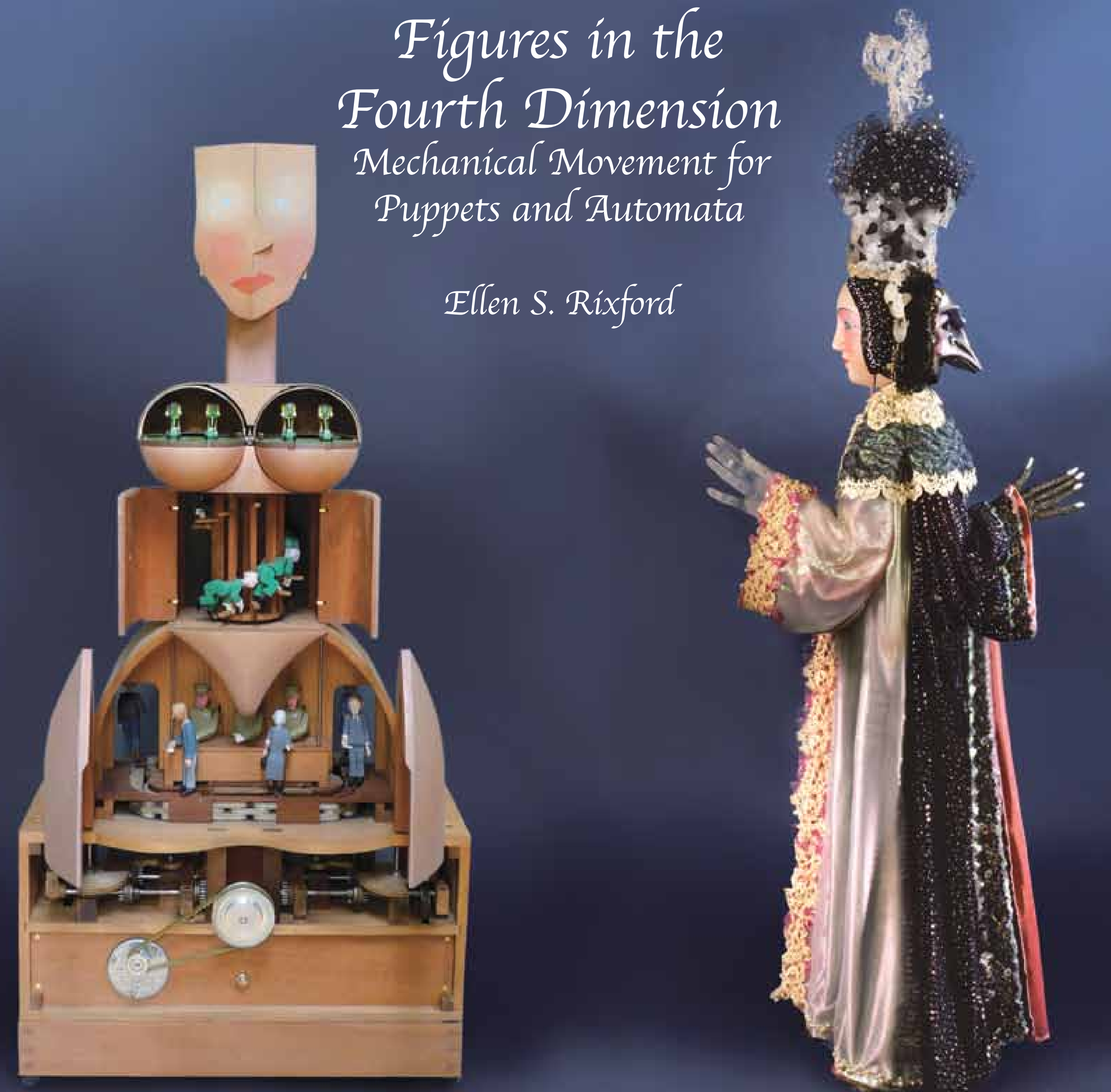
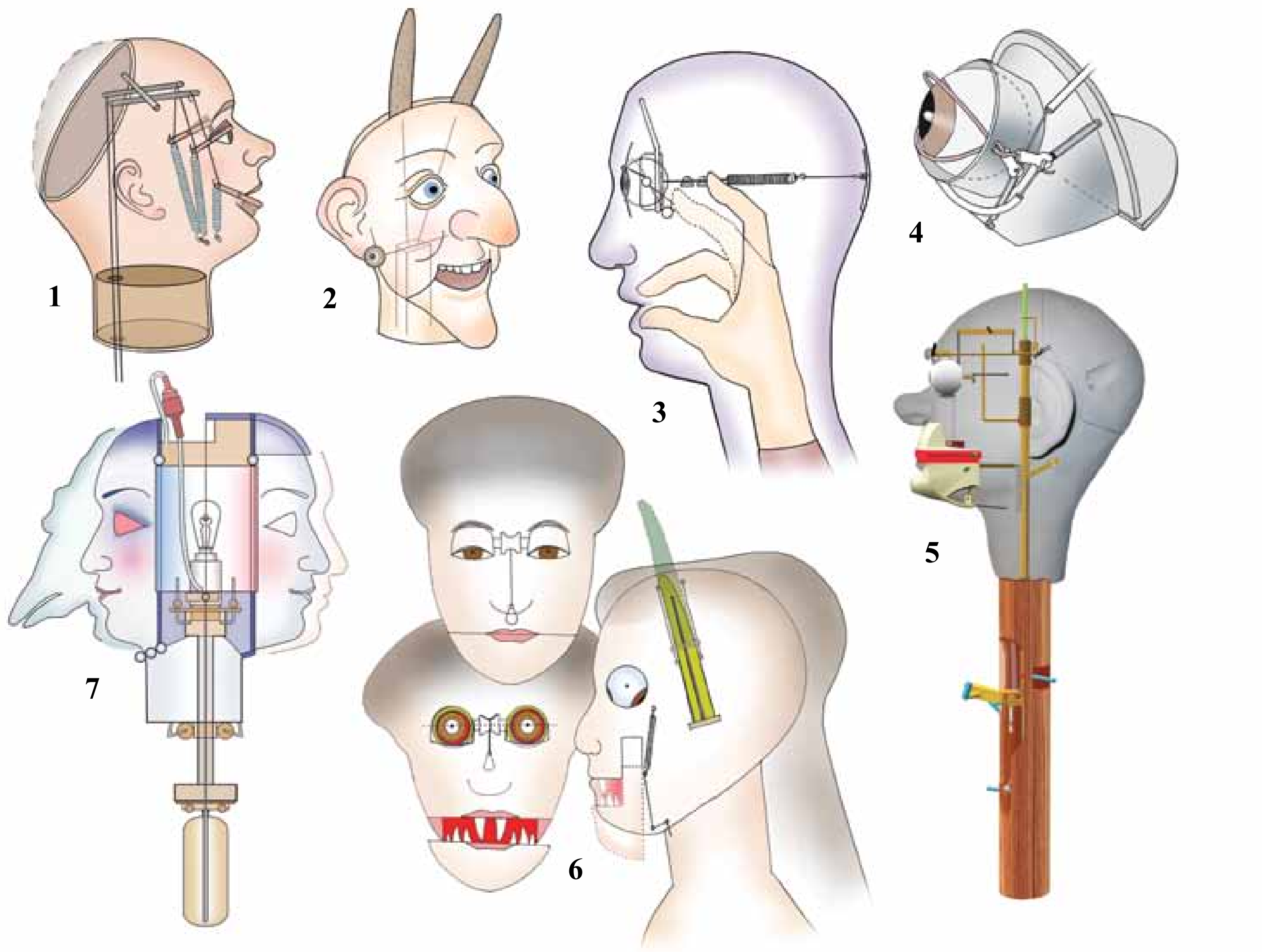
Figures in the Fourth Dimension

Mechanical Movement for Puppets and Automata

Ellen S. Rixford





Some samples of the many technical drawings you will find in this book: Clockwise from upper left: 1. Gustave Vichy's head of a French peasant, showing eye blinks and flexible lower lip. 2. Rixford Studio's Judy, with hinged jaw and horns. 3. Rixford Studio's all-directional rolling eyeballs with blinkers. 4. Jim Kroupa's eye-roll and blinker assembly. 5. Dan Lavender's ventriloquist figure head with control stick. 6. Japanese Bunraku puppet Kiyohime, a pretty maiden transformed into a monster by a dropping lower face section, and reversing eyeballs. 7. Ellen Rixford's Goddess of Heaven, a double-faced puppet with interior light and masks.

ISBN 978-0-578-15865-5
90000>

Sample pages from Figures in the Fourth Dimension — as a pdf

This book is a combination volume— a lovingly designed art book, and a meticulously researched technical "teaching" book. It is 512 pages long, all in color, with hard cover and dust jacket. It has over 1500 illustrations — beautiful photographs of puppets and automata in action, and carefully detailed technical drawings of the mechanisms that make them move. The book contains work from three major museums, and over thirty world-class artists from all over the planet. The purpose of the book: to show how to build mechanical devices and linkages for puppets and automata, and introduce these techniques to a readership ranging from the beginner to the sophisticated artist-craftsman. To that end, the artists included in the book had to submit not only excellent quality photos of their pieces (preferably in several positions) but detailed drawings and diagrams showing how the pieces are actually built, and how they really work. In this pdf, you will see, first, the table of contents, listing everything to be found in the book, and then sample pages, showing the artworks, and their technical drawings.

Because this pdf is meant as a sample only, to give you a good general idea of the book's contents, it concentrates on a few representative pages from each section, and shows their major visual elements. Because of space constraints, the pdf eliminates some of the extremely detailed text explanations and the extensive labeling of the drawings which are present in the actual book. More information at the website figuresinthefourthdimension.com. The book can be purchased at this website, and perhaps at a few other locations. To date, this website is probably the best place to find it. You can also email me at my personal email: ellenrixford@netscape.net.

Cover: At left, Untitled, automaton by Paul Spooner. At right, Goddess of Heaven, puppet by Ellen Rixford. Photos by the artists. Title page: At left, Piano, automaton by Peter Markey, photo by Michael Croft. At right, Thurston, ventriloquist figure by Bill Nelson; mechanics by Dan Lavender. Photo by Walter Gresham.

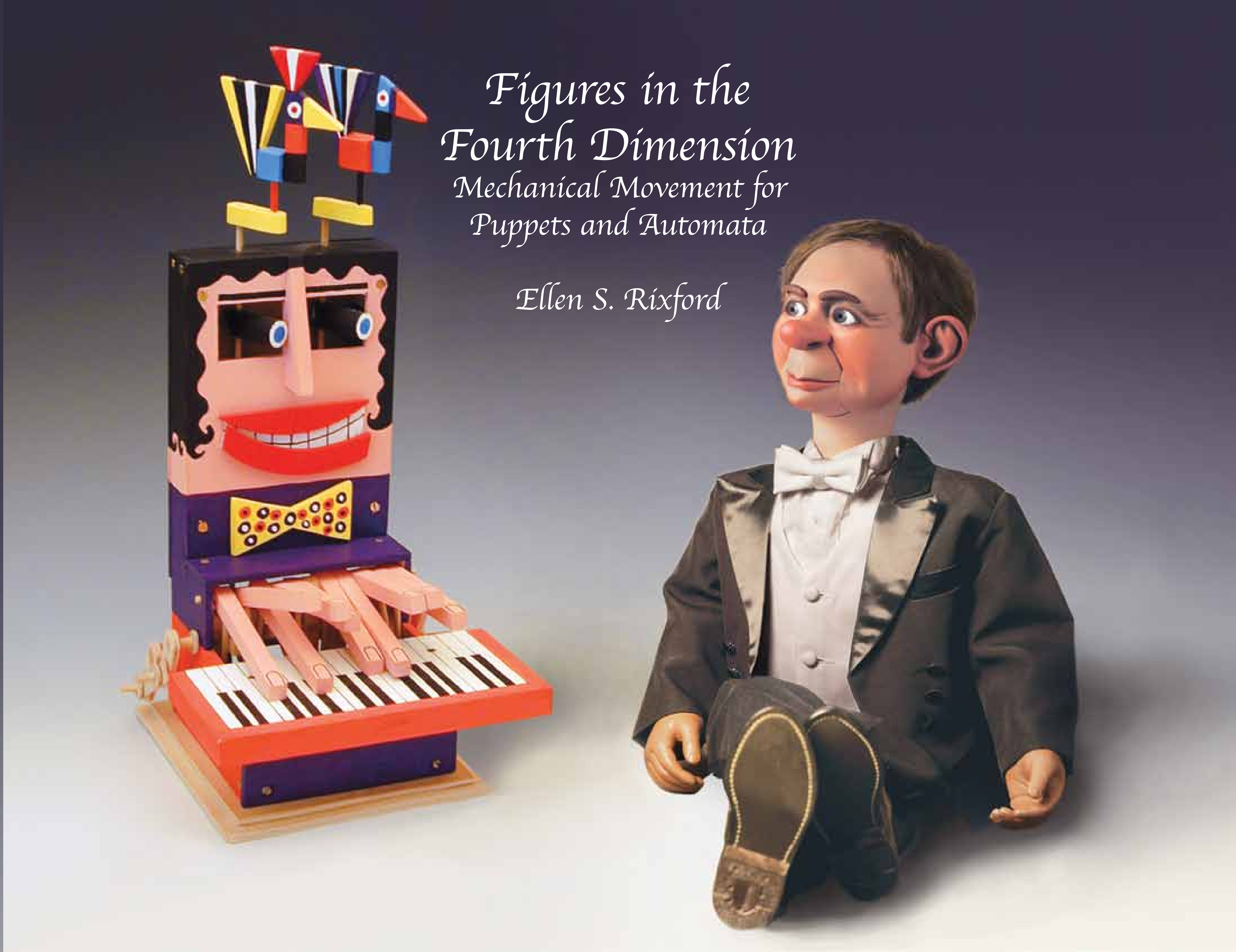


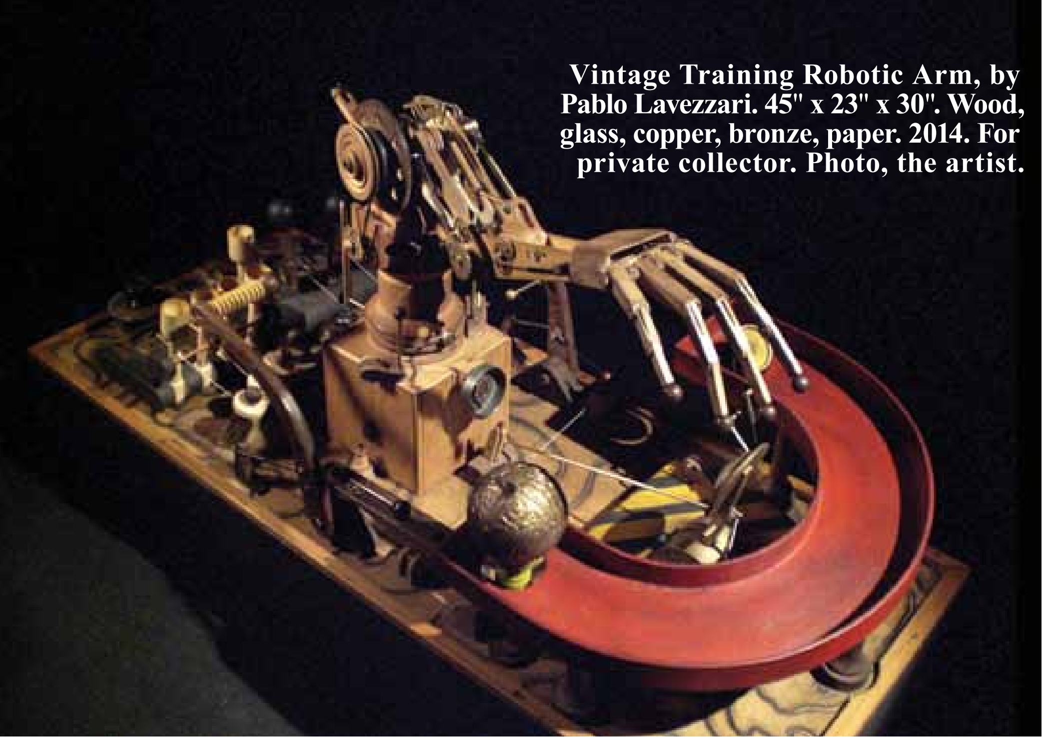
Table of Contents

The Basics.....For the Beginner.....

Puppets and Puppeteers

"Illuminated" Puppets — and Automata

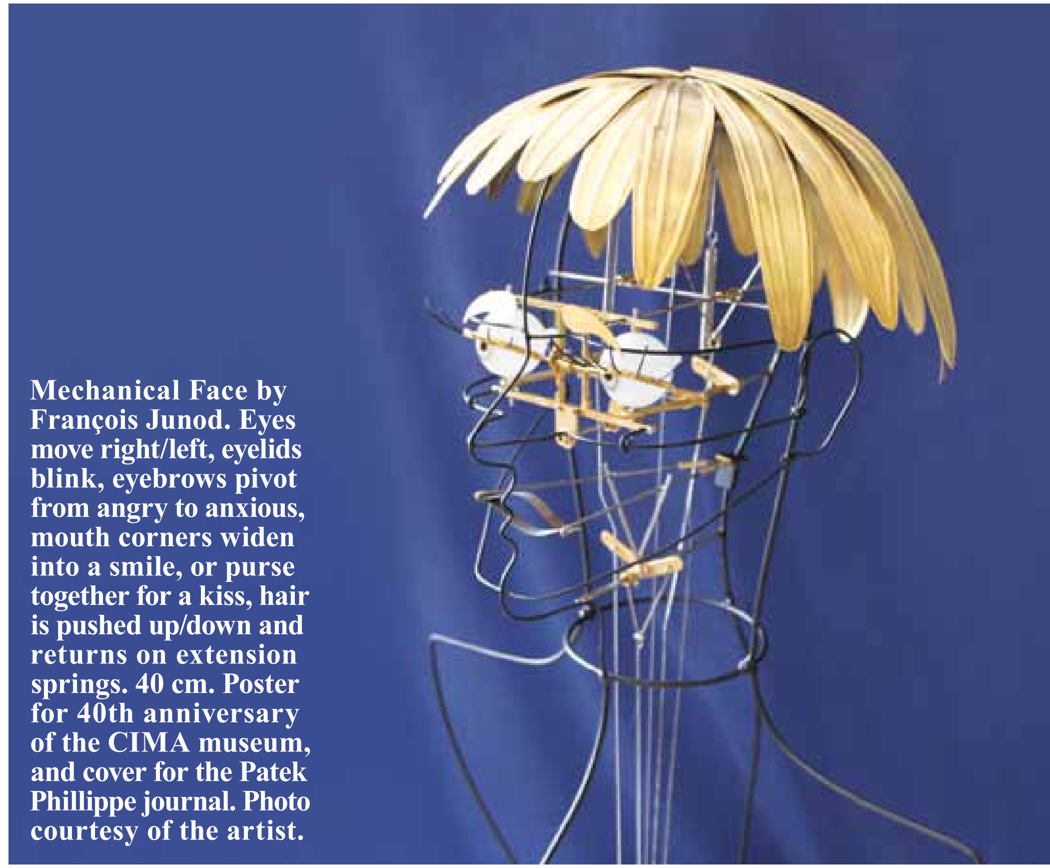
Diva, smoking chanteuse marionette by Phillip Huber: An LED at the end of the cigarette has two wires; one travels through the holder to the end, where a copper wire loop terminates at the mouthpiece. The second wire is threaded through the holder, through the hand, up the arm, through the shoulder and neck, into the head, where it connects to a 12-volt battery. The battery has a wire from the other end that terminates in a copper ring embedded in the Diva's lip. When the end of the holder contacts the ring in the lip, a circuit is completed, the LED lights up, and the Diva takes a drag on her cigarette. 28" tall. Wood, Celastic, theatrical fabrics, wire, epoxy putty, sheet stainless steel, and brass tubing. 2015. Photos, the artist.



Vintage Training Robotic Arm, by Pablo Lavezzari. 45" x 23" x 30". Wood, glass, copper, bronze, paper. 2014. For private collector. Photo, the artist.

Modern Automata:

*In this section, there are varying levels of difficulty. To make things easier, I suggest four levels. *= fairly easy to understand, **=moderately difficult, ***=complex, •=very complex.*



Mechanical Face by François Junod. Eyes move right/left, eyelids blink, eyebrows pivot from angry to anxious, mouth corners widen into a smile, or purse together for a kiss, hair is pushed up/down and returns on extension springs. 40 cm. Poster for 40th anniversary of the CIMA museum, and cover for the Patek Phillippe journal. Photo courtesy of the artist.

Clockwork Automata, Modern and Historical

These machines are powered entirely by a mainsprings. and regulated by either fan-bladed governors, or by escapements.

The website for this book, figuresinthefourthdimension.com, contains some supplementary information, images and an ebibliography that is far more extensive, with many more sites, than the one offered in this printed book.

Pierrot Writing, by Gustave Vichy. A sleepy Pierrot "writes" a letter to his Columbine, turning up the gaslight as it dims. 25" x 21½" x 14". Wood, papier maché, steel, brass, leather, gesso, oil paint, various fabrics. 1895. Photo, the Guinness Collection, Morris Museum

Bill Nelson's group portrait of celebrities: Barack Obama, Bill Gates, Julia Roberts, Alfred E. Neuman, Will Shakespeare, Michael Jackson, the Frankenstein monster, Sean Connery, Mark Twain, Albert Einstein, and Clint Eastwood. At right, series of assorted funny-face vent figures from Inspired Worx, collaboration between Bill Nelson and Dan Lavender.

Basic Mechanics

Power sources

At the beginning of mechanical movement is the source of power; it is what, if you like, sets the magic in motion. The puppeteer can bypass a good many of the problems which must be solved by builders of other kinds of mechanical figures; instead of needing to install a built-in power source which will drive and coordinate movement, the puppeteer directly connects to the figure in real time. Usually it's hands. Hand puppets, the most simply constructed of all little actors, use but three fingers for head and both arms. Even so, some hand puppets can be built so the head-finger can manipulate an opening mouth. For larger and more complex puppets the puppeteer can use various convenient body parts — fingers, hands, arms, sometimes legs, feet, torso, head, especially if the limbs of the puppet are connected directly to the manipulator's. Marionettes are held up by strings and a control; rod puppets, including ventriloquist figures and the Bunraku puppets of classical Japanese puppet theater, are mounted on and manipulated by vertical rods, or "head sticks," often with triggers powering individual features. As many as three puppeteers, shrouded in black, and standing behind the puppet, are required to give the more important Bunraku characters their delicate and expressive gestures. The master puppeteer manipulates the head, often with mechanical facial features, another puppeteer works the hands, a third controls the feet.

Some large modern puppets are mounted on body harnesses to distribute weight. Some puppets have their bodies locked to the puppeteer's, their hands and feet connected to the puppeteer's hands and feet, so the puppet closely imitates the puppeteer's movements. Large puppets can even morph into full body costumes worn by the puppeteer. Muppet-style puppets' heads have facial features worked by one of the puppeteer's hands inside the head, while the puppet's hands are worked by rods held by the puppeteer's other hand. If the puppet has to do complex hand movements, like playing the piano, a second puppeteer wears gloves that look like the puppet's hands, "Fozzie Bear" style. Whatever the form of connection, the puppeteer is in complete control of timing, and can decide whether, when, and how much to move a feature, or combine movements.

For the automatist, there are additional problems.

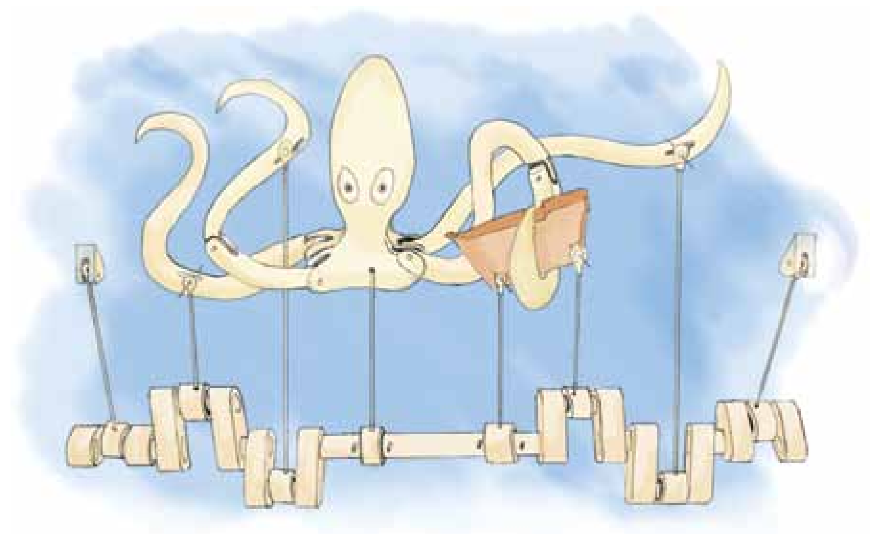
1. The figure isn't manipulated by the artist, so it has to be powered by a self-contained power source. The three major power sources are hand cranks, motors, and, mostly for the antique automata of the pre-electric age, clockwork — a strong mainspring, contained within a barrel. There are a few external sources: an occasional sand-powered automaton, the delicately balanced

Kiyohime: Bunraku character of a maiden who becomes a monster because her amorous advances are rejected by a Buddhist monk. ⅔ life size. Wood, human hair, whale baleen for spring return. Her eyes reverse, becoming bloodshot staring orbs, her jaw drops down revealing a set of pointed teeth, her horns extrude — all at the pull of a lever. Traditional puppet by master puppet builder Toru Saito. Both photos by Mr. Saito. Other photos, technical drawings and a detailed description of possible ways to build the mechanics for these movements appear in the next section—on mechanical devices..

mobiles of Alexander Calder, and recently, the wind-powered perambulating Strandbeests of Theo Jansen. While there is no reason why many new automata couldn't be powered by wind, water, changing magnetic fields, solar power, or even sand, these are, at present, exceptions.

2. Because timing, type and quality of a figure's movements are controlled internally as well, the automaton must rely on a whole series of mechanical devices to help it perform. I will describe them in order of simplicity, and explain their connections to each other. In writing about mechanical movement, there is a general term: **"linkages"** which is often used rather vaguely to describe mechanical devices in general. Linkages do link mechanical devices, transferring motion between them. But as there are a great many devices in mechanics, this can lead to confusion as to which device is technically a linkage. So for clarity, here "linkages" will mean those devices or combinations of them

If the drive shaft has bends in it, it becomes a crank shaft. When the drive shaft ends in a bend with a handle on the end of it, that is a crank handle, powering the automaton. Cranks and crank shafts are normally used when one wants to change direction from rotating to reciprocal motion — back and forth, side to side, or up and down. The bigger the bend in a crank shaft, the bigger the reciprocal motion. Cranks can be bent rods; crank shafts can be bent rods or combinations of rods, straight and/or bent. The bends are not always straight 90° angles, either. Curved or wavy bends (often made with wire) can result in a beautiful reciprocating wavy movement, like surf in a mechanical seascape, or the writhing of a mechanical snake or dragon. Cranks can be power sources, or links which transfer power to something else They can change the direction, dimension, and effort needed for a movement. When the crank is used as a lever turning the drive shaft, the length of its handle increases force or torque, making it easier to rotate the automaton's drive shaft. Many automata, even quite complex ones, are hand cranked. Nearly all automata contain some form of crank or crankshaft within their mechanics. And cranks and crank shafts offer many possibilities to the puppeteer, who can rotate a pair of eyeballs, raise or lower eyebrows, or swing open a pivoting jaw by connecting these linkages to cranks plus push-pull rods or pull-cables inside the puppet's head.



Here Be Monsters, by Wanda Sowry. Drawing of a crank-operated crank shaft powered writhing giant squid doing dreadful things to a lifeboat. 35 x 30 x 12 cm. Wood, 2005, Collection, the artist, who also did the drawing. See more details on this piece in the chapter on Sowry's work.

Levers

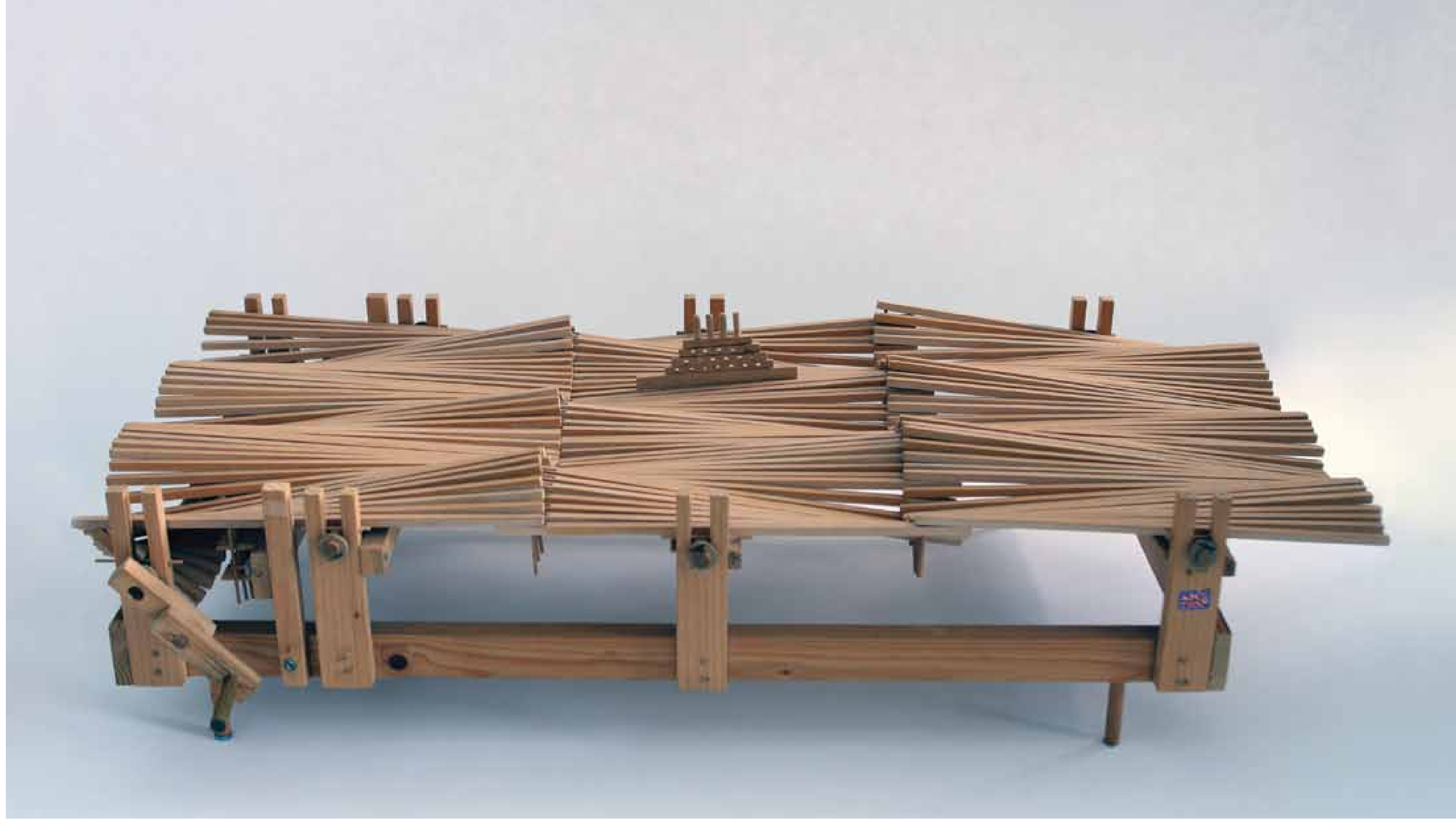
Levers are pivoted rods; the pivot here is called the lever's **fulcrum**. They appear in nearly every automaton, and in many puppet mechanics as well. They can help marionettists by vastly extending the "reach" of a movement on a control; they often serve the automatist as "rider-followers," transmitting motion from one device to another. Most often they are straight, but can also be bent; in French they are called a **"levier coudé"** or "elbowed" lever and in English, a **bell crank**, illustrated in the following pages. As discussed below, a bent lever or bell crank will, instead of moving something at a 180° angle, move it at a different angle, depending on the angle of the bend. It can also change distances.

There are three types, or classes, of levers.

A class one lever consists of a bar with the pivot point or fulcrum in the middle, the force moving the bar at one end and the load, or weight of something to be moved, at the other. When the force applied and load are equal, or perfectly balanced, that is equilibrium — no change in movement. When either the force or the load increases or decreases, equilibrium is lost; there is movement. Levers can vary the relationship between the force needed to move a load and the weight of the load, depending on the placement of the fulcrum. Using a lever, and placing the fulcrum or pivot appropriately, a small force can move a very large load. A longer distance between the fulcrum and the force and a correspondingly short distance between fulcrum and load proportionally increases the **mechanical advantage**, or the ratio of load/force. The greater the distance the greater the weight or number of units of load that can be moved by one unit of force. And vice versa. Examples of class one levers: children's see-saws, a long crowbar prying up a heavy rock; scissors, pliers, bolt cutters where the hinge is the fulcrum, the material being cut or squeezed is the load, and the force is the hand.

A class two lever has the fulcrum at one end, the load in the middle, and the force at the opposite end. Because in this configuration the distance between the fulcrum and the force must be longer than the distance between the fulcrum and the load, this kind of lever always results in positive mechanical advantage, less force moving more of a load. This kind of lever is useful for devices needing to greatly lessen the force needed to move a given load: nutcrackers, wheelbarrows.

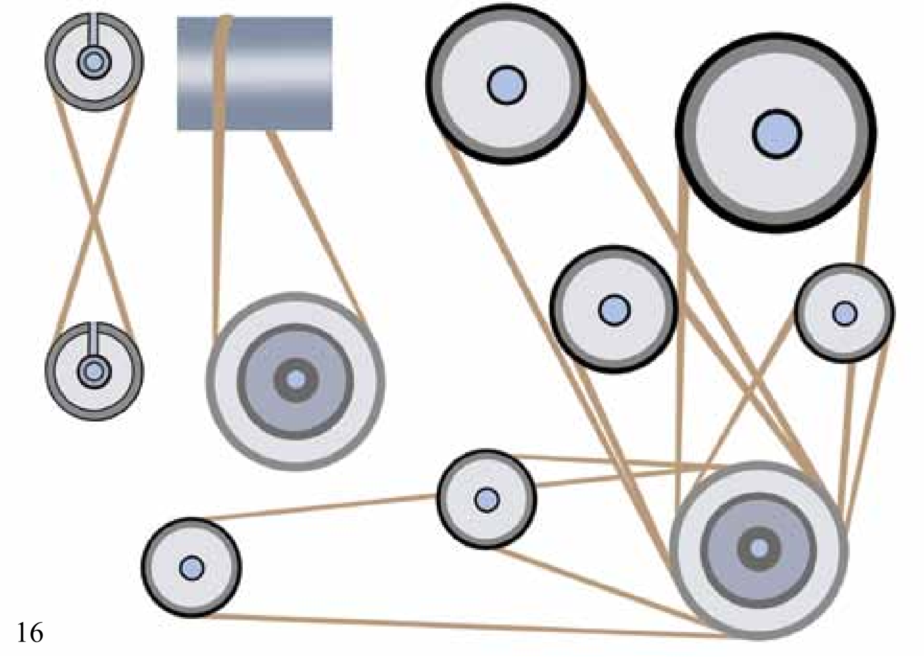
A Class three lever also has the fulcrum at one end, but the force is in the middle and the load is at the end. Here the distance between the fulcrum and the force is shorter, resulting in a mechanical advantage of less than one. This kind of lever is useful if not much force, but greater precision is required; example: a pair of tweezers. Class one and class two levers are very frequently used as followers in automata, and often appear as part of puppet mechanics and controls as well. Class three levers appear less often, but can be useful when one wants to "step down" the level of force for a very small, delicate movement.

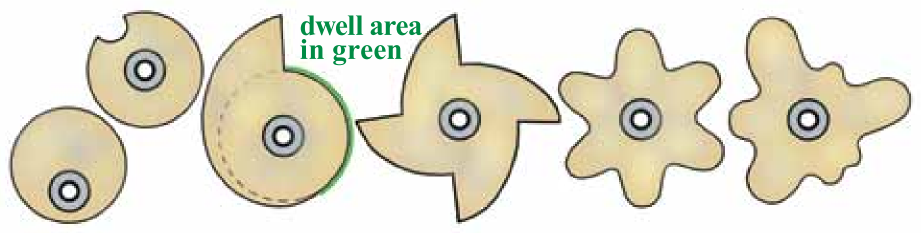


Big Wave, by Peter Markey. Storm-tossed seascape made entirely of first class levers. The left-hand set of levers transmits the motion from a lineup of staggered cams just underneath them on the left side. (See more on cams in cam section.) The left-hand set of levers is a little heavier on the left than the right, keeping them in contact with the cams. The right-hand levers, because they are heavier on their inner or left-hand ends, act as counterweights keeping all the ends of the bars in contact, and acting on each other. The middle set of levers are in equilibrium and follow the actions of the outer sets. A tiny ship rides the tossing middle set of lever "waves". Size is about 30 cm. wide, 30 cm. deep, 50 cm. tall. Sculpture is of wood — fir boards bought in ready-made sizes from do-it-yourself shops; the paint is also do-it-yourself water soluble acrylic based emulsion for house walls. Cabaret Mechanical Theatre. Credit, Falmouth Art Gallery, Collection, Falmouth Art Gallery. Photo, Steve Tanner.

Pulleys

They are wheels connected to other wheels via belts. The wheels can be made of any hard material (for example, wood, plastic, metal) and the belts can be any strong and flexible connector (for example, leather, nylon or rubber). One wheel turns the other due to the friction generated by the belt rubbing over the wheel edge and pulling it around. Thus, pulleys are classified as **friction drives**. The wheels can have various kinds of edges — most often concave rims at the wheel edge or a simple groove to hold the belt, increase friction, and keep it from slipping off. A common use for pulleys in automata and puppetry is transmitting rotational movement from one part of the piece to another part, or to several other parts. A primary pulley wheel on a drive shaft, rotated by the crank that powers the automaton, can be connected via one or several wheel and belt combinations to secondary wheels or shafts in other parts of the piece, causing many parts to rotate at once. If the pulley wheels are of different sizes, they rotate at varying speeds. If the pulley wheel at the beginning of the sequence is a large diameter one, say one foot, and the wheel (or shaft) belted to it is smaller, say, one-fourth the diameter, or three inches, one rotation of the first pulley will result in four rotations of the smaller one. In ALL rotating devices: pulleys, friction drives, gears, increasing the rpm speed of any wheel-related device proportionally decreases force; decreasing speed increases force. In automata, this is a major consideration. Some parts of a mechanical movement need to turn with more force to power heavy mechanical devices. Other parts need a very light force so they can be easily braked.

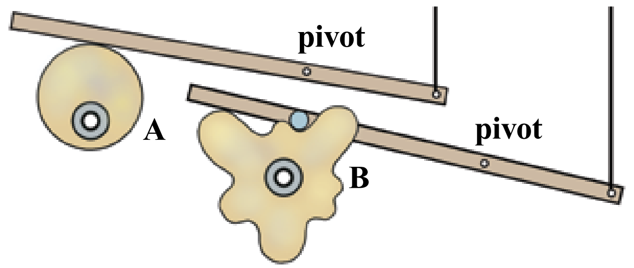




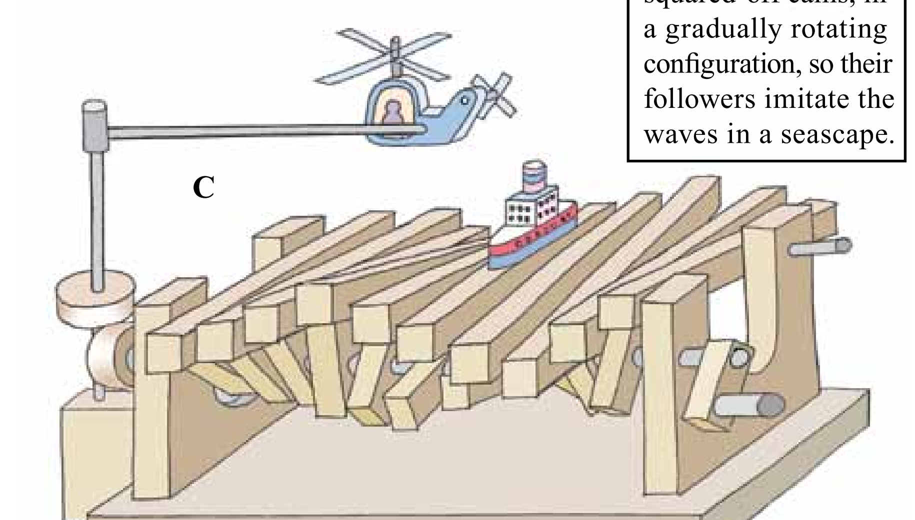
Varying cam profiles: Left to right, an eccentric; a cam used as a switch; a nautilus (green line on the nautilus indicates **dwell,** the time when the cam, turning, will not influence movement because its throw doesn't change); then a four-pointed nautilus (four sudden movements); a daisy/flower petal, and an irregularly-lobed cam. Infinite varieties of cam profiles are possible. Profiles depend on the kind of movement the automatist wants to produce.

Cams

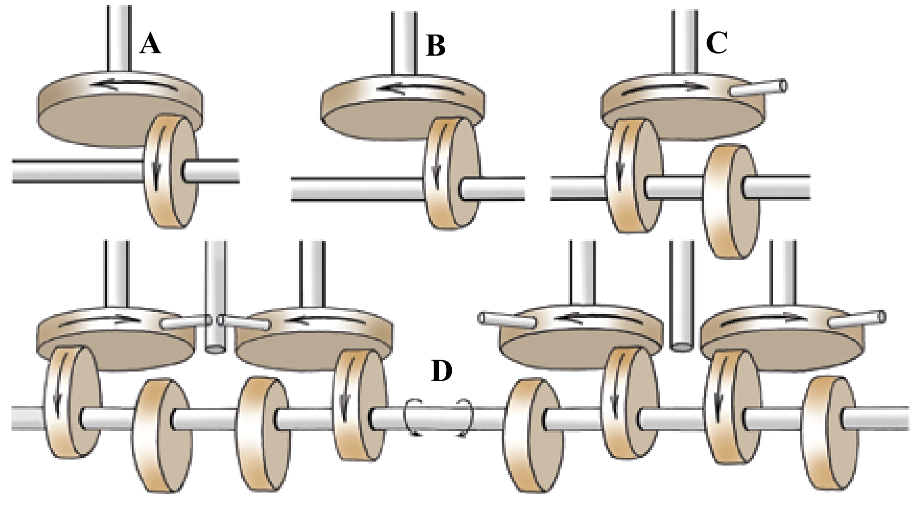
While the crank and shaft give fairly simple reciprocal movements, the cam offers possibilities for more complex movements, with more variety. Cams are disks, usually but not always two-dimensional, whose shapes or **profiles** modify movement as they rotate. They are used to control the nature and timing of movement. Cam profiles can come in any number of variations. The simplest are **eccentric** or off-center cams — a disk with an eccentric center pivot. Then come egg-shaped, heart-shaped, and multi-lobed shapes, sometimes called daisy cams because their shape reminds one of flower petals; and the so-called **nautilus** or **snail** cam, because of its resemblance to the shell. The nautilus cam has a gradually rising profile which suddenly drops back to the point nearest the center. If you measure the distances between a cam's center pivot point, and the cam's edges, you will get the **throw** of the cam. It is the difference between the shortest distance pivot-to-edge, and the longest distance pivot-to-edge. This would be the distance something attached to or resting on the cam would travel back and forth as the cam rotates. In the case of the eccentric circle, egg-shape or oval shape, the distance gradually increases and decreases in a regular pattern. The eccentric circle and egg-shaped type of cam will give gradual movements from one point to another — one cycle per revolution of the cam: an arm rising and falling, a head or body turning, wings unfolding and folding, a box or a door opening and closing, a mask removed and replaced. The nautilus cam's profile results in a gradual movement in one direction followed by a very sudden movement in the other: an executioner raising his axe and suddenly bringing it down to chop off a head, or a lion snapping off the head of a circus performer. This kind of cam can also be used as a **switching mechanism**. Another very simple switching device is a disk cam with a little "bite" taken out of it. **Multi-lobed** profiles result in many movements back and forth per cam revolution.



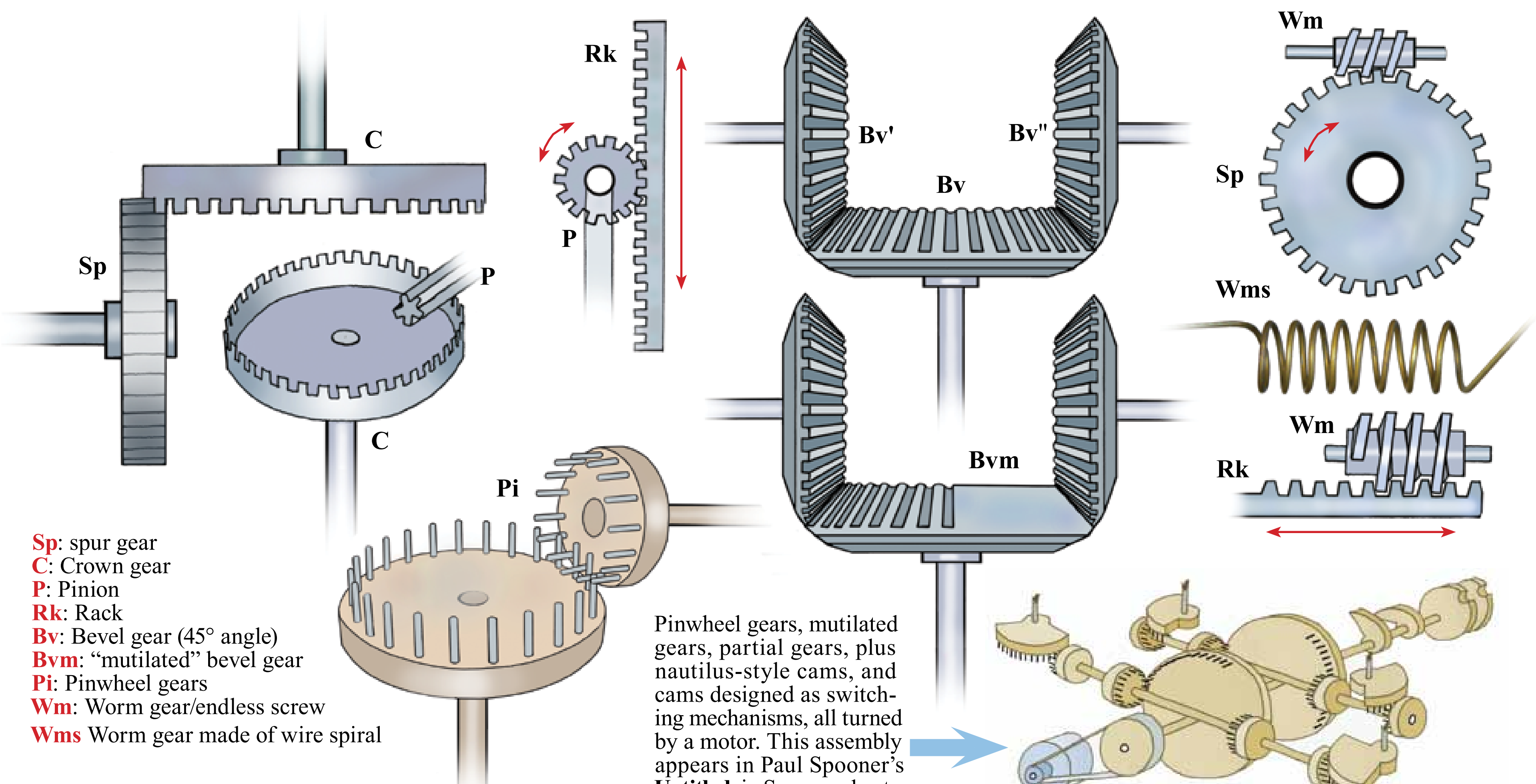
A, a simple offset disk cam can be read by a simple follower riding on the rim. B, more complex cams require a follower with a roller attached to the side. C, a line-up of simple squared-off cams, in a gradually rotating configuration, so their followers imitate the waves in a seascape.



Drawing of **Waves**, by Peter Markey



A Transport of Delight, by Keith Newstead. Rods and cables, connected to attachment points on the wheels make the driver pedal and move the handlebars, and wave the bat wings. Size: 12" x 8" x 15". Wood, brass, wire, acylic paint. July 1999. Private collector. Photo, Keith Newstead.



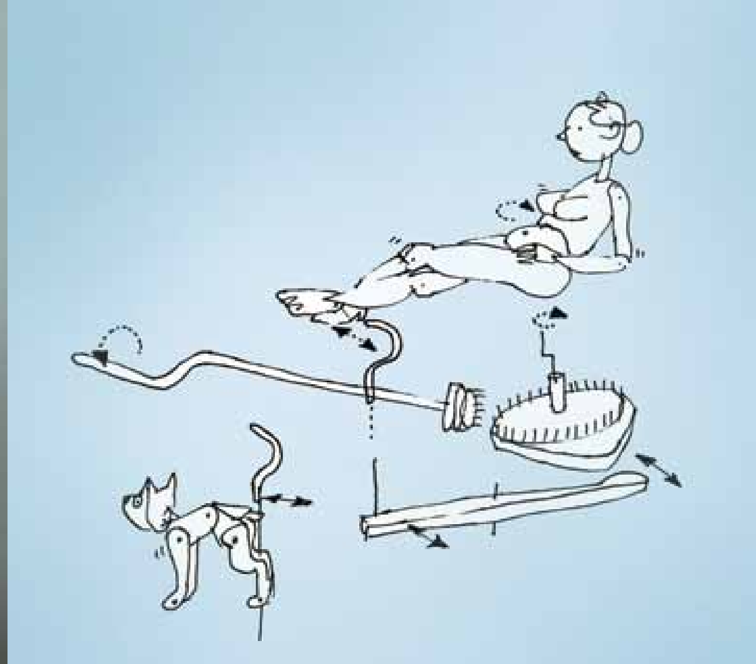
Sp: spur gear
C: Crown gear
P: Pinion
Rk: Rack
Bv: Bevel gear (45° angle)
Bvm: "mutilated" bevel gear
Pi: Pinwheel gears
Wm: Worm gear/endless screw
Wms Worm gear made of wire spiral

Pinwheel gears, mutilated gears, partial gears, plus nautilus-style cams, and cams designed as switching mechanisms, all turned by a motor. This assembly appears in Paul Spooner's **Untitled**, in Spooner chapter.

Gears and Gear-related

Remember the sprocket wheels and chain which appeared a few pages ago, along with the text and illustrations about pulleys? Where pulleys and other kinds of friction drives engage using surface-to-surface friction, positive drives engage using interlocking teeth. The teeth on the sprocket wheel receive or impart force as they lock into the links in the sprocket chain. The teeth in gears lock into the teeth in adjoining gears, or in another corresponding part. There are many kinds of gears. Industrial gears come in almost every conceivable kind of shape and size, including eccentric, elliptical, intermittent, hollow, and sun-and-planet. The above illustrations offer only a partial list, but they are the ones most commonly used in kinetic sculpture. A **spur gear** is a medium-sized gear, a fairly standard disk shape, with teeth spaced evenly around its rim. Occasionally, when two or more adjacent spur gears of the same or similar size are needed for a movement; they are placed so that one drives the others. The "extra" driven gears are called **idler gears**; they don't contribute any power to the actual gear sequence, but they are necessary to drive linkages connected to them. A spur gear is frequently paired with a **pinion**, a smaller-sized gear adjoining it, or on the same shaft. **Spur gear-and-pinion combinations** are often used in **gear trains** to speed up or slow down rotation and change force (torque) ratios. (See following pages.)

Changing the plane of rotation: Gears that mesh at a 45° angle, called **miter gears** if their diameters are the same, or **bevel gears**, if their diameters are different, change the plane 90°. Many automatists building gears in a home



Olympia, by Paul Spooner. 24 cm x 16 cm x 100 cm. Wood, steel wire, brass, painted in acrylic. Photo of the piece by Gary Alexander. Drawing by Paul Spooner. Collection, Cabaret Mechanical Theater.
The pinwheel gears visible in the drawing, are also visible under Olympia's couch. Spooner cleverly uses the tail on the leopard couch as a crank!

workshop resort to **pinwheel gears**, a clever alternative to the manufactured kind. Here, pins are glued into disks at regular intervals. The intervals must be very carefully spaced for the gears to engage smoothly, and the disks should be made of very hard and durable materials, so the constant stress on the pins won't loosen them. Pairing a spur gear with a **worm gear**, or **endless screw** also changes direction; this combination is frequently used in clockwork automata, where the screw gear is on a long shaft terminating in a fan blade, which slows down the speed of the automaton's mechanism. (See section on governors.) In the home workshop, a spiraled wire can take the place of a "store-bought" worm gear. Pinions and worm gears, paired with **racks** (as in **rack-and-pinion** combinations) change rotary motion into lateral movement. This is useful in providing a slider motion, an automaton raising his hat, or a figure with an extending body, limbs or nose.

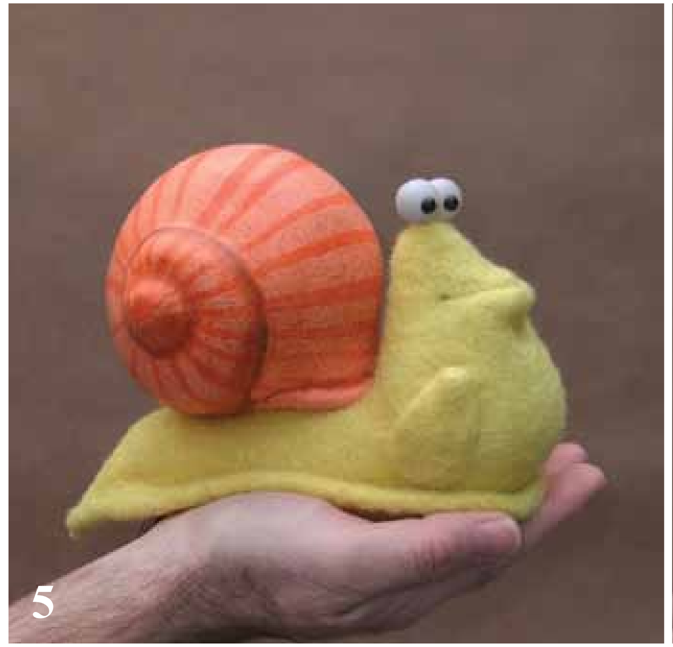
Intermittent motion: Sometimes it's necessary to temporarily stop a movement or to alternate movements. Simply removing the teeth from a gear can accomplish this. This device, called a **mutilated gear**, can stop the movement of one part of a mechanism while the other parts remain in motion, and stop motion in varying proportions, depending on the ratio of teeth that are removed from a gear. As in the diagram of the **Untitled** pinwheel gear assembly on the adjoining page, removal of all but ⅓ of the teeth in the large pinwheel gears mean that at any given time during the automaton's movement, ⅓ of the whole mechanism will be moving while the rest remains stationary.

1

2

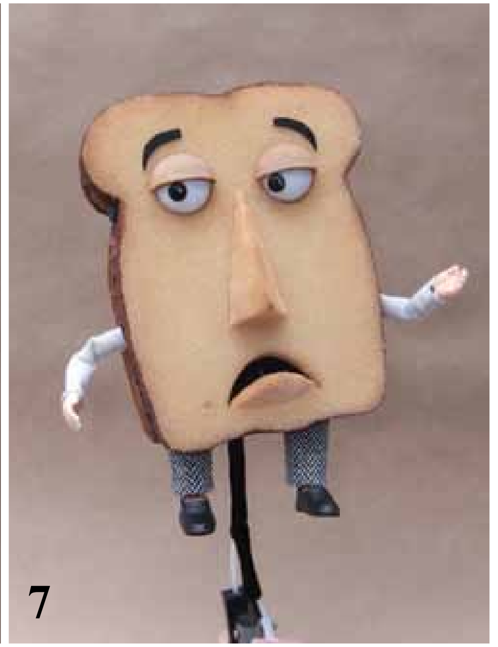
3

4



5

6



7

"A Spring and a String....."

.......is Jim Kroupa's light-hearted summary of his work. Here, a collection of his puppets, various sizes, for various clients. The drawing at right shows a general control design. The puppets use variations on this theme. (See the Kroupa chapter for more information.)

1, **Blue Guitar Player**: One of a bug rock group called the Beetles. About 9" tall, his body is made of blue fake fur, with plastic dome eyes, and pipe-cleaner antennae. His jaw is hinged, and he has a lip-synch trigger on his control rod. His arms are long skinny extension springs, which jiggle at the slightest touch This puppet was made in 1999 for Kroupa's birthday party show. The Beetles sang to sped-up versions of pop songs, so that the music sounded like it was being sung by a chorus of insects.

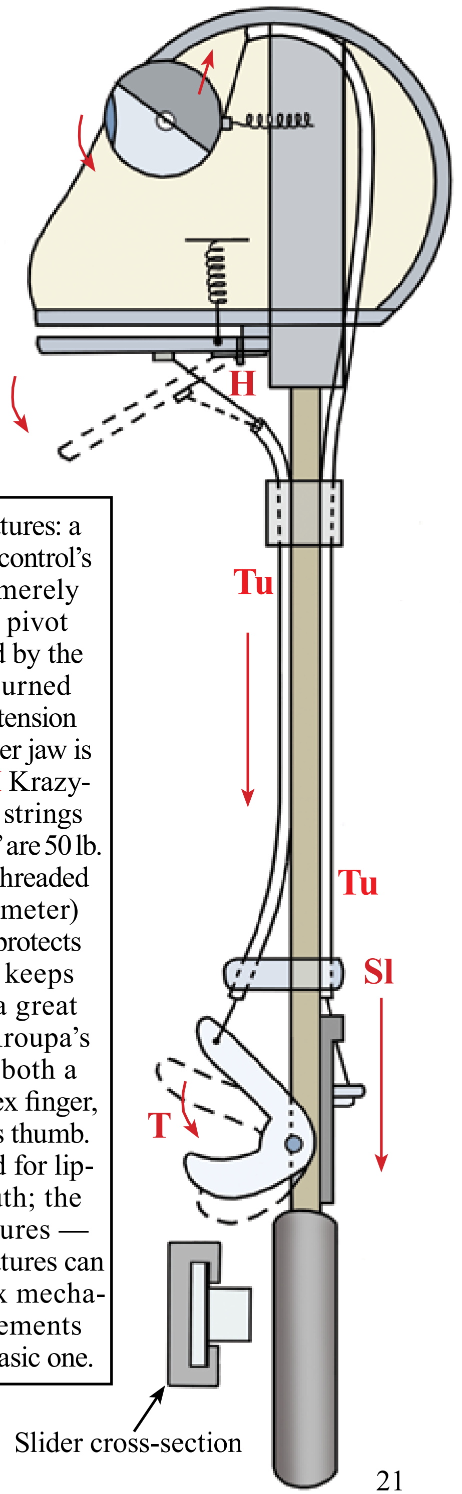
2 and 3, **Santa, Grumpy and Happy**, made out of urethane foam and fleece in 2014 as a teaching project for the O'Neill Puppetry Conference. Santa's hat tilts up, showing his eyes, his head turns left/right, and his mouth lip synchs on a small hinge. Kroupa's signature slider/trigger control powers the "mechs;" the slider raises the hat, the trigger synchs the mouth, and the head is turned by turning the central rod. The arms are worked by arm rods.

4, **The Booger**, made for a show pitch to the Cartoon Network for a show that never happened, this 6" tall character is fished out of giant child's nose, crying, "Don't eat me! Please don't eat me!" and is summarily wiped off on a chair seat, where he contemplates in amazement the giant (schoolroom) world around him. The body, made of various plastic parts, with mismatched dome eyes, and surfaced with suitably sculpted hot glue blobs painted in green acrylic, is on a tube, through which the control rod passes, for a piston-type control. The control, made of a circular disk on the rod where the handle would normally be, moves his head up/down and left/right, his mouth lip synchs thanks to a slider on the lower part of the control rod. The little shirt was stolen from a Ken doll.

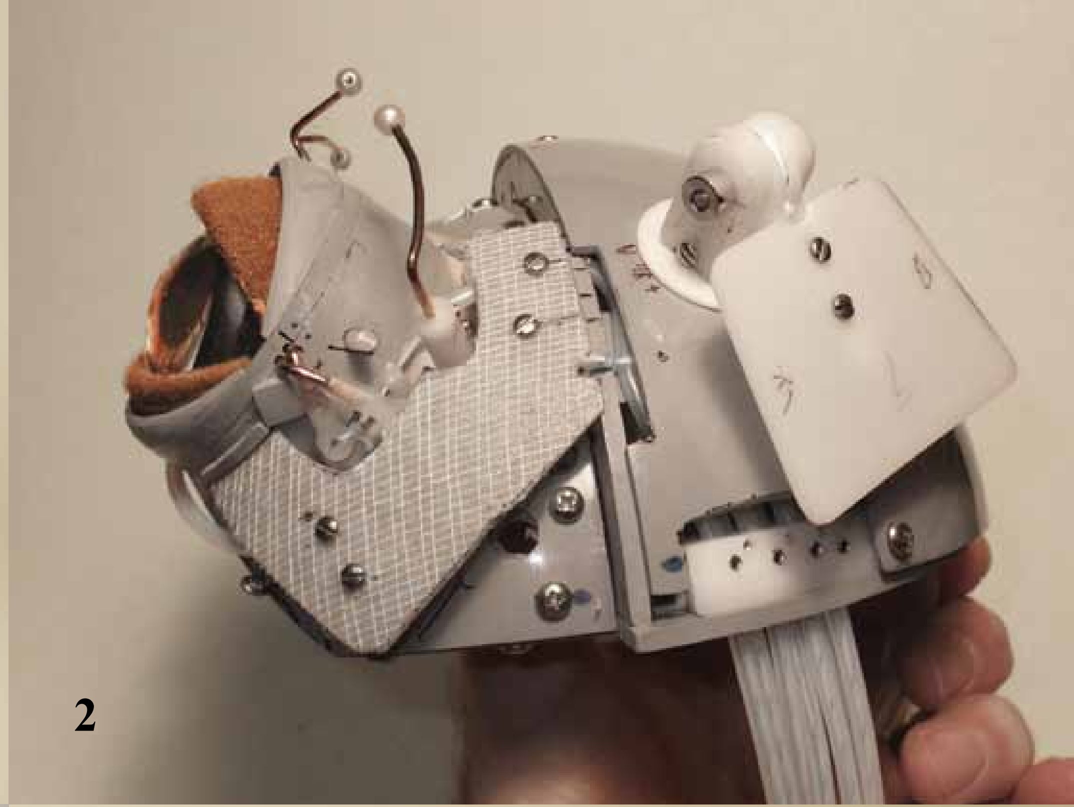
5 and 6, **Eugene, the Snail**: This 9" snail was one the cast of characters for a TV series, Johnny and the Sprites. Johnny is young man who lives in a house in a magical place in the forest, inhabited by sprites. Eugene is one of Johnny's friends — the "slowest" of them. The snail is made of foam and fleece, with plastic eyes whose eye stalks can extrude from the body and turn left/right. His little wings, on pivots, can open and close. His shell is carved from dense hard foam, the kind put in football helmets, surfaced with a skim-coat spackle putty, sanded and painted in acrylics. The eye stalks are spring steel wires covered in fleece, which are mounted on a wooden dowel, and pushed up/pulled down through a bike cable housing. Twisting the dowel left/right swivels the eyes left/right. The lip-synched mouth is worked by a trigger on the control, the wings by a slider.

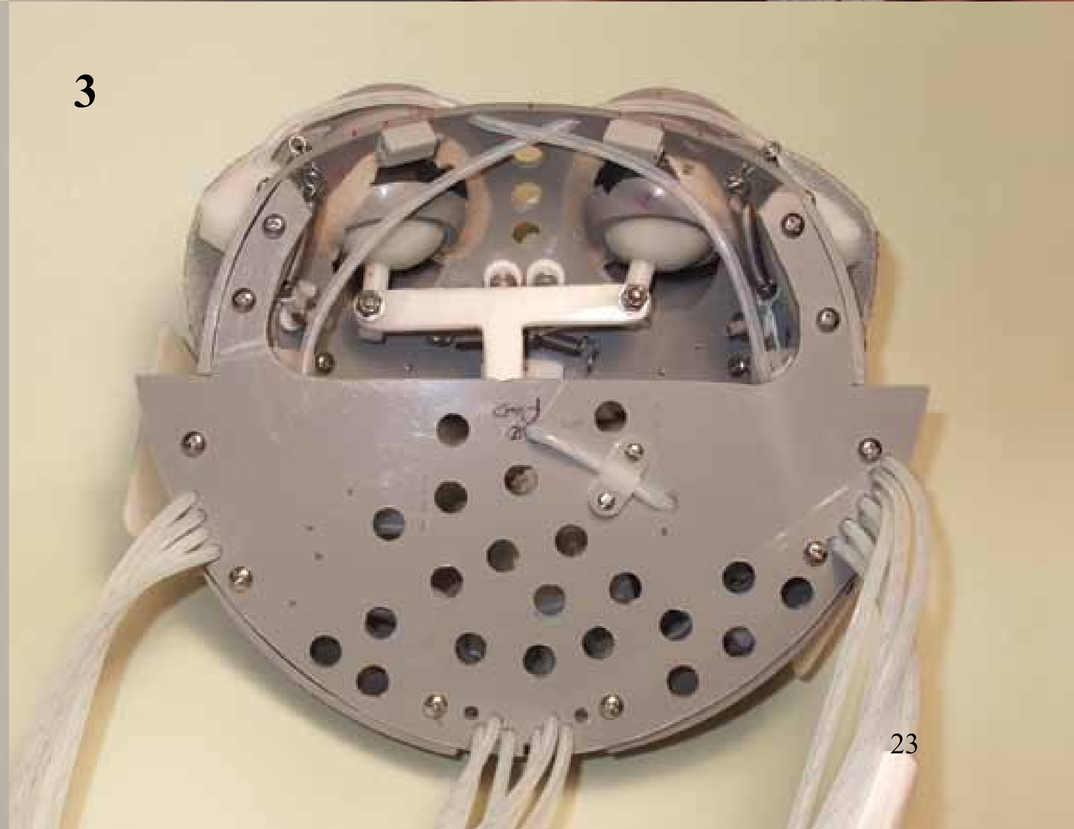
7, **Peanut Butter and Jelly Sandwich**: This puppet, the size of an average sandwich, was done in 2004 for "Between the Lions," a TV series for Public TV, as part of a children's story, teaching children about food. The "bread" is urethane foam, the "peanut butter and jelly" are hot glue painted in acrylics. The eyes are made of plastic domes, with pupils that move left/right via a slider on the control. The trigger lip-synchs the mouth.

In this head, there are two features: a hinged mouth, worked by the control's trigger, and an eye blink, merely a rotation around a central pivot through the eyeballs, worked by the slider. Both features are returned to normal by $\frac{3}{16}$" diameter extension springs. The hinge for the lower jaw is a heavy-duty nylon hinge, **H** Krazy-glued on, then screwed. The strings used for all Kroupa's "mechs" are 50 lb. test braided Dacron fishline, threaded through $\frac{1}{8}$" OD (outer diameter) teflon tubing **Tu**. The tubing protects the strings from wear, and keeps them from tangling when a great many strings are in play. Kroupa's preferred control type has both a trigger **T**, worked by his index finger, and a slider **Sl**, worked by his thumb. The trigger is normally used for lip-synching the puppet's mouth; the slider is used for other features — here, an eye blink. Other features can be added for more complex mechanisms where additional movements are required. But this is the basic one.



Jim Kroupa's iconic puppet Taxi dog, best friend of a New York taxi driver, this puppet has multiple moving facial features: eyes, eyebrows, tongue, teeth and ears. Puppet is the size of a mid-sized dog. Media: ABS plastic for skull parts, custom-made resin eyes, various radio control parts, such as ball links and steering arms, architectural model parts, such as I beams for slider control, mechanical parts such as thrust bearings. (See more information on Materials and Tools in the Basics chapter of this book.) © Taxi Dog Productions, LLC. Photos by Jim Kroupa, drawings by Jim Kroupa and Ellen Rixford. Opposite page: four views of the finished cranium, all "mechs" installed from: 1. front, 2. side 3. below and 4. above.



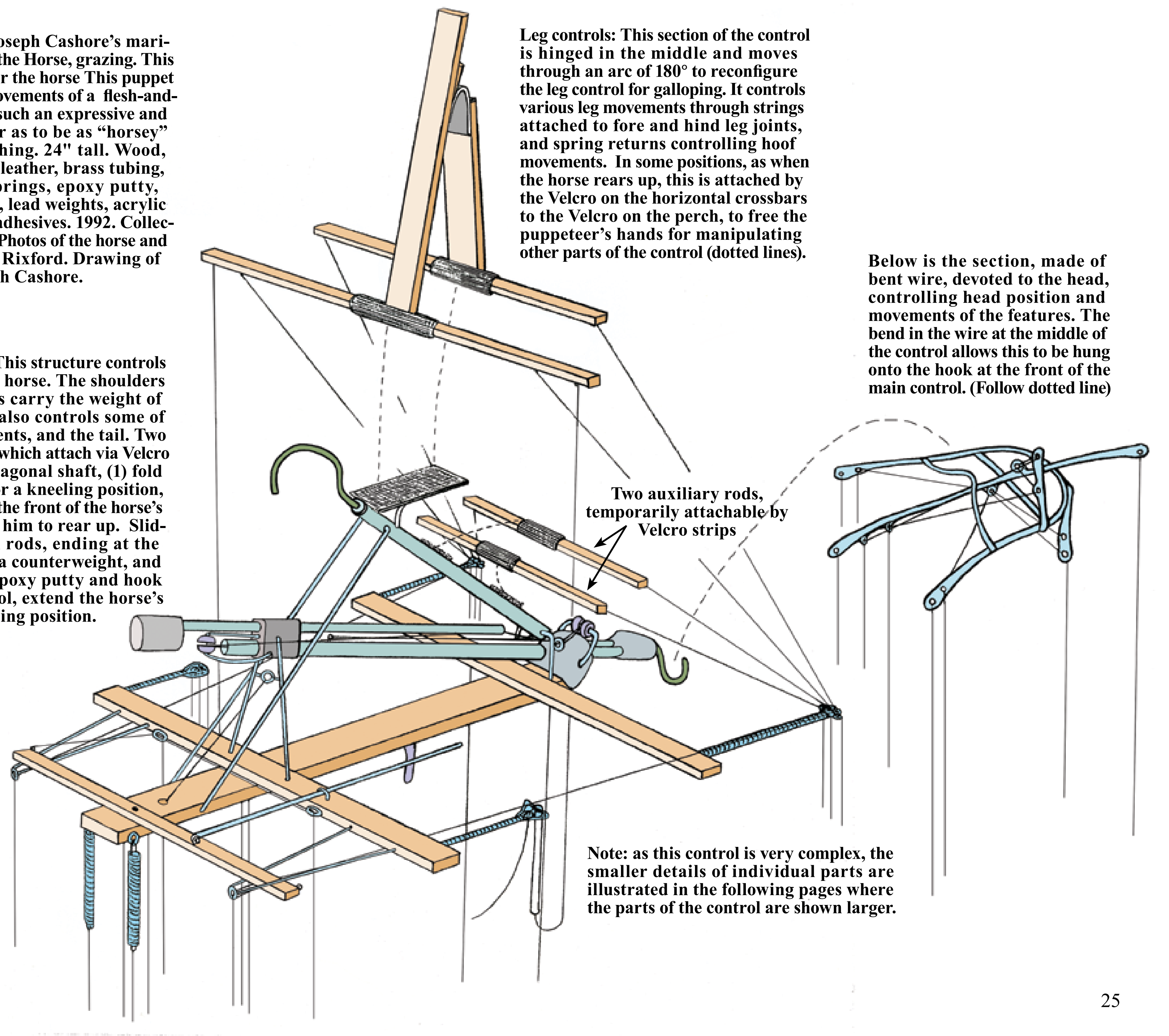


Facing page: Joseph Cashore's marionette Cyclone the Horse, grazing. This page: control for the horse This puppet captures the movements of a flesh-and-blood horse in such an expressive and lifelike manner as to be as "horsey" than the real thing. 24" tall. Wood, papier-mâché, leather, brass tubing, music wire, springs, epoxy putty, ostrich plumes, lead weights, acrylic paint, various adhesives. 1992. Collection, the artist. Photos of the horse and controls, Ellen Rixford. Drawing of controls, Joseph Cashore.

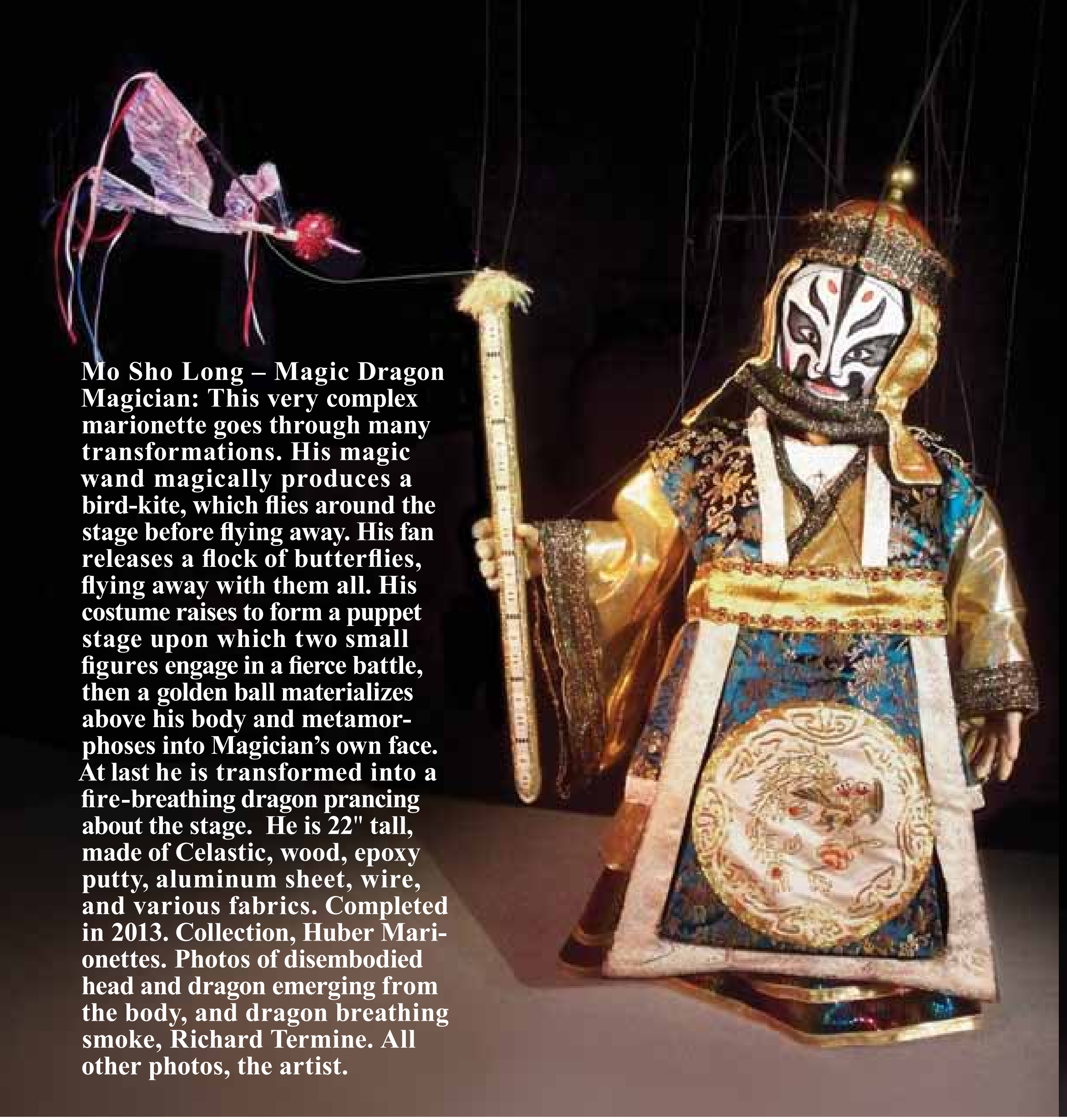
Main control: This structure controls the body of the horse. The shoulders and hip strings carry the weight of the puppet. It also controls some of the leg movements, and the tail. Two auxiliary rods, which attach via Velcro strips to the diagonal shaft, (1) fold legs in front, for a kneeling position, (2) and pull up the front of the horse's body, allowing him to rear up. Sliding horizontal rods, ending at the back end with a counterweight, and in front with epoxy putty and hook for head control, extend the horse's neck for galloping position.

Leg controls: This section of the control is hinged in the middle and moves through an arc of 180° to reconfigure the leg control for galloping. It controls various leg movements through strings attached to fore and hind leg joints, and spring returns controlling hoof movements. In some positions, as when the horse rears up, this is attached by the Velcro on the horizontal crossbars to the Velcro on the perch, to free the puppeteer's hands for manipulating other parts of the control (dotted lines).

Below is the section, made of bent wire, devoted to the head, controlling head position and movements of the features. The bend in the wire at the middle of the control allows this to be hung onto the hook at the front of the main control. (Follow dotted line)



Note: as this control is very complex, the smaller details of individual parts are illustrated in the following pages where the parts of the control are shown larger.



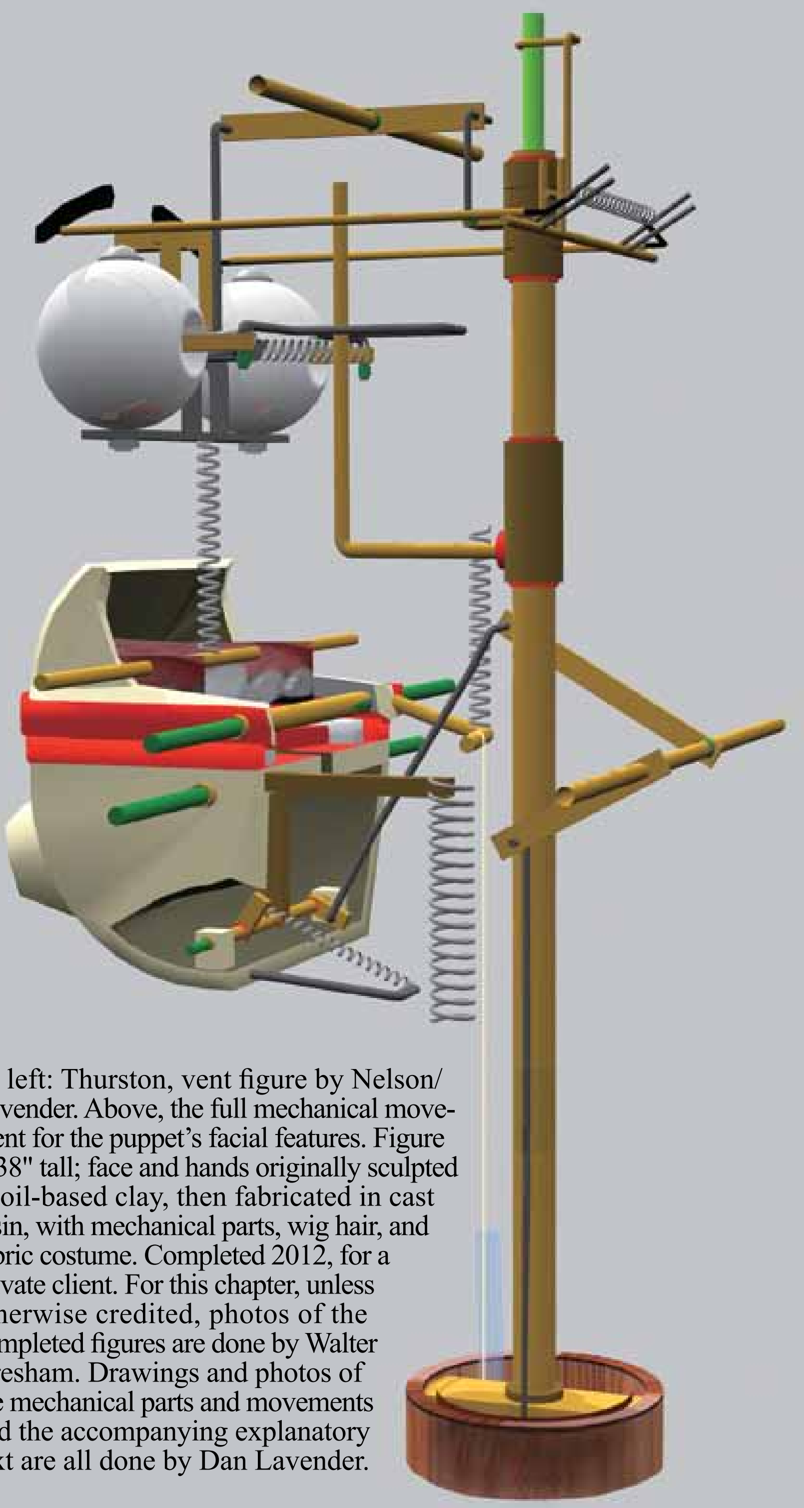
Mo Sho Long – Magic Dragon Magician: This very complex marionette goes through many transformations. His magic wand magically produces a bird-kite, which flies around the stage before flying away. His fan releases a flock of butterflies, flying away with them all. His costume raises to form a puppet stage upon which two small figures engage in a fierce battle, then a golden ball materializes above his body and metamorphoses into Magician's own face. At last he is transformed into a fire-breathing dragon prancing about the stage. He is 22" tall, made of Celastic, wood, epoxy putty, aluminum sheet, wire, and various fabrics. Completed in 2013. Collection, Huber Marionettes. Photos of disembodied head and dragon emerging from the body, and dragon breathing smoke, Richard Termine. All other photos, the artist.

Phillip Huber's magical puppet performance, which inevitably brings audiences to their feet, cheering, took years to develop and perfect. Huber learned some of the magic tricks used here at Magic Castle, an exclusive magician's club in Los Angeles, California. Members were asked to swear ***never ever*** to reveal secrets they learned there. For this reason, much in these pages, dear reader, is left up to your imagination. If you look very carefully at the excellent photos the puppeteer and photographer have provided, however, perhaps you can deduce how some of these wonders are created.

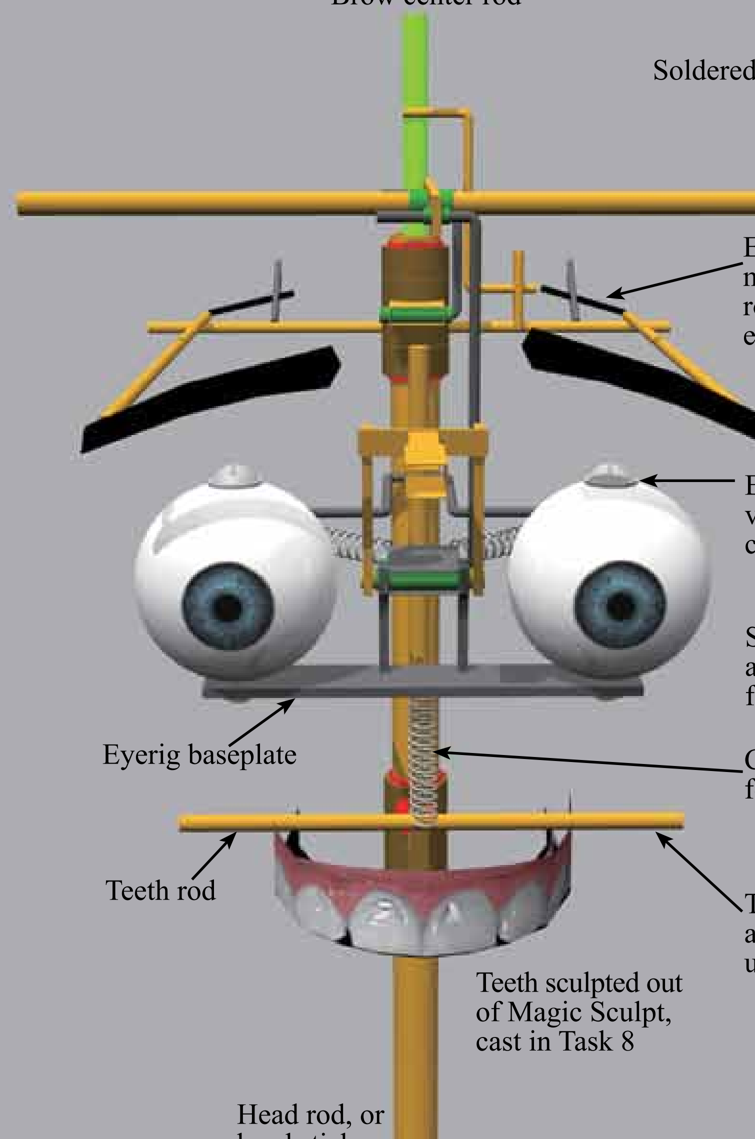
Initially, the Magician's face is painted black and white, to look like a character from the Peking Opera. This is significant, as the colors and styles of face painting represent different personalities. White symbolizes craftiness; black, seriousness and strength. Now he appears holding a wand. A bird-shaped kite suddenly appears tethered to end of the wand and flies around the stage, eventually flying off-stage, taking the wand with it. Kites shaped like birds, butterflies, and flying deities are a tradition in China.
Can you imagine how his holds the wand, and where the kite comes from?

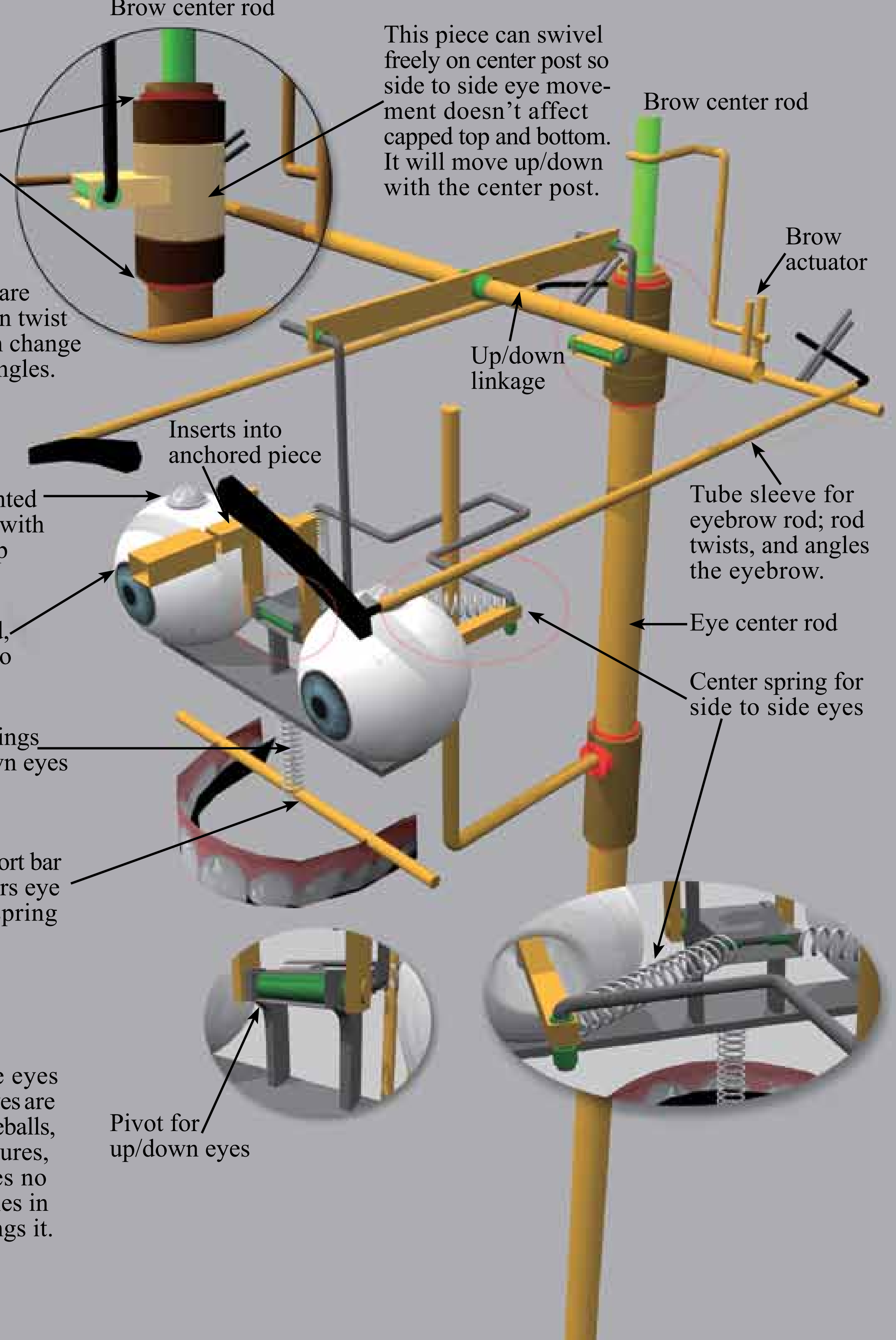
The Magician lifts the apron of his costume, hiding his face, and creating a miniature theater for two miniature hand puppets, who are battling each other with sticks. The symbol on the back of this apron means "Dragon" in Chinese. And the Magician's Chinese name is Mo Sho Long — meaning Magic Dragon. The hand puppets descend behind the stage and disappear, to be replaced by a golden ball, mysteriously floating above the apron. The ball transforms itself into the sweetly smiling face (on the disembodied head) of the Magician.

Mo Sho Long's head has disappeared! Now, out of his body emerges a dragon, breathing smoke, and prancing about the stage. The discarded body is cast off, and disappears. Huber often found it necessary to build several alternate mechanisms, experimenting again and again before finding one that worked perfectly and reliably. This creation is more than a technical marionette — it is a carefully staged series of magic tricks — theatrical illusions meant to perplex and amaze an audience.



At left: Thurston, vent figure by Nelson/Lavender. Above, the full mechanical movement for the puppet's facial features. Figure is 38" tall; face and hands originally sculpted in oil-based clay, then fabricated in cast resin, with mechanical parts, wig hair, and fabric costume. Completed 2012, for a private client. For this chapter, unless otherwise credited, photos of the completed figures are done by Walter Gresham. Drawings and photos of the mechanical parts and movements and the accompanying explanatory text are all done by Dan Lavender.





Lavender must drill holes in the eyes to install the mechanics, so glass eyes are not an option. He uses plastic eyeballs, usually acrylic, 1½" for large figures, 18 mm for smaller ones. He uses no special jigs or precisely sized holes in drilling into the eyes; he just wings it.

Corbian Arts puppets, with various characters: two giant birds, Phaedra, the tall bird, Verla, the green ostrich-like bird, a fish, Darwin the Dinosaur, and a giant flower that has sprung from the dinosaur's droppings. Opposite page: giant fish in swirl of water.

The puppets: varying sizes, from a third life size to over 14' tall. All puppets made from electro-luminescent wire sewn into fabric costumes utilizing aluminum wire, epoxy rods, foam padding, various fabrics, backpacks, springs, and various electronic parts. (See following pages.) Puppets built 2006-2012, and ongoing. All puppets: cast of Corbian Arts. Photos for this section, Corbin Popp, Ian Carney, Stephen Charles Nicholson, Eleanor Carney, and Whitney Popp. Technical drawings, Corbin Popp. Electronic diagrams, Ellen Rixford. Pictures of the cast members include Stephen Charles Nicholson, Eleanor Carney, Ian Carney, Michael Quintana and Tierney St. John.

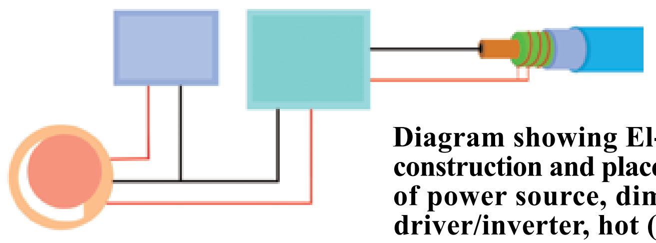
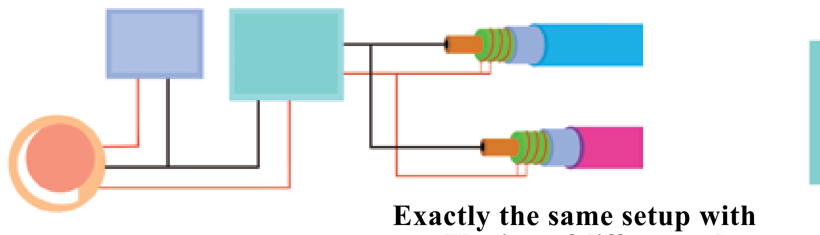
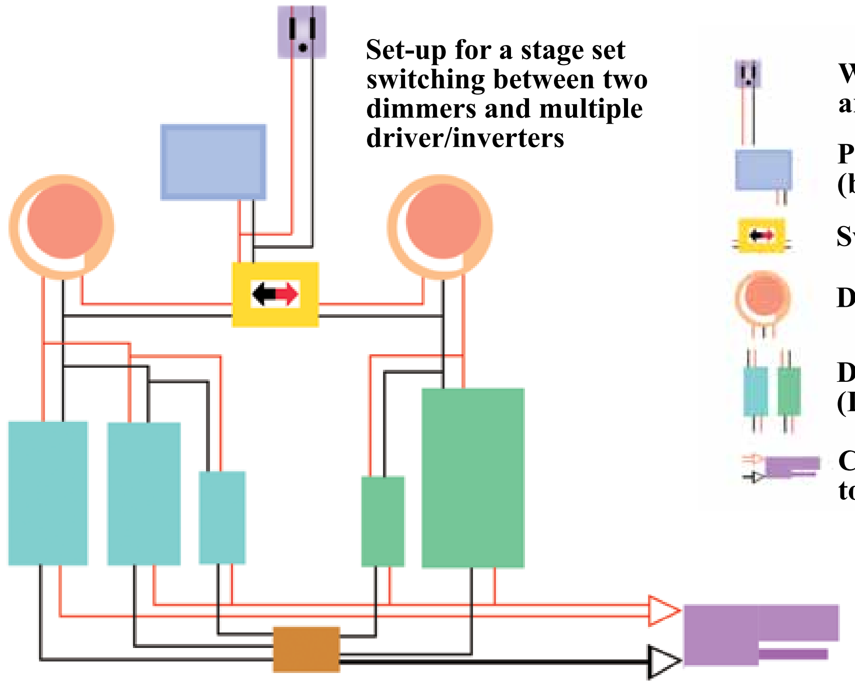


Diagram showing El-wire construction and placement of power source, dimmer, driver/inverter, hot (red) and ground (black) wires.

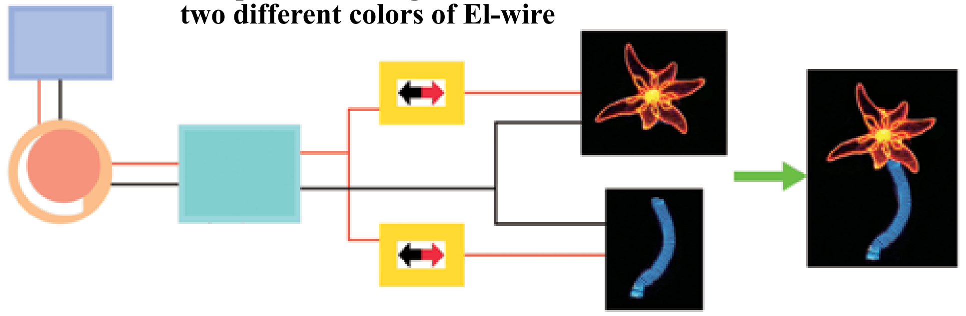


Exactly the same setup with two El-wires of different colors



Set-up for a stage set switching between two dimmers and multiple driver/inverters

Setup for switching between two different colors of El-wire

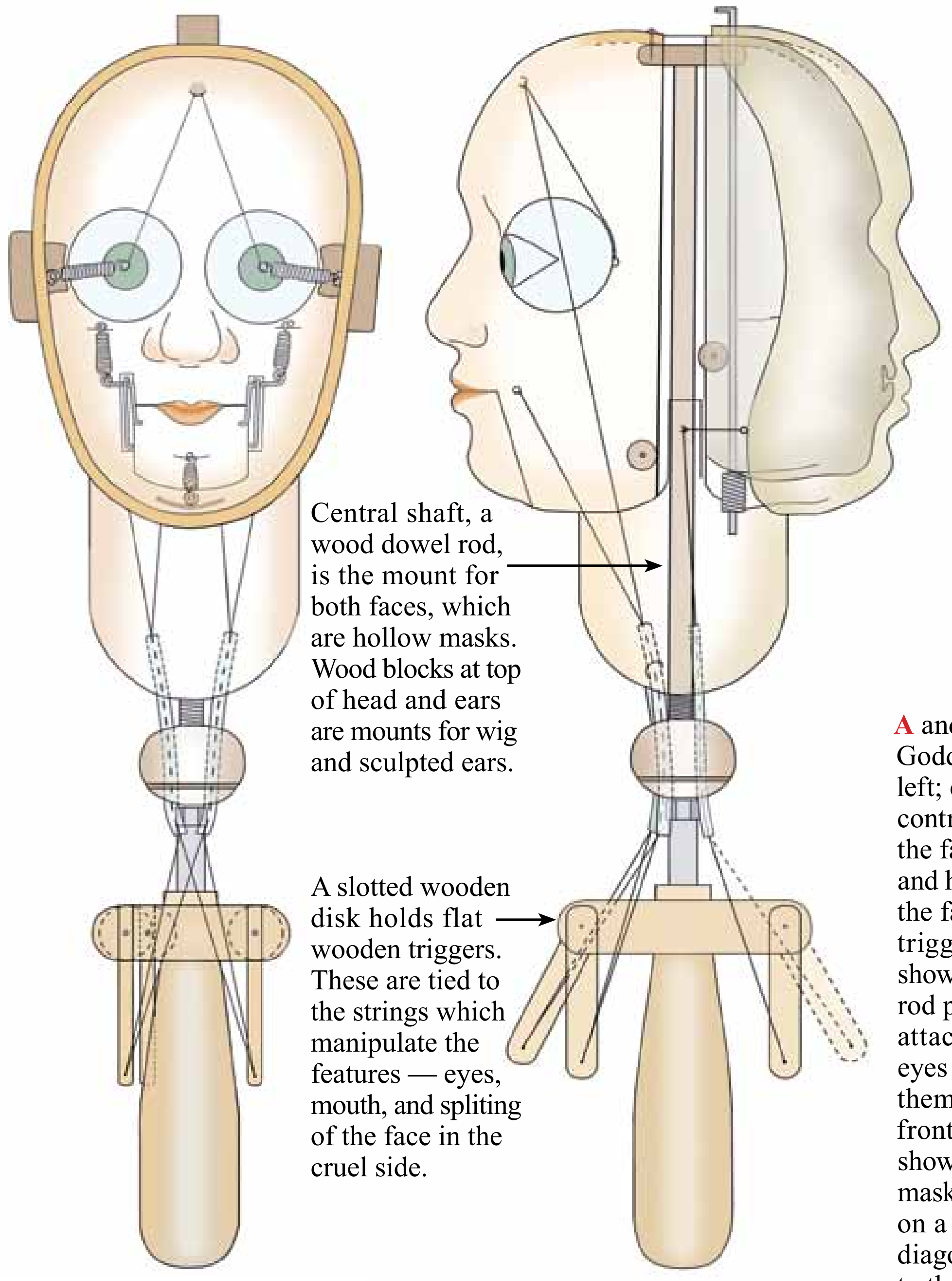


El-Wire: construction: consists of five components. At the center is a solid copper wire, coated with phosphor. Next is a layer which isolates this copper wire core from a very fine copper wire which is spiral-wrapped around it. Around this sandwich of phosphor coated copper core wire, isolating layer, and wrapped thin copper wire is a clear PVC sleeve. Around this sleeve is another colored translucent or fluorescent PVC sleeve. When an alternating current of about 90 to 120V at about 1000 Hz is applied between the copper core and the fine wrapped copper wire, it acts as a coaxial capacitor, having about one nF of capacitance per foot. The rapid charging and discharging of this capacitor excites the phosphor to emit light. Colors produced in this way are limited. When excited, the core produces blue-green light. But fluorescent organic dyes added to the clear PVC sleeves can produce reds and purples.

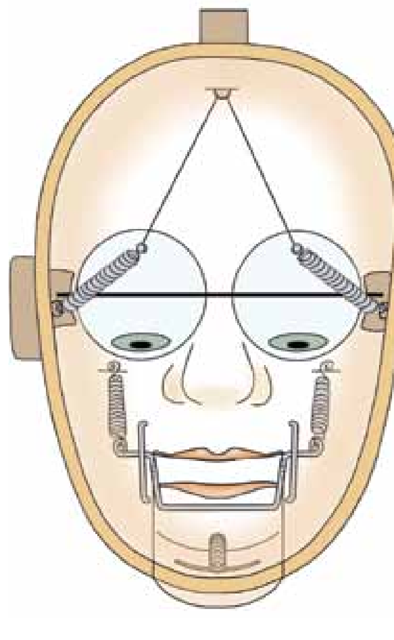
To generate the high-voltage drive signal from a small power source (AA battery pack of 7-12V) a resonant oscillator (driver/inverter) is used. Because of the capacitance load of the El-wire, the inductive, or coiled transformer makes the driver a tuned LC oscillator, thus very efficient — so efficient that a few hundred feet of El-wire can be driven by an AA battery pack. (With thanks to Wikipedia)

"The setup requires a battery source of about 12V, a DC dimmer, an inverter to change the power to AC, and the El wire load. We have struggled for years to find a smooth dimming system — three professionals and dozens of dimmers that dim DC circuitry. The ability to dim is a way to express emotion and make things appear or disappear smoothly. Connecting backgrounds to individual characters, changing scenic elements requires advanced dimming. Being able to set a timed 'push button' dimmer would allow dimming by a character without his needing to manually twist the dimmer control while busy acting. The manual dimmers that work best are either from an LED dimmer or a marine 12V dimmer. We hear that the dimmers made by the pros (the guys over at RC4 wireless (**www.theatrewireless.com**) won't work to theatrical standard due to the poor engineering of current inverters. Many inverters for El-wire can emit annoying high-pitched sounds which detract from a theatrical performance. We have yet to see our medium perform perfectly. The search goes on......"

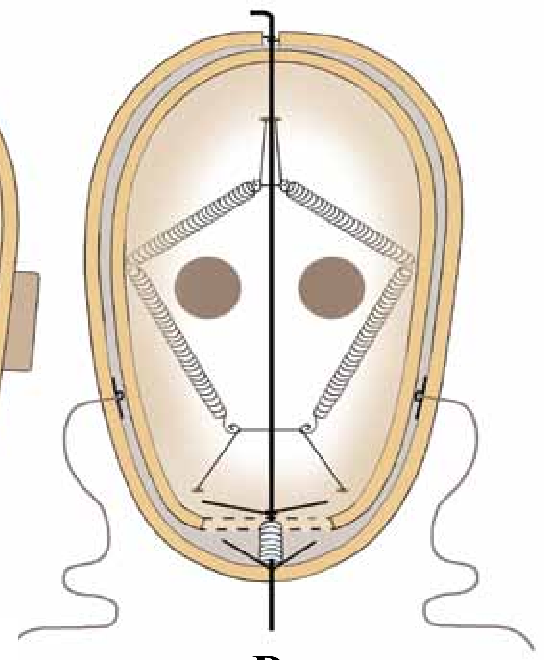
Goddess of Earth, or Mother Nature—kind and cruel aspects, by Ellen Rixford. This Bunraku style double-faced puppet was built shortly after a trip to Japan, where I was introduced to the Bunraku art form by friends. I was deeply impressed by the craftsmanship of the puppets, and their eloquent movements, especially the puppet Kiyohime, a maiden who becomes a monster when her love for Anshin, a Buddhist monk, is rejected. I decided to do some "transforming puppets" of my own and subsequently built the Goddesses of Earth and Heaven. Her two faces, upper torso, and double-ended (20 toes) feet are Celastic, hands are wood; hands of the cruel Goddess are articulated wood; costumes are mixed media. Completed 1985-87. Collection, the artists. Photos and drawings, Ellen Rixford.



A **B**

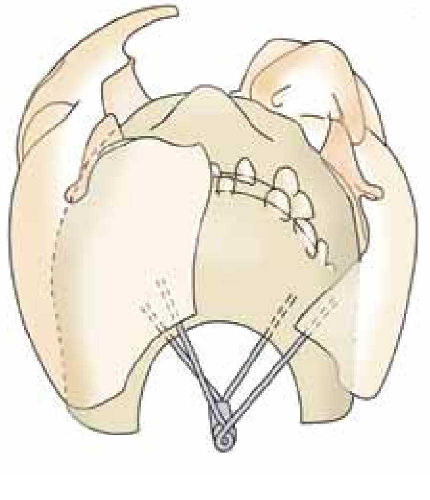


C



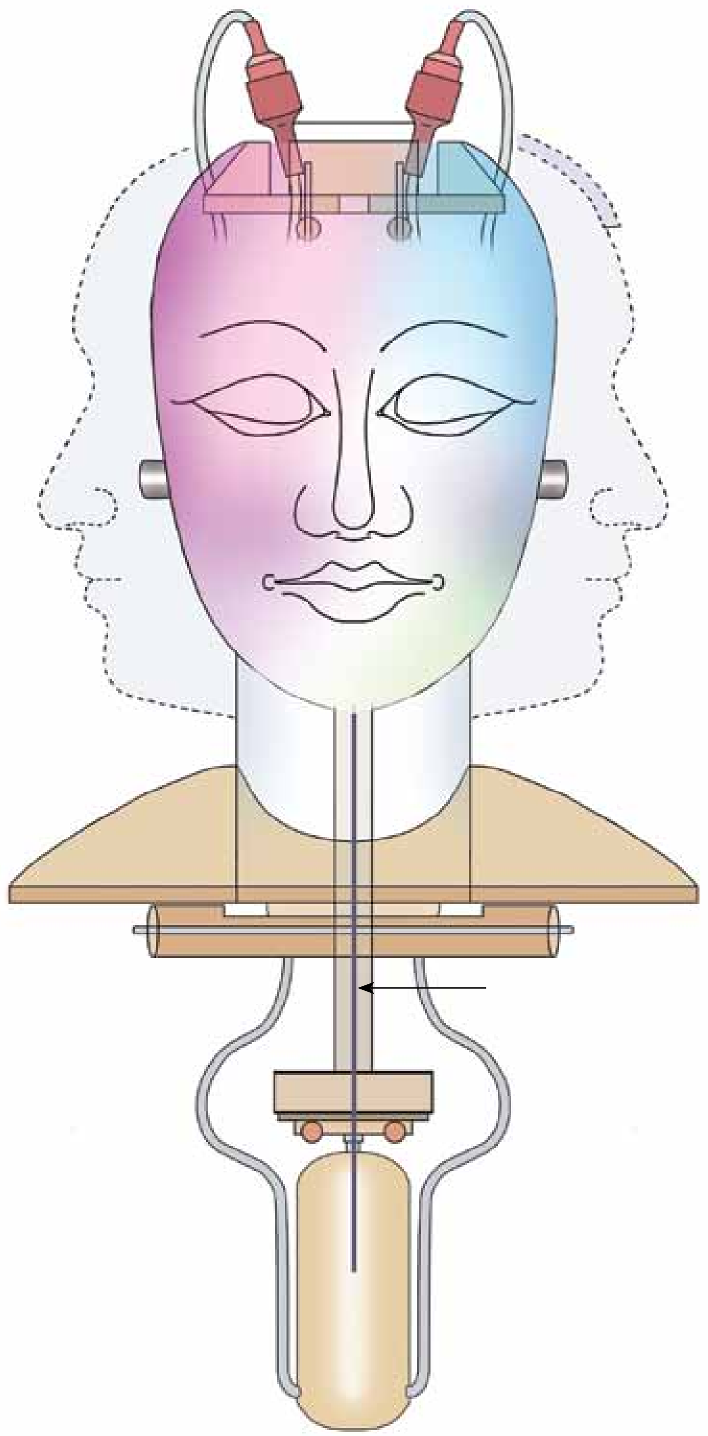
D

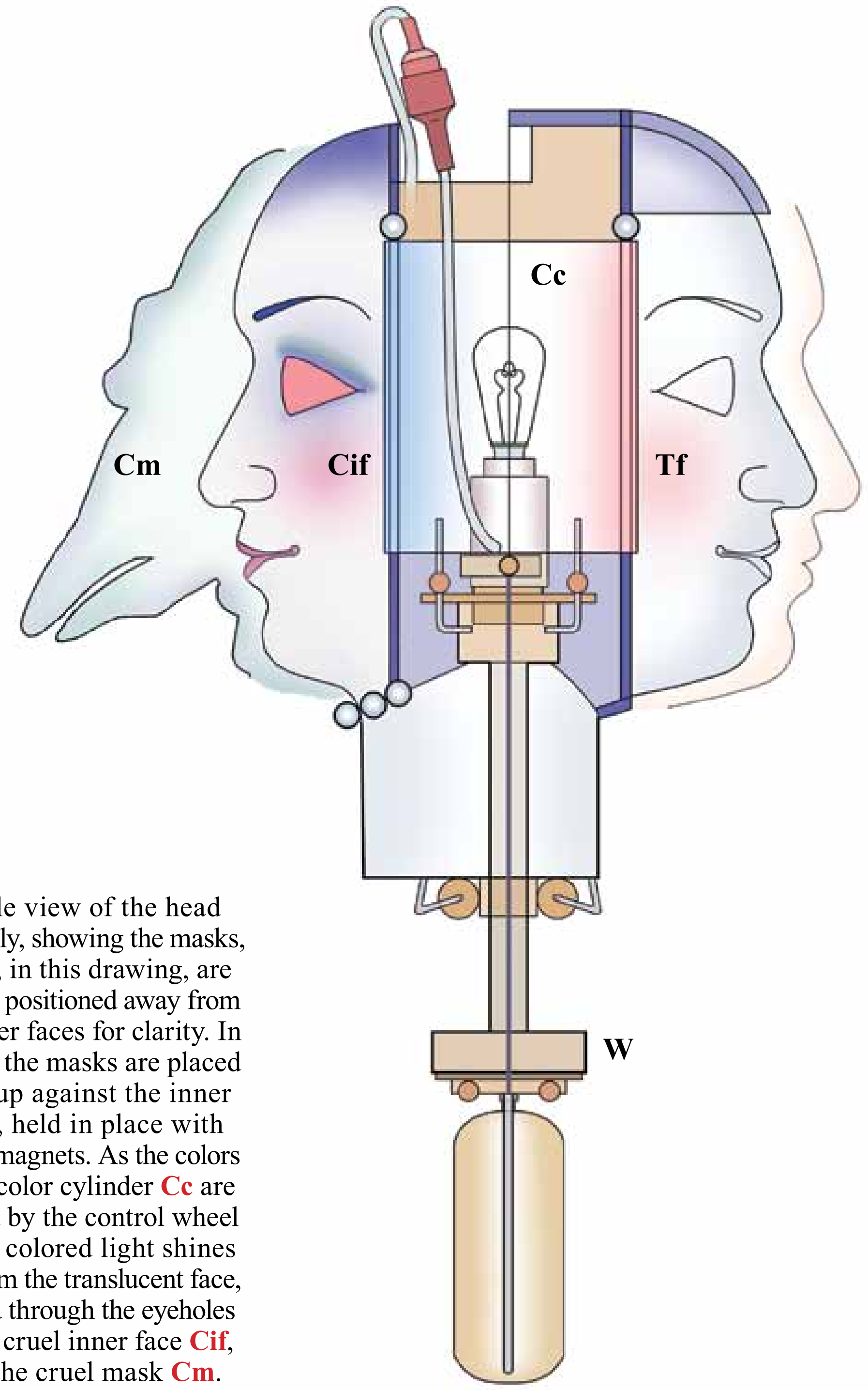
A and B: Frontal and profile views of the Goddess of Earth's "faces" (kind face at left; cruel face and skull at right) and the control rod and handle. These show how the faces are attached to the central shaft, and how the strings to the linkages within the faces are manipulated by the control triggers. C: front view of the kind face, showing the eyes pivoted on a horizontal rod passing through the eyeballs. Strings attached to the control trigger make the eyes blink or close. Return springs bring them back to straight-ahead position. D, frontal section and E, view from below, shows the mechanism of the cruel face's mask. The two halves of the mask, pivoted on a vertical rod,are held closed by four diagonal springs. Pulling the strings tied to the sides of the mask opens it, revealing the grinning skull beneath. The four return springs close the mask again.



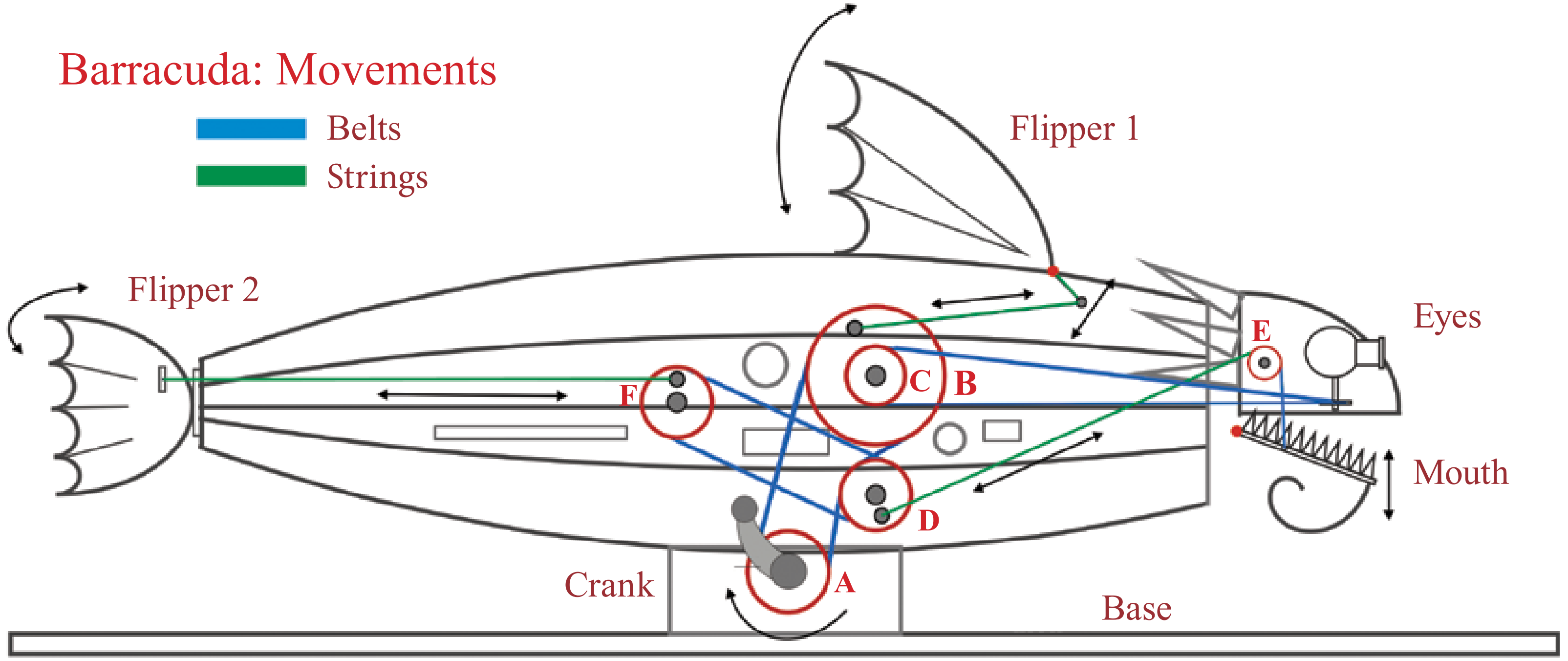
E

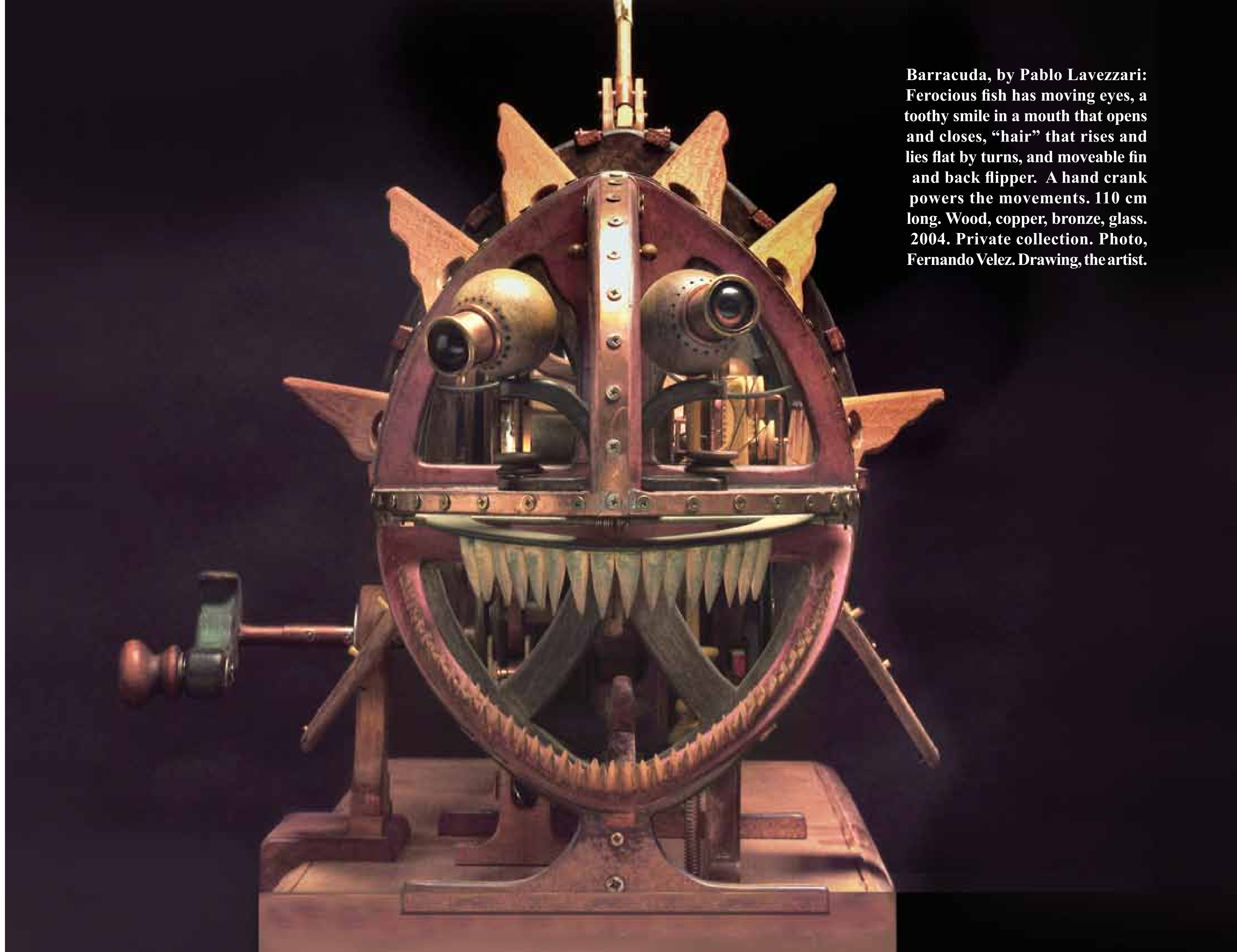
Goddess of Heaven, double-faced and double-masked Bunraku-style puppet by Ellen Rixford. In designing her, I considered the iconography: images of sky gods and goddesses in various cultures. Because the sky is full of light, and changes colors, I designed the inner kind face to be translucent, with a light assembly behind it which would change colors via a rotating control. The outer kind face is a fairly standard sculpture, but with blue-green glass cabochon "jewels" set in the eyes, which catch the light in an arresting and somewhat eerie manner. The cruel face is the same form as the kind face mask, but painted silver, with very richly hued features and open eyeholes which allow the light from the light assembly within to show. The bird mask is similarly painted silver, with the same kind of paint job accenting the features, and similarly open eye holes.





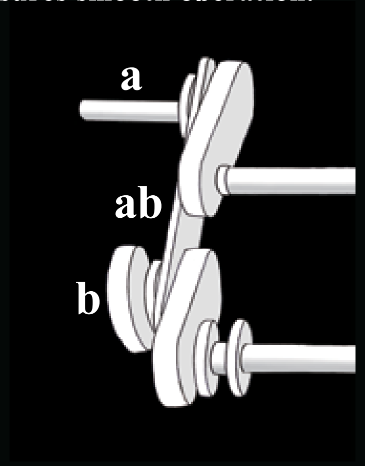
Profile view of the head assembly, showing the masks, which, in this drawing, are slightly positioned away from the inner faces for clarity. In reality, the masks are placed right up against the inner faces, held in place with strong magnets. As the colors of the color cylinder **Cc** are rotated by the control wheel **W**, the colored light shines out from the translucent face, **Tf**, and through the eyeholes of the cruel inner face **Cif**, and the cruel mask **Cm**.

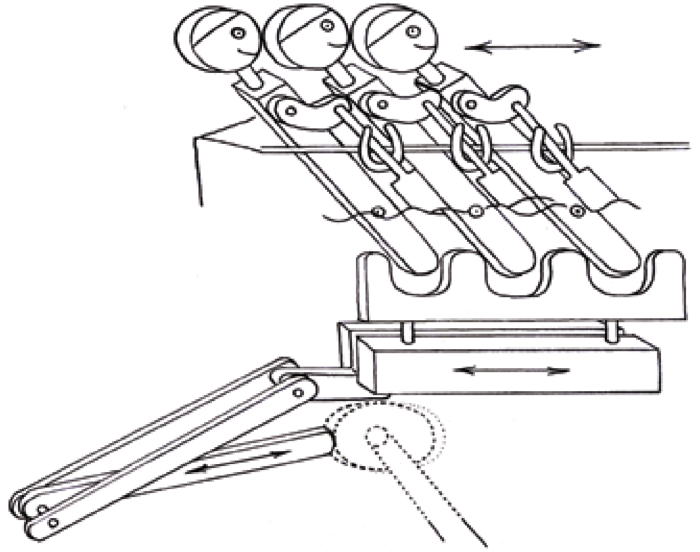




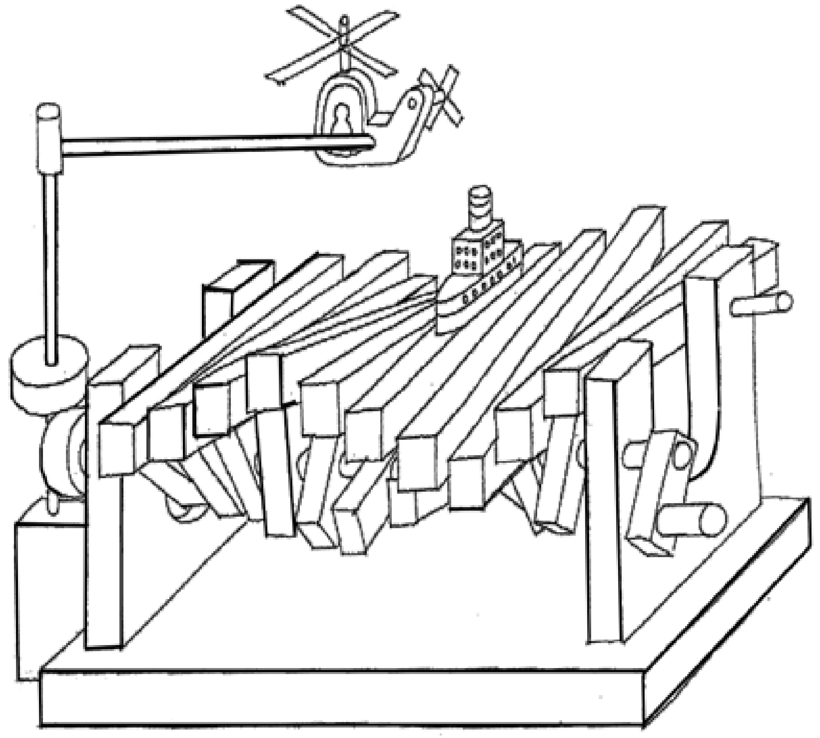
Barracuda, by Pablo Lavezzari: Ferocious fish has moving eyes, a toothy smile in a mouth that opens and closes, "hair" that rises and lies flat by turns, and moveable fin and back flipper. A hand crank powers the movements. 110 cm long. Wood, copper, bronze, glass. 2004. Private collection. Photo, Fernando Velez. Drawing, the artist.

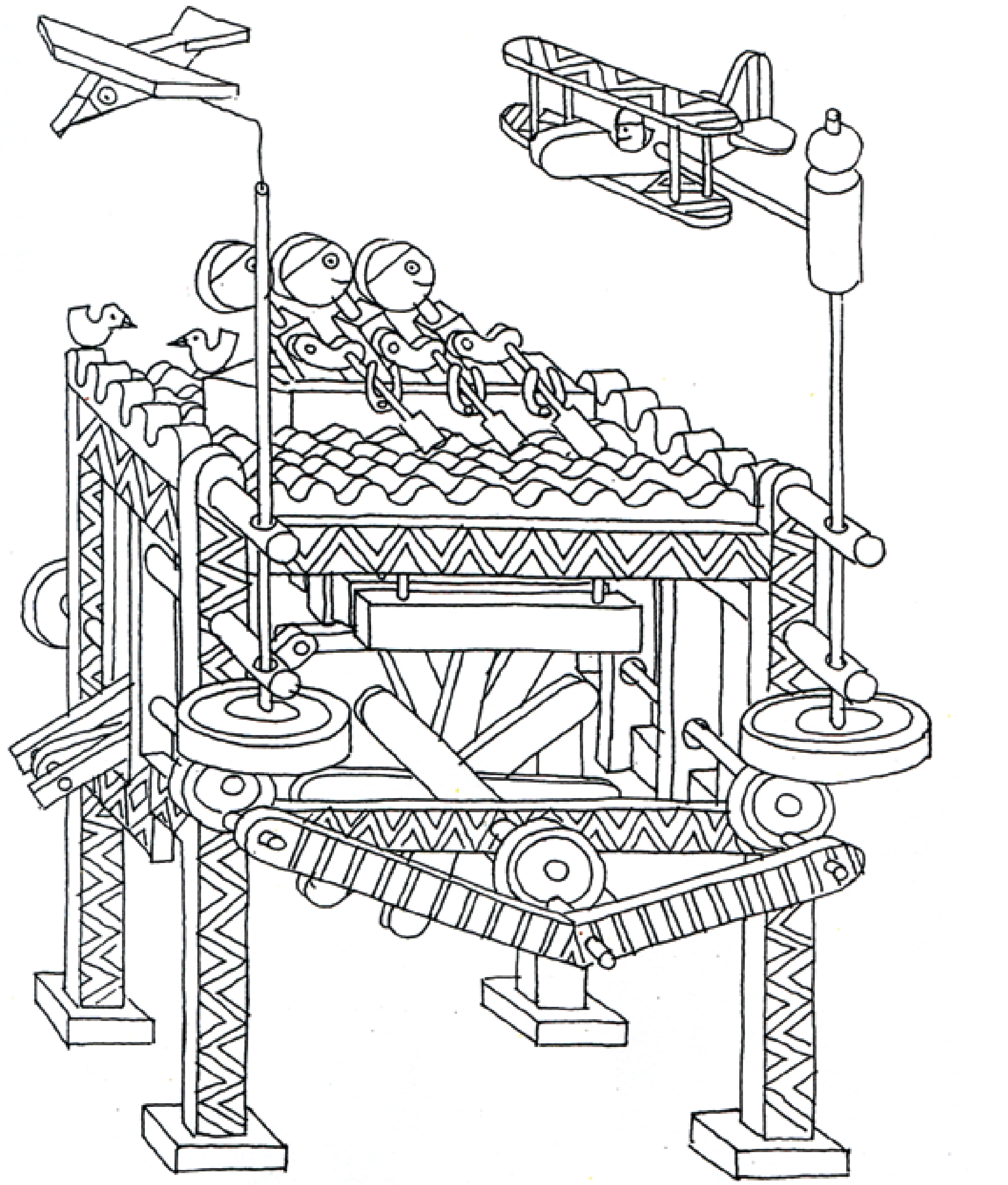
Peter Markey's masterpiece — Big Wave Machine: Painted wood, 50 cm. tall, 1980. Client, Cabaret Mechanical Theatre, photo by Heini Schneebeli. Waves move vertically, driven by the central camshaft via horizontal followers (unpainted in the picture). The sailors are driven by a crank visible on the right in the photograph. Now motorized, it was originally hand cranked by turning the central crankpin seen on the drawing. This pin drives the two shafts on either side through connecting rods in the shape of a shallow V. See more on multiple cranks and crankshafts in following pages. Directly below is a sketch of one of the more common ones Markey uses in many of his automata. Crank a is the main crank, Crank b is the secondary crank, ab is the link between them. Slightly offsetting the relationship between the 2 cranks assures smooth operation.

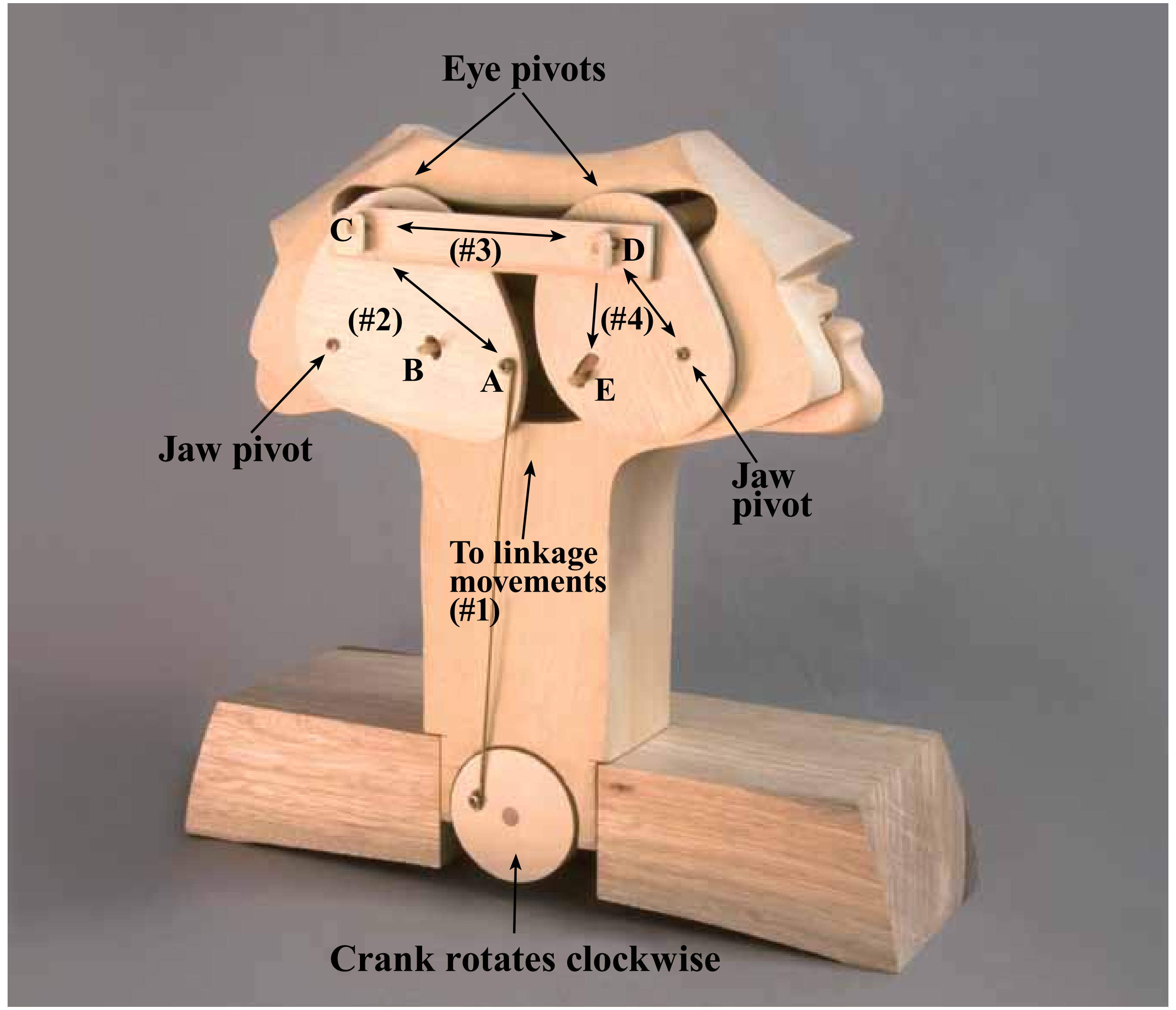




These drawings show Markey's trademark staggered cam lineup, and the multiple cranks he often uses. Below, cams and followers create waves. At right, drawing for Big Wave Machine, above, how the oarsmen work.

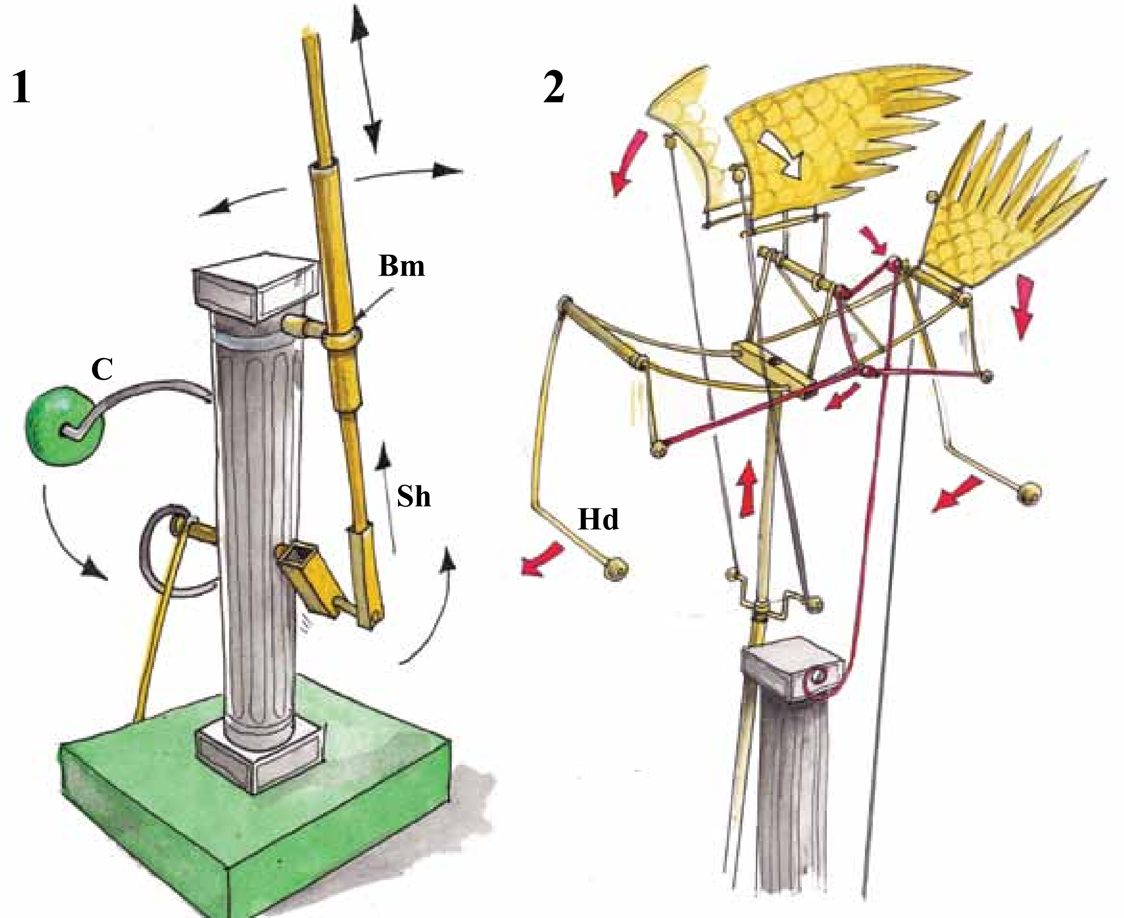






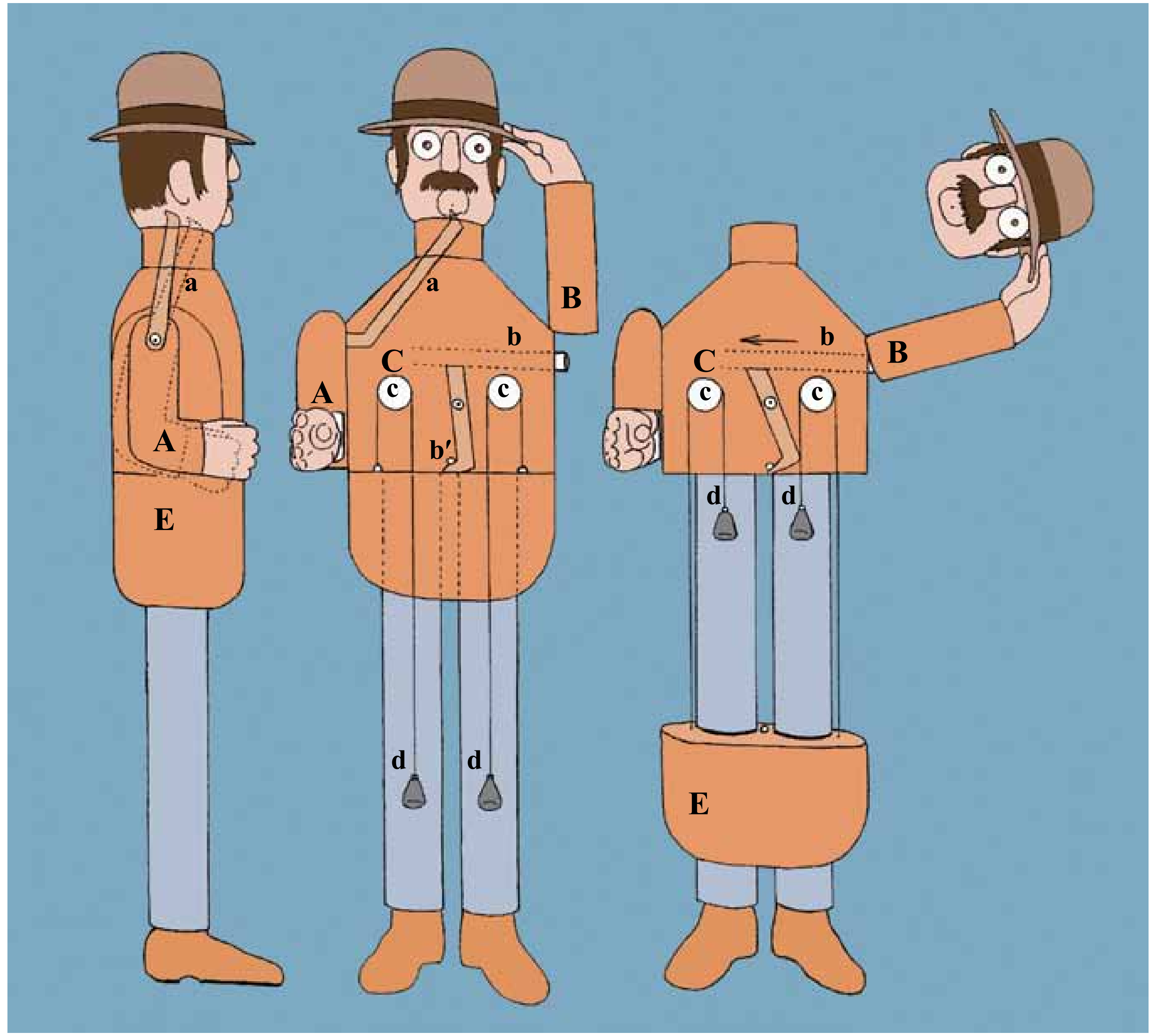
Your Turn: The two faces alternately "speak" as if having a conversation, moving their eyes and mouths, hence the title. The sculpture is approximately 30 cm tall. The head is carved in lime-wood (bass-wood), the base is zebra-wood. Done in 2006. Collection, the artist. Photos, the artist. The crank at the bottom rotates clockwise, pushing the linkage rod #1, alternately up and down. As its attachment point A pushes up and down, the linkage piece #2 rocks back and forth, raising and lowering peg B, which is attached to the back of the jaw of the face on the left side (in this view from the automaton's back). The jaw rotates around the jaw pivot, opening and closing the jaw. This linkage also causes the bar shaped piece #3, to slide back and forth, causing the eyes, attached at C and D, to move back and forth as well. #3 also pushes against linkage piece #4, and, as #4 alternately rocks back and forth, it pulls up and pushes down on E, which is attached to the back of the jaw on the right-hand face, opening and closing its mouth.

Icarus Flies Undone: by Keith Newstead — the Greek myth of the daring, unfortunate aeronaut who defies the god Apollo, builds himself a set of wings, and attempts to fly across the sky. In the real story, his wings, made of beeswax and feathers, melt and he falls into the sea. Here, far less disastrous but still very embarrassing, he discovers that his underpants have come undone at the front! 12" x 9" x 5". Brass and wood. 2001. Collection of Michael Croft. Photos by Michael Croft, technical drawings of the automaton by the artist.

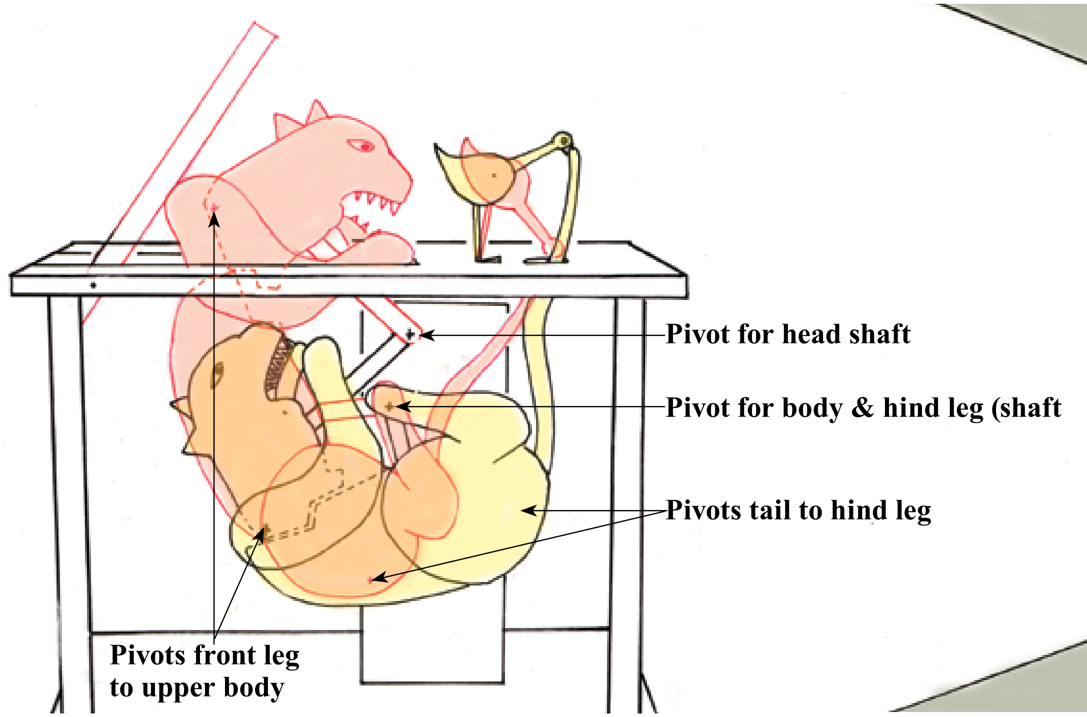


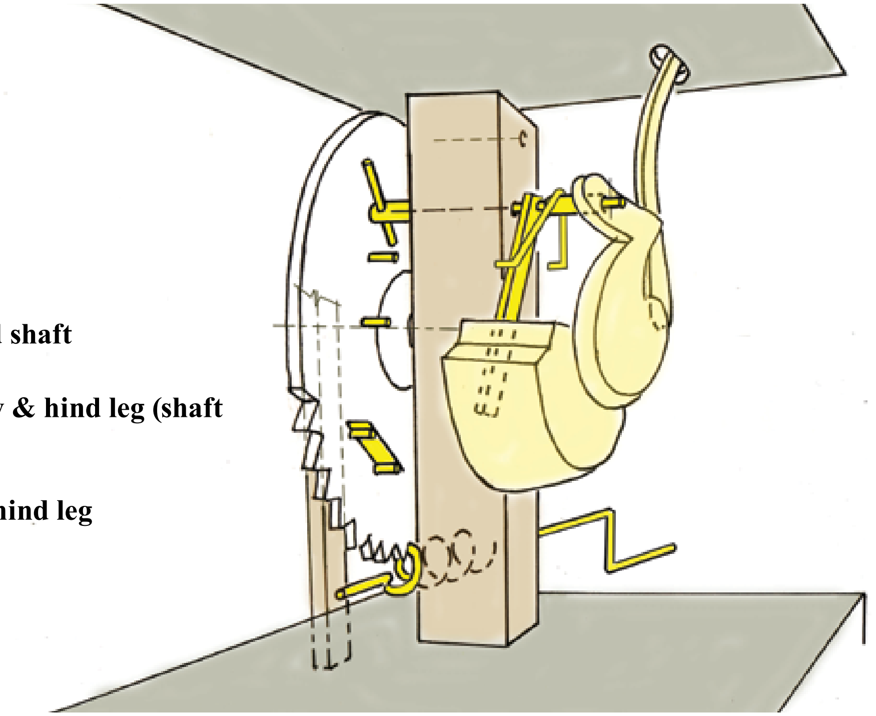
The mechanism is based on a crank slider. Drawing **1** (with the stand in green) shows the back of the base and the bottom of the crank slider, attached to an offset rod which passes, at a 90° angle, through the base pillar to the crank handle **C**. The primary shaft **Sh** passes through a piece of brass tube (a bearing mount **Bm**) attached to the pillar. This mount can pivot to allow the crank slider to rock back and forth. Drawing **2** shows the "bird cage" from the front. The shaft moves up/down and in a gentle rotary motion, following the motion of the hand crank, and providing the primary movement. Because the wings are fixed to the shaft housing, they are made to "flap" because of the motion of the crank slider. The internal rods, colored red in this drawing, work as a single unit, rotating at the joints. A longer rod **Rd** is fixed to the base, so that, like the wings, other parts must move to compensate for the action of the crank slider shaft. The Icarus figure's feet **Ft** are attached to the back crossbar; his hands **Hd** are attached to the front one. A tether attaches to the tail "feathers" and waves them up and down As the crank slider shaft follows the motion of the crank handle, Icarus' hands and feet alternately pull and push, as if he is "working" the wings.

Walter Einsel's Man Holding Hat, is also known as The Man With Falling Pants!



Man Holding Hat: This life-sized gentleman offers the viewer his right hand to shake. When the hand is shaken, his left hand doffs his hat, (with his head still attached to it) and his pants fall down with a loud crash, revealing his colorful striped shorts. Polychromed wood, copper, steel mechanical parts, wire cables, lead counterweights. 1960's. Collection, the artist. Photo, the artist. Drawing: Ellen Rixford. When his right hand **A** is pushed down, lever **a** releases the catch holding his head onto his neck. The weight of his left arm **B**, holding hat and head, causes it to swing down, pushing in lever **b**, and swinging in a pivoted lever with catch **b′**, which holds up his pants. The pants, released from the catch, fall down. Cables and pulleys **c** and **c**, and counterweights **d** and **d** allow the pants to be raised again. The left arm (and head) can now be replaced, the catch holding things together.



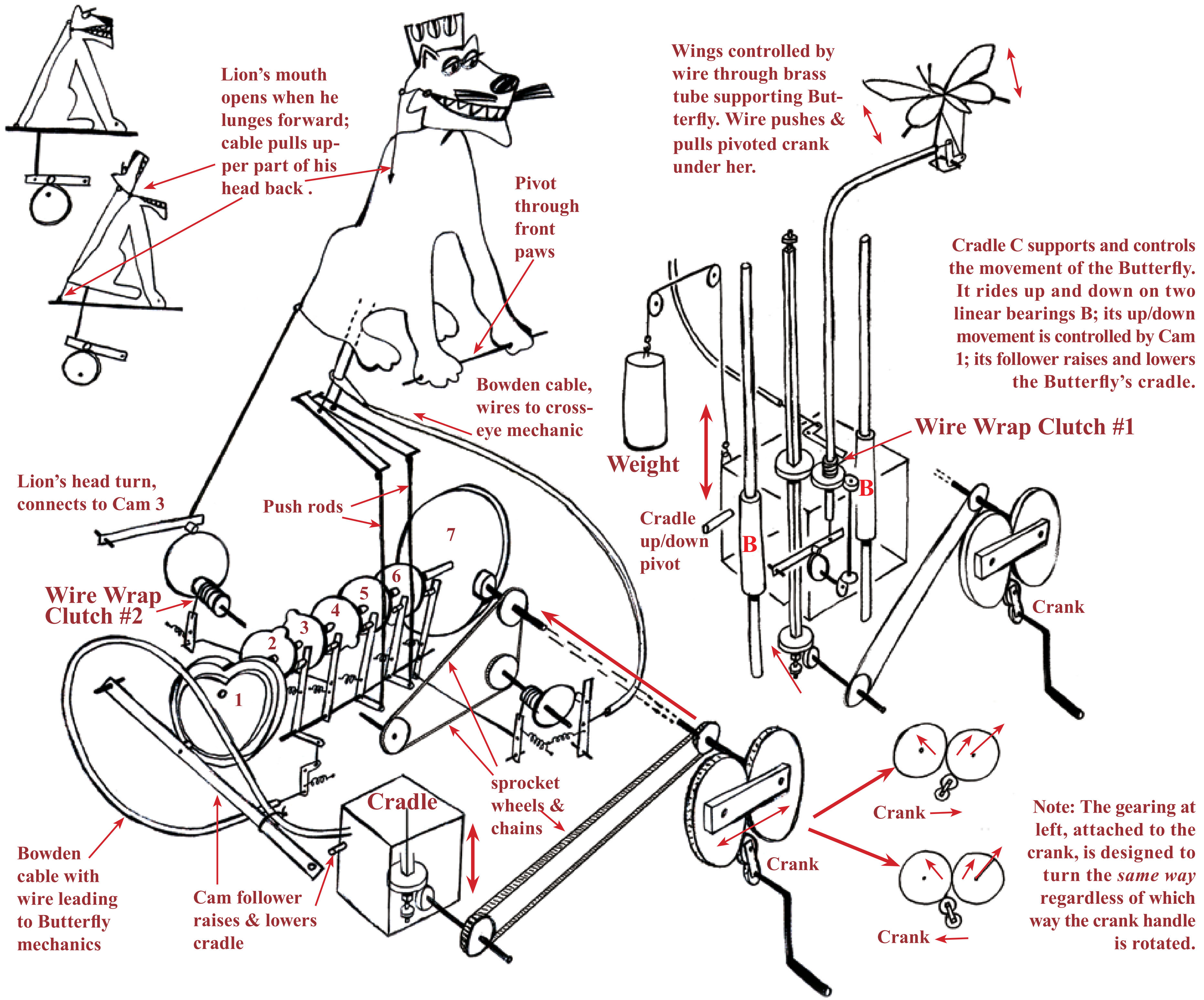


The Early Bird Nearly Catches it, Neil Hardy: bird tugs on a furry worm, only to discover that it's attached to something very dangerous. The bird's friends make the following comments, in sequence — "Damn, there's Eddy always getting there before us." "I've a feeling that ain't no worm!" "Mmm this could be mildly interesting." "Holy cow, is this for real, or is it one of those new-fangled automata?" Dimensions 7" by 7" by 5". Wood painted in acrylics, doors painted to look like subterranean soil layers, complete with bones; brass machine parts. 1994. Piece done in multiples for sale to multiple collectors. These photos taken by one collector, Michael Croft. All photos of the mechanism and all explanatory drawings by the artist.



Lion Lepidoptera, by Ron Fuller. The sequence of events: The Lion King snoozes amidst a garden patch of marigolds. The Butterfly is settled on one of the flowers. She takes wing, circles, and flies up to the Lion, fluttering closer and closer. The Lion turns his head to watch her, stares, goes cross-eyed staring at her, and irratably snaps at her twice. Then he gives up. The Butterfly, having escaped, circles, and flutters back down on the marigolds, where she descends once more. The Lion goes back to semi-somnolence. The six photos at left show, in sequence, the unfolding drama between the large sleepy mammal and and the agile — and cheeky — insect.



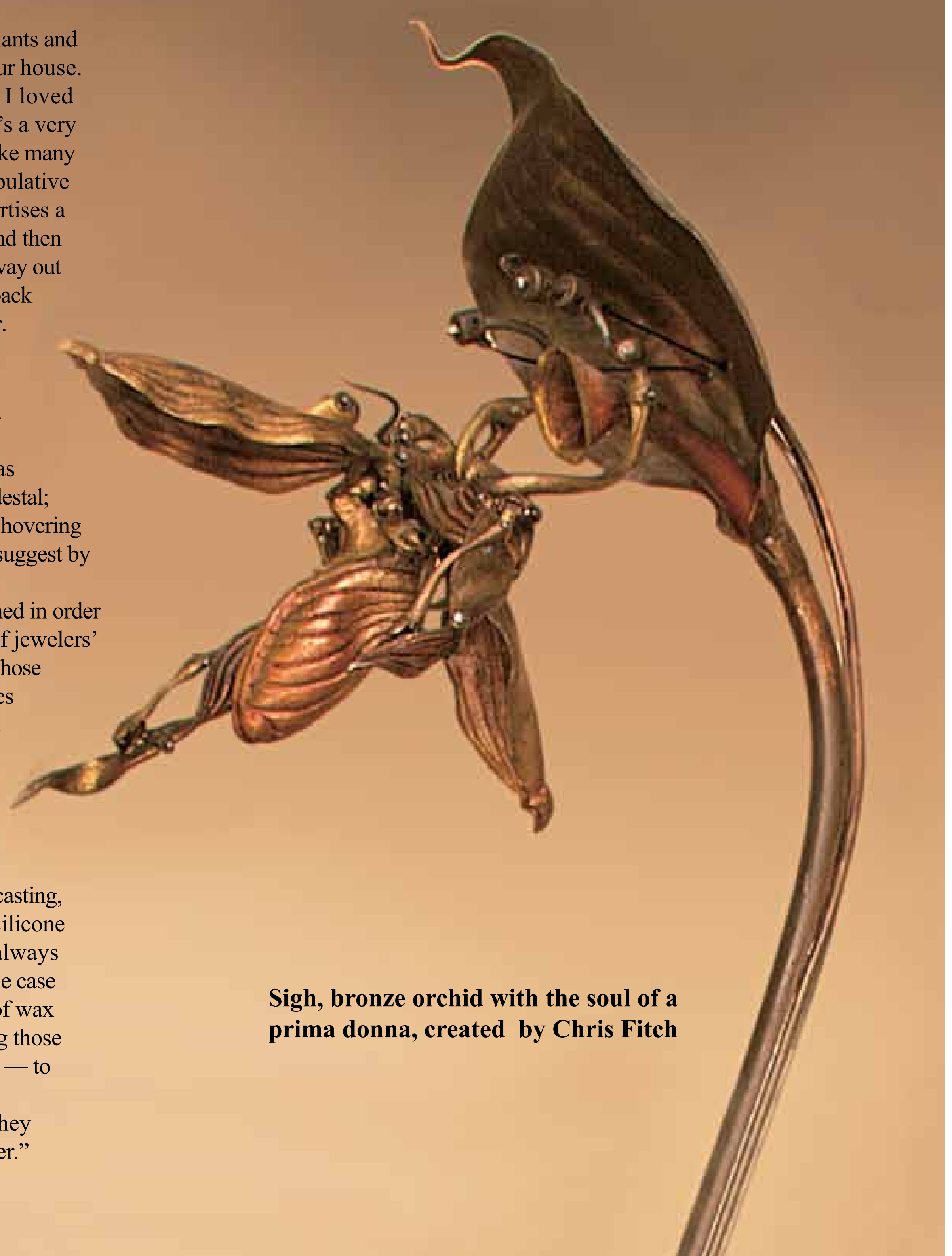


"When I was a kid growing up in rural Connecticut I was into weird plants and fell in love with a kind of wild orchid that grew in the woods around our house. Its scientific name is Cypripedium Acaule, or pink lady's slipper. I loved it because it was beautiful, but that wasn't all. When not in bloom it's a very unassuming plant, but in spring it puts forth a single blossom that is (like many orchids) a miracle of engineering and loveliness mixed with a manipulative agenda of deceptive bug psychology. In shape and redolence it advertises a reward of nectar, beckoning a bug to come a little closer… closer… and then —oops!— the bug falls into the "slipper" from which there is only one way out — through a narrow passage that forces the bug to pick up pollen on its back or deposit the pollen from its last similarly frustrating encounter. This way, the flower need not spend precious resources on making nectar. I felt sorry for the bugs, but I also wondered what it felt like to be the orchid, sitting there waiting around for something to happen.

"Later, as I set out to make a mechanical impression of the flower, the idea of a beautiful creation sitting on the forest floor struck me as a metaphor for art more generally. I imagined a bronze orchid on a pedestal; what a dull existence it must lead in a gallery, with art lovers like bugs hovering around it, debating its inherent value! It was this dynamic I wanted to suggest by having it occasionally release a deep, resonant sigh.

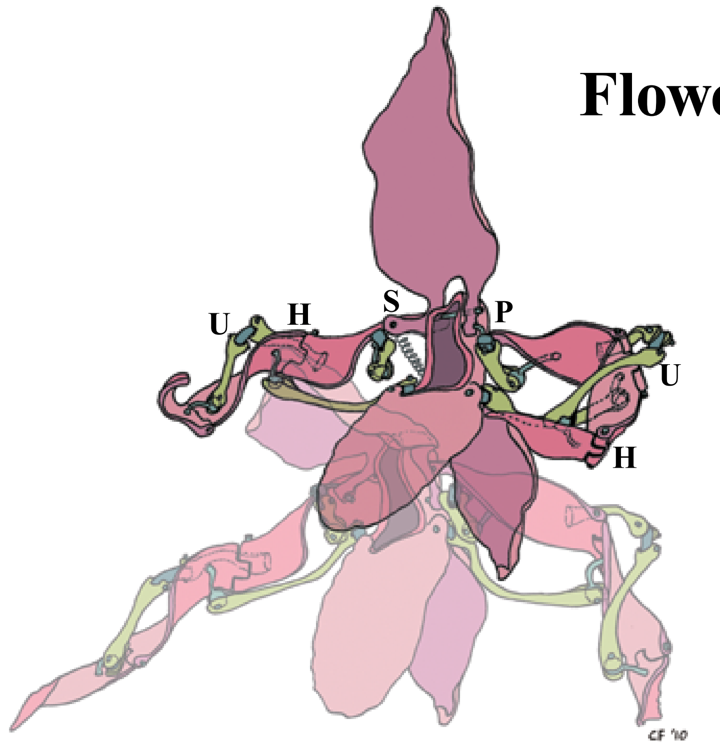
"I had to make the flower mechanism first because I needed it finished in order to figure out the next steps. I started by carving the flower parts out of jewelers' wax, which I knew could then be cast in bronze or brass or silver. I chose brass because it machines well; I wanted to drill some holes in the pieces after they were cast. The wax itself had enough strength so that I could mock up the mechanism pretty well in it, using stainless steel rods (I use welding rod) as pins for joints. When I disassembled the wax model I plugged the pinholes, leaving just little divots to mark where I would drill the holes in the brass casts. Then I sent them off to a jewelry caster. He had asked me if I wanted to make silicone molds for making extra waxes in case there was a bad casting, or in case I wanted more pieces. I was poor, so I decided to skip the silicone molds and take a chance. In retrospect, that was really dumb. It's always a good idea to have extras; something always goes wrong — as was the case here. The two main lateral petals I had carved out of a different kind of wax (probably cheaper!) and their castings failed. So I ended up fabricating those pieces out of brass strip, wire, and rod — soldered, forged and carved — to get them to more or less match the originals.

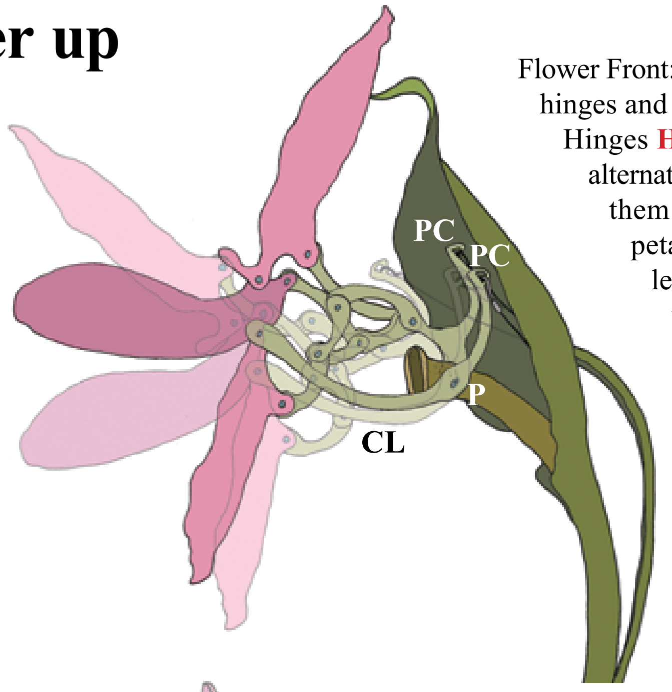
"The facing page shows the parts of the orchid sculpture, how they relate to each other, and how they move to open and close the flower."



Sigh, bronze orchid with the soul of a prima donna, created by Chris Fitch

Flower up

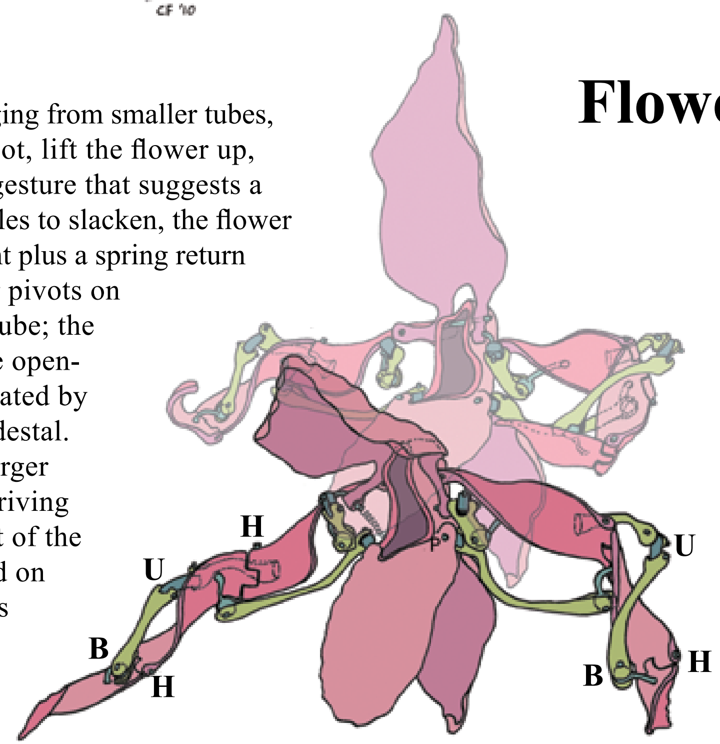


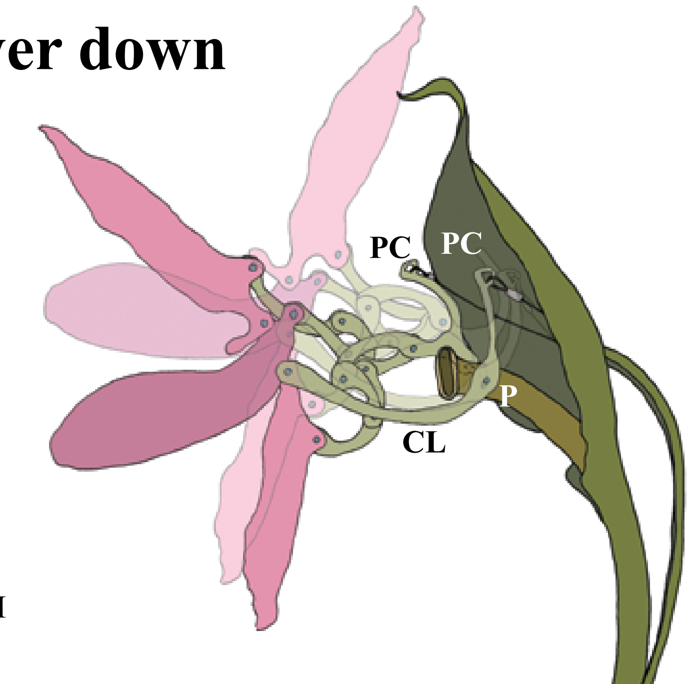


Flower Front: As the flower rises and falls, a series of hinges and joints act to open and close the petals. Hinges **H**, universal joints **U** and ball joints **B** alternately pull the side petals in, and articulate them. Pivots **P** allow the top and bottom petals to open and close as the compound levers change the position of the flower's various parts. Springs **S** on either side of the large central petal help the flower to return to a drooped position. The parts were originally carved in wax and then cast in brass.

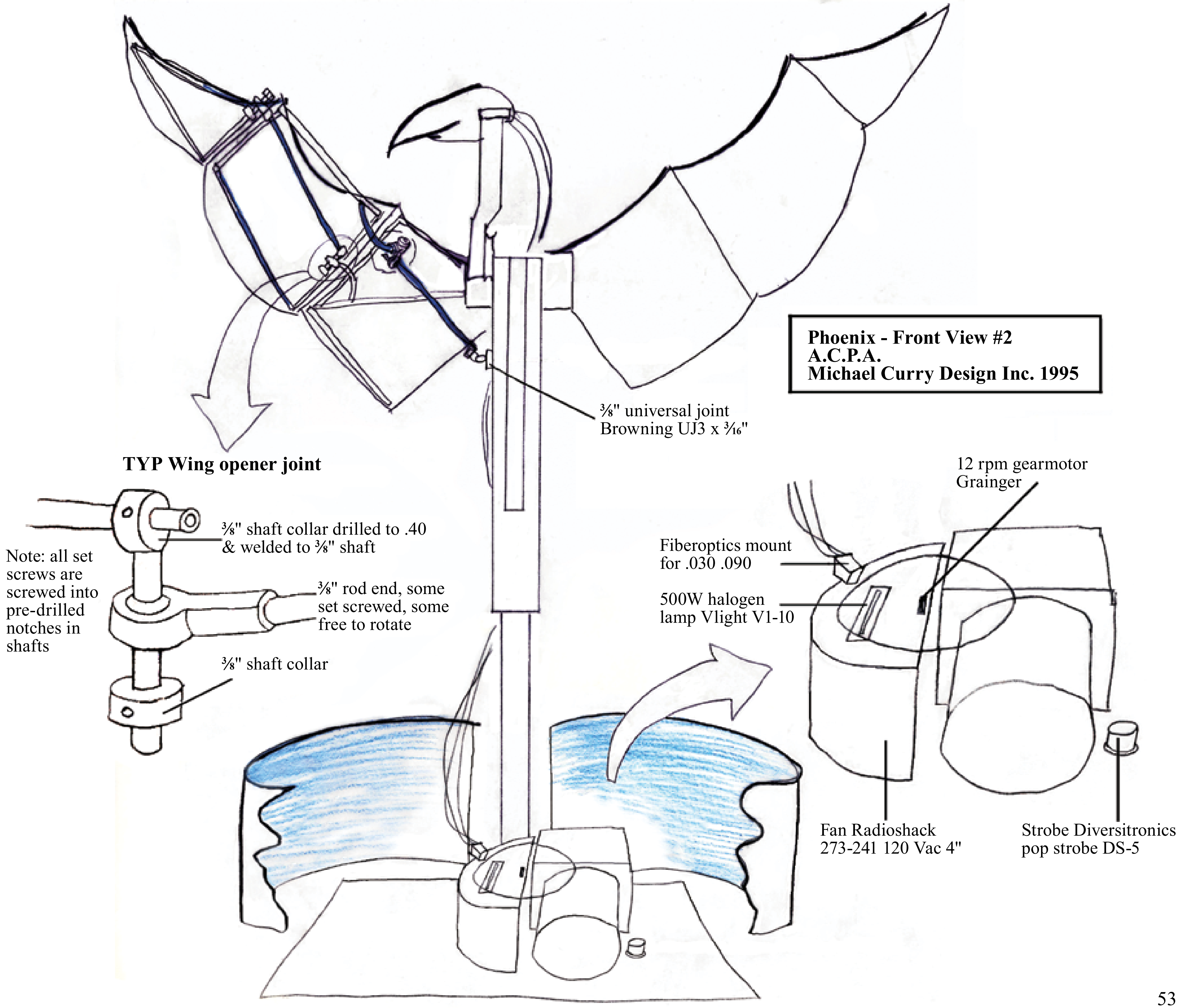
Flower down

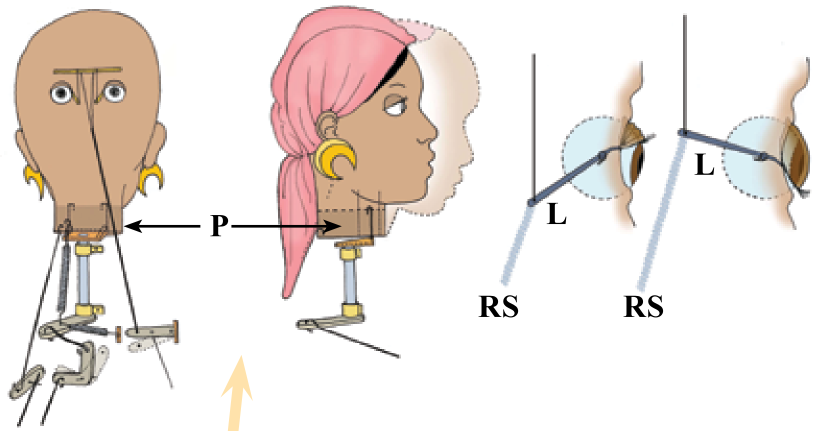
Flower profiles: Pull cables **PC** emerging from smaller tubes, pulled by the crankshaft inside the pot, lift the flower up, creating a stretching and shrugging gesture that suggests a sigh. When crankshaft allows the cables to slacken, the flower droops, pulled down by its own weight plus a spring return amongst the flower parts. The flower pivots on an attachment point **P** on the larger tube; the "breath" for the sigh comes out of the opening of the larger tube—airflow generated by the bellows and motor within the pedestal. Compound levers **CL** pivot on the larger "breath" tube, pulled by the cables, driving the motion of the flower petals. Most of the flower parts are of cast brass, pivoted on small (1/16th to 3/32nd) stainless steel axles with retention rings.





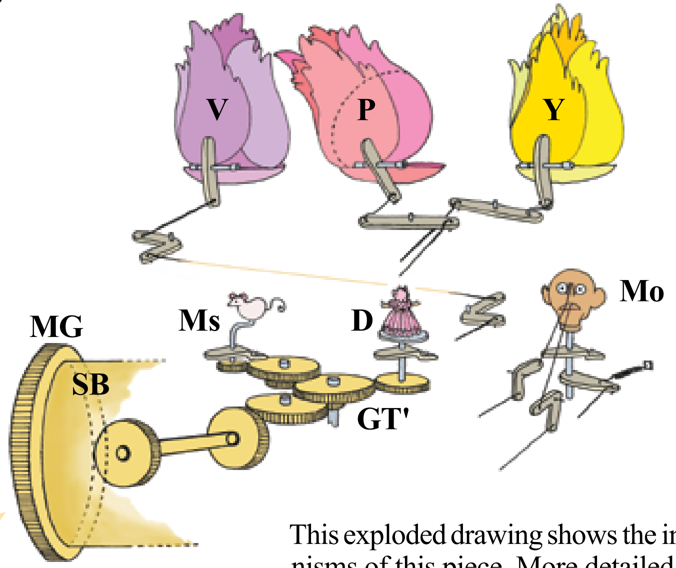
Trash Phoenix: Giant bird emerges from a trash can, by Michael Curry. Above: the trash can closed. Left: Phoenix fully opens. Facing page: drawing showing the trash can opening into the Phoenix; the technical diagram shows specifications for the sculpture. For the very technically minded among you, diagrams of motor interface and time control are on the book website. Size of puppet: 9′ tall. Materials: metal parts, fiberglass, electronic parts. Client, Center for Puppetry Arts. All photos, Melissa McCarriagher. Drawings and diagrams, the artist.



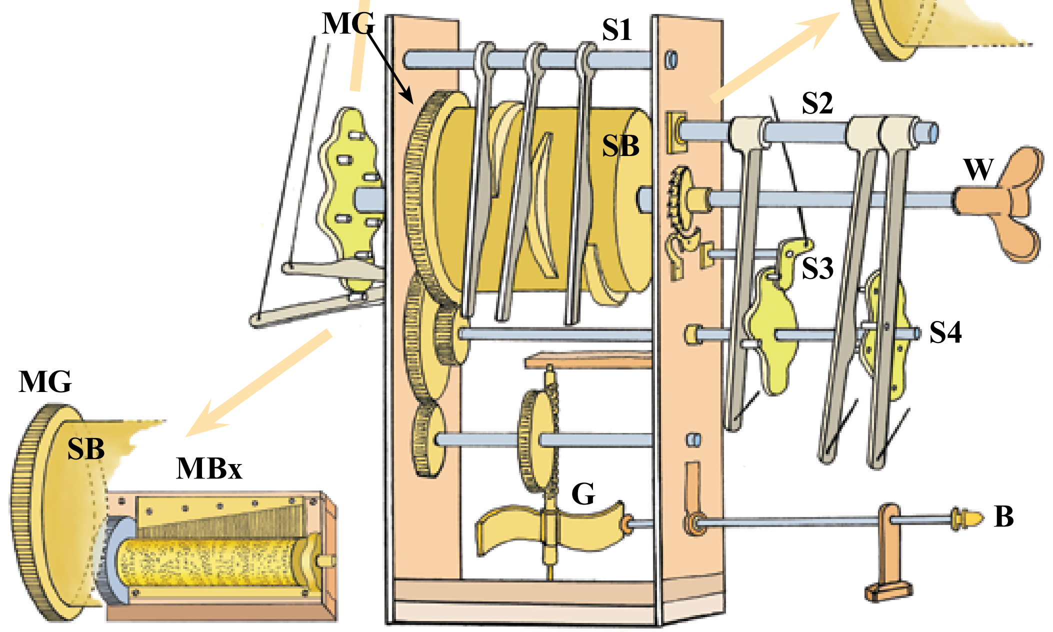


At left, the mechanisms controlling the movements of the Flower Seller's head and face. The base of the neck is a wooden "plug" **P** attached to a metal mounting piece at the end of a steel shaft. The neck plug can be tipped forward, nodding the head; the shaft can be turned, turning the head. Her eyes are on pivots mounted at either side of her glass eyeballs, and levers **L** attached to cables going up to the top of her head and then pulled downward blink her eyes. Return springs **RS** pull the eyes forward again.

At right, the mechanisms for the movements of the surprises within the flowers (**V**iolet, **P**ink, **Y**ellow) which, unlike the illustration on the facing page, actually open in turn, one after another. The main gear **MG** at the end of the spring barrel **SB** meshes at a 90º angle with a gear whose shaft leads to another gear again meshing at a 90º angle with a small gear train **GT'**. This gear train of spur gears and pinions decreases the torque, but increases the spin speed of the mounts for the doll **D** and the mouse, **Ms** so that they rotate many times faster than the main gear does. The monkey's **Mo** head movements are controlled by the followers (on **S2**) for the cams mounted on shaft **S3**.



Please note: in this drawing, in order to show the mechanics clearly relative to each other, the automaton is seen from the ***back***, rather than the front..



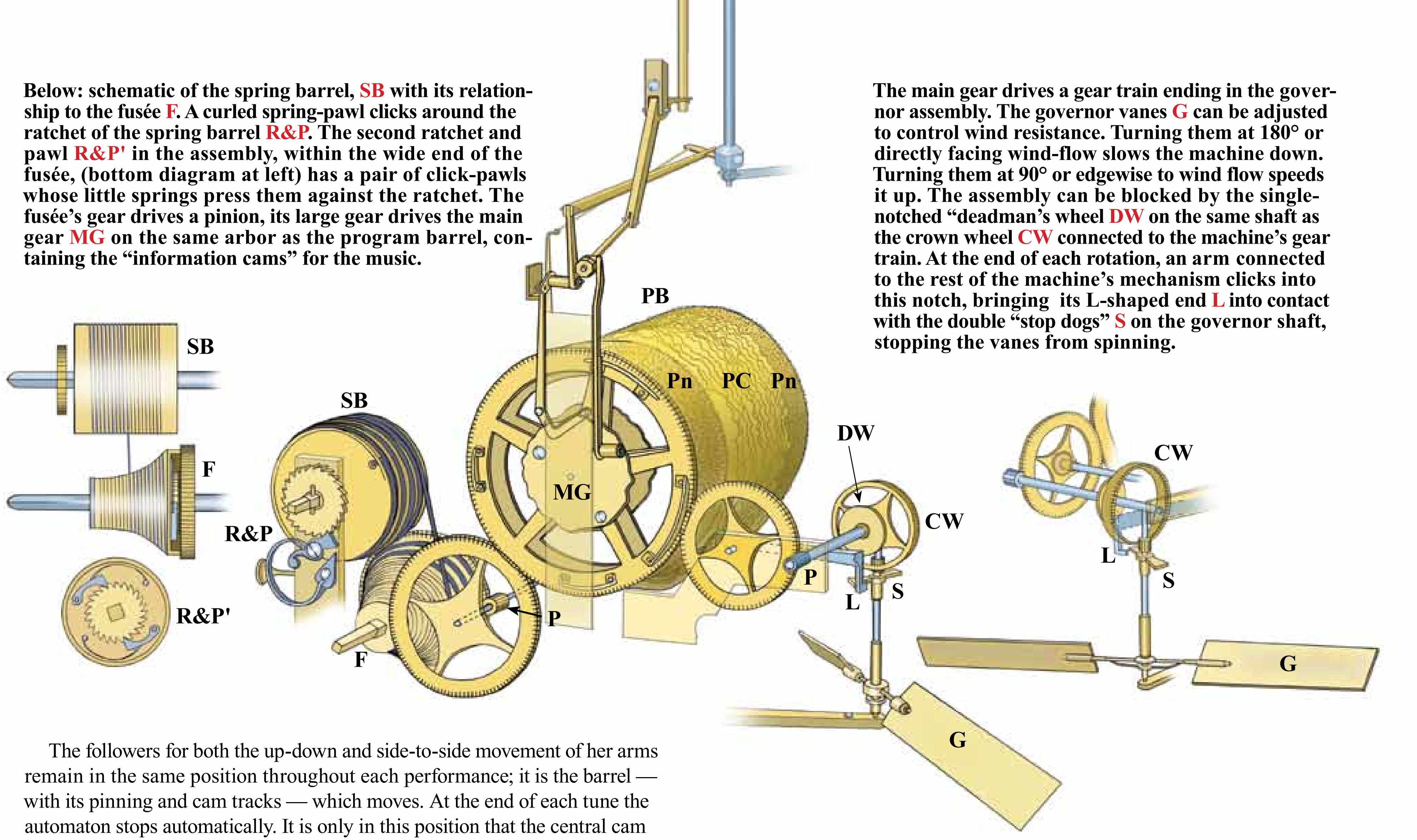
This exploded drawing shows the interconnection of all the mechanisms of this piece. More detailed closeups on following pages.

At lower left is the music box, **MBx** a fairly standard model, consisting of a gear driving the pinned barrel which plays the "comb". The musical movement's gear is driven by the main gear **MG** at the end of the spring barrel **SB** (partially sketched in here at the left). Center of the drawing, the spring barrel, with its main gear at the left end, the windup rod **W** and key sticking out at the right end, and the four-gear train **GT** driven by it. The spring barrel has three built-in "ribs" distributed on its surface, which act like cams, to open and close the flowers. The gears in the gear train drive the cams powering the movements of the "surprises" within the flowers, and also power the head and neck movements of the Flower Seller. The shafts holding the followers for the various cams are labeled **S1**, **S2**, **S3**, **S4.** The last gears of the gear train drive the worm gear (endless screw) shaft ending with the governor vanes **G** which keep the automaton running at an even, slow pace. A brake rod **B** at lower right, pushed inward will suddenly halt the governor — and with it, the entire movement.

La Joueuse de Tympanon, the Hammer Dulcimer Player, by Peter Kintzing and David Roentgen: this elegant automaton, thought to be a portrait of Queen Marie Antoinette, plays eight different classical pieces, with charm and verve, on a kind of dulcimer in the shape of a small harpsichord. Holding a small metal hammer in each hand, she strikes the chords with precision and skill. As she plays, her head nods and turns. Her eyes turn also, but with a slight delay. The figure is about 30 cm tall, the whole piece is about 107 cm in length. Her body, face and arms are made of painted wood; her wig is of real hair; her costume is of embroidered silk with lace and ribbons. The mechanism is of brass and mild steel. The tympanum is of wood, with gilded decorations. Date of completion 1770's to 1780's, though a more precise date might be 1784. This automaton is presently in the collection of the Musée des Arts et Métiers, Paris, France. Photos of the automaton ©Musée des arts et métiers-Cnam, Paris, photos P. Faligot. Photos of the mechanical movements were done by Jean-Luc Chazoule. All technical drawings in this chapter were done by Ellen Rixford.

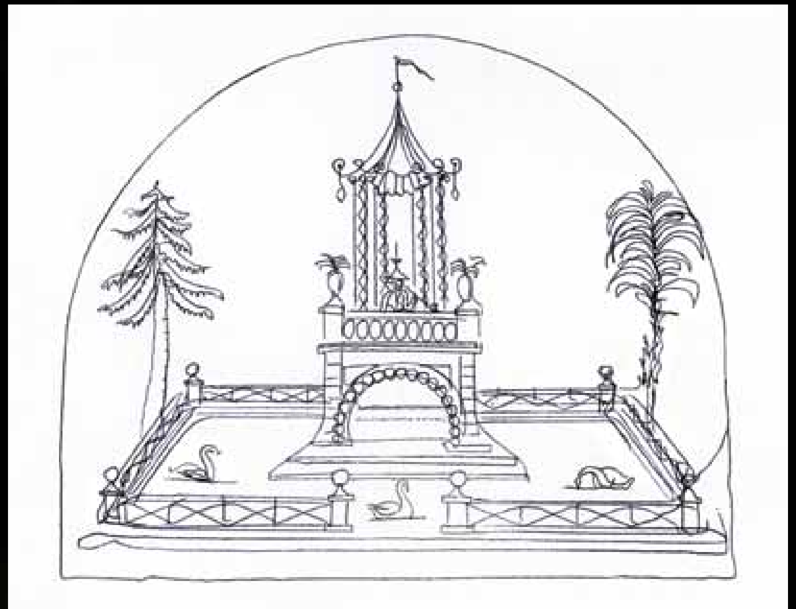
Below: schematic of the spring barrel, SB with its relationship to the fusée F. A curled spring-pawl clicks around the ratchet of the spring barrel R&P. The second ratchet and pawl R&P' in the assembly, within the wide end of the fusée, (bottom diagram at left) has a pair of click-pawls whose little springs press them against the ratchet. The fusée's gear drives a pinion, its large gear drives the main gear MG on the same arbor as the program barrel, containing the "information cams" for the music.

The main gear drives a gear train ending in the governor assembly. The governor vanes G can be adjusted to control wind resistance. Turning them at 180° or directly facing wind-flow slows the machine down. Turning them at 90° or edgewise to wind flow speeds it up. The assembly can be blocked by the single-notched "deadman's wheel DW on the same shaft as the crown wheel CW connected to the machine's gear train. At the end of each rotation, an arm connected to the rest of the machine's mechanism clicks into this notch, bringing its L-shaped end L into contact with the double "stop dogs" S on the governor shaft, stopping the vanes from spinning.



The followers for both the up-down and side-to-side movement of her arms remain in the same position throughout each performance; it is the barrel — with its pinning and cam tracks — which moves. At the end of each tune the automaton stops automatically. It is only in this position that the central cam readers and pin-followers find themselves clear of both pinning and cams. This will allow the program barrel to shift laterally for tune changes. It is also the only position in which the mechanism disengages a tune change cam TchC locking device, allowing the operator to freely rotate the tune change cam, selecting which melody is preferred. (See following pages.)

Adjoining the main gear at its right is a gear train leading to the governor assembly G. The gear to the right of the main gear drives a steel pinion P on the same shaft as a crown wheel CW (gear). This crown wheel drives another pinion at the top of the shaft leading to the fan blades of the governor. Just behind the crown wheel (gear) is a wheel with one notch cut into it — a "deadman's wheel" DW. The purpose of this wheel, and the parts adjoining it, is to make sure that the barrel's rotation is fully stopped when the barrel is changing position. This notch is located next to a short steel arm which has an L-bend at the end of it L. When, at the end of a tune, the arm's end slips into the notch in this wheel, it brings the L-bend of this arm into contact with a pair of "stop dogs" S at the top of the governor shaft. When it is blocked by the L-bend's tip, it will stop the rotation of the governor, bringing the mechanism to a dead stop. Then the barrel is free to slide over and change position for a new piece to begin. Once the barrel is in its new position, the mechanism can be restarted, and Marie Antoinette can continue her performance.



Above, Automaton's drawing of a Chinese temple. Below, a poem translated as: "Child beloved of the ladies, I am everywhere favored by women — and their husbands too!" The poem is signed: "done by the Automaton of Maillardet."

Above is an overhead photo of the mechanism contained within the case on which the doll (photo of doll and case at left) is placed. In succeeding pages, the parts of this machine, and their interaction, will be shown and explained in more photos and several drawings. Following are listed the major components visible in this photo. Additional components, not easily visible here, will be covered in the following pages, which describe the operation of the automaton in detail.

W are windup shafts which, through **F** fusées, and **C**, their chains, wind up the three independent clockwork motors powering the machine—two on the right, powering the rotation of the cam bank, one on the left, powering its lateral movement left to right. The mainsprings are contained by **SB** the spring barrels, tucked below the fusées, and largely hidden by them. **GT** is the gear train which connects the fusées on the right side, (gear trains on the left side aren't visible in this photo) to **MG** the main gear which, using two projecting rods **R** turns **PC** the program cams, on the main bearing **B** supporting the program cam bank. The program cams' edges, or profiles, as they turn under the cam followers **CF**, govern the movements of the doll's right hand as he draws and writes. The cam followers connect to **RF**, rod followers which operate **LR** linkage rods connecting to linkages **L** in the doll's body, controlling the movements of the hands and head.