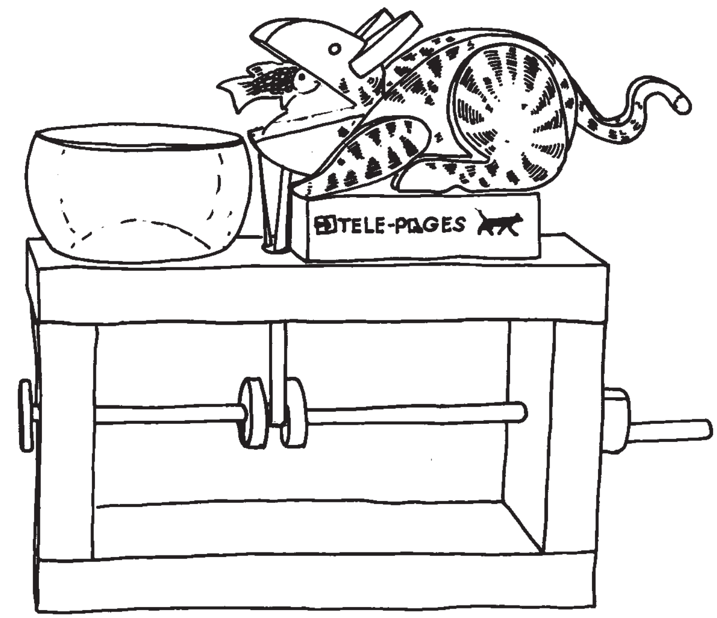
HOW TO DESIGN AND MAKE AUTOMATA

ROBERT ADDAMS



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Web Site: http://www.automata.co.uk

The web site is an educational tool available to everyone Worldwide,
as well as providing general information it also supplements parts of the book.

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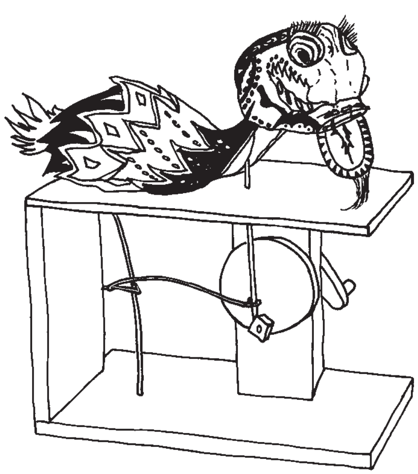

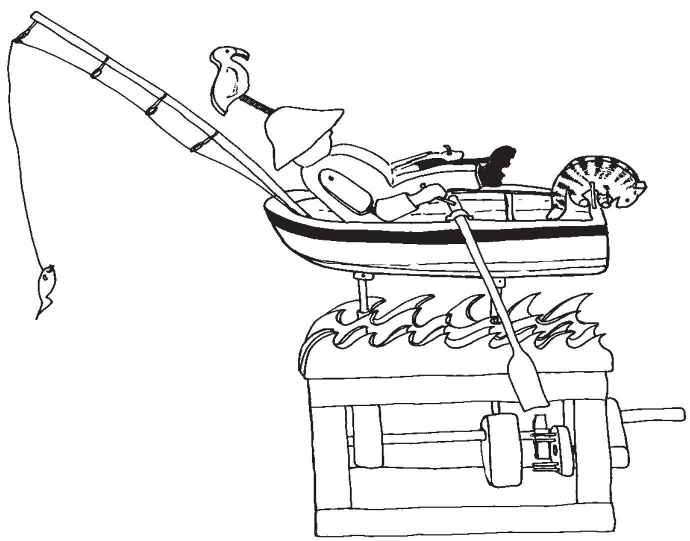

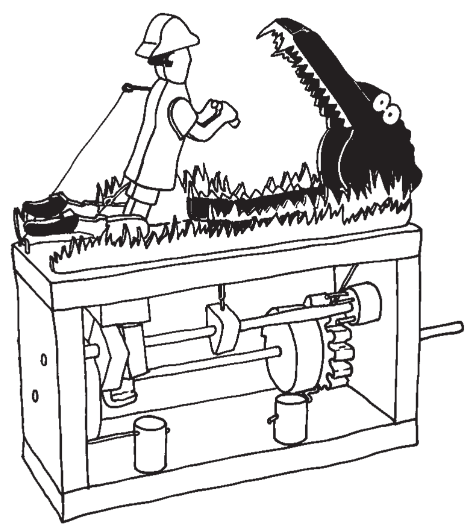

This book is dedicated with grateful thanks to my family, Beverley, Toby, Oliver and Dominic, who put up with so much during the writing and production. Also, special thanks to Selina Gamble and Ian Puttuck who had the task of proof reading and unralveling my transcripts.

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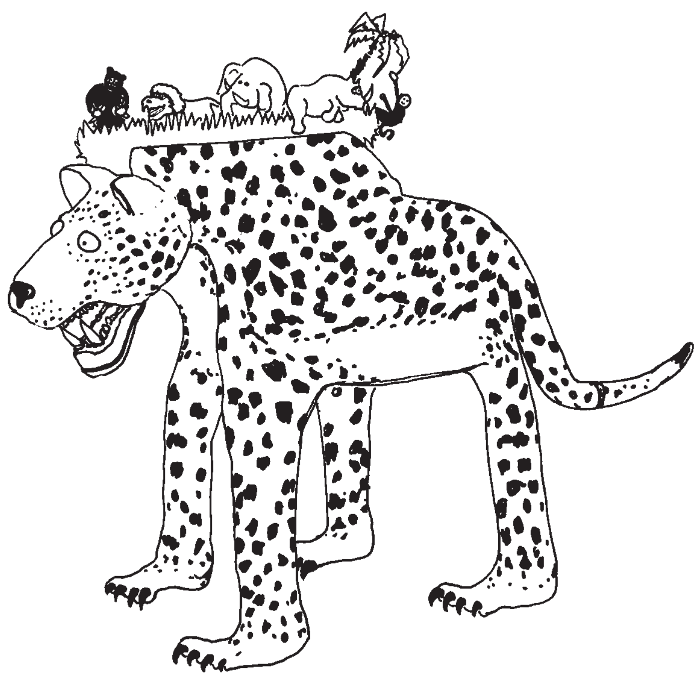
INTRODUCTION

This book is intended as an overview to the mechanical principles behind automata, as well as guiding the reader through the design process to make successful, exciting automata. The book also looks at construction methods, materials and useful tools.
The primary aim of this book is to provide both a stimulating project base for teachers delivering Design and Technology at levels 1, 2, 3 & 4, and help with lesson planning for the National Curriculum. Sections of the book can be photocopied and used as handouts for students.
In essence the book should provide a stimulating resource for teachers who can then disseminate the information to their students in the way they feel is most effective.

Automata are fascinating mechanical marvels that utilise a wide range of the mechanical processes found in modern machinery. Designing and making Automata covers a range of skills and processes from Art, Engineering and Maths through to craft skills involving card, wood and metal. It is an involving process that has a lot of potential for stimulating the imagination of students and providing a fun, practical learning platform.



Design and Technology in the National Curriculum provides a wide scope for the teacher to explore. The designing and making of Automata lends itself extremely well to this subject, encompassing all of the major criteria that need to be covered. Importantly, it allows this to be done in a fun and stimulating way. Many teachers already set projects based on automata and this book will be a useful guide for expanding upon this. It also provides a comprehensive look at all aspects of automata making, as well as suggesting fresh and exciting ideas for inclusion into lessons.
"How to Design and Make Automata" fully covers all aspects of the mechanical, design and construction processes, from simple to complex automata. It caters for all student abilities and skill levels and gives valuable advice on the design stage. As well as providing a sound basis from which to evaluate the work.

THE NATIONAL CURRICULUM

Every child in the UK has to undertake some form of Design and Technology activity. The design and making of automata is a great way of meeting the curriculum requirements.
It encompasses all the elements of Key stages 1, 2 ,3 and 4. Designing and making automata is a very wide topic, which covers skills not only in Design but Art, Maths and English. It can be used to help children understand more about the machines that surround them.
In education terms this book is designed to be a guide rather than offering prescriptive, pre-packaged course work, and to give practical advice as well as suggestions and ideas to be included into the lessons. The A4 format can be easily photocopied for use as handouts or wall charts. The design process has been covered in detail, in order to meet the basis of Design and Technology curriculum requirements.
Primary and junior schools may need to be more resourceful when making automata, if you do not have access to machinery or wood working facilities, alternatives have been explored in most sections.
A number of patterns have been included at the web site, **www.automata.co.uk**, which you may find useful as a practical introduction to automata, or for inclusion into your own projects.

MAKING A START

Although aimed at teachers and students this book will be of great benefit to anybody interested in making Automata or any other mechanical device, sculpture or toy. If you are not involved in education, parts of the design process can be tackled in a less structured way, without the need to be accountable to an assessor.
The book is broken down into logical sequences, starting off with mechanisms. You will need to study this section first as it underpins all the concepts and principles needed to make any automata or mechanical device. It should also help to give you ideas for your own projects, but feel free to copy or adapt any of the examples in the book.
Any creative work involves challenges, difficulties, triumphs, tragedies and rewards. Making automata will offer these in abundance but do not lose sight of the need to keep it a fun and enjoyable process. Do not expect to start and finish in a day, you will soon find out just how long it takes to make an automata, so give your self plenty of time and be prepared for things to go wrong. Take heart though, the more you make, the better you will become and the easier and faster everything will come together.

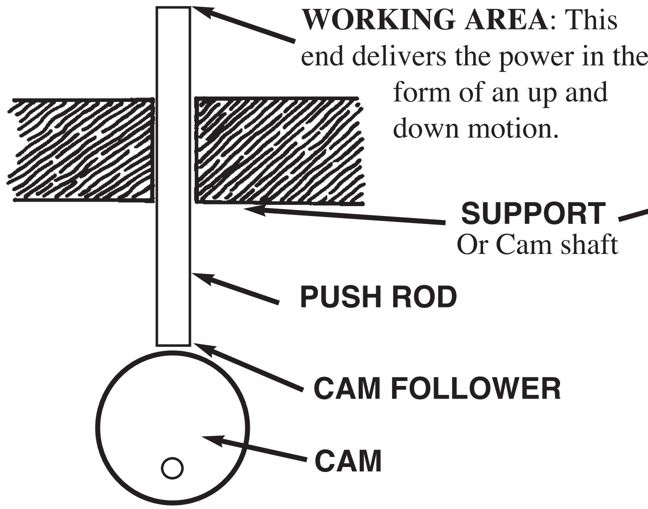
CAMS

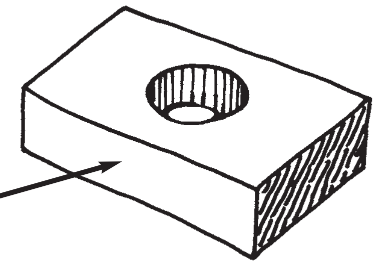
Cams act like small computers, storing information that can be turned into movement. They can be very simple or complex and the only limitation is their size.

The basic principle of the Cam is to turn a circular motion into a linear one. This is referred to as reciprocating movement.

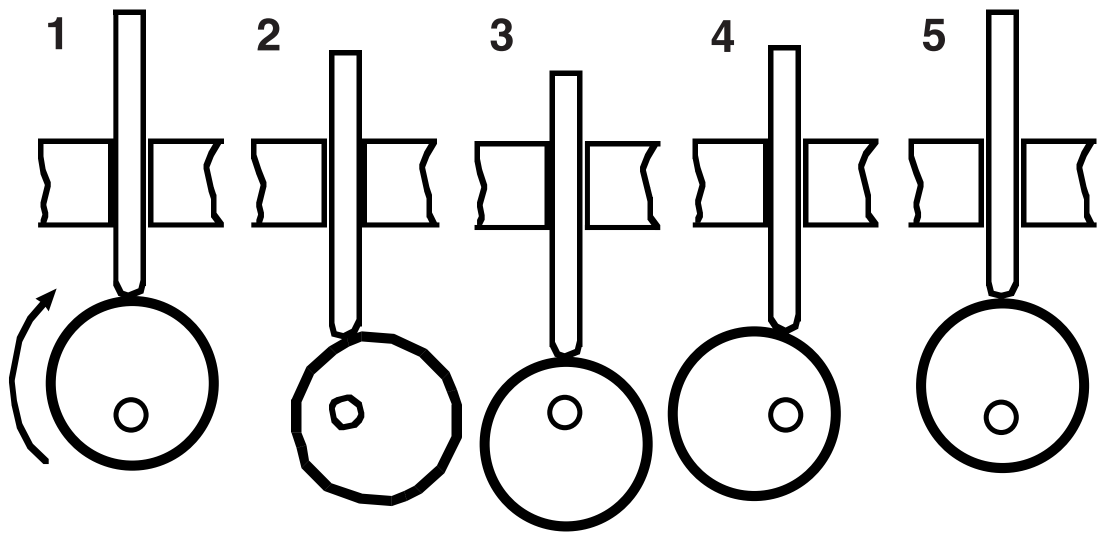
In automata the cam is very useful, and is probably the most commonly used mechanical action. As you will see, the Cam is simple to make and very versatile.

Cams normally work in conjunction with a "Cam Follower". As the name implies this follows the movement of the cam and transfers the movement to the working area. The cam follower is normally a rod made of rigid material such as wood or metal, which is supported by a shaft that limits the movement and direction. The cam follower is designed with a smooth end that can easily follow the cam's movement. This is a very important as the Cam and Follower will jam if not properly designed.





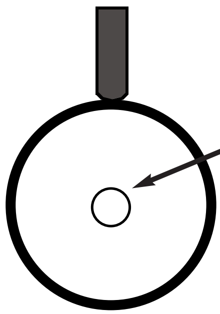
This block supports the cam follower and stops it from wobbling from side to side. This helps the push rod to only move up and down. In order for the Follower to rise and fall without jamming it is important to make this block fairly thick and reasonably close to the cam.



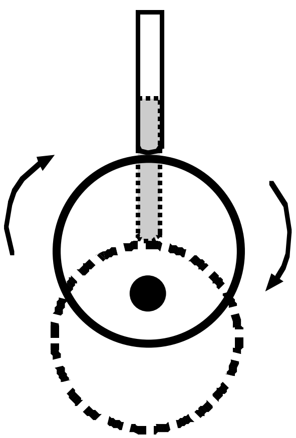
This cam is turning a circular motion into an up and down one. This is referred to as reciprocating motion. As you can see in stages 1-5, the cam follower steadily drops before rising up again. The whole process repeats as long as the cam keeps rotating clockwise.

CAMS

In order to design a cam you need to know what you want it to do. It may have just one or several movements per revolution.
Cams turn on a shaft and so need to be offset to create movement. If you have a circle with the shaft running through its centre then nothing happens. However, if you offset it you can create a mechanism that can lift. With this lift you can create many marvellous automata.



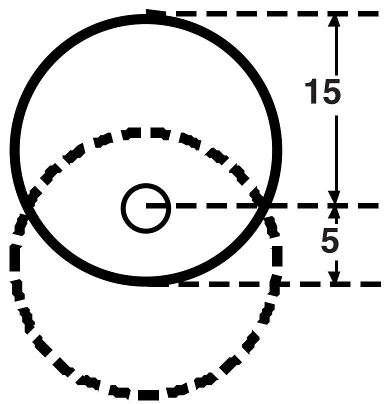
A circle with a shaft running through its centre will simply turn and produce no lift.



Offset the centre and you have made a cam.

The cam follower has lifted by this amount. So the more you off set the cam, the greater the amount of lift you produce.

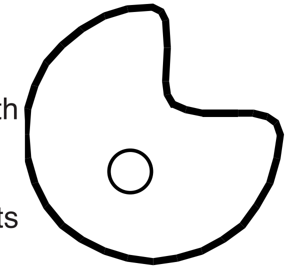
It is very simple to calculate the amount of lift by simply taking the measurement from the centre of the drive shaft to the lowest point of the cam and subtracting this from the measurement to the highest point from the centre of the shaft. This calculation will give the amount of lift the cam will produce.



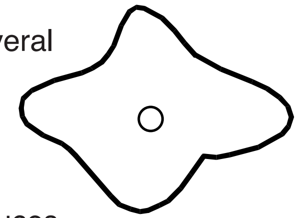
15 - 5 = 10

This simple equation will enable you to work out how much lift a cam will give. Later on we will come back to this formula to accurately work out the lift of any given cam.

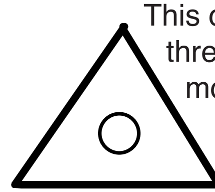
Different types of cam



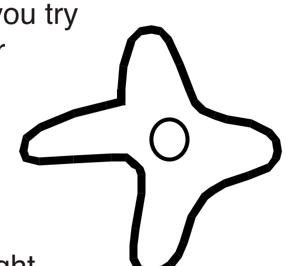
This cam produces a smooth uplift which suddenly drops down. It is often referred to as a snail cam because of its shape or contour. This cam can only work in one direction. If you turn it the other way the cam follower would jam. You need to bear this in mind when you are designing cams.



This cam produces several short up and down movements from one revolution.



This cam produces three very distinct movements from one revolution.

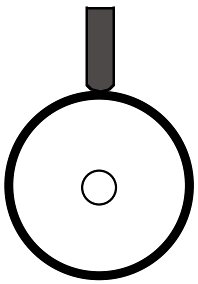


You can combine as many movements as your cam will allow. Remember that the cam follower has to work smoothly. If you try to make it do too much or make the contours too steep such, as this one on the right, it will jam. The cam followers can only move on gentle curves. Make them too tight and you will have problems!

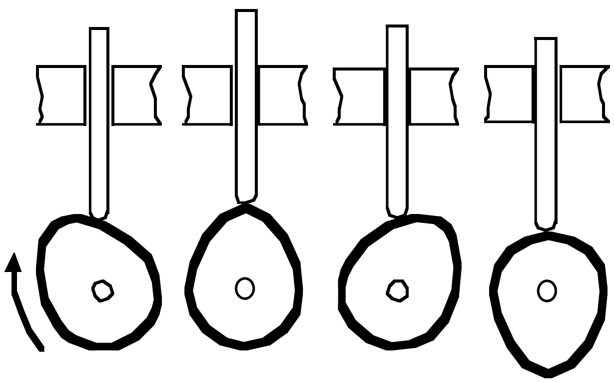
CAMS

LOBED AND DROP CAMS

From the basic round cam you can increase the diameter across one axis, to produce an egg-shaped, or “Lobed”, cam. Alternatively, you can create a recessed area that drops below the circumference of the circle, producing a “Drop” cam. You can, of course, combine these two elements in a cam, which is why they are so versatile.



The lobed and drop cams are based on a concentric circle with the drive shaft running through the centre. Obviously, without lobe or drop, this cam will not produce any effect on the cam follower.

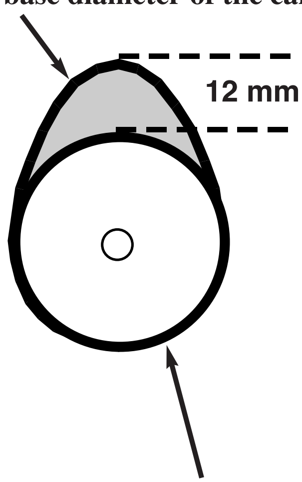


The cam follower is rising | **The cam follower is at its highest point** | **The cam follower is descending** | **The cam follower is stationary as it follows the circumference or dwell angle**

THE LOBED CAM

If you raise part of the circumference, you produce a lobe, hence the name lobed cam. This will lift the cam follower by the maximum height from the tip of the lobe to the circumference of the circle. When the cam follower returns to the circle it will pause and this is referred to as the dwell angle. You can produce a pause or dwell angle on top of the lobe if you design it properly.

A lobe refers to any part of the circumference raised above the base diameter of the cam.



The distance from the circumference of the cam to the highest point of the lobe will determine how much lift it will produce. In this example the cam follower will smoothly rise to12mm before dropping.

When the cam follower is not being lifted, that part of the cam is referred to as the dwell angle. This will produce a pause in the automata action.

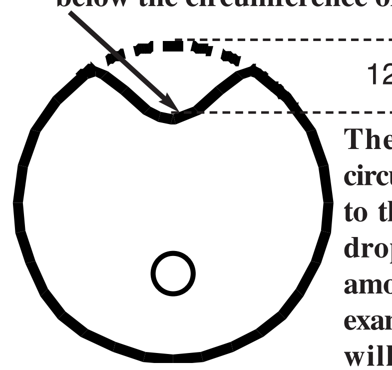
THE DROP CAM

If you dip below the circumference of the circle then the cam follower drops, hence the term drop cam.

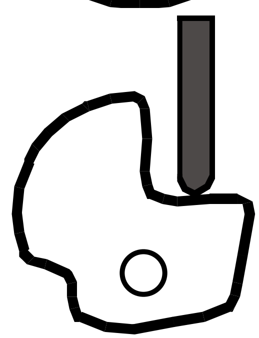
You can calculate the drop of the cam by measuring from the lowest point of the drop to the circumference.

A very popular form of drop cam is called the snail cam. This has a sudden drop that slowly rises to the next drop point. This cam is used a lot in automata and is a blend of both drop and lobe cam.

A “Drop” refers to any surface that goes below the circumference of the cam.



The distance from the circumference of the cam to the lowest point of the drop will determine the amount of travel. In this example the cam follower will smoothly drop to 12mm, before rising.

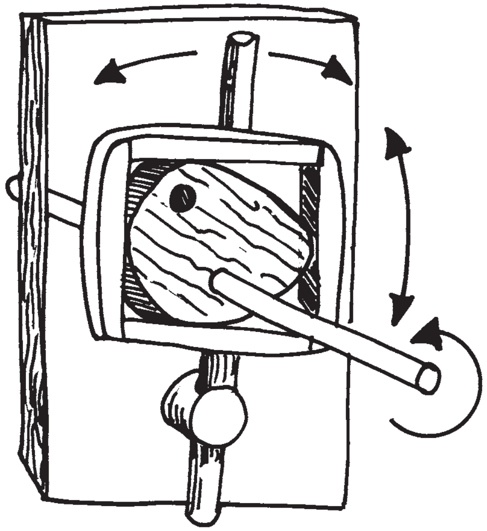


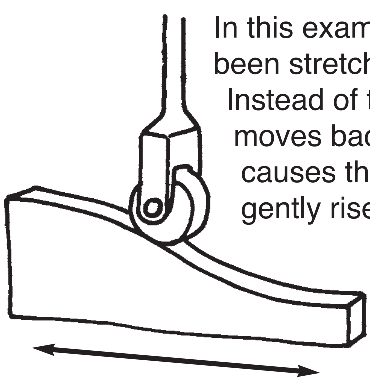
This snail cam both drops and lifts. You could even add some extra lobes and drops on the cam face.

SPECIALITY CAMS FOR AUTOMATA

The cams covered so far are fairly simple. They are the sort that can be found in many everyday machines like car engines and washing machines, but there are a range of more unusual cams that can be used for added versatility or sophistication when making automata. They are, in themselves, very simple but may require more skill when making them.

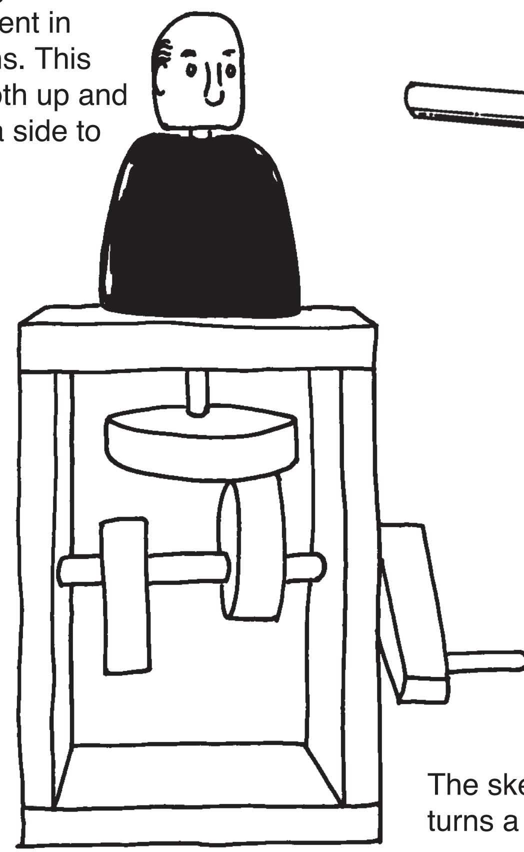
The self-conjugate cam works at high speed and has an unusual motion, producing both up and down as well as side to side movement.





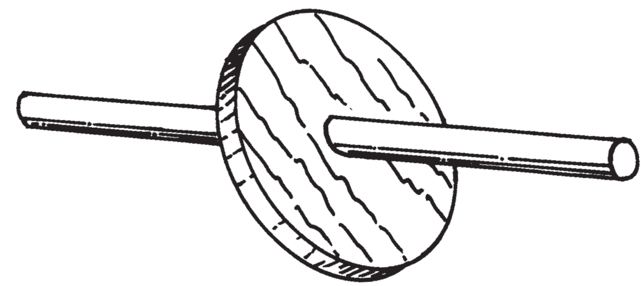
In this example the cam has been stretched out into a line. Instead of turning the cam moves back and forth, which causes the cam follower to gently rise up and down.

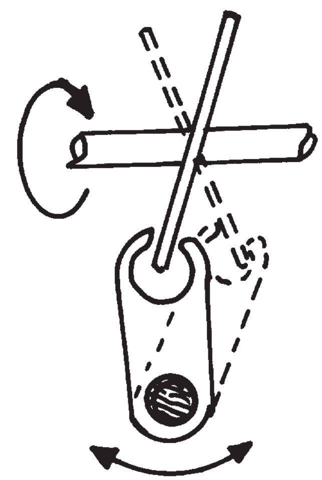
An offset cam not only moves things up and down but also in a circular motion. You must make sure that the cam contacts the cam shaft drive plate either side of the cam shaft. If it contacts directly underneath then it will only lift. Offsetting 2 cams either side produces movement in opposite directions. This then gives you both up and down as well as a side to side movement.



The man in this automata shakes his head from side to side. There is a small amount of lift but it is not really noticeable.

The skew cam has a thin plate which is attached to the drive shaft at an angle. As it turns, it contacts a forked lever which it turns from side to side. This twists a vertical rod and so transfers the movement.

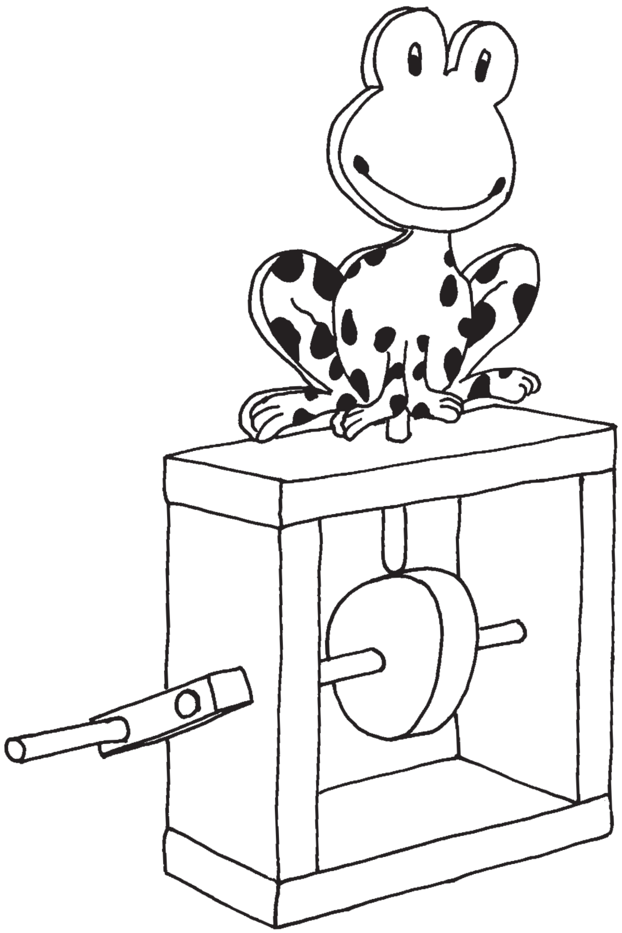




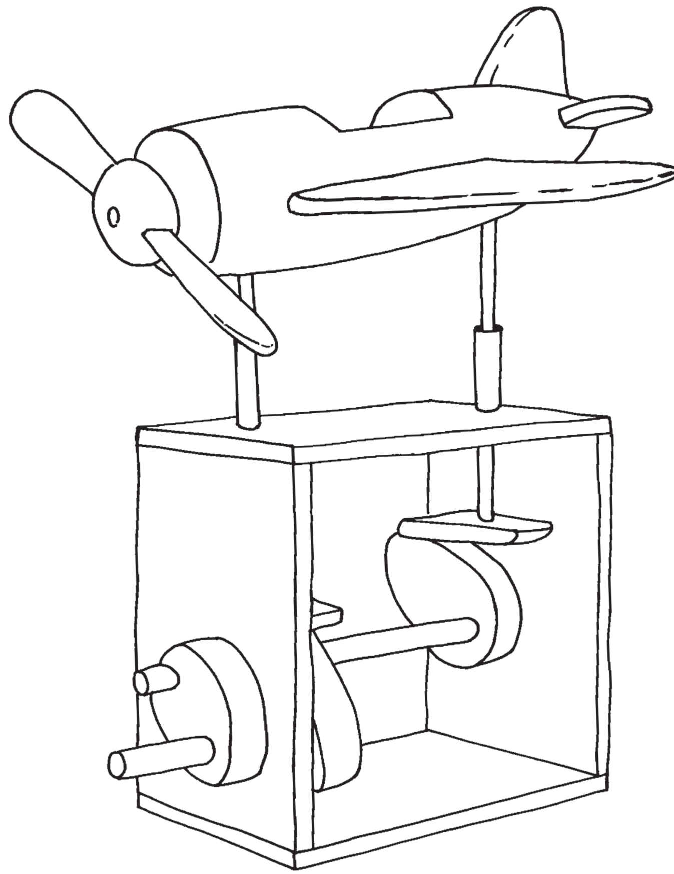
The skew cam is in effect a wobbly plate and turns a circular motion into a side to side one.

CAMS FOR AUTOMATA

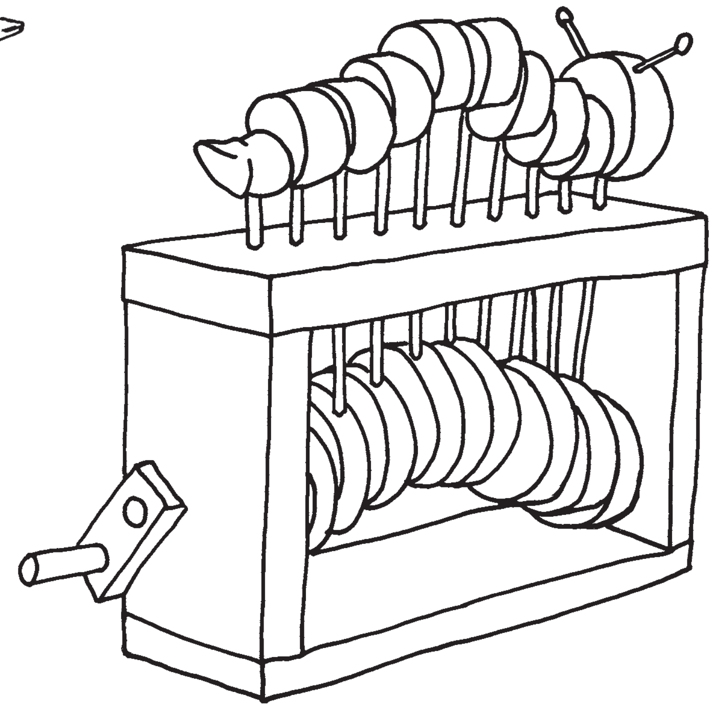
The examples below show how you can use the cam when it comes to making automata. The key point to make in mechanical terms is that it produces a linear movement from a rotating input and you can create an enormous amount of things with this. The illustrations below show a range of uses for simple one lobe cams.



FROG - USING A SINGLE LOBE CAM.
This will produce a single, smooth up and down movement.



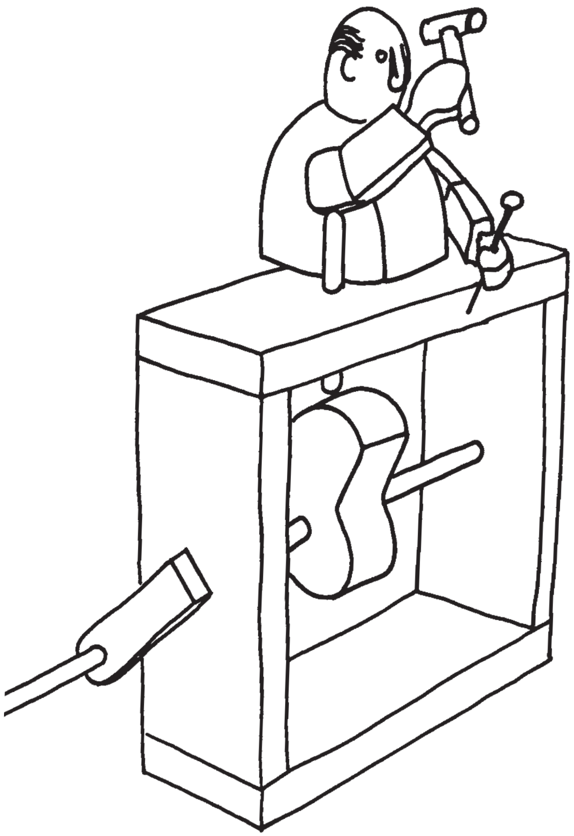
AEROPLANE - USING TWIN LOBE CAMS.
The two cams are at opposite ends and are set at 180° to each other. This causes the plane to dip up and down from nose to tail..



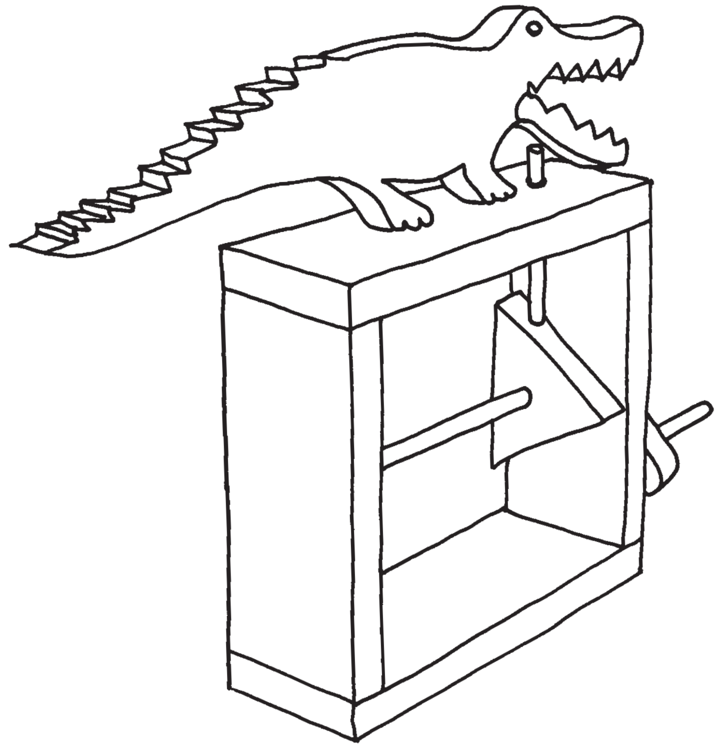
CATERPILLAR - USING MULTIPLE CONCENTRIC CAMS.
Each cam is slightly offset from the preceding one. This gives a smooth, wriggling motion.

CAMS FOR AUTOMATA

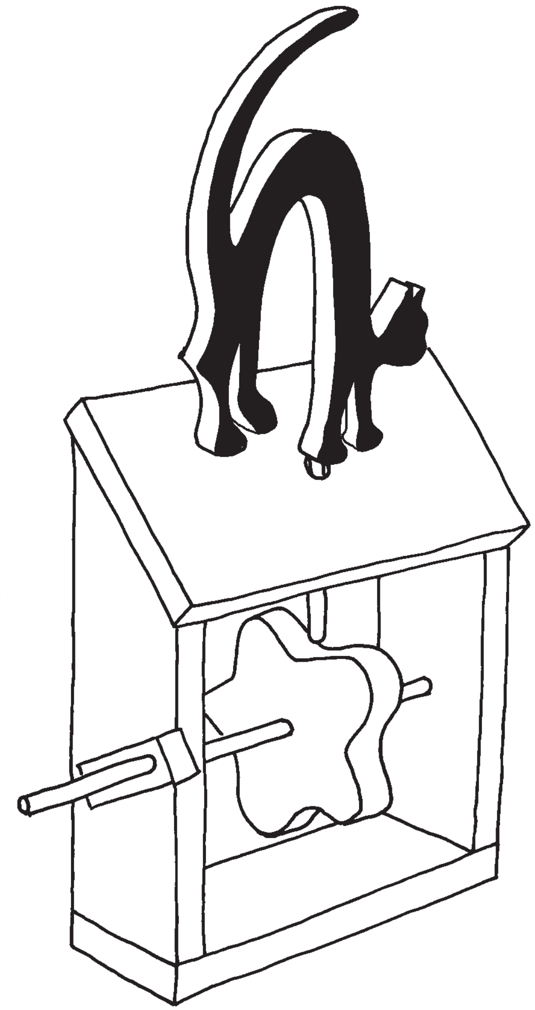
Cams can often have more than one lobe. Multiple lobe cams produce even more diverse and exciting movement.



This drop or snail cam allows the hammer to rise smoothly and then suddenly drop.



This pointed triangle will produce three equal sharp movements in one revolution, snapping the jaws open and shut.

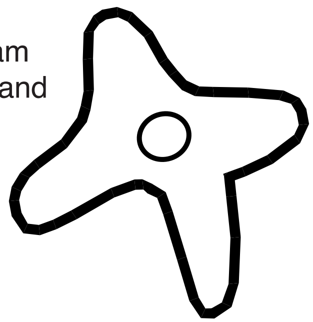


This cam has five lobes, one of which is higher than the rest. The cat will make four small jumps and then one big one.

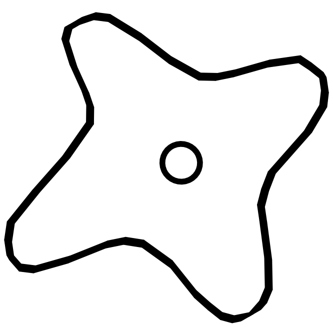
CAMS

DESIGN TIPS
When designing a cam, think about it creating a performance or event in one revolution. This can be simple or complex. Remember to use gentle curves to allow the cam follower to operate smoothly. If you design a cam that produces several events you may need to make it bigger.

The designer of this cam wanted to create 4 up and down movements per revolution.
This design would probably jam and not function properly.



This bigger cam will do the same job,



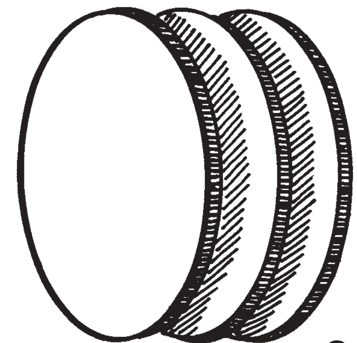
but now the cam follower is able to follow the contours as they are more gradual. It will still produce 4 varying up and down movements per revolution.

MATERIALS
When you have designed your cam, you will have to think about how you are going to make it. The ideal material should be soft enough to cut easily but strong enough not to break or wear out too quickly. Cardboard, for example, can be a useful material. Several thinner sheets can be cut to size and then stuck together (or “laminated”) using wood glue or PVA. This produces a very strong and durable cam. Alternatively you can use thick corrugated cardboard.

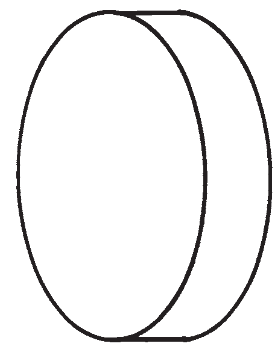
MDF (medium density fibre board) can be bought in various thicknesses. 4-6 mm works best and it is fairly easy to cut and then shaped with sand paper. The dust is harmful to breath in, always use a mask if working with MDF. We don’t advise you let children work with it.

Thin pine wood (again 4-6 mm) is another effective material to work with. It takes a little more time to cut and shape but is very durable, works well and looks good.

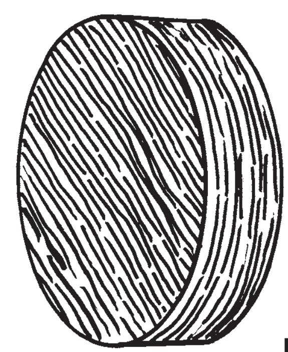
The later chapter on materials and tools goes into more detail.



CARD



MDF



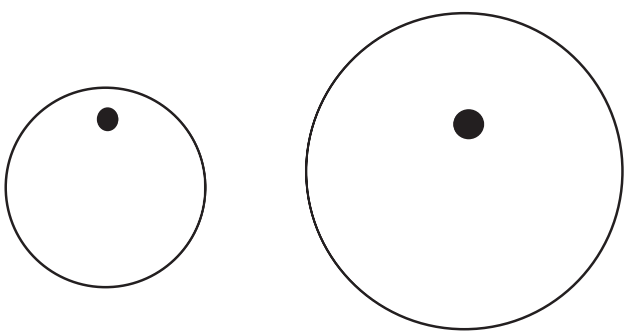
PINE

CAMS

MAKING AND MEASURING

This final section shows you how to use a simple mathematical formula to work out the lift for concentric cams.

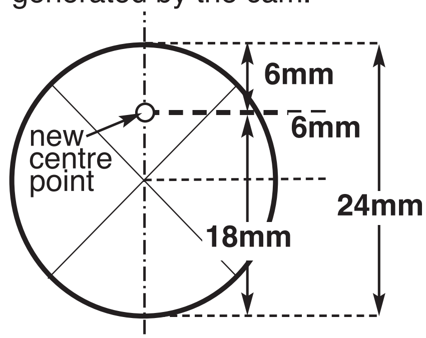
The concentric cam, is a circle with an offset centre. By offsetting the centre we are able to produce the lift and the further you move away from the centre point the greater the amount of lift you produce. Do not overdo things, it is better to make a larger cam that rises gently than a small one that rises rapidly. They will both do the same job but the smaller cam is more likely to jam.



Both cams lift by the same amount but the larger circumference of the bigger cam will produce a much smoother lift. As a rough guide, try to make the biggest cam that will comfortably fit into your Automata.

When making Automata, you need to work things out fairly accurately. This applies to cams when you need to produce lift to a specific height. The following formula is very simple and shows you how to quickly and accurately work out the centre point for the drive shaft.

For every millimetre that you move away from the centre point, you must double this figure, in order to calculate the amount of lift generated by the cam.



In this example you can see that the centre point has been moved up by 6 mm which will produce a lift of 12mm

You can confirm this by using the formula we looked at earlier by subtracting the two distances from the new centre point

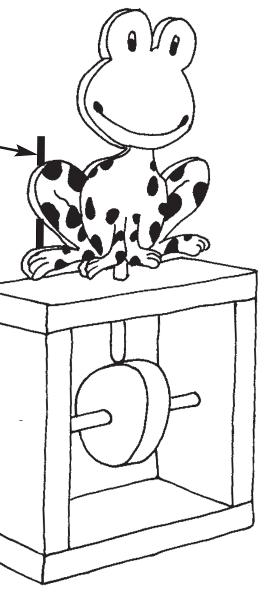
$$18\text{mm} - 6\text{mm} = 12\text{mm}$$

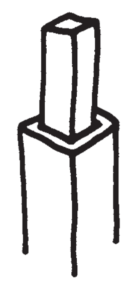
It's as simple as that. Remember you only have to accurately locate the centre point. The actual diameter of the drive shaft is not important.

TWIST AND TURNING

A rather annoying characteristic of the cam is that it produces a turning motion on the push rod. This may only be very slight but can cause problems. The leaping frog for instance slowly turns round as it moves up and down, which in some instances could be a problem. To eliminate the turning affect you can either build stops to prevent turning, (this can affect the overall look of your automata) or another method is to use square tube and rod which are readily available in brass, copper and plastic.These hold the push rod firmly in place and eliminate any turning action.

A small pin can be placed behind the frog which will stop it turning. Usually only one stop is needed as the motion is in one direction.

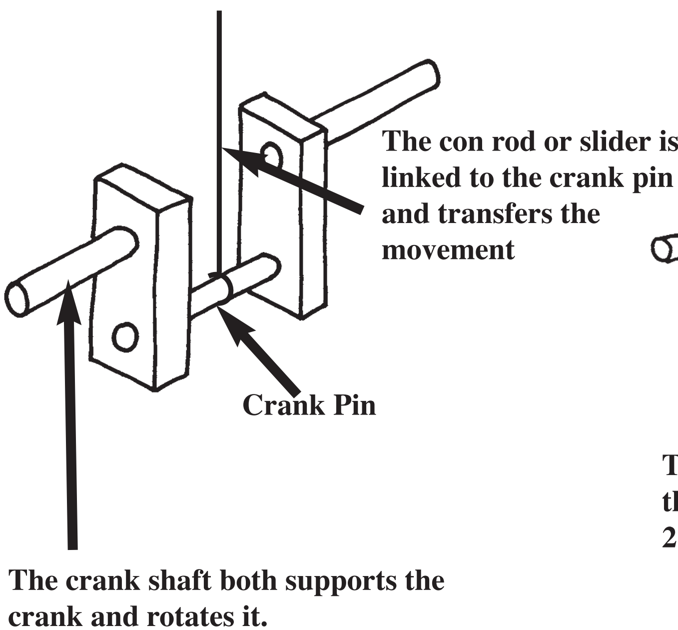




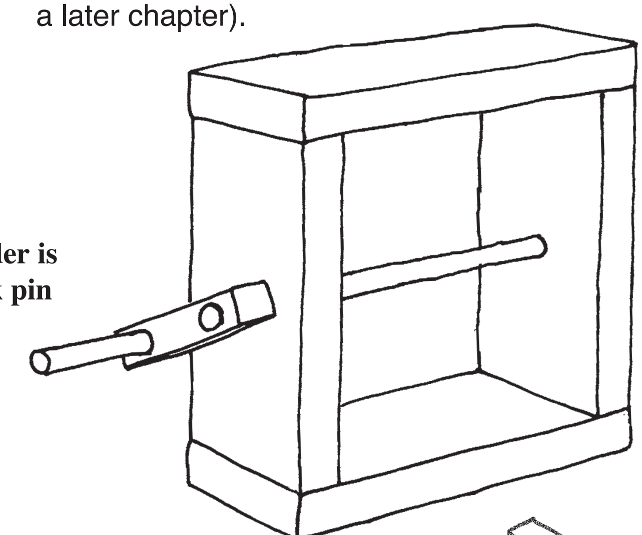
A square tube and rod eliminates any twisting action.

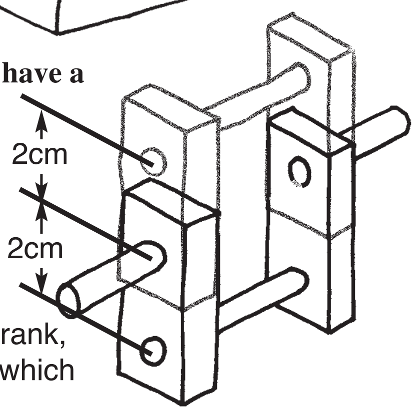
CRANKS

Cranks are similar to simple cams. They convert circular movement into a reciprocal one (up and down motion) or vice versa. There are, however, some fundamental differences. Firstly, cranks only ever work in a circular motion and they only have one drive action per revolution. That said, when it comes to automata you can make some amazing machines based on the crank.



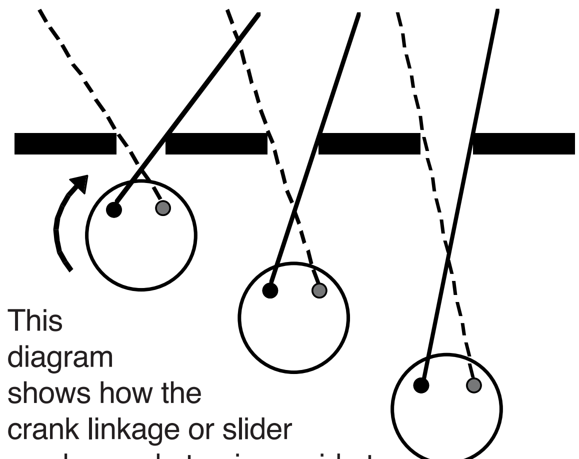
The crank has many uses. Firstly it is often the driving mechanism for hand operated automata. It is important to support the crank with some type of bearing. In this case it is the sides of the box that provide the support. (We will be looking at bearings and shafts in a later chapter).





The amount of up and down movement is called the **throw** of a crank, and is measured by the size of the circle it scribes when turning, which will be twice the diameter.

Although the crank only works in a circular motion, its drive can be made to go from side to side as well as up and down (which can't be easily achieved with a cam) and when applied to Automata you can create some very special effects.
Another big advantage with the crank is having power on both the upward and return strokes. This means you don't have to rely on gravity, which can be a problem with cams.



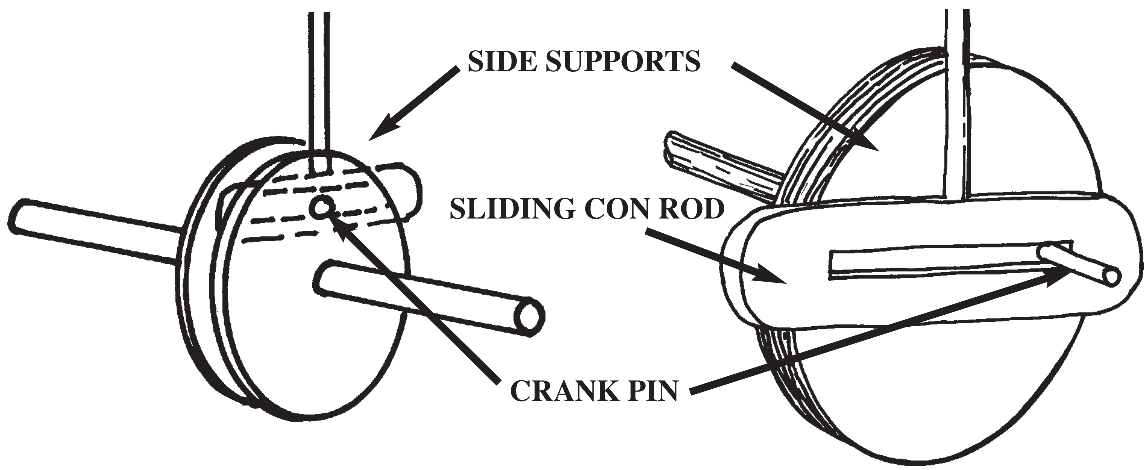
This diagram shows how the crank linkage or slider can be made to give a side to side movement. By adjusting the height from the opening you can increase or decrease the amount of sideways movement. Adjusting the size or aperture of the opening will also have an affect on the amount of lateral movement. As with many aspects of Automata you will find that trial and error play a big part in making things work.

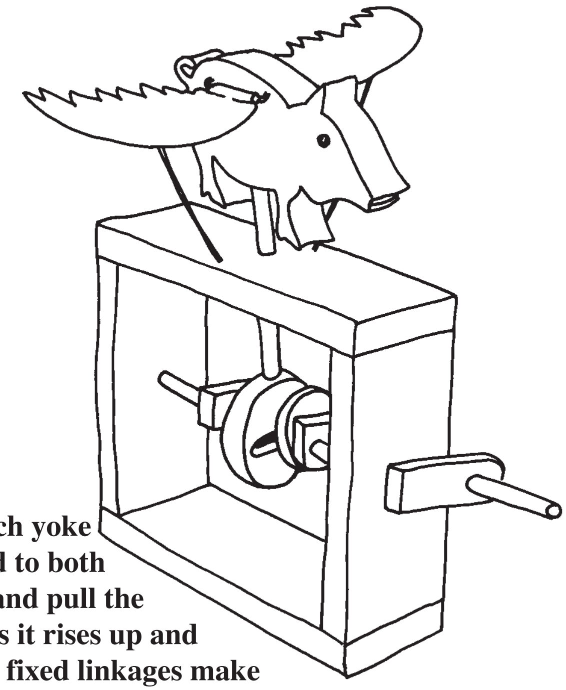
CRANKS

THE SCOTCH YOKE

A variation of the crank is the scotch yoke. This is more complex to make, but has a number of advantages.

The sliding con rod is held in position by supports placed either side. There should be be just enough room to let the slider move. The supports are attached to the main shaft and rotate with it.

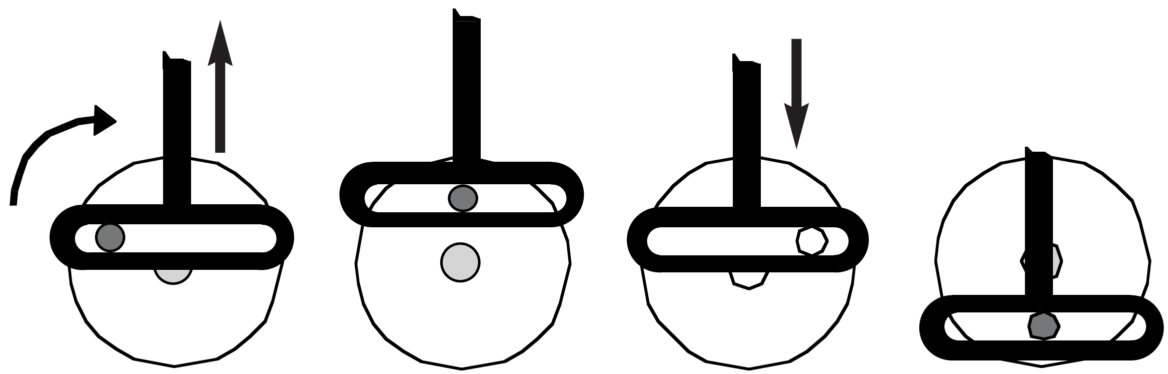




Here, a scotch yoke is used to both push and pull the pig. As it rises up and down, fixed linkages make the wings move in the opposite direction of the pig and it looks like it is flying.

As the crank rotates so the sliding con rod will be powered vertically up and down. The Scotch Yoke was used a lot in steam engines. Because of the design there is no lateral movement. If you want a simple reciprocating movement which is constantly powered and has no lateral play, then this is the perfect solution.

The throw of the crank is used to determine the amount of movement and must be less than the sliding mechanism on the con rod.



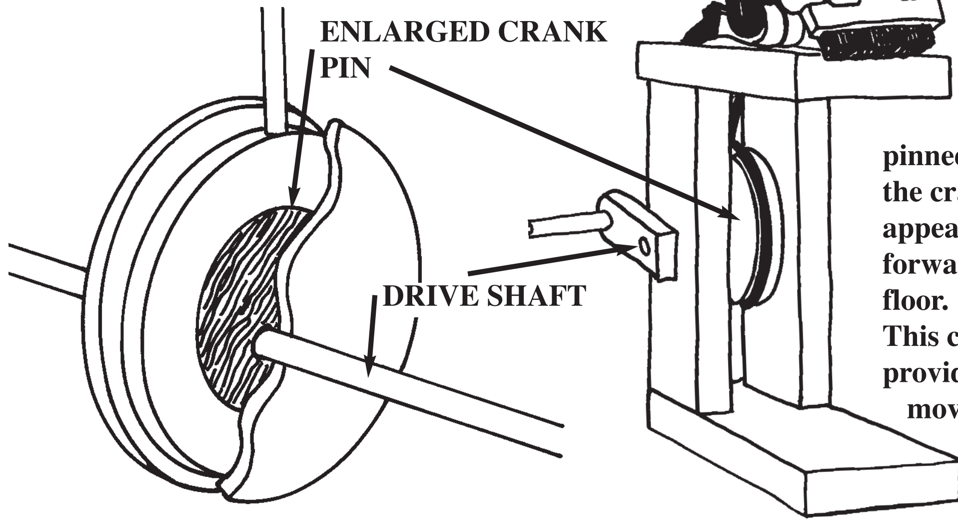
As the drive shaft rotates so the crank, which is offset, pushes the sliding con rod up and then pulls it down. Because the crank is able to slide back and forth, the con rod can be restrained and will only move in a vertical path.

CRANKS

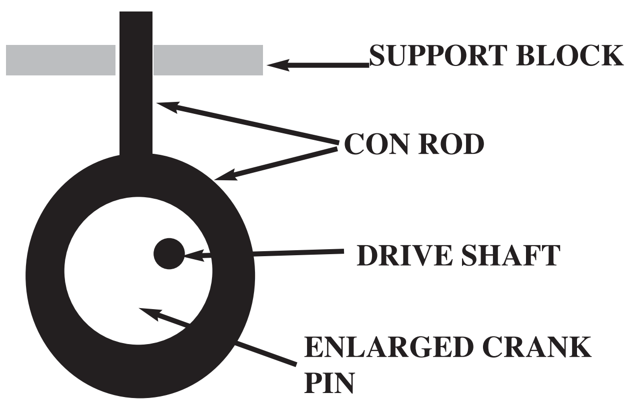
THE ECCENTRIC CRANK

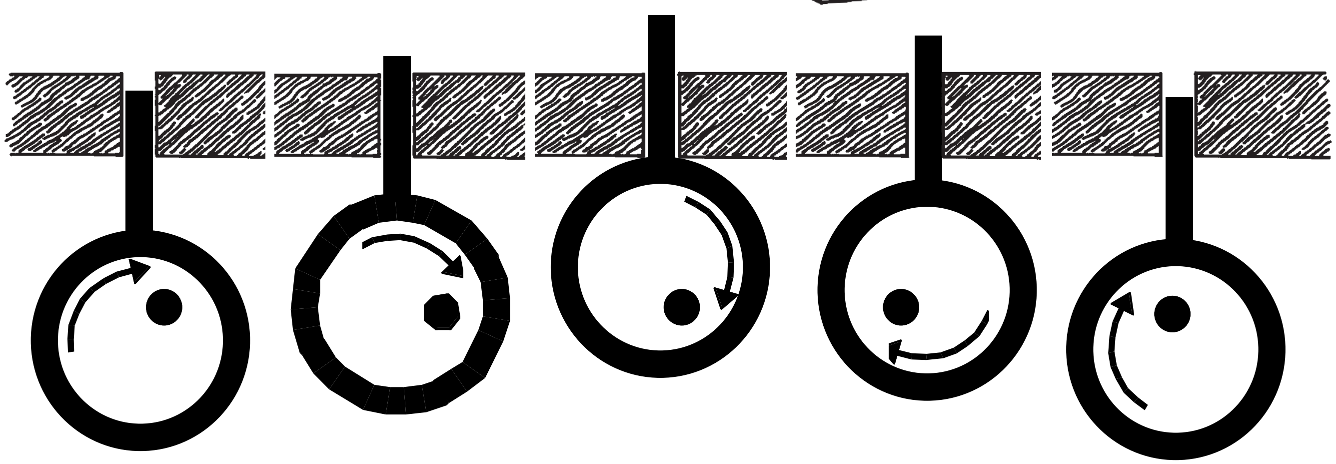
This next crank is known as the Eccentric Crank. The crank pin is greatly enlarged and sits within the con rod (or eccentric strap). This crank will produce up and down as well as side to side movement. It also uses a straight drive shaft and is therefore stronger and easier to make. It is necessary to support the con rod either side to stop it falling off the crank pin. There only needs to be two circles attached to the main shaft.
The distance from the centre of the shaft to the highest point of the crank pin will determine the throw. When constructed this is quite an elegant looking mechanism its real advantages over the traditional crank is the straight drive shaft, vertical travel and ability to fit into tight spaces.

The side supports are attached to the drive shaft constraining the crank pin. This stops any lateral movement.



**The eccentric crank is used to push the cleaning lady up and forwards, then back again. She is pivoted at the knees and her arms are pinned and free moving. As the crank is turned she appears to scrub back and forwards furiously on the floor.
This crank is excellent for providing a slightly irregular movement when not constrained.**

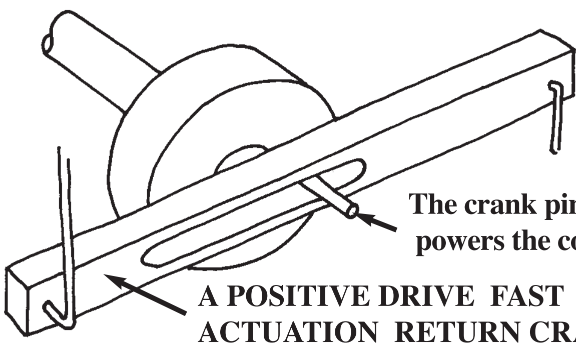


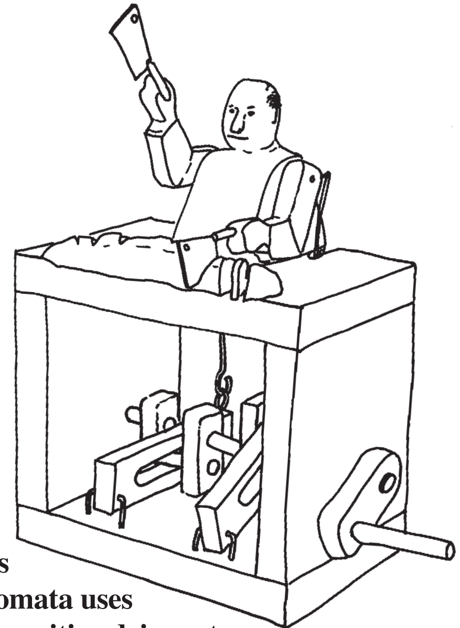


The concentric crank again raises and lowers the push rod as it rotates. As the push rod is free to rotate it can, like the scotch yoke, constrain the push rod to a vertical path or with a wider opening in the support block be used to also produce a side to side motion.

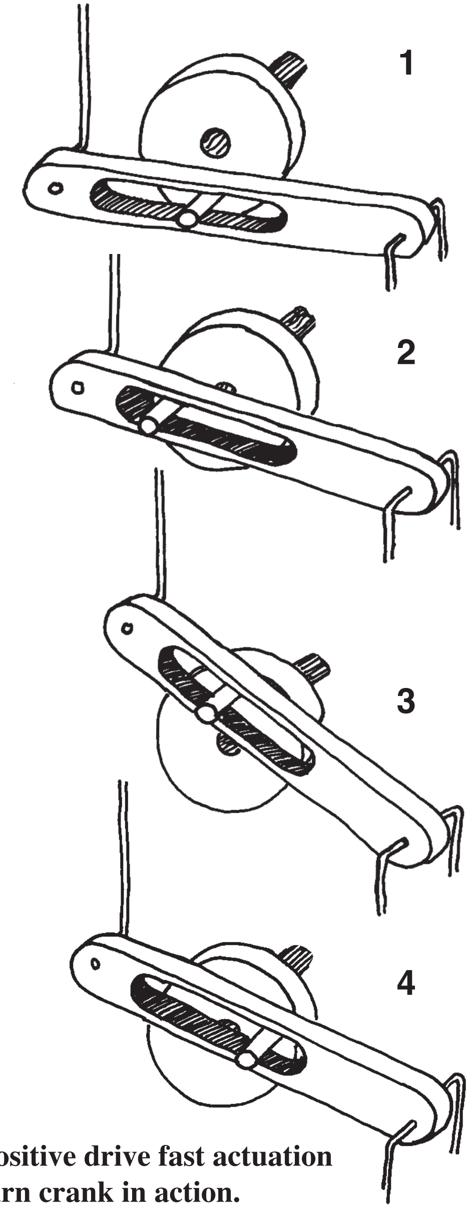
CRANKS

The fast return actuator crank.
This next crank is similar to the scotch yoke, in that it, too, is a positive drive mechanism. The main difference being that this crank has a pivoting con rod. The further you place the crank pin from the pivot the less lift it generates. You can also construct this crank with the crank pin under the con rod so that gravity pulls it down.

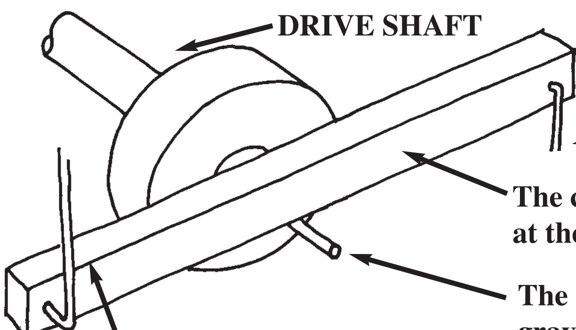




This automata uses two positive drive return cranks that are offset and connected to linkages which in turn move the arms up and down. Turn the handle and the baker furiously chops the bread.



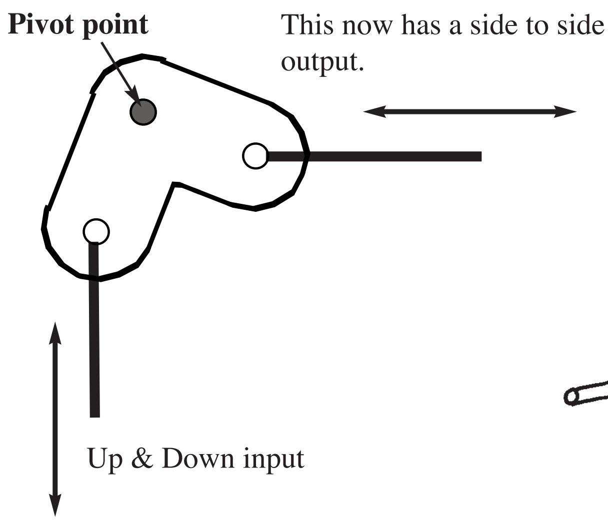
A positive drive fast actuation return crank in action.



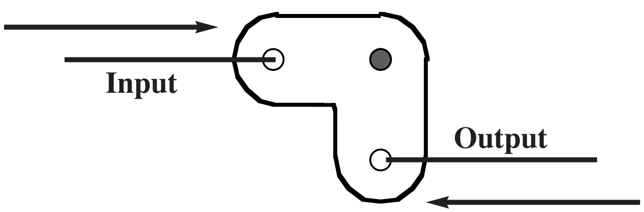
CRANKS

THE BELL CRANK

This very useful little device, so-named because its action resembles a tolling bell. It operates in quite an unusual way, although termed a crank it works in a reciprocating movement, not a circular one.
It is very effective for changing the direction of movement. In the example below, as the input moves up and down, the output moves from side to side.

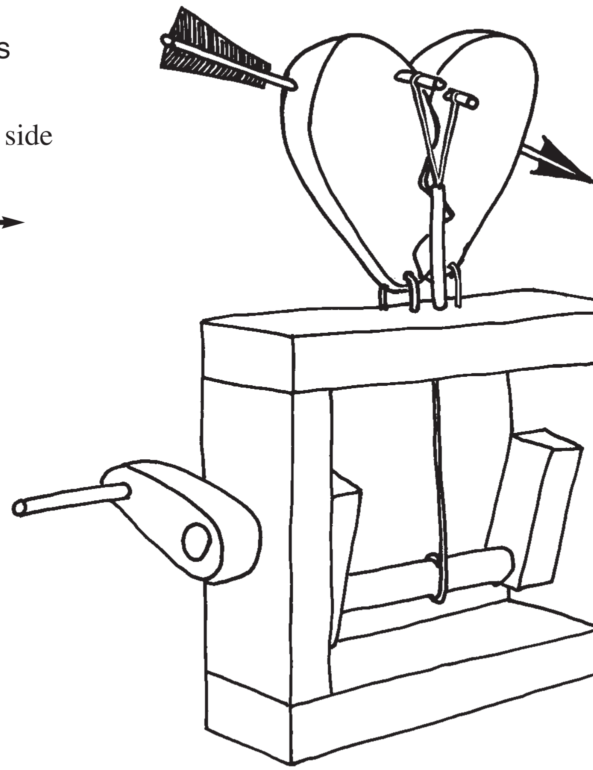


In this example the action is reversed, so as the input pushes, the output pulls.

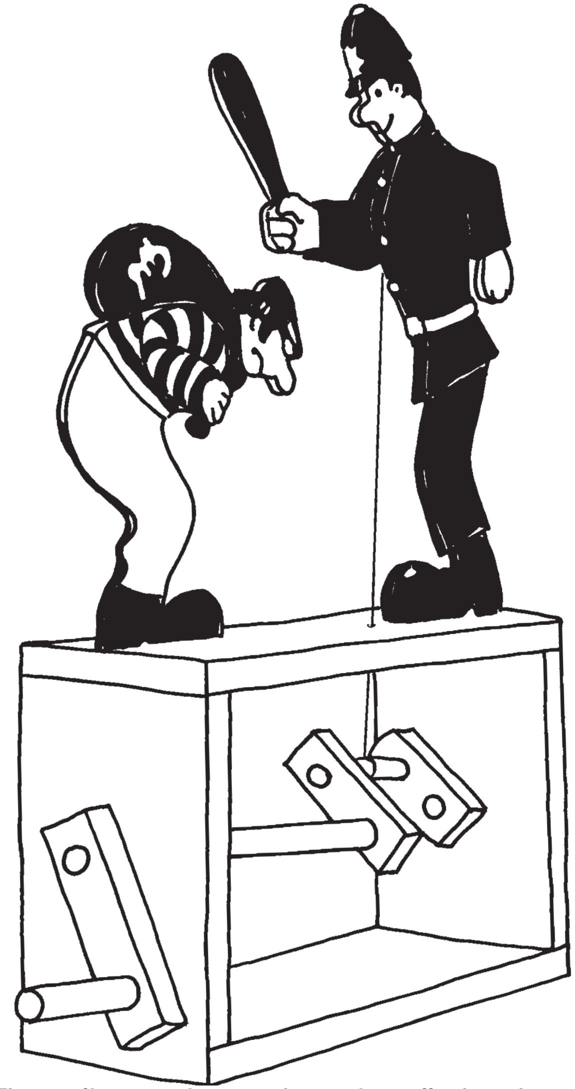


STRINGS ATTACHED

Most con rods are made of resistant material such as metal or wood. A great alternative in certain circumstances is nylon cord. This method works best if you need to pull rather than push. The automata below and opposite rely on gravity as a secondary moving force.



The two pieces of the heart fall apart helped by gravity and a weighted arrow. As the crank turns, it pulls the nylon cord which, in turn, pulls the two halves back together.

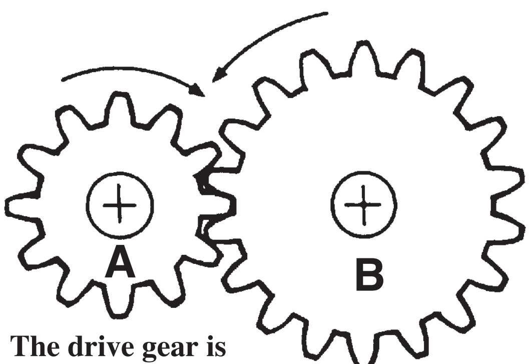


The policeman’s truncheon is pulled up by a nylon thread as the crank reaches its lowest point. When the thread slackens, gravity then pulls it down.

GEARS

THE WAY GEARS WORK

Gears are very versatile and can help produce a range of movements that can be used to control the speed of action.
In basic terms, gears are comparable to continuously applied levers; as one tooth is engaging, another is disengaging. The amount of teeth on each gear wheel affects the action on the gear wheel it engages or meshes with. The gear wheel being turned is called the input gear and the one it drives is called the output gear.
Gears with unequal numbers of teeth alter the speed between the input and output. This is referred to as the Gear Ratio.



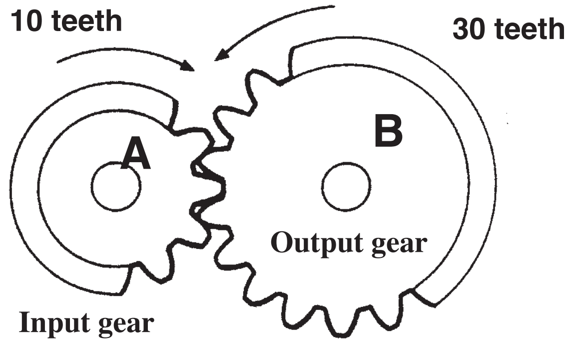
The drive gear is known as the input gear.

The gear that is being turned is referred to as the output gear.

Gears also alter the direction of rotation. In the above example gear wheel **A** is rotating clockwise but as it turns, gear wheel **B** is moved anti-clockwise.

CALCULATING RATIOS

The following example shows how the ratios are calculated.

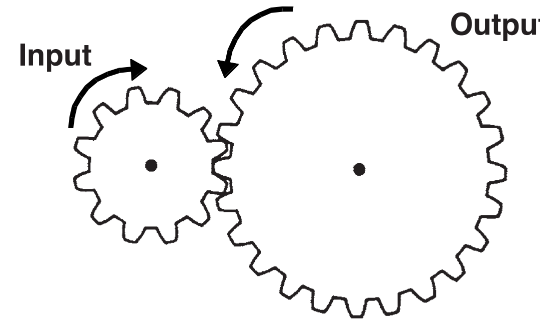


If the input gear (A) has 10 teeth and the output gear (B) 30 teeth, then the ratio is termed 3 to 1 and is written down as 3:1

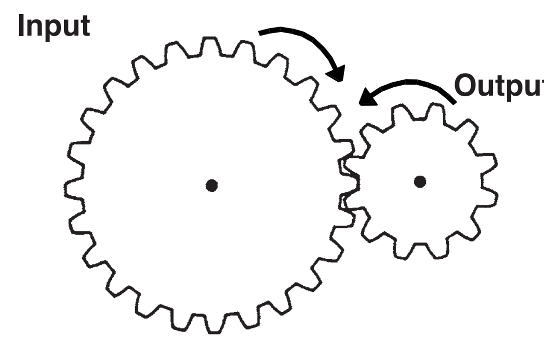
$$\text{Ratio} = \frac{\text{No. of teeth on the output gear B (30)}}{\text{No. of teeth on the input gear A (10)}}$$

$$= \frac{3}{1} \text{ and is written down as 3:1}$$

Simply divide the amount of teeth from the output by the intput gear to work out the ratio.
In the above example, for every complete revolution of the input gear the output turns 1/3 of the way round. In other words it takes 3 turns of A to rotate B once. This means you are slowing down the action and is referred to in engineering terms as “Stepping Down”. If B were the input gear and A the output gear, then the opposite happens and we “Step Up”. Then it would take 1 turn of the input gear to turn the output gear 3 revolutions, giving a ratio of 1:3.



Stepping down has the advantage of producing more power although at a slower rate. This is often a big advantage with automata as some of the mechanisms can get stiff or are under tension so it makes turning the handle easier.

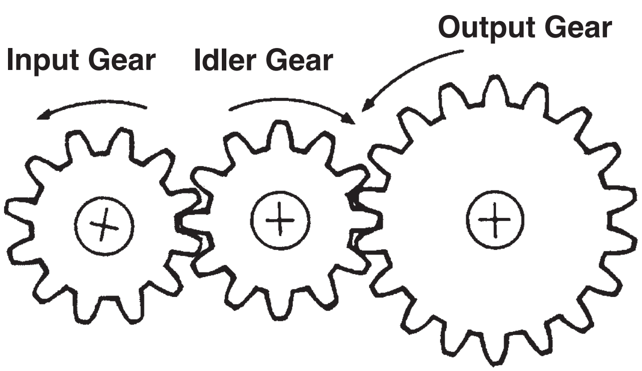


Stepping up produces a much faster output speed, but mechanically delivers less power. Be aware of this as you may find that your Automata does not work properly or the handle is very hard to turn. However, it is useful if you want something to move more quickly in relation to other components.

GEARS

GEAR TRAINS

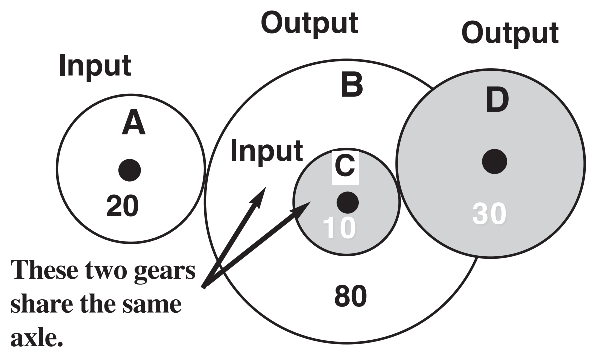
As we have seen, gears not only affect each other in the amount of movement they make but also in the direction they move. This is not normally a problem but there may be times when you need to keep things moving in the same direction. This problem can be overcome by introducing a third gear wheel which is the same size as either the input or output gear. (Gears are a bit fiddly to make so I would always go for the smallest one).
When you have three or more gears in a line they are referred to as a **Gear Train.**



The idler gear will reverse the direction so that the input gear now turns in the same direction as the output gear.
Providing you have the same amount of teeth as the input or output gear then your ratios will not be affected.

COMPOUND GEAR CHAIN

Automata tend to be fairly small, so mechanisms are sometimes packed in a bit tight. To save space when working with gears, more than 1 may be placed on the same axle. This is called a compound gear train.
You can have different size gears on the same axle, but this will affect the output and needs to be taken into consideration when calculating the Ratios.



The above example shows a compound gear train. Output Gear **B** and input Gear **C** share the same axle.
The gear ratios are as follows:
A= (20) - B =(80) This gives a ratio of 4:1
So for every one revolution of A, B turns 1/4 of its full cycle.
C =(10) - D = (30) This gives a ratio of 3:1
So for every one revolution of C, D turns 1/3 of its full cycle. You must take into consideration that B is moving slowly at 1/4 of the input speed of A. This needs to be taken into account in order to find the final ratio.

Although this is starting to get complex, let's look at it in automata terms and work backwards. You will have to turn the handle and make gear **A** turn a little over 12 times in order to make gear **D** turn once. The trick is to work out what you want from each set of gears and then combine them.
Do not worry if you find that the maths is getting complex. You are very unlikely to need to use a compound gear chain in the early stages of automata. They do not really come into their own until you move onto the more complex automata, by which time you will have a much better understanding of the mechanics involved and will be able to refer back to this section.
Below is the equation needed to find out the final drive ratio of Gear **D** in relation to **A**.

$$\text{Gear Ratio} = \frac{\text{No. of teeth on Output gear}}{\text{No. of teeth on Input gear}}$$

For gears A and B,

$$= \frac{80}{20} = \frac{4}{1} \quad 4:1$$

For gears C and D

$$= \frac{30}{10} = \frac{3}{1} \quad 3:1$$

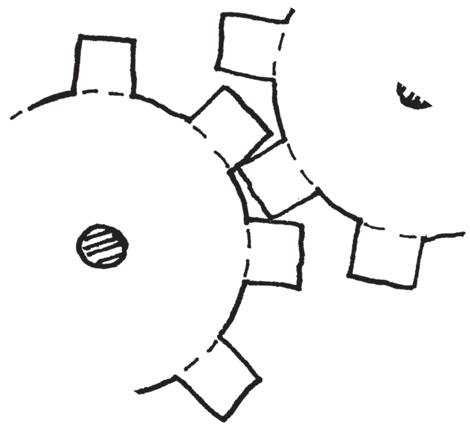
$$\text{Gear ratio of compound gear} = \frac{4 \times 3}{1 \times 1} = \frac{12}{1}$$

Gear ratio of the compound gear train = 12:1
This means it takes 12 revolutions of **A** to turn **D** once.

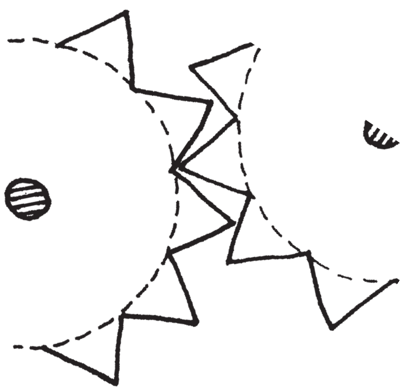
GEARS

GEAR TOOTH SHAPE

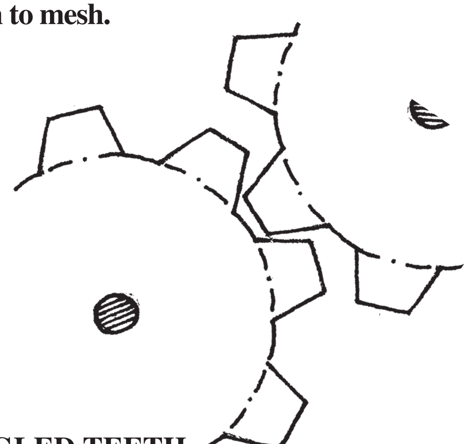
When it comes to designing automata, gears are very useful. I like to think of them as time machines that slow things down or speed them up. Until now, the automata we have looked at using cams or cranks complete their performance on one revolution. This is fine in many circumstances, but there are times in designing automata when it would be nice to slow things down. This extends the performance, allows more things to happen and builds up audience expectation.
Gears can be made from a range of materials as we will see later. The most important thing is to make sure that the teeth are of equal size on all the gear wheels. If they are not then they will jam. The shape of the teeth can vary, so lets look at some examples.



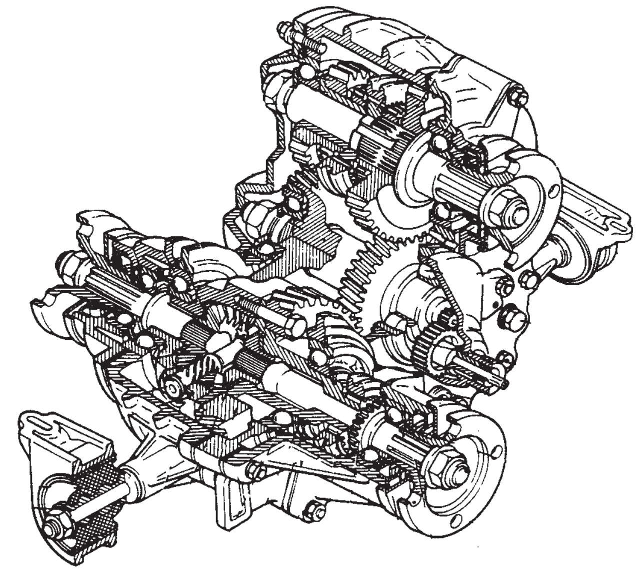
SQUARE TEETH
These are fairly simple to produce but you must be very accurate or they will jam. You will need to make the spaces wider than teeth in order for them to mesh.



SPIKED TEETH
These are simple to make and work well. I use them a lot when making automata.



ANGLED TEETH
These are slightly more complicated to make, but work well and allow for greater inaccuracy before they jam.

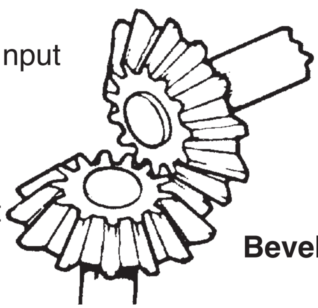


This gearbox from a car uses just about every type of gear you can think of. Most of the machines in our homes and work places make use of gears and they are probably the most widely used of all the mechanisms. Gears are used to control both speed and power. In the world of engineering you do not get something for nothing, and this certainly applies to gears. You can have more speed or more power, but you cannot have both at the same time.

GEARS

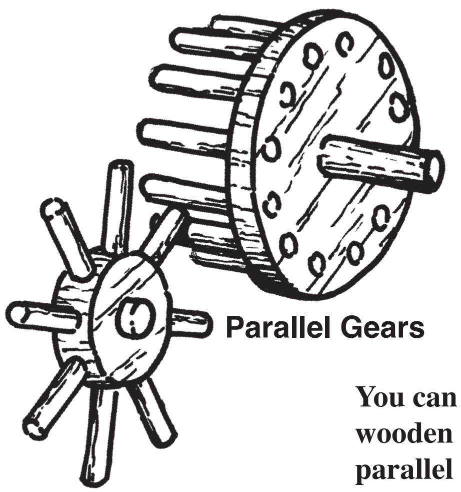
DIRECTIONAL GEARS

So far we have looked at gears that run parallel to each other but as well as slowing or speeding action, gears can also be used to change the direction of the drive shaft which can be very useful when making automata.



Bevel Gears

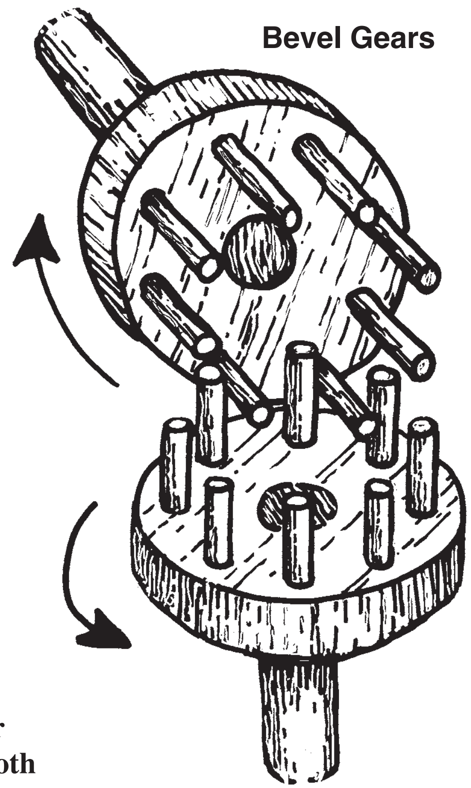
These gears are running at 90^{o} to each other allowing you to change direction. By varying the sizes of gears you can also change the ratio.



Parallel Gears

I usually make these types of gears using panel pins (small nails) which are hammered into wood after which I cut the heads off. You can also use wooden dowel which works very well and is surprisingly strong. If you find making gears too difficult at the beginning, you can use plastic ones which can be obtained from model shops.

Bevel Gears



You can use panel pins or wooden dowel to make both parallel gears and bevel gears.

DESIGNING GEARS

When designing and making gear wheels you need to apply a little common sense. The load or pressure put on the gears in automata is usually very small compared to that of a car gear box, for example. This allows you to get away with things that you couldn't in other machines. However, you still have to follow some simple engineering guidelines.
You will need to identify what you want to get from the gears so try running through this simple check list.

1) Do you want the gears to step up or step down (speed up or slow down the performance)?

2) Do you want the gears to run parallel, or at an angle of 90^{o} to change the direction of the drive?

3) What size do you need to make them? (small space means making smaller gears and this can get tricky)

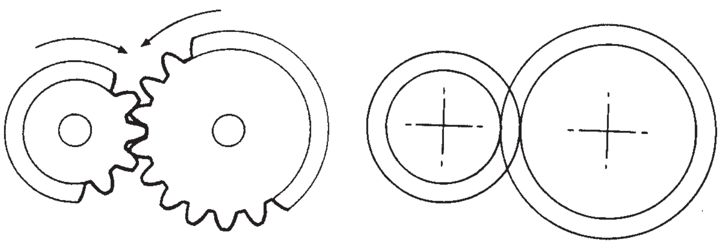
4) What is the best or easiest material to make them out of? (this may well depend on how heavy a load you want them to drive)

Each automata you make will have different design criteria to meet, but there are some common design and construction solutions which work well.

GEARS

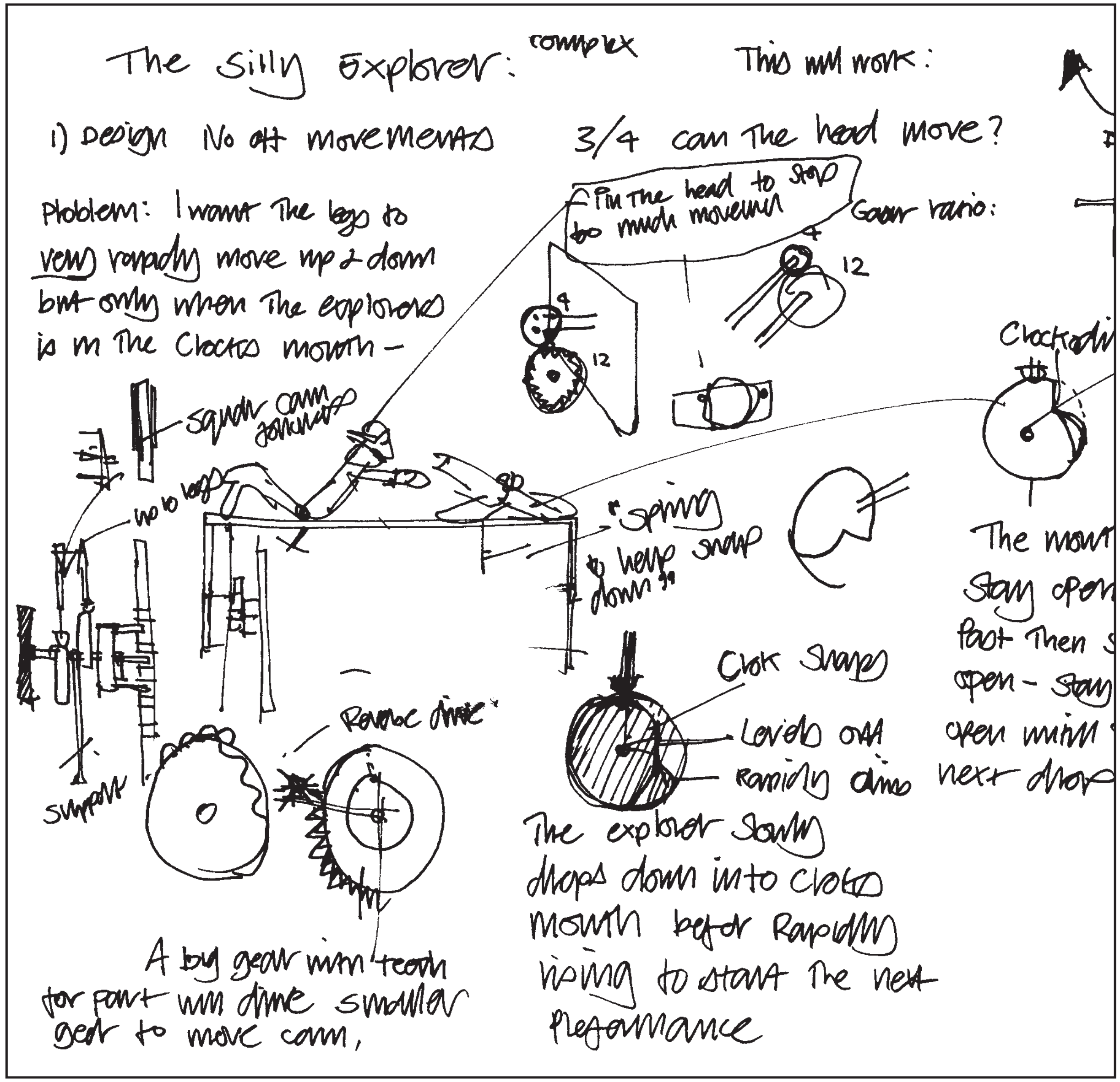
DESIGNING WITH GEARS

When drawing gears they are represented as either a circle with just a few teeth at the point that they mesh, or as twin circles denoting the teeth.



Although this may seem very technical it is good practice to visualise gear wheels like this, especially when it comes to drawing up your plans for making automata.

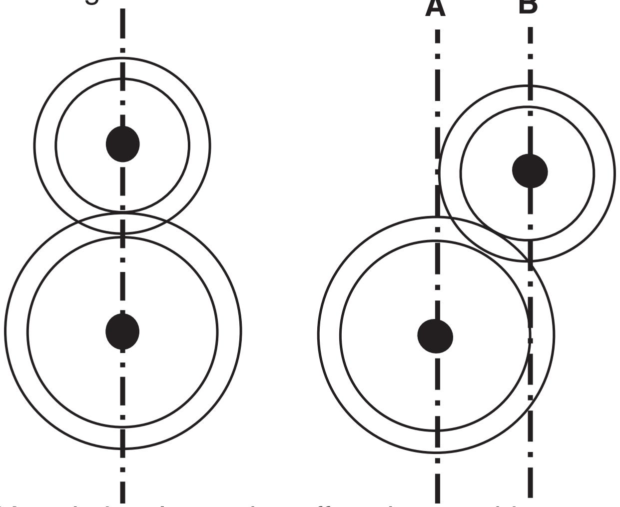
Opposite is a sample of drawings from my sketch book showing how I indicate the gears and other mechanisms. I work totally free hand and never use drawing tools. This is purely a personal way of working, and you may be happier working in a more technical way. Which ever method you use, clear indication of your intended mechanisms and the ability to interpret your drawings are the key factors. I often write notes to accompany my drawings precisely for this reason, as I often can not remember the details solely from the sketch. A few notes can explain a complicated mechanism. At the time of designing it all makes sense, but when you return to your plans 3 weeks later you will be surprised at how difficult it is re-interpreting your work - so make notes!



GEARS

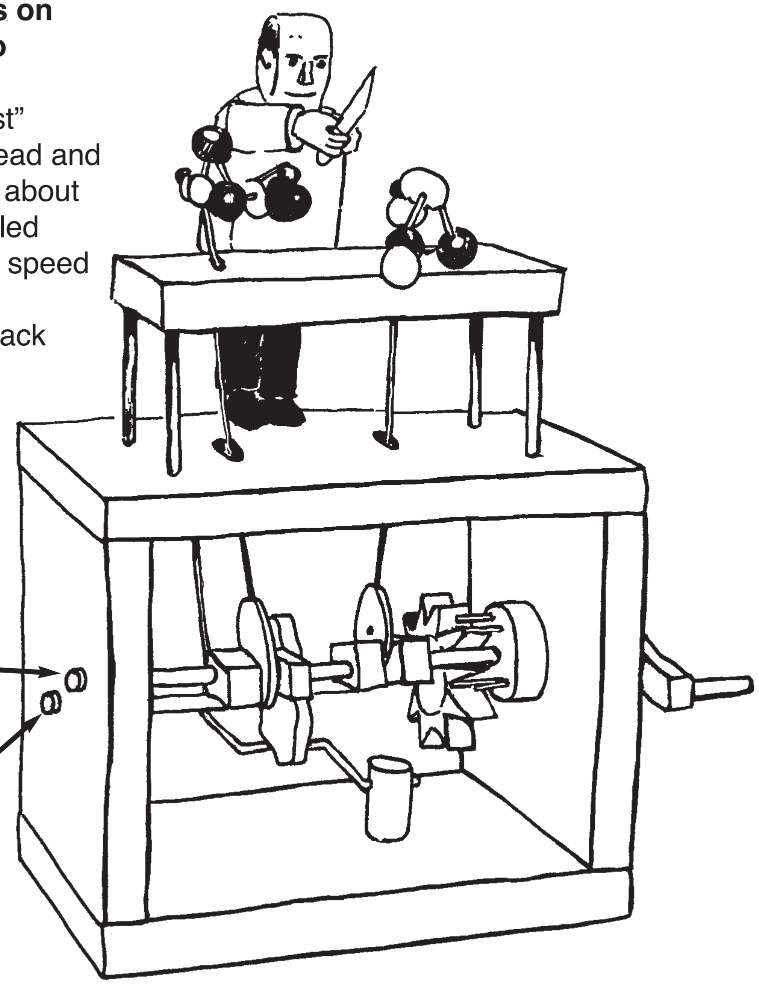
GETTING MORE OUT OF GEARS

A useful trick, when using gears, is to offset the two supporting shafts so that additional mechanisms can be used.
By offsetting the drive shafts, you will be able to run cams or cranks at different speeds without jamming or hitting other components. This can help to give your automata several speeds of movement and make things really exciting.



You obviously need to offset the two drive shafts, but the secret is to do it by just the right amount. This will enable you to drive other objects with cams, pulleys even cranks. The amount you offset is limited by the physical space available in your automata housing (Trial and error is the usual way of measuring.) The distance between **A** and **B** is determined by the amount you offset.

By offsetting the two drive shafts, as on the automata below, you can get two speeds of movement.
This automata called the “Mad Scientist” slowly raises a large knife above his head and tries to split the atoms that are leaping about wildly on the table. The scientist is pulled back by a cam running at a third of the speed of the handle on which the atoms are attached. The atoms move up,down, back and forth very rapidly in relation to the scientist . The whole thing works by simply offsetting the two drive shafts, **A & B**.
Note, you can not run them vertically parallel as the top shaft will block the drive shafts, cranks, etc.



The output gear (shaft **B**) turns once for every three turns of the crank handle (shaft **A**). The input gear is fixed to shaft **A** and turns a larger gear wheel on shaft **B,** therefore creating a ratio of 3:1. You can now use shaft **B** to run extra cams or cranks which will be running a third of the speed of shaft **A,** which you can also run cams and cranks from. To make things really exciting you could create a gear train and have another drive shaft!

GEARS

MATERIALS AND CONSTRUCTION

Gears are both challenging and fun to make. You can use a number of different materials and, as the mechanical load is very light, card and even paper can be used. these are cheap to buy and easy to work with. Other materials such as wood and metal are also very versatile.

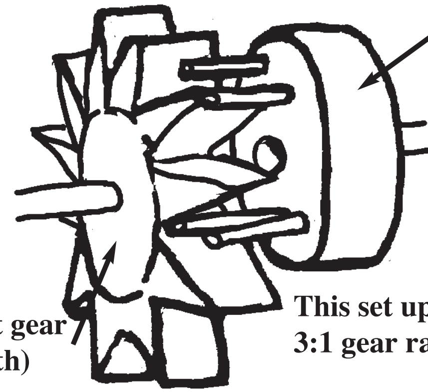
After designing your automata, you can make the gears in thin card first to sort out any problems. Amazing strength of construction can be achieved by using paper and card, and many automata are built solely using these materials.

The automata you make will all have different criteria to meet, but there are some common solutions which work. Before you start, bear the following golden rule in mind:

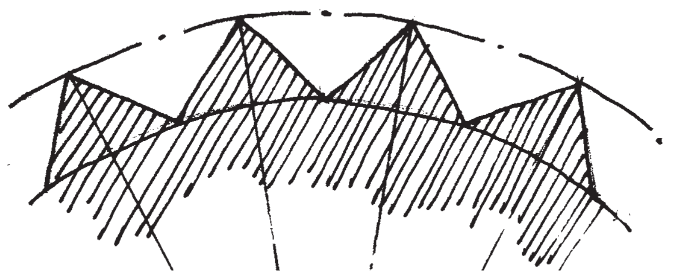
KEEP THINGS SIMPLE

You will want to experiment with your own gears, construction, and materials. But if you feel unsure about making gears then you can buy ready made ones from model supply shops. These are usually made from plastic and come in a range of sizes and ratios.

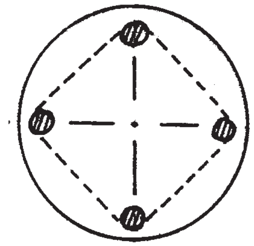
The gear set below is quick and relatively easy to make. It is used a lot, as it tends to do most jobs well and can easily be expanded upon. For ease of construction, work in pine which is a relatively soft wood that is easy to cut and at the same time reasonably strong.



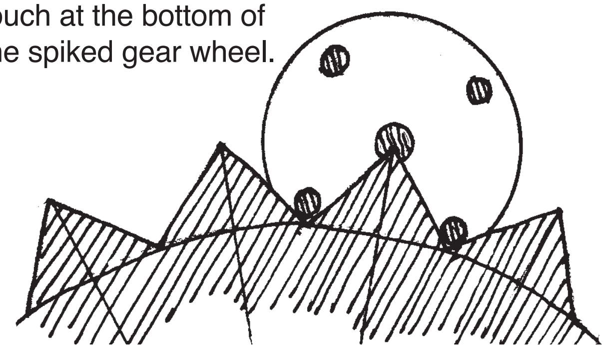
You need to work out the size of the output gear (The biggest that will fit in your automata) and then divide it into twelve parts. The next stage is to work out the depth of the teeth. 10 to 15mm is a good rule of thumb but, again, you can experiment. It also depends on the size of the gear wheel.



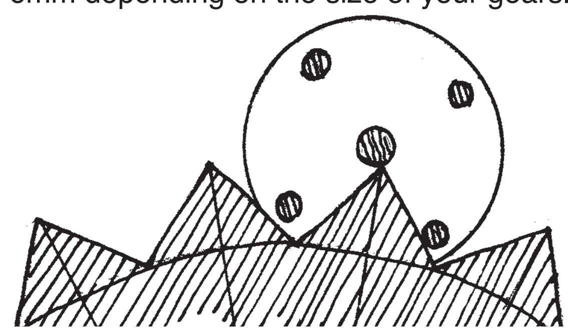
The output gear has only four teeth made from either panel pins or wooden dowel. The four pins should form a perfect square; the centre of which gives you the point to put the shaft in.



You need to space them in such a way that they engage the teeth on the output gear without jamming. Ideally they should just touch at the bottom of the spiked gear wheel.



You can make the gears mesh a little higher up without any problems, to as much as 5-6mm depending on the size of your gears.



GEARS

MASTERING GEARS

Aim to get the pins meshing about two thirds down the slope on the gear tooth. The ideal is to get the pin to just touch at the bottom. By getting the pins to touch further up allows for any inaccuracies that can occur and still allows the wheels to keep moving without jamming.
A little trial and error is needed when you start making gear wheels. Do not be disappointed if things do not work perfectly first time, as it may take several attempts. When you have got the technique mastered you will be able to construct working gear sets to any size and ratio, and that is some achievement.

WORKING OUT SIZE AND RATIO

When designing and making your gears you have to be very precise with your mathematical equations. You will need to take into account the number of teeth, the ratio and the size of your gears. Here is a practical example to help explain how to do this.
The “Mad Scientist” Automata had a gear ratio of 3:1. Assuming that the larger output gear would have to be 60mm in order to fit, this meant that the input gear would have to be 20mm. The measurement was calculated by dividing 60 by 20 to give a 3:1 ratio. So 20 goes into 60 three times.

By working backwards you can decide on the largest most practical gear wheel first and then calculate what the drive gear will be. You can of course do this the other way round.
The next thing to calculate is the number of teeth. Having twelve teeth on the larger output gear meant that they needed to be spaced at intervals of 30 degrees. (360 / 12 = 30).The input gear would have to have1/3 as many teeth. In this case four (360 / 4 = 90) and would need to be spaced at 90^0 from each other.
The formula below is used to work out the velocity ratio of gears:

$$\text{Velocity ratio} = \frac{\text{number of teeth on output gear (12)}}{\text{number of teeth on input gear(4)}}$$

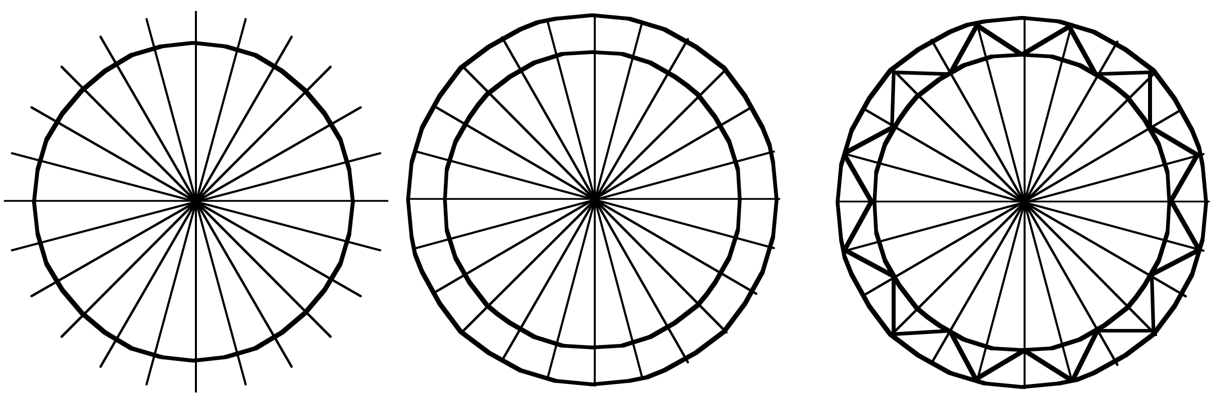
$$\text{VR} = \frac{12}{4}$$

Therefore the velocity ratio or Gear Ratio is $\frac{3}{1}$

It is unusual to write this as a fraction so the gear ratio is 3:1

The first figure relates to how many revolutions the input gear moves in relationship to the output. In this example, 3 revolutions of the input gear moves the output gear 1 revolution.

The maths for working out the number of teeth for each gear is not difficult, but it has to be done so that the teeth mesh properly.

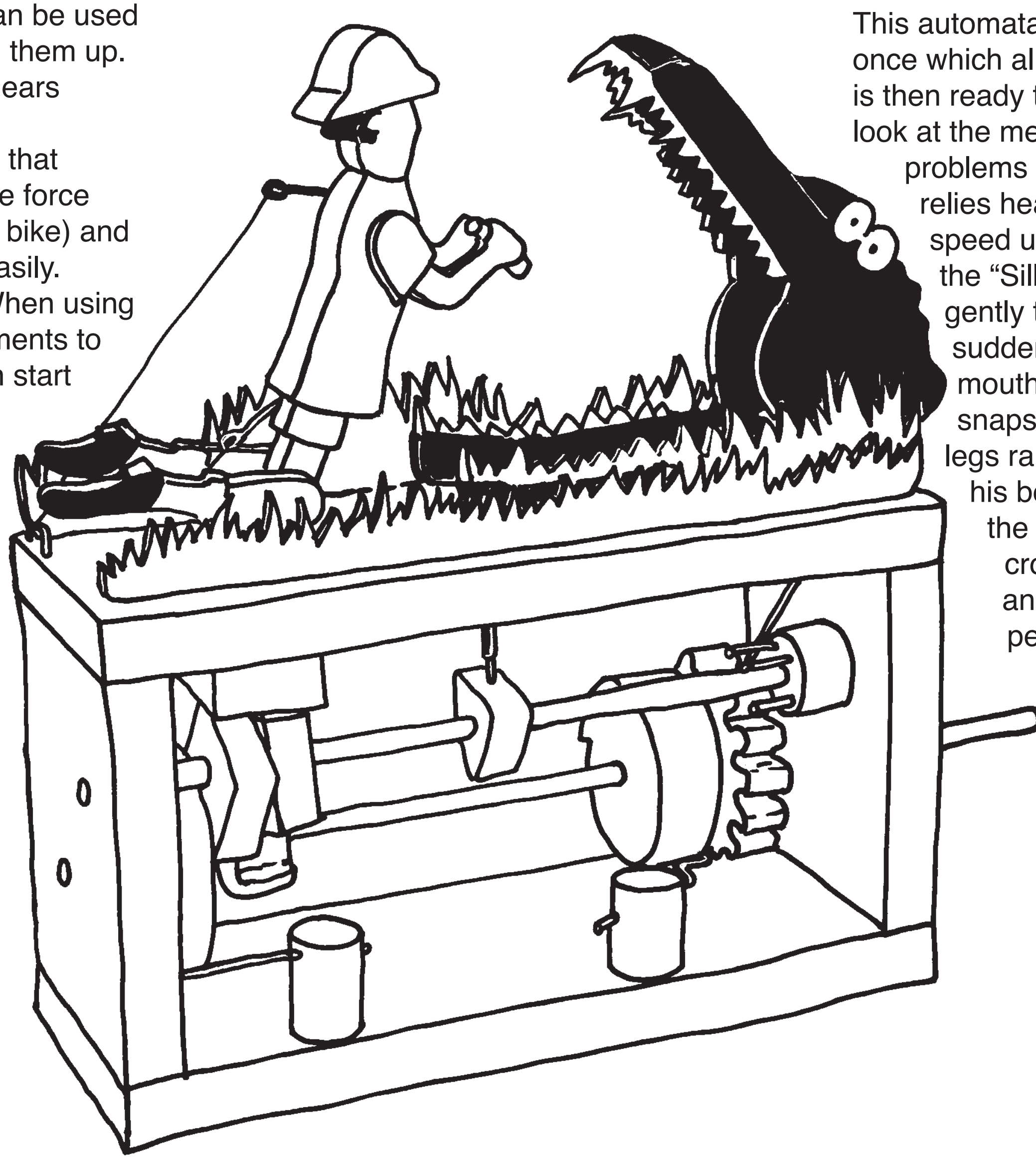


The best way to construct the spiked gear wheel is to divide a circle into 24 segments. Then draw a second circle to give you the height of the gear teeth; 10 -15mm is a good average. Then simply connect the lines to draw out the twelve teeth and you are ready to cut them out. This method can also be used to construct a pin wheel.

GEARS

TIMING

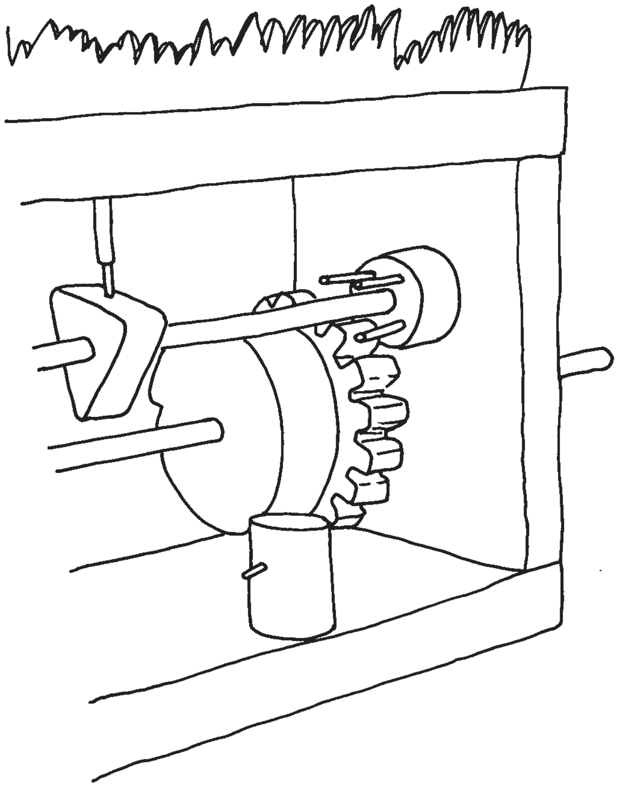
You are aware now of how gears can be used to either slow things down or speed them up. Most automata take advantage of gears slowing down and extending the performance. Another advantage is that “stepped down” gears produce more force (first gear on a car or low gear on a bike) and so can power the automata more easily.
The last thing to look at is timing. When using gears you may want several movements to culminate in a final activity and then start again from the beginning. This obviously needs to be worked out so that gear ratios and speeds all coincide from one starting point, and end at a common finishing point.
The examples opposite shows how to tackle this problem. It is fair to say that you are getting into advanced Automata-making territory at this stage. If you do not feel up to it come back to this part when you are ready.

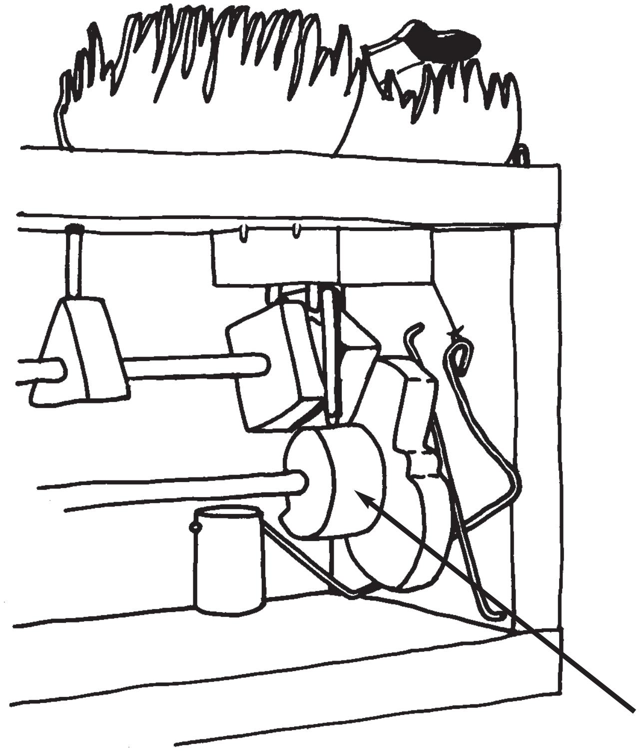


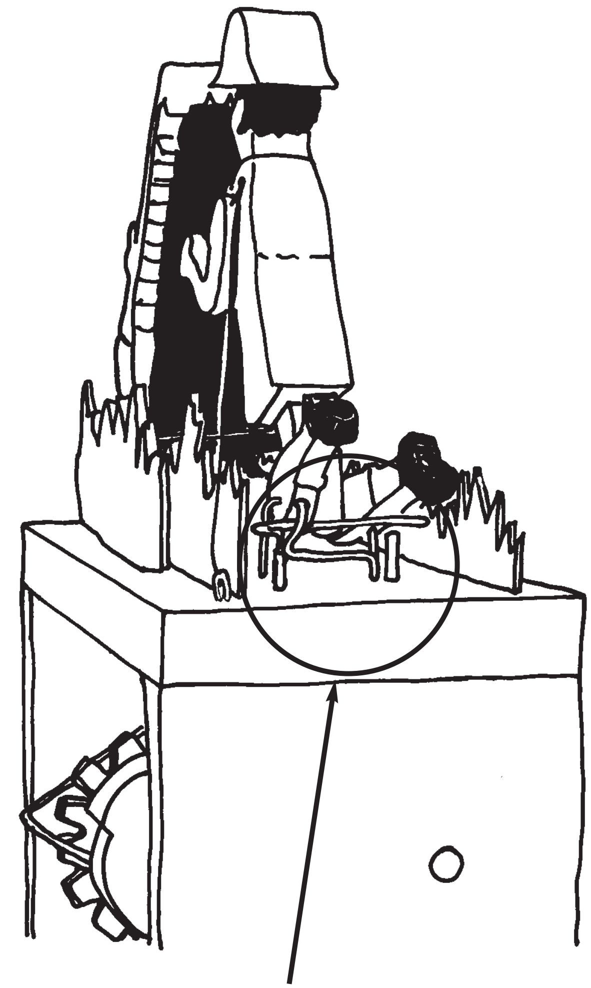
This automata has several actions going on at once which all culminate in a final outcome. It is then ready to start again. Let’s take a closer look at the mechanisms and some of the problems encountered. The automata relies heavily on gears to slow down or speed up various movements. Called the “Silly Explorer”, the main figure gently tips back and forwards before suddenly dropping into the crocodile’s mouth. The crocodile’s mouth then snaps down onto the explorer , whose legs rapidly thrash up and down while his body jerks several times inside the crocodile’s mouth. Finally the crocodile’s mouth springs open and the explorer rises up so the performance can happen again.

GEARS

The mechanisms below include the snail cam which controls the leg linkages. There are also two square cams that provide the rapid leg movement. A larger snail cam controls the dropping and pulling up of the explorer, and a triangular cam provides a rapid movement that jerks the explorer's body up an down when inside the crocodile's mouth. This is constantly moving as are the two square cams.





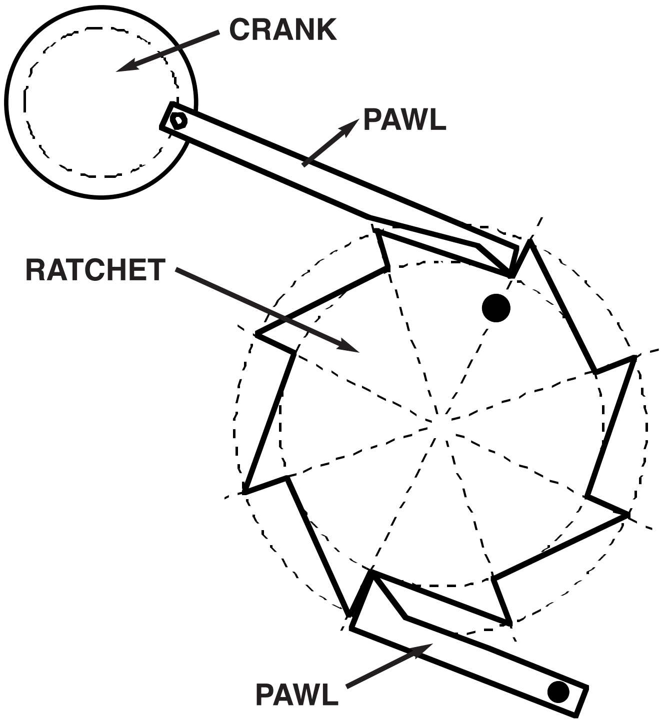


The gear ratio for this automata is 3:1. The output shaft is used to slow different parts down. A large snail cam controls the opening and closing of the crocodile mouth, while opposite is another snail cam that controls the explorer's body. All the parts are synchronised, so that by the fourth turn of the handle everything lines up and starts again from the beginning.

The mechanisms here show the linkages that move the feet up and down. A bar is raised by a snail cam and lifts both feet clear of the con rods that rotate directly on the main drive shaft and are moving all the time.
The snail cam drops the bar, so the feet are able to move up and down rapidly.

RATCHETS

ALTERNATIVE GEARS
The ratchet is really another form of gearing. Unlike gears, which can be used to speed up or slow down movement, the ratchet can only be used to slow things down and it happens in a very jerky manner. Below and opposite is an explanation of how they work.

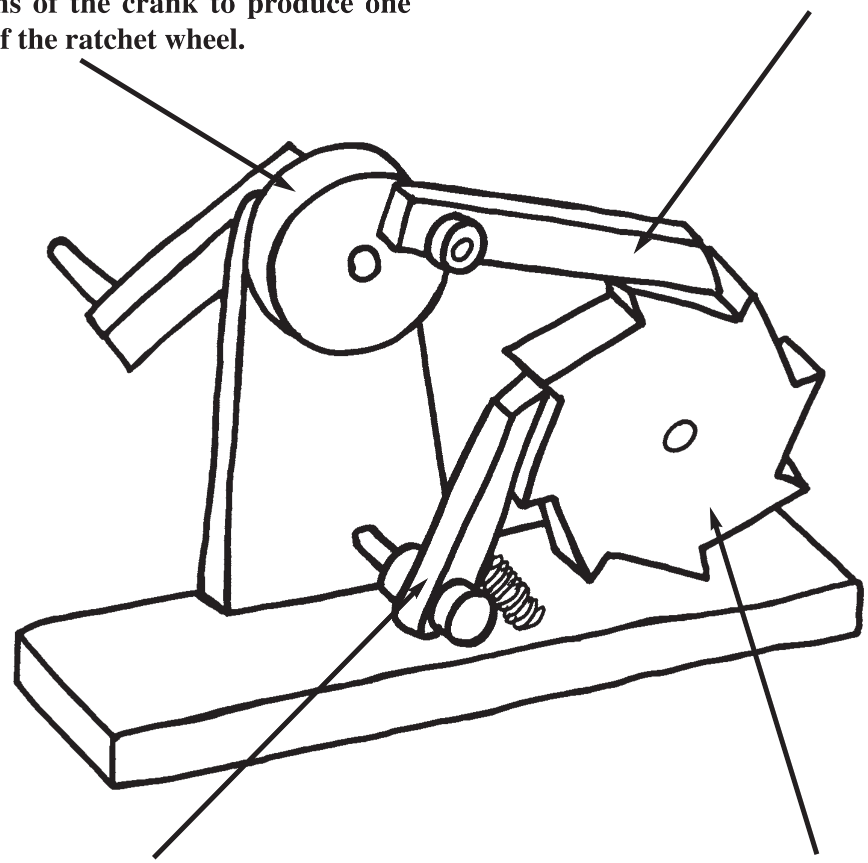


For every 8 turns of the crank, the ratchet wheel turns one complete revolution. This gives a ratio of 8:1.

Below is a 3D drawing of a simple ratchet. There are only a few moving parts to make but as with all mechanical things you do have to work out fairly accurately the size and distance of all the various components.

The pawl is rotated on a crank and pushes the ratchet wheel one notch for every revolution. It will take 8 turns of the crank to produce one complete turn of the ratchet wheel.

The crank turns clockwise which helps to push the pawl, or catch, down onto the ratchet



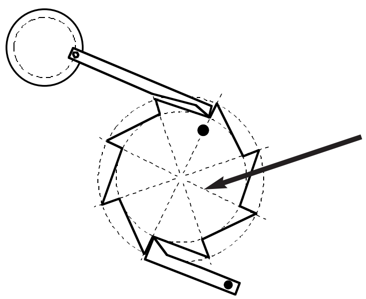
This 2nd pawl is lightly sprung, and locks into the ratchet wheel stopping it moving backwards.

If you add more teeth to the ratchet wheel it will take longer to rotate. With fewer teeth it will take less time.

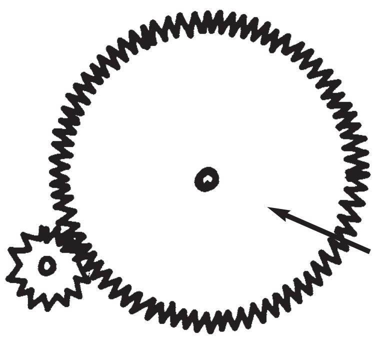
RATCHETS

SLOWING THINGS DOWN

As we have seen, most automata benefit from slowing down movement. The ratchet does this in a fairly simple way.



This ratchet wheel has 8 teeth so the equivalent ratio (like the gear set below) is 8:1



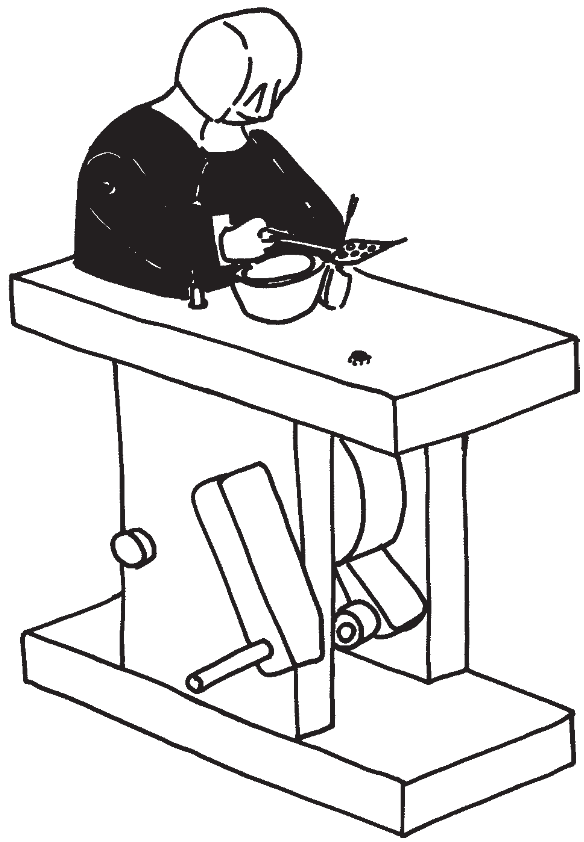
This gear set has 10 teeth on the input gear and 80 teeth on the output gear, giving a ratio of 8:1

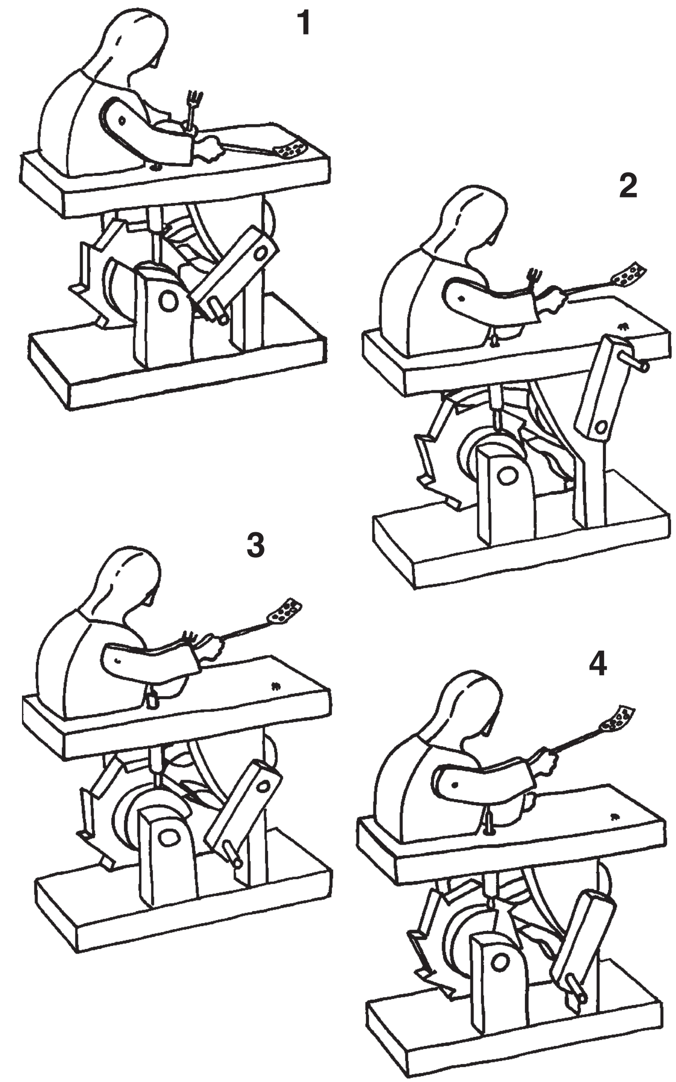
The gears above would turn constantly and give a very smooth action but cutting 80 teeth is a lengthy task. The gear wheel would need to be pretty big which would take up a lot of space. The ratchet on the other hand only has 8 teeth, is simpler to make and uses less space.

If you want to slow down movement a lot then the ratchet is a good alternative to gears. It does however give a jerky movement.

TAKING ADVANTAGE

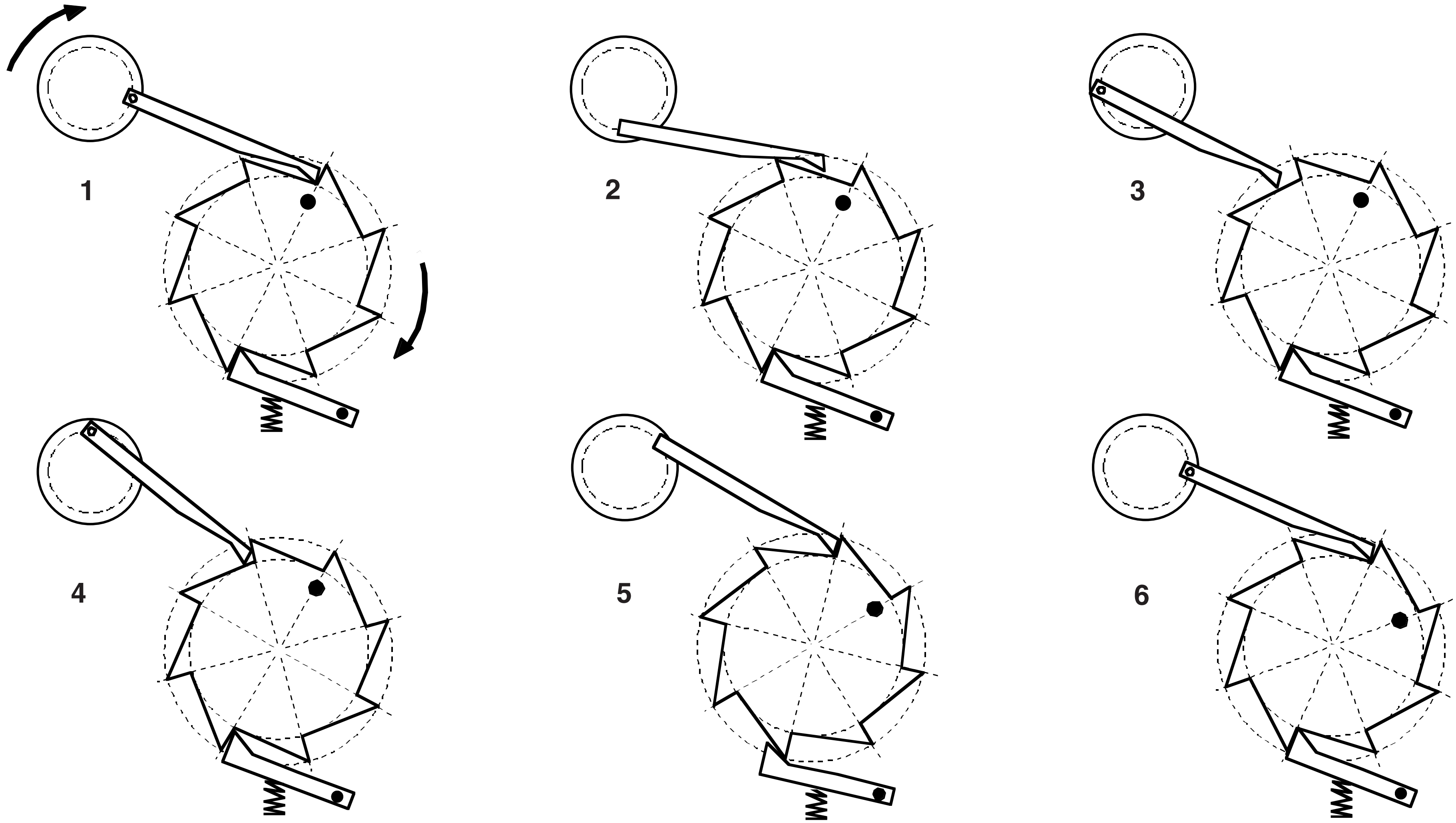
The ratchet's inherently jerky movement can be used to advantage. The automata below uses this movement to build up suspense before culminating in a big finish.





In the Automata above, the man's arm lifts up, hovers and then swats down on the fly. The ratchet has a snail cam attached to the same shaft so is turning at the same speed. The cam progressively lifts the arm and provides the sudden drop with a little help from gravity. The movement is jerky but doesn't detract from the performance, if anything it adds drama.

RATCHETS



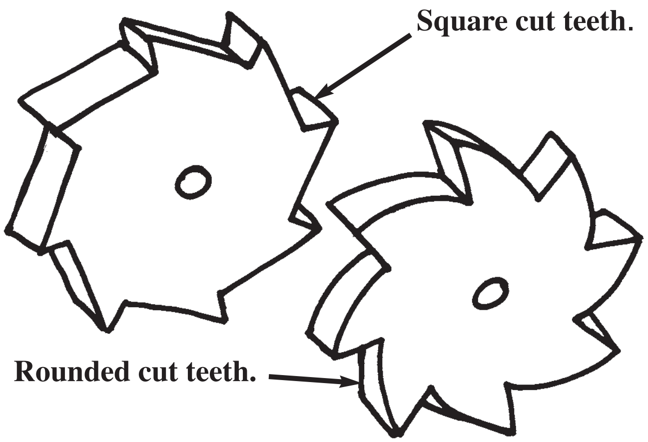
In the sequence shown above, the ratchet is being driven by a clockwise rotating crank. The ratchet has 8 teeth so it take 8 turns of the crank to complete one turn of the ratchet wheel. The black dot shows you that the ratchet turns 1/8 of a cycle per push of the crank.

The rotating crank pushes the ratchet wheel for half of the time and then pulls the pawl for the other half. In other words, for every complete cycle of the crank, it is only supplying an input motion to the ratchet for half of the time. This is why the ratchet has a jerky motion.

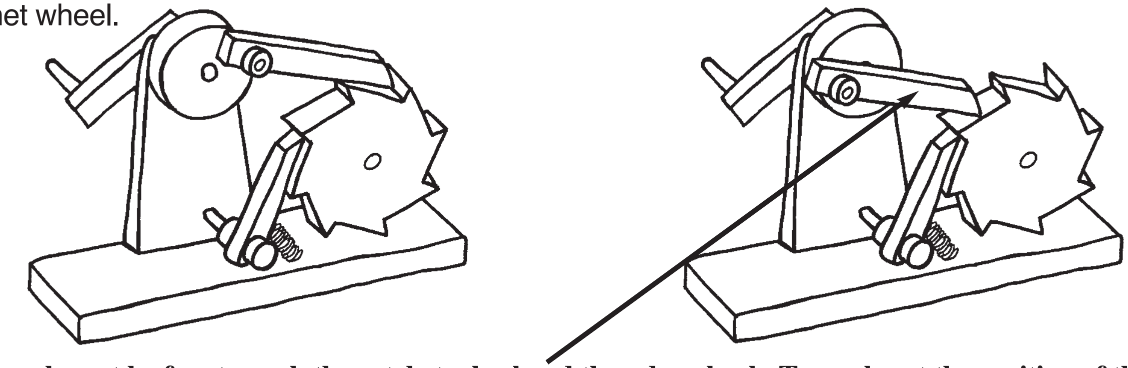
RATCHETS

DESIGN

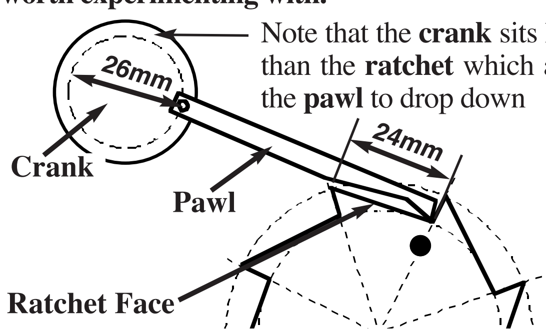
Like gears, the first thing you need to establish is the ratio you would like. This is very simple to work out as the ratio will always be something to 1. The pawl only turns or pushes once per revolution, unlike the input on a gear wheel which could have many teeth. The output or ratchet wheel determines the ratio. For practical reasons the smallest amount of teeth would be four but the upper limit is only determined by the amount you can fit on to the ratchet wheel and what size you want it to be.
Between 8 and 12 teeth will accommodate most automata needs while not being too difficult to make.
There are two kinds of ratchet teeth you can make, referred to as square cut or rounded. It is far easier and quicker to make square cut teeth.



When designing your ratchet you will have to give careful consideration to the size and location of the pawl. This must be positioned in such a way that it pushes the ratchet wheel one notch and then comes back and drops down in position ready to push the ratchet wheel on the next revolution. The second pawl, or catch, will have to be positioned in such a way as to lock the ratchet wheel.



The pawl must be free to push the ratchet wheel and then drop back. To work out the position of the pawl you need to calculate the amount of travel the pawl must move, so that it is able to drop down onto the next tooth. The pawl in this model is rotated in a clockwise direction which then helps push the pawl down onto the ratchet wheel. The reverse would be true if the model were reversed. You need to take this into consideration.
The diagram below shows that the crank has a throw of 26mm while the ratchet face is only 24mm. This allows the pawl to clear the ratchet and drop down. The position of the crank and the length of the pawl will probably need a little fine tuning in order to work. Ratchets are very useful in automata and well worth experimenting with.



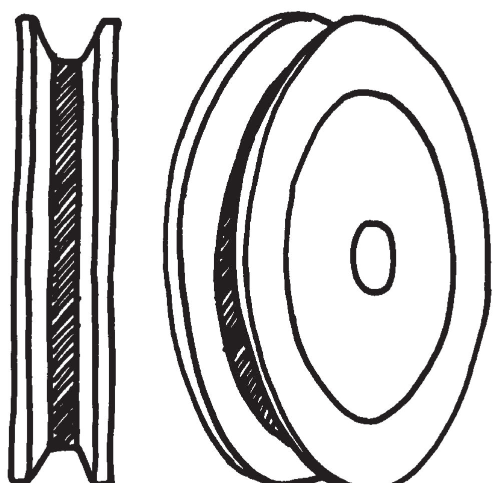
CONSTRUCTION TIP

Like gears, you can laminate several pieces of card to make a strong ratchet wheel. The same can be done with the catch and pawl. You can use elastic bands instead of springs and art straws or pencils can be substituted for wooden dowels. Alternatively you can work with wood or metal. Pine is easy to work with and fairly strong.

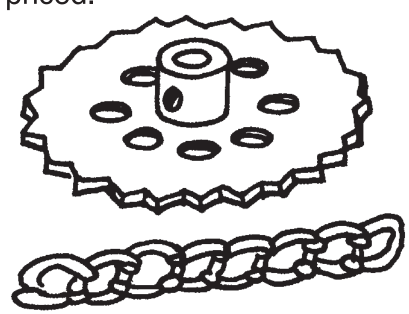
PULLEYS

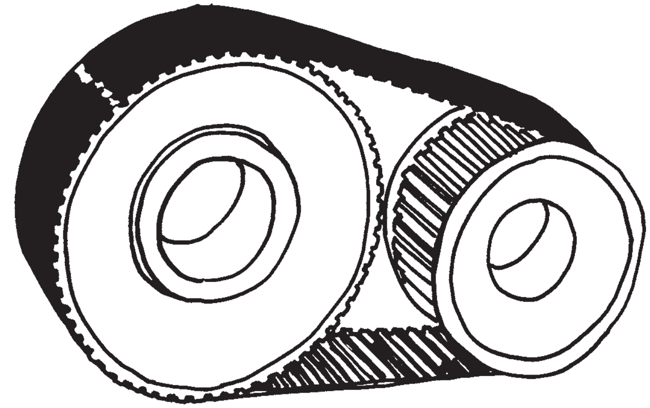
THE POWER OF THE PULLEY

Pulleys work in a similar way to gears, except they are not directly joined but linked by a belt made from elastic bands, tubular springs or some other flexible but strong material. A common example is the fan belt in a car that links a number of pulleys.
To stop the pulley belt slipping off, pulleys have grooved rims. This also keeps the belt running in a straight line.
Pulleys that use some form of belt drive are referred to as “Friction Drive” mechanisms.

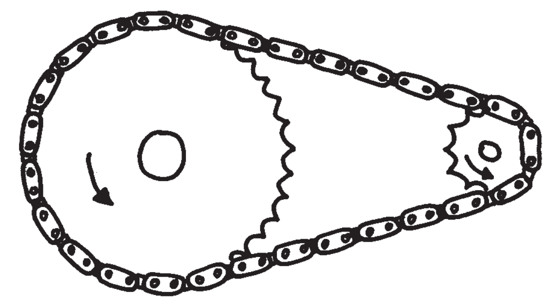


Pulleys have several advantages over gears, but also some disadvantages.
The main advantage is the fact that they are simple to make and can be used at a distance from each other, unlike gears that need to touch in order to work. The disadvantage is that they work by friction and so can slip, which could seriously upset the timing of a complex automata.
You can get a toothed pulley and belt which eliminates any slipping or timing problems. Many cars have a cam belt that works on this principle. Some model suppliers sell special toothed pulleys but they tend to be very expensive and are rarely used in automata which generally have a “Friction Belt” system. This is simple and very effective in most cases.
The belt can also be substituted by a chain, a bicycle being a good example of this system. Model suppliers often stock small plastic toothed pulleys or chain sets which are reasonably priced.

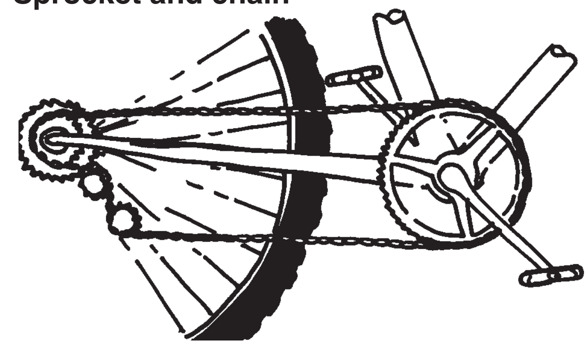




Toothed pulley and belt



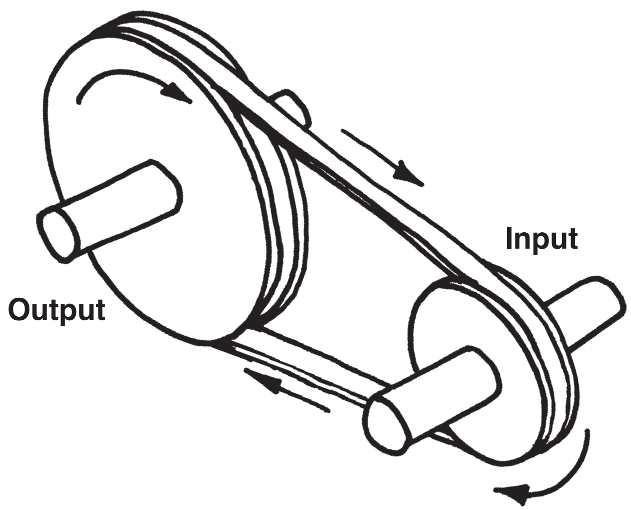
Sprocket and chain



A bicycle chain

PULLEYS

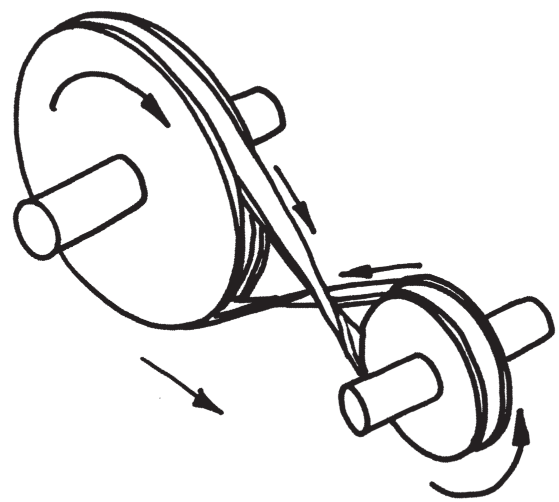
Like gears, you can use the pulley to either step up or step down the drive. But instead of counting teeth as with gears, you simply make the diameter of the pulley wheels larger or smaller.



Pulleys rotate in the same direction

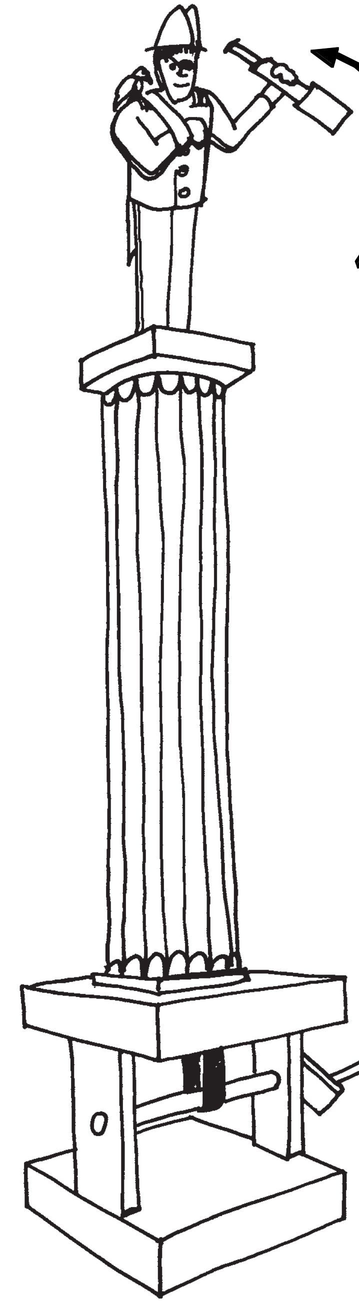
By dividing the input diameter by that of the output, you can work out a final ratio. In the above example, the ratio is 2:1. This means for every 2 revolutions of the input pulley the output turns one full revolution. You could reverse the input and output pulleys.
You can see that pulleys rotate in the same direction (unlike gears which do the opposite).

Pulleys are useful for getting the drive action to happen in awkward places. You can use the drive pulley to transmit its motion to the output pulley which may be some distance away.
We can also use pulleys to reverse the action by putting a twist into the belt. This makes the output pulley move in the opposite direction. Again this can be very useful.



A twist in the belt reverses the direction of the output pulley

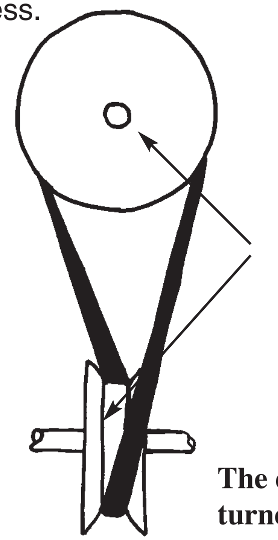
The Automata opposite uses a pulley to transmit the motion over a long distance. It also slows the action down and transmits it to the output pulley which is in a confined space (Nelson's body). Pretty good going for a simple pulley system!



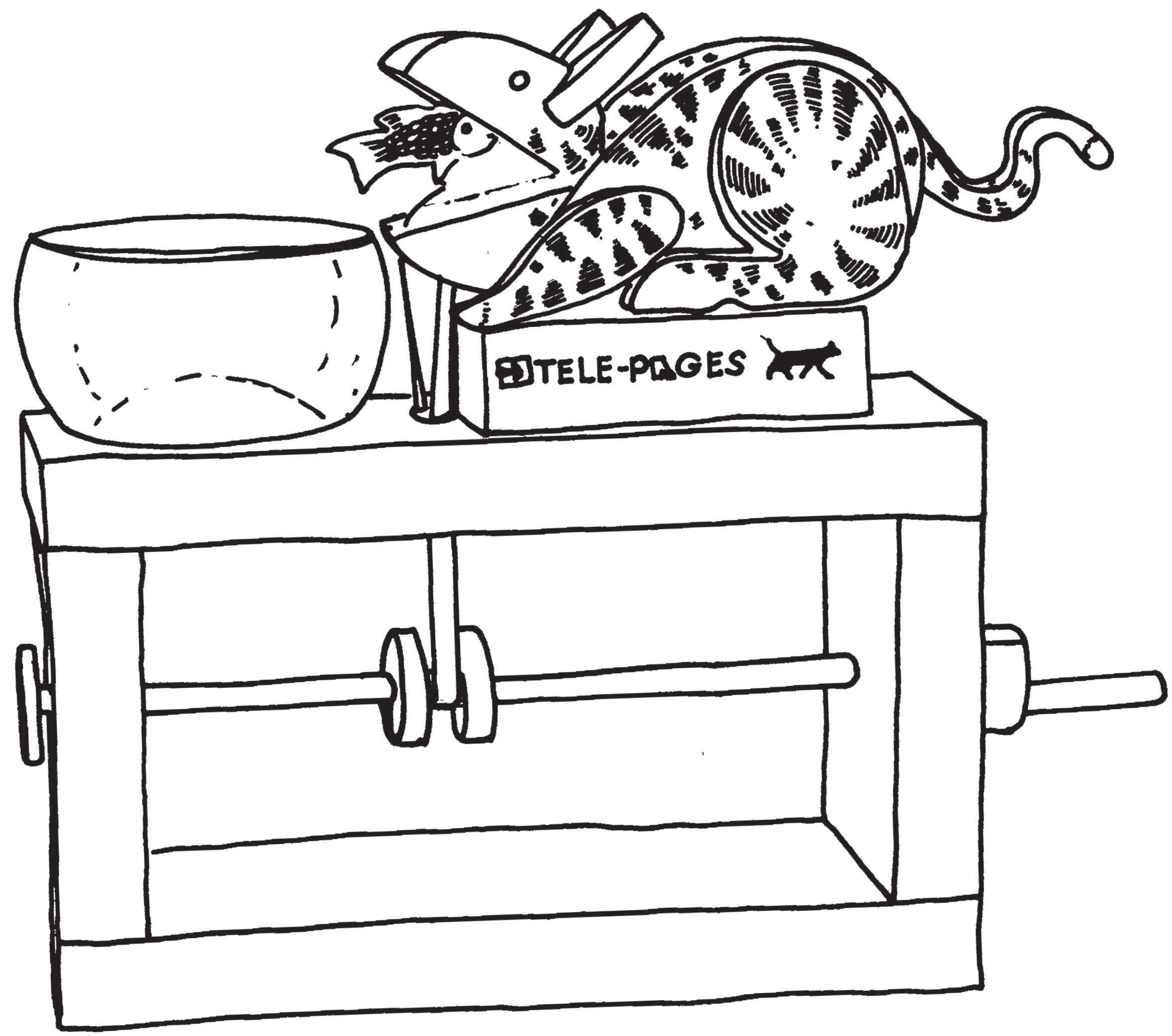
PULLEYS

APPLYING PULLEYS TO AUTOMATA

When you want to transmit the drive over some distance, pulleys are an ideal choice. As we have seen, they are simple to construct and take up comparatively little space. In fact, they share many of the virtues of the ratchet, with the big advantage of producing a constant and smooth drive force. But it doesn't stop there; the pulley can perform one other vital function, which is to change the direction of drive. This can be to any angle but the most common use would be to turn the drive through 90 degrees. This same task could be performed by gears but would be significantly more difficult to make. When It comes to making automata, this simple trick of changing the drive direction can be invaluable for its simplicity and effectiveness.



The drive is now turned through 90⁰



The "Cat eating Fish" automata above uses the pulley twisted at 90⁰. This avoided having the crank handle at the front and middle of the mechanism housing. The pulley drives a larger one in the cat's mouth which slows the action down slightly and, as with gears, provides more force. The fish is painted onto clear plastic which is shaped like a snail cam, so as it goes round it opens the cat's mouth. If the pulley slips it doesn't matter.

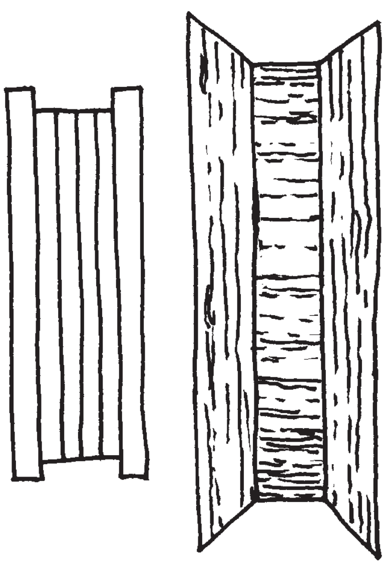
PULLEYS

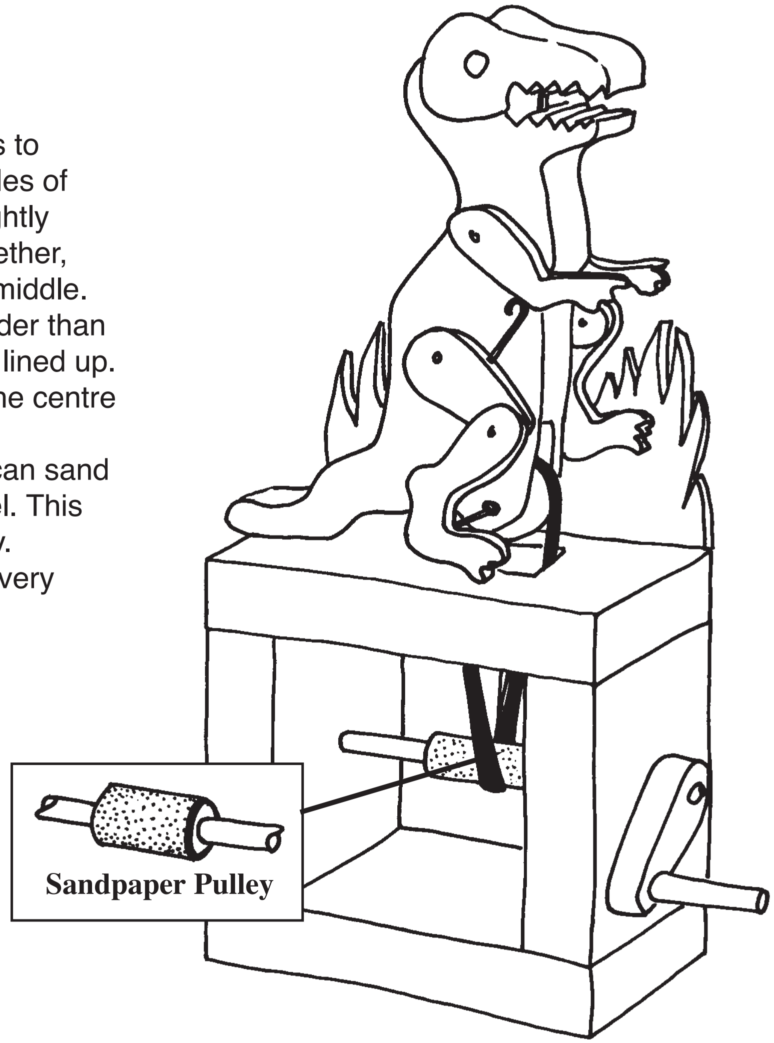
CONSTRUCTION TIPS

Laminating is one of the easiest ways to make a pulley wheel: cut several circles of wood or card making two of them slightly bigger (around 5mm). Glue them together, sandwiching the smaller ones in the middle. Make sure that the pulley is a little wider than your belt, and try to keep the centres lined up. When the glue has set you can drill the centre out to the size of the drive shaft.

If you are working in wood then you can sand the inner edge down to create a bevel. This will help guide the belt onto the pulley.

Use wood glue even on card, as it is very strong when dry.





The running dinosaur above is driven by a pulley. The top pulley is also an offset crank which turns the legs. Because the pulley has a lot of work to do, it was geared down. Sandpaper is wrapped around the drive shaft, giving the elastic band much more grip.

PUTTING IT ALL TOGETHER

Fitting the elastic band is often the final part of the assembly process before gluing everything. Should you find that your elastic band breaks, you could substitute it for a flexible steel spring driving belt. It comes open ended and can be cut shorter or extended by joining another spring to it. These can be purchased in most model shops and offer superior performance over elastic bands, which are prone to stretching, and can disintegrate if left in direct sunlight for long periods.

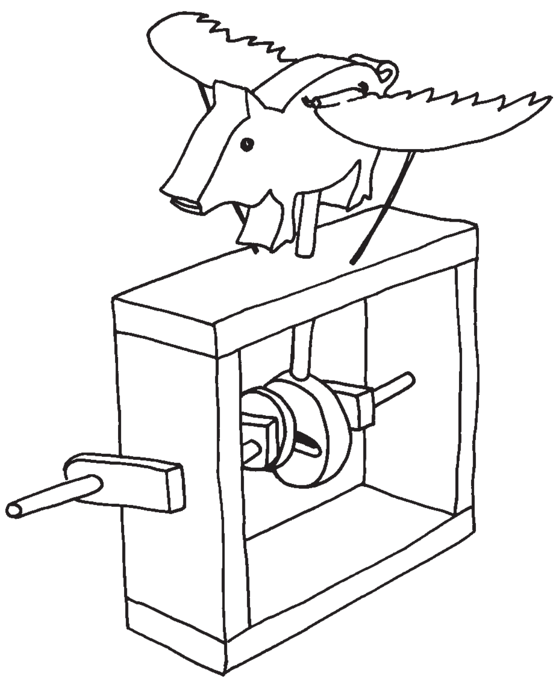
Finally, make sure everything is strong enough to take the tension of the pulley. Remember you are dealing with a friction drive, so the tighter the belt the less chance you have of it slipping. Make sure that any axles are strong enough to take the load.

Elastic bands make good cheap drive belts but have certain limitations. Flexible steel spring driving belts are much tougher.

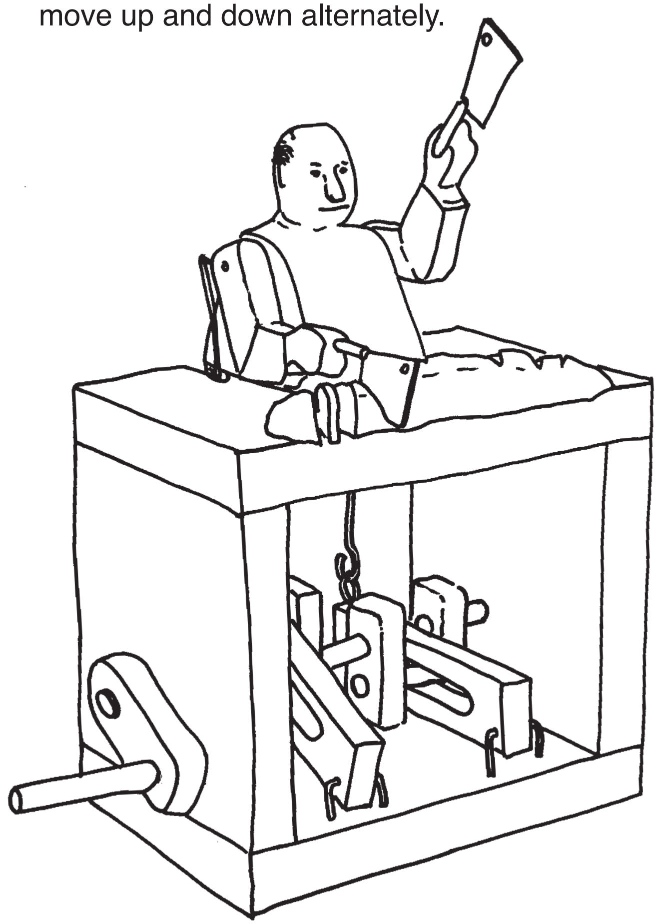
LINKAGES

WHAT IS A LINKAGE ?

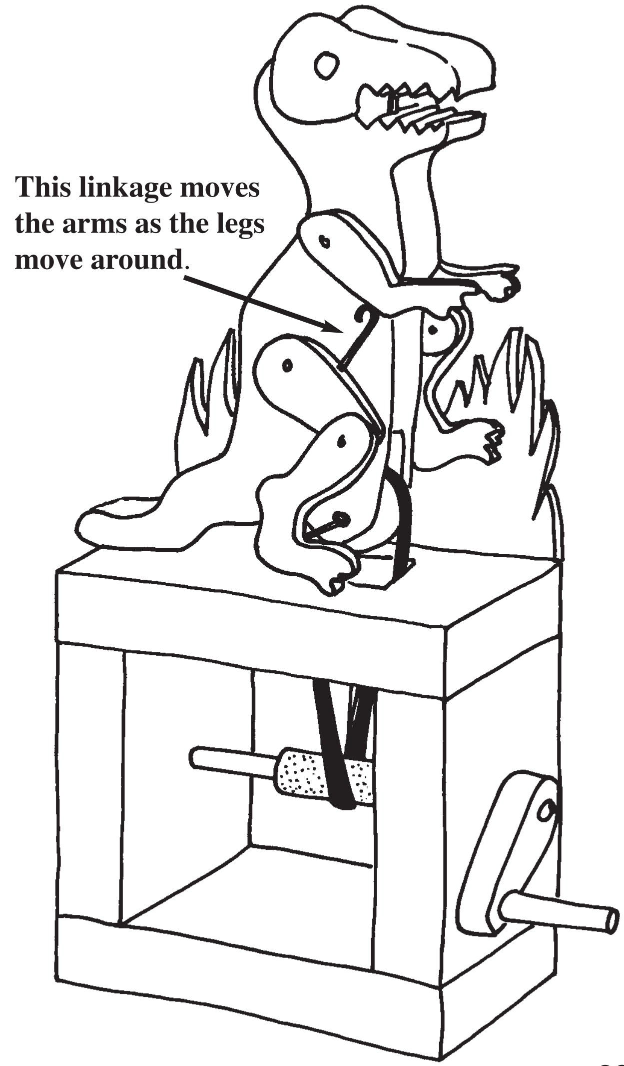
"Linkage" is the term applied to the parts of a machine or mechanism that connect moving parts together.
Many of the different drives that we have looked at use some form of linkage or connecting rod to transfer the power or motion. Linkages can be used to control movement as well.
The flying pig below uses a good example of linkages. The body is pushed up and down (by what is effectively a linkage) and, as the wings are held in position, it gives the illusion of the pig flying.



In this automata the linkages are used to both control and transmit movement.
The cranks have linkages attached to them, which are in turn attached to the man's arms.They pull the arms up and push them down. As the cranks are offset by 180° they move up and down alternately.

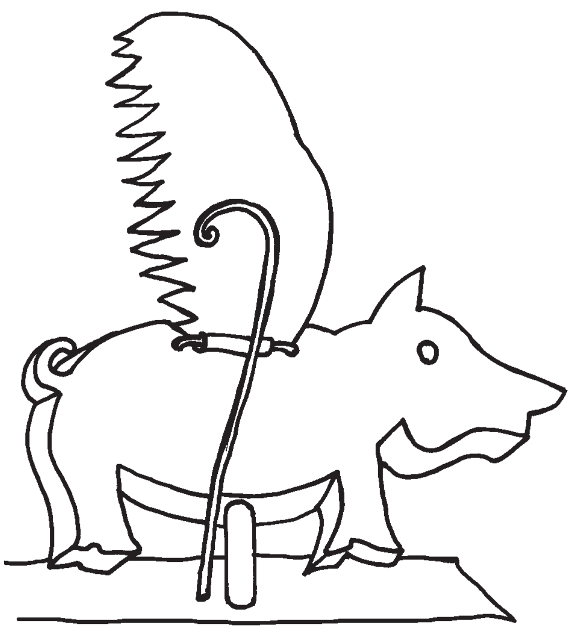


This automata shows how useful a pulley can be. What makes this one so interesting is its use of linkages to move the arms and head.

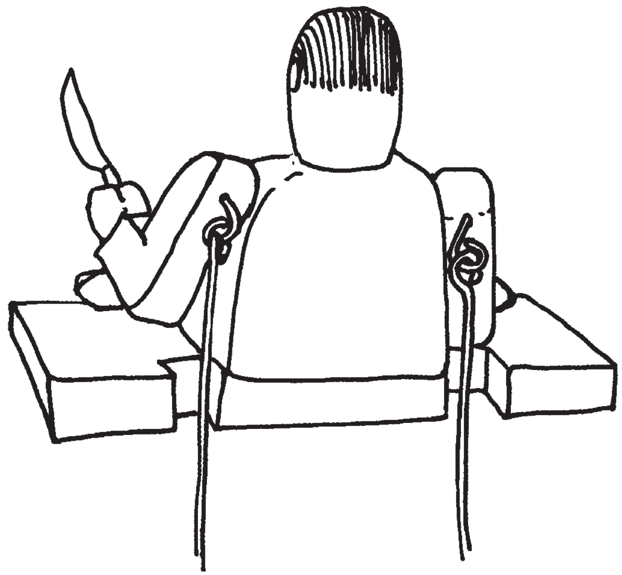


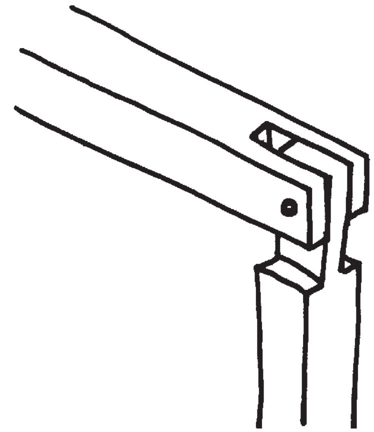
LINKAGES

Linkages can be made from a range of materials, but wood and metal are perhaps the strongest and most commonly used.
It is important to note that where there is movement between materials there must be some form of free movement otherwise the mechanism will jam.
Linkages are used to transfer motion, so they must be properly designed in order to function as intended. Although the mechanical stresses in automata are very low, you still have to apply good solid engineering principles. Let's take a closer look at the automata on the previous page and see what does and doesn't work.



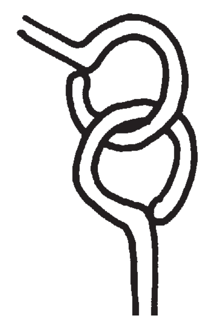
With the man and his chopping knives, the linkages play a vital part in allowing the movement to happen. The ends of the linkages are made into rings and joined together which allows them to move freely. You may find that, very occasionally, the linkages jam because the ends allow for too much freedom of movement.





This mechanism is more complicated to make but is a much better design, as it only allows movement in its intended direction (up and down) not side to side.

The rings allow for movement in the required direction but also in unwanted directions.

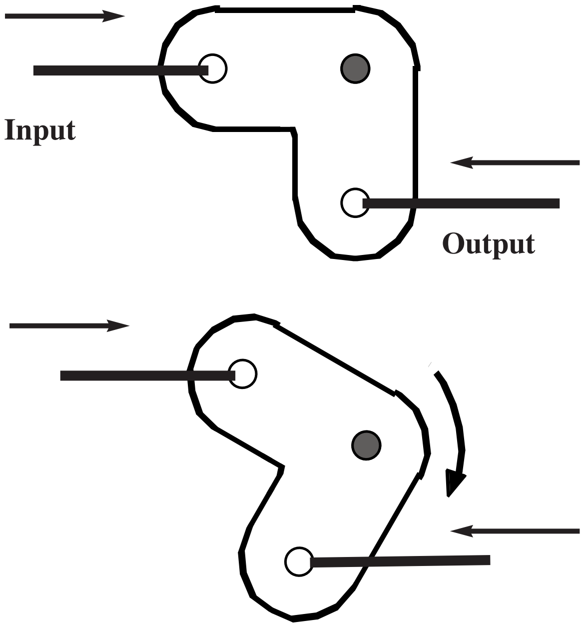


The Pig's wings are linked to the body and are pivoted, which allows them to move freely up and down, but not backwards and forwards.
As the pig is moved up and down, the wings are forced to either rise or drop. This can only happen if the linkages are not attached, otherwise the wings would not move.

LINKAGES

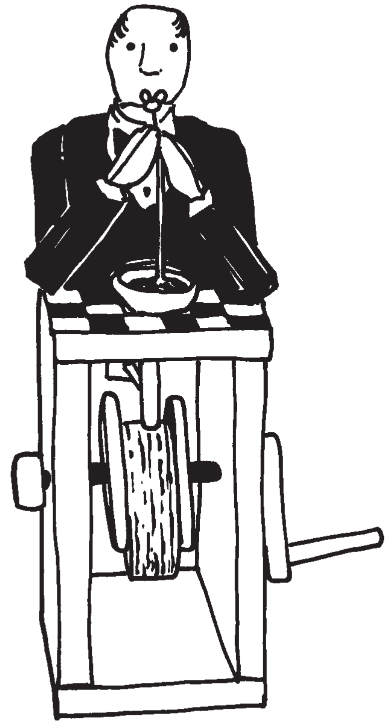
TRANSMITTING AND CHANGING MOTION

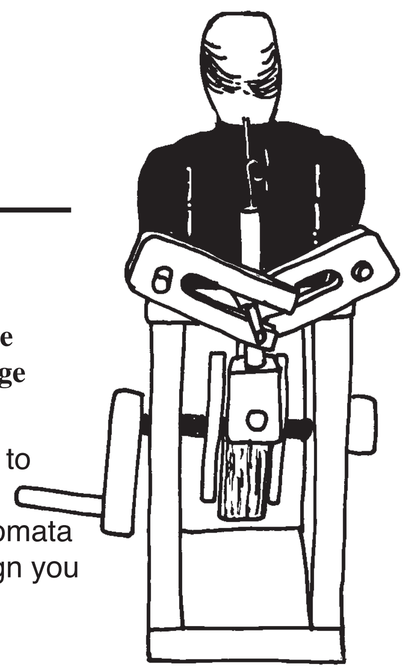
Linkages can be used to transmit and change the direction of movement. One of the most common methods to use is the bell crank.



In the example above you can see how the input linkage pushes, so the output linkage pulls in the opposite direction.

It is important that the linkages are free to move when attached to the bell crank. Linkages are a vital part of making Automata function. With careful thought and design you should be able to produce the exact movement you require.





This automata uses another variant of the bell crank. The cam pushes a rod up and down, with a horizontal linkage that connects with the two bell cranks, and makes the hands clap as the diner tries to catch the fly in his soup.

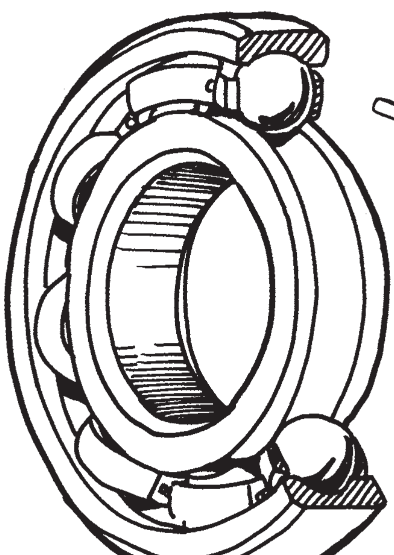
The Golden Mechanical Disciplines.

Design your mechanical parts so that they are free to move, but constrained to only move in the intended direction. It is often better to make things a little on the loose side. But be aware that for every slack part in the mechanism there will be a loss of input motion. It is possible to make a machine with so many slack parts that all of the input motion is lost and the output is nil.

BEARINGS, SHAFTS, FRICTION AND LUBRICANTS

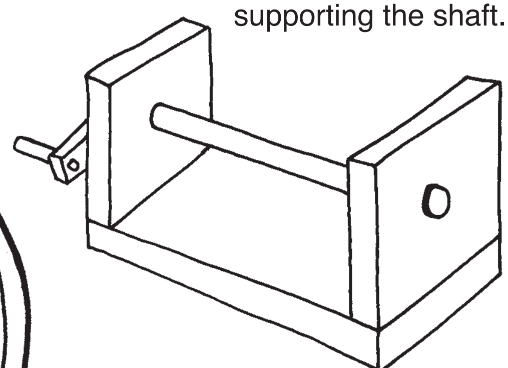
LOW SPEED, LOW STRESS

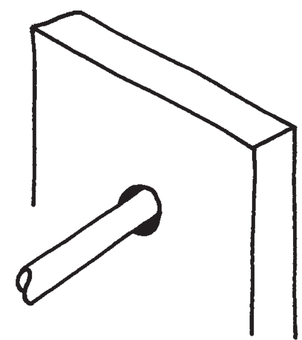
So far we have looked at very simple mechanical mechanisms which, when applied together, are capable of producing very complex automata. For the most part, wood and metal have been the most convenient and best materials to use, although there are alternatives such as card, paper and straws etc. All the automata we have looked at so far have several things in common in engineering terms. They can be described as working at slow speeds, under low stress and with low output. In practical terms this means you do not have to worry about special lubricants and bearings to keep things moving. However here are some simple ways to keep things running smoothly.



BEARINGS

Lets start by looking at bearings. Bearings usually support a moving shaft and help it rotate freely under as little stress as possible. Many commercial machines have bearings made up of a metal case called a “chase” that houses hardened steel ball bearings. An inner case holds them in place and is attached to a rotating shaft. The ball bearings help spread the load and force of the shaft, they are usually lubricated to cut down friction. It is usual to construct an open box to house the mechanical parts of an automata, which are powered be a central shaft. This shaft sits within the outer wooden walls and is free to rotate, so the box acts as the bearing supporting the shaft.

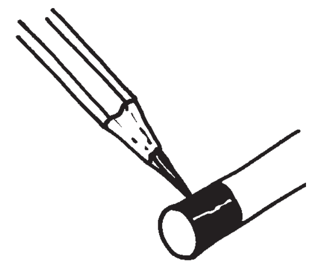


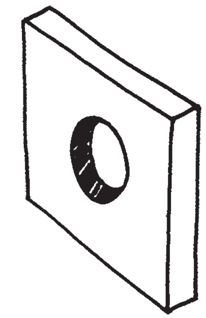


You need to make sure that the drive shaft is free to rotate and is not “sticking” as it turns. The hole it goes into should be slightly larger than the shaft itself but not so big as to to give you too much play. This could cause more sensitive mechanisms, like gears, to jam.

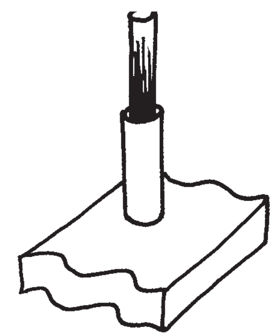
LUBRICANTS

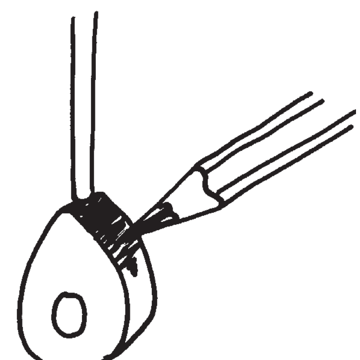
An ideal lubricant to use when working with wood is graphite, which is used in lead pencils. When applied to wooden surfaces, it makes an ideal lubricant.





Apply the graphite from a pencil in to the hole (bearing) or drive shaft to enable the shaft to turn more freely. Do not get it on any areas you need to glue.

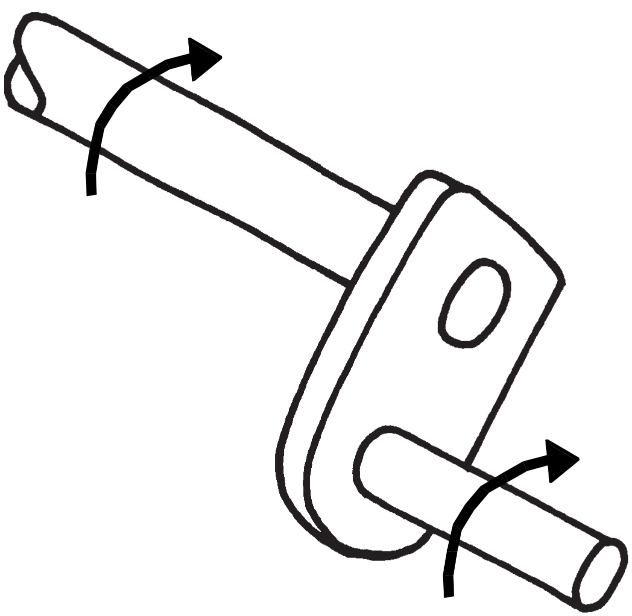




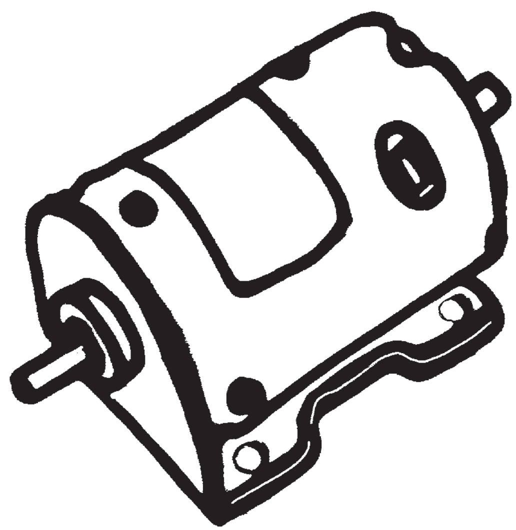
Graphite works well on cams and cam followers. It also works well on copper or brass tube. Never use oil, as it is not necessary and can cause the shaft to stick.

DRIVES

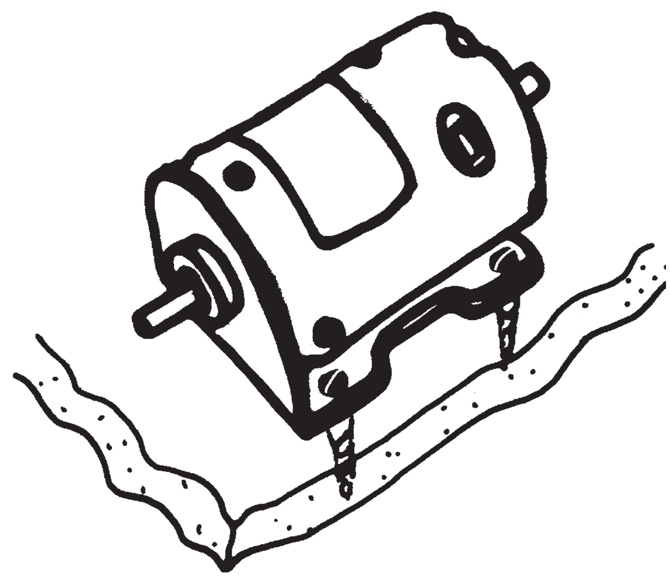
HAND POWER
There are two main ways of powering your automata. One is to turn it by a handle (human power), and the second is to use a motor, the most practical being a small electric one.
I design all my automata to be hand driven, which helps bring the mechanism to life and makes the user feel part of the performance they are watching.
Power is transmitted through a crank, which is more than sufficient to work an automata, and is quite comfortable for the operator to use.



ELECTRIC MOTORS
One advantage of electric motors is that they give a constant output, so the automata is less likely to be damaged. This is an important consideration if your work is going to be on display and used by the public.
Most electric motors turn at very high speeds. The typical revolutions per minute (or rpm) of a small 12 volt motor is between 200 and 12,000 rpm, so you will usually have to step down. Most hand crank speeds work out to be between 30-50 rpm, which is a good speed to aim for.
The best options for stepping down speeds are either gears, pulleys or a combination of the two. Many electric motors come with a small gear wheel, which is a good starting point.



If you decide to use a motor there are a few things to consider. Firstly, what voltage does it run at? Most cheap motors run at between 1.5 to 9 volts. As a rough guide, the higher the voltage the more powerful the motor. Even a small 1.5 volt motor can give out a lot of power when stepped down.
The second consideration is how easy the motor will be to attach to a board, or anchor down. Better motors have two lugs with holes to allow them to be screwed or bolted down.

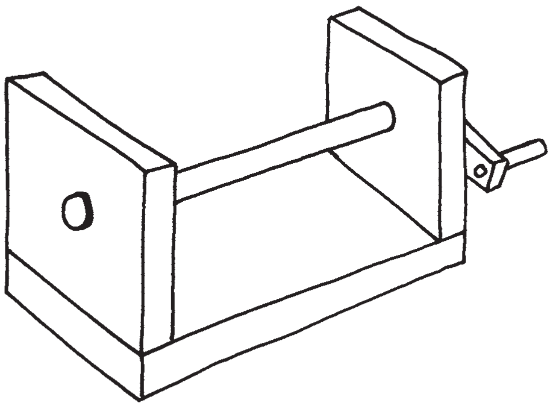


DRIVES

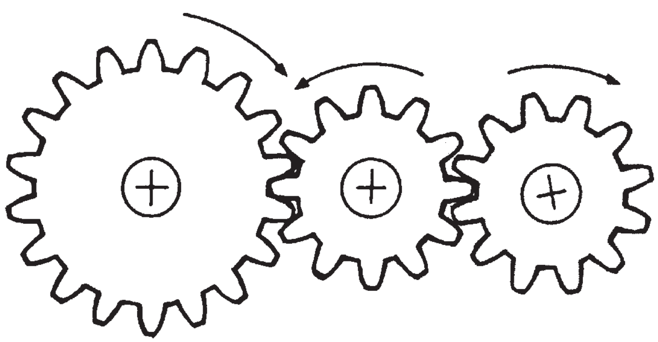
Drives can be broken down into two types:

Positive Drive and Friction Drive

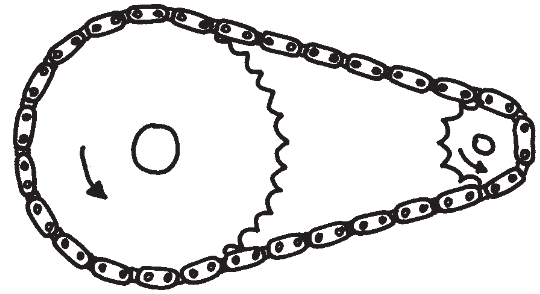
Positive drive means that the input and output force are connected directly. They are locked or synchronised and can't slip out of place.



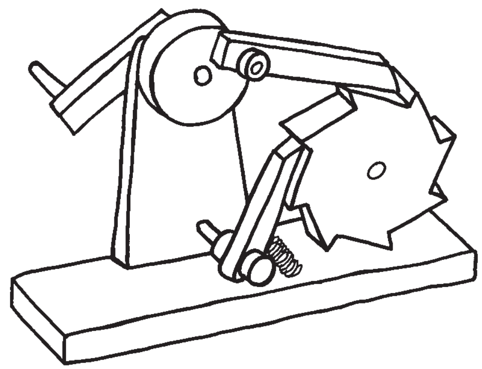
The crank handle is a positive drive. The crank is connected to the drive shaft and is turned by hand.



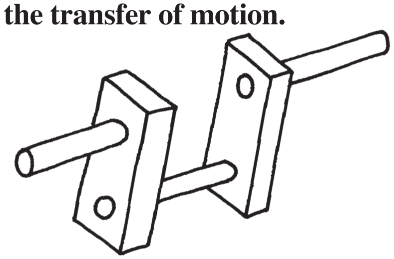
Gears are positive drive. They can't slip as they are always in contact with each other.



Sprocket and chains are linked so the drive can't slip. They can be considered to work like gears.

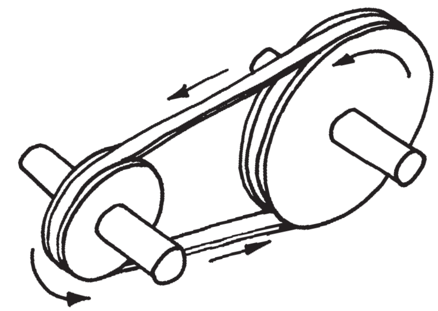


The ratchet is a positive drive mechanism. One pawl stops the ratchet slipping, while the other provides the transfer of motion.

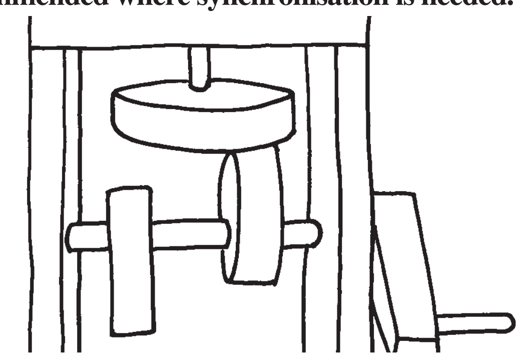


The crank is a positive drive, as the connecting rod that transfers the motion is directly connected to the crank and so can't slip.

A friction drive relies on two surfaces gripping when the force is applied to them to transfer the movement. "Slipping" is the term given when the drive input and output do not turn properly because there is not enough friction to keep the drive in contact. Pulleys are very susceptible to this. A screeching car fan belt is a good example a slipping friction drive.



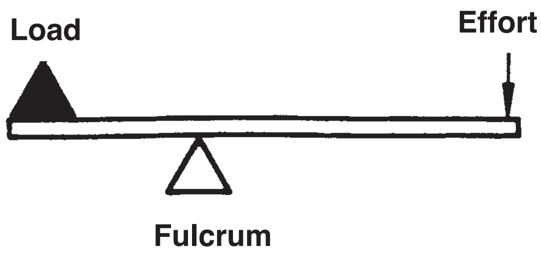
The pulley is a friction, or indirect, drive. It relies on the friction of a pulley belt to keep the two wheels connected. It can easily slip and is not recommended where synchronisation is needed.



The cam can be both a direct and frictional drive. An offset cam will directly drive the cam follower but also act as a friction drive to give a circular motion.

LEVERS

A lever is a device that applies or transfers force. It is a simple mechanism that usually consists of a rigid length of wood or metal, which pivots round a fixed point called a fulcrum.



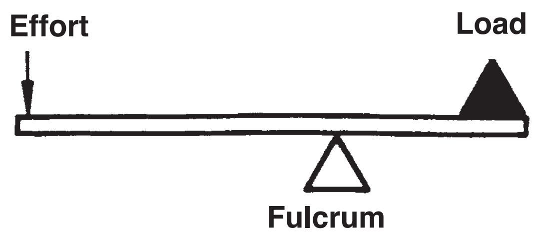
Most machines employ some form of lever, and you will find that they are used a lot in automata. It is useful therefore to understand how they work and how to use them in your own designs.

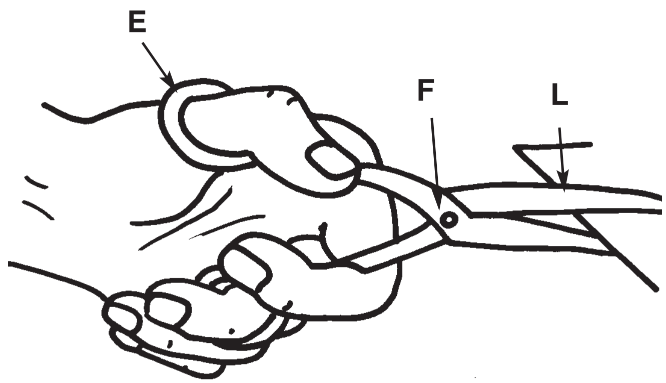
Levers work on the principle of “mechanical advantage”, which can be calculated by a simple equation, and is used to compare the effort applied to the load moved. We will look at this formula a little later on.

Archimedes established the Law of the Levers in his book “On the Equilibrium of Planes”. He described the three separate types (or orders) of levers, which have their fulcrum, effort and load arranged in different ways.

First order lever.

A first order lever has its fulcrum point between the load and effort.

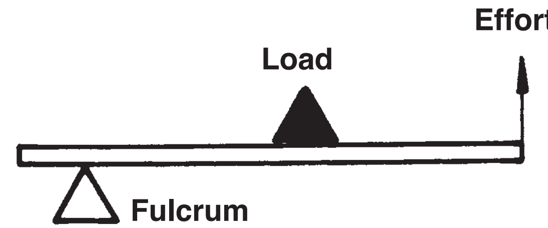


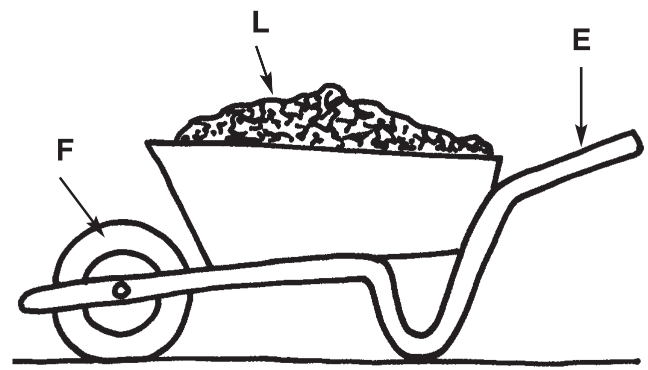


A good everyday example of a first order lever is a pair of scissors.

Second order lever.

A second order lever has its fulcrum and effort at opposite ends, and the load somewhere between the two.



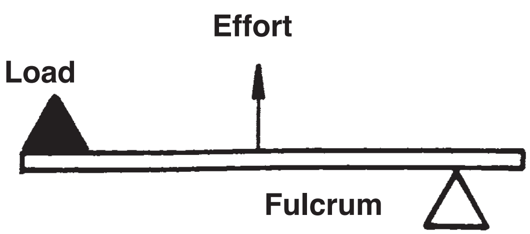


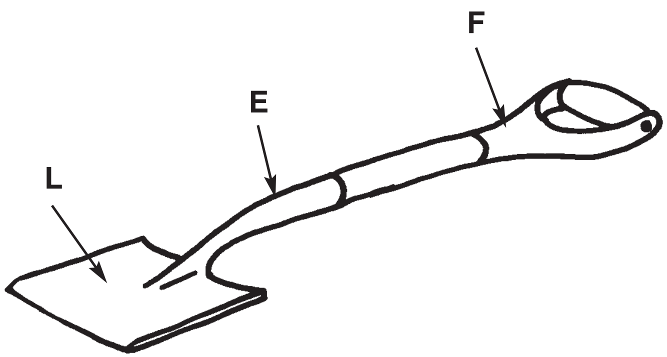
A good, everyday example of a second order lever is a wheelbarrow.

LEVERS

Third order lever

The third order lever has the fulcrum and load at opposite ends with the effort somewhere between the two.

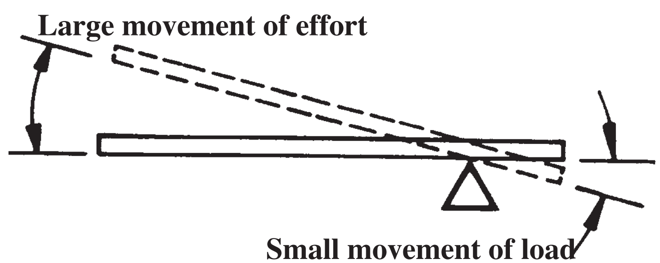




A good, everyday example of a third order lever is a shovel

A little bit of theory

A lever can produce a small output motion from a large input force, as when using a crowbar. A lever can also be used the other way round, where a small input movement can be increased by a lever to create a larger output movement such as a pair of scissors. Moving the fulcrum point, the effort or load points can change the effectiveness of a lever. For example if you move the fulcrum point on a first order lever towards the effort, the load travels further but takes more force to move it. The opposite happens when you move it towards the load.

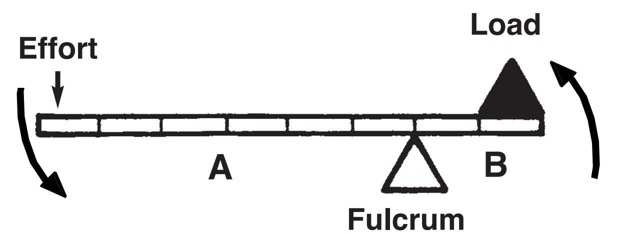


The important thing about levers is the way that they can be used to transmit, amplify or decrease movement. In engineering terms you are experimenting with the “Mechanical Advantage” of the lever. When a small effort moves a larger load the smaller effort has to move a much greater distance than the larger load. There is a price to pay for gaining mechanical advantage. However, at the scale we normally work with in automata, much of this will not really affect you.

The formula for working out the ratio of a lever can also be used to work out the “Amplification”, or amount of movement a lever will travel. Just like a cam, this is referred to as the “Throw” and can be used to great advantage when designing and making your own automata.

$$\text{Mechanical advantage} = \frac{\text{Load}}{\text{effort}}$$

If we apply this formula to the example below you will see how to calculate both the ratio and the throw of the lever.

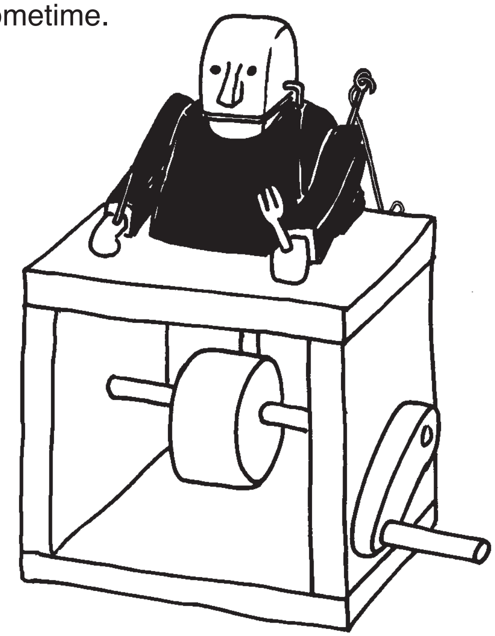


We can see that the ratio of A to B is 6cm to 2cm, so applying our formula we get a ratio of 3:1. This means for every 3cm of travel at effort (A) the load (B) will move 1cm. Reverse this by moving the fulcrum towards the effort and we magnify the movement for every 1cm of travel on the effort (B), so the load (A) will travel 3cm. It is also important to remember that levers travel in (describe) an arc and do not move in a straight line.

LEVERS

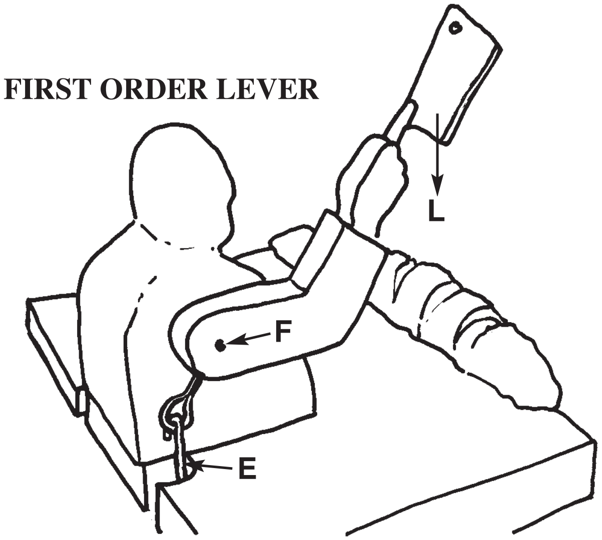
Using levers in automata

You will find that you use all 3 types of levers in designing and making your automata. They can be used to produce a variety of movements, but their main function will be transferring motion from cams or cranks. They are, in effect, used as linkages, and you will probably not be too concerned about things like mechanical advantage. However, understanding how they work is important as you will need to explore their full potential at sometime.

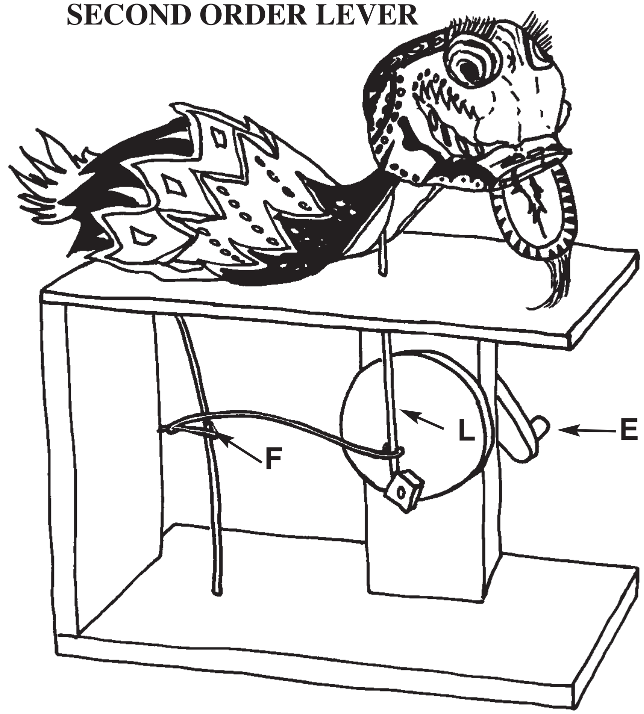


This automata is called the "Angry Diner". He rapidly bangs his knife and fork on the table, impatient for his dinner. His arms act as levers, amplifying the lift from the cam.

FIRST ORDER LEVER

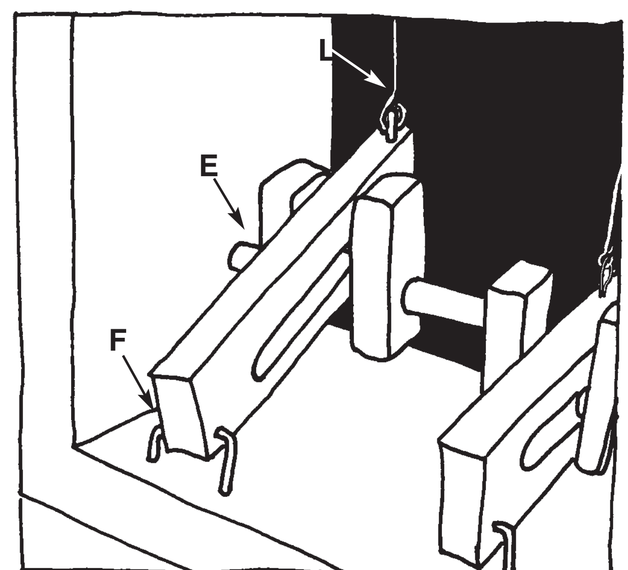


SECOND ORDER LEVER



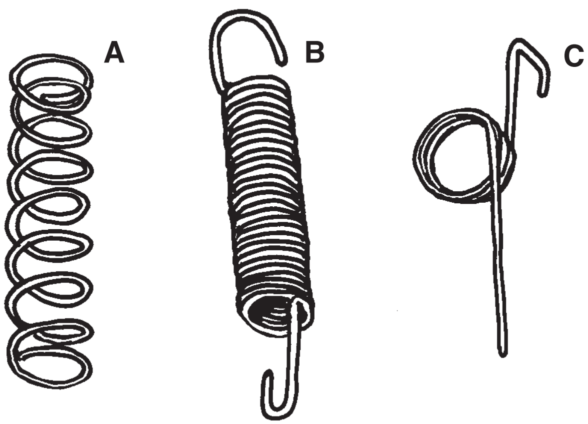
Levers play an important role in transmitting movement within automata mechanisms. They are often used as linkages, but the rules of the lever still apply. You can increase or decrease the amount of travel they have. It is important to be aware of this when you design and make automata, as you may well find parts of your mechanism moving too much or too little.
The model on the left is a good example of this. The distance from the Effort to the Fulcrum is quite short and the distance from the Fulcrum to the Load is about fifteen times longer which means that only a small amount of movement was needed in order to lift the arm quite high. The original cam needed to be made smaller as it caused the arm to lift too much.

THIRD ORDER LEVER

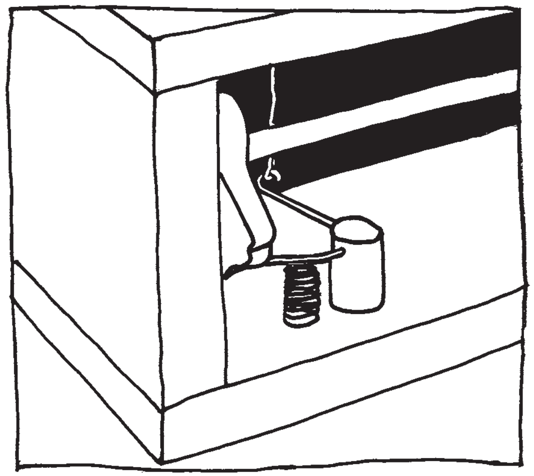


SPRINGS

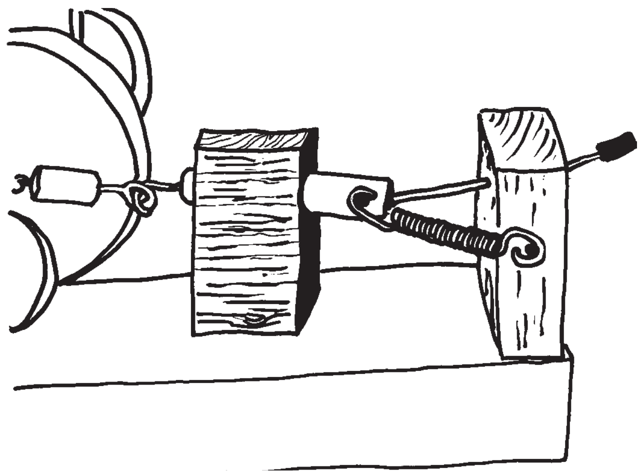
Most automata, when designed properly, should use mechanical force or gravity to achieve the desired motion. There are times when things need a helping hand. Springs are very useful for providing that little bit of assistance when necessary. Keeping the cam follower on a cam is a good example of where a spring can come in handy.
As you design your automata, you will probably find the need to use springs. They are very useful in helping to overcome some design inadequacies. It is not cheating, just creative problem solving!
Springs come in three main varieties.



A is called a Compression spring. When squashed it tries to push back to its original shape.
B is called an Extension spring. When stretched it tries to pull back to its original shape.
C is called a Torsion spring, and can be used to both pull or push.

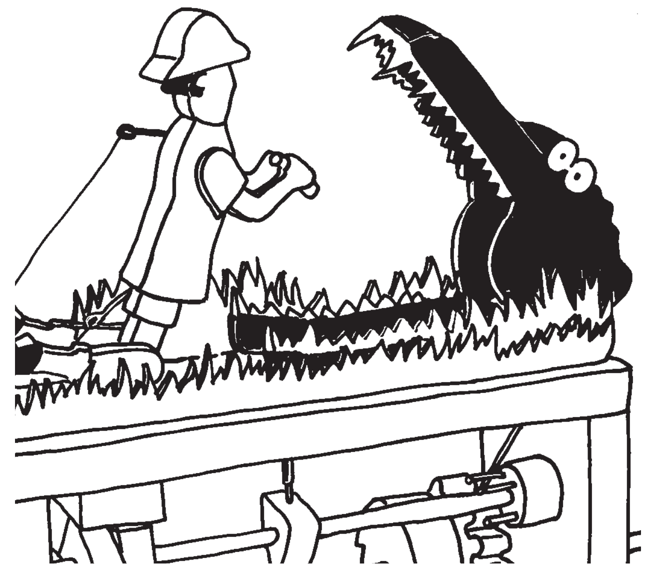


In the example above, the compression spring keeps a wire (which is acting as the cam follower) pushed against the cam



In this example, the con rod (which is attached to a crank) is pulled back by the extension spring.

The Automata below uses a torsion spring in side the crocodile's mouth to help it close with a fast snap.



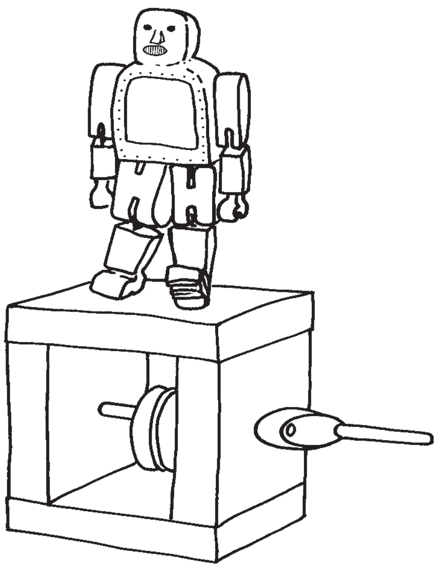
Most model shops sell bags of mixed springs ranging in shape and size. They are useful to have, but do not become over-reliant on them. It is very easy to put a spring in when a mechanism is not working properly. Try to resolve the problem or redesign the parts if you can.You should only use a spring as a last resort or when it is vital to have one.
Springs provide varying tensions, not a constant load. Trying to find the spring with the perfect tension can be difficult, as they are often too strong or too weak. You can make your own out of sprung steel, such as piano wire if you are unable to buy a suitable one.

FREE MOVEMENT

GETTING SOMETHING FOR NOTHING

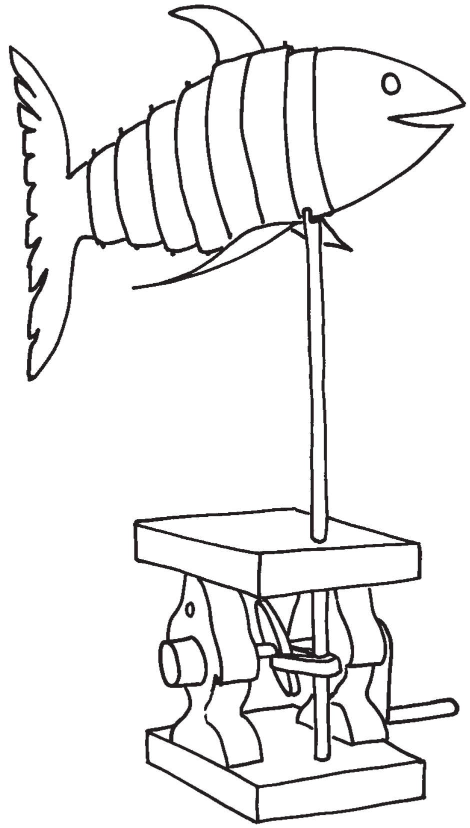
So far we have looked at a wide range of mechanisms and engineering principles. In this section I would like to show you how to get something for nothing!

The automata and mechanical principles that we have covered in previous chapters have all been carefully designed to move in a certain way. But we can also tap into the power by applying the principles of free movement. I will explain this phenomenon with the example below:



The Robot's body is fixed to a con rod attached to a crank. As it moves back and forth, the arms, legs and head flop about as they are free to move. This gives much more life and action to the automata. The beauty is in the simplicity. There is no need to make complex linkages to do this.

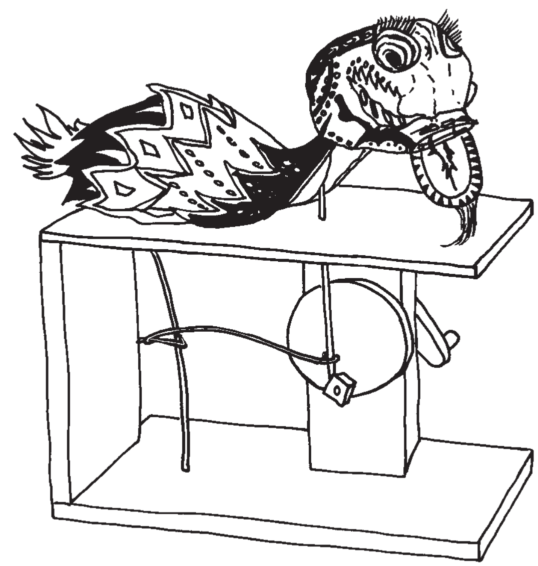
Try to explore and exploit "free movement" in your automata wherever possible. It is a great way of getting in extra action without extra work.



The fish turns back and forth but, because the tail and head are free to move, they swing from side to side. This use of free movement makes the automata far more exciting and life-like and does away with extra complex mechanisms.

The key to achieving free movement is enabling parts to be free to move. This may sound obvious, but you have to make sure that joints and linkages are designed to move freely. You also have to give thought to the designing of your automata and work out precisely what is going to happen.

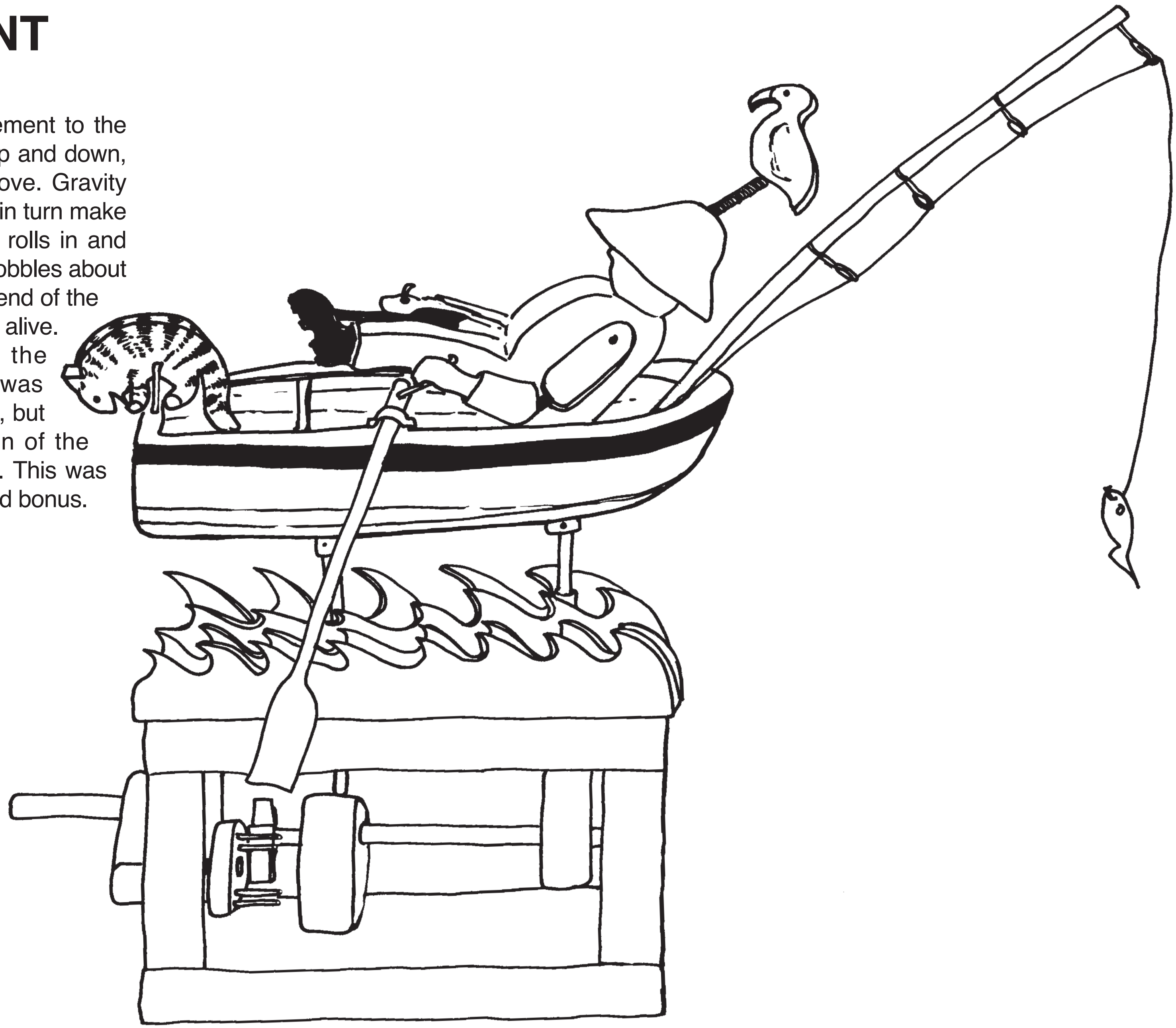
Given the random nature of free movement it can often bring an automata to life. Movements are sometimes jerky and may not follow a precise path. But this can all add to the charm. If you want precise and smooth motion you have to control things mechanically.



The Dragon's body is made to move in a certain way using a crank but the mouth is hinged and flaps about freely.

FREE MOVEMENT

This automata explores free movement to the full. The twin cams rock the boat up and down, while everything else is free to move. Gravity pulls the oars back and forth which in turn make the sailor rock to and fro. The cat rolls in and out of the boat whilst the sea gull wobbles about on a spring. Finally, the fish on the end of the line leaps about as if it is very much alive. This fish is a good example of the uncertainty of free movement. It was expected mainly to wave to and fro, but somehow it picks up the variation of the mechanism and wildly leaps about. This was totally unplanned, but is a real added bonus.



THE DESIGN PROCESS

INSPIRATION

Mechanical toys and automata often appear to have a life of their own, the simple mechanical parts seeming to produce an almost magical response in the figures that they move. Automata come in a vast range of sizes and varying degrees of complexity. Some may keep your interest for several minutes whilst others you may just pass over. What makes an automata “good” is very subjective. We all like different things and we do not all find the same thing funny. As the old saying goes: “You can’t please all of the people all of the time.” So where do you start. The check list below gives some simple suggestions against which to test your ideas.

1) Is it visually exciting?

2) Is it funny?

3) Will it intrigue the viewer?

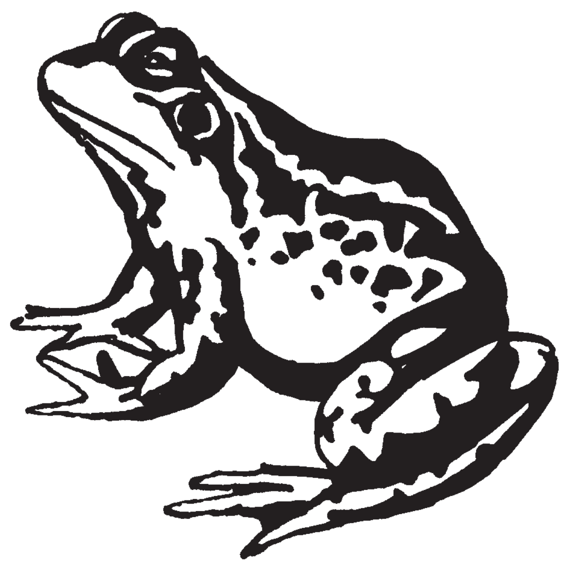
4) Will it hold the viewers attention?

5) Is it too complex?

6) Is the humour too obscure?

7) Will I enjoy making it?

This is just a general check list, and is by no means a fool-proof system for producing the perfect automata, but it will help to weed out good ideas from the bad. At the start, base your ideas on something that you are interested in such as a sport or a hobby. Animals can provide a wonderful subject on which to base a theme for an automata.
As with any creative process, coming up with the idea is often the hardest part of the whole process. You may, on the other hand, be lucky and be brimming with ideas. But it is probably fair to say that most people have to work hard at the inspirational, or ideas, stage.



RESEARCH

Once you have come up with an idea, the next stage is to research it. The purpose of research is to get as much information as you can about your subject. This helps you to work out how something moves, the colours, the scale etc. Research can be broken down into two areas.

1) Primary Research: This is where you make drawings of your subject from life.

As an example, you may draw a camel at the zoo. You do not have to be a great artist, but just looking and observing will help you understand your subject. You may not always be able to draw from life, and the temptation is always to work from the easiest sources however, the best and most creative works evolve from good observation. This is true for all arts and crafts, and is the reason why many artists spend so much time drawing.

2) Secondary Research: Refers to things such as photos, pictures, photocopies etc.

This is usually the most accessible material to get hold of. The library is a good place to start, and you can often photocopy relevant pages from books.

THE DESIGN PROCESS

Designers often put together a “Mood Board” or “Ideas Sheet” which is made up from a range of materials that reflect the theme. It can include colours, textures and surroundings. They are often used in the fashion industry yet are of great benefit to any designer. In its simplest form you could paste up all of your research material onto A3 or A2 paper. Remember your ideas sheet is there to inspire you, so make it interesting.

Designing:
When you have got your research material, you need to begin developing it, into a working solution. A good idea is to start by writing a “Statement of Intent”. This is simply a few sentences about the automata you want to make. It is a great way of focusing your thoughts and forms the basis for a design brief. The following headings will help as a guide to the sort of things you need to think about.

1) Who is my automata intended for? A small child, 12-14 year old or adult etc?

2) What size will it be? Automata can range from miniature pieces for dolls houses, through to hand held ones or large scale works.

3) Simple or complex? One golden rule is to keep things simple, but even simple automata can get complicated.

4) What materials do I want to work in? Automata can be made in paper, wood, or metal. Often you will work in a range of materials.

5) Deadlines: How long have I got to make it?

You will find you often have to complete your work within in a certain time. So you will need to plan carefully.
Once you have established a basic working brief you are ready to start designing your automata. Begin by thinking about the movements needed to make it behave realistically, and then try to match these to the mechanisms covered in the first part of the book.
Start sketching out your ideas. For complex automata, you may find it easier to break down all the movements and design the mechanisms individually. When this is done you can then work out how to join the whole thing up.
The actual design process is both exciting and frustrating. Once you have solved the initial mechanical problems, it is often helpful to evaluate your work and see if you can simplify anything. It is vitally important to keep sketching down your ideas. It is helpful to make accompanying notes as well. The reason for this is that what appears to be very simple and straight forward can often turn out to be confusing and complex when looked at a week later. You may think you understand drawings at the time, and all the mechanisms make sense, but things do not always stay clear. A few accompanying notes can help to explain and make sense of your drawing. They can also jog your memory.

THE DESIGN PROCESS

Design Notes

It is a good idea to work in black felt tip pen which makes a committed and permanent mark, and will help you to draw and sketch in a clearer, more simplified way. Try it for yourself and see. You should also work in a sketch book which can be purchased from art shops and stationery stores. This keeps all your drawings in one place so there are no individual bits of paper to lose and you can also refer back to past work for inspiration or to find solutions to mechanical problems.

Development

You will need to take your ideas through to a final design and eventually draw them up in full detail, showing how all the mechanisms and moving parts will work.

You may find that none of your initial ideas were suitable, so a modification or combination of ideas can be put together to provide a workable solution.

Developing your work is a vital part of the design process. You will need to be very objective about your own work, whilst not being too dismissive of your ideas. Taking an idea and developing it into a final solution is the very essence of the design process. So enjoy it and have fun “pushing” your talents to the limits.

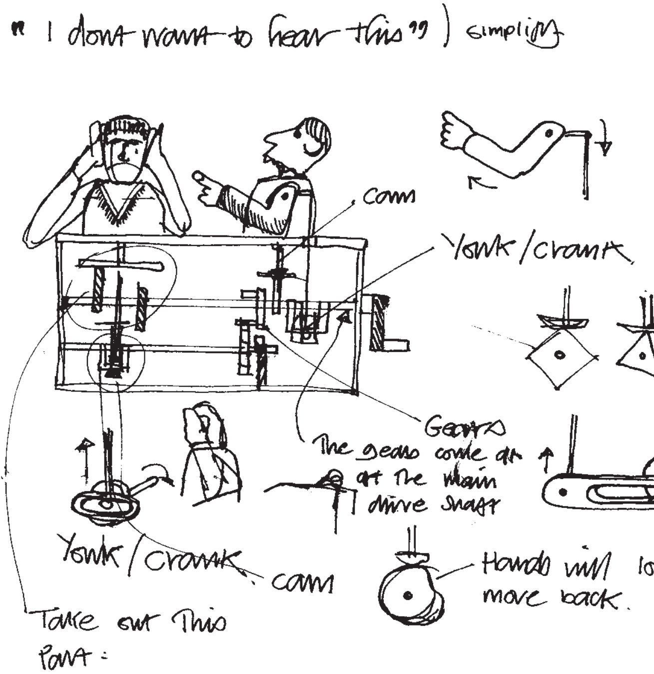
Working Model

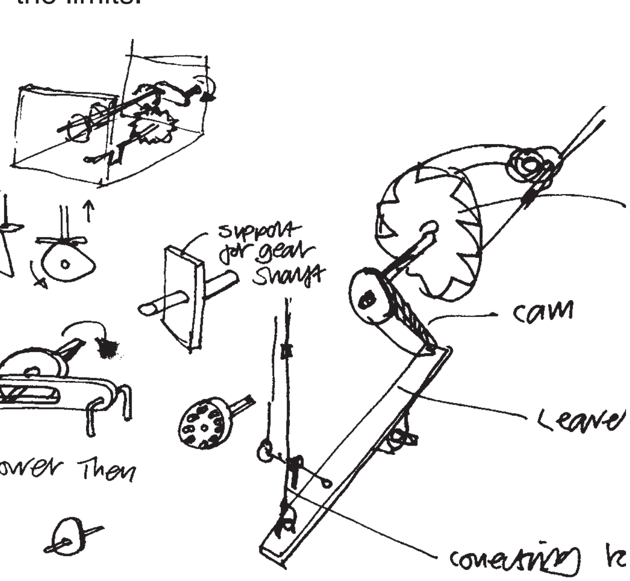
Making the working model helps to highlight any design and construction problems. It can also save you a lot of time and effort later on. At this stage the design can be modified and construction details finalised. It is also a vital part of the design development process, as the working model helps you to evaluate your ideas and, if necessary, make changes. In some extreme cases it can highlight the fact that the automata just will not work as intended and a major redesign is called for. This is where the phrase, “back to the drawing board” originated from, and it happens to all of us at some time or another.

The working model or prototype is best made with card, wood and string as they are flexible and quick to modify. Card is surprisingly strong and can be used for the final automata if you wish.

Your working model or prototype plays a big part in the evaluation. At this stage the practicality and feasibility of your design can be assessed. You will find that there is almost always something that needs changing in order to make things work, and you often discover an even better way of construction comes to light.

It is also at this point you should evaluate your work, and make sure that it still fits your original criteria, ie: intended use, etc.





THE DESIGN PROCESS

Finished Automata
With the working model complete, functioning properly and evaluated, you are ready to start on your finished piece.
The choice of materials to work with is up to you, as the designer. An appropriate choice should logically come out of the design process and working model. Wood, metal and hard plastic, termed “ resistant” materials, are hard and strong and should be used if the automata needs strength, otherwise use card or paper.
The working model can form a template from which to make many of the mechanical parts such as cams, gears and pulleys. Be prepared for some things to need modification.
Resistant materials are less tolerant then softer ones, and whereas a card gearwheel may work, a wooden one may jam or stick, if not properly designed.

Evaluation
The final evaluation is used as a guide with which to test the success of your design against your original intentions.
Every stage of the design process will include some form of evaluation. Indeed designing is really a continuous process of evaluation.
The evaluation may just be a process of making mental notes about what did and did not work. Alternatively you can write up notes in your sketch pad. This is the best method to adopt as it forms a valuable source of research material to refer to in the future, especially when you encounter problems.

Below is a flow diagram of the design process:

INSPIRATION

↓

RESEARCH

↓

DESIGN

↓

DEVELOPMENT

↓

WORKING MODEL
& PRELIMINARY EVALUATION

↓

FINAL OUTCOME

↓

EVALUATION

A finished automata is a wonderful thing and you can rightly be proud of your achievements. Few things are as rewarding as seeing people enjoying your work and asking , “How does it work”?

THE DESIGN PROCESS - SUMMARY

Two golden rules to keep in mind when starting are:

1) KEEP IT SIMPLE

2) MAKE IT INTERESTING

When you have come up with an idea for an automata run it through this check list:

1) Is it visually exciting?

2) Is it funny?

3) Will it intrigue the viewer?

4) Will it hold the viewers attention?

5) Is it too complex?

6) Is the humour too obscure?

7) Will I enjoy making it?

You will then need to do some research about your subjects, trying to get as much visual information as you can. There are two main types of research:

1) Primary Research: This is where you make drawings of your subject from life.

2) Secondary Research: Refers to things such as photos, pictures, photocopies etc.

The following headings should help as a guide line as to the sort of things you should be thinking about when you start designing.

1) Who is my automata intended for? A small child, 12-14 year old or adult etc?

2) What size will it be? Automata can range from miniature pieces for dolls houses, through to hand held ones or large scale works.

3) Simple or complex? One golden rule is to keep things simple, but even simple automata can get complicated.

4) What materials do I want to work in? Automata can be made in paper, wood, or metal. Often you will work in a range of materials.

5) Deadlines: How long have I got to make it?

After making the initial working model, it is useful to evaluate its effectiveness and highlight any design problems that may still need to be resolved.

1) Does it work the way it was intended?

2) Can anything be improved or simplified?

3) Is it going to be reliable?

In the final evaluation you need to test against your original intentions. Below is the procedure you run through.

1) Does it appeal to its intended user?

2) Does it work as intended?

3) Is it safe for use by the intended user?

4) Can it be improved in any way?

5) Is it going to be reliable?

6) Will any of the parts wear out too soon?

7) How easy will it be to repair if something goes wrong or breaks?

8) Were suitable materials used for the final construction?

9) Could alternative materials be used (recycling)?

10) Can it be adapted in any way?

DESIGN & CONSTRUCTION

Where to start

Knowing how the mechanisms work and what movements they are capable of making is of great importance when it comes to designing your automata.

But just how do you come up with ideas and make them work? This section looks at the design process and gives suggestions and ideas on which to base your own work.

It is a considerable challenge to design and make automata, so keep in mind two golden rules:

1) KEEP IT SIMPLE

2) MAKE IT INTERESTING

These two design criteria are useful to base all your work against. If the designs pass this simple test then go on and make them.

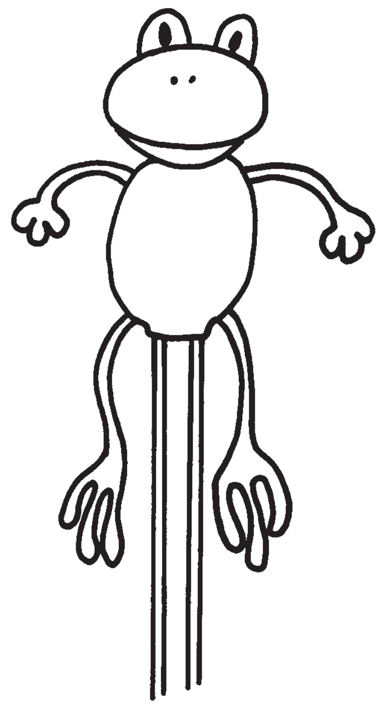
Look for inspiration from the people and things happening around you. The animal kingdom is a very rich source of ideas, and can be a good point from which to start your own work.

The following section runs through the complete process of designing and making two automata. This should help give you an insight to the principles to follow and the problems you may encounter, as well as ways to find solutions.

The Frog

Stage 1) Inspiration

The inspiration for this automata came from a rubber that goes on to the end of a pencil. Frogs have interesting features as well as an exciting way of getting around which is very distinctive and relatively simple to emulate.



Stage 2) Research

This is one of the most important processes. If you want to get the best out of your automata then this is the stage you need to get right.

Begin by producing an “Ideas Sheet”. This is simply a large piece of card onto which are pasted as many images of your subject as you can find. They can range from simple cartoons to drawings, paintings and photos. Magazines are a good source of material. You can take photocopies from books and if possible try and take some photos first-hand.

From the ideas sheet start making simple line drawings to determine the best shape and angle to work at. Simplify the shapes as you are going to work in wood or card eventually.

Try and find the thing that makes a frog look like a frog etc. (The key features of shape and form that make the frog or your subject recognisable).

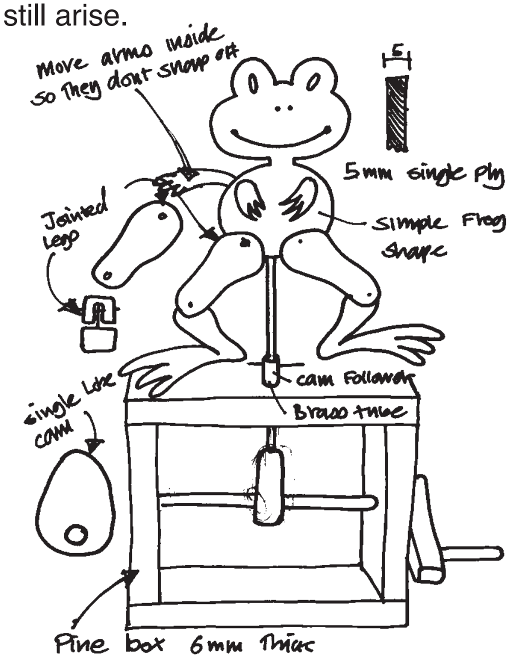
The next thing to do is try and simplify the movement of the frog by looking for characteristic movements. (In this case a hopping or jumping movement).

Finally choose the main colours to work with. In this case it was easy - Green.

DESIGN & CONSTRUCTION

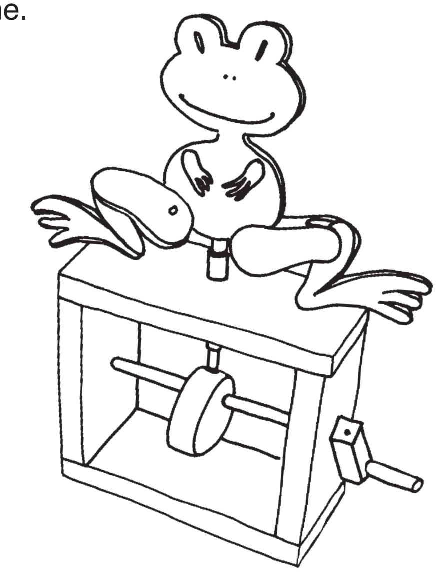
Stage 3) Design
This is the stage where you make decisions about size and colour, and begin to devise the simplest mechanism which will make your automata work.
The first thing to establish is a “User Profile”. Simply put, decide who the automata is intended for, i.e. children or adults. The frog automata or mechanical toy is intended for young children aged 3 upwards. This now means designing something which is strong, durable and with no sharp edges or small pieces that could break off. It also needs to be colourful and slightly cartoon like (whimsical). With this information you can begin designing.
The frog needs to move up and down, which provides a choice of two mechanisms - a cam or crank. The cam in this instance seems the best choice. The crank could be adapted but would make the mechanism more complicated.
The next decision is what sort of cam to use. A single lobe would give one big jump, a triangle or square would give a faster action. Earlier research showed that frogs jump in big leaps, so it makes sense to go for a single lobe cam. Small children should be able to follow the action better if it is slower.

The next task is to finalise the design as a working drawing. At this point decisions about the mechanisms, the box they are housed in and the materials to work in will all be made. Next the design of the frog is developed.
A “working drawing” will contain all the information needed in order to construct a “working model”. At this stage everything is theoretical and it should work, but problems can still arise.



The basic design is starting to look like this. There are still a lot of problems to resolve, but drawing ideas helps to clarify the design process.

Stage 4) A Working Model
From the design sheets, a working model is made out of a mixture of card and wood. This is the exciting part of the process where your drawings come to life. It is also a time for discovering what does and does not work.
You can save a lot of time and energy by producing a working model even though the temptation is to go ahead and start on the final one.



A number of things came out from this working model that were not apparent in the drawing. One is that the crank handle needs to be bigger so that children with small hands can turn it easily. Secondly the frog needs to be double sided. This will enable left and right handed children to use it.

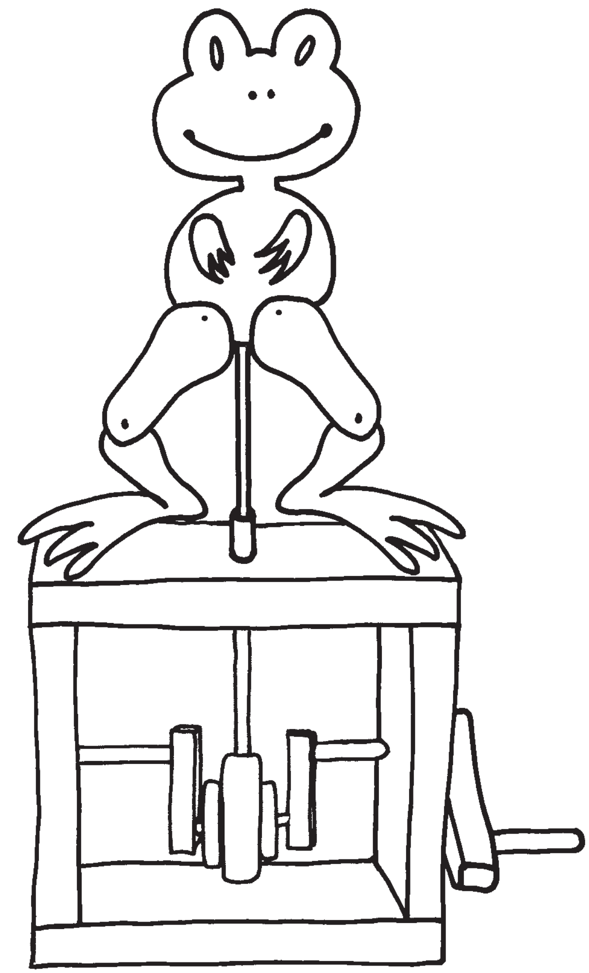
DESIGN & CONSTRUCTION

Stage 5) Evaluation and Development
After making the initial working model it is useful to evaluate its effectiveness and to highlight any design problems that may still need to be resolved. Try working to a simple check list:

> **1) Does it work the way it was intended?**
>
> **2) Can anything be improved or simplified?**
>
> **3) Is it going to be reliable?**
>
> **4) Does it look and move in a frog-like manner?**

Inevitably, you will need to adapt some aspect of your design. Apart from a larger handle and the need to paint the frog on both sides, in this instance a much bigger problem has been highlighted. The frogs legs are too long and do not leave the base when the frog is at the top of its travel. The cam is just about as big as it can go so a major re-think is called for. One possible solution would be to slightly shorten the legs and make the cam larger. The most practical solution is to replace the cam with a crank, and the scotch yoke crank is a good choice if side to side movement is to be avoided. This makes it a more complicated automata than originally planned.

Stage 6) Final automata
All the design problems have, in theory, been ironed out, so the final stage is to make the automata out of what is termed "resistant materials". Wood was chosen (in particular pine which is soft and easy to cut).
The final automata is assembled and painted. Most of the parts are made directly from patterns that were produced for the working model and have been tested so should work without any problems. The scotch yoke has been substituted to provide more lift. It worked well in card and so should be fine when constructed in wood. Because of the new design, the frog is attached permanently to the rest of the automata which makes it safer for younger children. In this case switching mechanisms has proved useful, and shown how things can easily be overlooked.
Now finished, and working as intended, there was a teething problem with one of the legs sticking. This was due to the paint taking out the free play in the joint. A bit of vigorous push-pulling soon bedded it in.
Several problems were highlighted when designing and constructing this simple automata, so take heart when you encounter problems with your own work. There is usually a way to overcome the setbacks you meet.



The final automata works as intended and has evolved into a more practical toy for the children it was intended for.

DESIGN & CONSTRUCTION

Stage 7) Evaluation
This final stage is very important and you now need to test against your original intentions. Below is the procedure that was run through.

1) Does it appeal to its intended user?

2) Does it work as intended?

3) Is it safe for use by the intended user?

4) Can it be improved in any way?

5) Is it going to be reliable?

6) Will any of the parts wear out too soon?

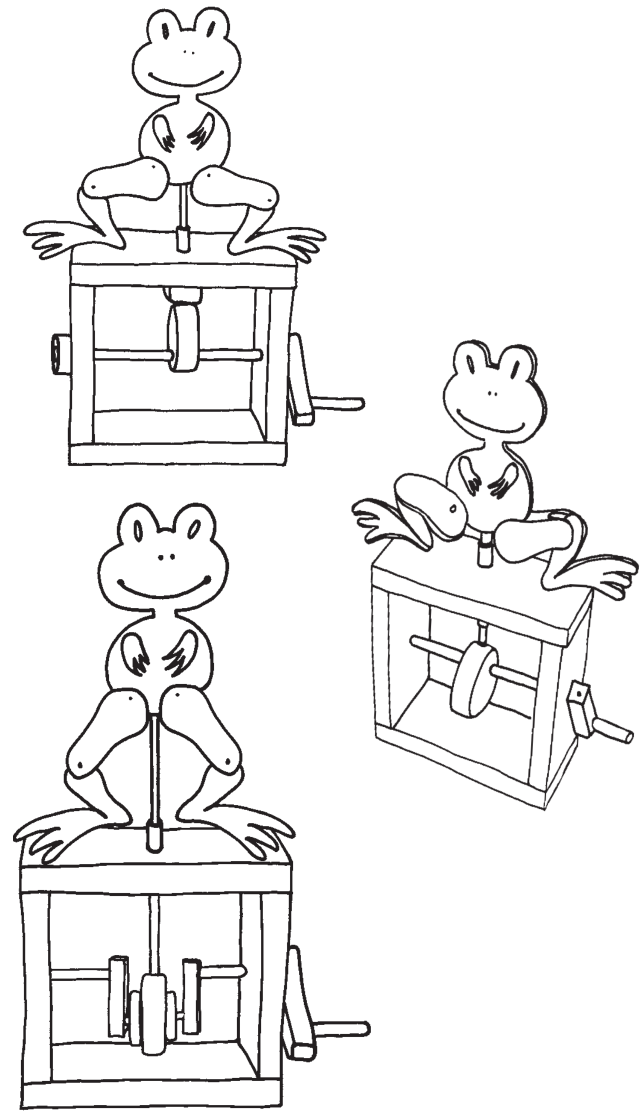
7) How easy will it be to repair if something goes wrong or breaks?

8) Were suitable materials used for the final construction?

9) Could alternative materials be used (recycling)?

10) Can it be adapted in any way?

The procedures that are followed are common to most designers. It is important to work in a clear and methodical manner. This does not have to be at the cost of creativity but, if anything, should help you channel your ideas and energies towards a successful solution. It is worth mentioning that you face two problems. The first is what to make, the second is how to make it.
I try to design and make automata that have a fun aspect to them. Often they turn out as simple jokes or whimsical aspects of everyday life. Do not be offended in the least if people think of your work as toys because that is exactly what they are; objects to play with and stimulate the imagination.
The design process is essential in order to produce a working solution. Making automata is not easy, but it is a rewarding and satisfying thing to do, especially when they work!
As you can see from this example, things do not always go to plan. However, a thorough approach to the design process will help you make successful and exciting automata.



Be prepared to have to make and modify several versions of the final automata.

DESIGN & CONSTRUCTION

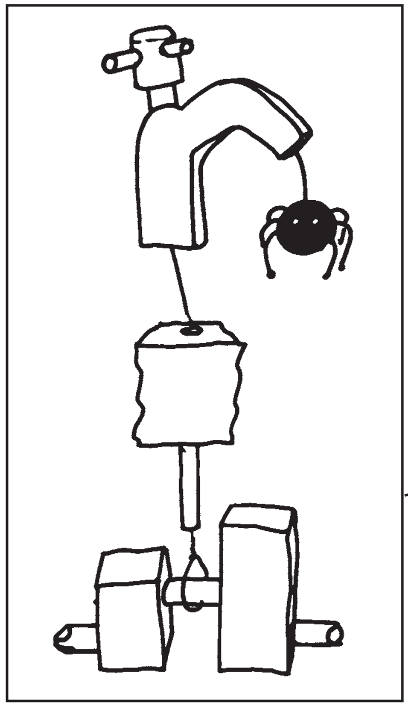
Mechanisms and Design process
This section looks at the process of designing a complicated automata, and takes a more detailed look at the mechanisms.

1) Inspiration The idea for this automata was based on reversing objects in their environment. I felt that it would be fun to see a fish taking a bath.

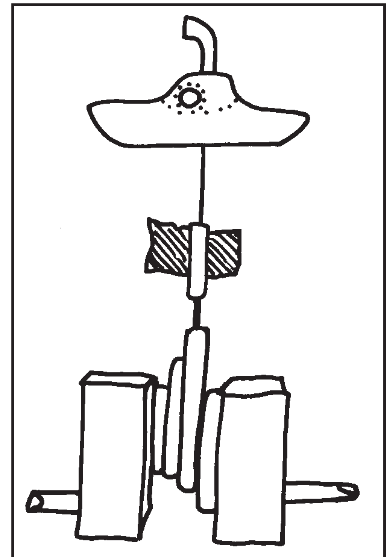
2) Research An ideas board was made up with fish and baths cut out of magazines as well as drawings from life at a local aquarium.

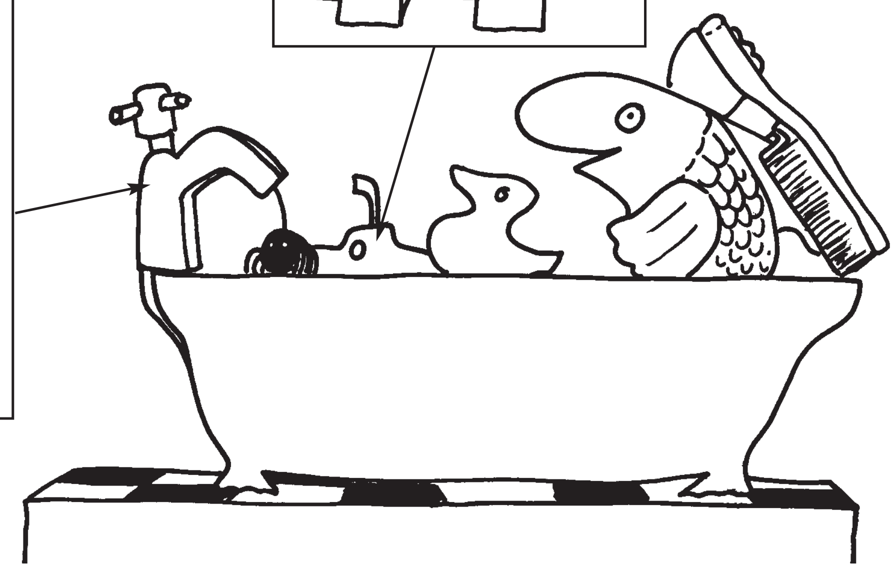
3) Design The initial designs came from making different sketches based on the research material. The automata needed to be simple, so the big problem was to keep it flat yet 3D. This could be achieved by working in layers rather like a theatre set which would give the automata a feeling of depth.
Having sketched out a simple diagram, objects were added in the bath to liven things up. At this point there was no thought of how they would move or what mechanisms to use, so that was the next thing to resolve.
In this example the mechanisms were designed individually and then combined at the end of the design process.

The spider
This needed to appear to crawl up and down out of the tap. The best way to achieve this was to have some fishing line on a crank, which lifted the spider up while gravity pulled it down. This meant that it had to made out of something heavy, which was important because the line passed at least 3 places which restricted movement.



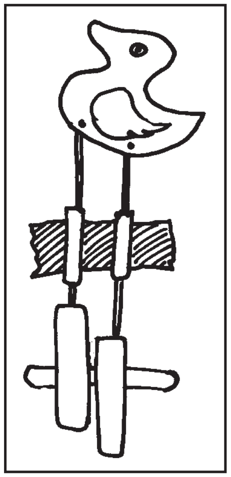
The submarine
The submarine needed to rise up and down. A simple double cam achieved this.





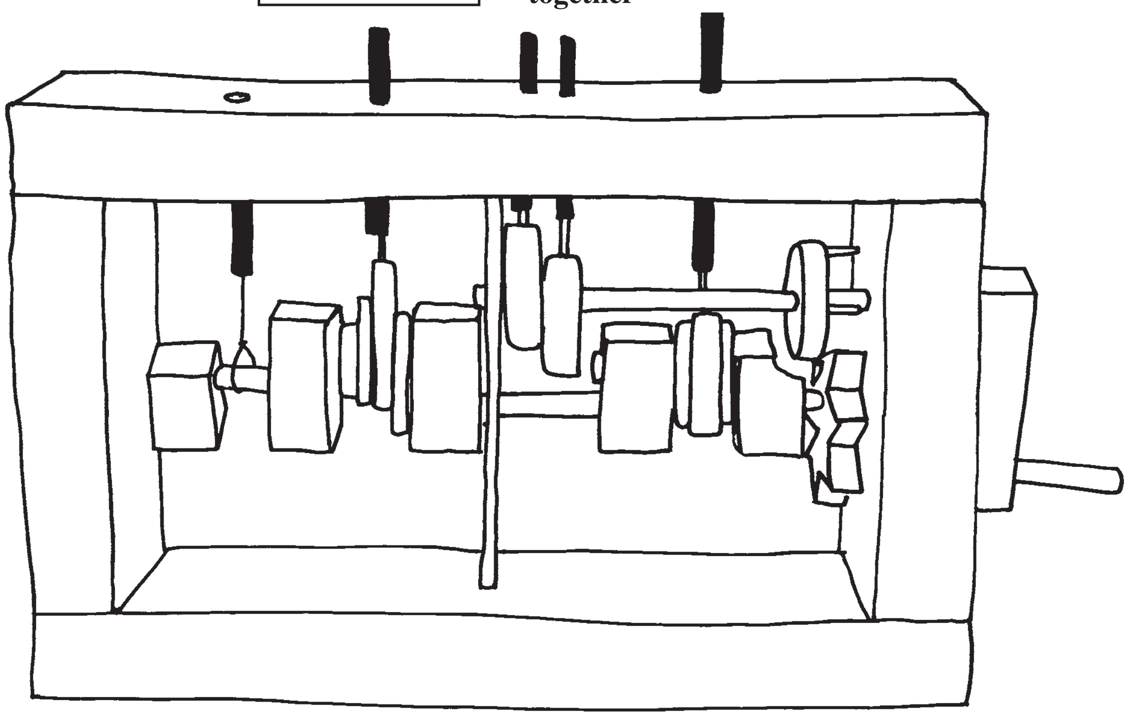
DESIGN & CONSTRUCTION

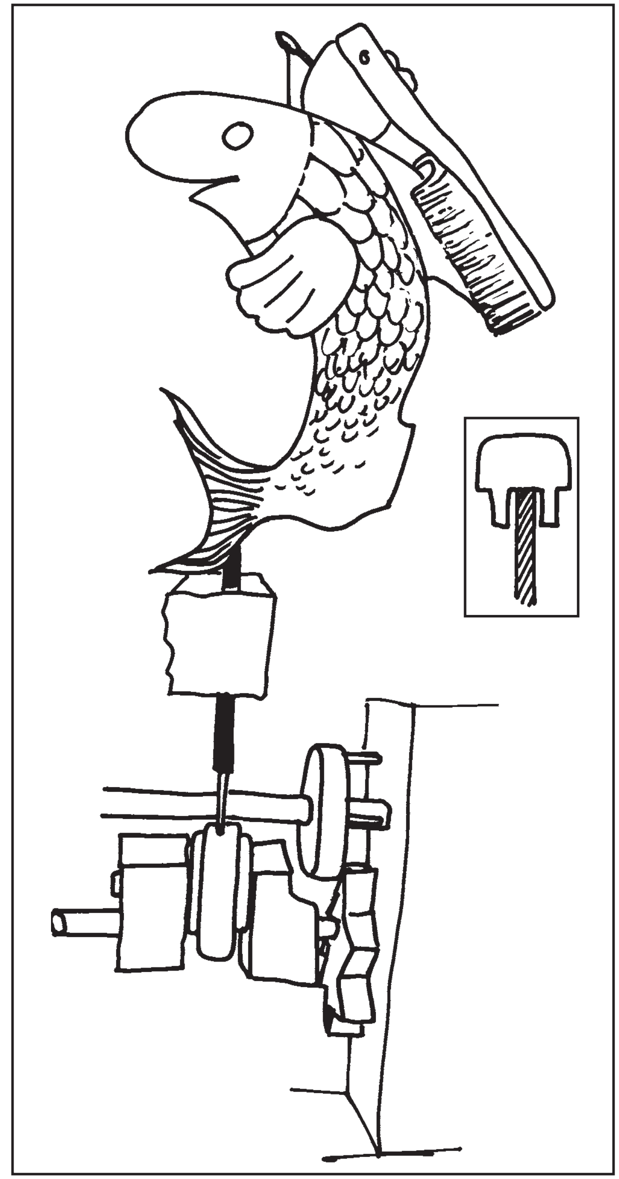
The duck
The duck needed to give the impression of bobbing up and down as if on choppy water. Two cams on the input shaft (for speed) were placed next to each other and offset, giving a nice bobbing motion.



The fish
The fish needed to give an impression of scrubbing his back, requiring a back and forth movement. The best way to do this was by pivoting the fin and moving it up and down. The brush was then pivoted on the end of the fin. This made the brush's movement fairly flexible. It also needed to follow the contours of the fish's back, so the brush was indented ensuring it stayed in position. A Scotch yoke was used to power the fin.

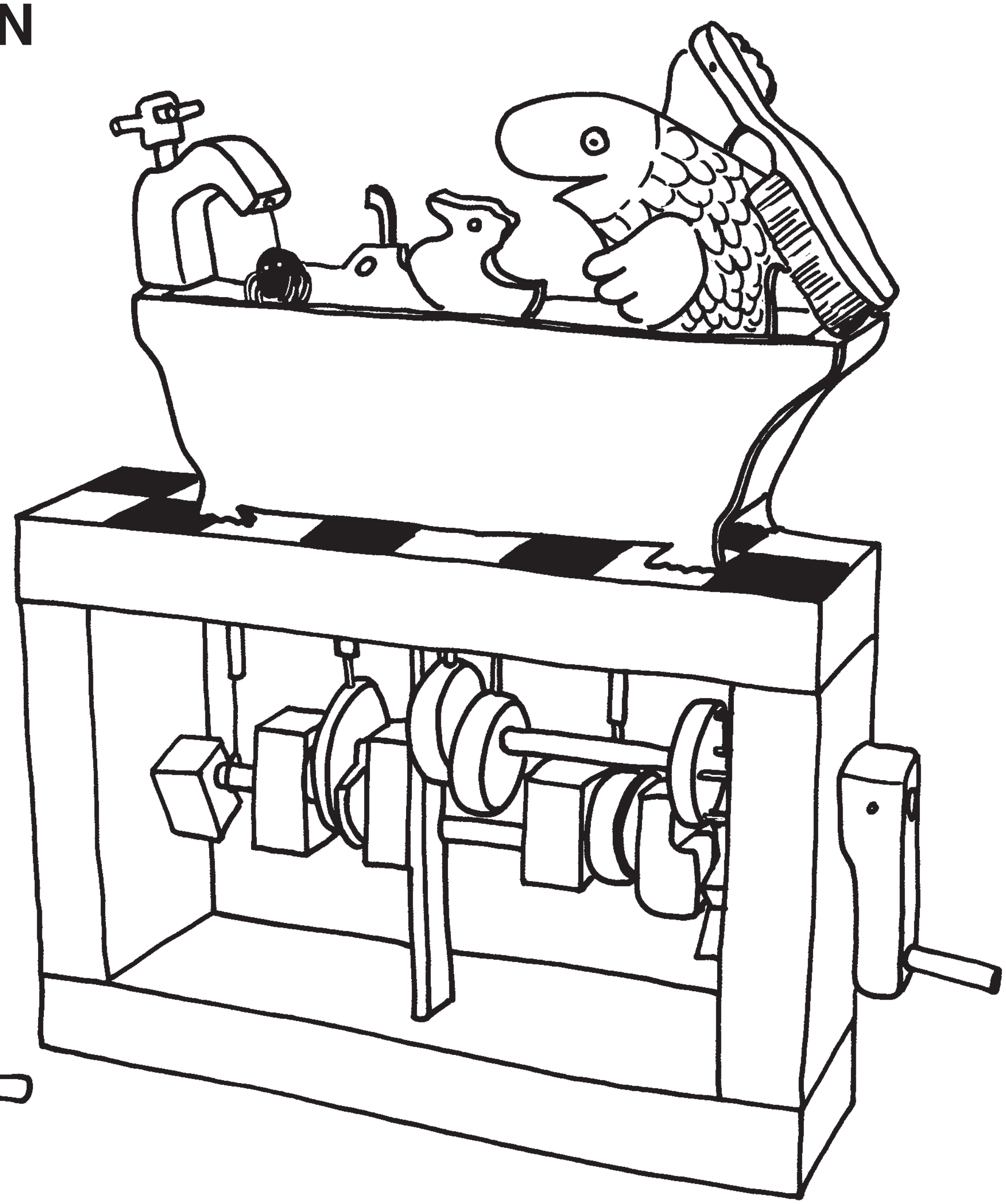
The next step was to put all the mechanisms together



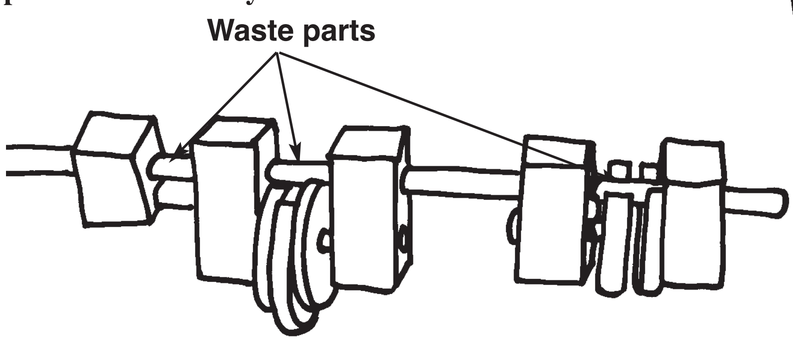


DESIGN & CONSTRUCTION

All the mechanical problems have been resolved. A working model made in wood was adapted for the final automata. The working model showed that the brushing movement was sufficient, but not really convincing. A crank with a longer throw was therefore substituted. The other objects, duck, spider, fish and submarine were all fine, however the second output shaft had to be cut and supported half way along. This was because it jammed the submarine and spider mechanisms something totally overlooked at the design stage. A gear ratio of 3:1 was used to both slow down the movement of the fish and also to add contrast to the fast bobbing duck. Overall this has been a success.



The illustration below shows the main crank shaft. It was made with the shaft running through the cranks which kept everything straight whilst the glue set. Then the unwanted parts were cut away.

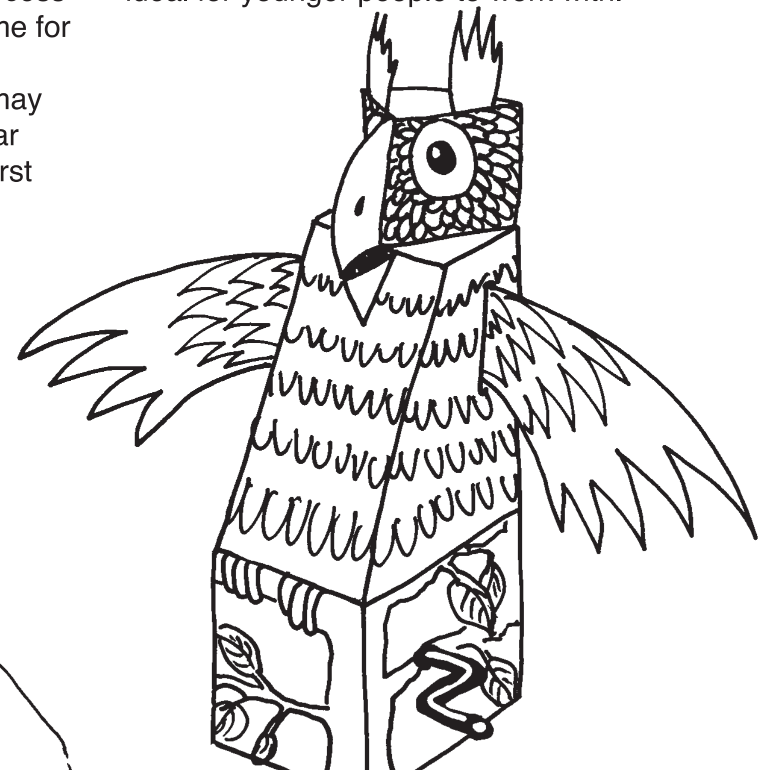


DESIGN & CONSTRUCTION

The last automata we looked at was fairly complicated, involving several mechanical components. If you break things down and do not try and be too ambitious, most things are achievable.
I hope you have found this section on designing helpful, especially those people using this book as part of the education curriculum and who need to help their students to document the design process.
While it really does pay off to do things thoroughly, as you get more experienced you may well find yourself going straight into the final work without making a working model.
There is a wealth of inspiration for ideas, but like most creative activities you may find starting a bit of a stumbling block.
Be prepared for things to go wrong with your first few automata and do not be disheartened. Even experienced makers still have disasters every now and then, but learn so much from these attempts so that successive automata are much better.
Personal experience has shown how frustrating those early attempts can be. Even the simplest automata will need a bit of fine tuning.
If younger people are making automata, it is vitally important that they do not try anything too complicated, as failure will quickly lead to frustration and lack of interest.

The other thing to mention is the amount of time it takes to make an automata. It will surprise you just how long the whole process is, so do not rush, and allow plenty of time for planning and making.
There are many skills to learn and you may find you have to use a range of unfamiliar tools. Also you may be working for the first time with wood and metal.

Do not overlook the properties of card, there is not much it can not be made to do, and it is ideal for younger people to work with.



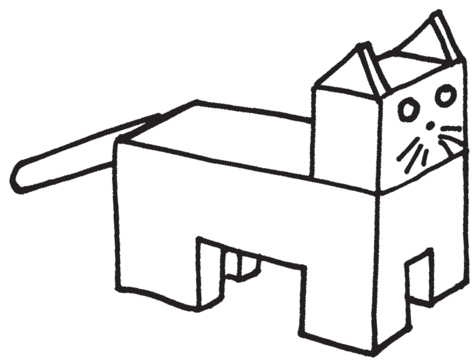
This automata is made from thin card and is very strong. It was also easy to cut out and glue.

The automata on the left used both wood and metal in its construction. The tall buildings and cars were all made out of thick card.

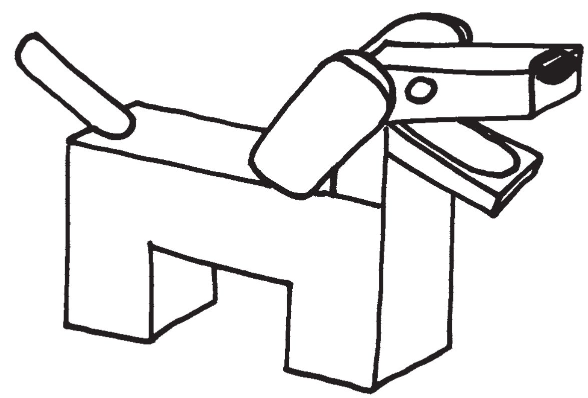
AUTOMATA FOR YOUNGER PEOPLE

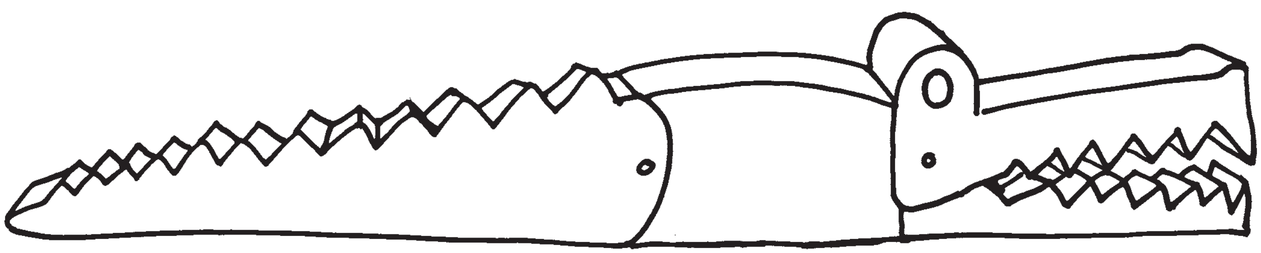
Possibilities, Problems and Solutions
This section looks at the possibilities, problems and solutions for younger people making automata. It is important to start by stating that you should never underestimate the capabilities of young children. However, do not encourage them to tackle too complex or ambitious work at the start. This is because children, especially younger ones, can have an over-abundance of natural enthusiasm, which needs careful guidance. Properly channelled they will be inspired and enthralled with the automata they make. Repeated failures, or work that doesn't meet expectations, will soon leave them uninterested in the whole process.
Personal capabilities differ for every child, and many factors, such as manual dexterity, concentration or artistic ability will have a bearing on their level of skill. So as a guide this section is divided into 2 age categories: **5-7** and **7-11**. There will obviously be some crossover between the two, but splitting them helps to identify key skill areas within each group.

Younger Children 5-7
The design process was covered in some detail in the previous chapter, and this needs to be simplified for young children but can be used as the basis from which to start.
Many factors come into play with younger children in this age group (manual dexterity and conceptual awareness of the design process are, for many, likely to be fairly limited). Help and encouragement from adults, teachers and even older brothers or sisters will help them to achieve a higher level of success.



Inspiration and Research
Animals are a great starting point for younger children. They can start by cutting out animals from magazines and sticking them down on an "Ideas Sheet". You may want to theme this i.e. farm animals, dogs, cats, or be able to coincide this with a trip to the zoo. The best approach is to focus on some aspect of the animal kingdom and then look for key movements such as a snapping crocodile, kitten chasing its tail or frog jumping.
When it comes to designing, stick to the very simple mechanical movements such as cams and cranks. These will still produce a range of exciting actions. Making the animal forms should also be simplified and either kept flat or constructed from simple shapes.





AUTOMATA FOR YOUNGER PEOPLE

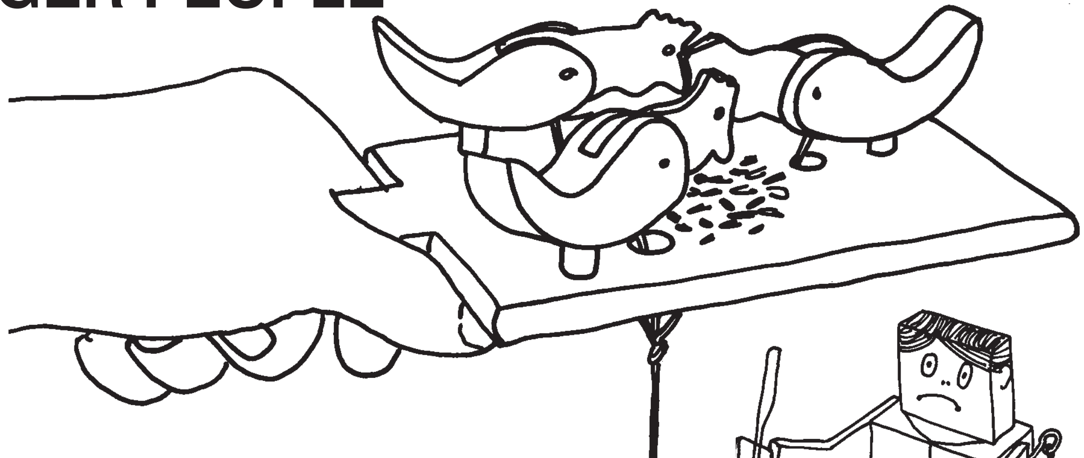
Getting results fast

Young children want results fast, in order to keep them interested. You may decide to skip a working model and go straight into the final work. This can result in some fine tuning being needed to get things working properly. You should test each component as it is made so all the parts should work when combined together.

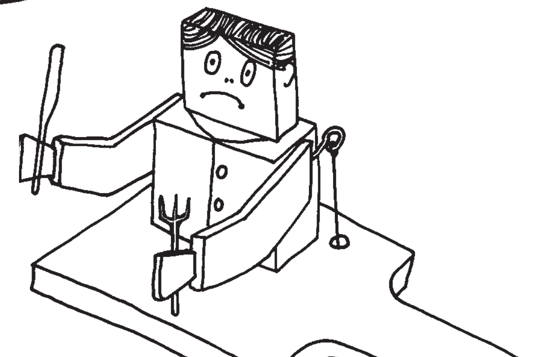
Working with card and paper is recommended as these materials are easily cut and worked. Household packaging is very useful; toothpaste boxes, plastic bottles and drinks cartons, for example, can all be used to construct bases or animals. Simple origami animals can also be very effective when incorporated into automata.

You may find that for very young children even simple cranks and cams may be too complex, so push-pull mechanisms can be used instead. Pecking chickens are an a old favourite and rely on weight and gravity to produce movement. Pulling the string on a simple figure makes the arms and legs move and is a very simple way of producing and learning about movement. This is an area well worth exploring, and can be easily adapted for many things.

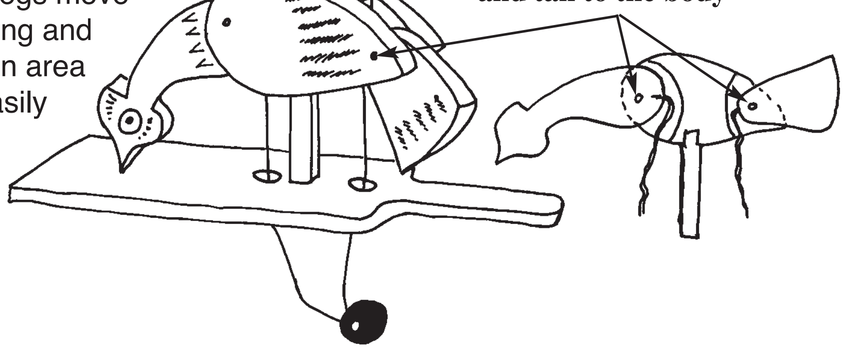
The following automata make use of linkages and levers to create movement.



This simple mechanism is very versatile. As mentioned, the pecking chickens are an old favourite, but you can adapt the movement to most things. In fact, you can replicate the action of a simple crank, without having to make any mechanical parts. It is this simplicity and adaptability which makes this a great starting point for young automata makers.



The hungry diner is thumping his knife and fork as he waits impatiently for his dinner

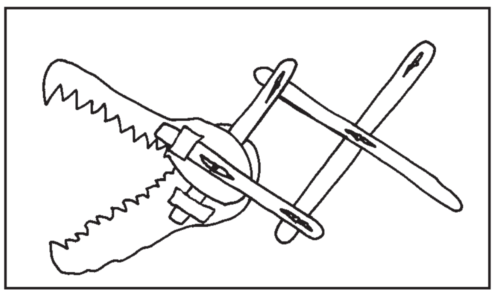


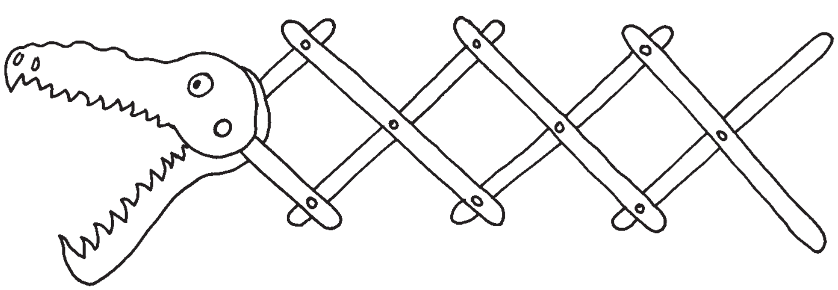
Pin attaching the neck and tail to the body

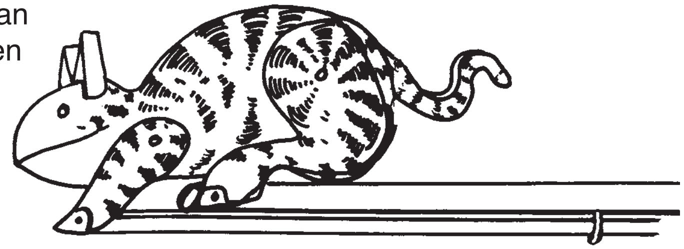
The trick when using this technique is to make sure that the parts you want to move are pinned in such a way as to allow gravity to pull them down. It is also important that they can move freely. In the example to the left you can see that that the pin is placed close to the string, the neck of the chicken is quite long and so dips down, the swinging weight then pulling it up. The weight should be fairly heavy; a large nut or wooden ball works well.

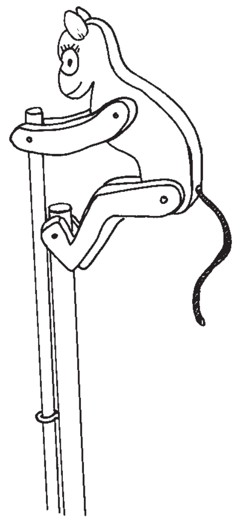
AUTOMATA FOR YOUNGER PEOPLE

Using lolly sticks or something similar you can create a scissor like action that extends when the ends are squeezed together and contracts when opened. This simple device is easy to make and is very effective. The more sticks that you use, the greater the reach and more dramatic the action. The example below is made from lolly sticks that have been drilled to allow split pins to join the sticks together. Two separate jaws are centrally hinged and taped on each end, which will create the snapping action. This could be adapted for different animals. You can substitute thick card or art straws for the lolly sticks.

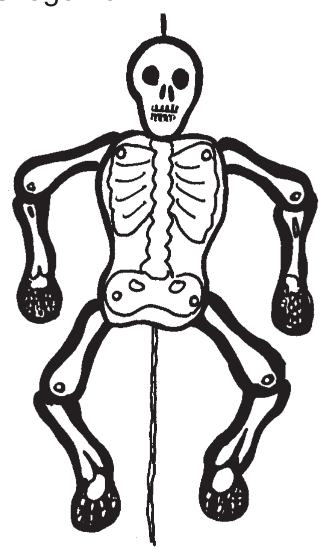


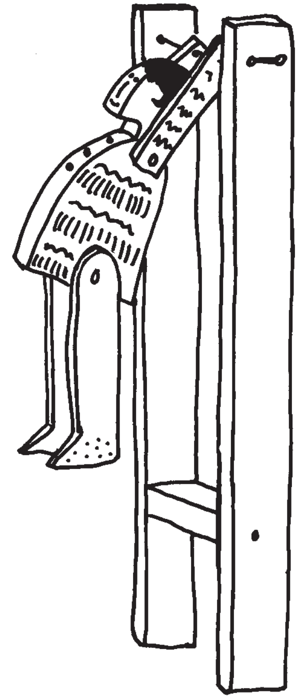


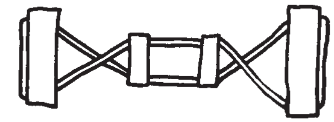




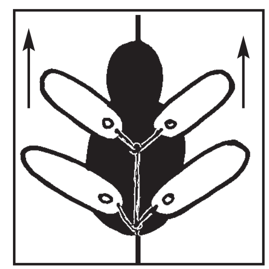
The cat and monkey work by placing two sticks of wood of slightly different lengths on top of each other. The characters are hinged at the ends and when the sticks are slid back and forth the animals leap up and down. A simple eye- screw is used to guide and hold the sticks together.

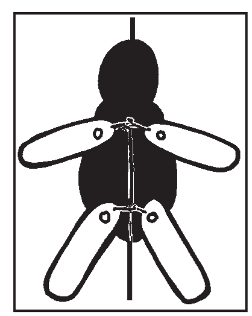






This toy uses elastic threaded through two sticks and then crossed through the character's arms (see above). When the lower ends of the sticks are squeezed together the elastic stretches and twists which makes the acrobat leap up and down depending on the pressure applied.





Jumping Jacks can be made from wood or card. When the string is pulled it makes a single jerky movement, pulling the limbs up, and then when you let go gravity pulls them back down. The simplest way to construct one is to use card and split pins, making sure that everything can move freely. The diagram on the left shows how to thread the cord.

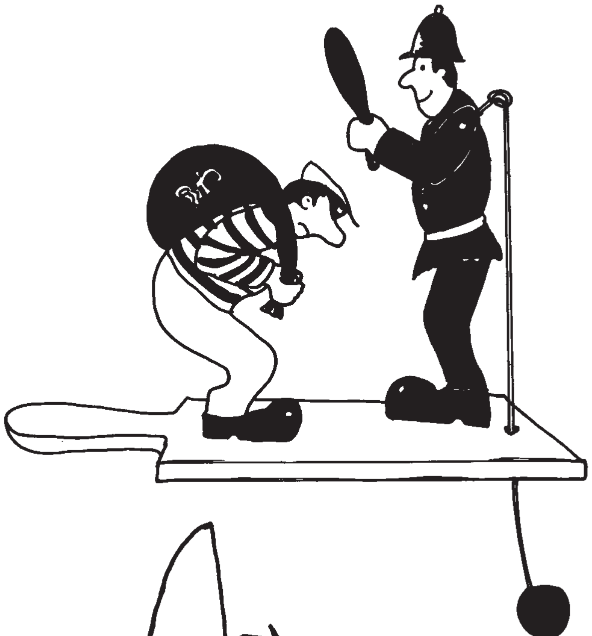
AUTOMATA FOR YOUNGER PEOPLE

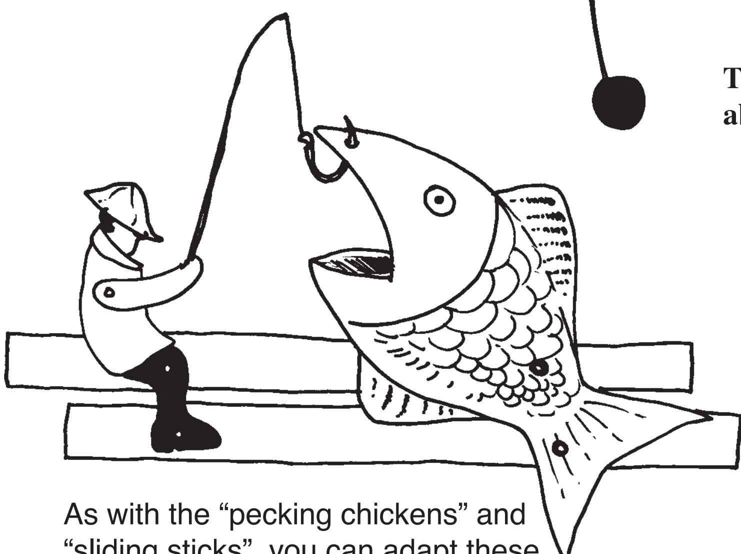
Older Children 7-11
As children get older their comprehension and dexterity improve. A consequence of this is that individuals are able to undertake more complex tasks. They still need a little supervision, but should be able to play a much more active role when making automata. As with younger children, it is suggested that they take ideas from the animal kingdom and use them as the basis for the first couple of automata they make.
Then look at the child's interests for inspiration; football, cars, dinosaurs, horses etc. Remember to keep things simple. Older children tend to be far more ambitious with their ideas, and may need help in scaling things down to achievable levels. It is important to negotiate and explain why an idea needs modifying. Children must feel that they are playing an active role and not just being told what to do.
You may also want to start working, in part, with resistant materials, especially with 10-11 year olds. You will also find that older children are able to work through the design process, but keep it within their scope and make it as enjoyable and interesting as you can.
Encourage them to research and design their own automata. The drawings may be crude but they will feel they are part of the process and in control.

You will probably have to "down size" initial ideas, but this can be negotiated and used as part of the design and evaluation process.
Children enjoy drawing and find it comes naturally. Making and painting things is a little more difficult as they are not everyday activities. It takes time to make even the simplest of automata, so try and break things down into stages rather than trying to complete them in one session.
As with younger children, you may find working in card easier to begin with.
Recycling old household objects and packaging also offers many possibilities.
Balsa wood is another malleable material, which can be easily and safely cut and sanded into shape. Although fairly soft it can be used successfully to make the casing to house simple mechanisms.

Mastering Mechanisms
Cams and cranks offer the best mechanical principles for this age group. They can produce a wide range of movements, yet are still relatively easy to make. Simple gearing or pulleys could also be introduced for more ambitious and able students. This allows for more complex actions to take place, and can help slow or speed things up. Again, simple materials can be used such as wooden dowels, art straws and lolly sticks.
Papier-mache and "mod rock" make good modelling materials and offer a lot of scope.

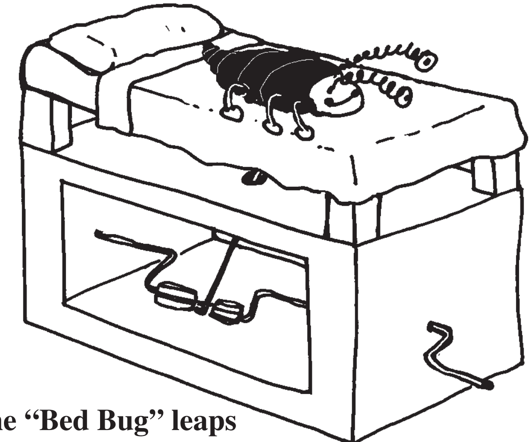
AUTOMATA FOR YOUNGER PEOPLE



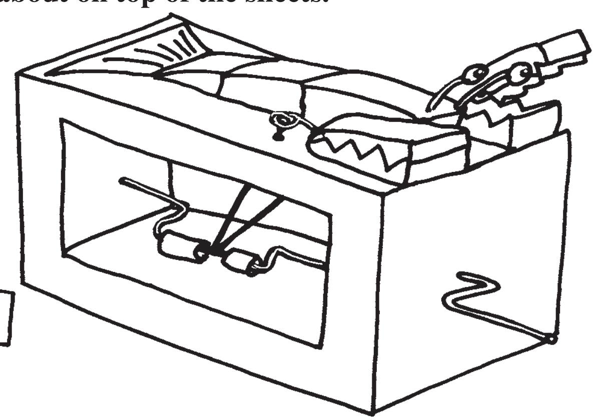


As with the “pecking chickens” and “sliding sticks”, you can adapt these mechanisms to make more sophisticated automata. They are still easy to make, but offer more creative scope.

A simple crank is a good mechanism to start with. It can be adapted in many ways to produce exciting and lively movement. You can make all these automata out of card and wire.

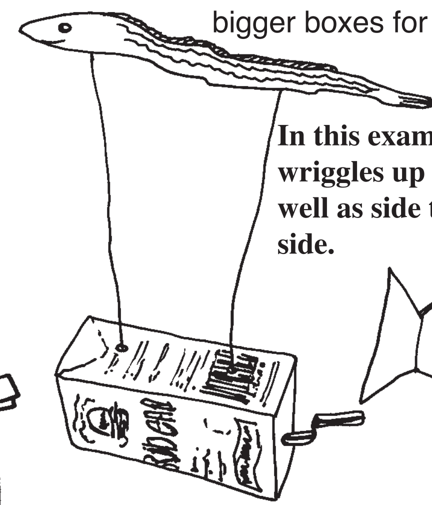


The “Bed Bug” leaps about on top of the sheets.

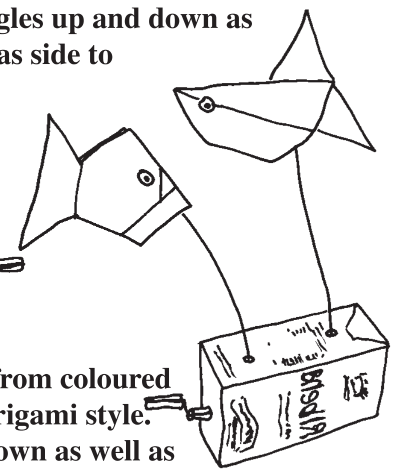


This snappy lobster makes use of 2 cranks that alternately pull the claws open. This could be adapted to the pendulum mechanism

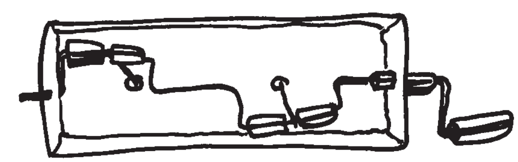
You can make good use of household packaging. The recycling is a very positive aspect. The automata below use a small drinks carton to hold the mechanism. Florist’s wire is used to make the crank and handle, while a drinking straw has been cut for use as spacers to keep the crank pins in place and make a handle. You can adapt this to use bigger boxes for larger automata



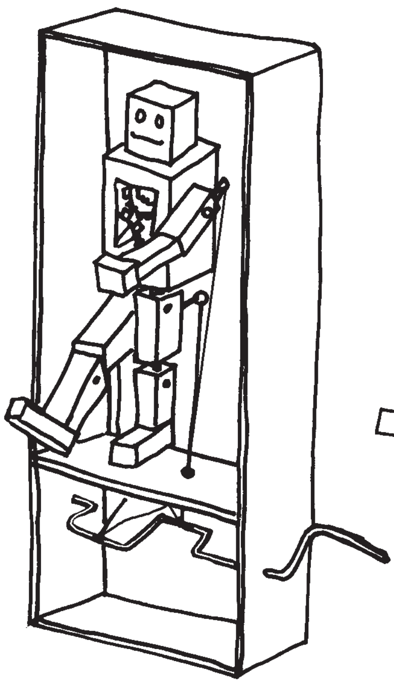
In this example the eel wriggles up and down as well as side to side.

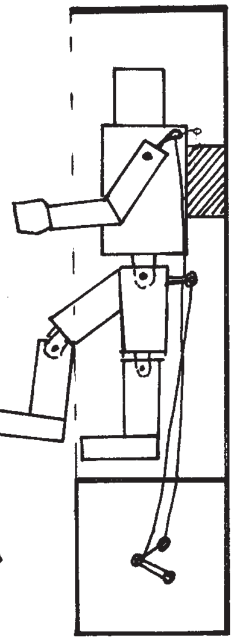


The fish are made from coloured paper and folded origami style. They bob up and down as well as side to side. Below you can see the mechanism inside the drinks carton. It is very simple and effective.

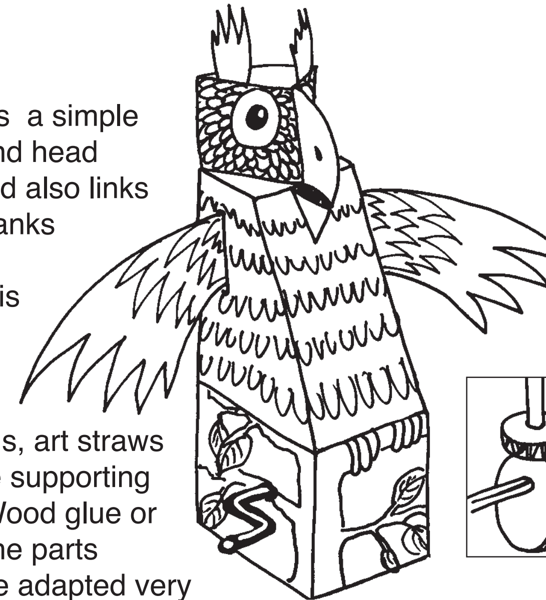


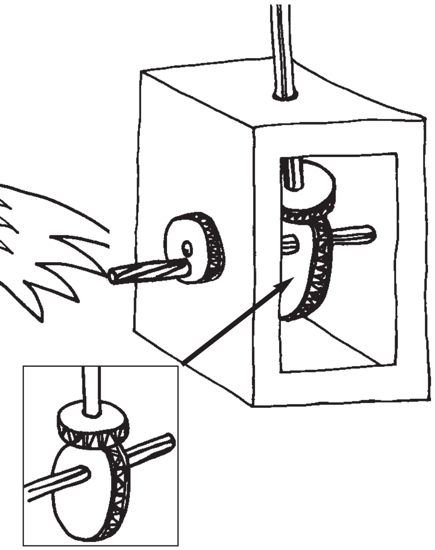
AUTOMATA FOR YOUNGER PEOPLE





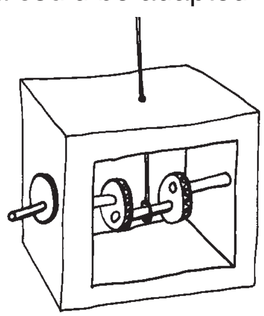
The automata on the right uses a simple cam to make the owl's beak and head snap up and down. The con rod also links the wings, which act as bell cranks and give the appearance of flapping. This entire automata is made from paper and card.
The lobed cam is constructed from thick corrugated card. As with cranks you can use pencils, art straws or wooden dowels to make the supporting shafts, cranks and con rods. Wood glue or PVA can be used to stick all the parts together. This automata can be adapted very easily to make other birds such as Penguins or Parrots, and even animals or people.

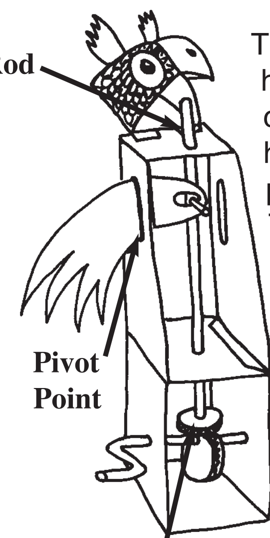




The lobed cam above is made from corrugated cardboard. The base is made out of a cereal box.

The robot, above, again makes use of a cardboard box (the robot is also made of card), with a simple wire crank that lifts his legs and arms up to give him the appearance of walking. This automata could be adapted to other characters, and you could even have 2 or more figures moving.
You can make a stronger crank out of thick corrugated card and use pencils for the shafts.

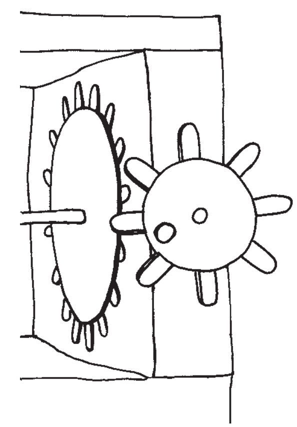




This illustration shows you how the mechanisms are constructed. The head is hinged at the back and is pushed up by the con rod. The wings are slotted through the body (which acts as a pivot) and are attached to a rod that is in turn connected to the con rod. This provides the lift for the wings. Both the head and cam follower are assisted by gravity which provides the downward force.

Gears

Older children can be introduced to the principals of gearing. They can make very effective gears out of lolly sticks, pencils and wooden dowel stuck to cardboard. The example on the right uses a ratio of 2:1 The driver has 8 lolly sticks whilst the driven gear has 16. (This means that the driven gear's circumference will have to be twice that of the driver gear.) This sort of gearing is very simple and fun to make.

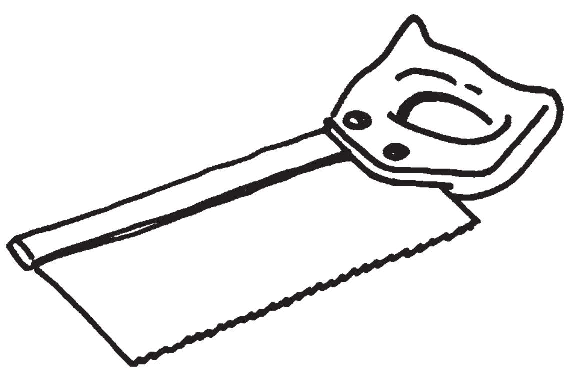


TOOLS & EQUIPMENT

TOOLS

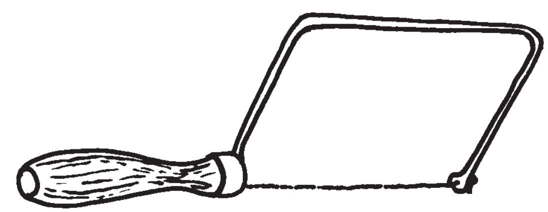
You don't need a vast range of tools in order to make automata but there are a number of essential items you will need to work with. Power tools are great labour saving devices, but all the hand powered equivalents work well and can be better to use especially when working on small scale pieces. Below is a list of useful tools to have when working in resistant materials such as wood, metal or plastic.

Tenon saw
A tenon saw is a good tool to cut wood. It has a fine blade which cuts both hard and soft woods very cleanly. It should be used in conjunction with a wooden mitre, which helps to hold the wood firmly and lets you cut accurate straight or angled lines. The tenon saw has a metal seam running along the top of the blade this gives it strength but also limits the depth of cut to about 10cm. The tenon saw should handle most small scale jobs and is essential.



Wood Saw
A small wood saw with a 12 inch blade and rough teeth (which gives a rougher cut) is capable of cutting to any depth and is much easier to use on larger pieces of wood. This again is an essential item.

Fret Saw
This saw has a very fine, thin blade which is kept under tension so that it can not bend. The saw frame is deep, enabling you to work on larger pieces of wood. The fret saw is mainly used for cutting out intricate shapes and patterns. The blade is thin, so it is capable of turning very sharply, giving it extra versatility. It is useful for cutting out shapes such as animals in ply wood. A fret saw can be used on both wood and metal (using special blades) and is also essential.



TOOLS & EQUIPMENT

POWER SAWS:

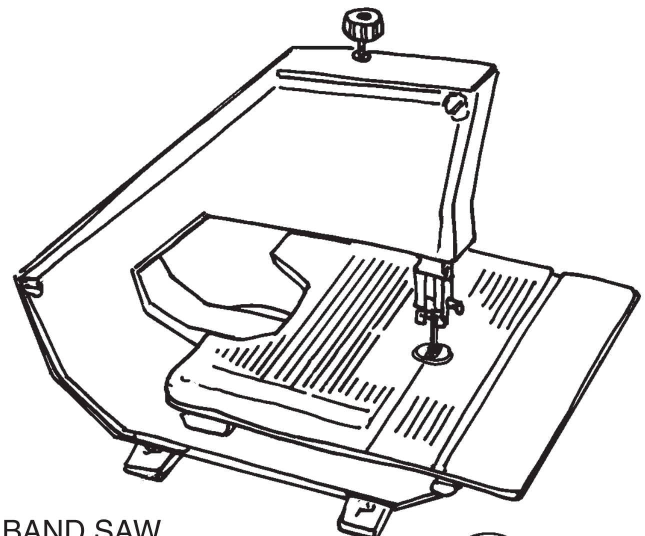
Power tools are great labour saving devices and can considerably reduce the time it takes to make automata. However, they do demand a great deal of care and common sense when being used. Power saws are the most dangerous tools to work with as mistakes can be very harmful. **When working with power tools always wear safety goggles, and keep jewellery and any loose clothing or articles away from moving parts.**

BAND SAWS

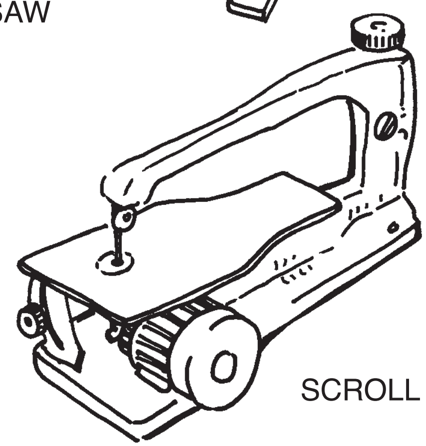
The band saw is a very versatile power tool. It enables you to cut wood in a very straight line (with the use of a mitre), and there are attachments to enable you to cut circles, or even turn it into a scroll saw. When used with a narrow blade you can cut curved shapes and, with care and practice, quite intricate shapes can be cut out of wood, plastic and even thin metal. It is not really practical for using on small work .

Band saws come in all shapes and sizes and are often referred to as two or three wheel types. This refers to the actual wheels the blade rotates around. Many come with variable speeds, which is useful when cutting materials such as perspex that need to be worked at a slower blade speed to stop it melting and rejoining.

The band saw is a very useful tool to have and small relatively inexpensive ones are available from many tool suppliers. Although for the serious automata maker they are useful but not essential. Children should never use one. If you do not like the idea of working with a band saw then stick to hand saws.



BAND SAW



SCROLL SAW

Scroll Saw:

The scroll saw has a very fine blade that is powered up and down at about 1400 rpm. It is the power version of the fret saw and can cut very intricate shapes, even to quite a small size.

As with any power tool, avoid getting your fingers too close to the moving parts. The scroll saw is quite forgiving (unlike a band saw) but should still be used with care. When operating a scroll saw your fingers are often very close to the blade and it is important not to push them into the front of the part which has the cutting edge. However, an accident with a scroll saw is unlikely to cause a very serious injury. It is this comparative safety that makes them popular in schools and suitable for older children to use if closely supervised.

The scroll saw can be fitted with a range of blades and can cut wood and metal up to two inches thick. They are extremely versatile and useful labour saving devices. A real must for the serous automata maker.

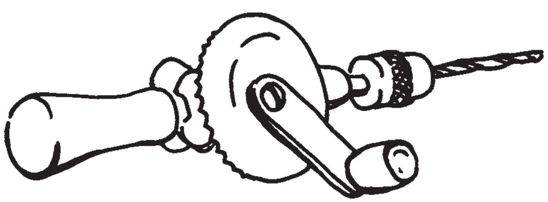
Check the web site www.automata.co.uk for details of our training video.

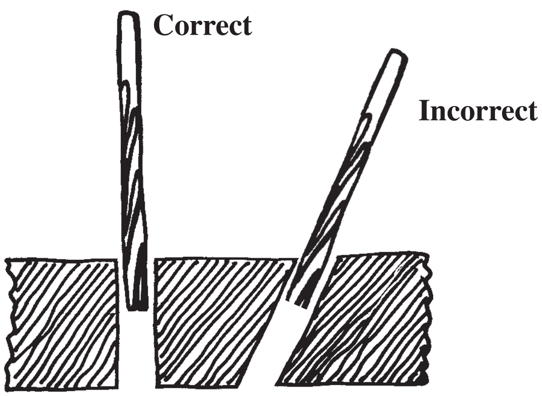
TOOLS & EQUIPMENT

DRILLS

Hand drills

A good bevel gear hand drill will give you lots of control, and is an essential item to have. You do not often have to drill deep holes when making automata, so hand power is not too exhausting. The trick to using a hand drill (in fact any drill) is to try and keep the drill bit (that's the the part that does the cutting) as vertical (90°) to the work as possible so that the hole is straight. This can be a little tricky with hand drills, as they tend to wobble a bit when you turn the handle.

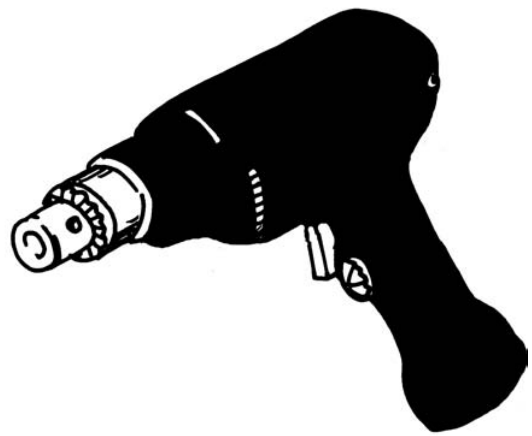




Try to keep the brill bit as straight as possible to the work.

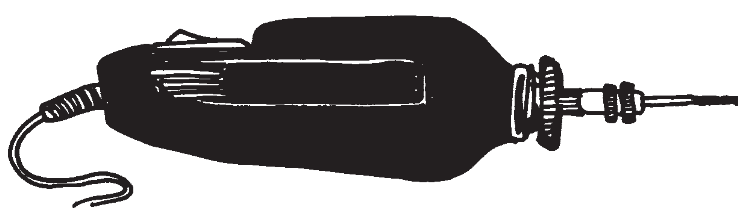
Power hand drills

Power drills are really a little too big and fierce, especially when working on smaller pieces. However, smaller battery powered ones with variable speed control can be useful, and are much safer to work with.



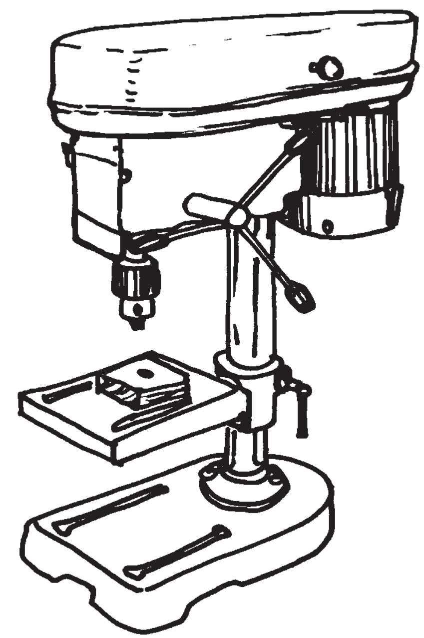
Mini Drills

Variable speed (12 volt) mini drills used by model makers can be very useful. They take a range of specifically made accessories for cutting metal, grinding, polishing, as well as very fine drill bits. I find them particularly useful on small delicate work. Their big advantages are size and controllability.



Pillar Drills

The pillar drill normally has five speeds which are changed by repositioning the drive belt onto different size pulleys. They are operated by a handle that pulls down the drill bit. This gives you control over the depth of hole as well as a straight vertical cut. The work can be held in a vice which increases safety. The pillar drill is a very versatile power tool, which can be purchased for a very good price (similar to that of a powered hand tool - but a much safer alternative). A must have item for the serious automata maker!

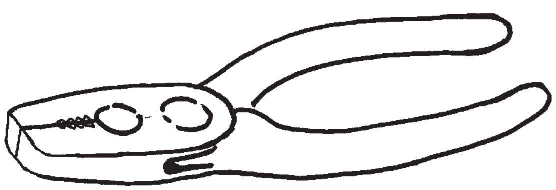


TOOLS & EQUIPMENT

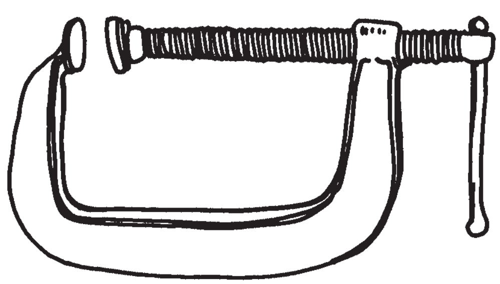
When working with resistant materials you will find it useful to have a range of small hand tools.

Long Nose Pliers

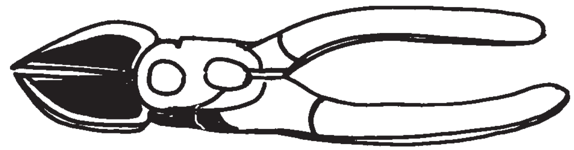
Short nose pliers



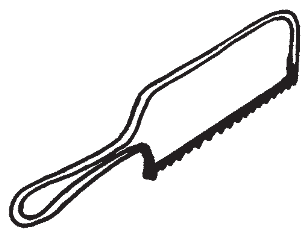
G clamps



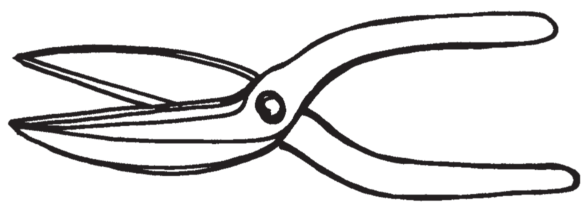
Wire cutters



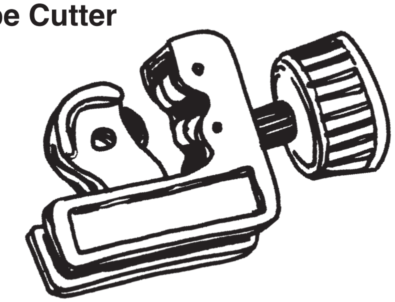
Junior Hack Saw



Tin Snips



Small Pipe Cutter



You can make working prototypes of your automata or even finished work using card. Below is a list of equipment you will find useful to work with:

Large and small pair of scissors

A scalpel or craft knife

A steel rule, with a handle that keeps your fingers away from the edge

General items that you will find useful are as follows:

A compass

2B Pencil

Rubber

Masking tape

Rubber Bands

Sellotape

Wood glue (this can also be used on paper and card).

Mitre Square

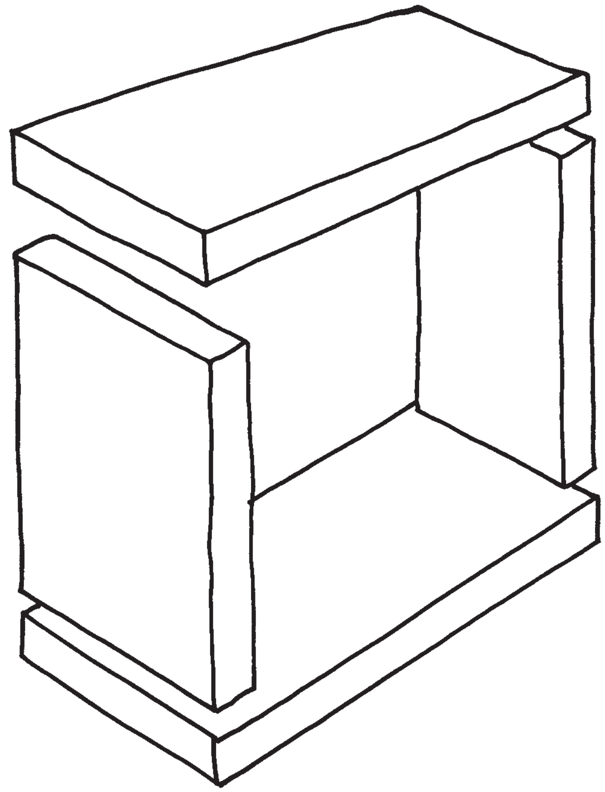
Protractor

CONSTRUCTION

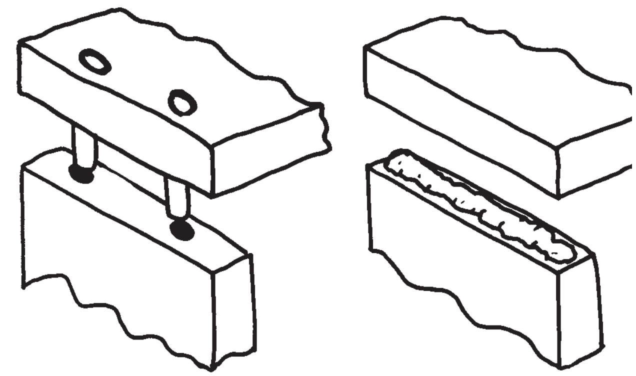
An open sided wooden box is an ideal housing for automata mechanisms, and is very simple to make. You will need to work out the length and depth needed, then simply glue together, placing the ends onto the base and then the top. Wood glue sets fairly quickly, so you only need to put pressure on the pieces for a couple of minutes before letting go, or you can g-clamp them in position.

You can vary this design; if you are good at wood working you may want to dovetail joint the box to give it a professional look. Alternatively you may want to use wooden dowels to pin the sides together. Whatever construction method you use, this simple design is a good starting point.

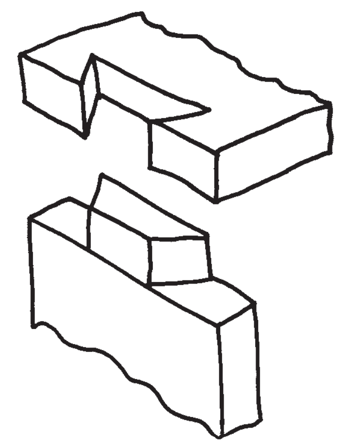
6mm pine is a nice wood to work with. You can, of course, use whatever is to hand, even plywood and thick balsawood will work. Fairly thin wood can still be alright especially for smaller automata but, as a rough rule, the larger the automata you make, the thicker the base needs to be in order to support the mechanisms.



A simple 4 sided box makes an ideal housing for an automata mechanism. You can make it out of a range of materials such as cardboard or wood.



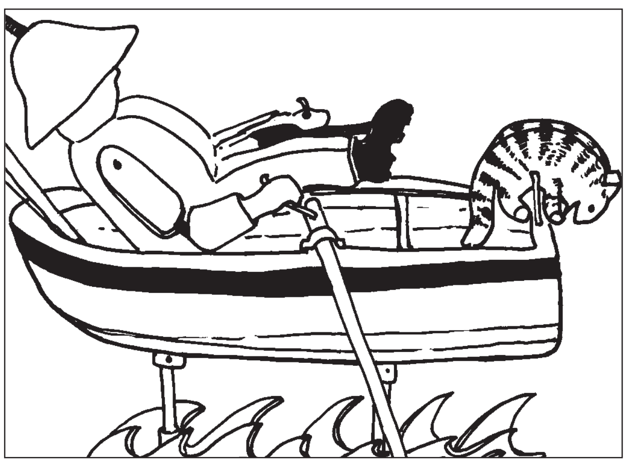
To join the pieces together and to make a strong joint use wooden dowels, wood glue or both.



If you are good at woodwork you may want to make simple dovetail joints to create the box.

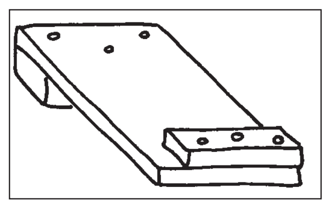
CONSTRUCTION

Cams, gears and figures
Most components can easily be made out of pine. It is a lovely soft wood, easily shaped and sanded which is very useful when modifying your cam's shape. 6mm thick pine is fine for constructing most cams. Avoid wood with knots on the surface, these cause problems when cutting. Do not use MDF as it produces a harmful dust when sanded or cut. Plywood can be useful for making cams but is most suitable for figures such as animals, people or dinosaurs. It comes in a range of thicknesses, also referred to as "plys" or layers. 3ply is the thinnest you can get. It is worth working with a quality plywood as cheaper ones tend to splinter very easily.

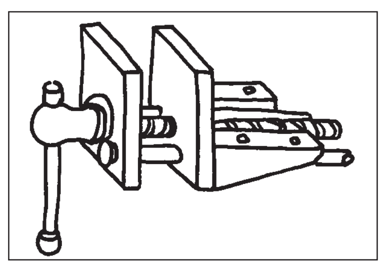


You can use a combination of woods to make different parts of an automata. In the above example the boat, cat and waves were made with plywood whilst the fisherman was made out of lime

Plywood is made by gluing strips of wood together with their grains running in opposite directions. This gives it tremendous strength; the more layers it has, the stronger it becomes. For making automata, the outer wood face should be of a high quality such as beech. This will give you a much better finish. The inner sections are often made of cheaper wood. When cutting small intricate shapes a poor quality plywood can break or split, and small pieces of the inner layers can fall out. Because of it's construction plywood is very strong, this also makes it tough to cut. Hand saws are fine on the smaller thicknesses but thicker wood may need to be cut with a power saw, if you want to produce more intricate shapes.

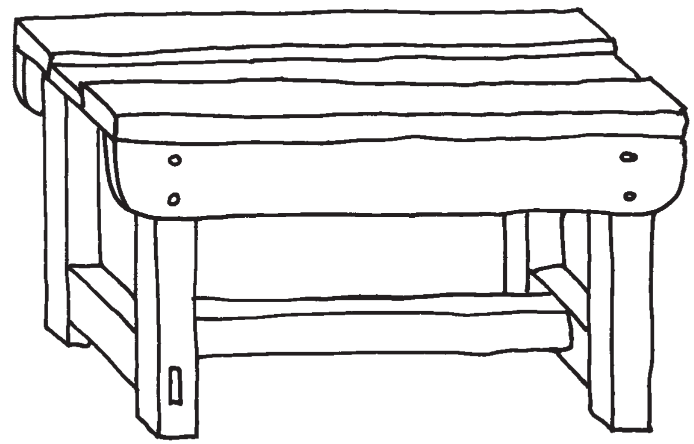


Bench Hook



Workbench Vice

If you want to produce more detailed work (which may involve whittling or wood carving), then lime is excellent to work in as it is reasonably soft but holds a good edge. This allows you to put in very small details. More complicated characters are often made up of several types of wood.
If you are carving wood then make sure that you always cut away from yourself and hold the work squarely in a vice. It is worth reading up on the subject and there are many good books on wood carving for the beginner.



A work bench offers a safe and convenient place to work when making automata out of wood or metal. You should also use a bench hook or vice to hold work securely when cutting or carving.

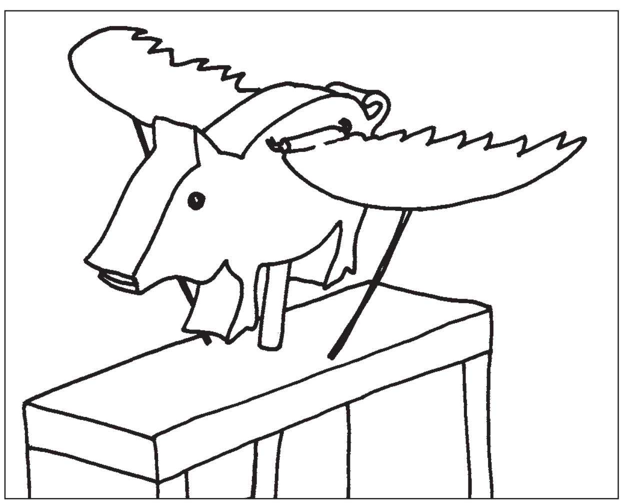
CONSTRUCTION

Working with metals

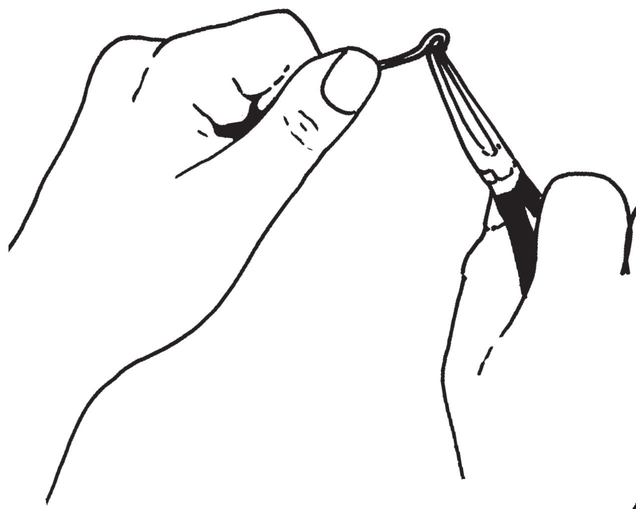
Sometimes you may want to work with metals. Linkages are an example where thin brass rods are very useful.

The most common metals used in automata are copper, brass, tin and mild steel. All can be easily worked and can be joined by soldering or even gluing.

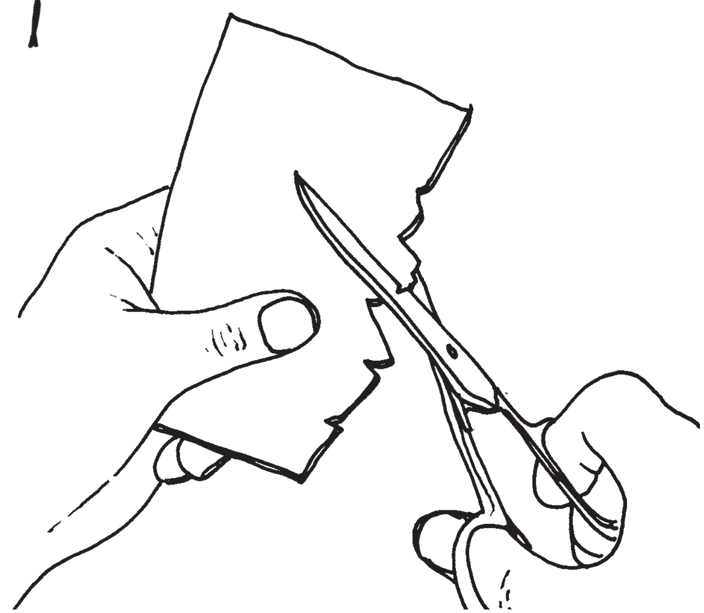
Brass tubes and rods make excellent cam followers; they are easily cut with a junior hack saw or mini tube cutter. Thin brass and copper sheet can be cut with scissors and formed into shape. The flying pig’s wings were made from brass sheet. It is a very quick and effective way of putting detail into your automata. I use brass for much of my own work. It is easy to bend, cut or solder and has a lovely bright finish.



Brass wire comes in many thicknesses. 2mm is excellent for making linkages, as it can easily be bent with long nose pliers to make hooked or circular ends.



Brass and copper tubes and rods come in all sizes. Square rods and tubes are very useful, as they can stop the turning action of the cam and follower which you get with round tubing. Whichever tubing you work with make sure that the inner rod moves freely. Use graphite as a lubricant, not oil, which causes the mechanism to drag. Metal to metal contact is fine. Most automata work at a slow speeds and under fairly light loads, so friction will not be a problem.



Be aware that when working with metal that it can have sharp edges that can cause cuts. Cutting metal can also create sharp edges. These can be smoothed down with emery paper or a metal file.

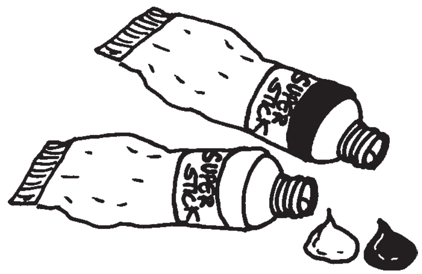
CONSTRUCTION

Gluing
There are a number of glues that work very well for various needs.

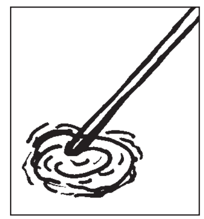
Wood to wood, cardboard or paper:
Wood glue is a great all round adhesive. It dries clear and sets fairly quickly. Paper and card are wood in origin, so it works well with them. There are many different brands on the market; they all seem to do a good job and are readily accessible from most hardware stores. If you can find it professional wood working glue (which is often yellow, and sometimes referred to as aliphatic resin) gives excellent results.

Wood or metal
A two-part epoxy resin is very useful as it dries in about 10 minutes and sets clear. You thoroughly mix equal parts and, when first mixed, the glue is fairly runny. As it begins to set, it gradually becomes stiffer until it eventually starts hardening, When stiff, you can place it on the objects that need joining. Be watchful, as the glue very quickly turns from stiff to set. Give yourself enough time to work, and only mix up as much glue as you can use in that time.
Warning: Two part epoxy resin glues contain harmful chemicals. They should be used with care, and if you get any on your skin, wash immediately with soap and water.

Two part epoxy resin glues are incredibly strong, dry quickly and stick most things. They work very well on metal and wood, and are an invaluable aid to the automata maker.

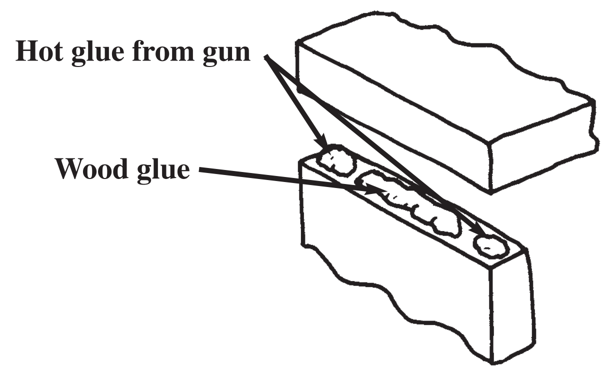


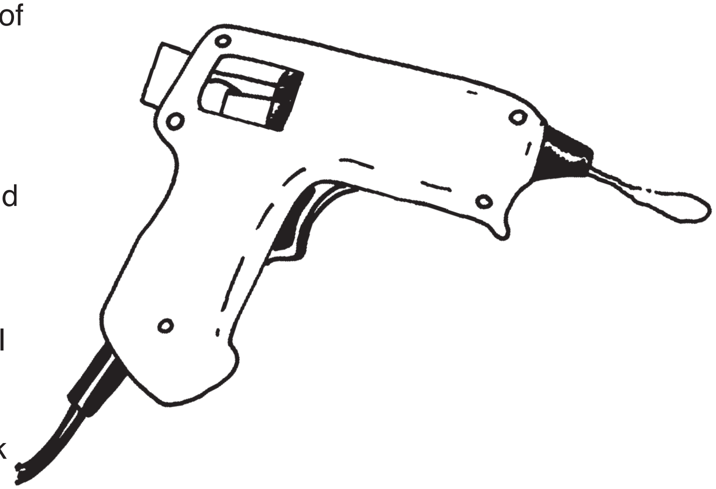
The secret to epoxy glues, is to mix both parts thoroughly and in even amounts. (Always follow the manufacturers guidelines.)



Glue guns:
Glue guns are very useful. They use sticks of ordinary or wood working glue. Be warned the glue is very hot when it comes out and burns if touched. However, It does cool quickly. It will join most materials together, although it does not form such a strong bond as wood glue or epoxy resign.
You do not have much control over the spread of glue, so a trigger type of gun is recommended. This at least lets you control the flow of glue and can be used with one hand. A glue gun will work on metal, wood card and paper, depending on the glue stick you select.

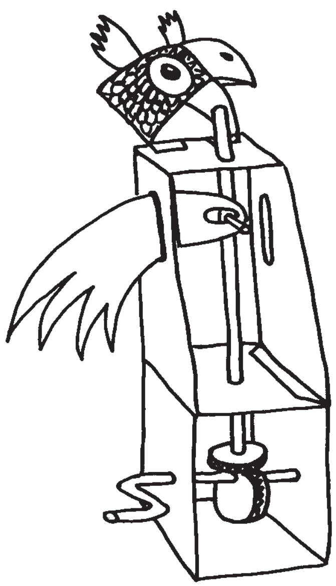
A useful tip for using wood glue (to make a base for example) is to put a few spots of glue down with the glue gun and then use traditional wood glue. The hot glue will dry in about a minute and hold the work whilst the wood glue sets in about 15 - 20 minutes. This will avoid you having to clamp the work.





CONSTRUCTION

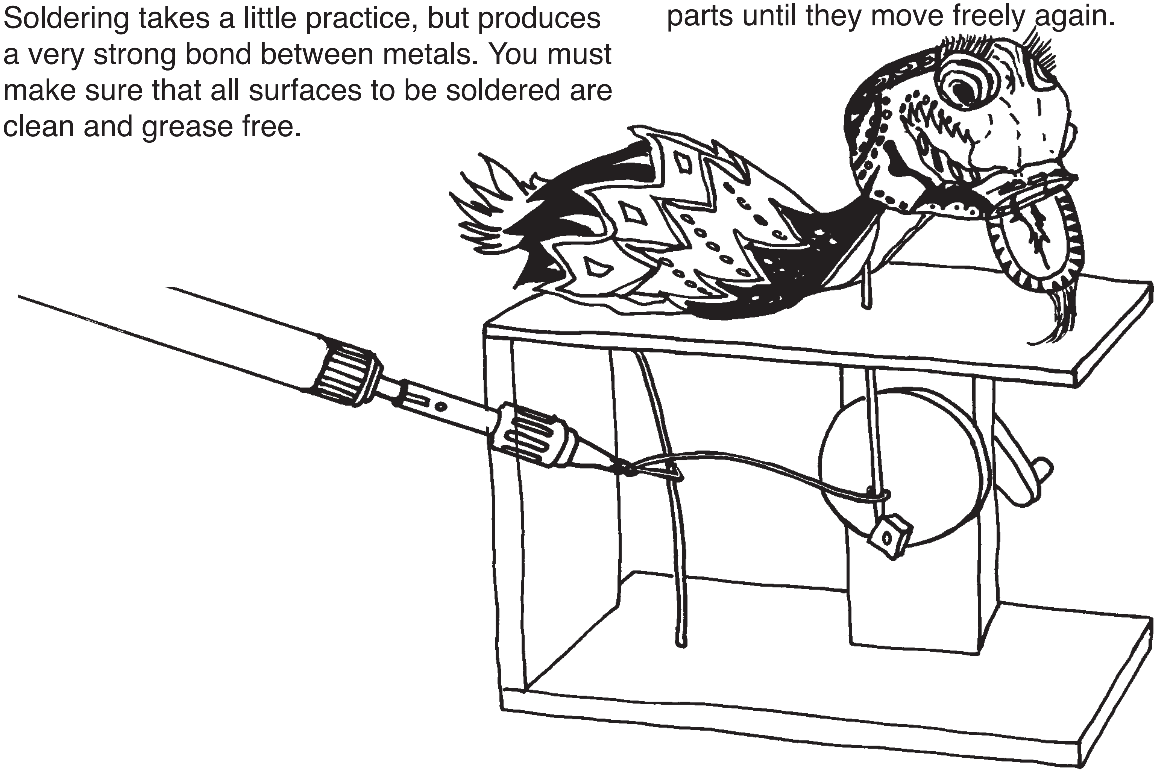
Paper and card glues
Wood glue is excellent for bonding paper and card but is not suitable for children to use. PVA glue is a good alternative. It takes a little longer to dry, but is relatively harmless and safe for younger people to work with under supervision. All purpose adhesive is excellent in its solvent base form. It dries very quickly and makes a strong bond. Again this is not suitable for children. It also comes solvent free, a form that is safe for children and works well.



If you are working with card or paper then there are several glues you can use that are safe and solvent free. You can also use tape to stick things down.

Soldering
Brass, steel and copper can all be soldered in order to join them. There are a number of good quality lead free solders on the market that work well and are safer to use. Many also have a flux core that helps the soldering process. The soldering iron needs to be handled with care as it gets very hot, as do the splashes of solder that can drop off the end or from the soldered parts. You should wear goggles and take care not to breathe in any fumes.
Soldering takes a little practice, but produces a very strong bond between metals. You must make sure that all surfaces to be soldered are clean and grease free.

Painting
It is often nice to finish automata by painting them. Acrylic paints work well, they give a good finish and are non toxic. You can also get craft paints made specifically for wood. They come in a gloss or matt finish (I prefer the gloss) and again give very good results. Finally a word of caution, when you paint wood with waterbased paints it invariably swells a little. This means the parts can sometimes jam, as the free play disappears. This can be overcome by moving (easing) the parts until they move freely again.

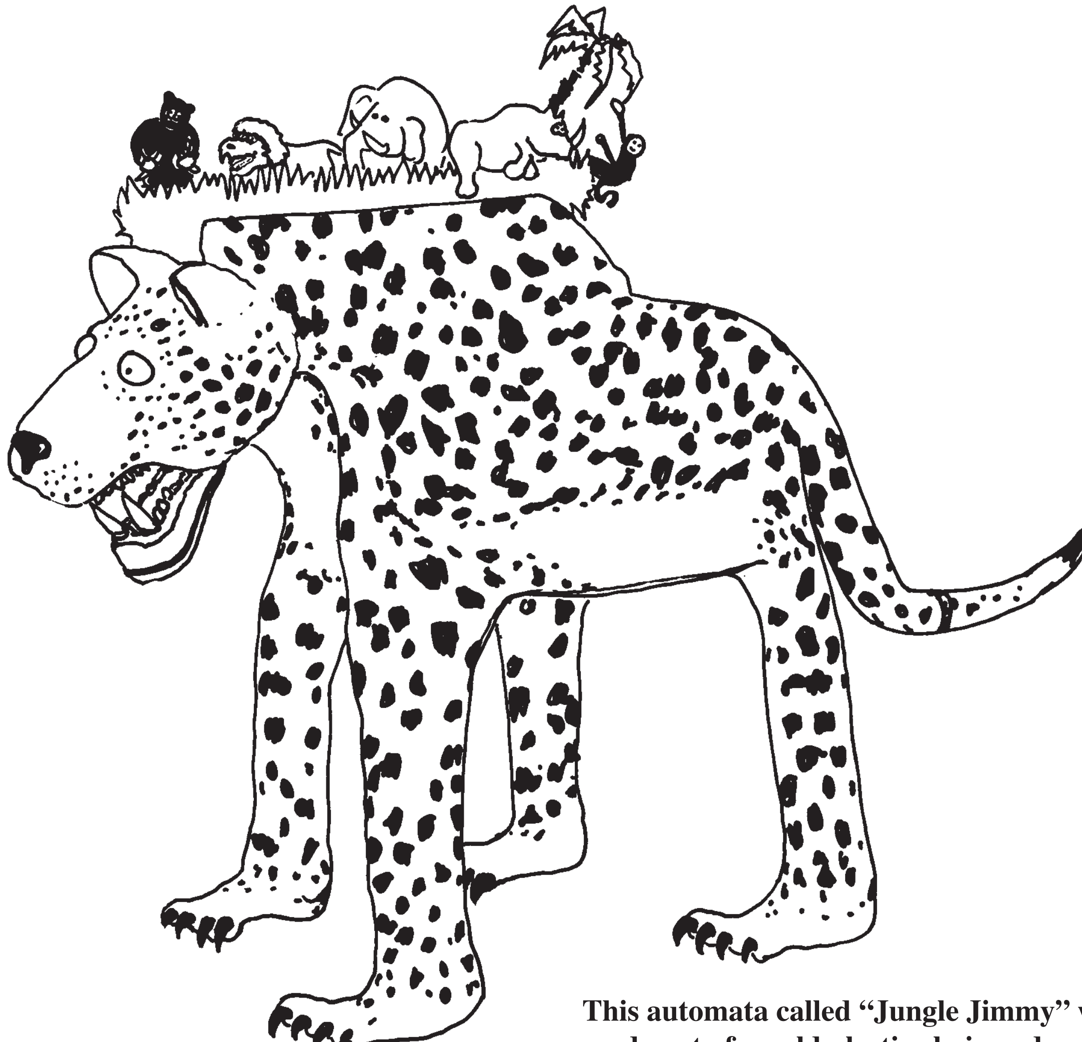


SUMMING UP

Making automata can be challenging, frustrating, and fun. Sometimes mechanisms work well initially, but the next day they don't work properly. Bits drop off or they fall apart. On other days everything works well and keeps on working, so you know you are having a good day! Whatever you do, do it for fun. It really does get easier and, like anything, the more practice you have the better you get. It is easy to be dismissive of automata as just whimsical toys, but they are much more than that. Even the simplest piece of work can encompass a whole host of artistic and craft skills, not to mention engineering theory and practices. But when you turn the handle something magical happens as your work comes to life. We humans love movement and in this modern age we are bombarded with it, yet it still captivates us.

You will have triumphs and tragedies. Many automata makers who have been working over a period of time have a collection of odd mechanisms and body parts which are a testament to their failures. The parts still maintain something special, which is enough to keep them, and they can often be recycled into other automata.

Be proud of what you make and enjoy the whole process. The automata you make today could be tomorrow's antiques, so a little bit of the magic can live on.



This automata called "Jungle Jimmy" was made out of an old plastic chair and covered in paper pulp to form the shapes. When you turn his tail the animals on his back jump about.

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