely.

Bend the wire attached to the head of the figure forward in a gentle curve so that it will reach the upright posts somewhere near the top. Trim the wire if it is too long and use long-nose pliers to form an eye at the end. Adjust the curve of the wire so that the eye passes just inside the upright posts as the figure is rotated.

Tie the insect on its thread securely onto the eye at the end of the wire. The thread should be about 70–90mm (3–3½in) long. This length may need adjusting to get the escapement working well. Tie one end of a length of string, or strong thread to the screw eye in one of the blocks or beads, feed the string once right around the central shaft, underneath the platform, and tie the other end onto the other block or bead. The length of string needed will depend on the drop available: a shorter string will be needed if you have mounted the framework on a stand than if the drop is from a table to the floor. Arrange the string in the two M-shaped wire cradles, with the beads or blocks hanging down. As indicated above it is important that the string coming from the top of the loop around the shaft passes over the taller M.

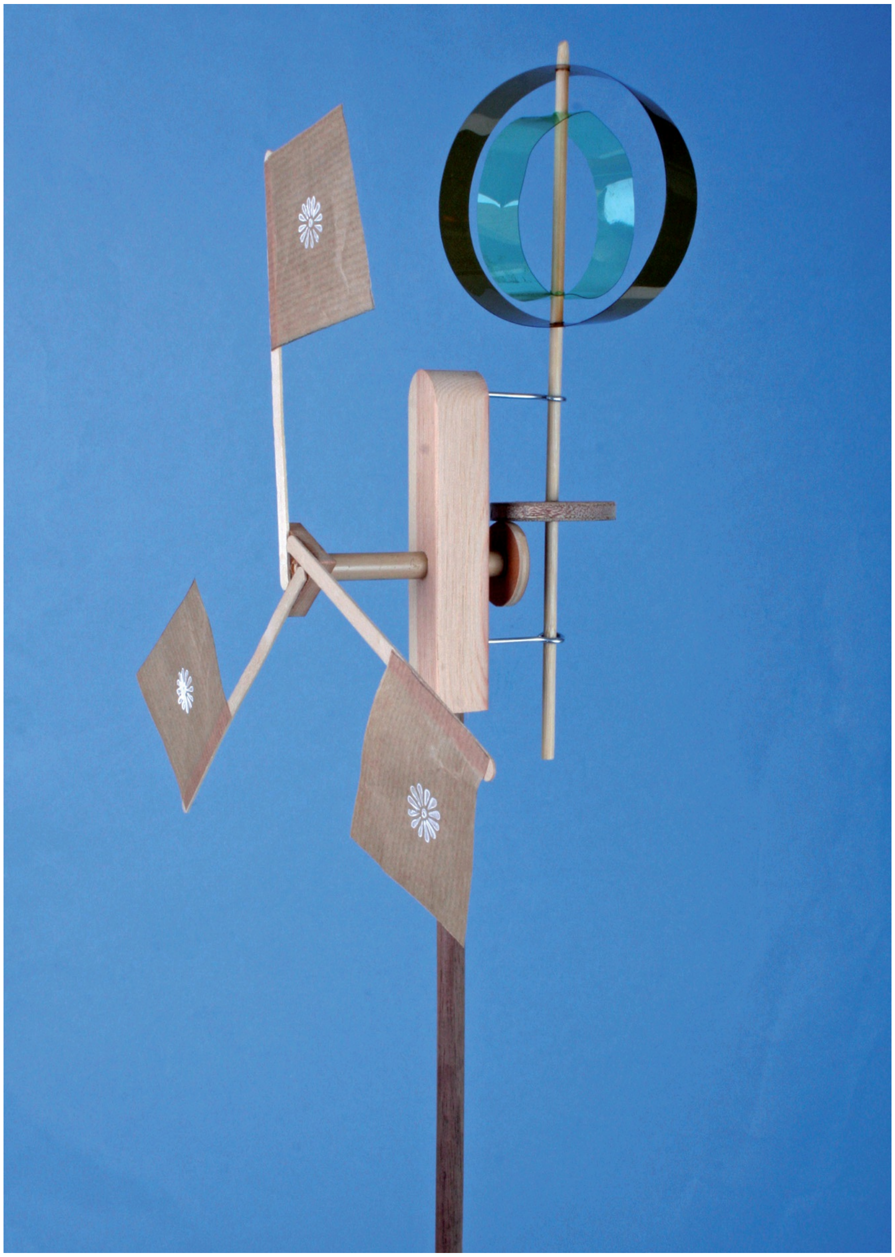
Using its hook, hang the weight under the bead or block on the higher end of the string. The weight should fall, pulling the string and rotating the shaft with its attached figure, but the insect should swing out on its thread, wrapping around one of the two posts, then unwrapping and moving round to wrap around the other post. Various adjustments will probably be needed to achieve this: the wire from the head of the figure must be carefully shaped to travel close to the upright posts, but not hit them; the thread supporting the insect may need lengthening or shortening; you may

need a slightly heavier or lighter driving weight. When the adjustments are right the weight should continue to the bottom, with the insect on its thread wrapping around each post in turn and checking progress twice for each revolution. The weight can then be unhooked and hung at the other end of the string to rotate the shaft in the opposite direction.

CHAPTER SEVEN

IN THE WIND – Harnessing power

Simple toy windmills, or ‘pinwheels’ as they are sometimes called, are found all over the world, made from all sorts of materials: torn leaves, woven rushes, feathers, woven split bamboo strips, wood veneers, tin cans, paper and plastic.



A bubble spinner, which uses a three-vaned windmill to turn a vertical shaft via a friction drive. Two rings cut from plastic bottles are thus spun to give the illusion of a translucent sphere within a sphere.

In Britain they are traditional seaside toys, often on sale with the buckets and spades. It tends to be windy at the British seaside, and the movement of the air past a pinwheel will make it spin on its fixed axis. The beach is also a good place to run and, in the absence of wind, the pinwheel can be made to spin by moving it through still air.

Mounting a toy windmill on a stick that can be held up vertically is slightly

tricky. You need a horizontal axis for the windmill to turn on, and it must be securely fixed to the vertical stick. Using a short pin or nail as the horizontal axis does not work very well, because the blades of the windmill tend to rub or catch against the stick.

An elegant paper windmill. Japan, 2005.

Medieval toy windmills

A medieval version of the toy made a virtue of necessity by mounting the pinwheel directly on the end of a stick that was held not vertically but horizontally and was often used as a lance to play at jousting. There are many illustrations of such windmills in medieval illuminated manuscripts, and they also feature in paintings, such as Pieter Breugel's *Children's Games* and Hieronymus Bosch's *Christ Child with a Walking Frame*, both in the Kunsthistorisches Museum in Vienna.

This kind of toy windmill has a minimal but effective structure: in its simplest form it consists of a stick, a pin or nail, and a short flat strip of wood with a hole in the centre and with a square of paper glued on at each end, projecting on opposite sides. The strip of wood is attached with the pin to the end of the stick so that it is free to move. Held in the wind, or moved through still air, it will turn. It does so because the wooden strip itself is rigid, and remains flat, but the unsupported sides of the two pieces of paper are bent back by the moving air, one on one side, one on the other. They now take the form of a simple airscrew: the pressure of the air on the bent-back surfaces produces a torque, and the strip of wood spins on its pin. Interestingly if the windmill is now moved through the air in the opposite direction the pieces of paper will be bent back the other way, and it will continue to rotate in the same direction. The design works best if the squares are made with fairly thin paper. If thicker paper or card is used a greater airspeed will be needed to bend back the blades and produce the airscrew effect. A number of the medieval illustrations show four-bladed versions, made by fixing two pairs of blades together to form a cross.

A simple two-vaned windmill, mounted on the end of a horizontal stick, as often illustrated in medieval manuscripts and paintings. The paper vanes remain flat until moved through the air, when they assume the form of an airscrew, and the windmill spins.

Returning to the problem of mounting a windmill horizontally on a vertical stick: one solution is to use for the horizontal shaft a pin or nail that is long enough to allow not only for the depth of the windmill, and for fixing into the vertical stick, but also for a generous spacer, such as some beads or a short length of drinking straw. There is an even simpler solution, with the advantage that the horizontal shaft can easily be made as long as required,

which is to use a piece of wire. The wire is wrapped around the stick in a spiral to secure it. Before threading on the windmill a small loop is formed in the wire, at a suitable distance from the stick, preventing the windmill from being pushed back against it. After threading on the windmill, a second small loop can be formed to stop it from slipping off.

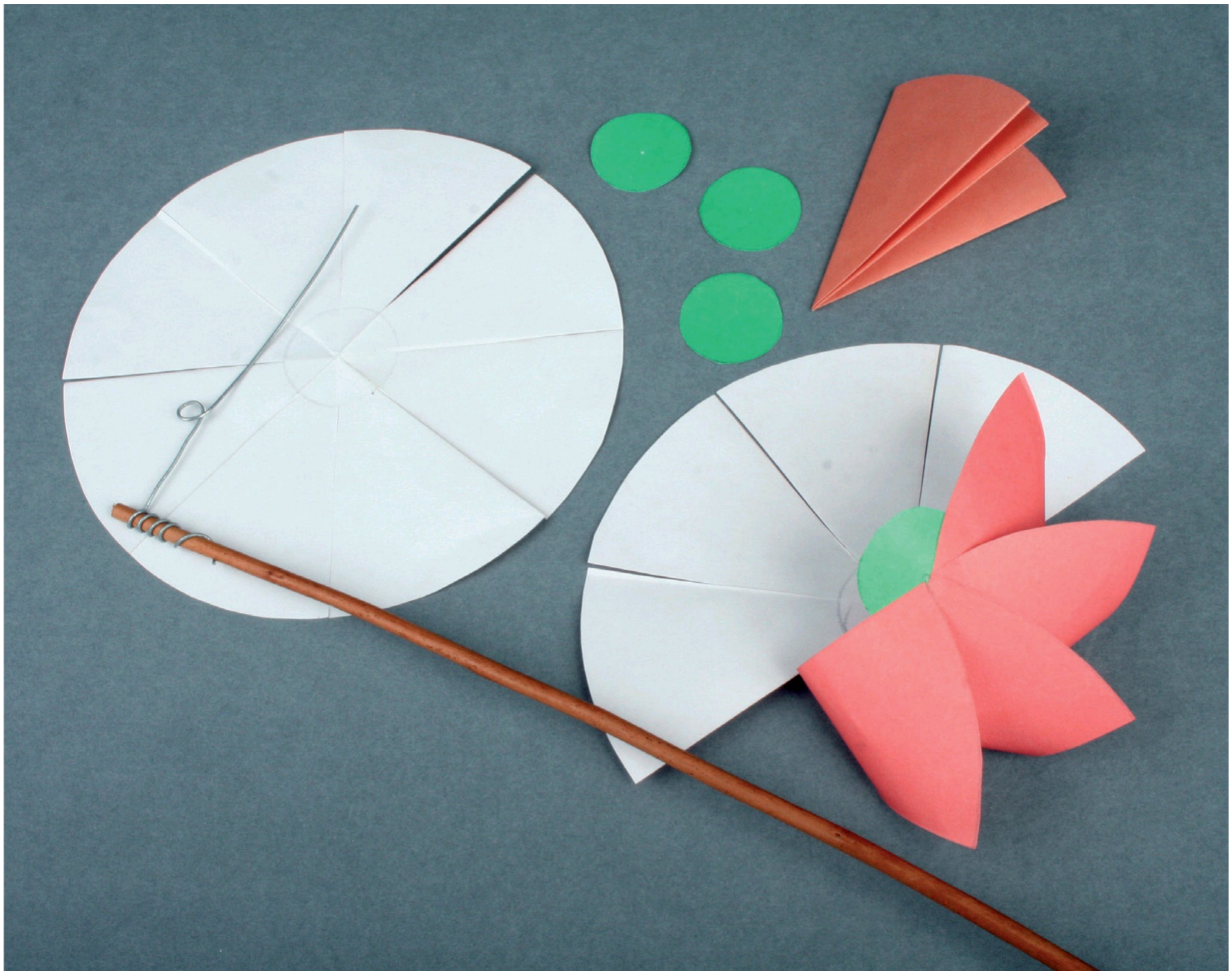
It is an advantage to have a three-dimensional structure to a paper pinwheel, with two holes, one at the front and one at the back, acting as bearings: This ensures that the pinwheel is held straight on the shaft. A flat paper windmill can be made to work, but there is a tendency for it to wobble about and sag on its shaft, and it will often snag against the vertical stick, even with a spacer. There are many ways of making a paper windmill with such a three-dimensional structure. One that I like is seen in a decorative double windmill from Indonesia. The pinwheels are eight-bladed and made from circular pieces of paper cut from a magazine and painted on one side.

Two windmills with a decorative paper fan. Each windmill is made from a single circular piece of paper, cut from a magazine, and painted on one side.

Making an eight-bladed paper pinwheel

Materials

Paper, glue, wire, a stick (willow, split bamboo or thin dowel).



Stages in making an eight-vaned windmill from a paper circle. The stick has a thin wire secured to it by wrapping round several times. A small loop is formed in the wire, which will hold the windmill away from the stick when it is threaded on.

Tools

A pair of compasses; scissors; a bradawl, a needle or very fine drill bit for making holes; long-nose pliers to bend and cut the wire.

Method

The paper wheel

Choose your paper and draw concentric circles 75mm (3in) and 15mm ($^5/_8$in) in radius. Cut out the large circle. Fold it in half, in half again, and in

half again and press the creases firmly before unfolding: eight radial creases now divide the circle into eight equal segments. Cut in along the radial creased lines as far as the inner circle. Draw and cut out three more circles 15mm (5⁄8in) in radius. Make a small hole in the centre of each circle.

Choose which side of the large circle will be the front of your windmill and glue one of the small circles on in the centre as reinforcement. Now turn the large circle over and lay it down flat, with the side of the paper chosen for the front of the wheel face down. Place the second of the small circles on the large circle so that the holes are lined up in the centre. Put a small dab of glue on the circumference of the large circle at one of the corners of the segments formed by the radial cuts. Bend the corner in towards the centre and stick it down onto the small paper circle, with the point of the corner just at the centre. For this first corner try to leave the edge free, because when you glue down the eighth and final corner it will need to tuck under here for a neat effect. Apply glue to the corner of the next segment, bend it in and stick it to the small circle, over-lapping the first corner. Do the same for each of the other six corners. Make sure you choose the corners on the same side of the radial cuts as the first one. Depending on whether you choose the left or right hand corners your windmill will spin clockwise or anticlockwise.

Now glue the third small circle on centrally, as reinforcement for the back. Try not to squash the pinwheel too flat. It will work best with a smooth curve to the paper and a generous space in the middle.

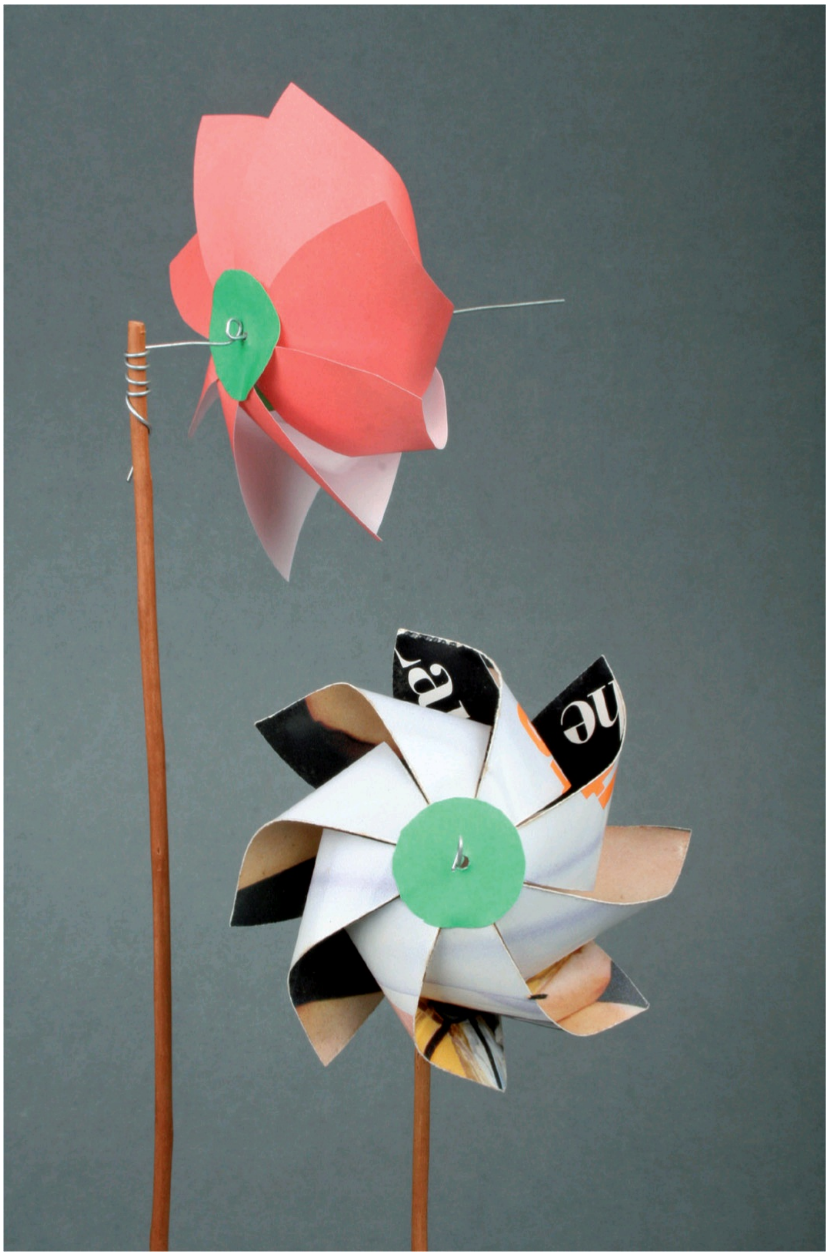
The stick and the wire shaft

Take a piece of wire about 250mm (10in) long. Hold one end near the end of the stick and wrap it firmly round four or five times to secure it. Bend the wire out at right angles to the stick. About 30mm (1¼in) from the stick bend the wire into a small loop. This will hold the windmill away from the stick.

Mounting the windmill

Without squashing the windmill too much, use the awl or a needle to reform the central holes front and back, if necessary. Thread the windmill onto the wire. Note that the front of the windmill (away from the stick) is the surface

that was underneath during construction. It is a bit of a fiddle to get the wire through the hole at the back, and then the hole at the front of the wheel. When achieved, blow on the wheel to check that it spins freely, and finally use the pliers to make a second small loop in the wire to retain the wheel. Cut off any excess wire.



Mounting the windmill on the wire.

Making a flying pinwheel

In another version of the pinwheel that I like to make the moving air is supplied by blowing into a straw and the pinwheel spins on, and moves freely up and down, a vertical shaft.

Making a flying pinwheel. Stages in construction.

Materials

A piece of paper, about 80mm (3in) square; a small paper circle about

20mm (¾in) diameter; a plastic drinking straw, preferably one with a bendy section and a large diameter (6mm (¼in) is good); a small block of wood about 40 or 50mm (1½ or 2in) square and 20mm (¾in) thick; a long thin skewer, or a thin wooden dowel: this does need to have an appreciably smaller diameter than the drinking straw, around 3mm (⅛in) is good, otherwise a metal rod, such as a bicycle spoke could be used; a bead that will fit tightly on the skewer, dowel, or rod; glue.

Tools

Ruler; scissors; a drill with a bit that matches the diameter of the drinking straw, and a bit that matches the diameter of the skewer, dowel or rod; an awl to make holes in the paper (a large pin or a really sharp pencil would do).

Method

The wheel

Fold the square of paper diagonally in half both ways. Open out and cut in 40mm (1½in) from each corner along the diagonal crease. Using the awl, make a hole in the centre of the square, and also in the centre of the small paper circle. These holes will need to be a loose fit on the thin skewer. You can enlarge them later if necessary. Lay the square on a flat working surface. Place the small circle on the square so that the holes are lined up in the centre. Put a small dab of glue on one of the points at a corner of the square, bend it towards the centre and stick it down onto the small paper circle. Do the same for each of the other three corners. Make sure you choose the points on the same side of the square corners as the first one. Try not to squash the pinwheel too flat; it will work best with a smooth curve to the paper and a generous space in the middle.

The base

Drill a hole in the centre of the square piece of wood that goes halfway, or a little further, into the thickness. This hole should be a reasonably tight fit

on the drinking straw. Using the same drill bit drill a hole into the side of the block to meet the hole that you have drilled in the top. Remove any debris from the holes and check that there is a clear airway through. Change the drill bit for one matching the diameter of the skewer (or other thin dowel or rod) and drill a little further down into the hole in the top of the block.

Assembly

Glue the end of the thin dowel, skewer or rod into this hole. Cut 25mm (1in) or so from the end of the plastic straw, feed this short piece onto the skewer and push it a little way into the hole in the block – not too far, or the connection to the hole in the side may be blocked. Push the remainder of the straw into the hole in the side of the block. Blow into this straw and check that air passes through. Feed the pinwheel onto the skewer, with the small paper circle downwards. It should fall freely to the bottom and rest on top of the short bit of straw. If it does not, the holes in the pinwheel must be enlarged a bit. Stick the bead on the end of the skewer and blow through the longer straw: the pinwheel should spin and rise up the stick. With breath control you can make it hover. If you remove the bead from the end of the skewer and puff hard you can launch the pinwheel to fly free.

The flying pinwheel in action.

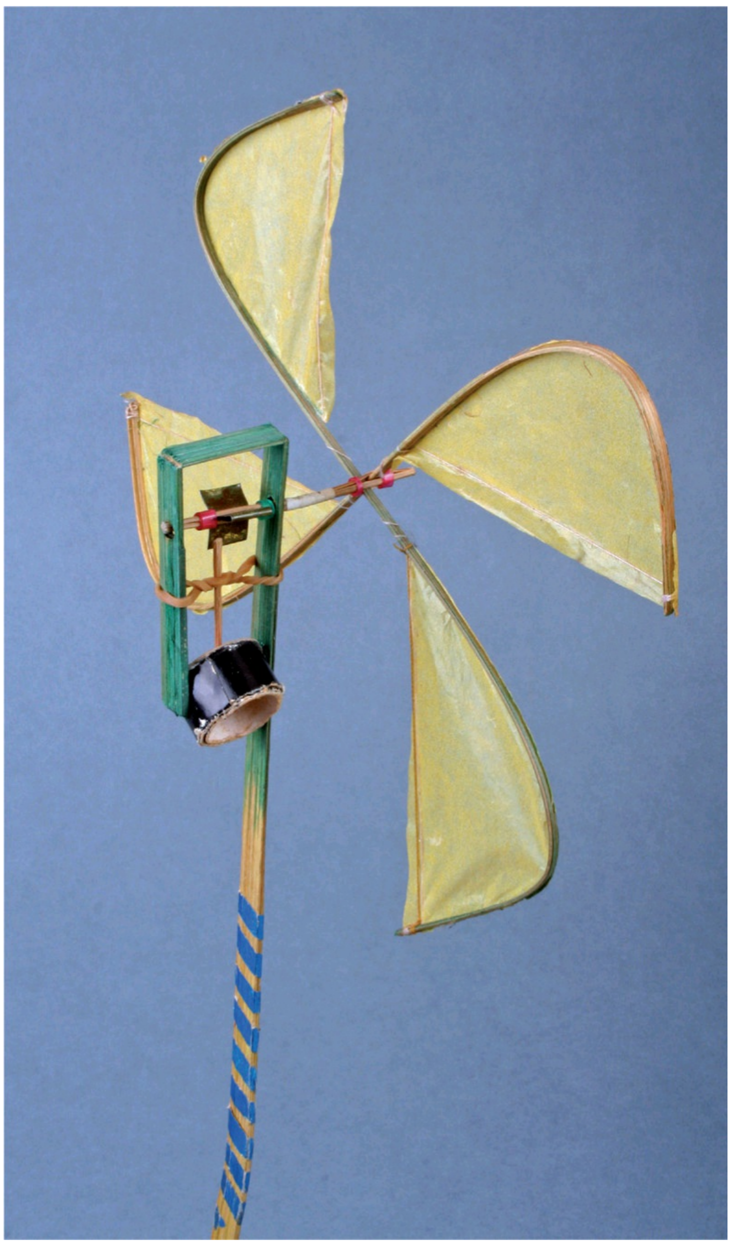
Developing the design for an automaton

In a real windmill the sails are not spinning loosely, but are attached to a shaft, which consequently rotates. Through a mechanism, power can be transmitted from this turning shaft to do work, for example to turn millstones and grind corn. A simple, small-scale example is the traditional Balinese bird scarer. In its most basic form it consists of a bamboo

framework with three bamboo bars mounted over a bamboo tube, which acts as a resonator. The bars are hit by hinged strikers mounted on a shaft which is attached to a bamboo cross piece bearing two sheet metal vanes, set at an angle. The shaft turns in the wind, and the strikers are arranged to produce a rhythmic tinkling sound as they hit the bars in sequence. In slightly fancier examples the shaft also has a crank at the end, which is linked to small movable figures cut from sheet metal and painted.

A Balinese bird scarer. Bamboo and sheet metal. The main shaft, driven by a windmill with two sheet metal vanes, bears hinged strikers which hit bars mounted on the frame to make a rhythmic and fairly melodious noise. This example is embellished by jointed figures of a farmer and a buffalo moved by a link to a crank at the end of the shaft.

Some toy windmills also use the power to do work: an ingenious Indonesian toy, one of my all-time favourites, combines a drum rattle, like a small-scale version of that described in Chapter 5, with a paper and bamboo windmill. The blades are attached to a shaft bearing a cam, made from tinplate, which raises a beater, held in place by a twisted rubber band. The beater then springs back to strike the drum. The bamboo and tissue paper sails on this windmill are a rather more elegant version of the medieval pinwheel, and in a similar way remain flat until moving air twists them into an airscrew form.



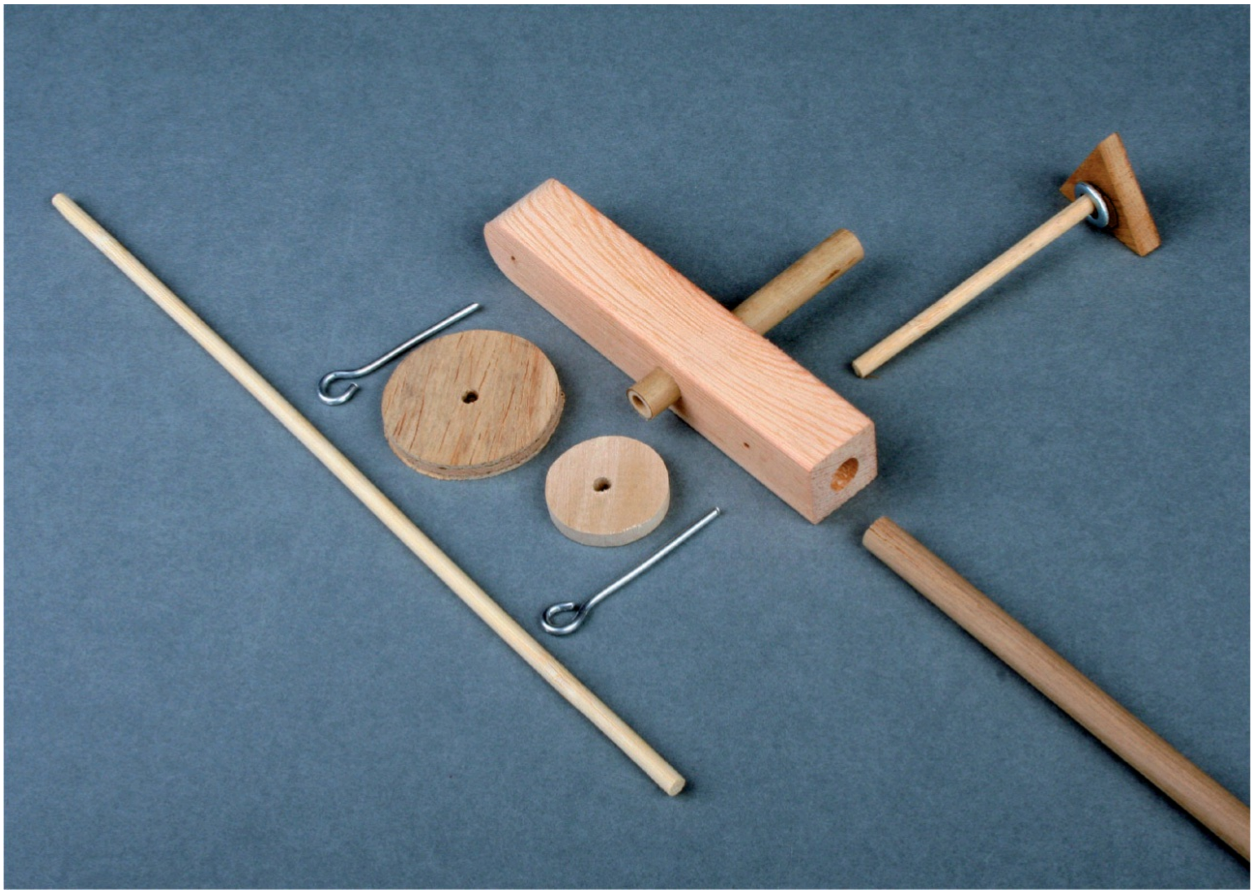
A delicate windmill, operating a small drum rattle (see Chapter 5). The vanes of the windmill are flat, only assuming the shape of an airscrew when in the wind, or moved through the air. Indonesia, 1980s.

Inspired by this Indonesian windmill, for a final project I have played with the idea of a really simple structure for harnessing wind power to do work. The result, shown at the beginning of the chapter, is probably better described as another moving toy than as an automaton, but it has ideas above its station. It consists of a horizontal shaft driven by a windmill, and bearing a cam that rotates a second, vertical shaft carrying a circular ring cut from a plastic drinks bottle. When this ring is set spinning it gives the illusion of a transparent spherical bubble. With two rings from different sized bottles you can get a bubble within a bubble.

Making a bubble spinner

Materials

A piece of wood about 20 × 20 × 110mm (¾ × ¾ × 4¼in); thin wood or plywood to cut discs and a triangular hub; hot drink stirrers; paper; plastic bottle; wire; bamboo tube (or a piece of the outer casing of an old ball point pen); dowel or stick for a handle; thin dowel or skewer for the shafts; metal washer; glue.



Parts for the bubble spinner: the body, the handle, the shafts, the triangular windmill hub, the wire bearings, the bamboo tube, the circular cam and the cam follower.

Tools

Fine-toothed saw; scissors; long-nose pliers; awl; drill and drill bits; sandpaper.

Method

Sand the piece of wood. Drill a hole in the bottom to fit the handle, and round off the top. Drill a hole through it, about 50mm (2in) from the bottom, the right diameter to mount the bamboo tube or pen casing that will form the bearing for the driveshaft.

Cut two pieces of wire, about 50mm (2in) long, and bend at one end to form an eye. These eyes will form the bearings for the vertical shaft and they should be a loose fit on the dowel to be used. Drill holes to mount

these wire bearings, one near the top, and the other about 20mm (¾in) from the bottom.

Push the bamboo tube, or pen casing, into its hole so that about 10mm (⅜in) protrudes on the side with the wire bearings.

The windmill itself is a variation on the simple medieval design, with three vanes instead of two: cut from thin wood an equilateral triangle with 30mm (1¼in) sides for the hub, and a circular disc 25mm (1in) diameter for the cam. Drill a hole centrally in each, to fit tightly onto the thin dowel or bamboo skewer. Glue three hot drink stirrers onto the triangular hub as shown. When the glue has set, glue on three squares of paper to form the three vanes.

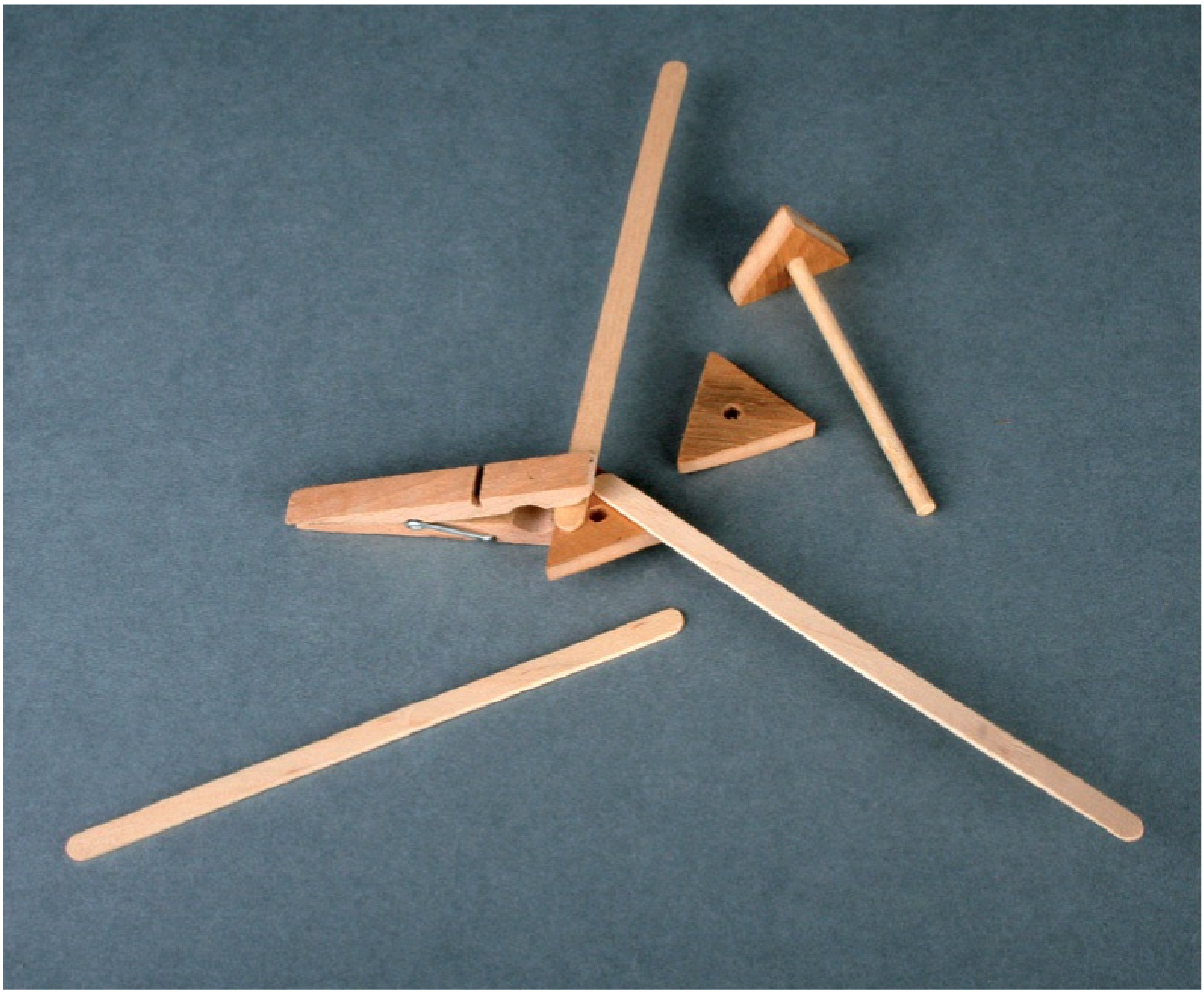
Cut the driveshaft to length: it needs to stick out from the bamboo tube or pen casing just far enough to attach the triangular hub on one side (with a metal washer), and the wooden disc (the cam) on the other, leaving just a little bit of play. Glue the triangular hub onto the shaft, then slide on the metal washer, push the shaft through the tube, and glue on the wooden disc.

Cut another thin wooden disc about 40mm (1½in) diameter and drill a hole in the centre that gives a fairly tight fit on the dowel used for the vertical shaft.

To finish the assembly, check that the wire bearings are the right length to hold the vertical shaft so that the wooden disc mounted on it will just overlap the disc on the driveshaft. With the wire bearings in place, feed the shaft down through the top wire eye, slide on the wooden disc and work it up the shaft until the bottom of the shaft can be fed through the bottom wire eye. Slide the wooden disc up a little higher so that enough of the shaft protrudes at the bottom to prevent it from becoming unseated from the lower wire eye. If necessary, secure the wooden disc in place on the shaft with a dab of glue.

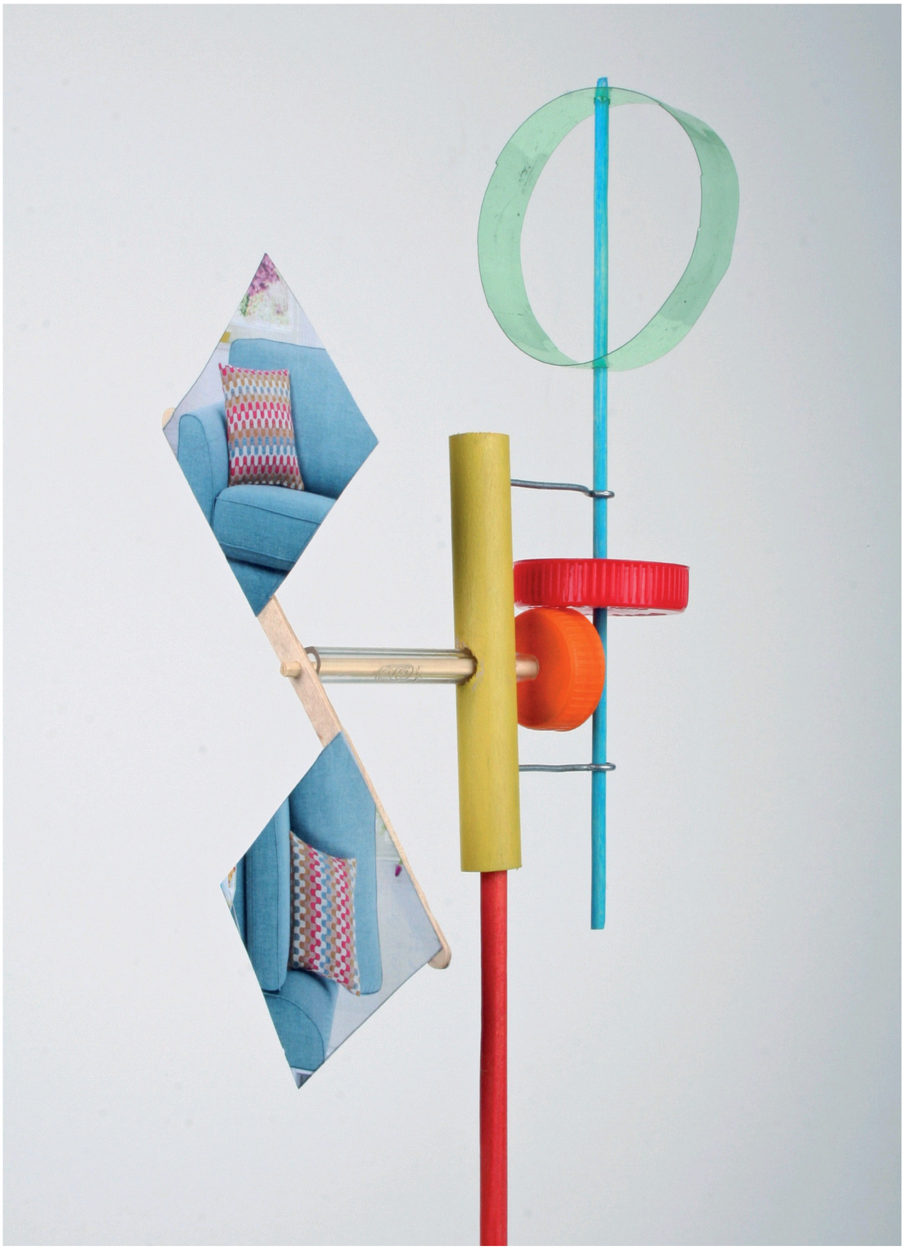
Check that the larger wooden disc sits on the edge of the smaller one, and that both the shafts move freely in their bearings. Now if you hold the handle up vertically, and move the windmill through the air, the rotation of the circular wooden cam should be transferred to the vertical shaft through the wooden follower that rests on it. This is known as a ‘friction drive’.

Finally, cut a ring from a plastic bottle, or possibly two rings from two different sized bottles. Use an awl to make holes to mount them as squarely as possible on the vertical shaft.



The windmill. Gluing on the hot drink stirrers.

For a slightly smaller version I used a two-bladed medieval type windmill, and plastic bottle tops instead of wooden discs for the cam and follower.



An alternative version of the bubble spinner with a two-vaned windmill. It uses a ballpoint pen casing to support the drive shaft and plastic bottle tops for the cam and cam follower.

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