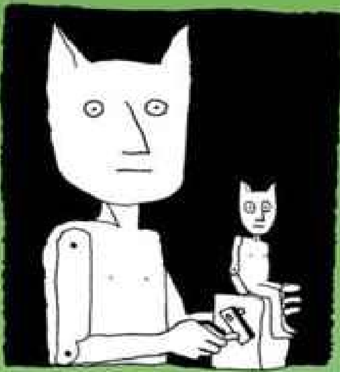
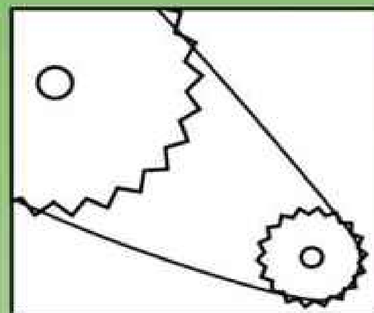
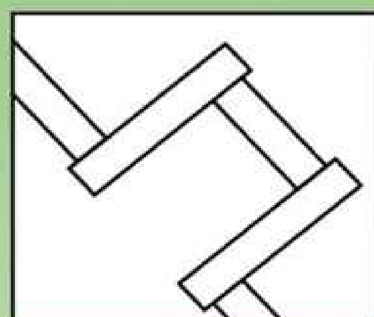
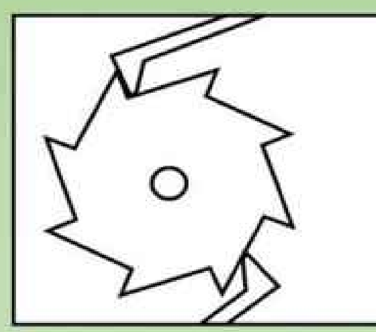


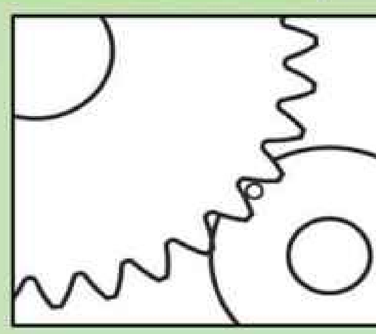
Digital Edition

CABARET MECHANICAL MOVEMENT









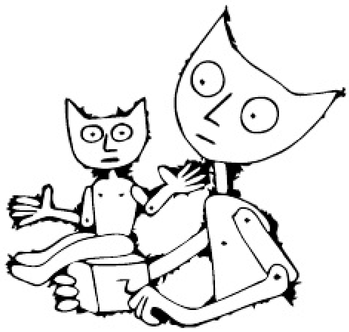
Understanding Movement and Making Automata

Aidan Lawrence Onn & Gary Alexander

Colophon

Cabaret Mechanical Movement

Understanding Movement and Making Automata



Aidan Lawrence Onn
& Gary Alexander

Published by Cabaret Mechanical Theatre

Web Site: www.cabaret.co.uk

By visiting a Cabaret Mechanical Theatre exhibition you should find that everything in this book is easier to understand. As well as being a globally accessible alternative, the web site supplements parts of the book and will have details of current shows.

Front Cover: The Barecats by Paul Spooner and Matt Smith. Photography by Heini Schneebeli.

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Contents

Who, What, Why?

Who?

This book is aimed at people who want to make their own automata. It will also be useful to people who want to make any other sort of mechanical toy / sculpture / device. Design and Technology students should be thrilled. Even if you don't actually want to make anything yourself it will also be useful if you need to understand the practical basics of mechanisms.

What?

The first chapter is a light introduction to the history and principles of movement. This is followed by eight chapters on different types of mechanism. Each of these contains the basic theory and practical tips. The whole book is illustrated with many examples of the automata of Cabaret Mechanical Theatre (CMT). The chapter on control is followed by the final chapter which gives a step-by-step guide to design and construction.

Why?

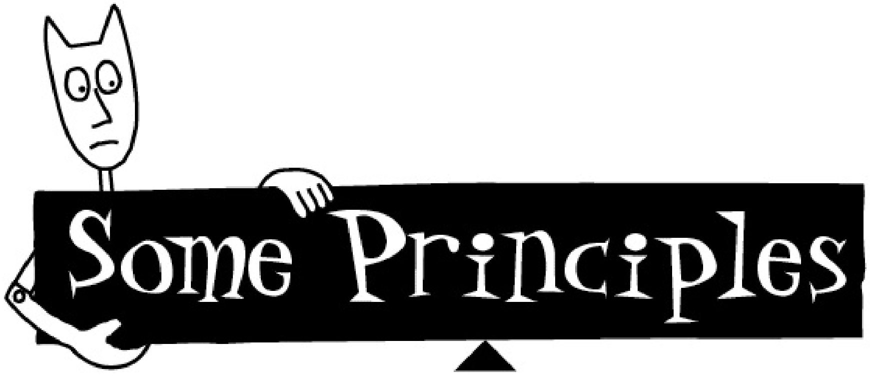
Remember that making machines like this is supposed to be fun. It won't feel that way when you've thrown your latest creation into the bin for the fifth time but please don't blame this book. Just read the relevant parts again and get started on version six.

Thanks

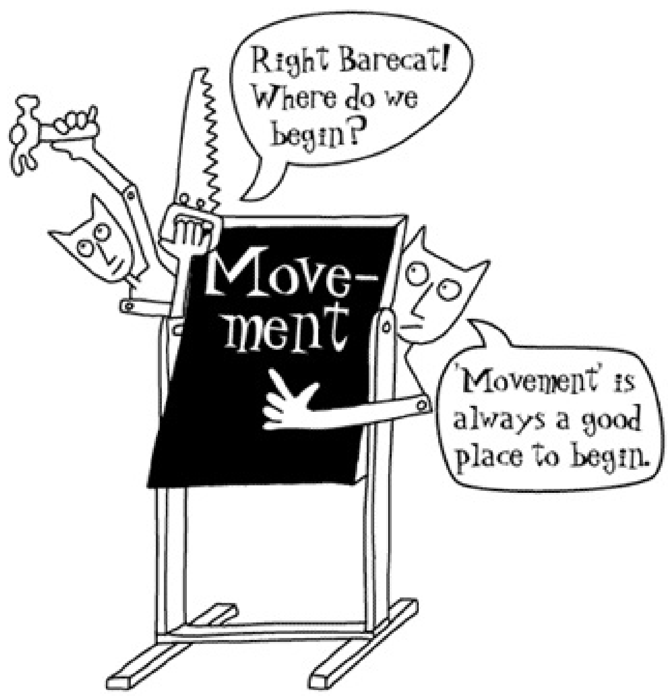
In no particular order, we'd like to thank the following people for their help: The Spooner Family, Tim Hunkin, Sarah Alexander, Alan Chapman, William Jackson, John Lumbus and finally, Sue Jackson, the founder of CMT, without whom this book probably wouldn't exist.

You can find out more about CMT on our website: www.cabaret.co.uk

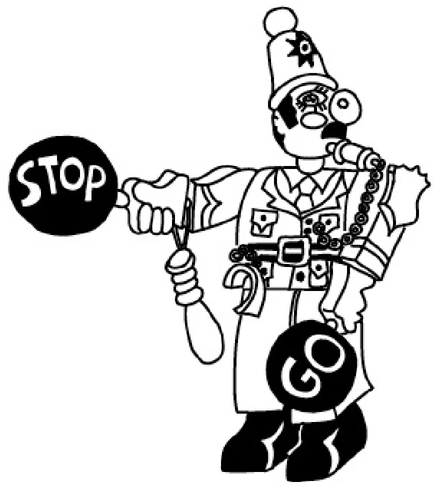
Some Principles



The theory might help you to understand how mechanisms work. On the other hand, it may put you off making things. If this chapter gets too heavy, try skipping on to something more practical.



The history of automata usually begins around 500 B.C. and you may think that making automata in this digital age is daft and irrelevant. However, the movement of the most complex of today's industrial robots is based on long standing mechanical principles. They use the same mechanisms that are used in the simplest piece of automata or mechanical sculpture.



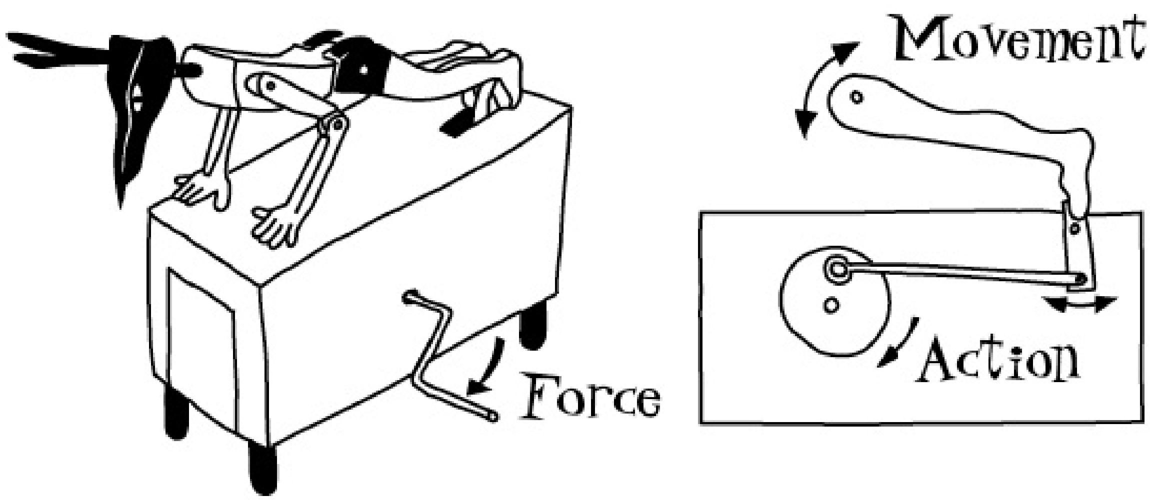
Pink Policeman by Ron Fuller

Before we look at mechanisms it's worth spending a bit of time thinking about what movement is. In this introduction we'll show you some of the basic principles that govern movement and a little of the history of the subject.

Observation

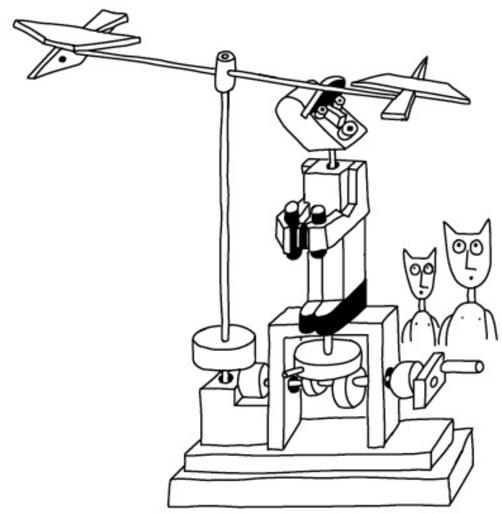
Just look around...

Everything you see is moving. Electrons are moving in atoms. You and the things you see are rotating with the Earth. Appearances can be deceptive and even when you can see the movement it's not always obvious what is causing it. If you didn't already have an idea of how muscles work do you think you could work out what is going on when you bend your elbow?

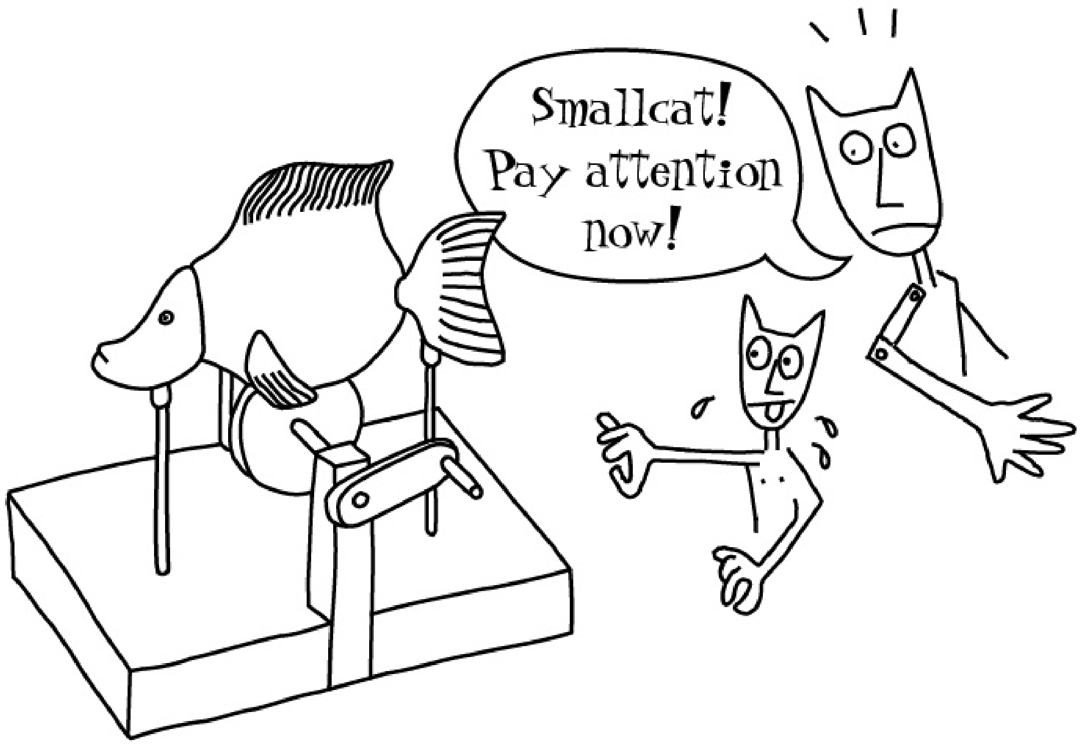


Press-up Anubis by Paul Spooner

Bird Watcher by Peter Markey
In this piece, turning the handle causes the man's head to turn from side to side. The birds just rotate so their mechanism is simpler. We'll cover these mechanisms in later chapters but can you see how it works just by looking at the drawing?



If you want to make things move be sure to spend some time studying how other things move.

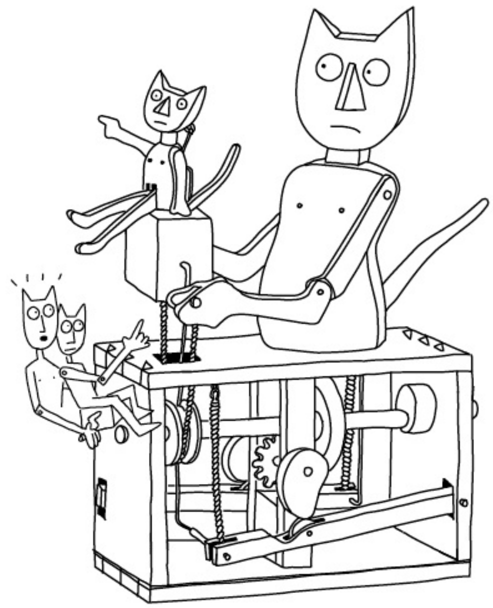


Wiggling Fish by Jan Zalud

Principles

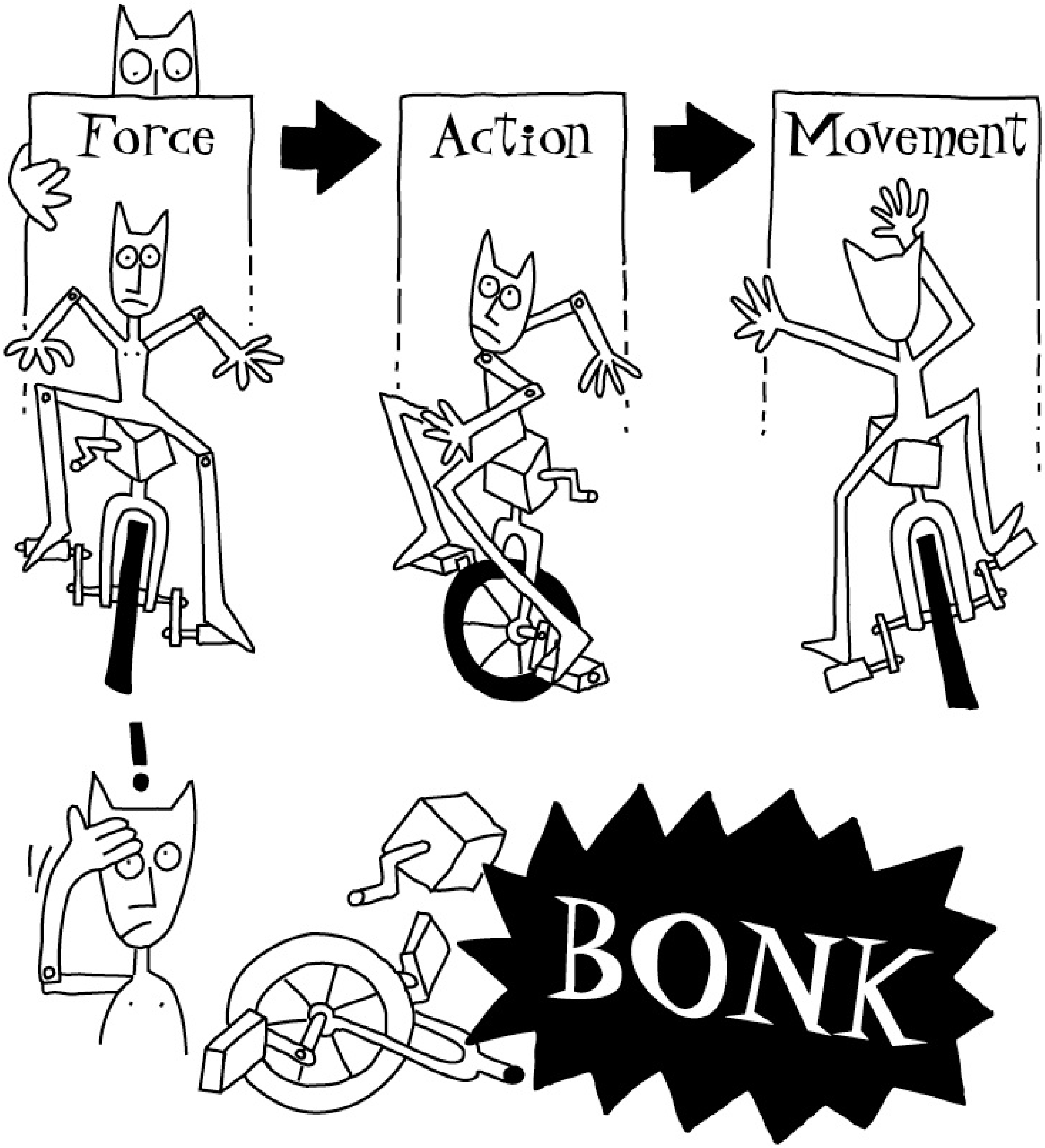
All movement is governed by certain mechanical principles. The observation of movement all around you will provide lots of inspiration for your own ideas. But before you create something with mechanical movement it will help you to understand a little about those mechanical principles.

The Barecats by Paul Spooner
Who is winding-up whom? When the small cat points the big cat looks up. When you look at mechanisms try to work out which part is driving and which part is driven.



Machines

A machine is something that modifies FORCE. For example, a unicycle is a machine. When the force comes from an outside source, it’s called INPUT. The mechanical action of the machine produces OUTPUT. So, legs pushing the pedals (Input), produce a rotating wheel (Output). The motions and forces that occur between Input and Output are described by the science of Mechanics.

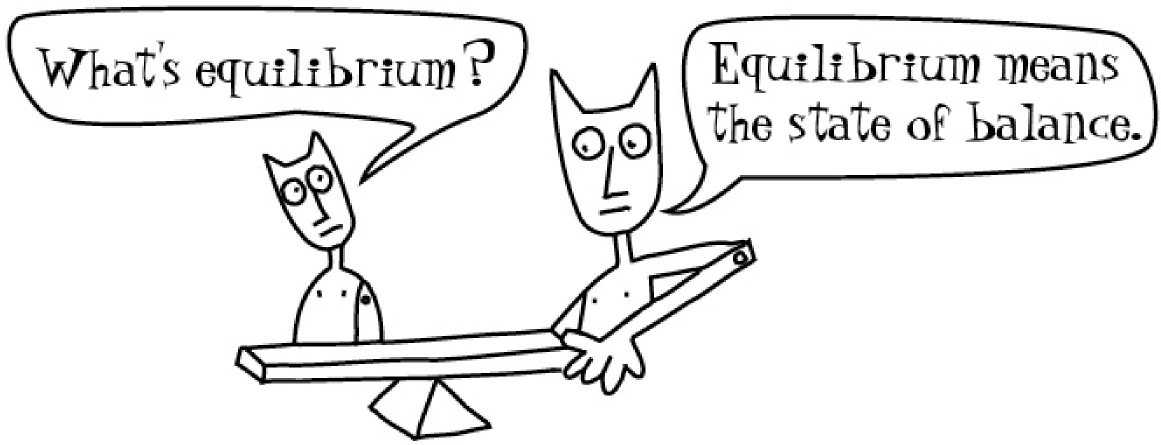


Mechanics

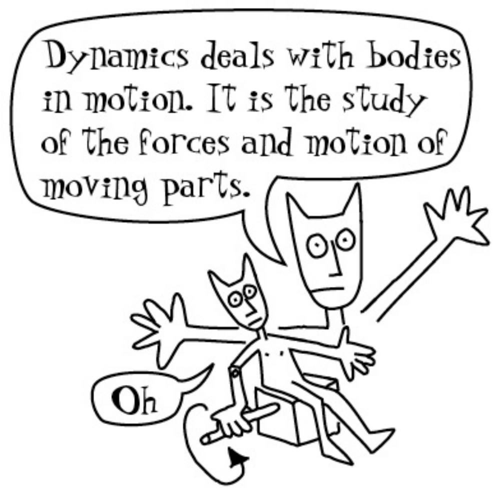
The science of mechanics has been studied for a very long time. The origins can be traced back to the early dynasties of ancient Egypt.

The first recorded scientific foundations for mechanics were developed in the 3rd century BC by a Greek mathematician called Archimedes. He worked out formulae for the equilibrium of simple levers and centres of gravity.

Archimedes' classification of levers into three different types persists to this day. (Levers–chapter 2)



Another important historical development was recorded almost two thousand years later by Galileo Galilei (born 1564). He studied the theories of Archimedes and in particular, the use of mathematics to solve physical problems. Galileo advanced Archimedes' work on mechanics by developing the science of Dynamics.

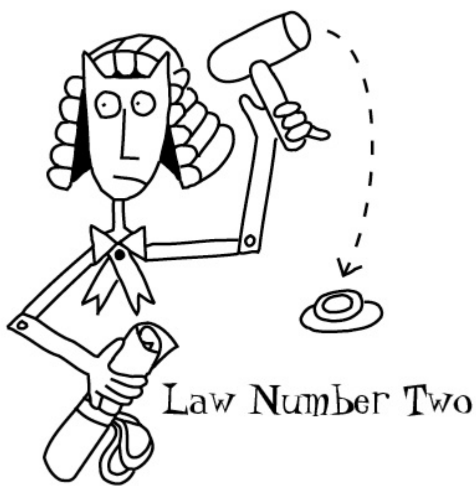


In the year that Galileo died (1642), Isaac Newton was born. He introduced the concepts of force and mass. From this he formulated his Three Laws of Motion.

Newton discovered that motion does not require force. Force is only required to accelerate or decelerate motion.

Basically, any moving object will continue in a straight line and at a constant speed indefinitely unless some force interferes with its motion.

In reality, a moving object usually slows to a stop because friction or air resistance drain its energy.

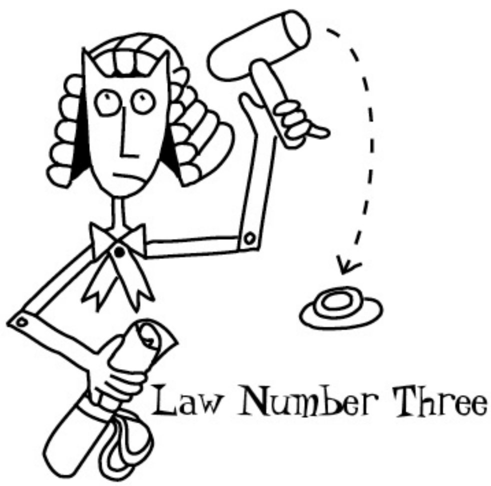


Newton's second law relates the acceleration of an object to the forces acting on it. It's not too hard to understand:

The greater the force, the greater the acceleration.

Therefore, a force acting on a moving object will speed it up, slow it down, or change the direction in which it is moving. A force acting on a stationary object may start it moving.

Running Men by Peter Markey
The front foot of each of the runners is attached to a crank. The cranks are offset from each other so that each runner moves forward at a different time. (Cranks–chapter 4)

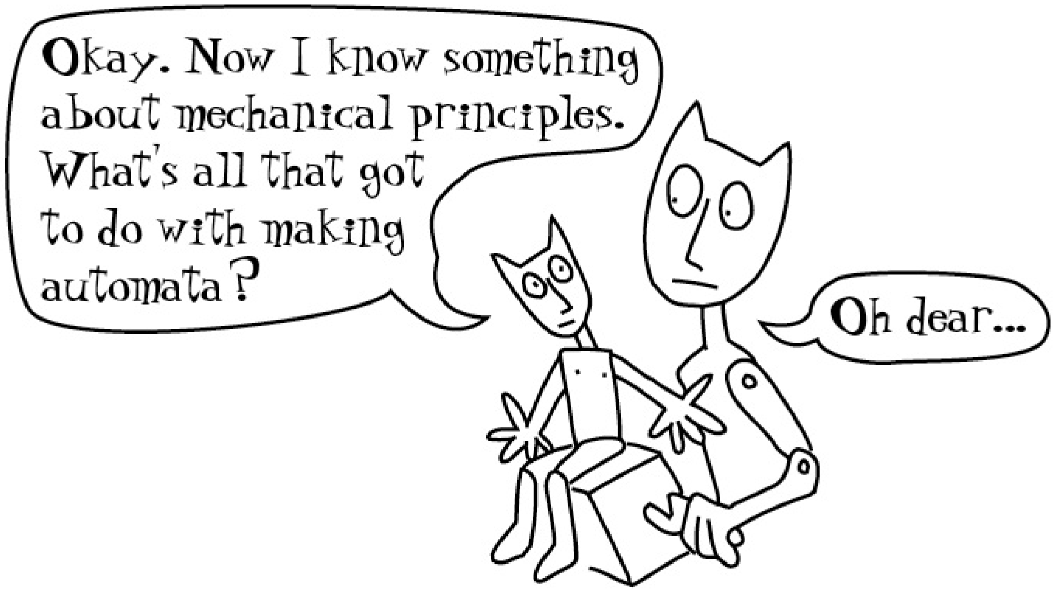


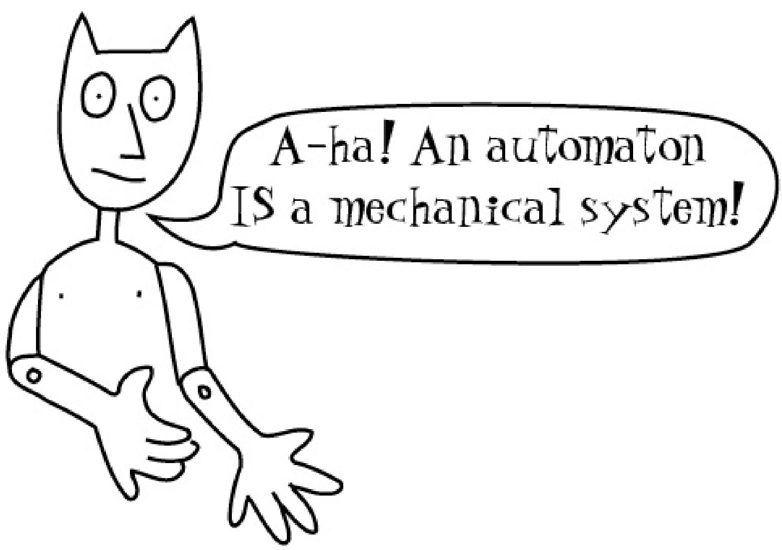
Newton's third law expresses the equality of action and reaction. A principle that can be demonstrated by the case of a rocket launch.

The downward expulsion of gases causes a reactive force that drives the rocket upward.

So, if an object is pushed or pulled, it will push or pull equally in the opposite direction.

These laws of classical mechanics–or Newtonian Mechanics, as they are sometimes known–play an important part in understanding mechanical principles. Whether or not they are any help when it comes to making things is debatable.





Let's have a look at some mechanical systems now.

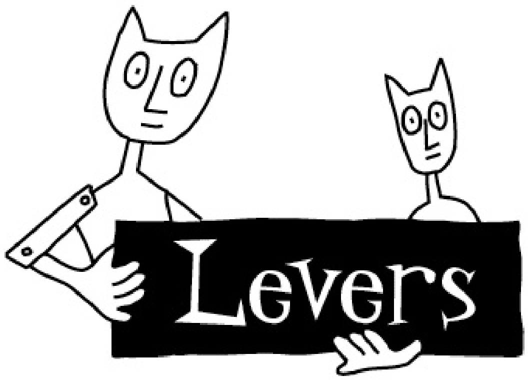
All mechanical systems are made from combining the same basic mechanisms. It can be shown that there are really only 5 basic mechanisms. These are;

1. The Inclined Plane, or a slope
2. The Wedge
3. The Screw

4. The Lever
5. The Wheel

However, the wedge is like an inclined plane, or two inclined planes joined together, and the screw is like an inclined plane wrapped around a shaft. The wheel is like a lever which rotates through 360o. This means that there are really only two basic mechanisms–the lever and the inclined plane–and all other mechanisms are based on them. We’ve divided the next part of the book into eight chapters which cover the most commonly used mechanisms.

Levers



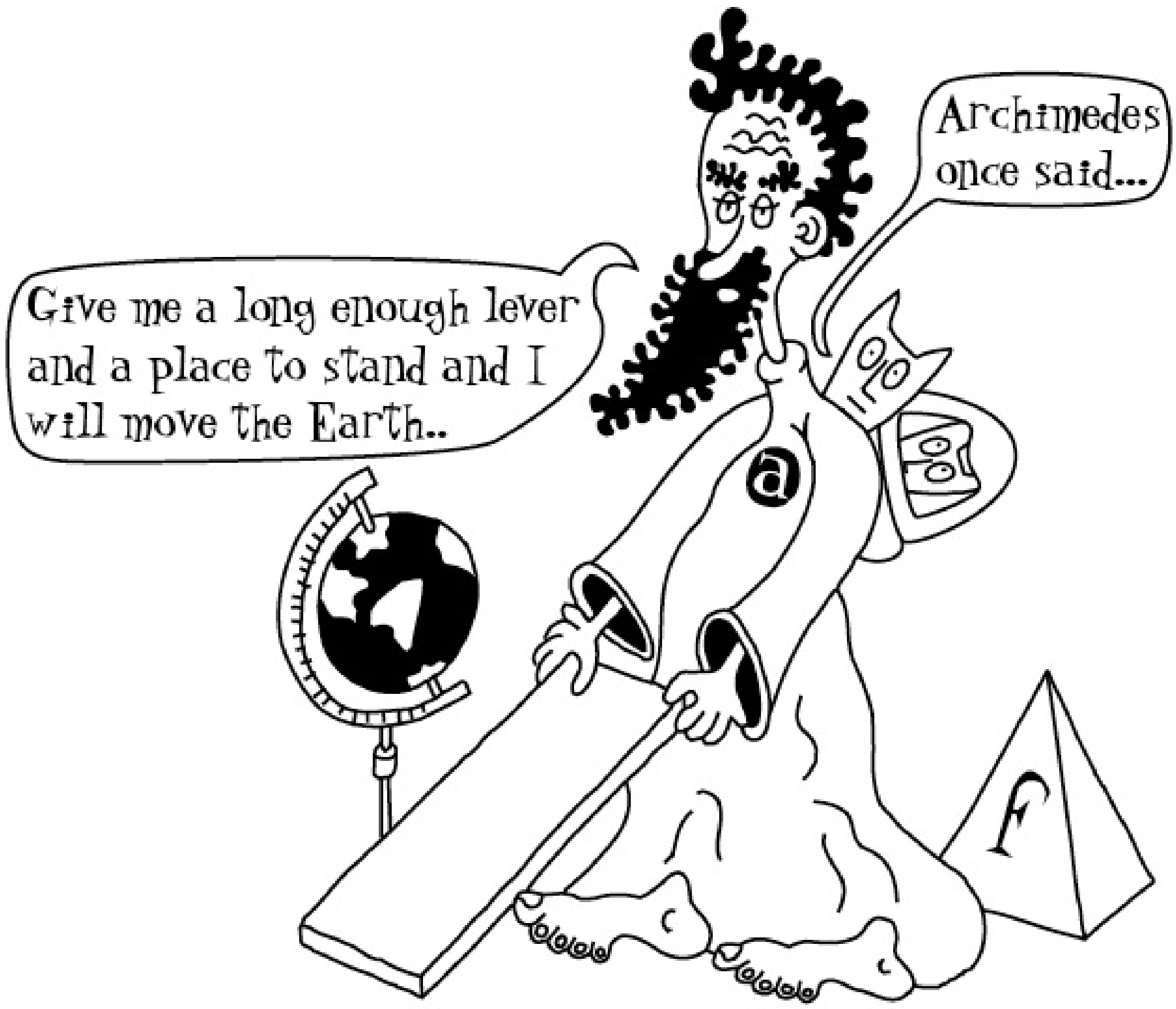
All machines, including automata, will almost certainly employ at least one lever. Of course, if a machine only had a single lever it would be quite a simple thing and most machines will use a combination of levers and other mechanisms.

However, it’s still possible to have some fun with single mechanism machines and levers are the best place to start.

A lever is a very simple device. It consists of a rigid bar which pivots (turns) on a fixed point. This pivot point is called the Fulcrum.

Archimedes wrote lots of books on mechanical principles. In the one called ‘On the Equilibrium of Planes’ he establishes the ‘Law of the Lever’.


Levers are used to convert a small effort...
Into a large effort!
Yes, and vice versa.
Brilliant! That'll make life easier.

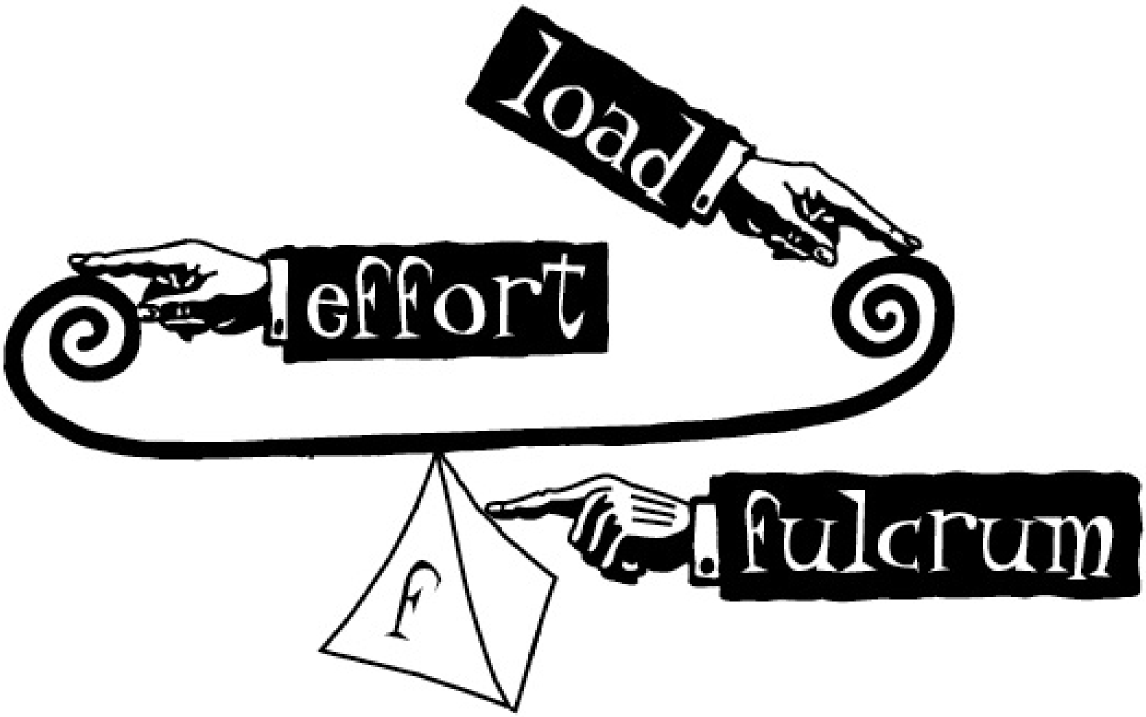


Archimedes may have been very clever but he wasn’t Superman. To operate his lever he would have needed a very big fulcrum and we’re not sure what he was going to rest it on. Also, to gain this super mechanical advantage the load, in this case, the Earth, would need to be close to the fulcrum and the lever would need to be very, very long. Of course, Archimedes knew all this and space suits weren’t invented anyway.

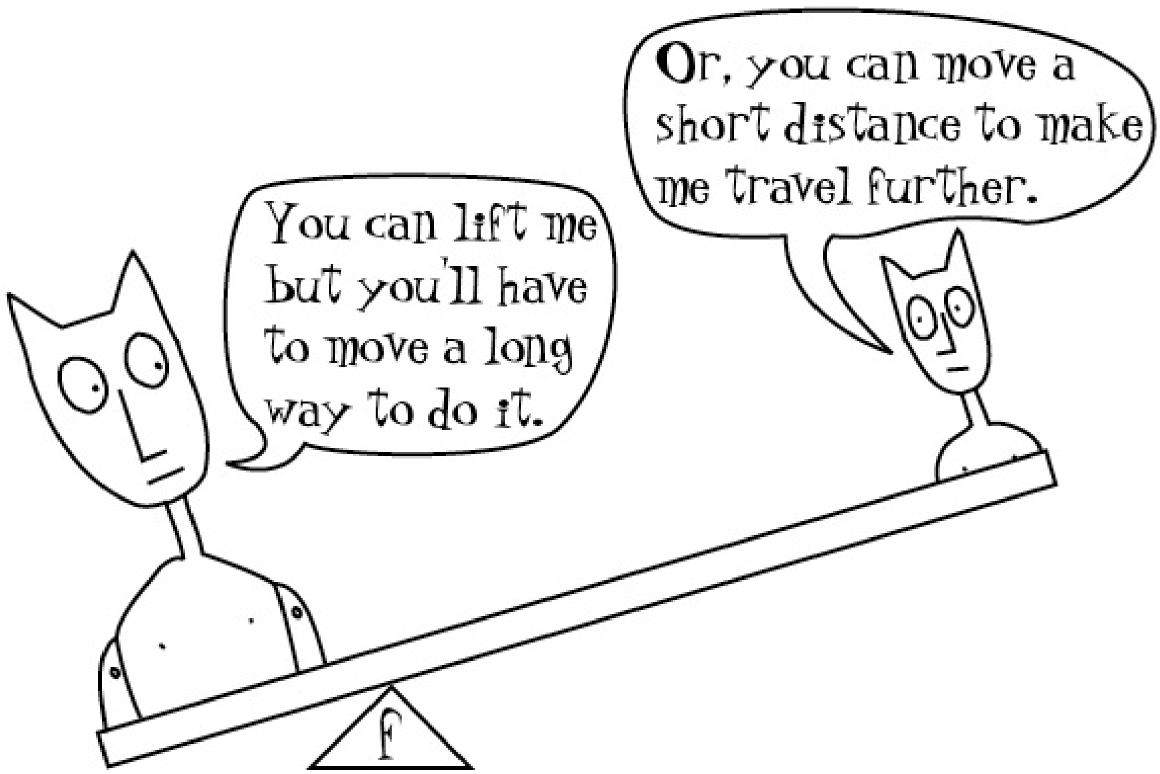
As with the opening chapter, you might want to skip some of this theory. However, levers are key to understanding mechanisms and there are real world examples of each type to help you through.

Archimedes divided levers into three separate types (or orders). Each one has the fulcrum, load and effort arranged differently.

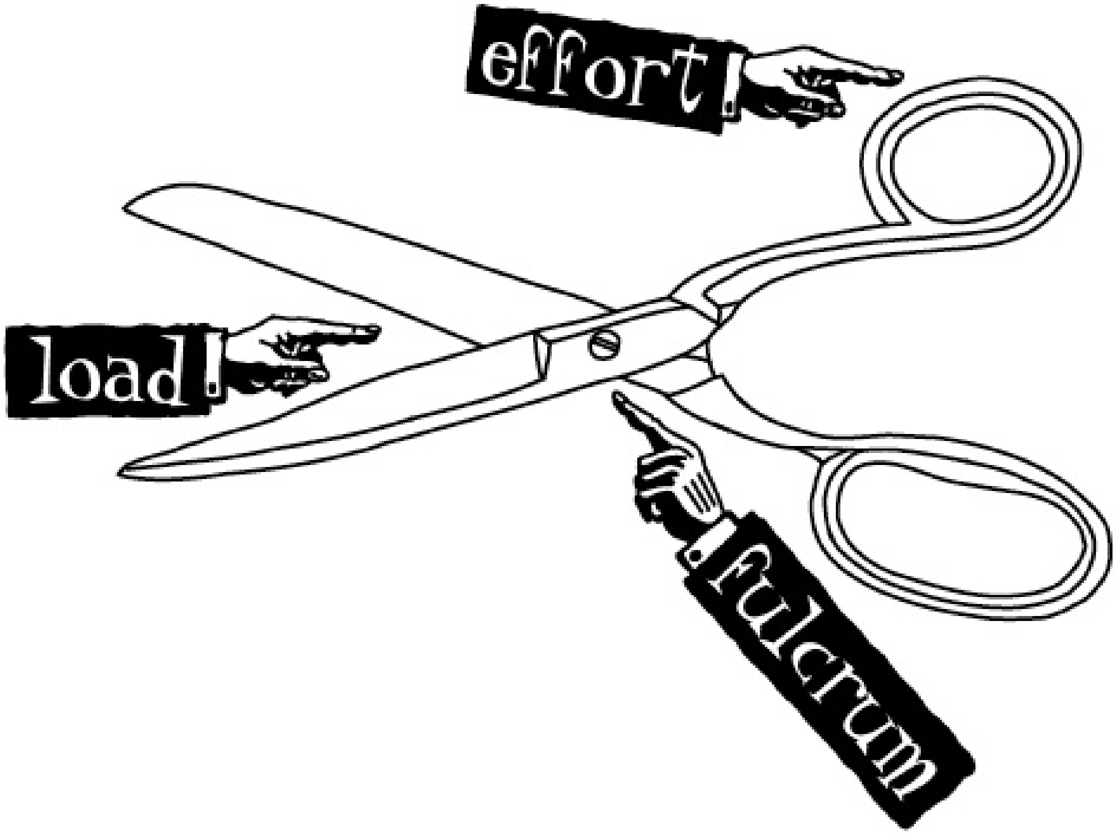
A Lever of the First Order



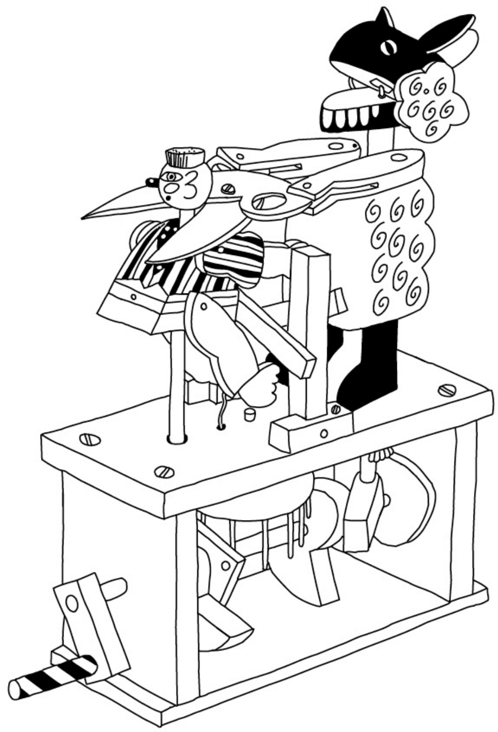
By moving the fulcrum closer to, or further away from the load, you change the distance the lever must travel and the amount of effort required to move the load.



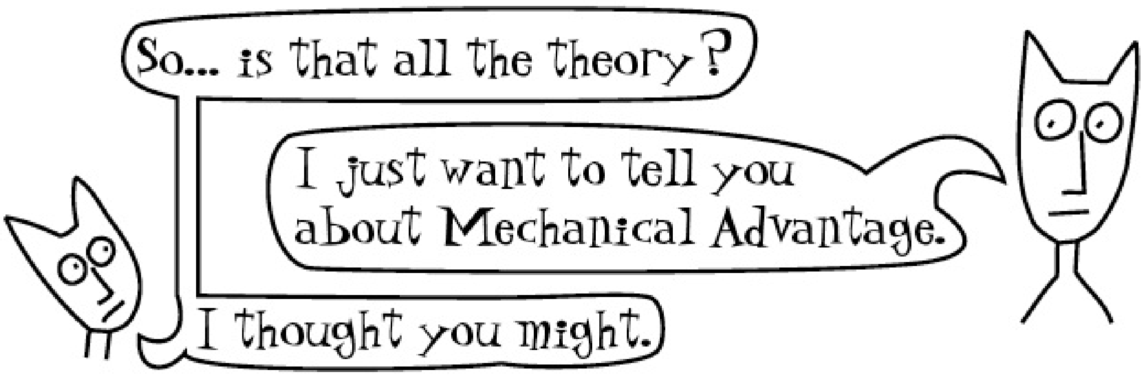
A pair of scissors is an example of a lever of the first order. The effort is applied to the ends held in the hand. The load is at the cutting edges. The fulcrum is the rivet or screw which holds the two halves together. If you experiment, you should find that it's easier to cut thick paper when it's closer to the fulcrum.



A lever of the first order always has the fulcrum located between the load and the effort.

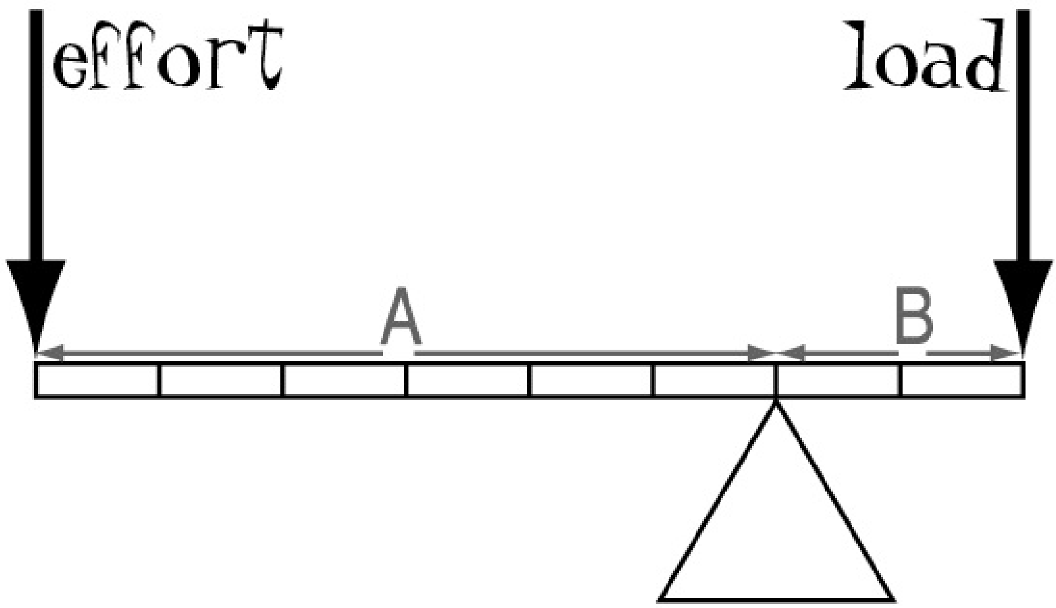


Sheep Shearing Man by Ron Fuller
The man goes up and down and on every twelfth turn of the handle he stays up long enough to have his head chopped off by the scissors. Luckily, the head is attached to a string so it's pulled back with the next turn



Mechanical Advantage

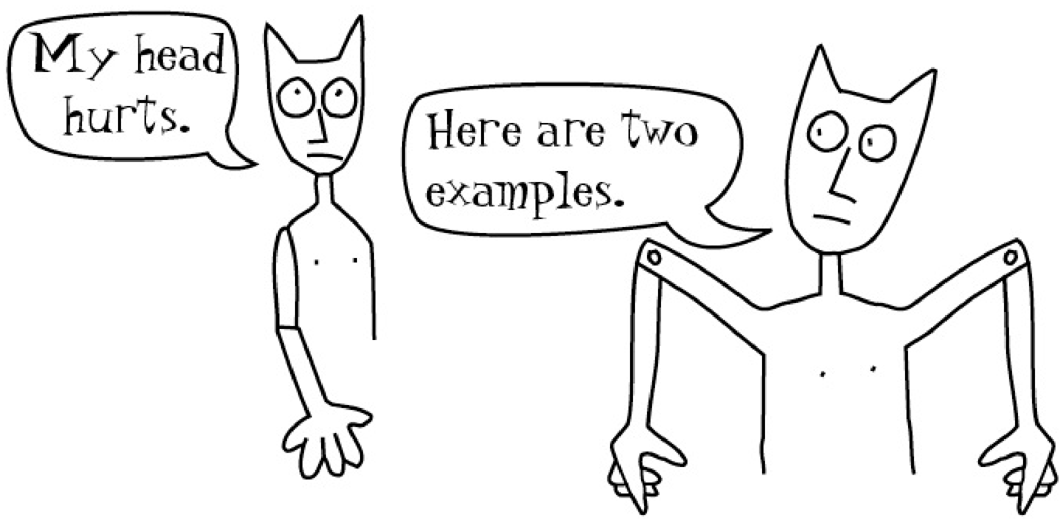
Mechanical Advantage is just a comparison (ratio) of the effort put in to the load moved. The leverage is the ratio of the distances of the effort and load to the fulcrum(A and B below). When we look at these ratios we can tell how the lever will work.

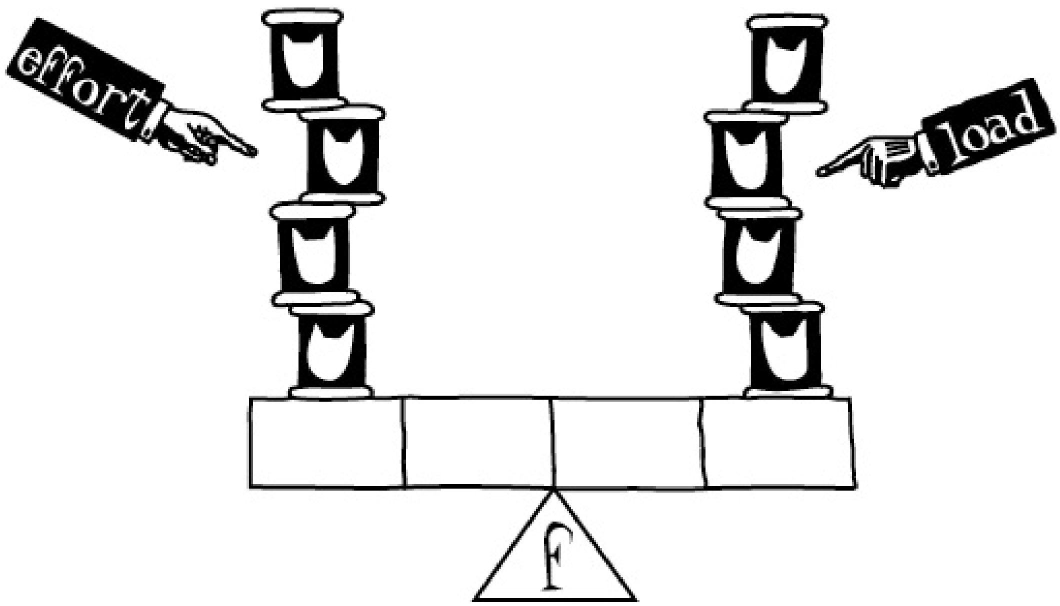


In this example, the leverage is the ratio of A and B, which is 6:2, or 3:1.

Mechanical Advantage =Load / Effort (that's load divided by effort)

So, an effort of 1 could move a load of 3, but as you'll probably have realised by now, you will have to move the effort end of the lever three times as far as the load end moves.

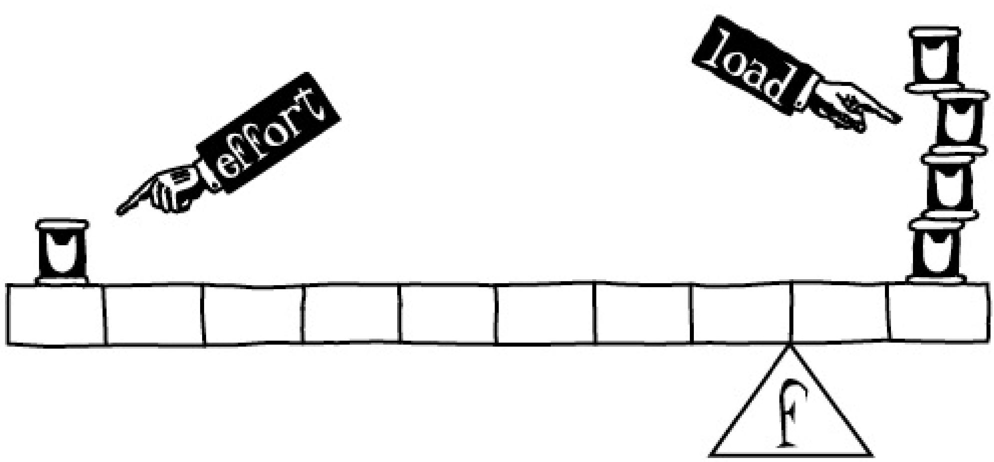




On the left, four tins of cat food are two units away from the fulcrum. On the right, four tins of cat food are two units away from the fulcrum.

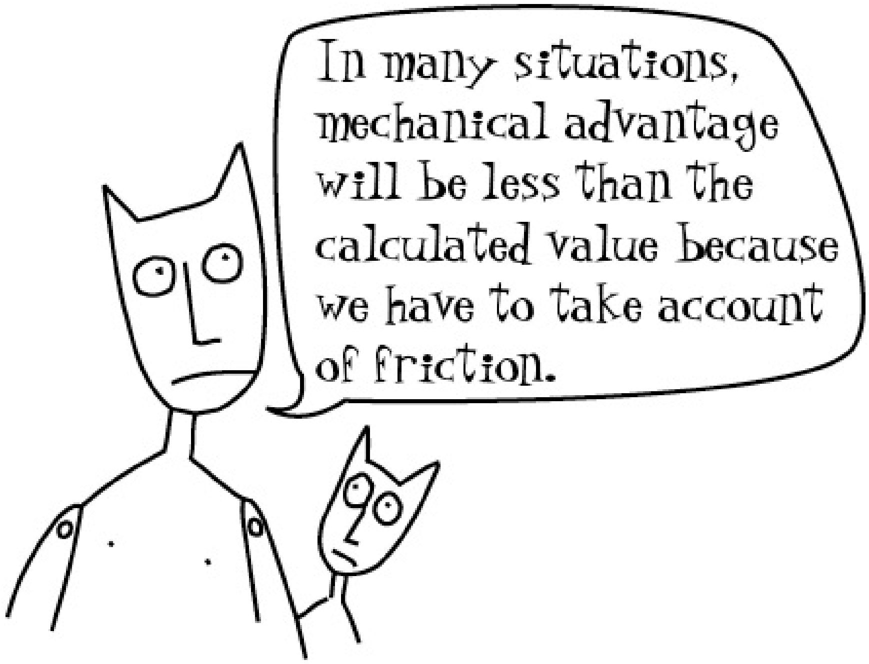
The Mechanical Advantage is 4/4 =1. Because the distance to the fulcrum is the same on both sides it should be obvious that the tins will balance.

In the next example the fulcrum is off centre. This means we have some leverage and a mechanical advantage.



On the left, one tin of cat food is eight units away from the fulcrum. On the right, four tins of cat food are two units away from the fulcrum.

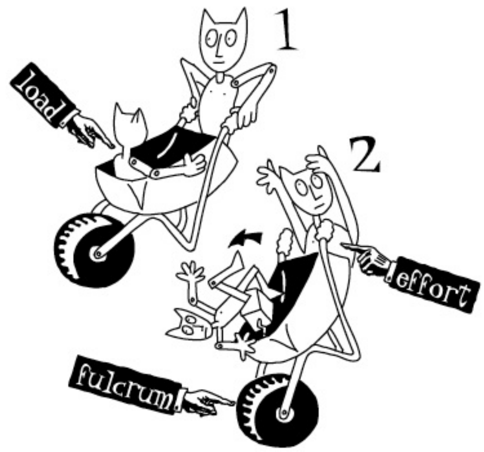
The Mechanical Advantage is 4/1 =4. The leverage is also 4 (8:2 = 4:1) so the tins will still balance.



A Lever of the Second Order

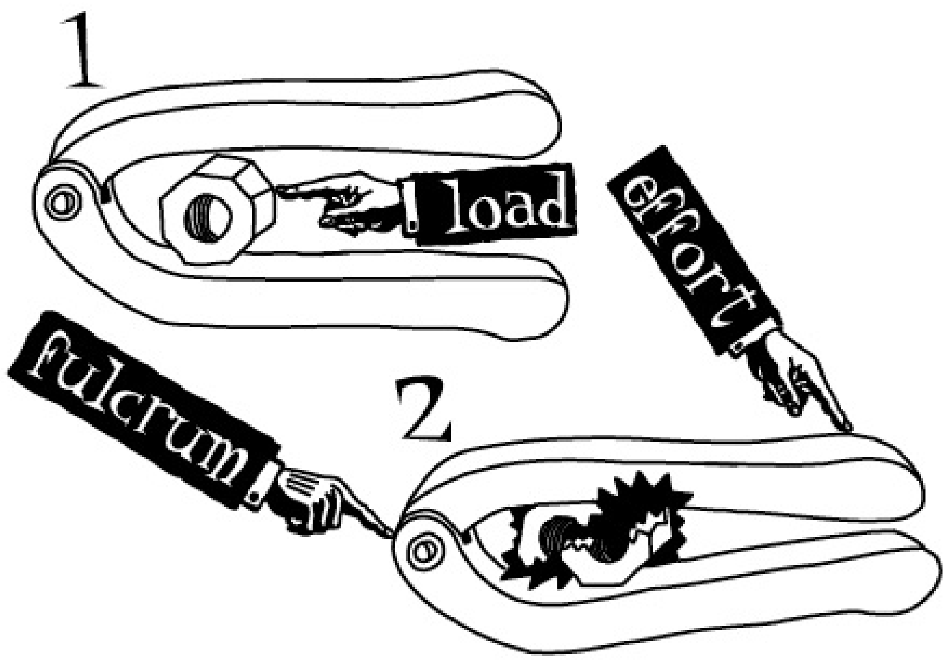
Here the load lies between the fulcrum and the effort. This kind of lever can be described as a force magnifier, having very good mechanical advantage.

The wheelbarrow is an example of a lever of the second order. It is used to overcome the resistance of a heavy load by using a small force. To achieve this mechanical advantage, the wheelbarrow obeys a rule that applies to all force magnifiers: The effort must move a greater distance than the load.



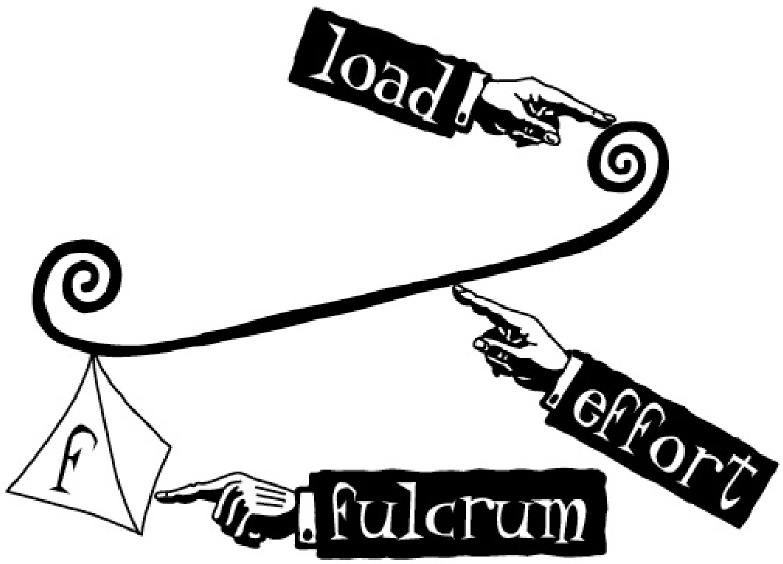
Lifting the handles using a relatively small effort raises a heavy load. The fulcrum is the axle of the wheel.

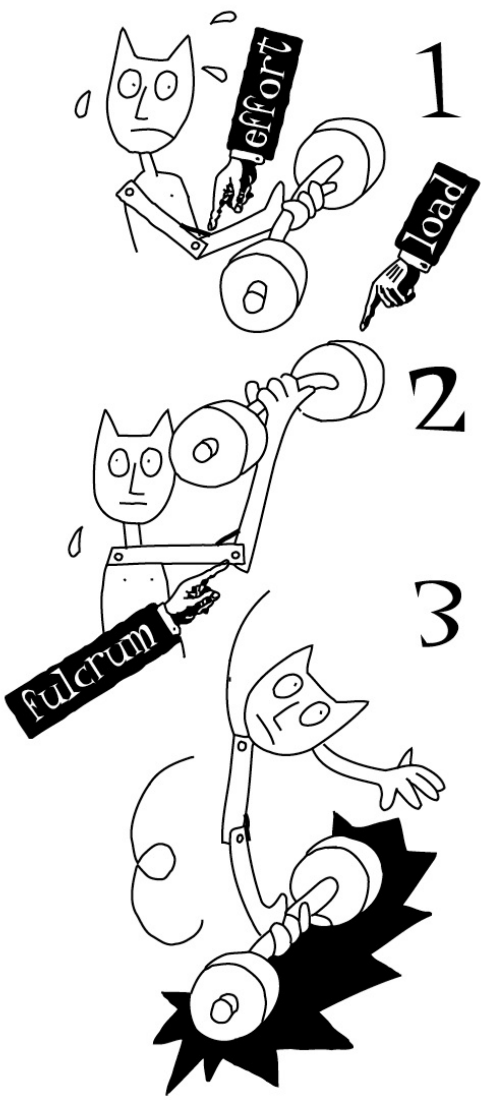
Nutcrackers are another example of a class two lever. Because a class two lever is a powerful force magnifier, the toughest of nuts can be cracked with a relatively small effort.



A Lever of the Third Order

In a class three lever the effort is applied between the fulcrum and the load. This kind of lever can be described as a force reducer since the effort will always be greater than the load.

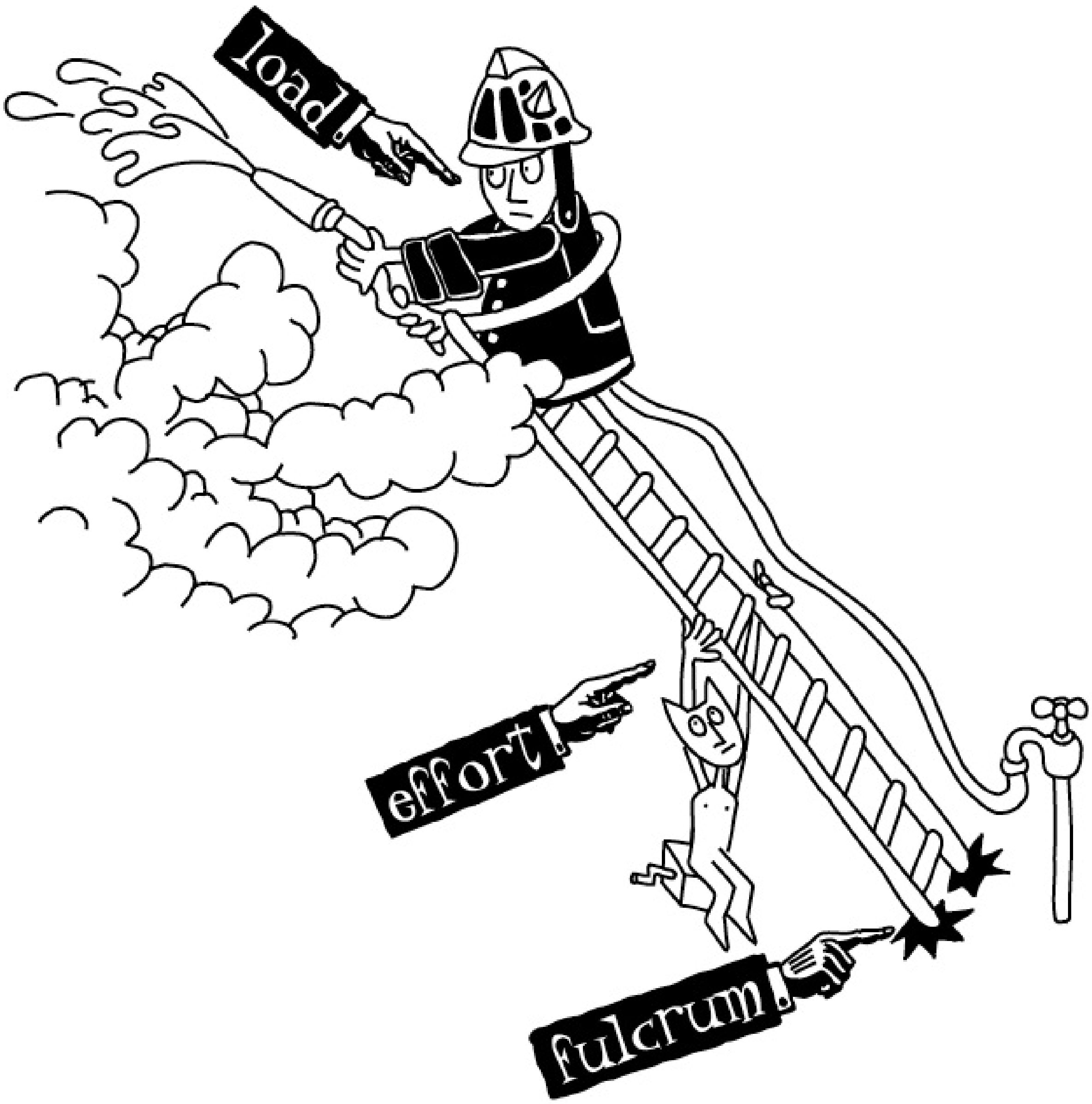




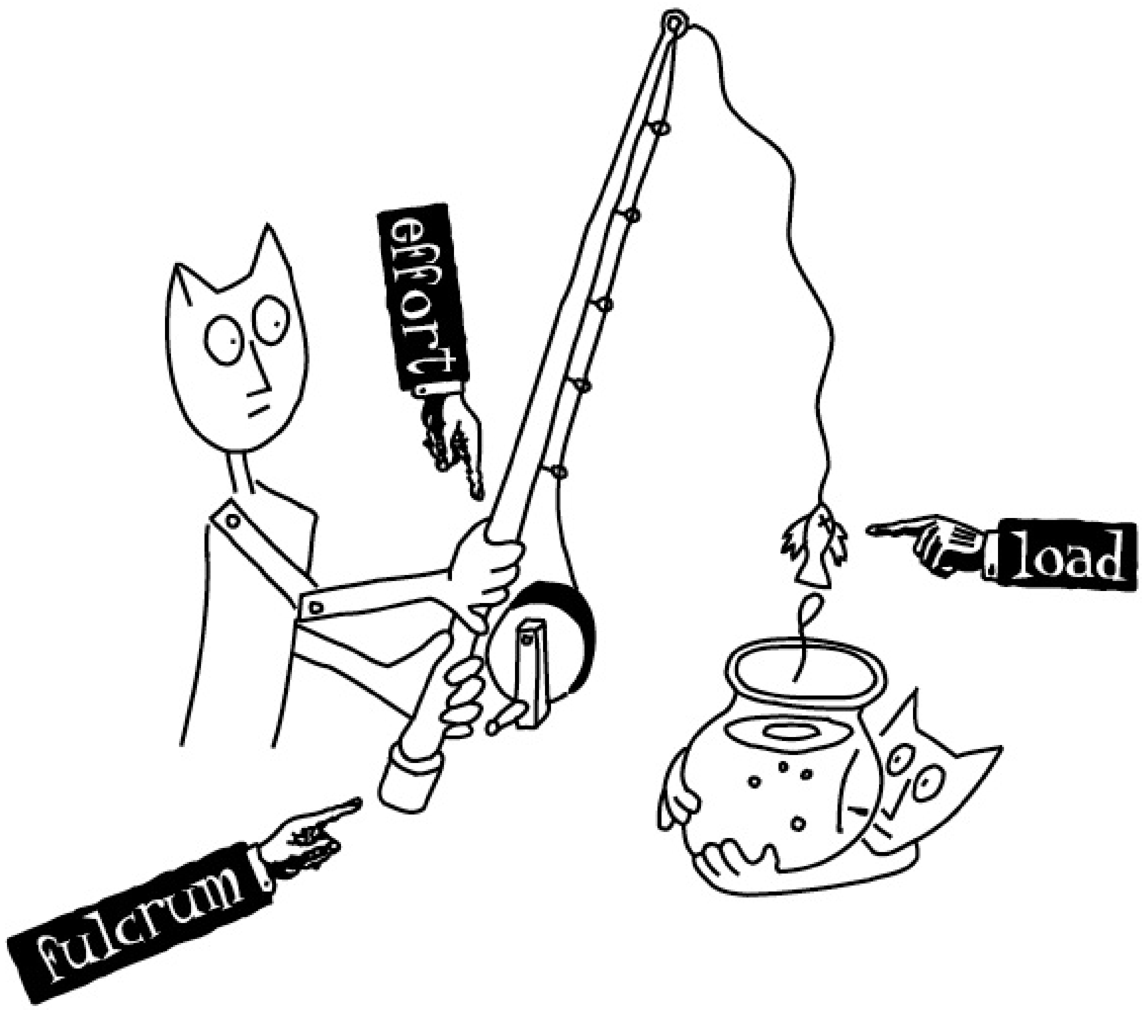
This may not sound very useful but in certain cases it may be the only possible arrangement. It also has the advantage that the load moves faster than the effort. So you could call it a movement amplifier.

Your arm is an example of a class three lever, with your elbow as the fulcrum. The effort comes from the bicep muscle which attaches to your forearm just below the elbow. The load, held in your hand, requires effort from the muscles to pull up against the fulcrum.

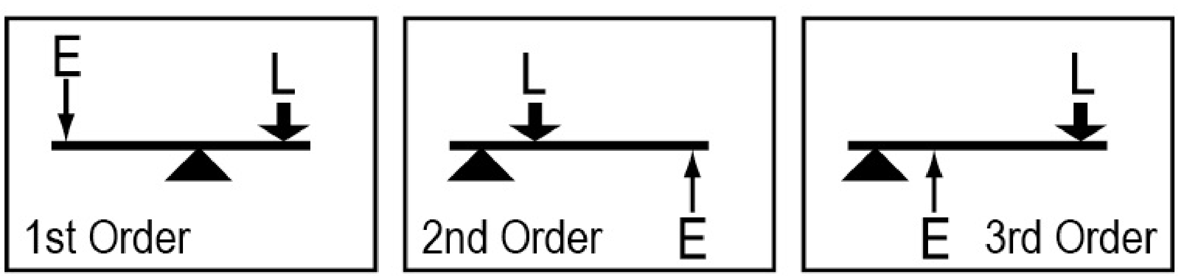
The ladder below is a class three lever. The effort to lift the ladder, or hold it in place has to be applied between the load and the fulcrum. So the higher up the ladder the fireman goes, the greater the effort needed to support him.

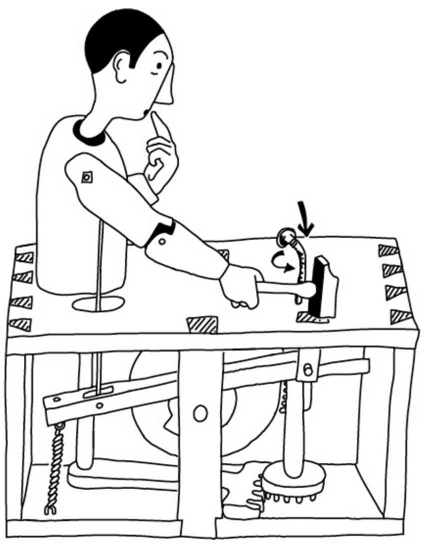


A fishing rod is another class three lever. One hand acts as the fulcrum while the other applies the effort to move the rod up and down. The load is the weight of the tackle, bait and perhaps, a fish–which is raised a long distance by a short movement of the hand.



Most levers you'll encounter will be 1st or 2nd order. 3rd Order levers are used in situations where the other types are impractical or when they give another advantage. For example, a pair of tweezers (3rd Order) are easier to control than a pair of pliers (2nd Order) because the effort is applied closer to the load.





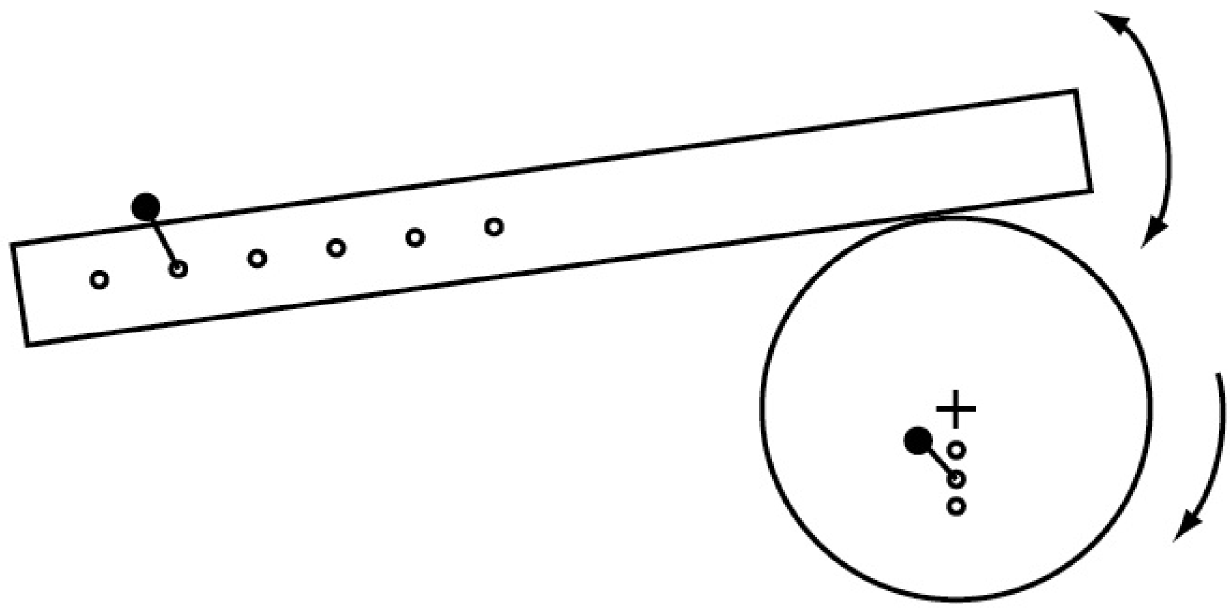
An Allegory of Love by Paul Spooner
The man keeps trying to hit the nail on the head but always misses on either side. This is mainly because the nail moves as well!

Practical

When designing a mechanism which uses any of these three classes of lever remember that the movement of a lever will always be through the arc of a circle and not in a straight line.

Get some cardboard and 2 pins. Cut out a long straight piece (your lever) and a circle. Experiment by pinning them down onto another piece of card as shown on the next page. Pin the circle down off-centre.

Rotate the circle and notice how it moves the lever. Try changing the pivot point (fulcrum) of the lever. Then try moving the circle closer to lever’s pivot point.



You should see that positioning the circle close to the fulcrum is equivalent to trying to push a door open near its hinges.

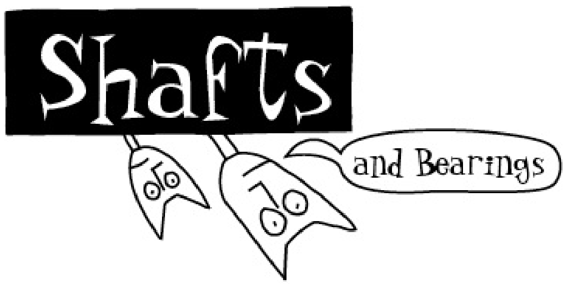
Make pencil marks on the backing card to indicate how much the lever moves in different arrangements.

You’ve probably realised that the circle is a cam (chapter 5). This combination of cam and lever is one of the most common mechanisms in automata making.

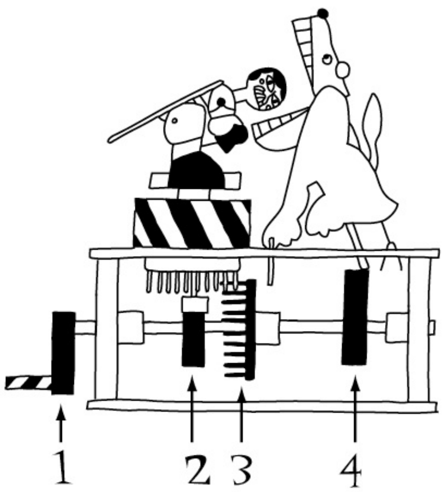
It’s often a good idea to make flat representations of your mechanisms from card. It allows you to test ideas very quickly and cheaply. The method shown above could be used to decide on the size, shape and position of a cam when you know how much movement you need from the lever.

You might want to consider how you could use the cam and lever mechanism in your own design.

Shafts



If you're just beginning to make moving things it's easy to overlook the importance of shafts. A rotating shaft, or axle, often has all the other mechanisms attached to it, so if it's not running smoothly it's likely that the rest of the machine will have problems too.



1–The handle (a crank)

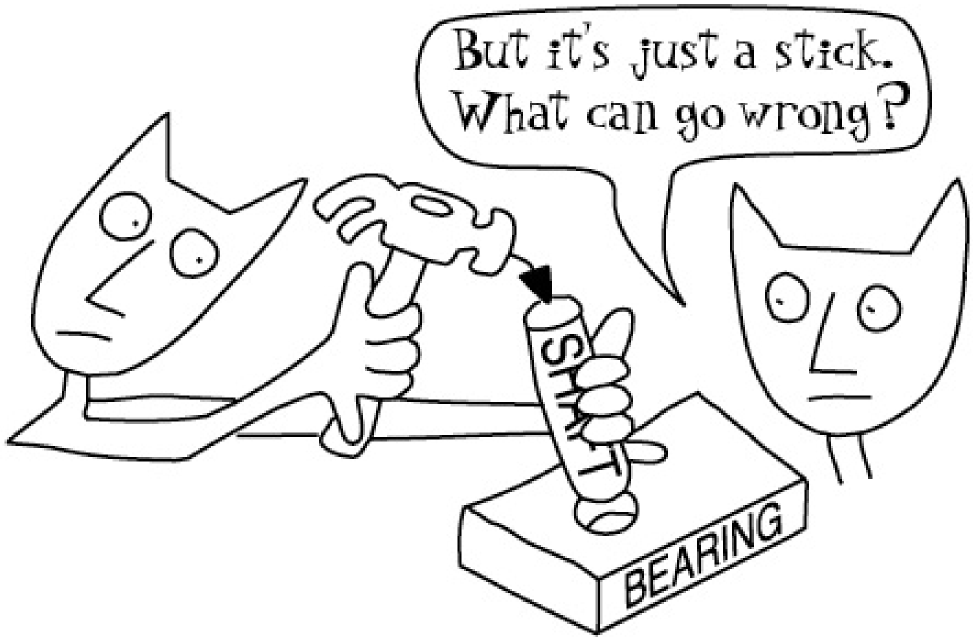
2 – An eccentric cam lifts the Lion tamer up

3 – A pin wheel rotates the lion tamer

4 – A snail cam opens the lion's mouth

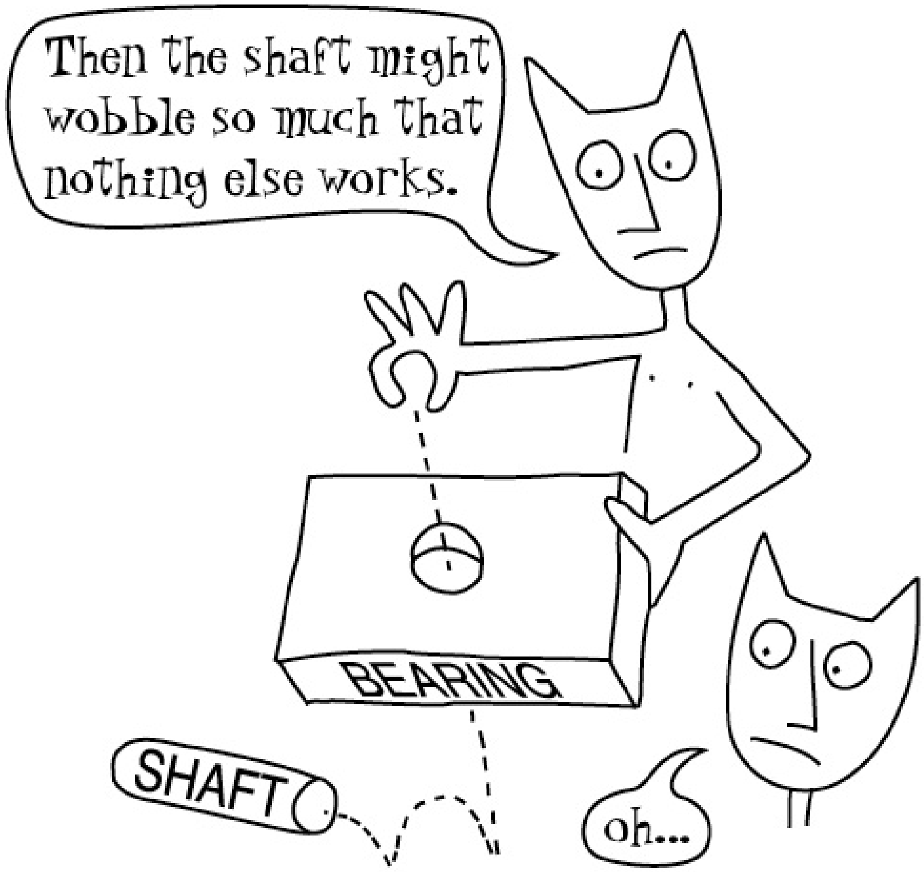
In this piece, the Lion Tamer (by Ron Fuller) spins and drops his head into the lion's mouth. As the lion's mouth closes, the lion tamer moves out of reach. For this sequence to remain constant the mechanisms are fixed to the shaft so that the lion's mouth is always open when the lion tamer's head is in his mouth.

We will be covering each of the Lion Tamer's mechanisms in more detail later.



Shafts can be anything from a piece of stiff wire or a wooden dowel to an accurately engineered steel rod. The part with the hole that supports the shaft is called the bearing.

Shafts should be strong enough to support the mechanisms they carry and the right size to fit the bearings that they run in. Not too tight and not too loose.



Bearings

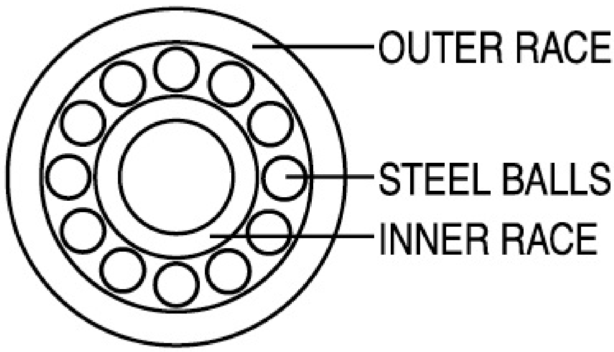
To keep the rotating shaft stable and to help it to run smoothly it is supported by a bearing.

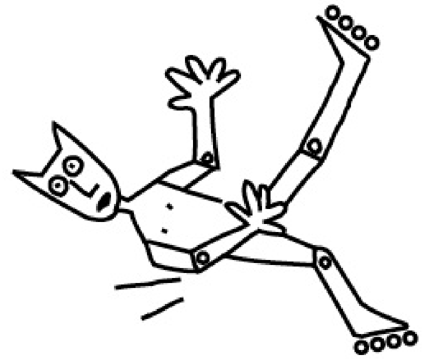
The bearing and shaft need to be chosen together. If all your components are heavy and you use a steel shaft you don’t want to have it supported by a thin plywood bearing. Even if the machine works for a while, you’ll probably find the shaft eventually makes the bearing hole bigger. That is, friction will wear out the bearing.

Sometimes the bearing is made by simply drilling a hole but if better support or less friction is needed something more substantial might be called for.

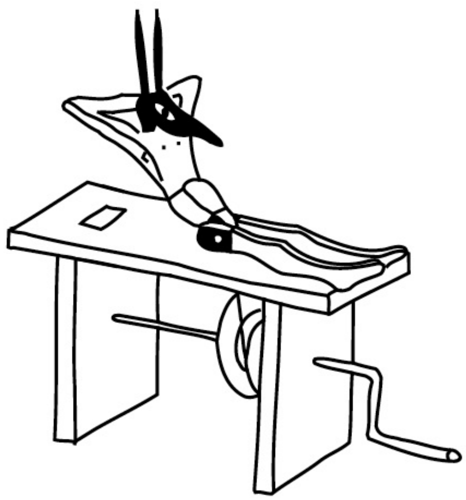
Ball Bearings

If you’ve ever tried inline skating with an expensive pair of skates you’ll know that the wheels turn very easily even with the heavy load of your body weight on them. This is because they have good quality bearings. The simplified illustration below shows how they are put together.





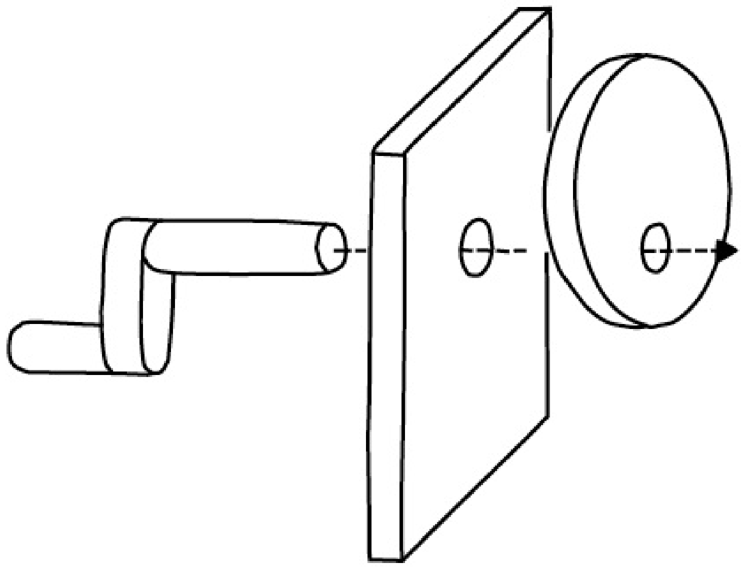
The outer race is fixed and the inner race rotates with the shaft. Because the balls can roll with a small area of contact with the races, the friction is very low. They are made very accurately from hardened, polished steel which also helps to reduce friction.



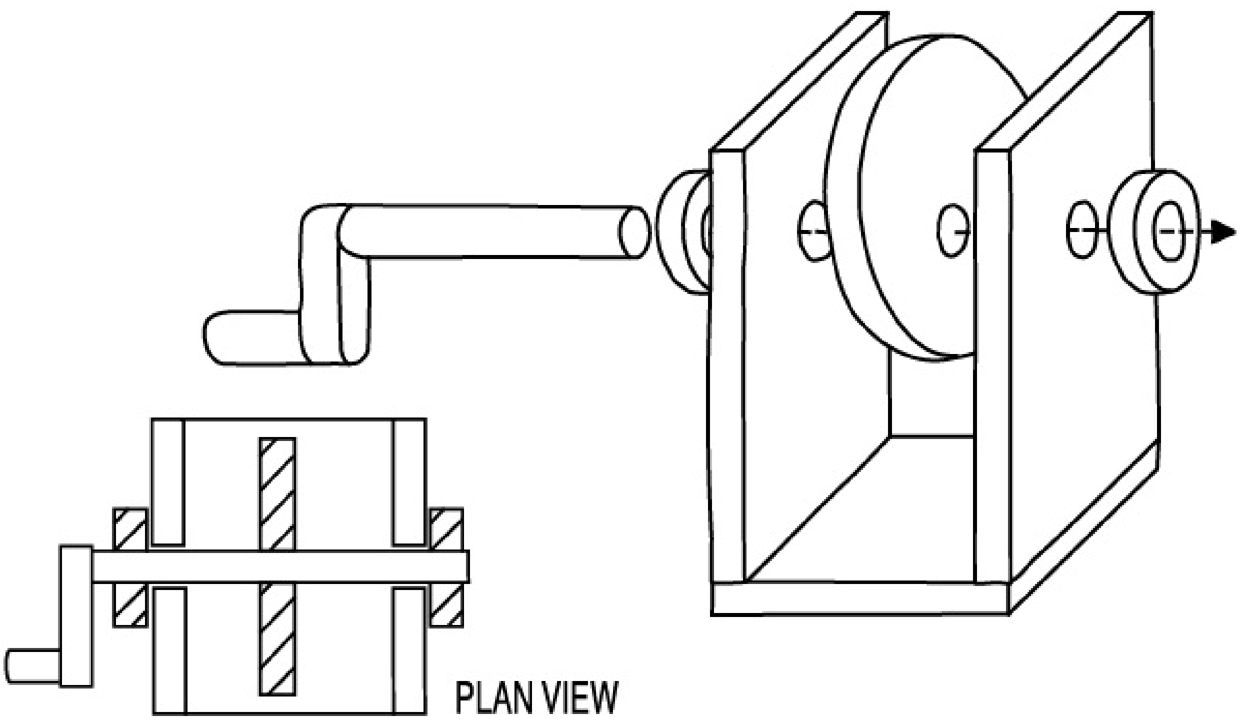
Sit-up Anubis by Paul Spooner
A simple wire shaft is bent at one end to make a handle. A thin shaft works because the moving parts are so light.

You should try to constrain the movement of shafts so that they only move in the way that you want them to. For instance, if you only want the shaft to rotate try to ensure that it doesn't move sideways.

In this simple example the shaft passes through a single bearing. It's attached to a handle and a disc. You could copy this with two pieces of cardboard and a drinking straw. Try it and see what problems you have. Make the hole in the disc off-centre and see how much weight you can lift up and down.

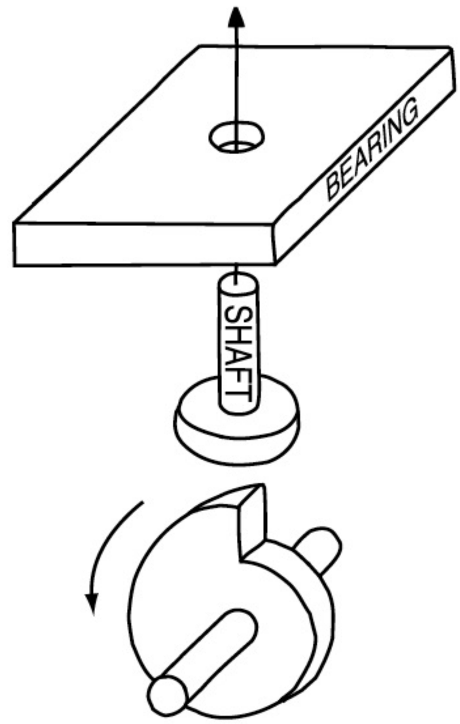


Here, a second bearing has been added to provide better support to the shaft. The discs, or collars, at each end of the shaft stop it from moving from side to side.

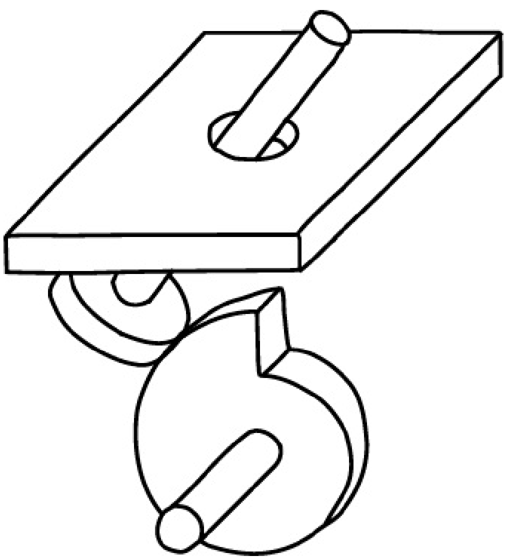


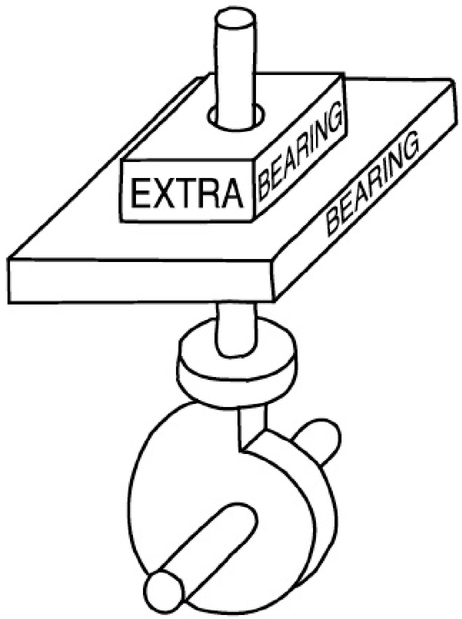
Shafts don’t only rotate in bearings. The snail cam shown here pushes a shaft upwards. This shaft also needs the support of a bearing.

If the bearing (in this case, just a hole) is too big, the shaft could easily move off-centre causing extra friction or jamming.

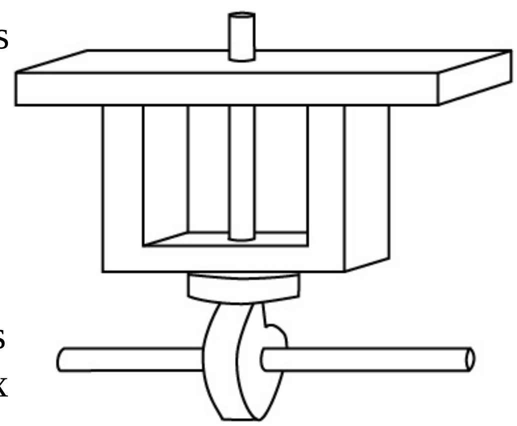


The same effect can occur if the bearing is too thin to provide adequate support, or if it’s too far from the cam.



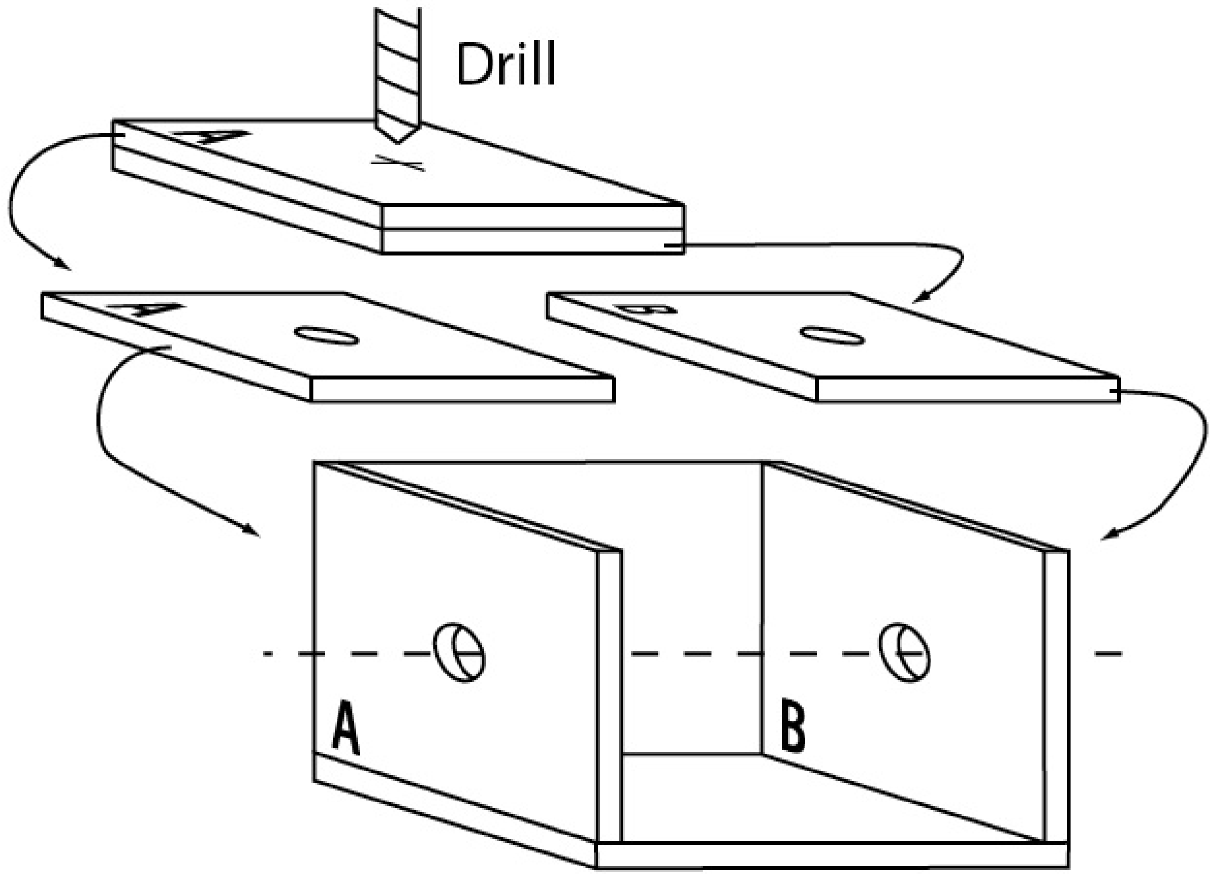


By adding thickness to the bearing the up and down movement of the cam follower is much more predictable. The diameter of the hole which forms the bearing should be just big enough to allow free up and down movement.



The additional u-shaped bracket shown here is a way to position a bearing as close as possible to the end of the shaft where the cam is pushing up.

Whenever bearings are working in pairs you need to take care that they are properly aligned. For example, if the bearings are holes at each end of a box, you could design the box so that the ends could be drilled at the same time.



If you’re working in wood and using dowel for shafts, then it’s always worth test drilling. You will find that the diameter of the dowelling can vary. A couple of test drillings (with a sharp bit!) into scrap wood will tell you which drill bit to use for your bearing holes.

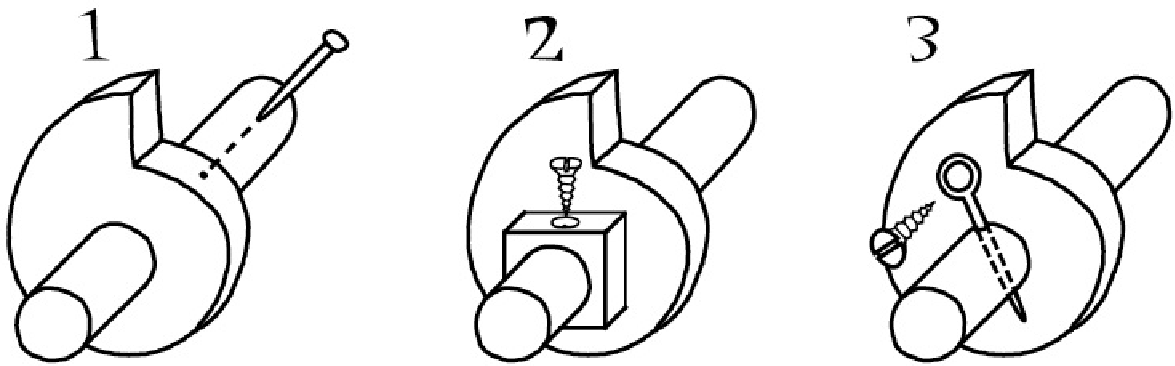
Fixing

You also need to think about how you will fix your cams and other mechanisms to the shaft. Below are three practical methods for avoiding the problem of the cam slipping on the shaft.

1- Pin the cam. A pin is pushed through a pre-drilled hole into the cam and the shaft.

2–Cam with hub. The hub is part of the cam or glued to it. A screw passes through the hub and into the shaft. This keeps the fixing away from the radial surface of the cam.

3–Screwed cross pin. This is similar to 2, but easier to make. A wire, or split-pin passes through the shaft only. A screw in the cam holds it in position.

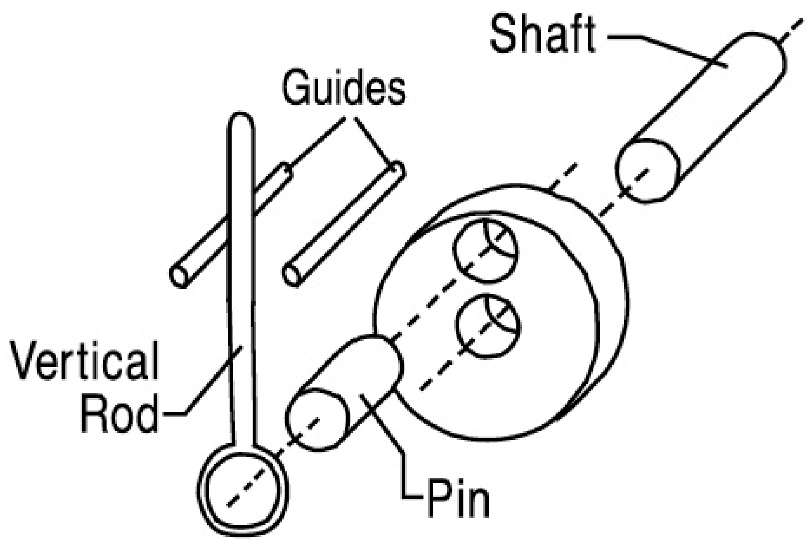


Yet another way is to have a square shaft. This is provides good fixing between the cam and the shaft, but it’s harder to make square holes in your cams. You also have to make the square shaft round at the ends if you want it to rotate smoothly.

If you decide to glue the cam and make the fixing permanent, you might want to give yourself a way of removing the complete camshaft from its box / bearings.

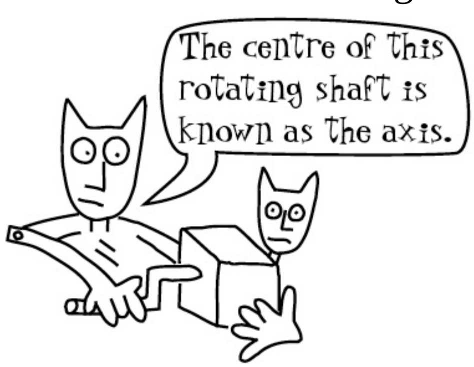
Cranks

A crank is a lever attached to a rotating shaft. Sometimes the crank is used to turn a shaft–for instance, when it is used as a handle, and sometimes the crank is driven by the rotating shaft. In this case the crank will change the type of motion.



The circular disc, with the pin, forms a crank on the end of the shaft. The pin connects to the vertical rod (it has to be loose enough to allow the crank to rotate). The movement of the vertical rod is constrained by the guides. When the shaft rotates the vertical rod moves up and down like a piston. This up and down movement is called reciprocating motion.

So the crank is converting the circular motion of the rotating shaft into the up and down motion of the rod.



The diagrams below show the crank in four different positions.

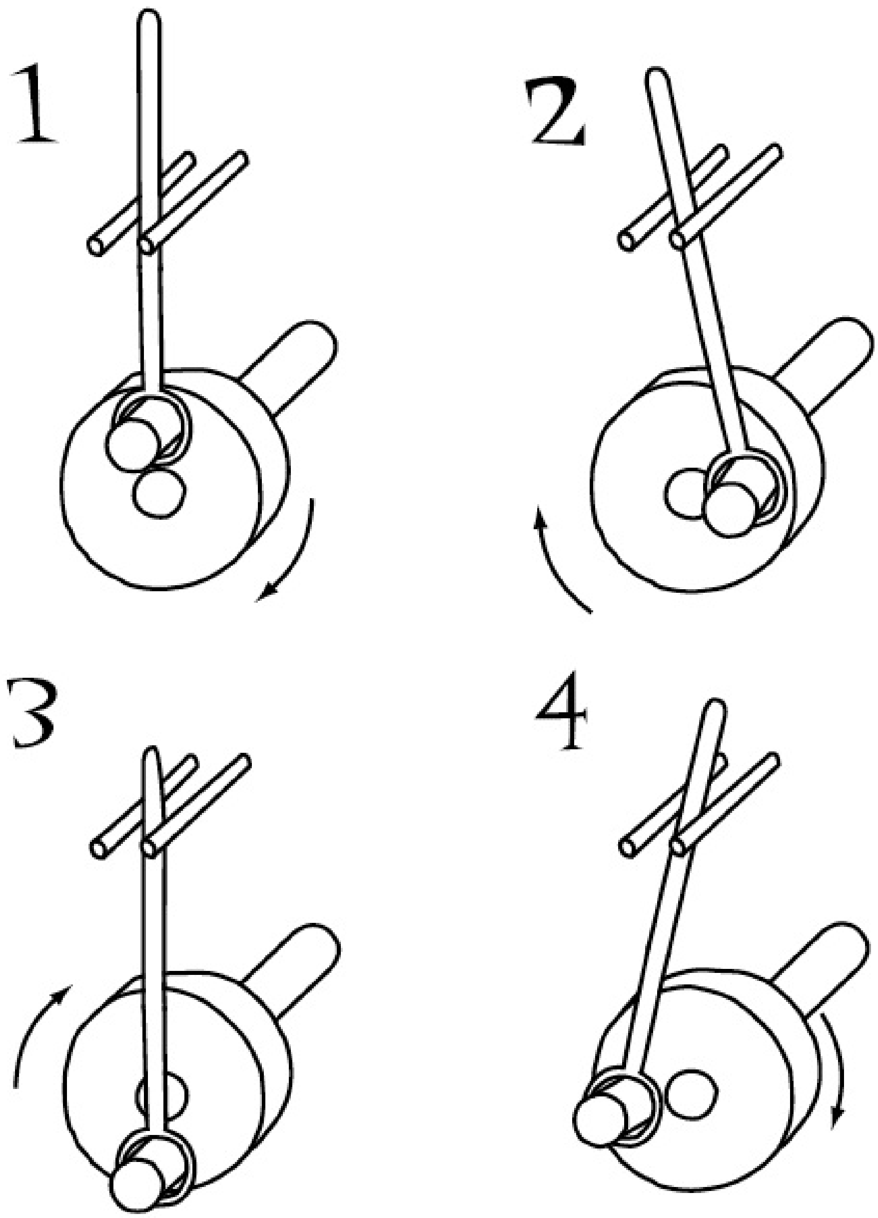
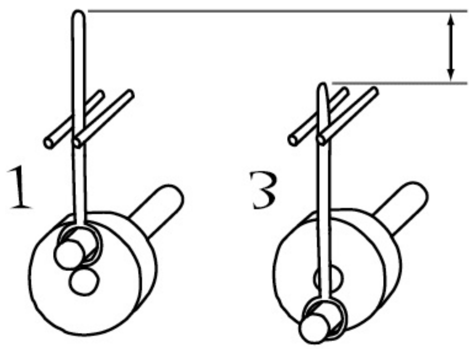
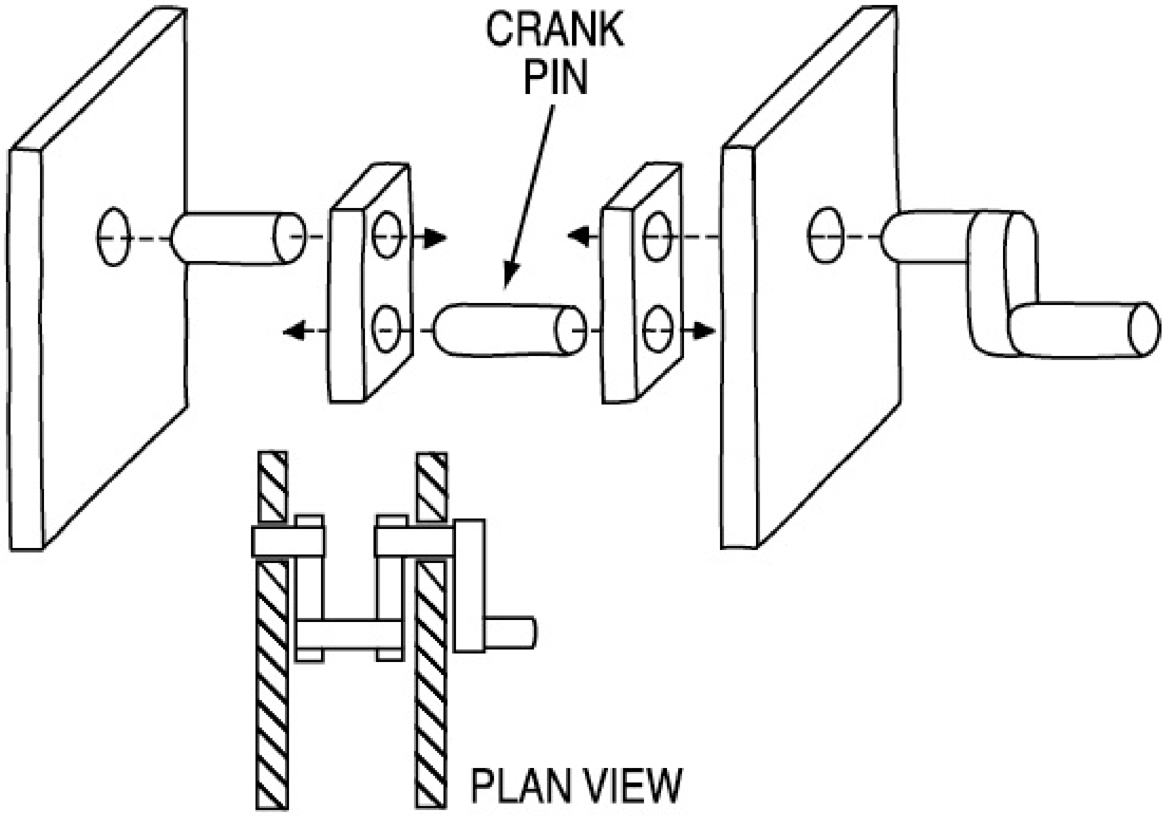


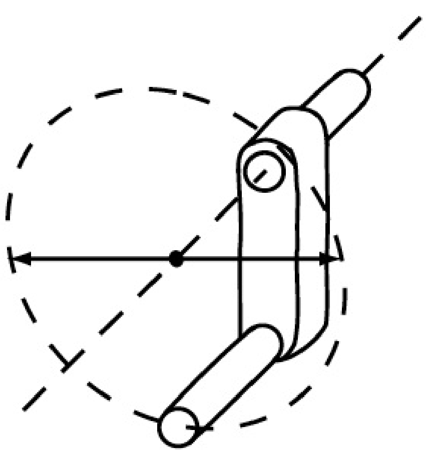
Diagram One shows the vertical rod at its highest position. Diagram Three shows the rod at its lowest position.



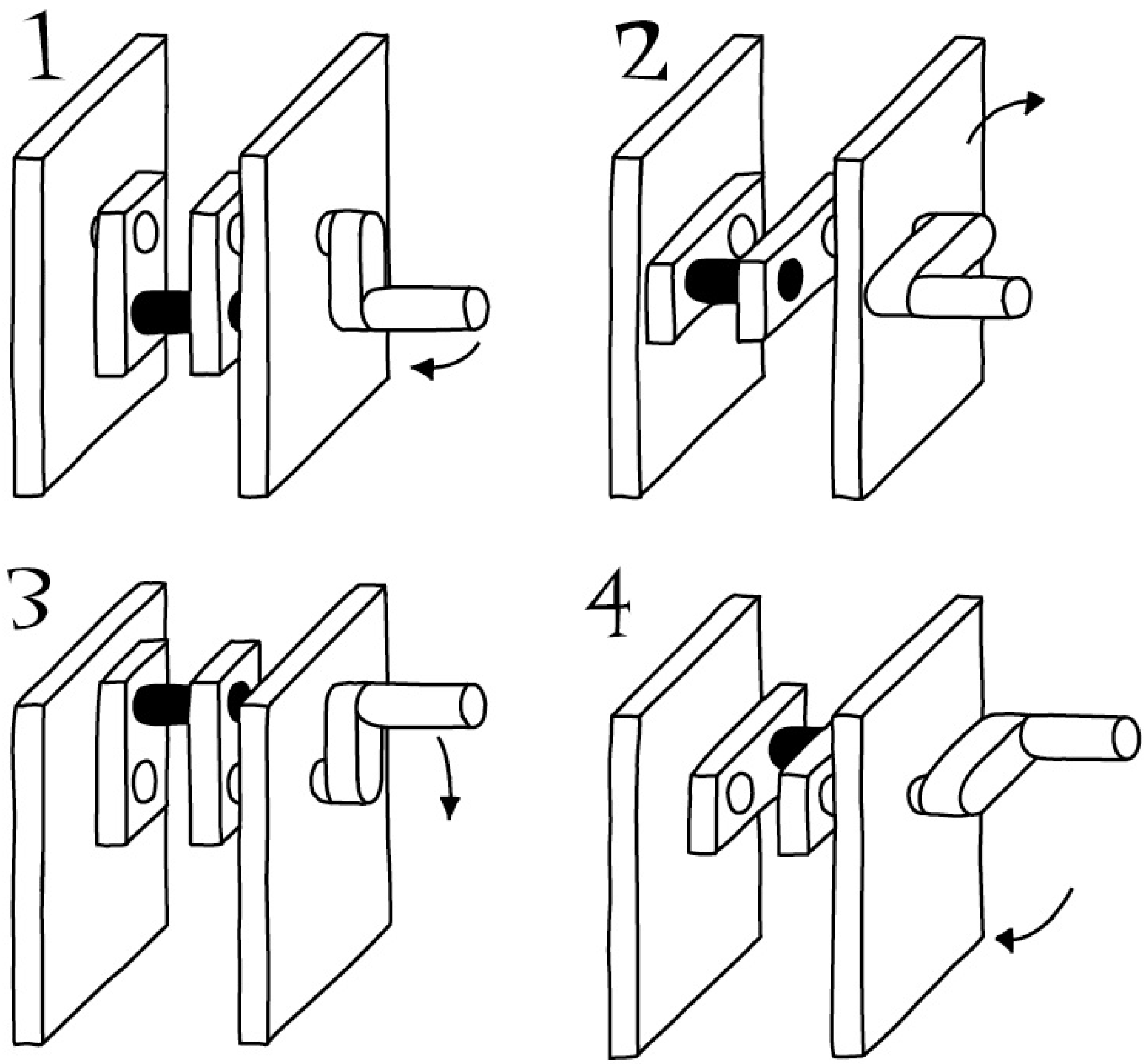
The difference between the rod’s highest and lowest positions is shown in this diagram. The lines indicate the amount of vertical movement created by the crank.



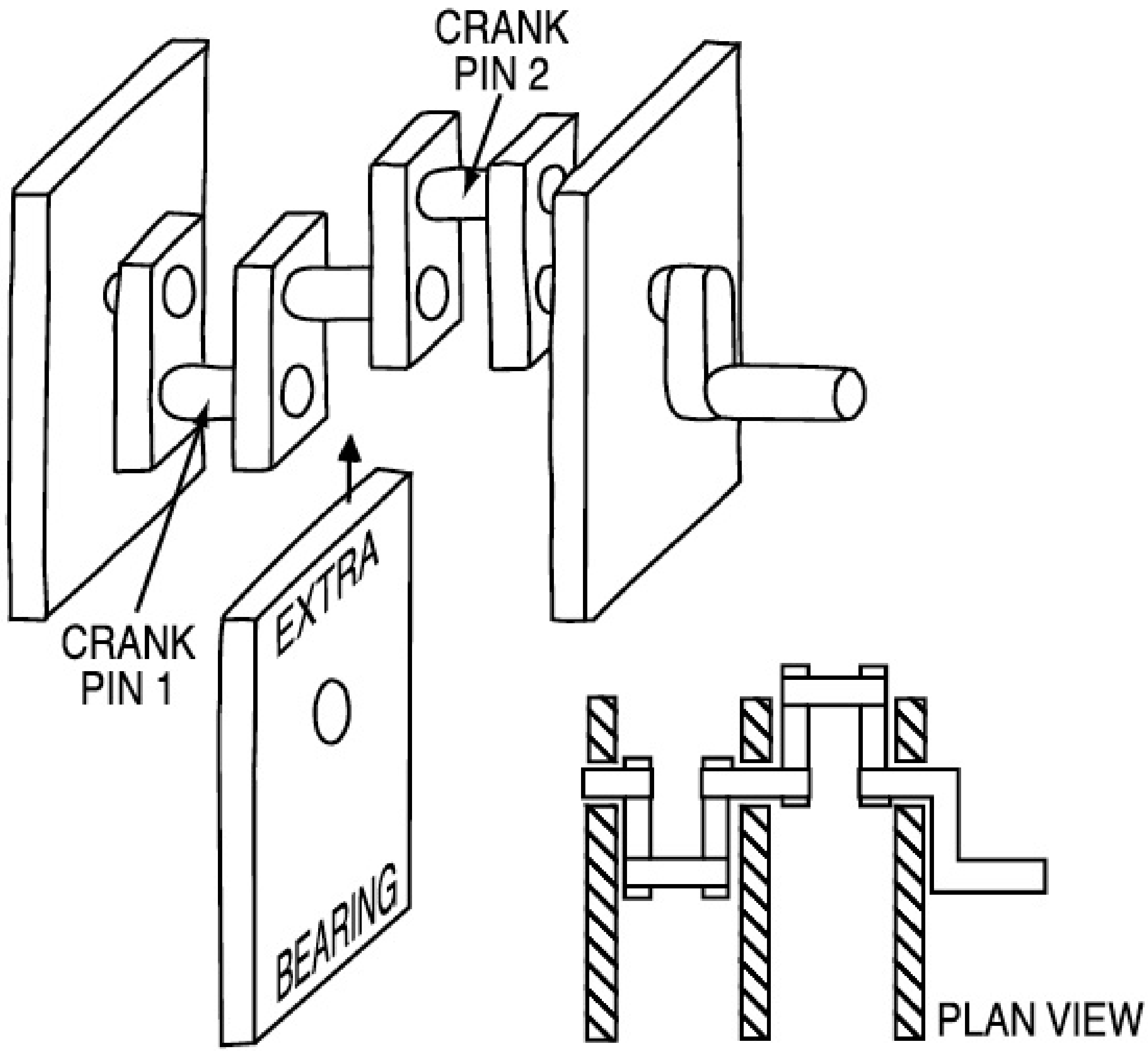
The rotating shaft will often need to be supported (by bearings) on both sides of the crank. In this case, the crank will look more like the illustration above.



The arrows in this diagram also show the ‘throw’ of the crank. The throw of a crank is the diameter of the path it travels.

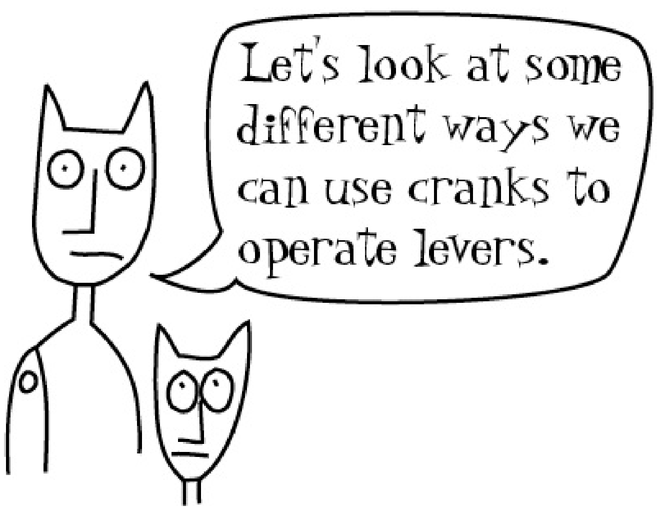


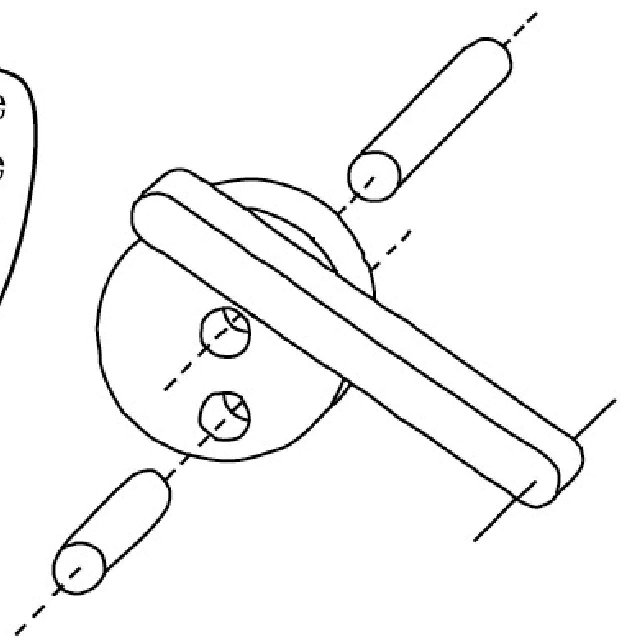
In this sequence it can be seen that the crank pin (black) is simply repeating the motion of the handle.



You can add as many cranks to a shaft as you want but you will probably need extra bearings to support the shaft.

You can also offset the cranks from each other so that they are in different positions at different times. In the example above, when one crank is up, the other is down .

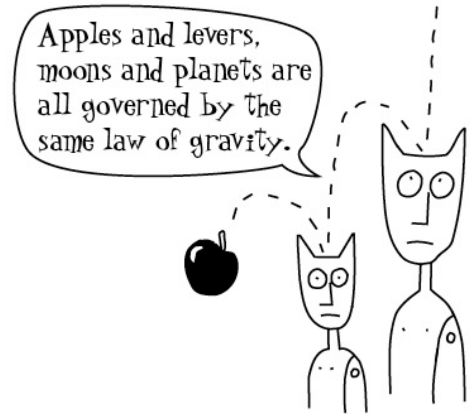


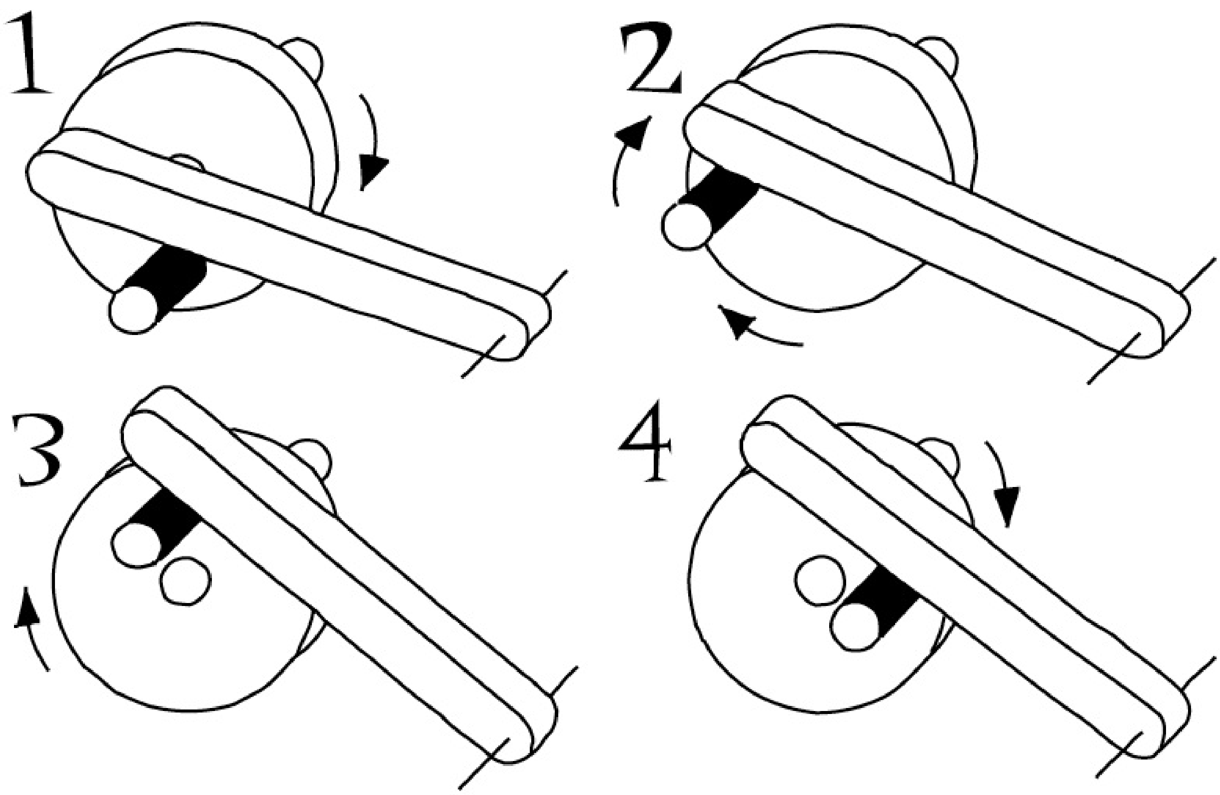


Here the crank will lift the lever through a small arc as the shaft rotates. Gravity will tend to keep the lever in contact with the crank pin. There's an assembled view on the next page.

Gravity

Gravity is the force that attracts bodies to the centre of the Earth. This happens because objects are attracted to each other with a force which is proportional to their mass. The Earth has a lot of mass so it pulls all the smaller objects towards its centre.

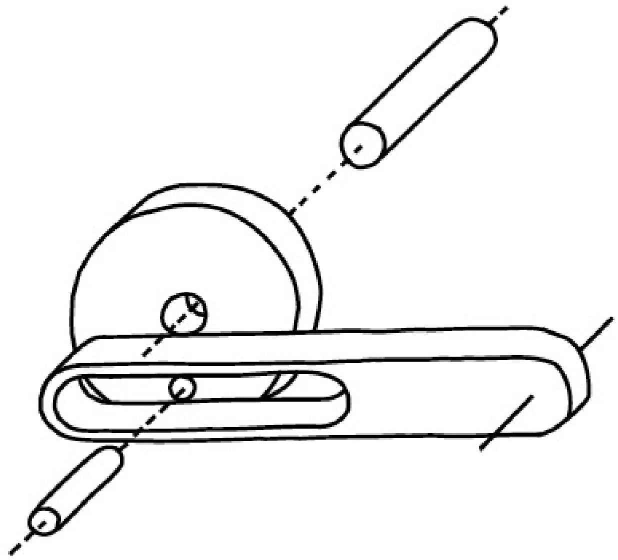




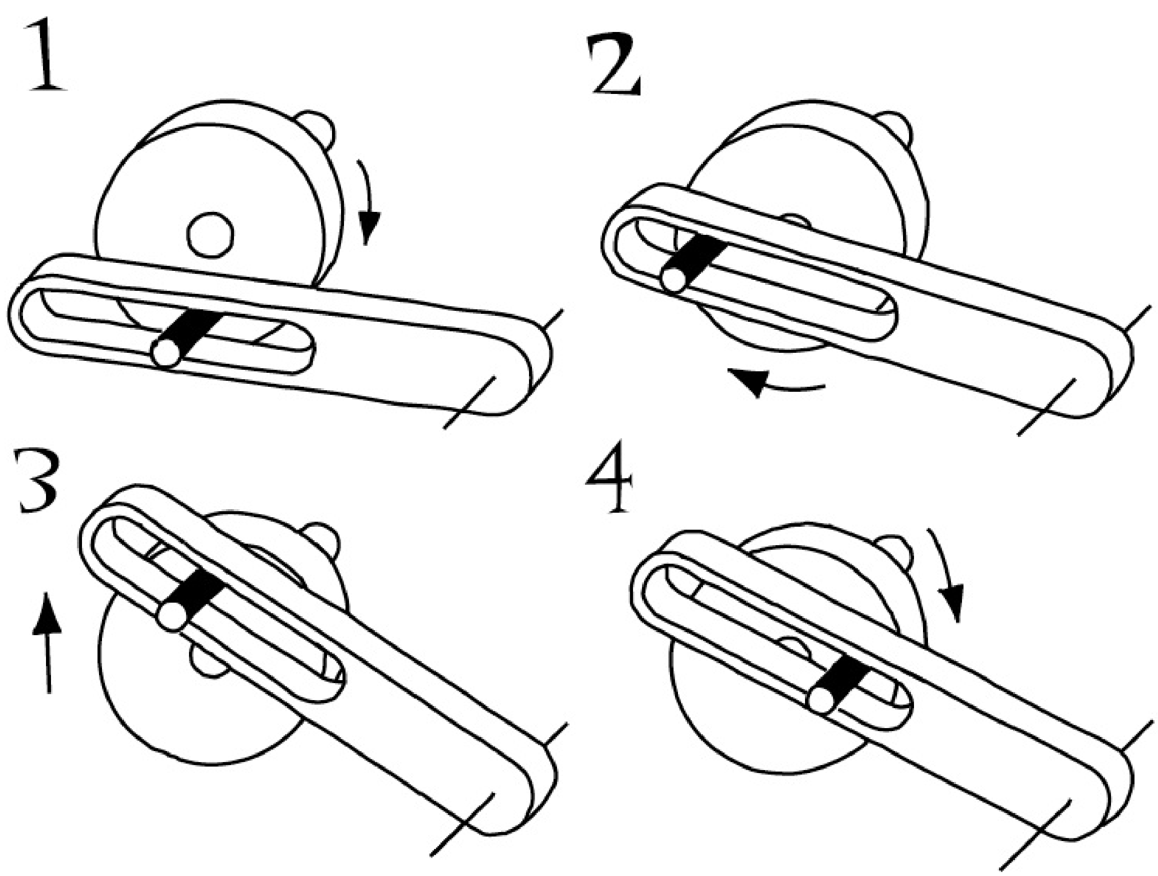
Here a lever is raised and lowered because it is resting on the rotating crank pin.

Number 1 shows the lever in its lowest position and 3 shows it in its highest position.

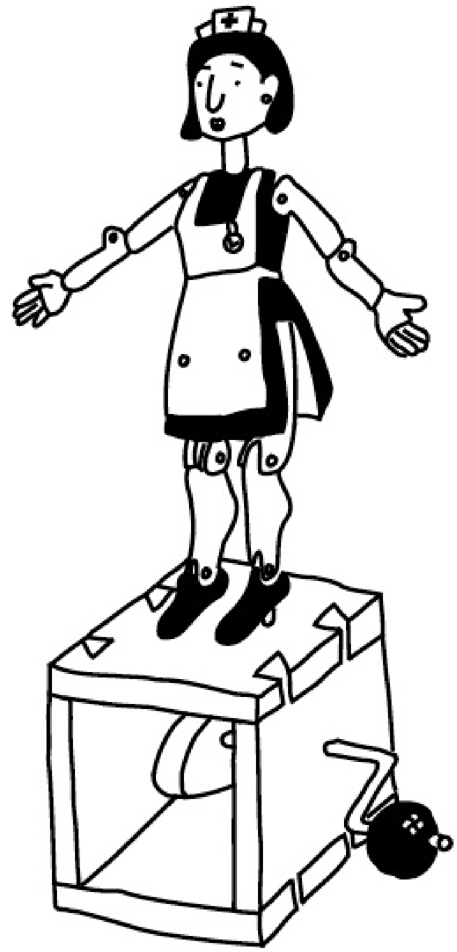
If the shaft rotates at high speed it is possible that the lever will not stay in contact with the crankshaft. If the lever is struck hard it may bounce up higher than expected. Also, It may not have time to fall back while the crank shaft is at the lowest position. The next design overcomes these problems.

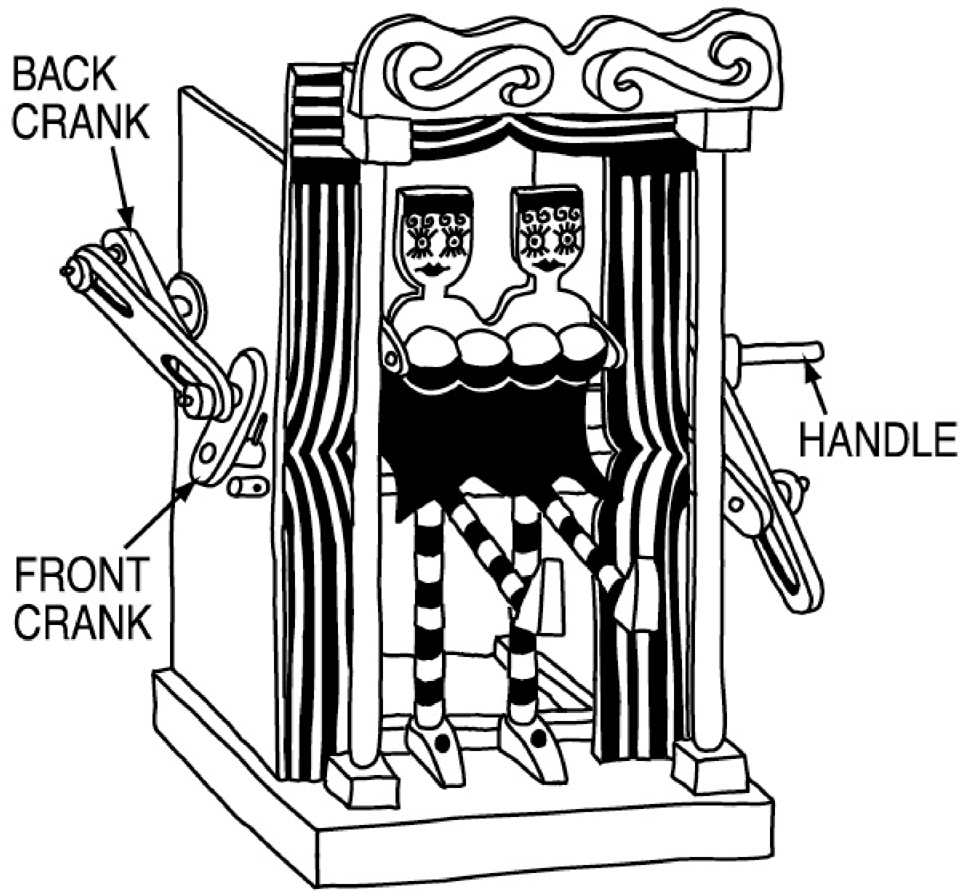


In this design the crankshaft passes through a slot in the lever. This means that the lever is driven up and down by the crank. This ‘positive’ connection doesn’t rely on gravity and the lever should always move through its expected path.



Jumping Nurse by Paul Spooner
The nurse has joints (shoulders, elbows, etc) which are loose enough to give a bit of "extra" movement when she's pushed up in the air by the crank and cam mechanism. The bead on the handle can rotate. This makes the crank handle easier to turn. Dancing Girls by

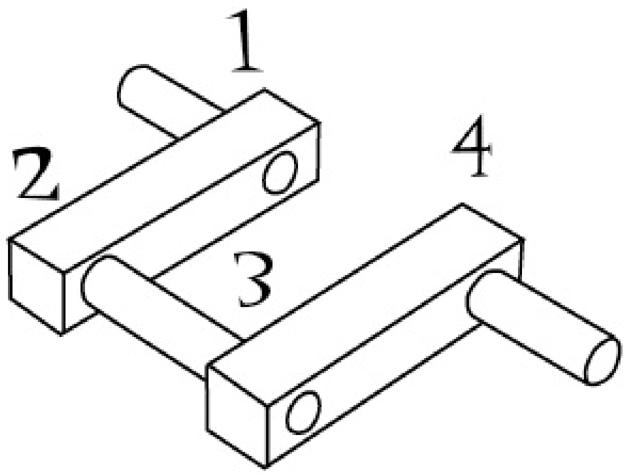


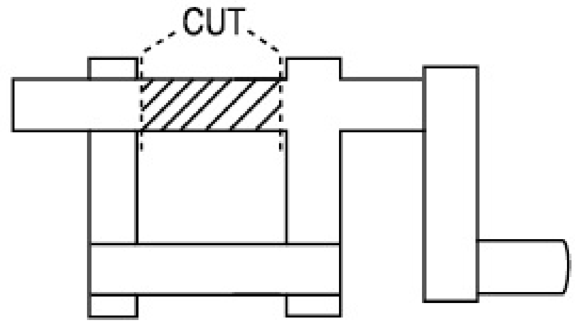


Peter Markey
The handle rotates a crank at the back which is connected to a crank at the front. You can see that the connecting piece has two slots which allow the cranks to rotate. Can you work out how the front crank will move? (Clue: It doesn’t do a full revolution).

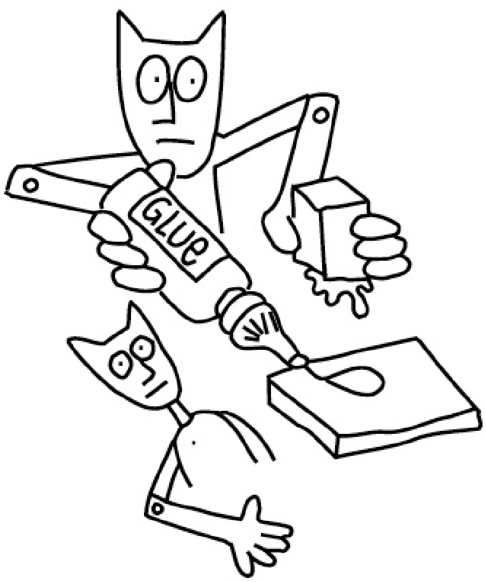
Practical

Although cranks seem simpler than cams they can be harder to make. A cam on a shaft has only one fixing point but if you make a crank from parts there are four points to fix.





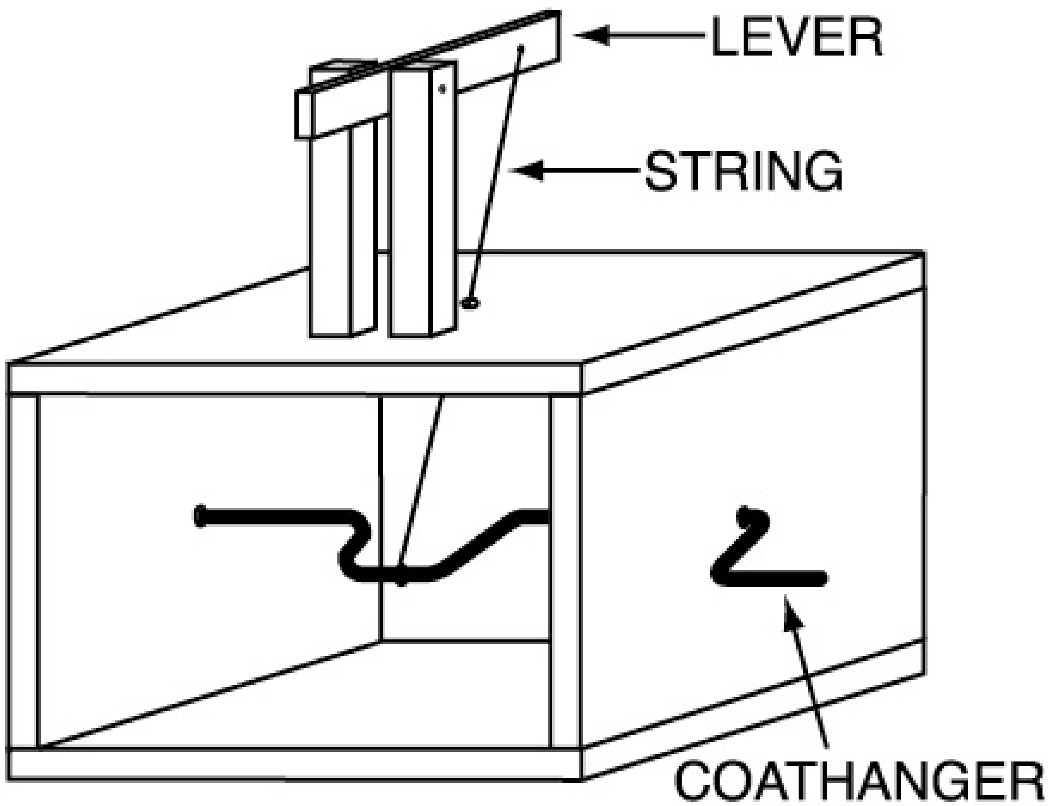
A tip for getting the shafts to line up is to make the crank on a single piece and then cut out the part you don’t want when the glue has set.



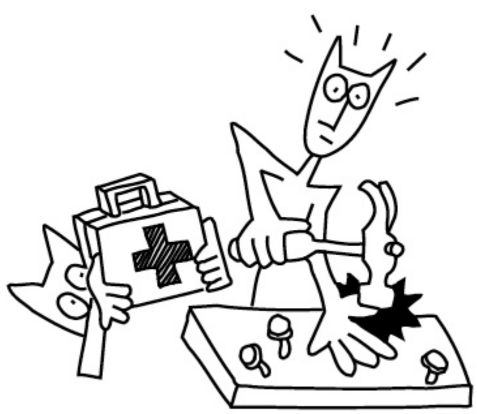
Whichever way you construct the crank it’s important to make sure that everything is “square” (at 90O or parallel), in alignment and firmly fixed. Work out the throw of the crank first because it will be hard to change after you’ve made it.

However, wire is quite easy to change, so see what you can do with a pair of pliers and a coathanger (welding rod may be easier if you happen to have some).

If you’ve read everything so far but still haven’t got your hands dirty then maybe it’s time to start. You will learn much more about the practicalities by playing with materials and mechanisms than by reading.



If you've never made anything mechanical you might be tested by the simple device above. We've left out lots of information, but here are some points to consider: What material will you use for the lever pivot? If the string pulls down the lever, how will it go back up? How can you stop the string from slipping off the crank?

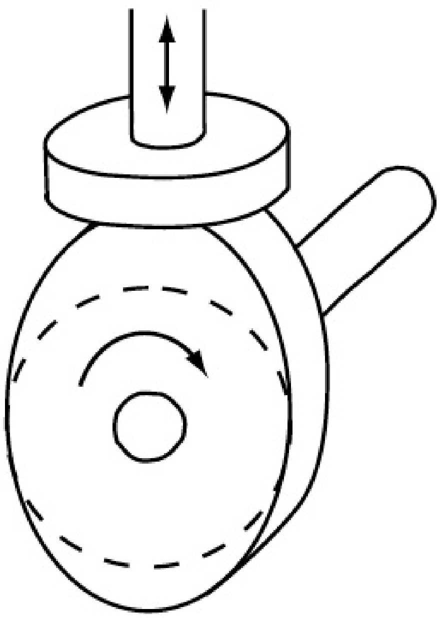


If you find it easy, attach something to the lever. How about a jointed leg and foot? Add another crank and another leg and you'll have a pair of dancing legs.

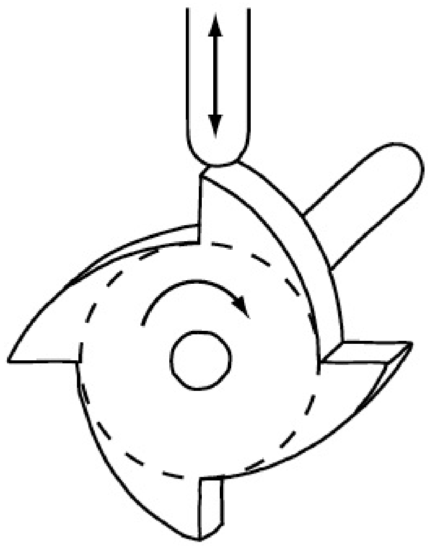
Don't be scared–make a mess with cheap materials and don't be put off if it's a struggle.

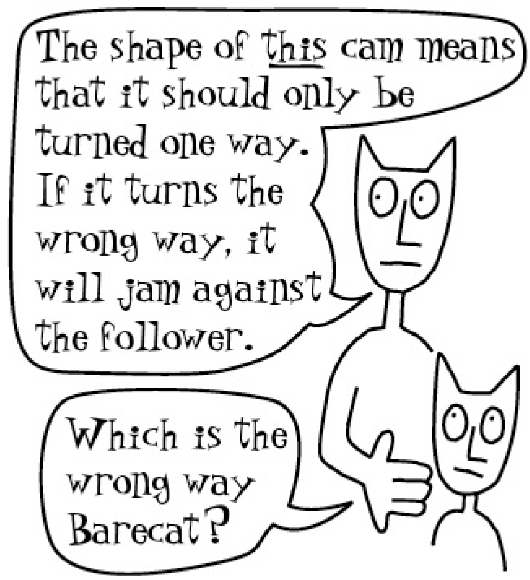
Cams

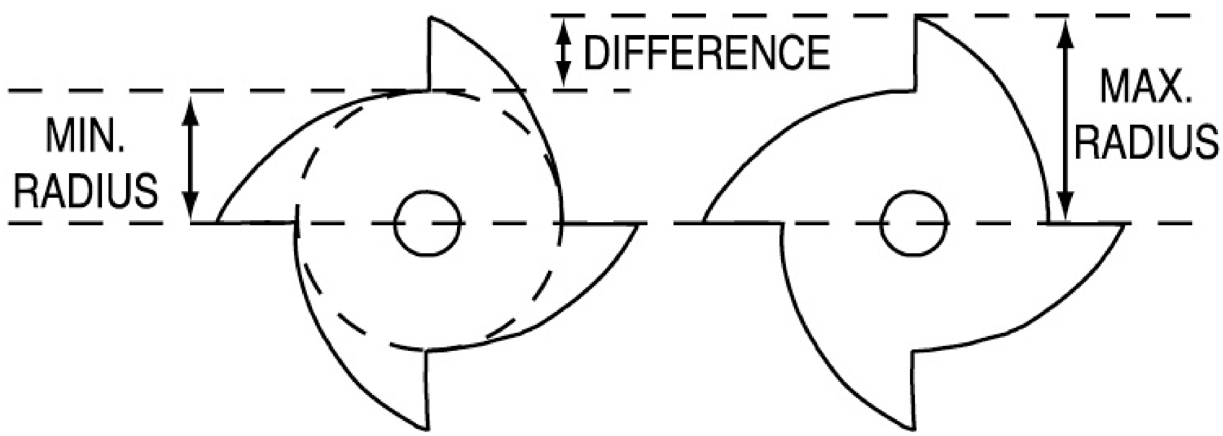
Like cranks, cams can also turn a rotary motion into an upward and downward motion. But they can also do lots of other more complicated things. Cranks are useful but you can have some real fun with cams.



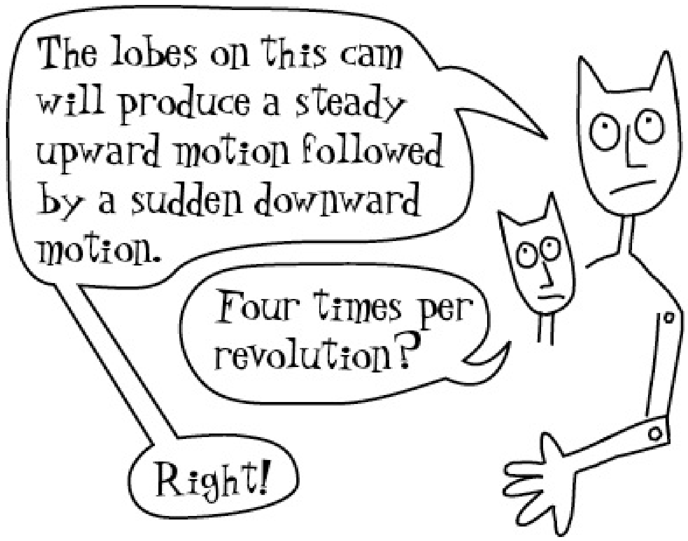
Cams come in many shapes. The two on this page are called lobed cams because they have lobes. A lobe is just an addition to the circular shape.







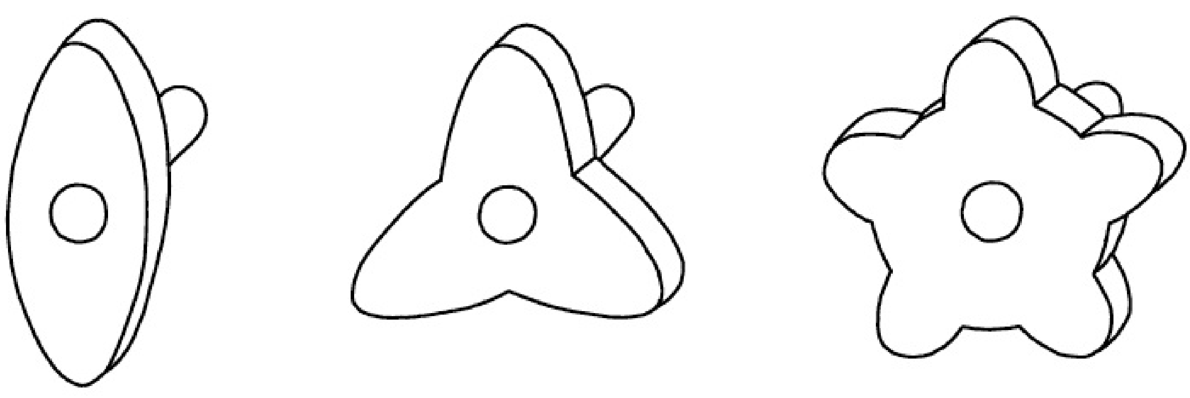
As with cranks, the throw of a cam and the amount of movement it creates, is the distance between the maximum and minimum radii. This diagram shows the difference between the lobed cam’s highest and lowest points. The arrows (at ‘Difference’) indicate the amount of movement or throw created by the rotating cam.



One complete revolution of the cam is called a cycle. For the four-lobed cam there will be four distinct events per revolution. The timing of the events in a cycle depends on the speed of rotation.

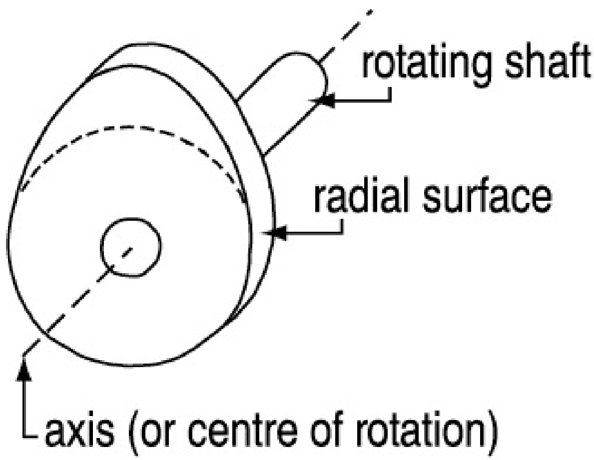
This cam will produce one event per revolution. Not surprisingly it’s known as a snail cam.

These lobed cams will produce two, three and five events per revolution. You can probably guess that to produce a very long sequence of events you need more space on the cam profile. That means you need a bigger cam.

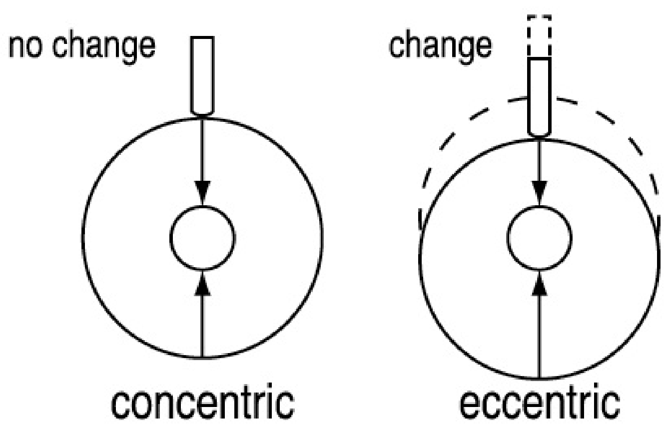


Who are you calling eccentric?

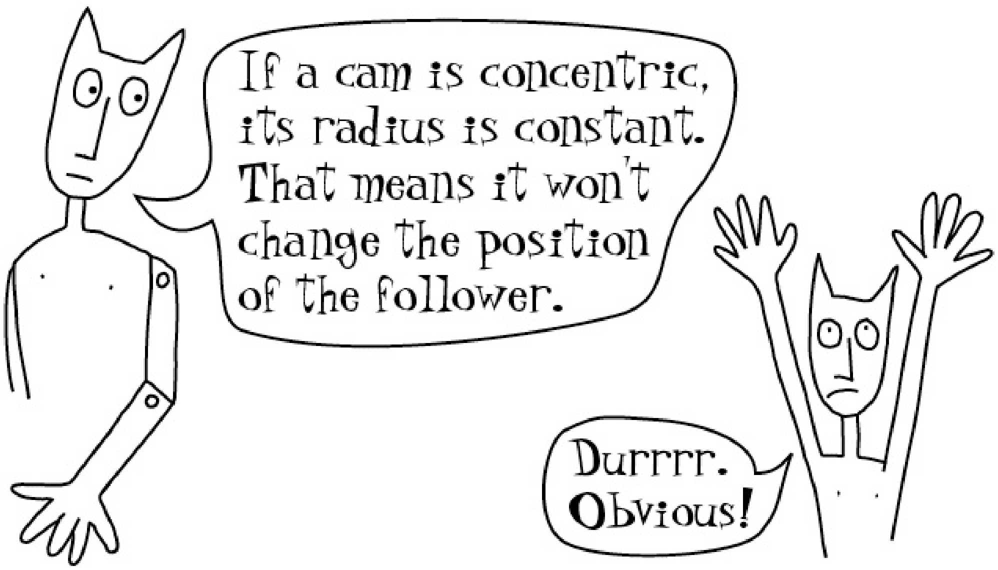
In this illustration, the variation of the cam's surface from the axis will cause a follower to either lift or drop.



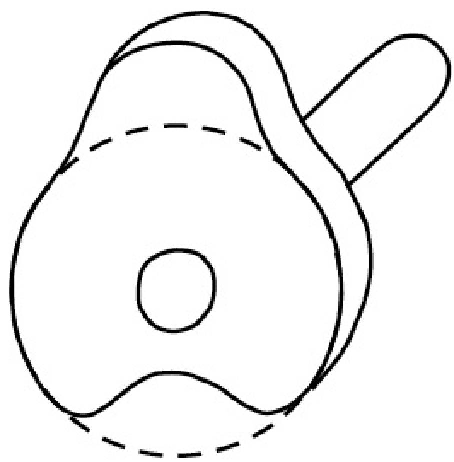
It is also possible to make a cam from a circle. You do this by moving it's centre of rotation. This type of cam is known as an eccentric cam and The part that the cam moves is called the follower. This is because it follows, or tracks, the profile of the cam.

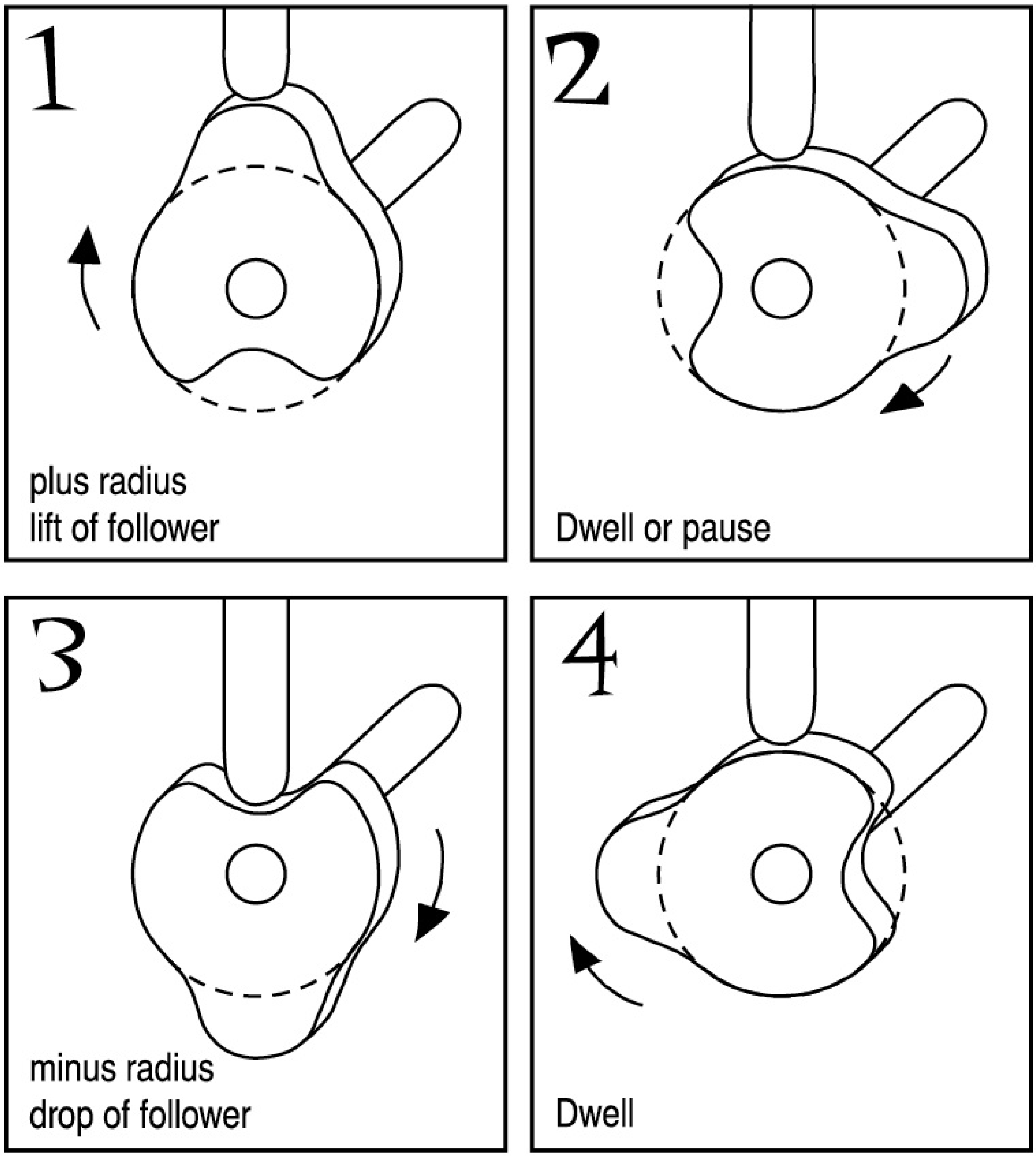


So, being eccentric just means that you're a bit off-centre. If you take a circle and rotate it off-centre you'll have an eccentric cam. This produces a very smooth movement which makes it good for lifting heavier loads. Be careful not to make the eccentricity too extreme though.



This cam has a raised and a dipped radius. At the points where the profile returns to the constant radius no movement will occur in the follower. This part of the profile is known as a pause or dwell angle. You can see this more clearly in the sequence below.





Getting Practical

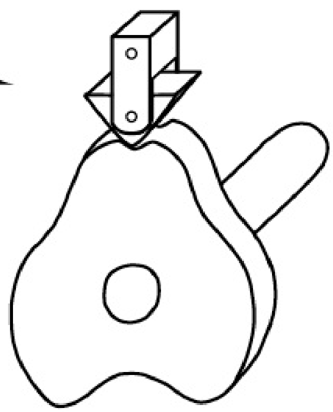
It’s one thing to draw a cam that does exactly what you want but it’s another thing to make one that actually works.

Firstly, remember the previous advice about bearings. A smooth and true running shaft is always a good starting point. As well as the camshaft, don’t forget to consider the shaft which the follower is attached to–this should be well supported too.

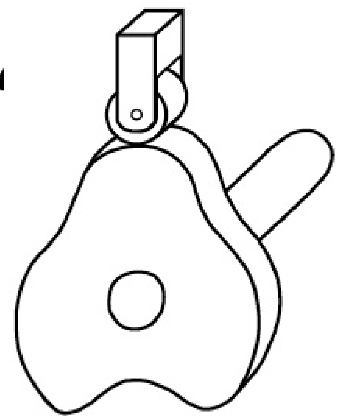
Don’t try to get a massive movement out of a tiny cam. Think of the cam as a lever–more leverage will make the work of the cam easier. So a bigger cam will produce small movements relatively easily.

The shape of the follower where it’s in contact with the cam is an important design point. You need to consider how it will follow the profile of the cam. A sharper point on the follower will be more able to track intricate variations (1, below). The other important consideration is friction and if you want to reduce it, then it’s a good idea to use a free-running bearing or roller (2).

1



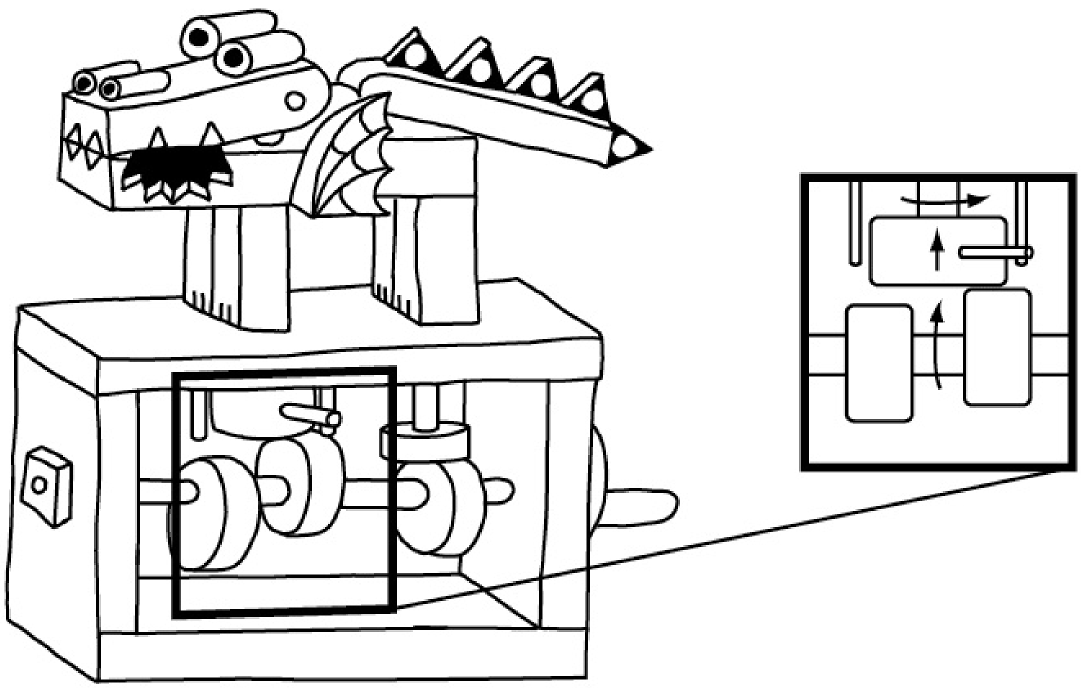
2



You also need to consider the direction of rotation. Some cams, like the snail cam, will jam against the follower if they rotate in the wrong direction.

A lot of the simpler machines that are sold in Cabaret Mechanical Theatre use cams to rotate a follower and produce rotation in a different plane. Strictly speaking, this sort of mechanism is a friction drive (chapter 9). The cam and follower are working like a pair of gear wheels at right angles to each other.

For example, the fire in the Dragon’s mouth (below) moves from side to side as the top jaw moves up and down. In the diagrams you can see how it works.



Dragon by Peter Markey

The cam on the left lifts and rotates the follower clockwise (if viewed from above). Then the second cam, on the right, lifts and rotates the follower anti-clockwise. So, a single mechanism is acting as a cam and a friction drive.

The small pins on either side of the follower stop it from rotating too far.

It should be clear that using cams this way is not terribly efficient. However, these mechanisms work well enough for use in simple wooden toys. In more serious applications, you might use bevel gears to achieve the same result. We’ll look at gears later.

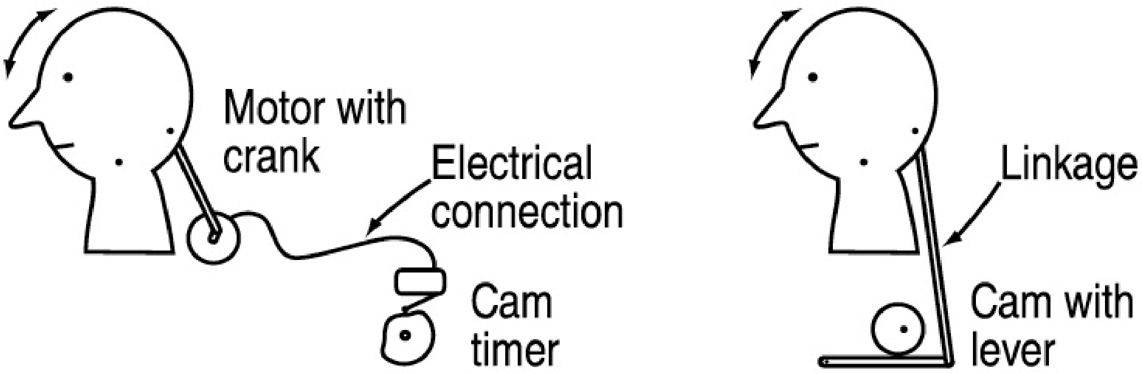
Cams for Memory and Switching

Unlike cranks, cams have the ability to store information. So another way to look at cams is as the mechanical version of a computer program.

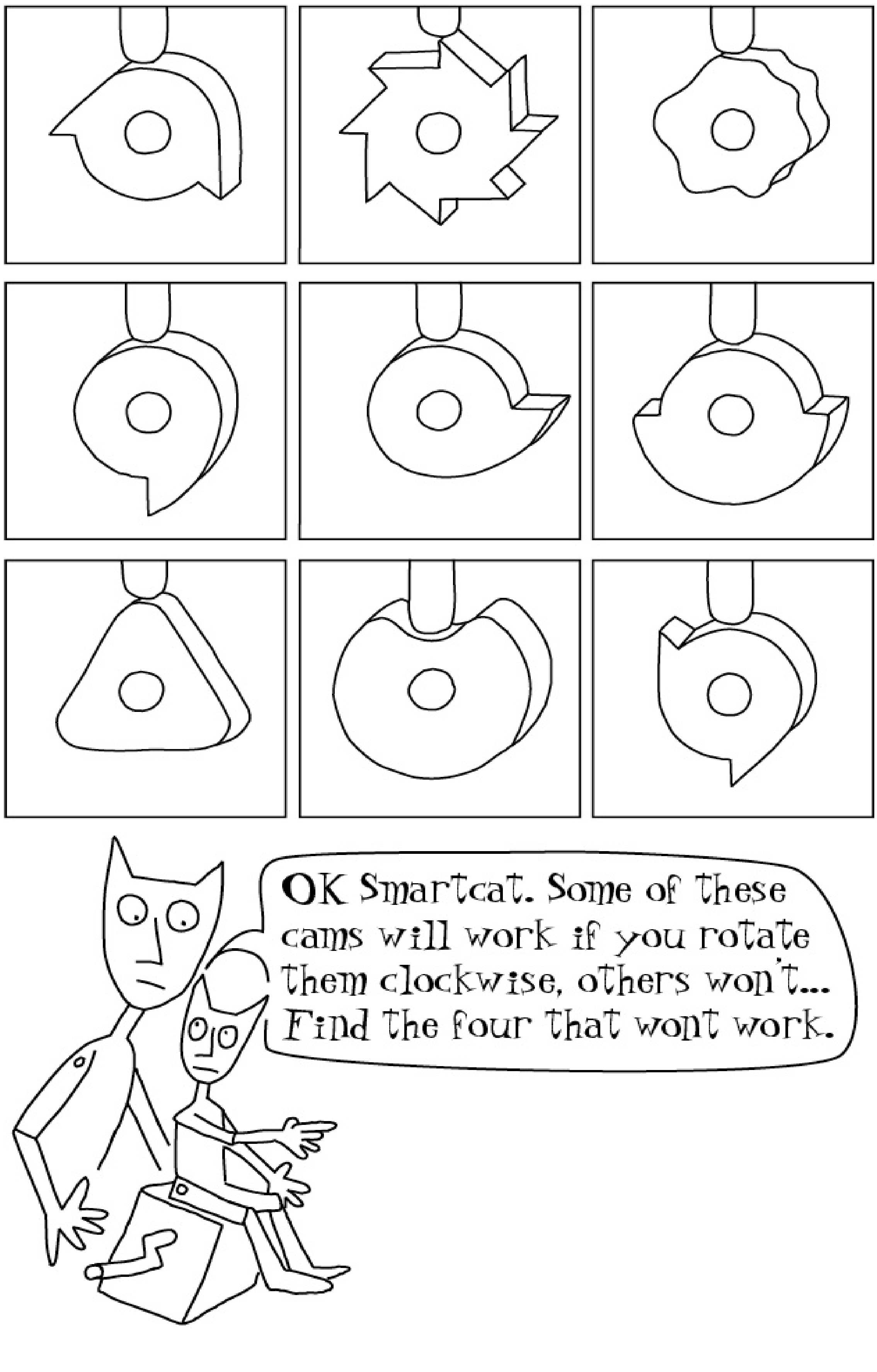
The information is stored in the shape of the cam. As the cam rotates, this information is retrieved by a cam follower. The follower tracks the cam’s profile reproducing the same movement for each revolution of the cam.

A series of cams on a single shaft can carry out quite complex programs. This is the way a lot of industrial processes were controlled before microprocessors took over and you might still find older washing machines with cam timers to control their various functions.

In these sorts of examples the cams operate switches which then operate relays, motors or other electrical devices. This is a way of simplifying, or replacing, the mechanisms in a machine.

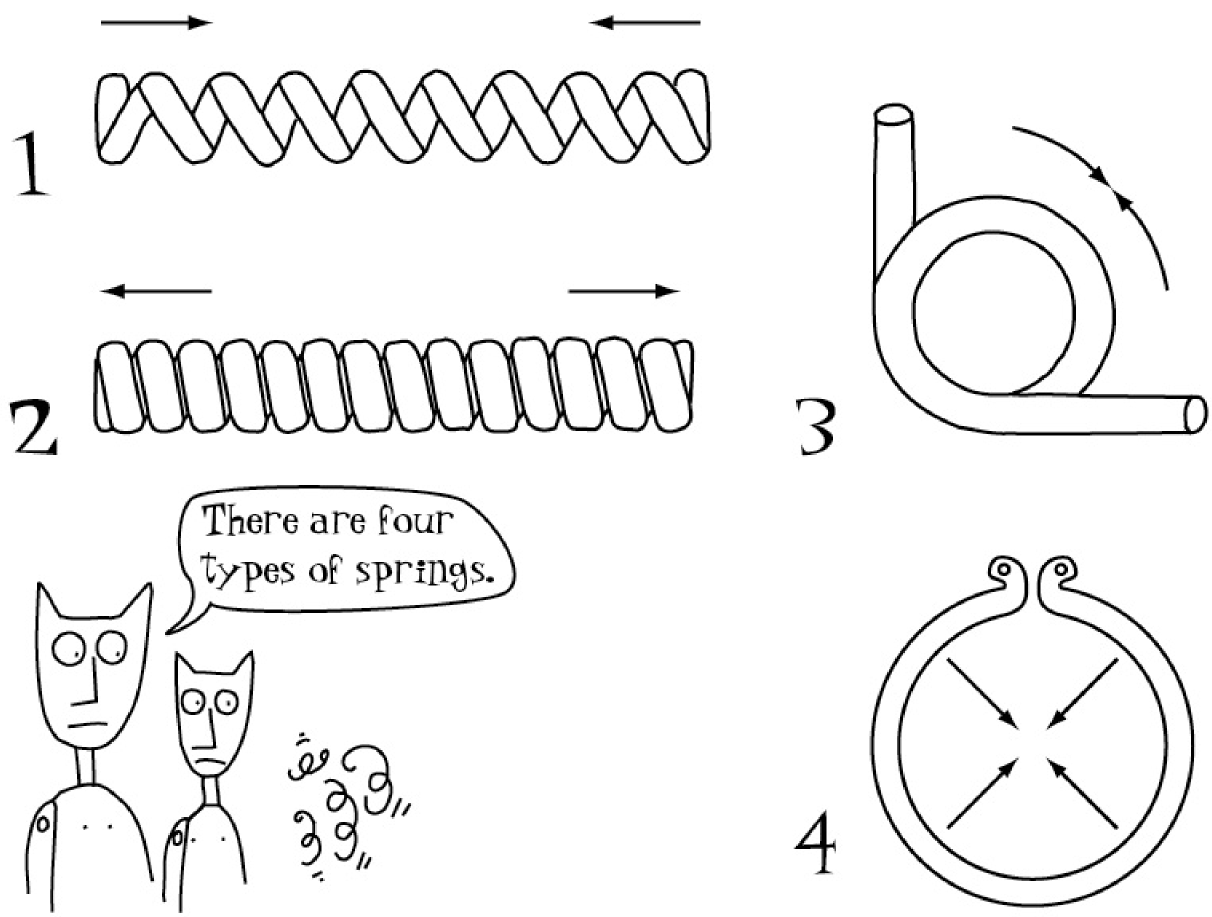


Two Different Approaches


OK Smartcat. Some of these cams will work if you rotate them clockwise, others won't... Find the four that wont work.

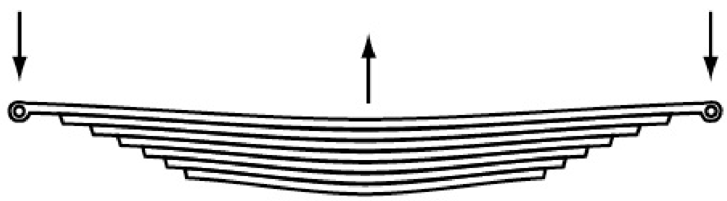
Springs

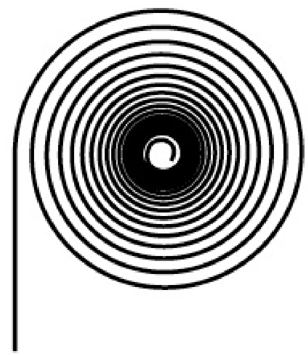
Springs have the ability to return to their original shape after stretching or compressing. This means they can be used to keep other components together or apart. Like cams, springs are also memory devices because they can be used to ‘remember’ a position and return to it after a particular action has occurred.



Springs come in lots of different shapes and they can be used in a number of different ways. These are the four basic types: 1. Compress (push), 2. Extension (pull), 3. Torsion and 4. Radial.

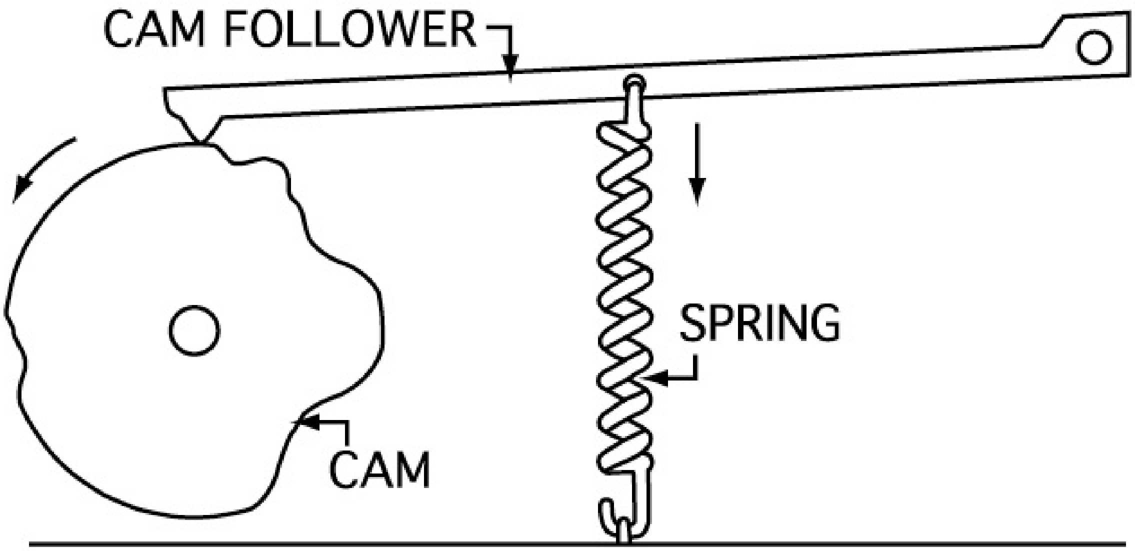
The definitions of spring types can be a little confusing. For instance, an elastic band can be used as an extension spring (firing pieces of paper across the classroom), a radial spring (stopping a rolled up poster from unrolling) or a torsion spring (driving the propellor in a model aeroplane). So you shouldn’t worry too much about the correct names.

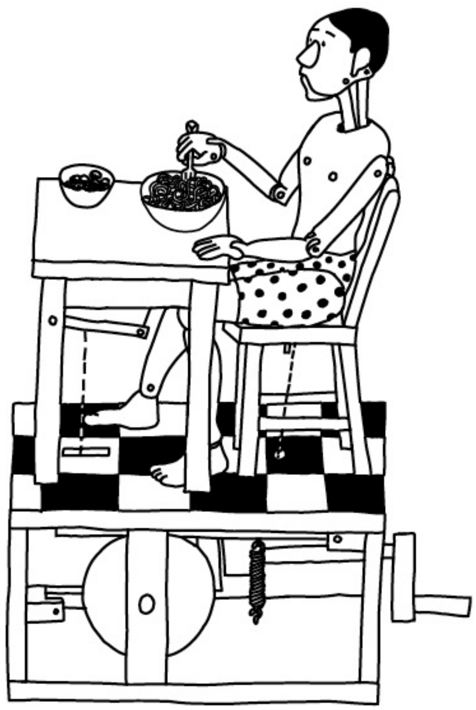




The laminated leaf spring above (left) is a special type of compression spring that is used in the suspension system of some cars. The coiled, or clock spring (right) is a type of torsion spring. In a clockwork toy, winding it up tightens it and the winding energy is stored in the spring. As it unwinds slowly the energy drives the mechanism which operates the toy.

A common example of spring usage would be when you need to keep a lever against a cam so that it follows its profile correctly.





In the previous diagram, the lever (or cam follower) should follow the shape of the cam through the action of gravity but if the cam rotates quickly the lever may tend to skip over some of the low points. The spring helps to ensure that it tracks the shape correctly. Of course, there is always a downside and in this case the spring will also increase the friction between the cam and the follower. For this reason, springs are often arranged so that their tension can be adjusted.

Most door handles have springs inside. After you've pulled the handle down to open the door, you want the handle to return to the up position with the latch out to hold the door closed.

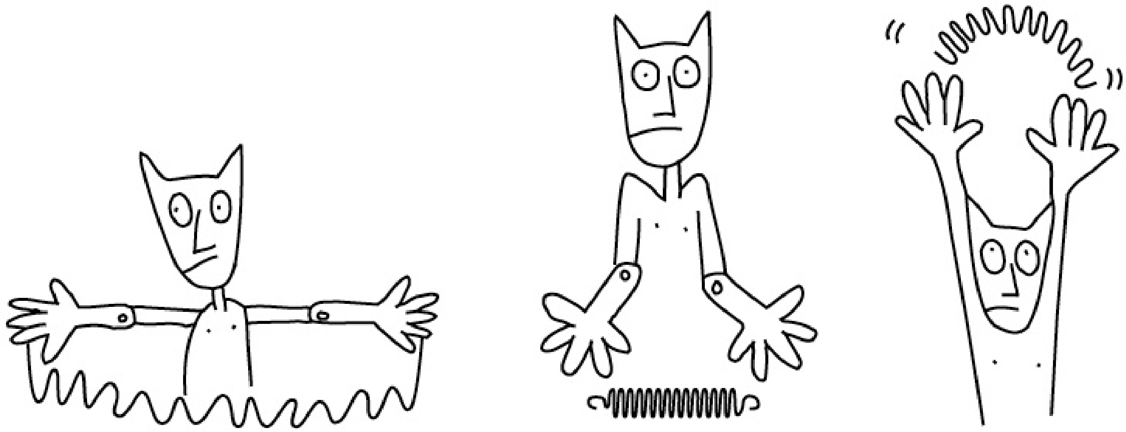
How to be Foreign by Paul Spooner

In Practice

You may find it’s easier to use a weight instead of a spring. In the cam example, a weight would give a constant load, whereas the load would vary with the spring. It may also be easier to adjust a weight.

If you do use springs, you may find yourself making your own from spring steel wire (piano wire) because all the springs you can find are either too strong or too weak. Old typewriters and small domestic appliances can be a good source for light springs.

If you ever meet an automata maker who boasts about his* fine and extensive collection of springs, ask him how many he has ever used.



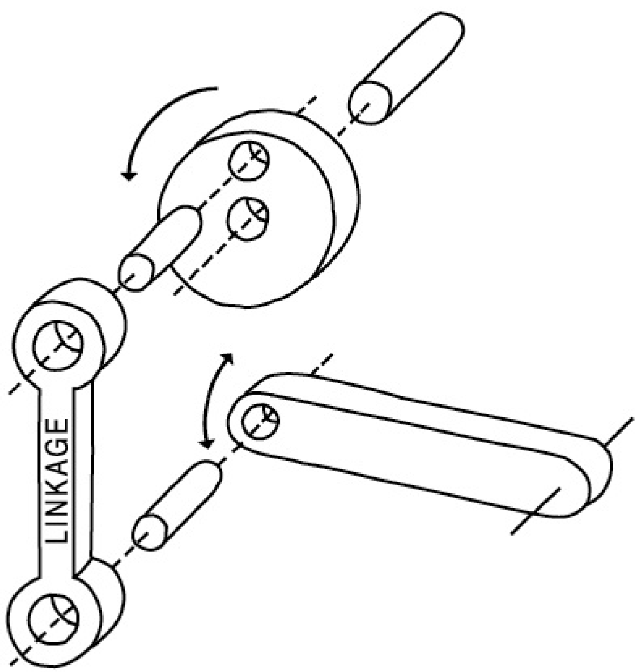
*his–only men boast about such things.

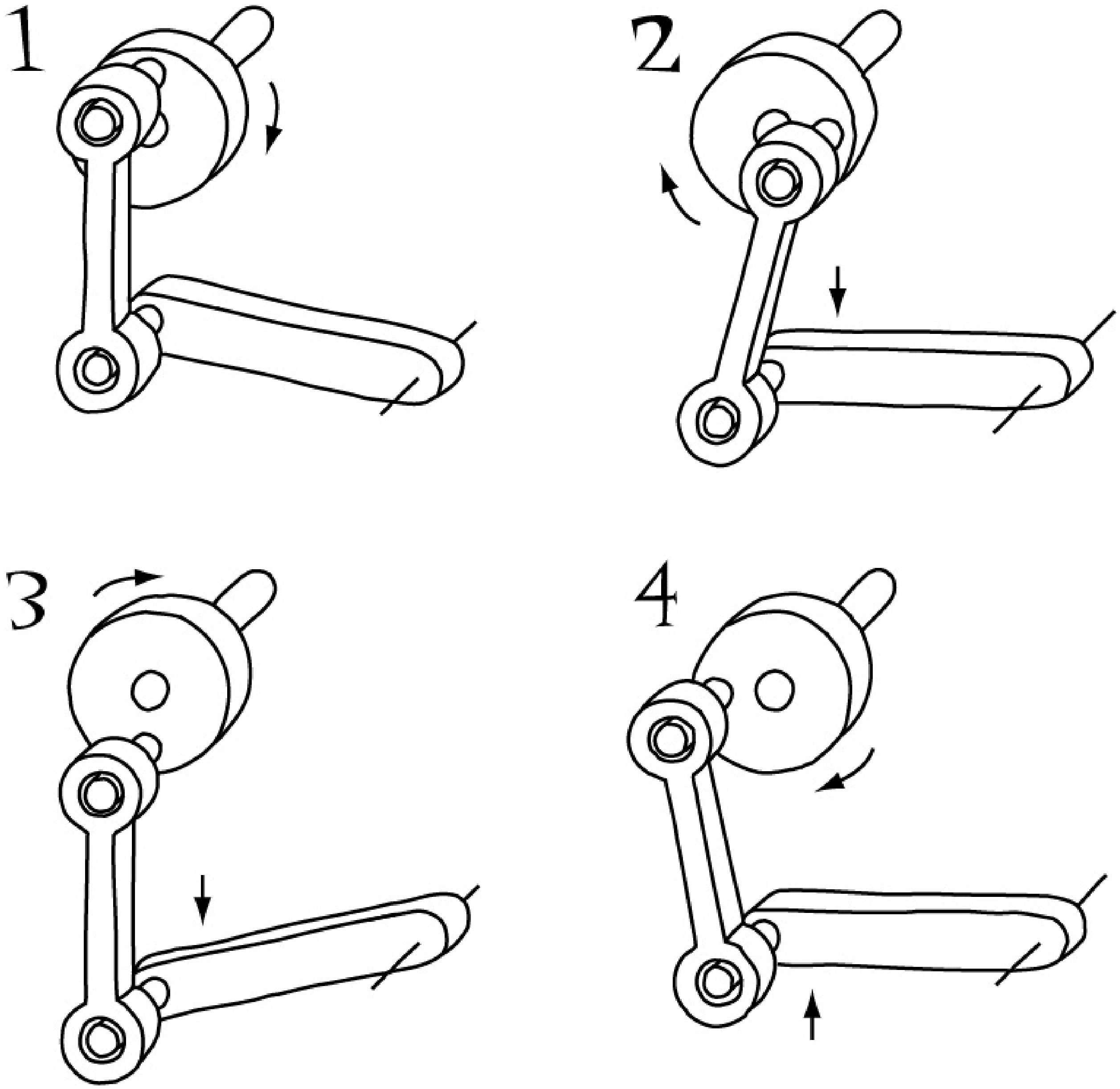
Linkages

A linkage is a connection that transfers motion from one mechanical component to another. Sometimes a linkage is a lever. So this is another occasion when you shouldn’t worry too much about the terminology.

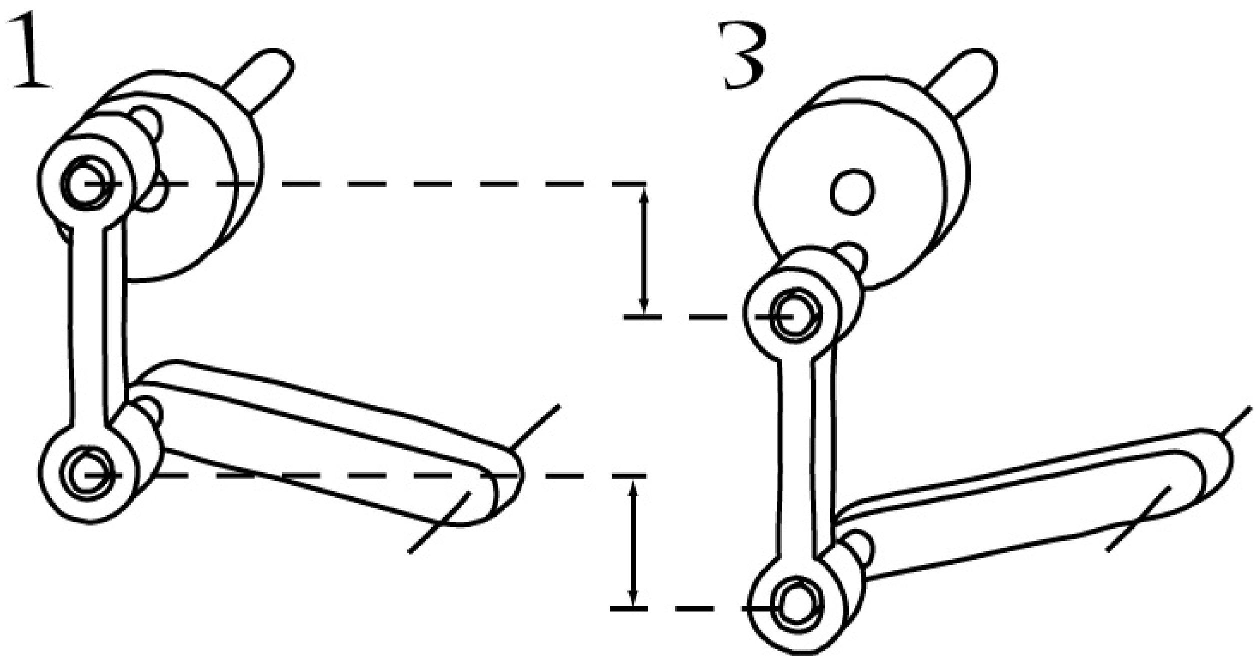
This exploded diagram shows a linkage connecting a crank to a lever.

As the crank rotates, the linkage transfers motion to the lever.



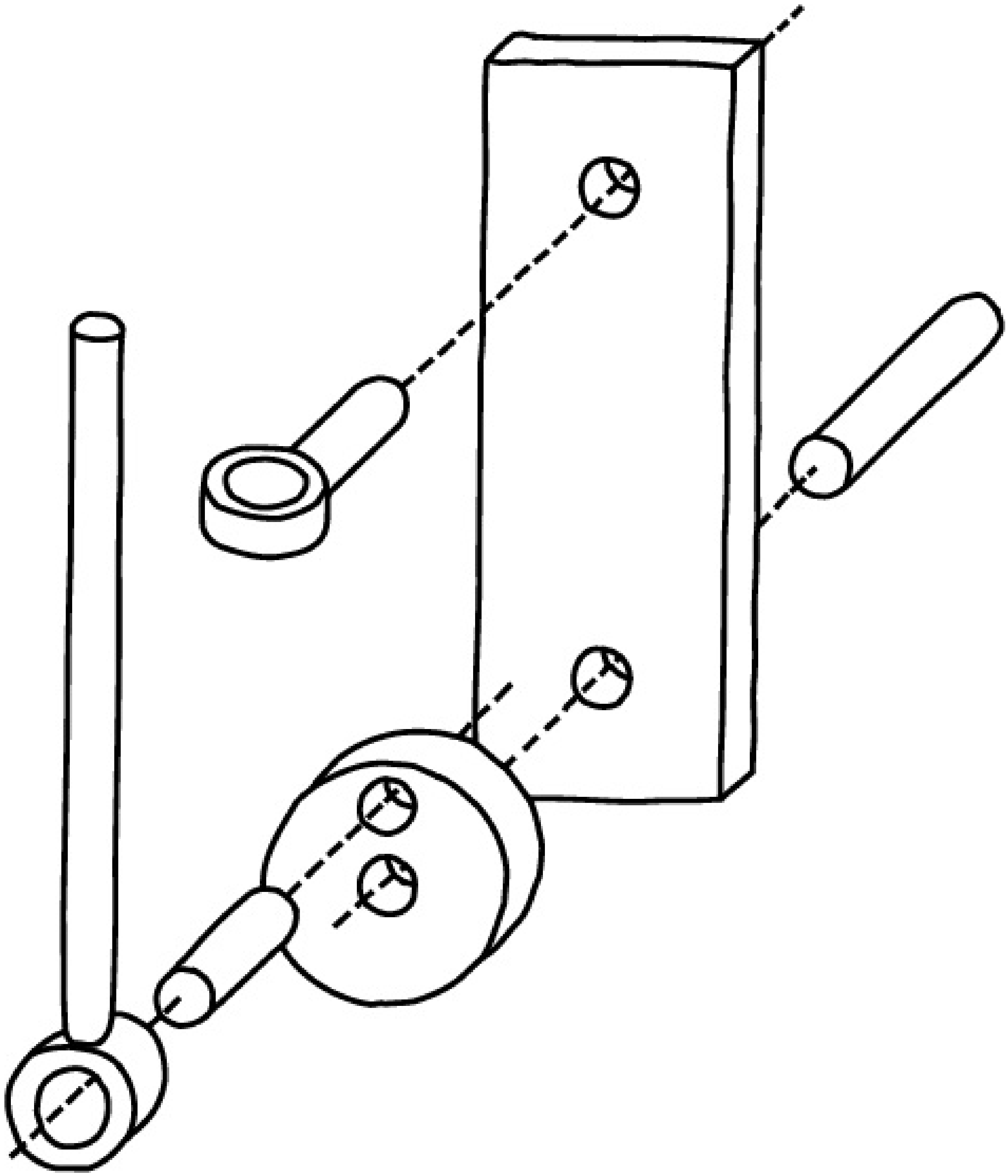


The difference between the lever's highest point (1) and the lowest position (3) will always be equal to the throw of the crank. The length of the linkage will not affect the distance travelled.

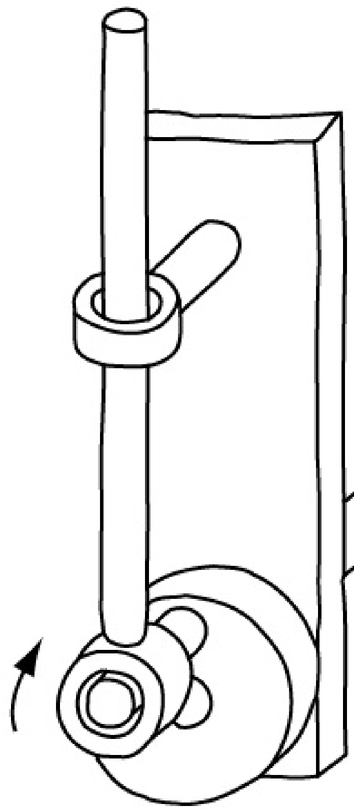


The Crank Slider

In this diagram the lever's motion is restrained by a bearing which allows it to slide up and down with some side to side movement. This mechanism is known as a crank slider.



1



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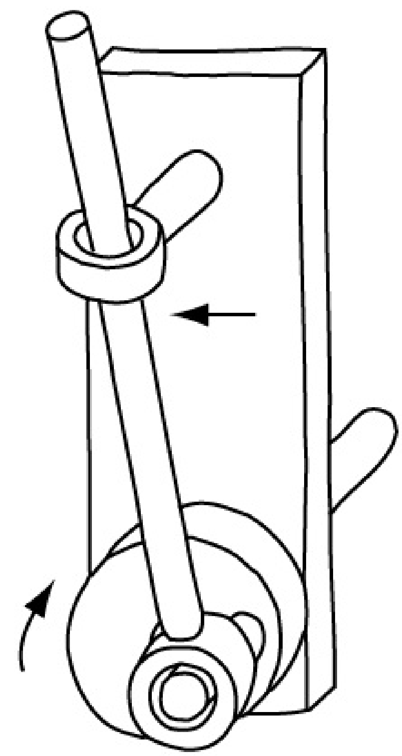

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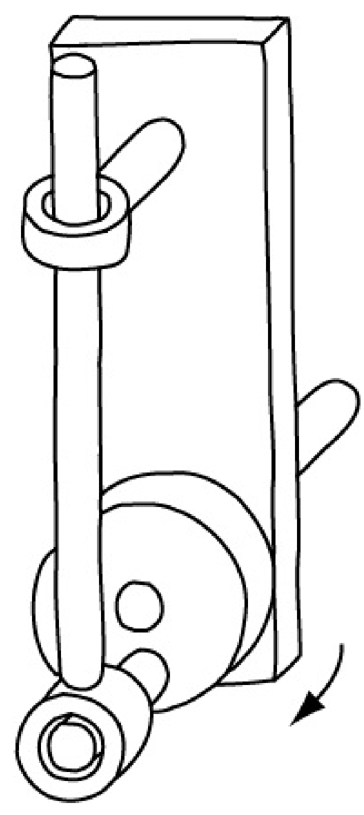

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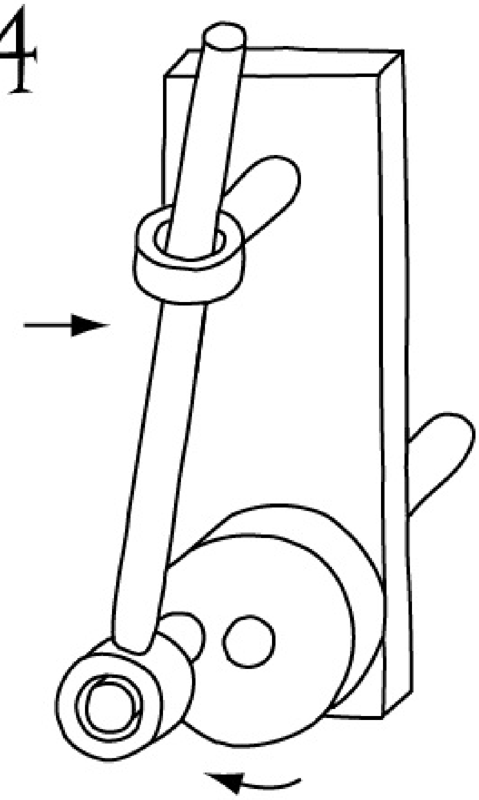
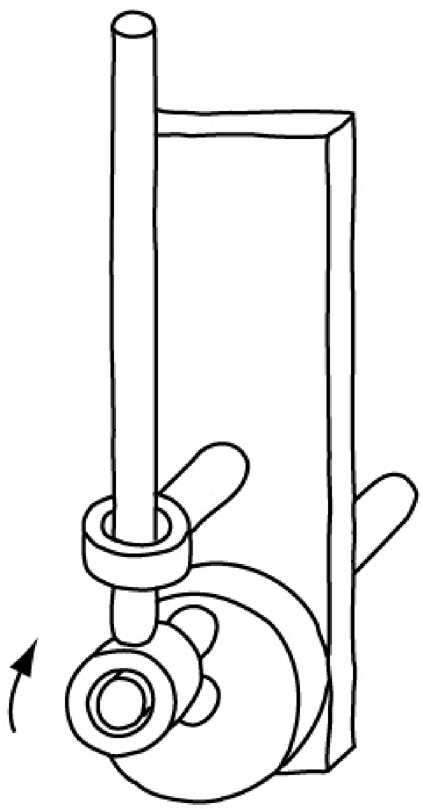


Crank Slider with high bearing

As the crank turns it pushes the linkage up and down and from side to side. The amount of sideways movement can be altered by moving the bearing up or down.

1



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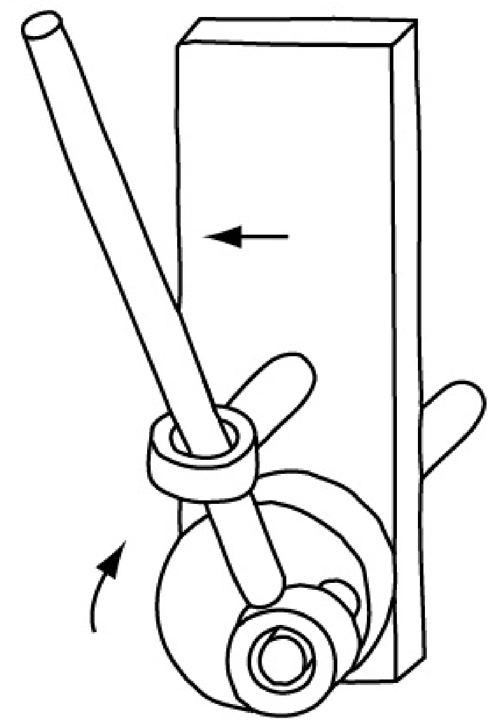

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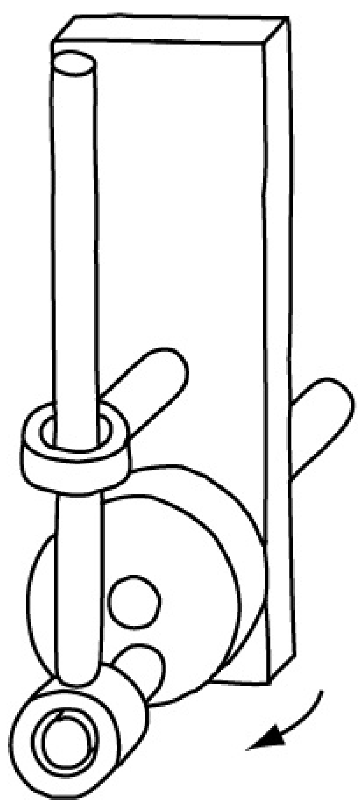

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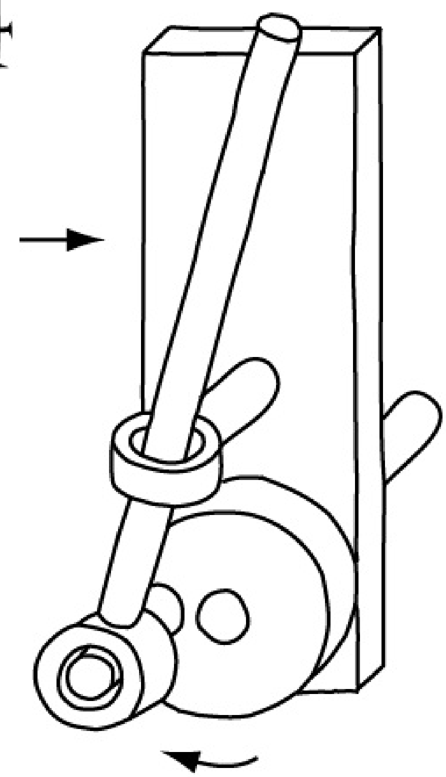
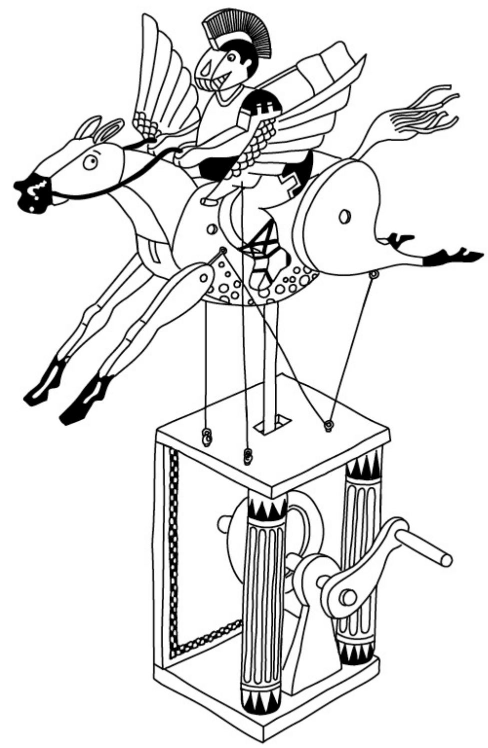
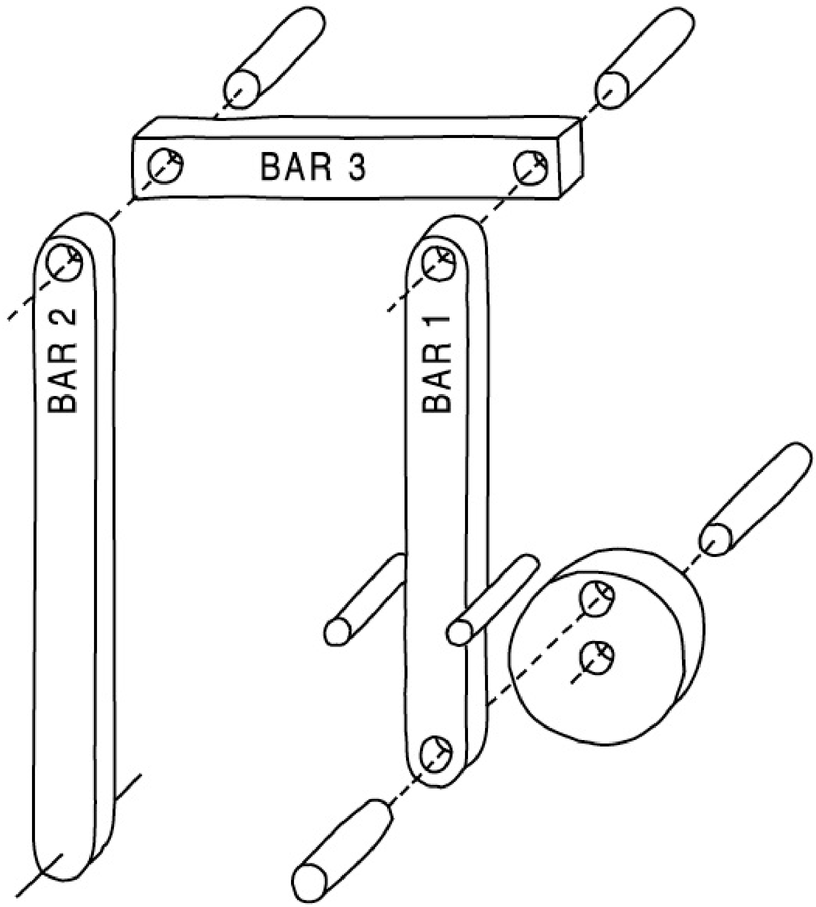


Crank Slider with low bearing

The closer the bearing is to the crank, the more sideways movement there will be. The high and low points remains the same.

The Birth of Fast Food by Keith Newstead
The up-down / forward-back movement of the horse is produced by a crank slider similar to the previous diagrams. Additional movement in the wings and legs is gained by the clever use of linkages.
The wings and legs are levers. They are pushed or pulled by the linkages (strings and wires) which are attached to the base. When the body of the horse is pushed up and down the linkages give movement to the wings and legs.

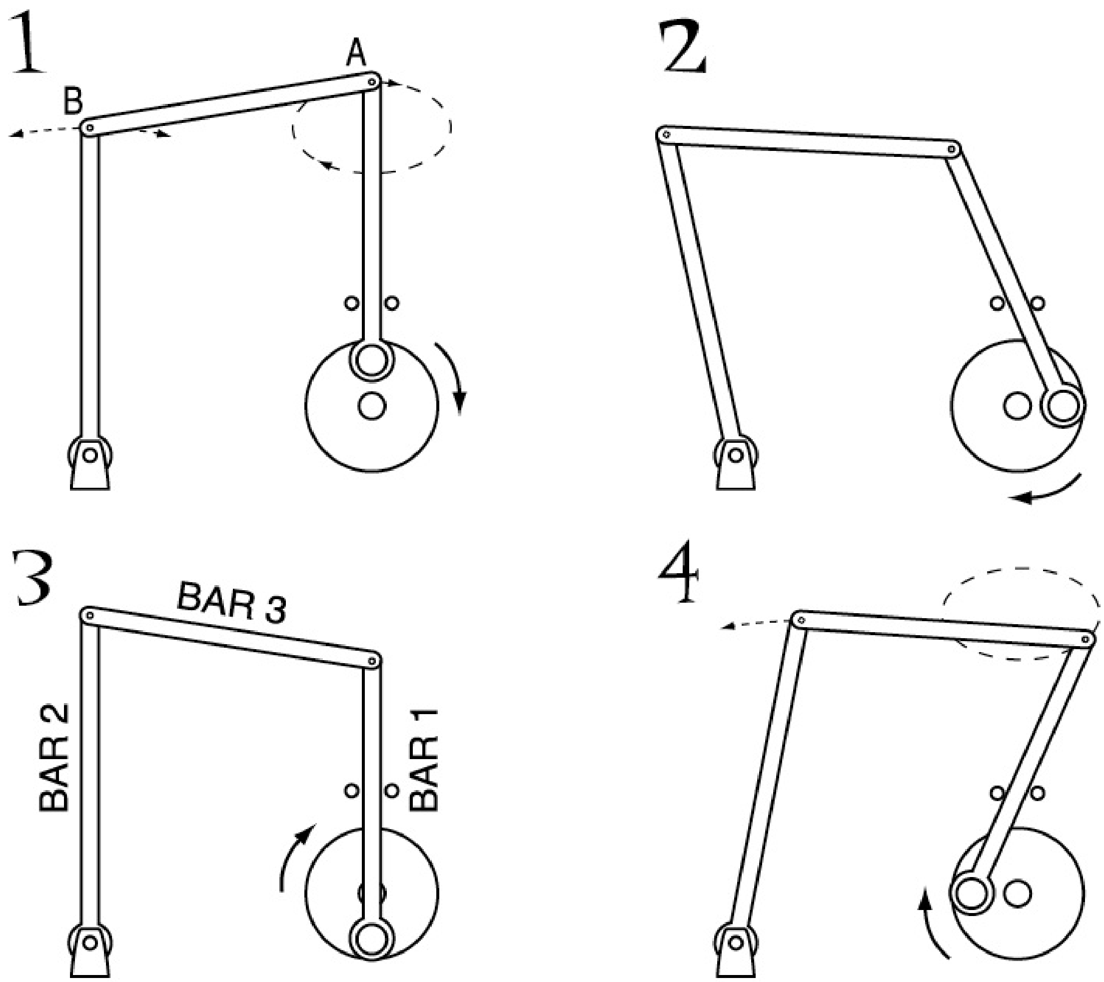




The Three Bar Linkage

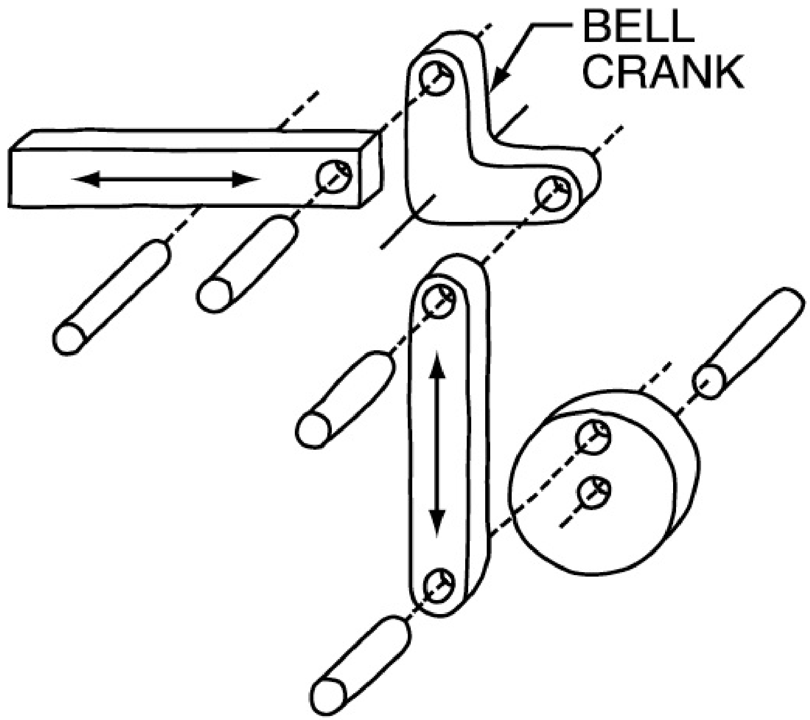
We’ve seen how levers move through the arc of a circle so what happens if you want the movement to be in a straight line? Here’s one way...

This exploded diagram shows a three-bar linkage. It transfers the rotating motion of the crank via bar 1 and bar 3 to a side-to-side motion of bar 2. The pegs beside bar 1 limits its movement and stop it rotating too far with the crank. The sequence on the next page makes the action clearer.



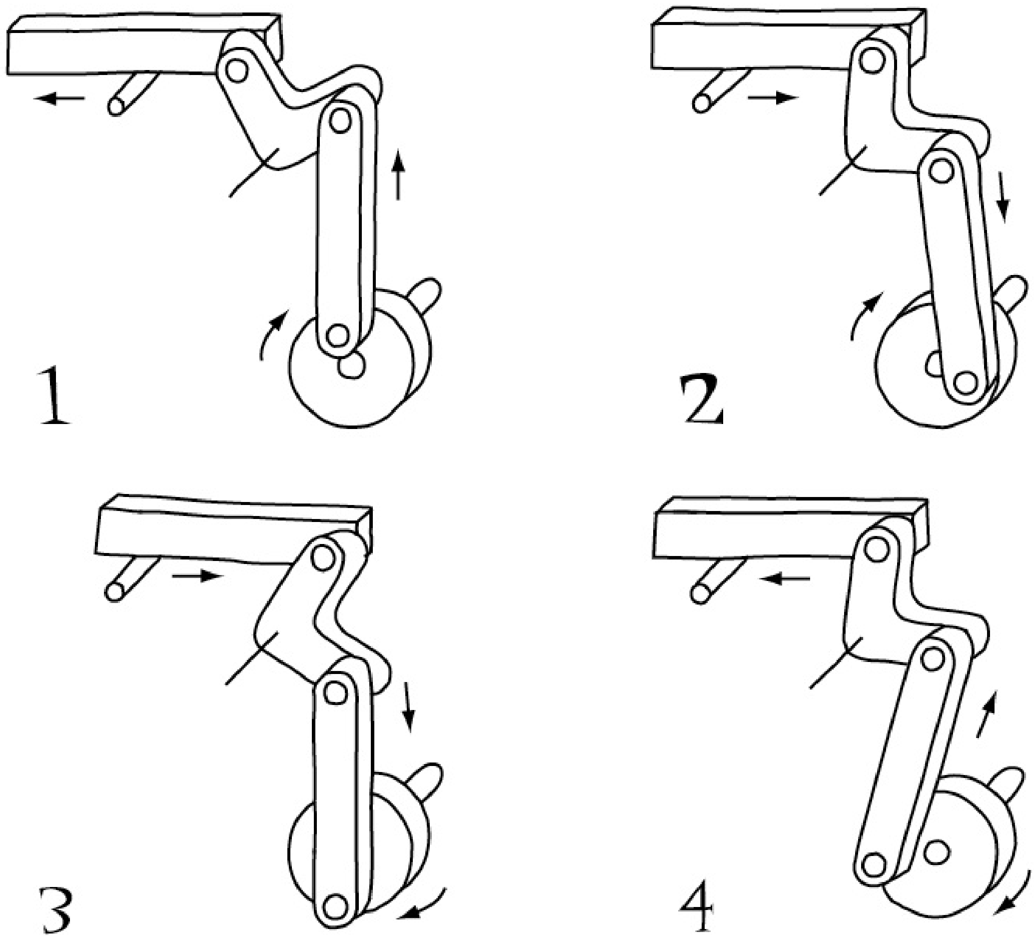
The crank-slider arrangement makes the top of bar 1 describe the shape of an ellipse (A). Bar two is a lever with a fixed pivot point at the bottom. Bar 3 connects the other two bars so that the top of bar 2 (B) approximates a straight line movement.

You can see from the diagrams that you don’t get a perfect straight line but it’s worth understanding the effect. The rotary action of the crank, is turned into an ellipse and then an arc by constraining levers at different points.



Going Another Way–The Bell Crank

A bell crank linkage is useful for changing an up-down movement to a side-to-side movement or vice-versa. The diagram shows a crank which pushes the vertical rod up and down. The bell crank rotates around its pivot point and moves the horizontal rod from side to side.

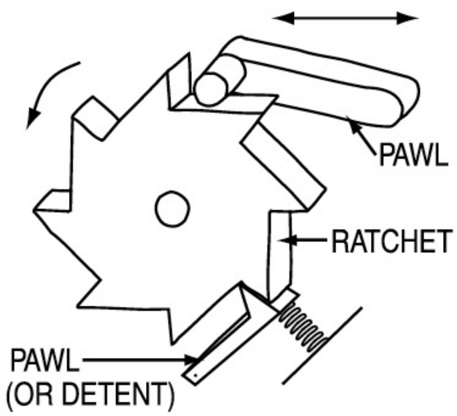


The bell crank is really just another type of lever so the amount of movement can be increased by making it bigger or smaller. You can also make one end of the bell crank longer or shorter to change the amount of leverage.

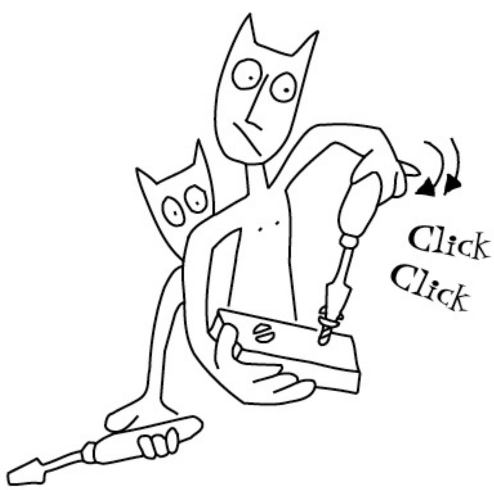
It would be possible to devote a whole book to linkages but we only have space to cover a few. However, if you've understood everything so far you should be able to look at machines and find some more for your notebook.

Ratchets

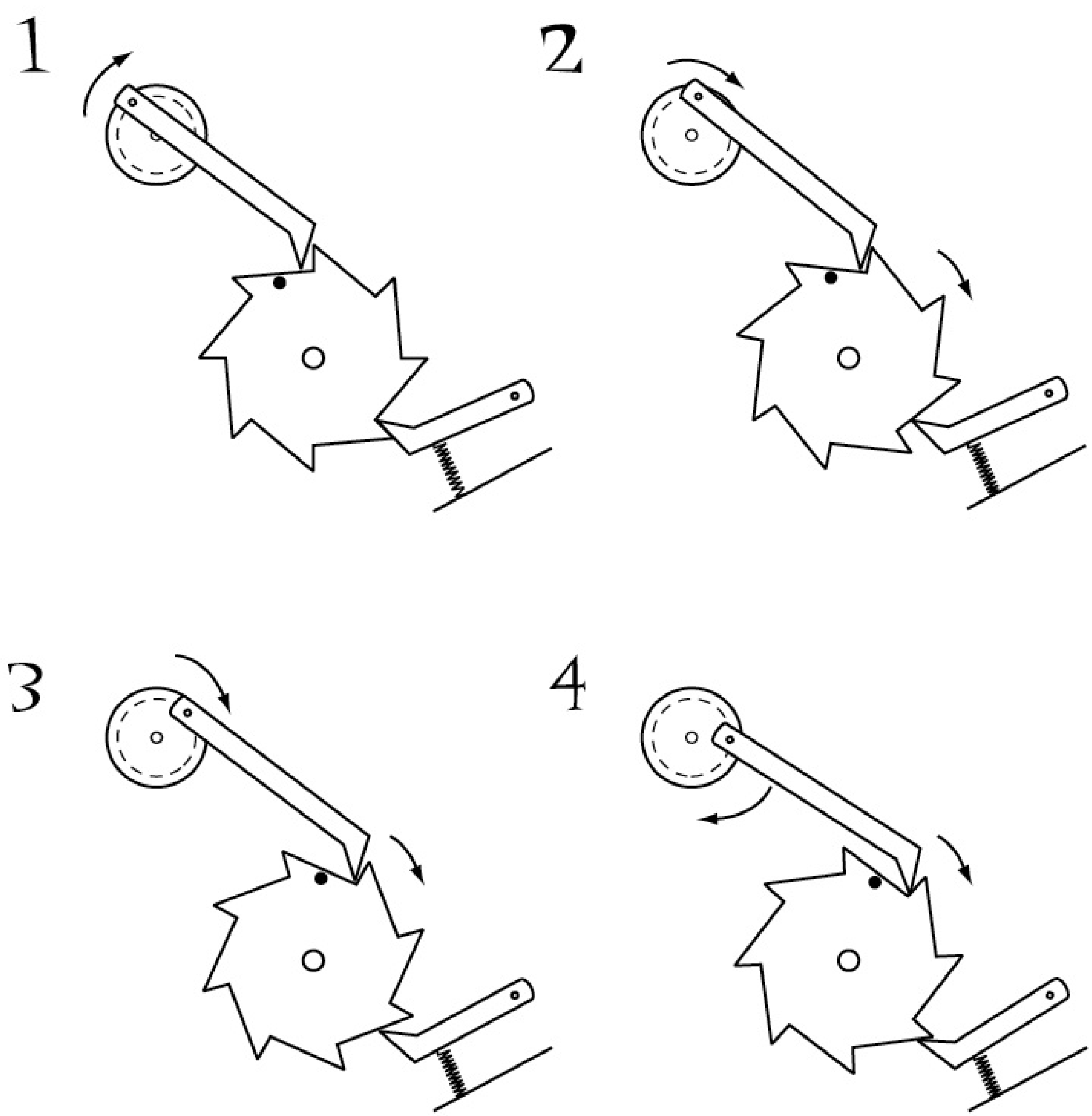
Up until now we've been looking at mechanisms which give a continuous motion – as long as there is an input there will be an output. The ratchet is a mechanism which gives a motion that is not continuous. This is known as stepped or intermittent motion.



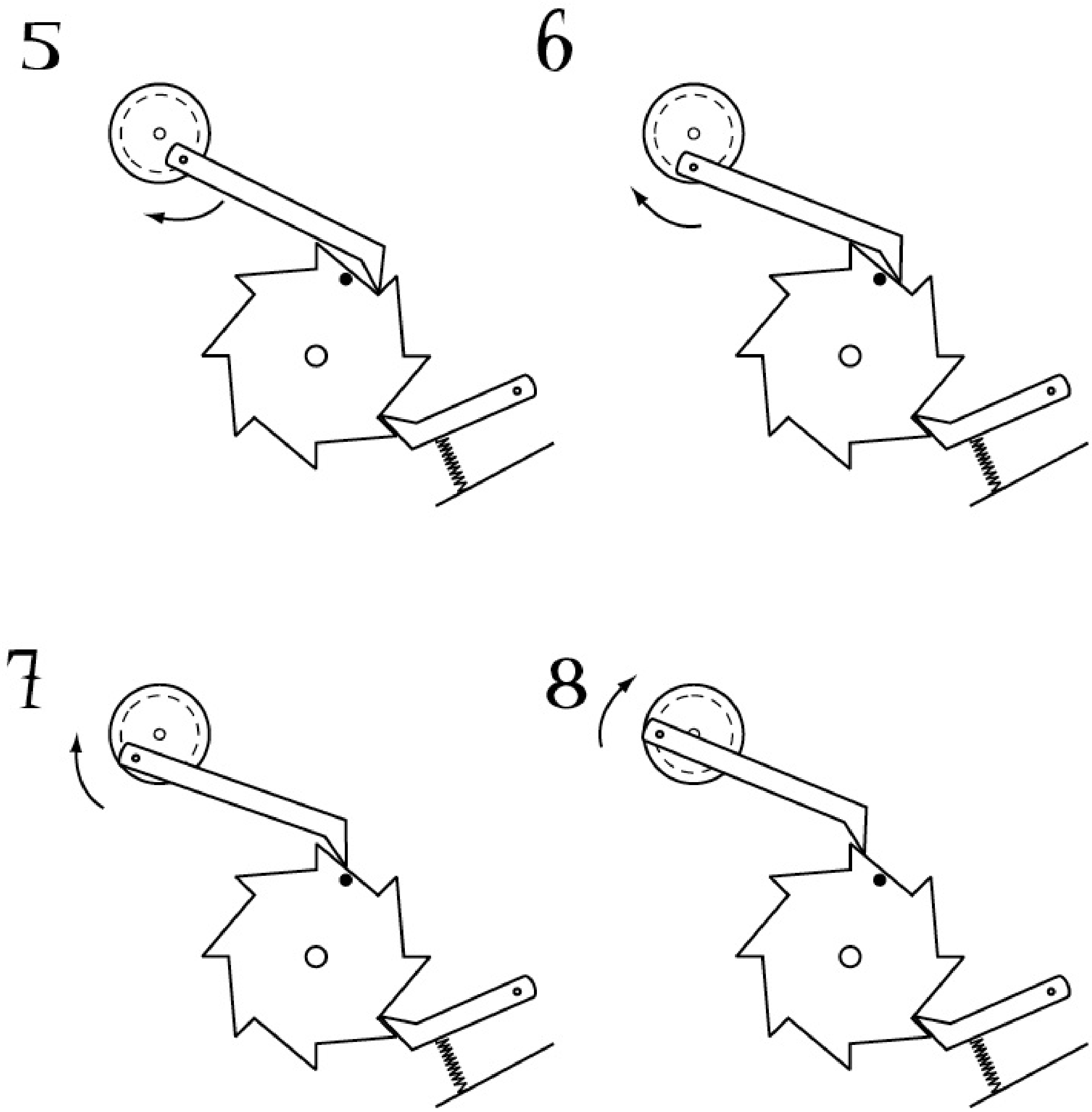
The ratchet is a wheel with notches cut into it. A pawl pushes against the notches and drives the wheel around in steps. A second pawl (or detent) stops the wheel from slipping back.



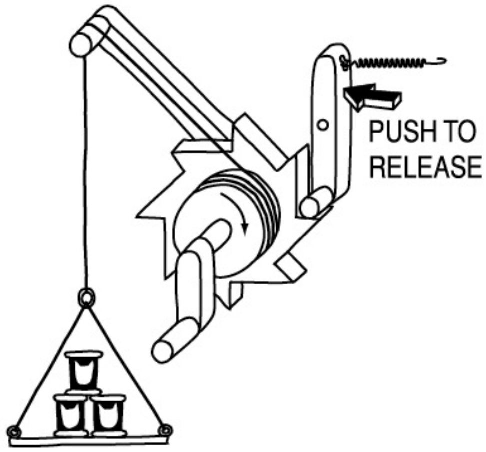
Some screwdrivers have ratchets so that you can keep the driver in contact with the screw. You have to set a switch so that the ratchet turns in the right direction for tightening or un-tightening.



In the sequence shown here the ratchet is driven by a crank. One revolution of the crank moves the ratchet one step. So the crank has to turn 8 times to complete one turn of the ratchet wheel. In the diagrams, the dot on the ratchet shows how far it turns with one turn of the crank.

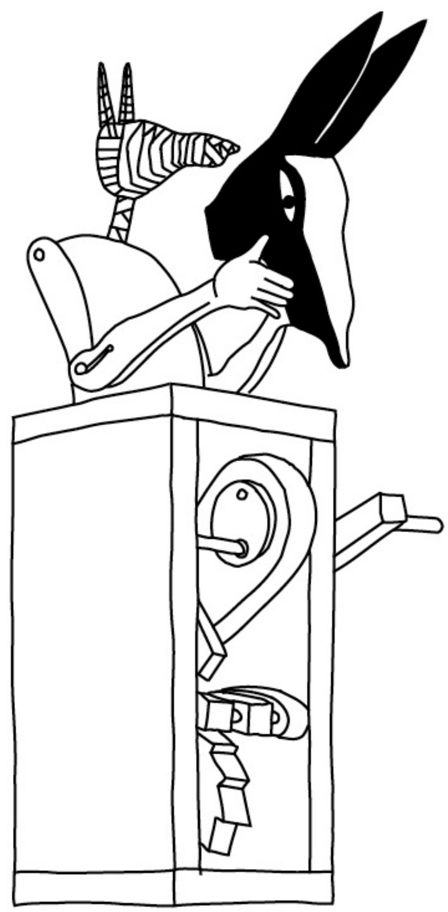


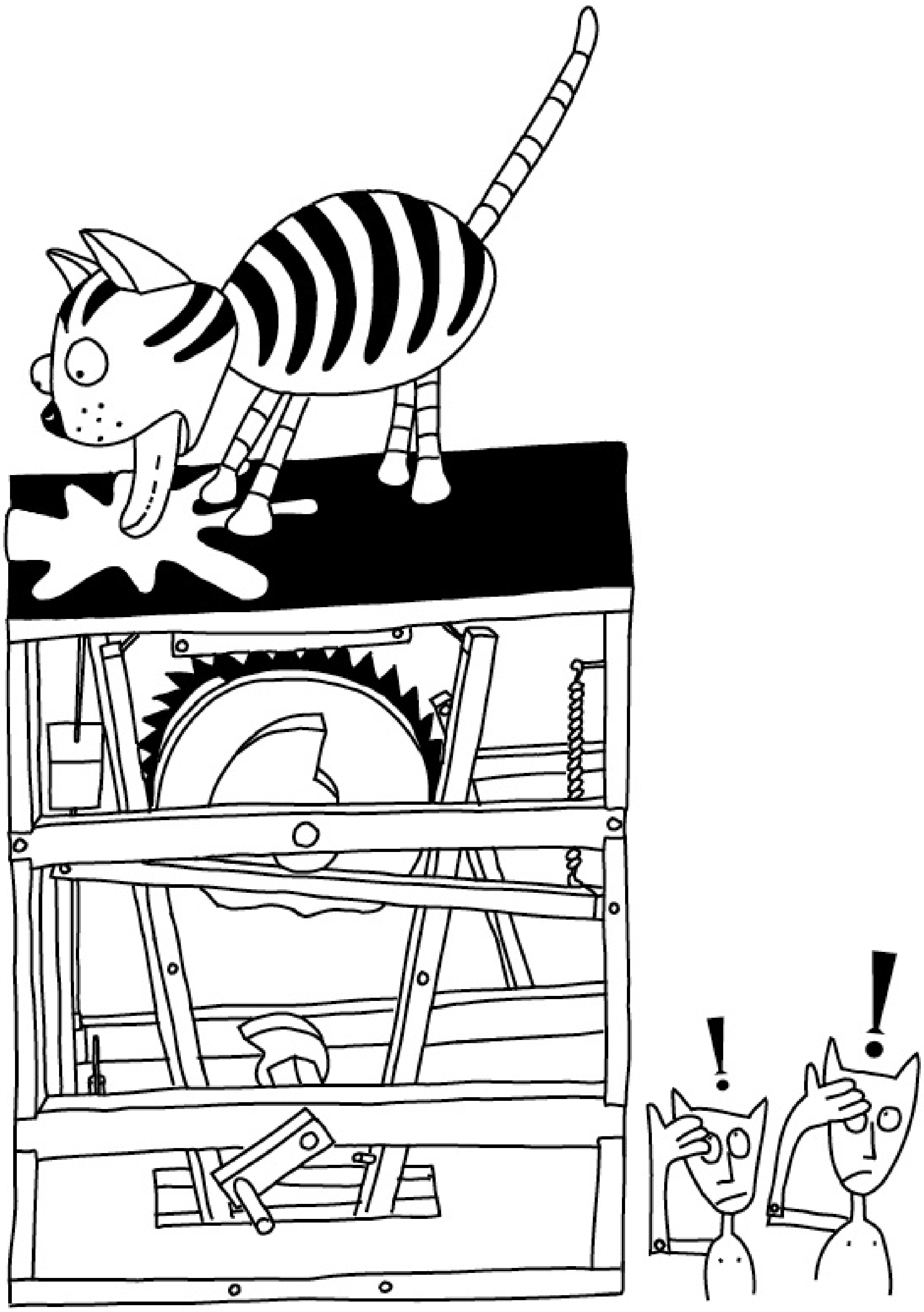
The action of the second pawl is important because the ratchet must stop at the correct point to be in position for the next push from the cranked pawl. The second pawl often has a spring to ensure that it maintains contact with the ratchet.



Ratchets are also used as a locking mechanism to stop wheels from turning the 'wrong' way. In this illustration a heavy weight can be moved in short steps as the pawl stops the ratchet from turning very far in the anticlockwise direction. A release mechanism on the pawl is provided to allow the lift to be lowered.

Head Off Anubis by Paul Spooner
The handle turns an eccentric cam which pushes a ratchet wheel around in steps. The rachet's shaft also has a snail cam on it. This is used to pull the arms forward. Other linkages, levers and a spring complete the mechanism. Anubis takes his mask off in steps to reveal mummy wrappings, but then it snaps back on very quickly.



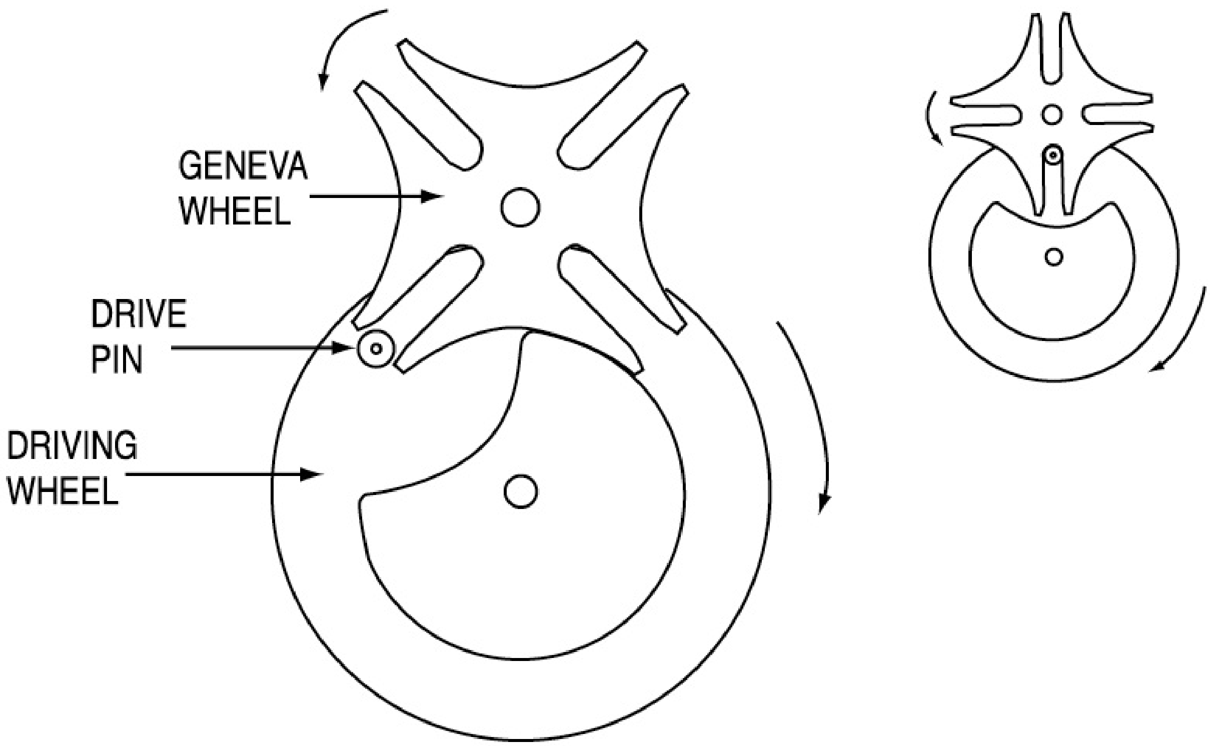


Poisoned Milk by Paul Spooner

In this piece the milk is made from leather which is pushed up, rapidly from below. The movement of the leather is what makes the tongue move up and down but when you look at it, the cat appears to be lapping. This method avoids running a complex mechanism through the body to the tongue and is typical of Paul Spooner’s approach to making automata.

The cat laps enthusiastically at the spilt milk for a while. Then it collapses in a heap. The body is loosely jointed and held together by string. When the string is released the cat falls down in a fairly random way. The lack of stiffness in the string makes it difficult to control but it’s ideal for this piece.

Another mechanism which produces intermittent motion is the Geneva wheel. This is used in cinema film projectors and cameras to step the film on one frame at a time.

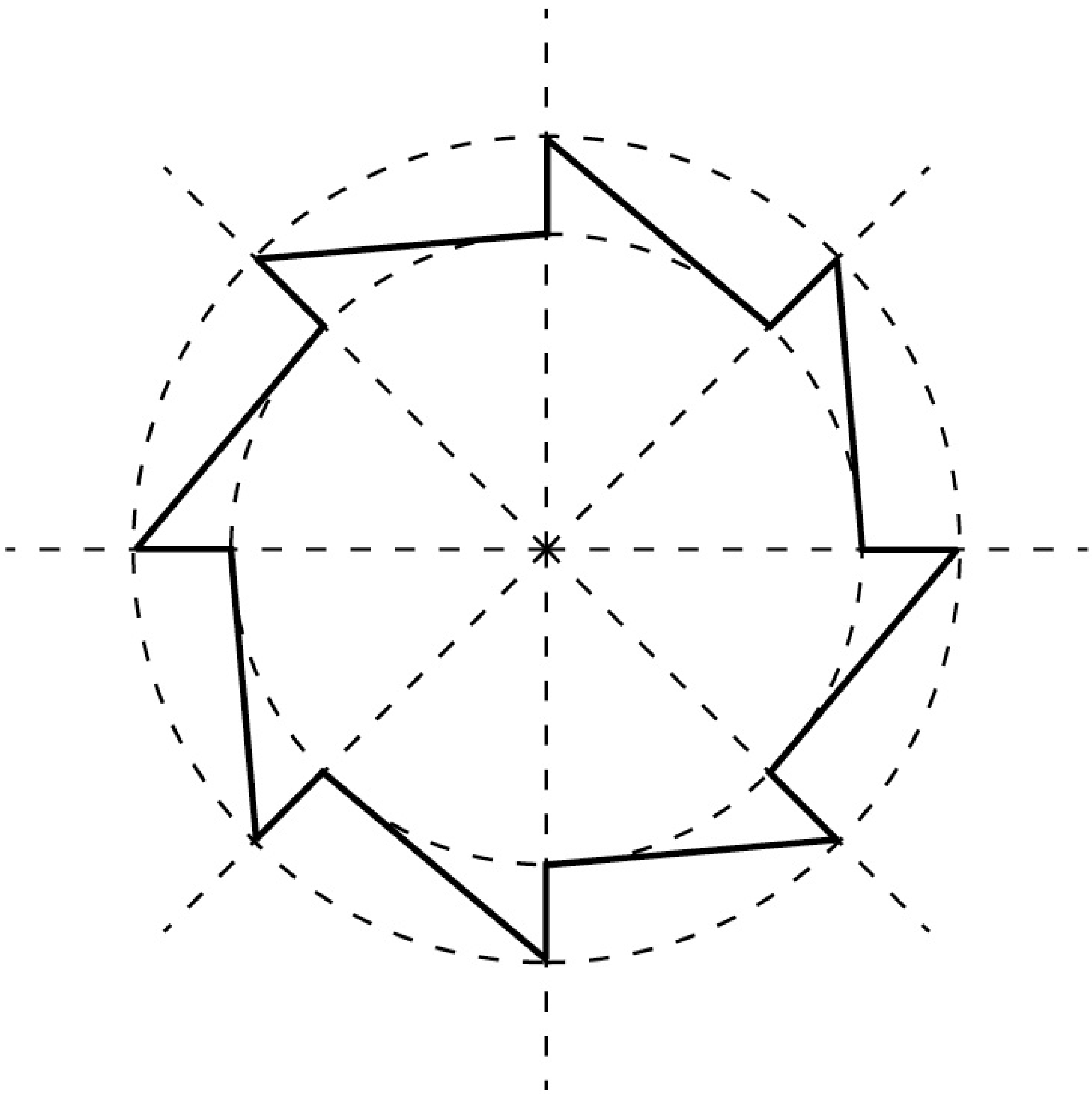


This is really a specialised form of cam but it’s in this chapter because it’s a mechanism for intermittent motion. Can you see how it works? There is an animation on our website which makes it clearer: cabaret.co.uk

Another Practical

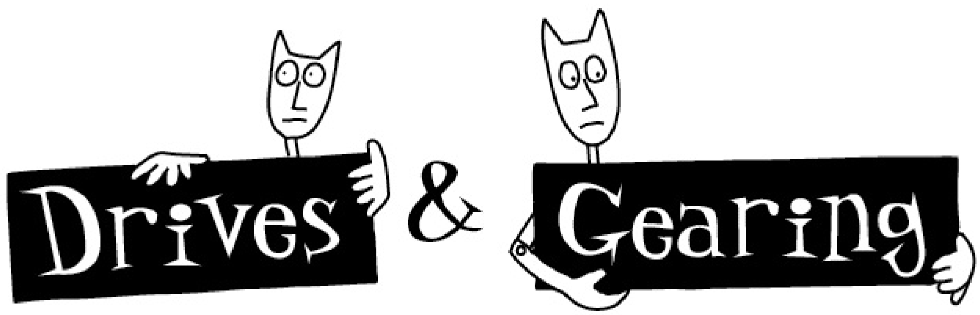
Try making your own ratchet wheel using the diagram below as a guide or a template. Use thick card to start with and see if you can make a crank the right size to drive it. It’s getting hard now, isn’t it!

If you’re stuck, try making a flat crank, (like the one in the previous 8-step ratchet diagram), pinning everything down on a board and working it out by trial and error.

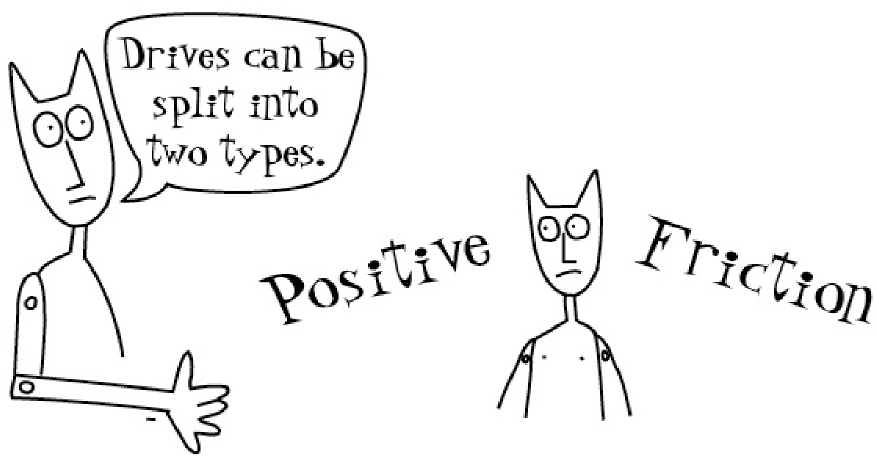


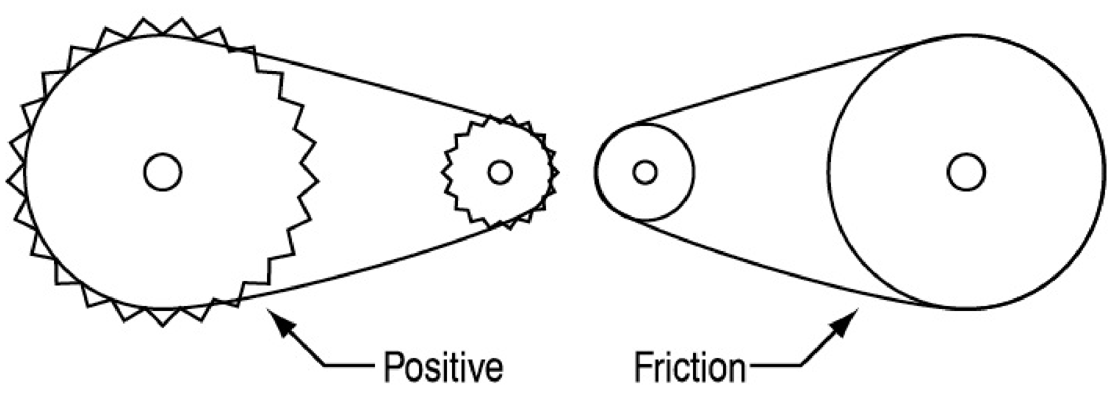
Template / Guide for a Ratchet

Drives & Gearing



Like linkages, drive mechanisms connect other mechanisms together but in this case we are talking about rotary to rotary connections–things like pulley wheels and bicycle chains. A drive mechanism may also involve gearing or changing the angle or direction of movement.

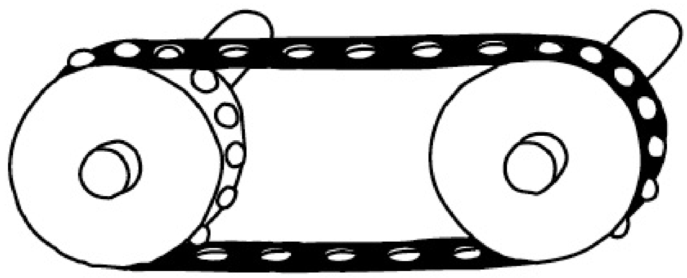


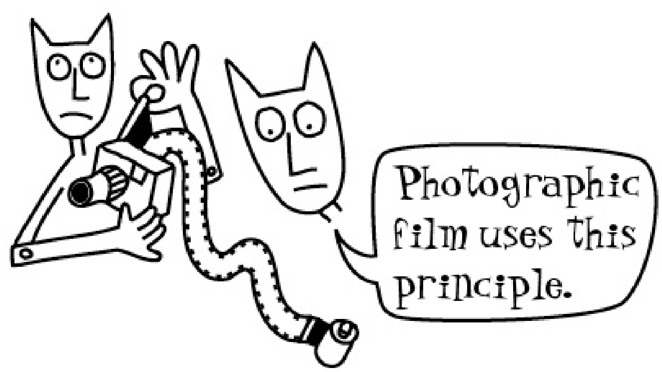


A positive drive is one where the input and output are locked together in synchronisation. A friction drive, as its name implies, relies on friction to transfer the movement. As usual, it’s clearer if you look at examples.

Teeth Locked Together

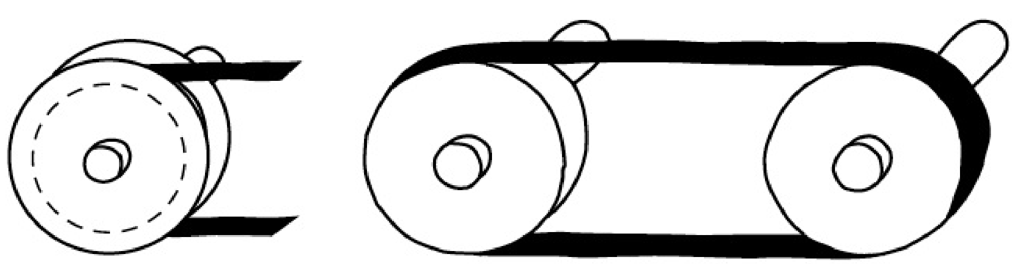
The wheels in this positive drive have teeth around their radial surfaces. (Toothed wheels like this are sometimes called sprockets). The teeth engage with the holes in the belt. This means that the driven wheel will duplicate the movement of the driving wheel. The wheels are locked together.





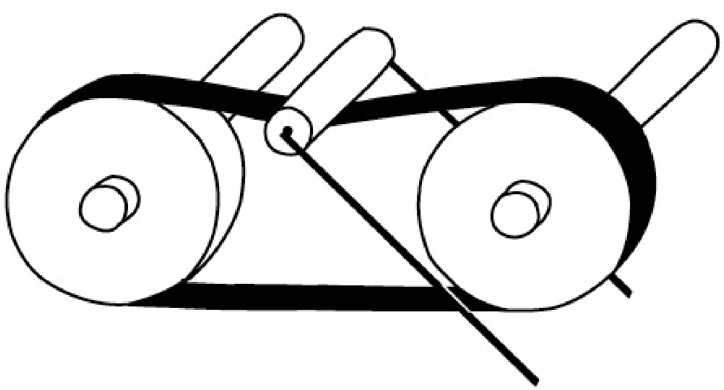
A Frictional Connection

The drawings that follow have been simplified for clarity. They would normally have flanges to stop the belt slipping off the sides. This drive has plain, toothless wheels, so it uses the friction between the radial surface of the wheels and the belt to transfer the motion.

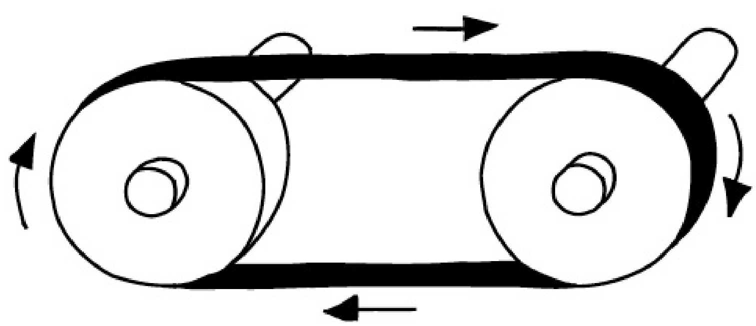


A number of factors can affect the efficiency of this type of drive. If there is too much friction (for instance if the belt is too tight) the wheels may be difficult to turn. If the belt is too loose it may just slip around the driving wheel and fail to transfer any motion.

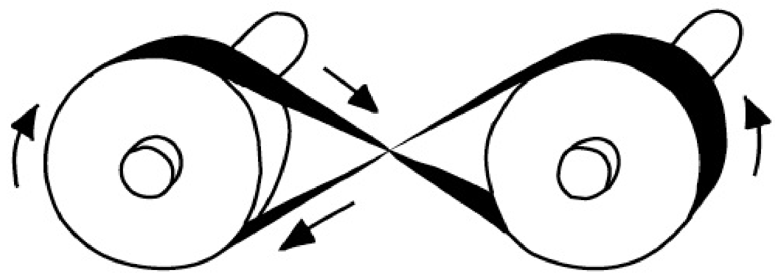
To overcome the problems of too much or too little friction there is often a mechanism to adjust the tension of the belt. The tensioning device shown here is known as an idler or jockey wheel. It can move to take up any slack in the belt. It also has the advantage that it increases the amount of belt that is in contact with the wheels, therefore increasing the friction and efficiency.



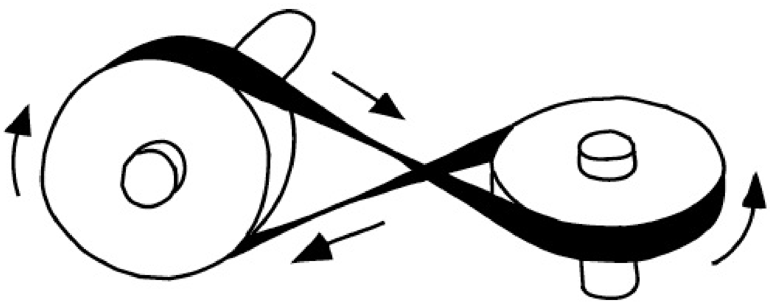
The following diagrams show most of the ways belts can be used. This is the drive we’ve seen already. If we assume there is no slippage in the belt, it doesn’t change anything. That is, both wheels move at the same speed and in the same direction. It’s used if you need another shaft in a parallel position.



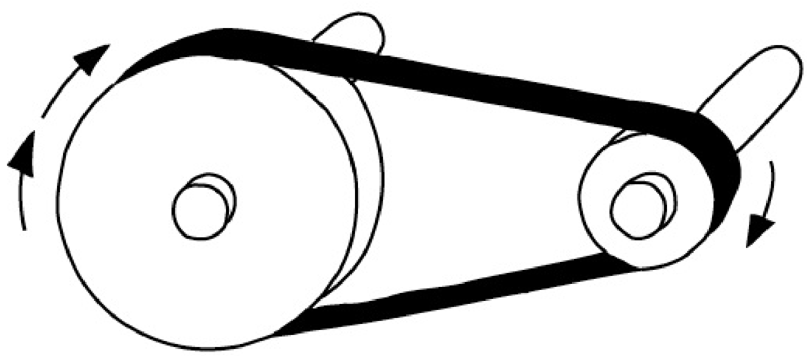
With a twist in the belt you can see that there is more belt surface in contact with the wheel (like using the jockey) but more importantly, the wheels will rotate in opposite directions.



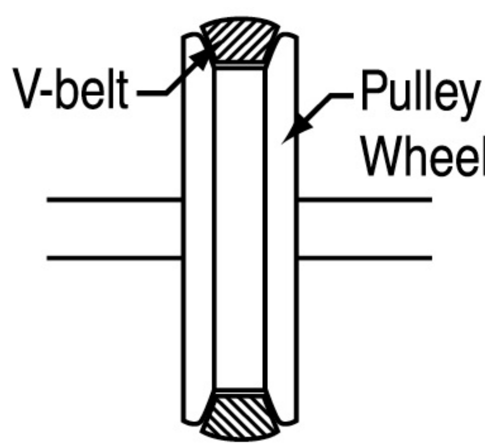
This drive shows a way to change the plane of rotation. The first shaft is turning at 900 to the second.



This drive incorporates gearing. The big wheel will rotate more slowly than the small wheel.

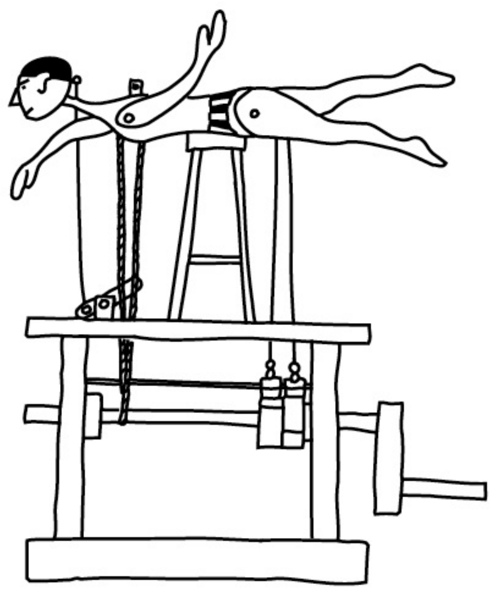


Belts for friction drives come in many shapes and sizes. You might use a rubber band on a cardboard prototype but the same principles are used in industrial machinery. V-shaped belts and pulley wheels give a bigger frictional area and increased efficiency. The belts in a workshop pillar drill are usually like this.

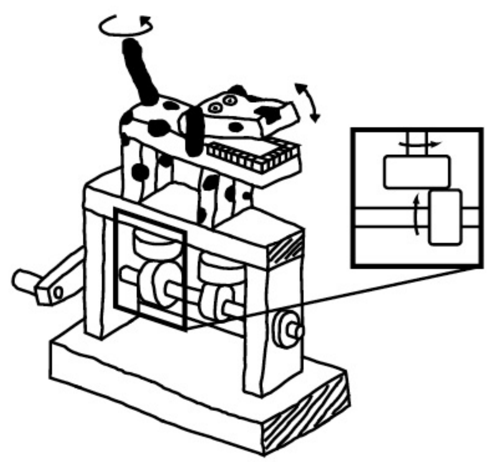


You can also get polyurethane belts that can be joined by heating the ends. Rubber belts can be bought from model shops and washing machine spares shops.

Friction drives are usually simpler and therefore cheaper than positive drives. However, there is likely to be some slippage between the driven wheel and the driver. This means that the driven wheel will rotate more slowly than it is supposed to. If you need the two shafts to stay in perfect synchronisation you need something more positive.



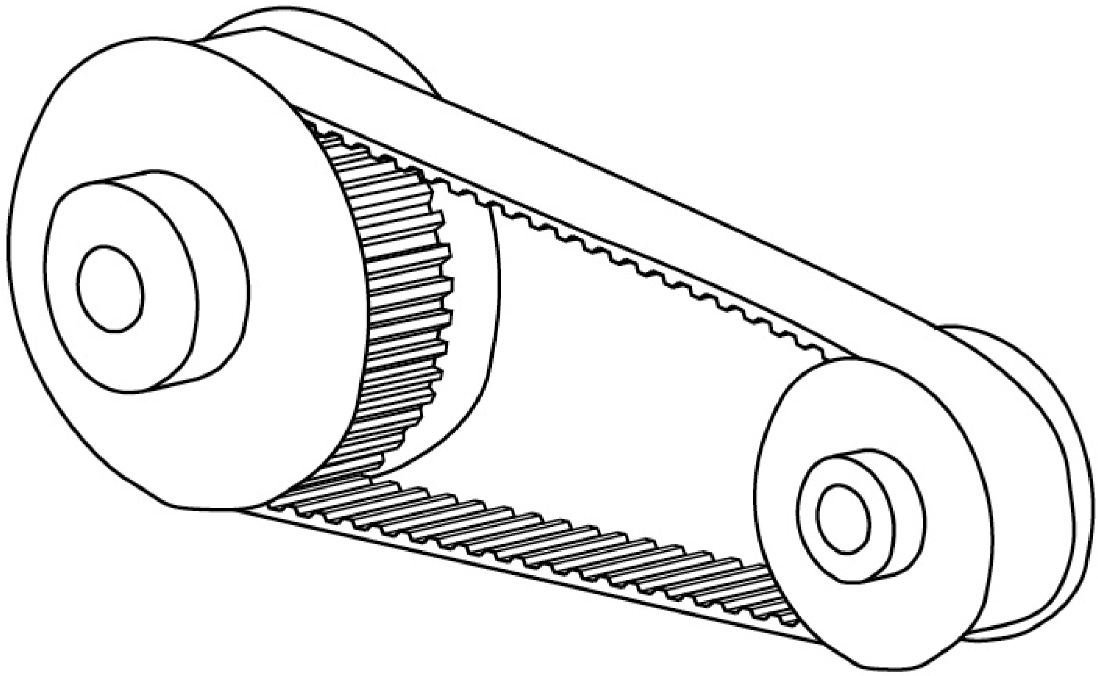
How to Swim No. 17 by Paul Spooner
The swimmer uses a spring drive belt (the sort that is also used in model steam engines) to connect the main shaft to a pulley wheel which makes the arms rotate. The belt is twisted so that the arms rotate at 900 to the main shaft.



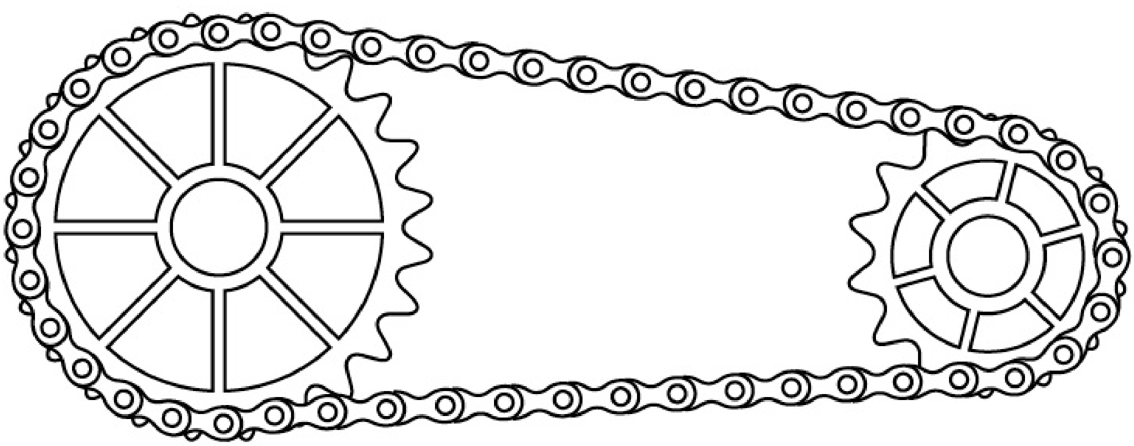
The mechanism for the dog's tail below is similar to the cam mechanism which lifts its jaw. In fact this is a simple friction drive. The plane of rotation is changed from the horizontal to the vertical with the aid of the friction between the two wooden discs. The lower disc rotates the upper one because it is positioned to one side of the upper disc's centre. It's like spinning a plate with your finger–nothing happens if you drag your finger across the centre, you have to spin at the outside.

More Positive Drives

Like friction drives, positive drives come in many different forms. Toothed belts (or timing belts) have teeth which engage with the notches on the pulley wheels.



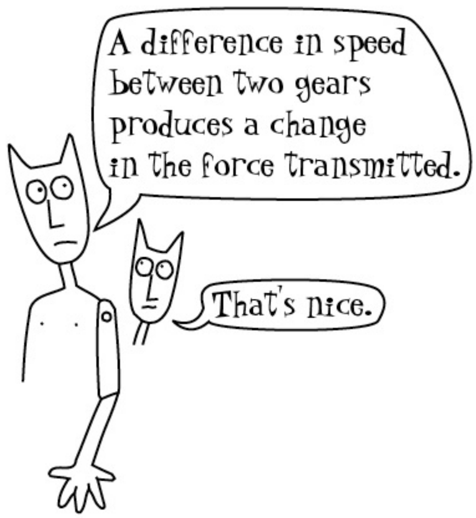
Chain and sprocket systems work the same way except that the teeth are on the sprocket wheel. Chain systems can usually be adjusted to the right length by adding or removing links.



Get On Your Bike

Anyone who rides a bike (and uses the gears) should understand the relationship between speed and power. Gears make it easier to get up the hill but if you want to go at the same speed as you did on the flat you'll have to work harder at pedalling.

When designing a machine you may find that you want some parts to move



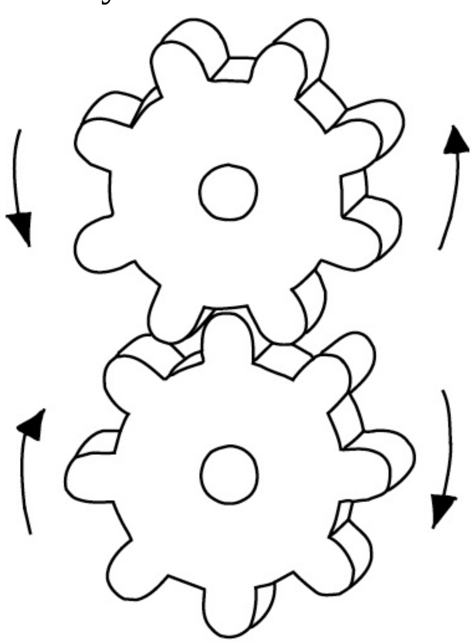
faster than others. Gearing is used to change the speed but it will also change the power delivered.

So you don't get something for nothing. This notion should sound familiar. Does it remind you of levers? Good, because gear wheels are yet another form of lever.

The teeth on gear wheels are like a series of levers. As one set of teeth disengage another set engage so the leverage is applied continuously.

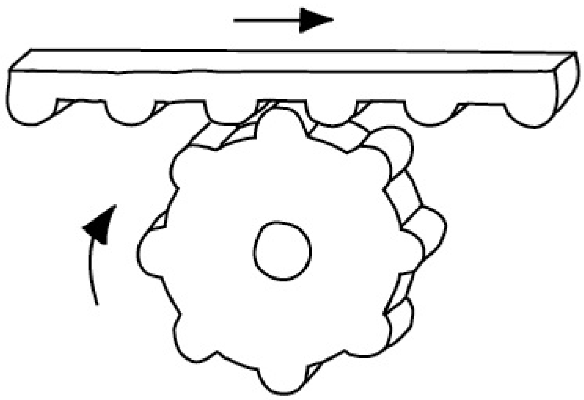
The design of gear teeth is quite a complex subject and beyond the scope of this book. However, it's quite possible to produce gearing mechanisms which are appropriate for the sort of machines we want to build without understanding all of the details. If you were making a machine which needed high precision gearing then you probably wouldn't make the gears yourself anyway.

When you look at the following examples try to think of ways you could make your own versions.

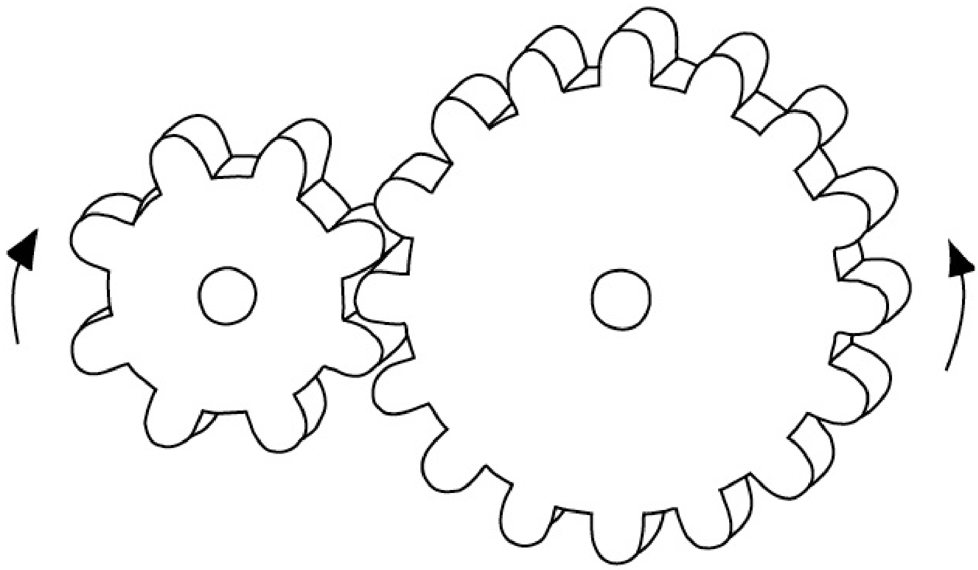


Here the spur gears are the same size, with the same number of teeth. This means the force and speed of motion is the same for both. This is called regulated motion. Notice that the direction of rotation is reversed.

In the more common situation, with wheels of different sizes, the smaller is called the pinion.



In this diagram of a rack and pinion gear, the gear wheel meshes with a toothed rack which slides horizontally, This is another way to convert a rotary motion into a reciprocating (back and forth) motion.



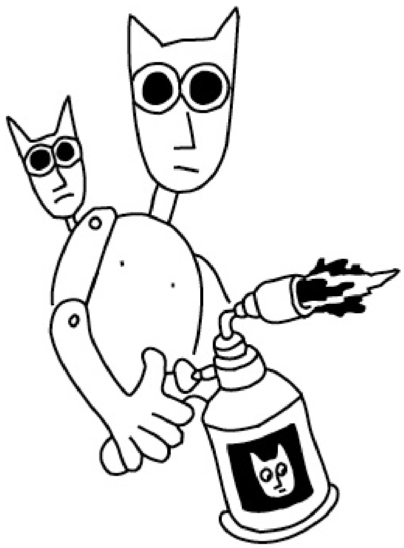
In this diagram, the pinion drives the larger wheel. Because the larger wheel has twice as many teeth it must rotate at half the speed but it will do so with twice the force. If you imagine the bigger wheel as a bigger lever you can see it will have more force.

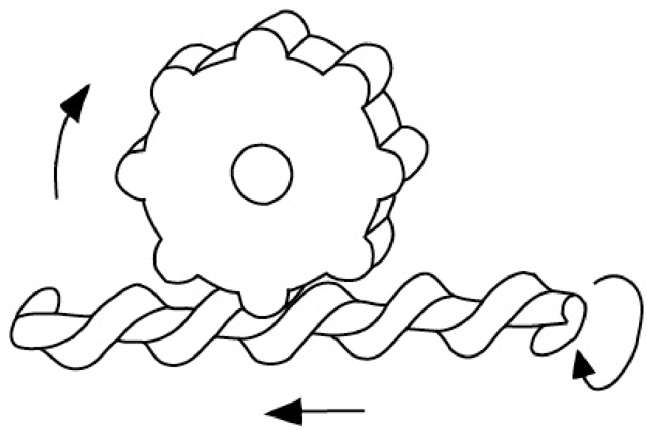
If you reversed the situation so that the big wheel was the input, or driving wheel, then you would say that the small wheel turns twice as fast but with half the force.

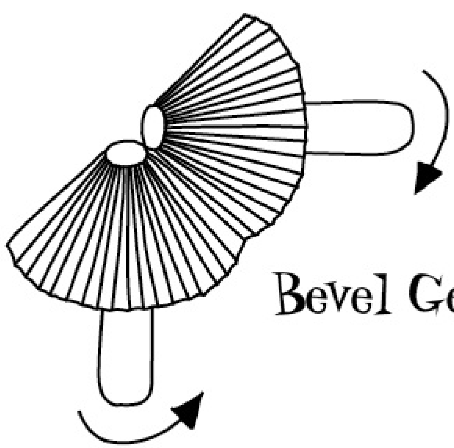
It all depends what you want. You usually won't mind if the gearing gives you more power but if you want more speed and more power then you will have to make sure that you have extra speed at the input to start with.

These principles of gearing apply to friction drives as well. If you're using pulley wheels, the gear ratio comes from comparing the diameter of the wheels rather than the number of teeth.

In this diagram of a worm gear, the shaft has a screw thread on it which meshes with the toothed wheel. This is normally used to give a very slow but powerful force to the shaft of the toothed wheel.

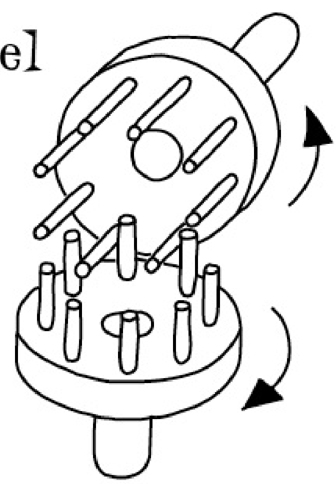






Bevel Gears

Pin Wheel Gears



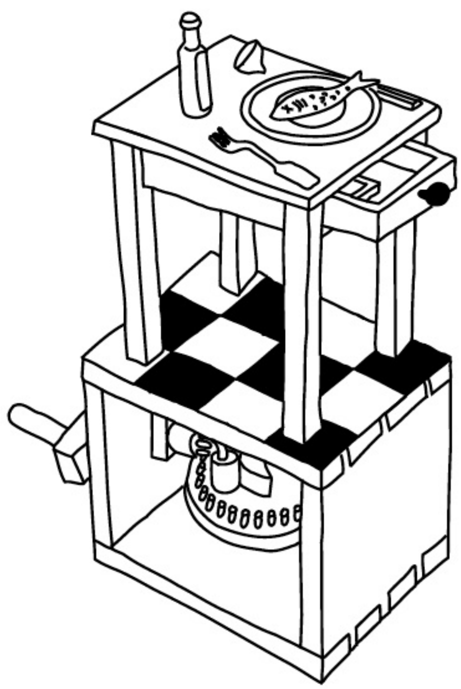
The diagram on the left is a bevel gear. The two wheels mesh at an angle of 45 degrees so that the plane of rotation is changed from horizontal to vertical (or vice versa).

Of course, it's not too easy to make your own bevel gears. The pin wheel gears (on the right) give similar (although less accurate and efficient) results and are much easier to make with simple tools. Unlike the friction discs in the dog that we looked at previously, the pin wheel is a positive drive which means it doesn’t rely on friction.

Practical with Computers

To make your own pin wheels the first stage is to divide up two circles so that the pins on each wheel will mesh properly. If, for example, you decide on a 3:1 ratio you will draw two circles with a 3:1 ratio in their diameters. In the example shown below the diameters are 20mm and 60mm. Note that this is the diameter of the circle on which the pins will be positioned. This circle is known as the pitch circle. The actual size of the wheels will be slightly larger.

The pitch circles then have to be divided so that the number of pins are also the same ratio. This will ensure that the space between the pins is the same on both wheels and allow them to mesh correctly. In this example we have chosen to have 12 and 36 pins. To find out the angles for the pin positions, you divide 3600 by the number of pins. So, 360/12=300 and 360/36 = 100



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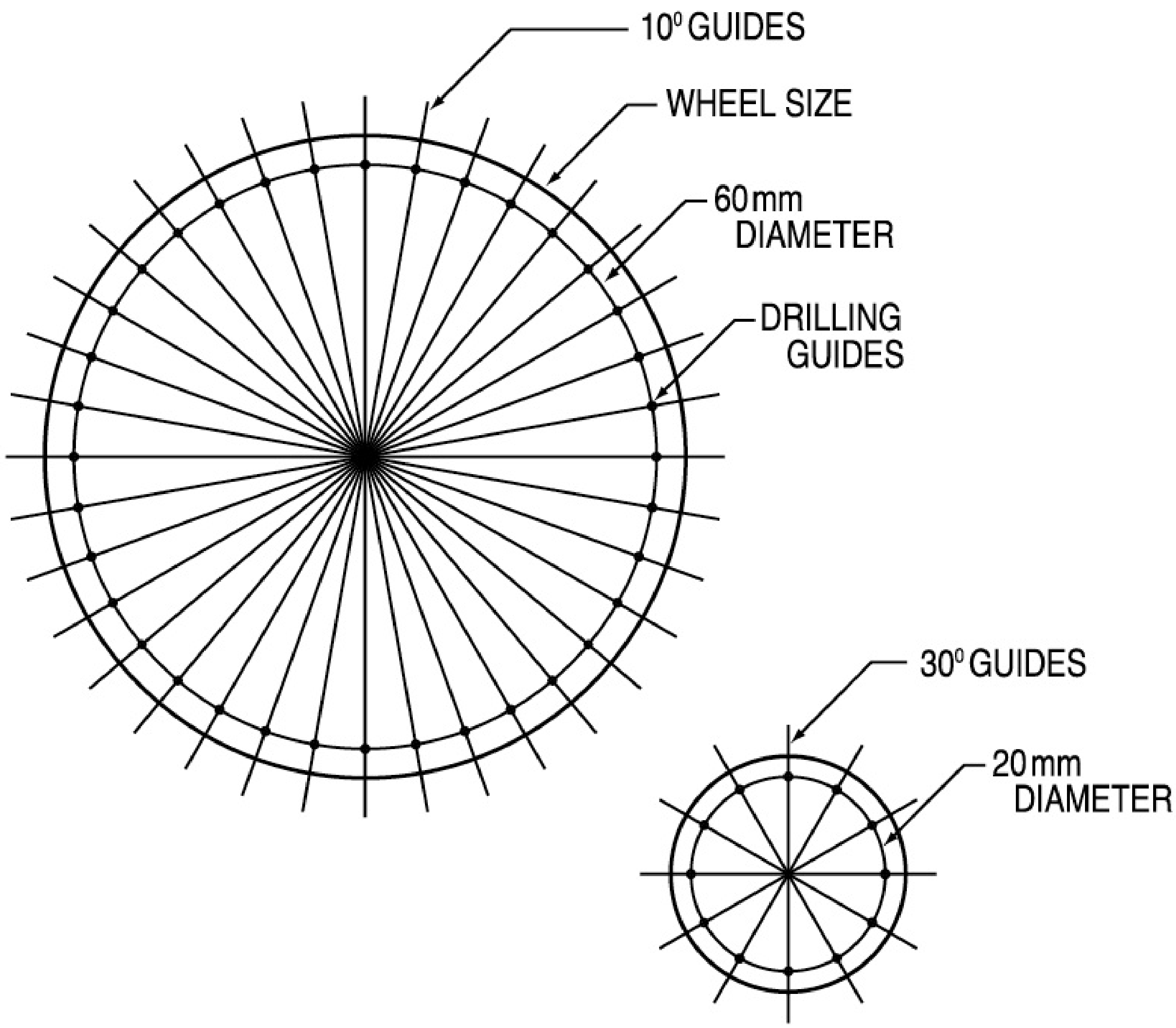
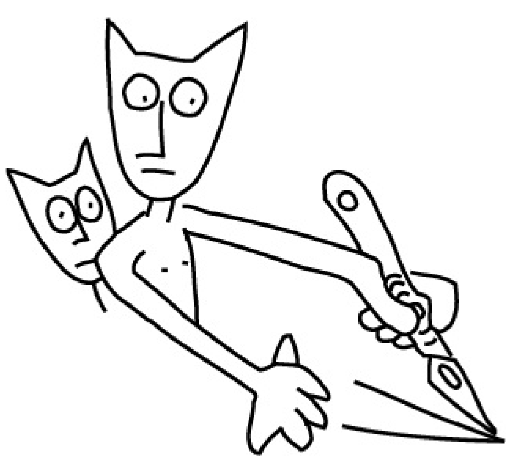
Still Life by Matt Smith
The pin wheels in this piece serve two functions. A small pin wheel on the handle shaft drives a larger wheel. This slows down the action and changes the plane of rotation. As you will have guessed, the normally inanimate objects in this still life aren’t still at all.

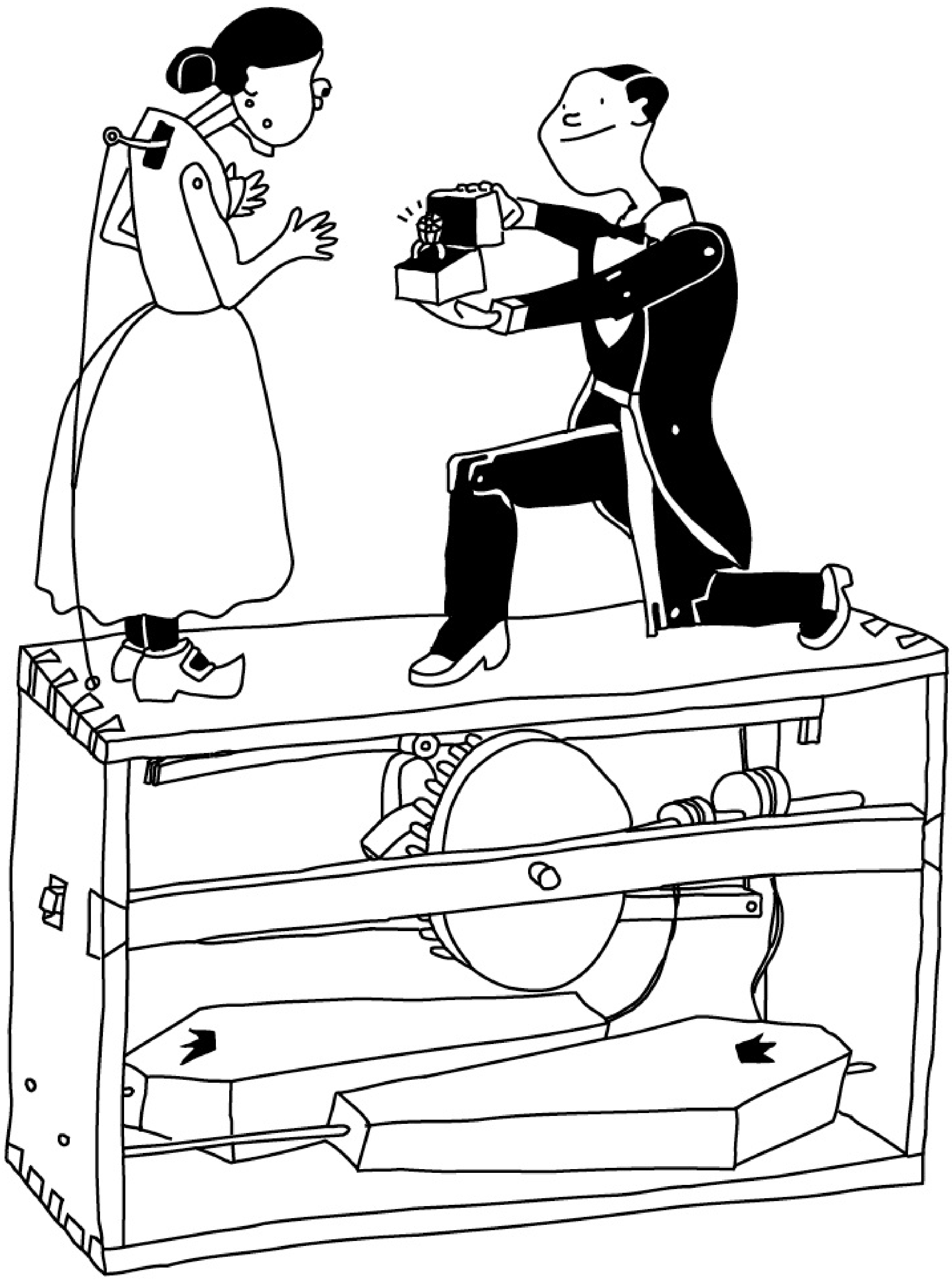
It’s hard to make pin wheels from cardboard so you might want to try some 6mm plywood for the wheels and some welding rod or nails (with heads removed) for the pins.



Templates for a pair of pin wheels



Using a lathe or pillar drill with a dividing head is the easiest way to make pin wheels but if you don't have access to such devices then you can draw drilling templates with a compass and protractor. However, it's much easier to produce accurate templates like this with a computer drawing program. Full instructions for doing this are on the CMT web site. (link).



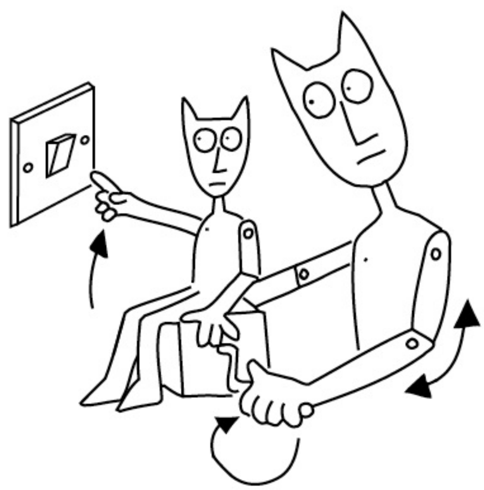
The Mill Girl and the Toff by Paul Spooner
The pin wheels in this piece are used in the same way as the Still Life. Here, the Mill Girl is so surprised by the presentation of a ring from her posh suitor that her eyes are popping out unwittingly. Meanwhile, their relatives are turning in their graves below. (One is made from

expensive wood, the other is cheap)

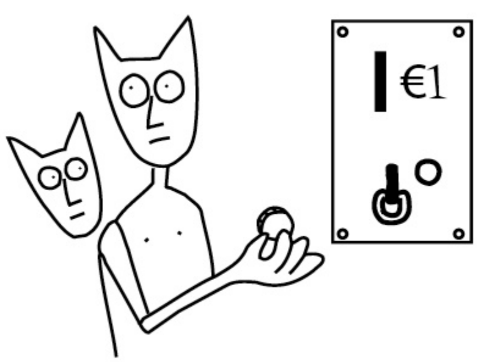
Control

Control is a term which is used to describe the parts of a system which accept the input and instigate the output. Control can be as simple as a light switch and as complex as a computer program.

The parts of a light switch come between the physical action of pressing the switch and the connection of electricity to the light bulb.

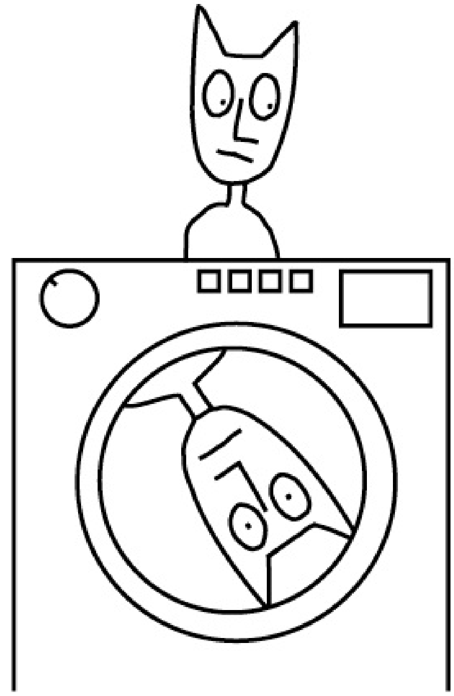


Because it’s so simple, a light switch would not normally be described as a control system, so here’s another example where the input is more removed from the output.



A slot machine has to notice the insertion of a coin and begin it’s operation. The machine may have to work for a specific period or it may need to complete a specific cycle of events. In both of these cases we have to deal with the fact that dropping a coin is an event which doesn’t last long. The momentary action that can be registered when a coin passes through a slot has to be converted into something more substantial if we are going to provide some value for the money.

For a Limited Period Only



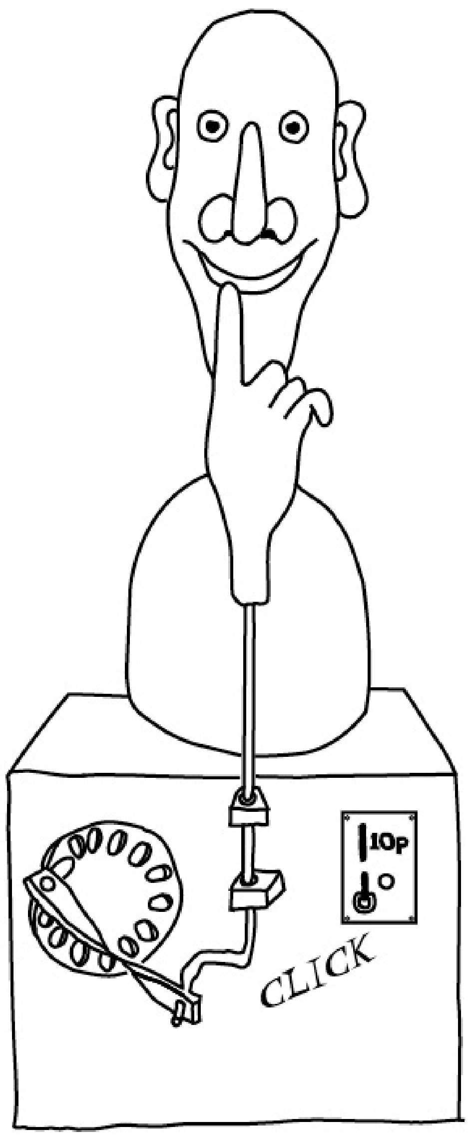
Some machines don’t have an inherent cycle of events. They perform an action continuously and any point in the action is similar to any other. When you turn on a simple* laundromat tumble dryer you expect it to go around and around blasting hot air at the clothes. When the time is up the clothes may or may not be dry. To control this type of machine you need a timing mechanism which can count down a specified number of minutes. The timing mechanism is responsible for keeping the motor and heater operating until the specified time has expired. So a timer is another simple form of control mechanism.

***footnote: Some tumble dryers are more complex. They may have a reversible drum action which stops the clothes getting too tangled. They may also monitor the dampness of the clothes and decide when to stop. These are both control mechanisms–the first time-dependent and the second would require a sensor to monitor the humidity.**

A Cycle

The Disgusting Spectacle (by Tim Hunkin) lifts its hand and twists its finger in its nose. Then the hand goes back down again.

Although the Disgusting Spectacle is a very simple machine, it does have a specific start / stop position. The joke wouldn't work if the finger finished a previous cycle still up the nose.

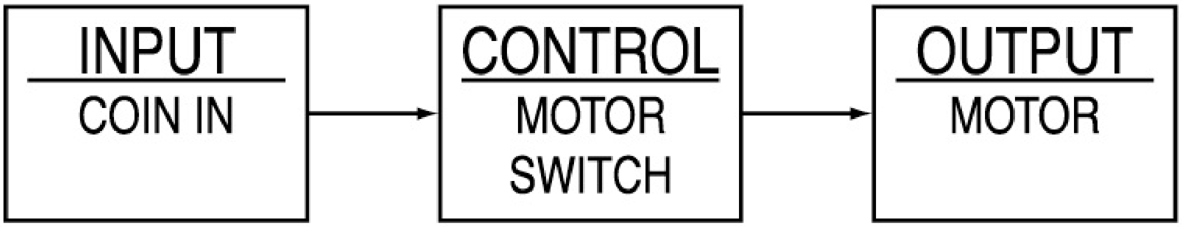


If you used a timer it would have to be set accurately to match the length of time that the machine takes to complete one cycle. However, even if you did get the timing right it may be possible for the mechanics to get out of synch (synchronisation) with the timer. A better solution would be if the control system actually knew when the hand was in the end position.

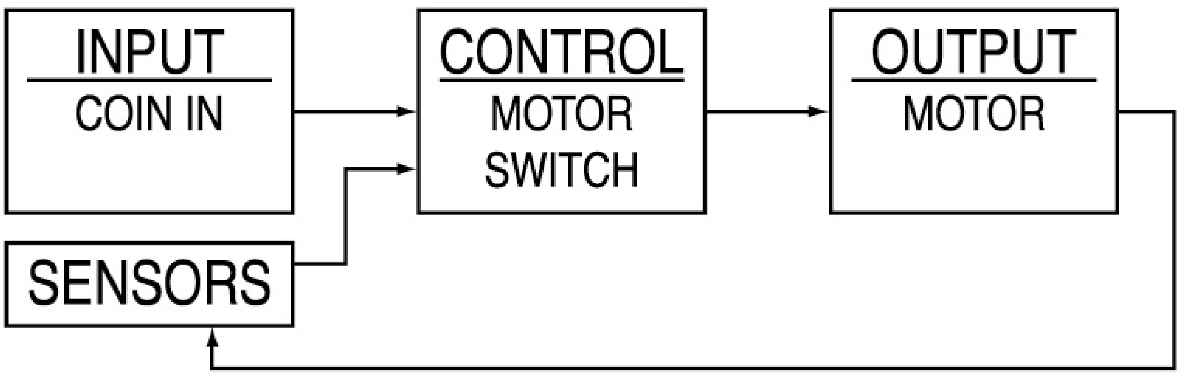
When the control system knows what the mechanics are doing this is called feedback. In this case, a switch could be activated by some part of the machine when the arm is in the up position. The switch would then be a kind of sensor.

Thinking in Blocks

When machines start to get complicated it's often useful to group their operations together into a number of blocks. This makes it easier to think about the design without getting bogged down in too many details. So, at the simplest level the Disgusting Spectacle could be defined like this:



It becomes more useful to design this way when there is some feedback in the control system because you can show the way the feedback will work by adding links between the blocks. Each block may contain another series of blocks, or they may define specific operations. In the Disgusting Spectacle there are sensors which tell the system what position the arm is in.



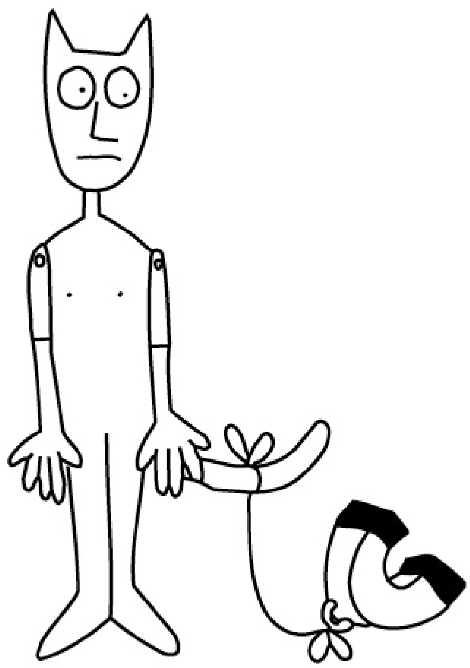
This shows that the switching of the motor is dependent on a coin being put in and on the arm position. This is still a simplification. It could be expanded to show that there is one sensor for the up position and one for the down position.

Cat Flap

You may think that this is starting to seem dangerously close to things like flowcharts and computer programming and you'd be right, but it's still relevant. It's all to do with problem solving.

Even though Tim Hunkin didn't draw a diagram like this when he designed the Disgusting Spectacle, (it's quite a simple machine and he already knew what he was doing), you should still find that designing like this can be useful.

Say you wanted to design a lockable cat flap from scratch. You're starting

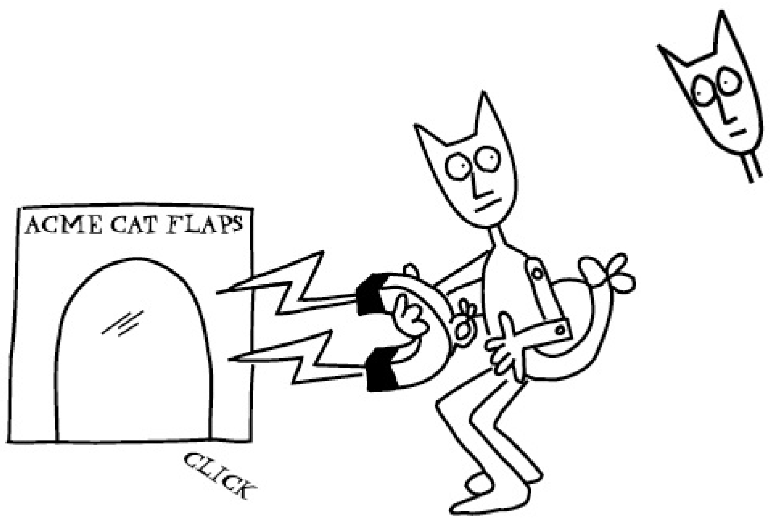


with a problem. How do I let a fairly stupid animal in and out of the house and not allow entry to all the other cats in the area?

Assuming you don't know anything about magnets and reed switches you can still approach the problem because you know what you want to happen. You can define the problem.

a) When our cat is at the door, unlock it.

b) When another cat is at the door, don't unlock it.

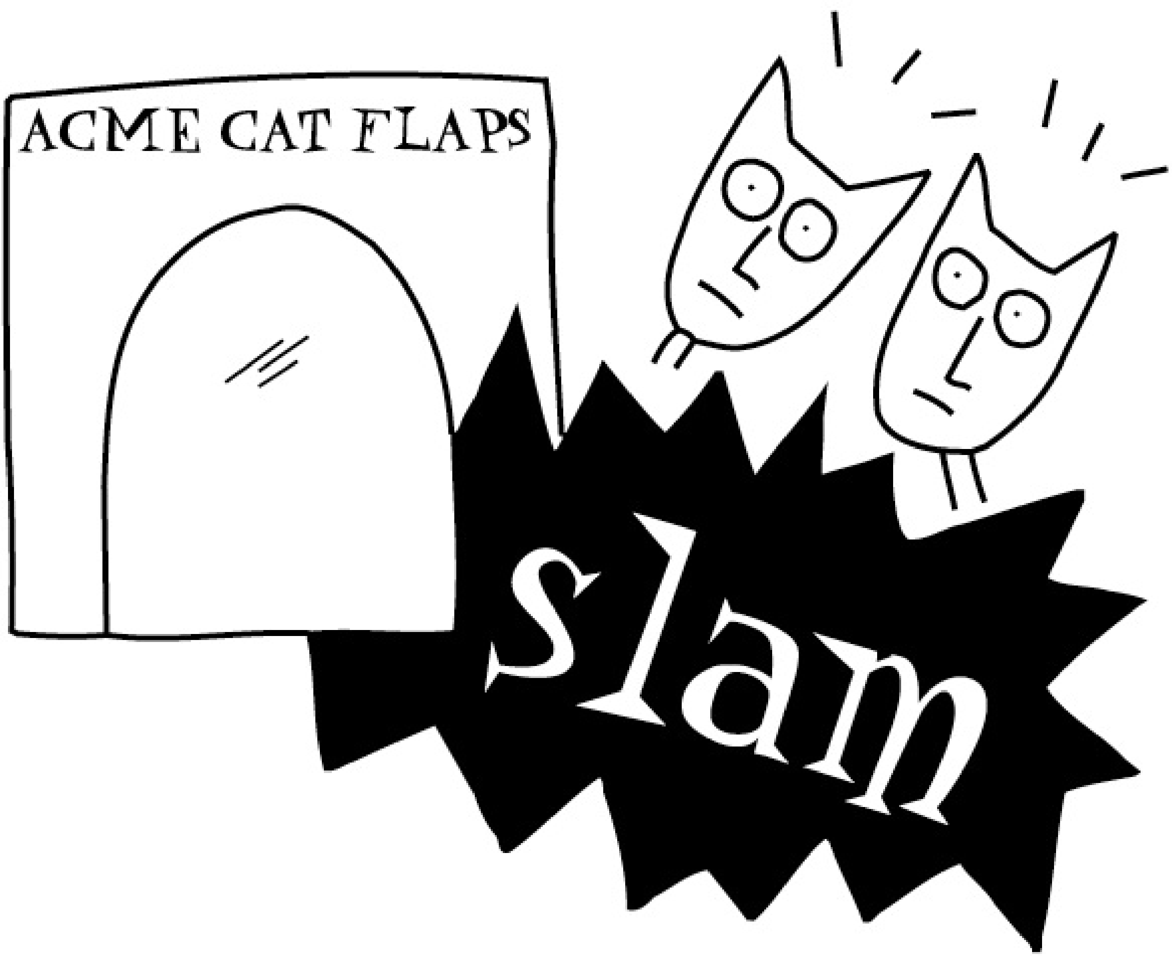


Now you can see that you need a way of identifying your cat from other cats while you're not around. So then it's a simple jump to attaching something to your cat that other cats don't have and building a sensor into the flap that will recognise the thing that the cat is wearing.

So now you have to go away and research sensors. After this you'll probably get to the usual solution; Your cat will wear a magnet which will operate a switch. Now you have another problem. What use is an electrical switch? You need something mechanical to activate the catch on the door.

So it goes on. You may even build a prototype and find that there are other local cats that wear magnets. So you may decide that you need a way to make the system unique to your cat.

The point is that any method that helps you solve problems is useful. In reality, you'll probably use a lot of different methods. Trial and error, drawing, block diagrams and research all have their place. With experience and practice you'll realise which is the most appropriate. If you don't have much experience then the final chapter should help.



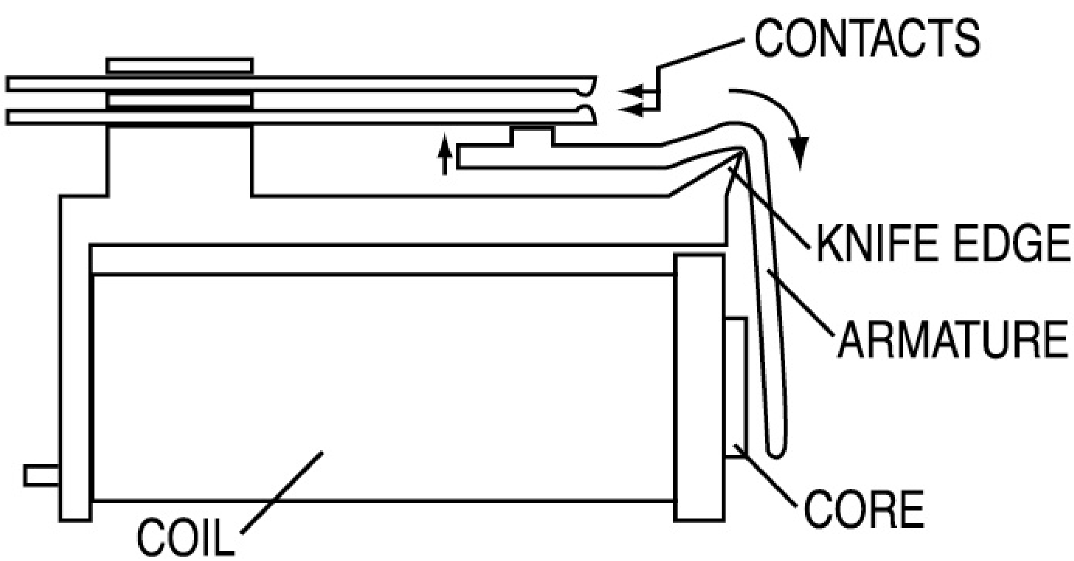
A Latching Relay Circuit

When you drop a coin into a conventional (non-electronic) coin mechanism a switch is operated for a fraction of a second while the coin passes it. To operate a machine you need to turn this momentary action into something longer. One way of doing this is to use a relay in a latching circuit. A latching relay circuit can also be used when you want a push button start on a machine with a long sequence and you don’t want people to have to hold the button for the whole time.

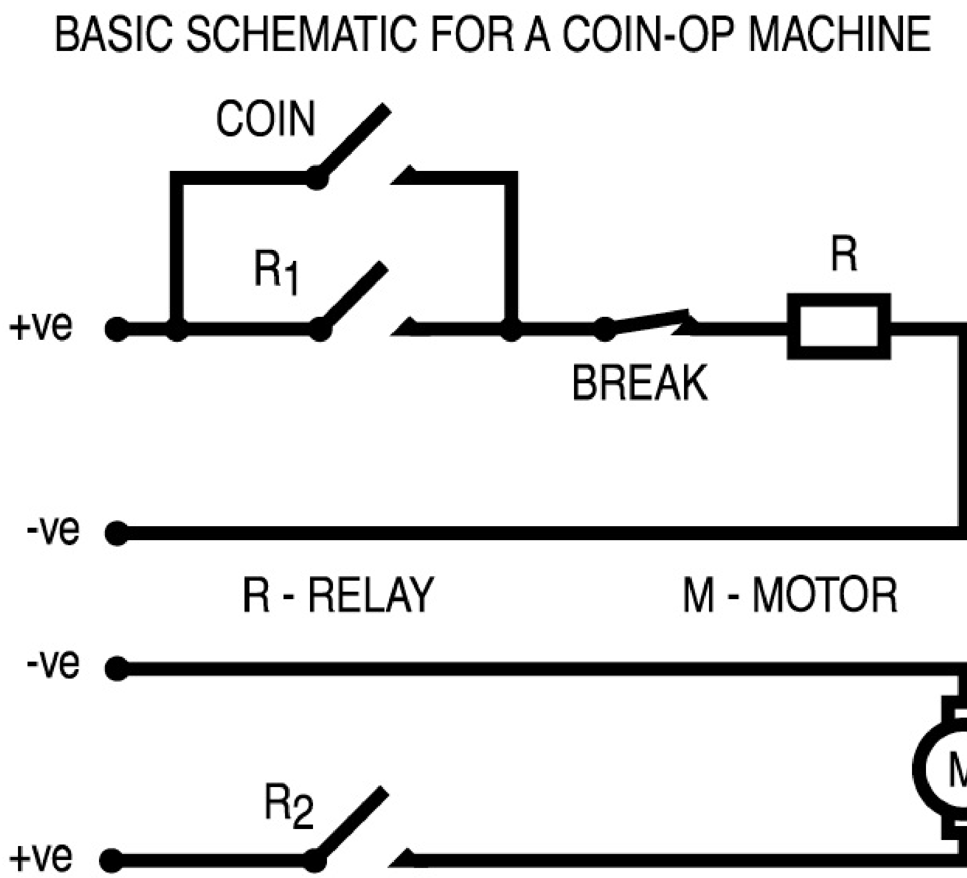
This circuit requires knowledge of basic electrical principles and you should only try it with a low voltage supply unless you really know what you are doing.

Before we look at the circuit, here’s a description of how a relay works. A relay is an electro-magnetic switch. This means it uses the magnetism which is produced by passing an electric current through a coil, to operate switch contacts.

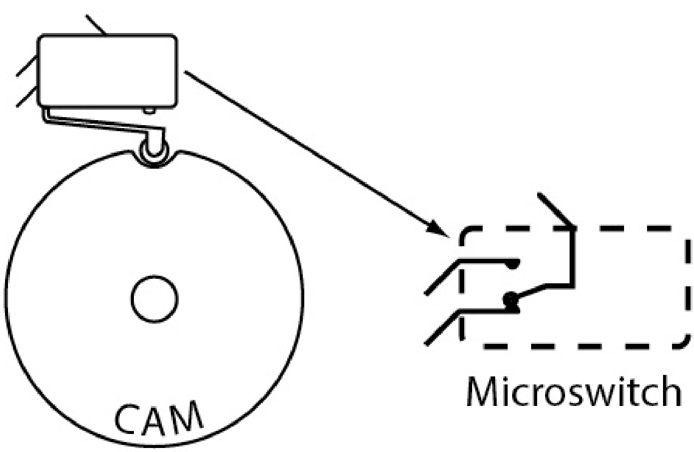
In the diagram you should be able to see that when the core is magnetized it will pull the armature towards it. The armature is a lever (surprise!) pivoting on the knife-edge. As it moves towards the core, it also pushes up the bottom contact into the top one.



When the coin is dropped the switch operates which then operates the relay. The relay holds itself on via it’s own contacts (R1). When the machine has finished the relay is released by the switch (Break). This switch also has to operate momentarily so that the circuit is reset ready for the next coin.



The break switch usually takes the form of a microswitch. Microswitches come in lots of shapes and sizes but they usually have a lever arm which operates the contacts inside the body of the switch. The diagram below shows a cam that could control the timing of the machine. The lever and roller microswitch has a small button which is pressed when the lever is pushed up.

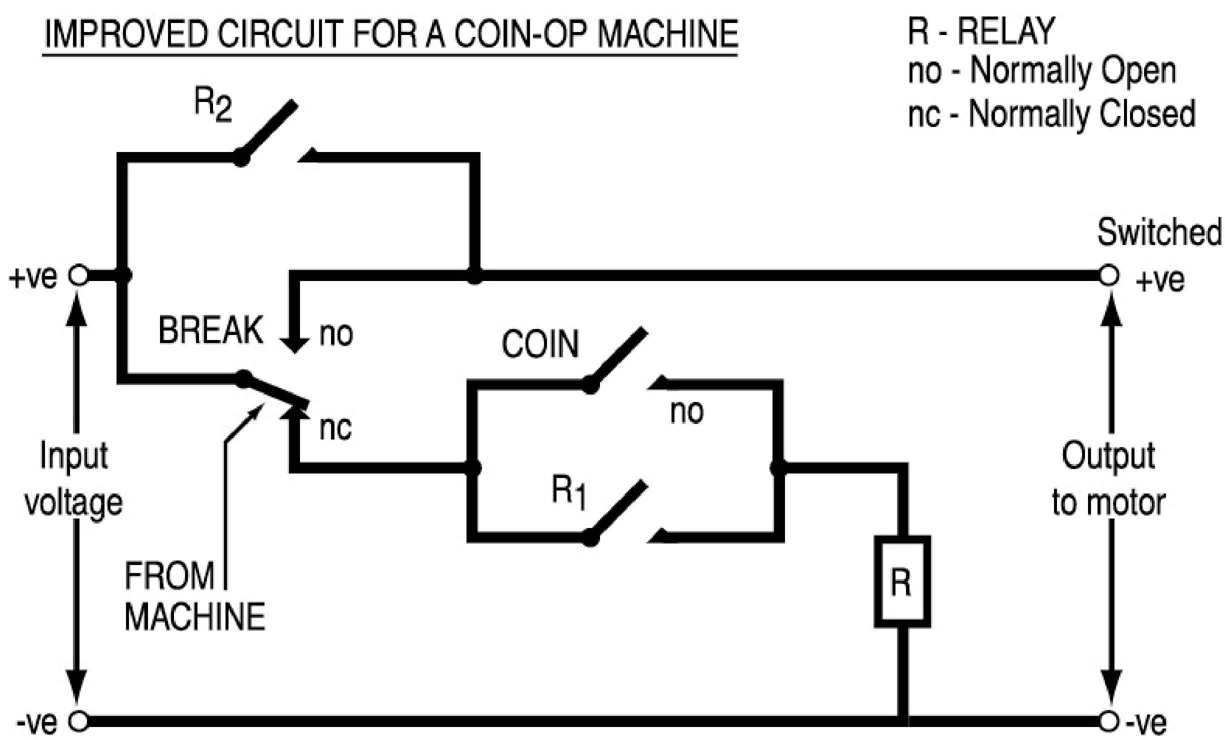


The Improved Circuit

Operating the break switch with a cam often leads to a problem. If the machine stops dead the break switch may not reset. If this happens, the relay can’t operate however many coins are dropped in. The following circuit overcomes this problem.

It works in basically the same way but making the break switch a changeover (toggle) switch makes the operation less critical. The power is held on by the relay or the break switch. When the break switch is first operated it provides the power and also releases the relay. As the machine stops the break switch returns to the starting state.

Make sure you understand how the first one works before you try to figure it out.



The Checklist

This chapter is intended to be a guide to one way of making automata. It does not, for instance, tell you how to operate a lathe. We have also avoided directing you towards particular materials. You may want to cut your cams from plywood on an electric table jigsaw; alternatively, your preference may be plasma-cutting steel plate. So if you need a particular craft skill, want to learn how to use certain machinery, or want to know more about working in particular materials there a lots of other books to help.

So now it’s up to you to apply the principles to your own ideas. But remember that the simplest ideas are often the most effective. By keeping your design as simple as possible you are much more likely to succeed.

The Checklist

Most people don't like to follow lists while they are trying to make something. The checklist that follows should be read and absorbed so thoroughly that you don't have to refer to it while you are making.

Stage One

It's hard to make automata quickly so allow yourself plenty of time to complete each of the stages.

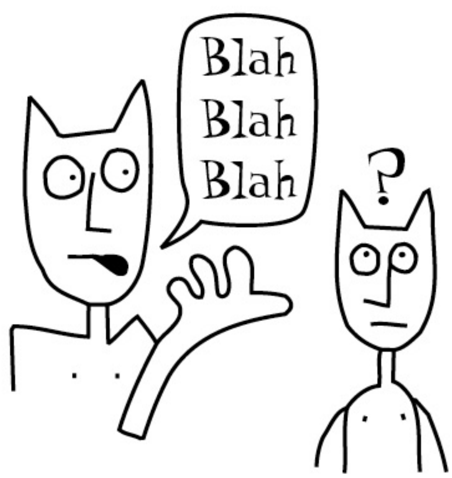
Observation

Collect ideas! Look closely at the way things move. Try to work out how the machines operate. Study how moving objects interact with other objects. Listen to the noises that they make.

From your observations, make detailed sketches and notes. Try to show how you think objects move. Keep all this information in your ideas book with other clippings from newspapers and magazines. Look out for pictures that inspire or amuse you. Think about how you can turn things you find into automata.

The more notes and sketches you make, the more ideas you will have. These ideas will generate more ideas. Making things generates ideas. The more you do, the easier it gets.

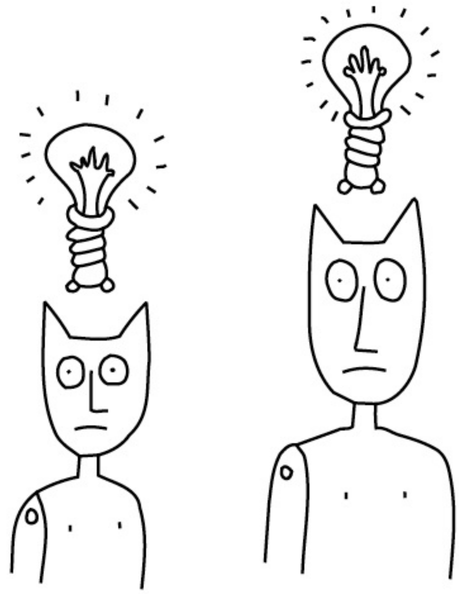
Discussion



It can be scary, but it's worth discussing your idea with other people. If you're worried about negative reactions you can approach it indirectly. For instance, rather than saying I'm going to make a piece of automata and this is what it does, you could discuss the idea or joke that's behind it. By sharing your ideas with others you might discover a fresh perspective or an alternative solution to a problem. Good ideas can even come out of misunderstanding and accidents. The discussion process should also help you to clarify your ideas.

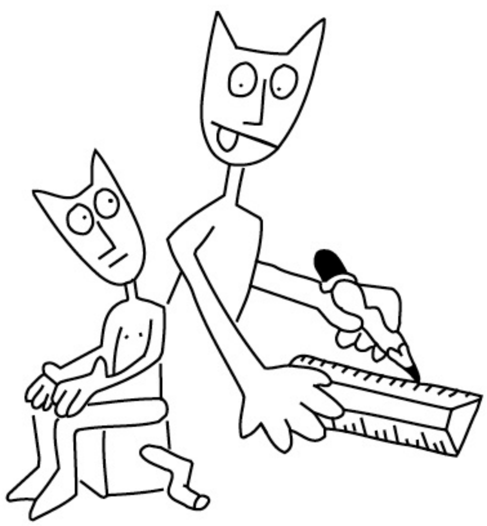
Inspiration

At this stage you should have gathered lots of material and given some time to thinking about and discussing your ideas. Now you should focus on a few of your best ideas. Is one particularly appealing? Or could you combine some of the best elements from a few different ones? If you're not inspired at this stage you can either go back to gathering and thinking or you could proceed in the hope that you will become inspired as you're working.



Drawing

Don't worry about how well you think you can draw. Use lots of diagrams to show how your idea will work. If you can illustrate how the mechanics will work you'll have a much better chance of actually making them work. Keep thinking about how the different pieces will be constructed and how they will fit together. A loose initial sketch is ok as a starting point but at this stage you should also be considering the engineering and construction that will be involved. You should also make up a list of the parts and different materials you will need.



Prototyping

Making a cardboard prototype is a fast way of visualizing and testing your idea. You may be able to check the mechanism by pinning flat pieces to a board. This is a good way to check things like lever pivot points and the throw of cranks and cams.

You may want to consider making a complete card prototype before committing it to another material that's harder to modify. Beware of making prototypes from thin card. Big models may be too floppy to work properly. If you've ignored our previous advice and are making something complex then it might be a good idea to break the prototyping down into small sections.

Prototype Evaluation

It's important that your prototype works convincingly before you move on. Be wary of a prototype that nearly works–unless you want the finished piece to nearly work as well.

This is a good time to make adjustments and improvements. Look for ways to simplify the mechanics. See if you can make it with fewer parts. Do you need to do any new prototyping? Should you start from scratch?

Stage Two

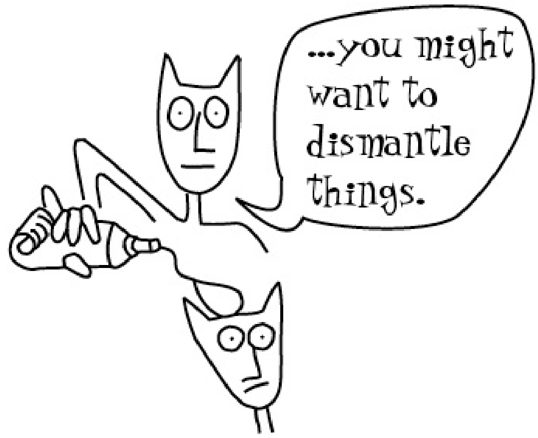
Planning

Even the most experienced automata makers always take longer to make things than they think and say they will. However, it's still worth trying to plan your time. A schedule may turn out to be wildly inaccurate but unless you have one, you'll never know how wrong you can be. Always leave plenty of time for making adjustments to the mechanism and finishing. Consider the following: What materials will you use? What are the appropriate tools? How long will it take to make compared with the prototype?

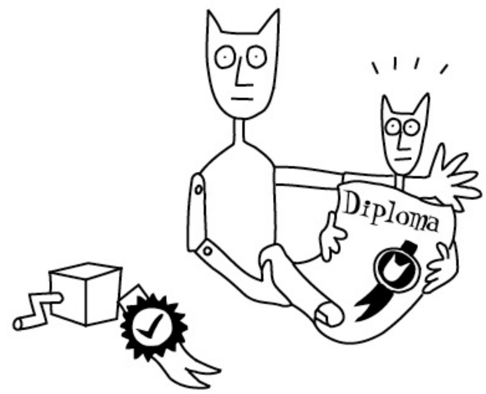
Construction

It's a good idea to make the parts so that they can be easily taken apart and reassembled. Obviously it's no good if the parts are loose when they need to be tight but you will find the ability to dismantle very useful.

Another important point is to make parts so that they can be adjusted. For instance, give yourself a method to change the length of a linkage or move the pivot point of a lever.



Test



So it's finished! Or is it? How long and how vigorously you test your design will depend on how long you expect the machine to last and what sort of abuse you expect it to receive. You might begin to realise that all you've really done is made another prototype. Don't be disheartened though–just remember the last time you experienced a "real" machine breaking down.

Critical Evaluation

Does your machine work efficiently and achieve the aims described by your original plans? If it does, then congratulations.

If it doesn't, don't despair. You are not alone and you've probably learned a lot. If you can see what went wrong and where it went wrong you'll be better prepared for the next one.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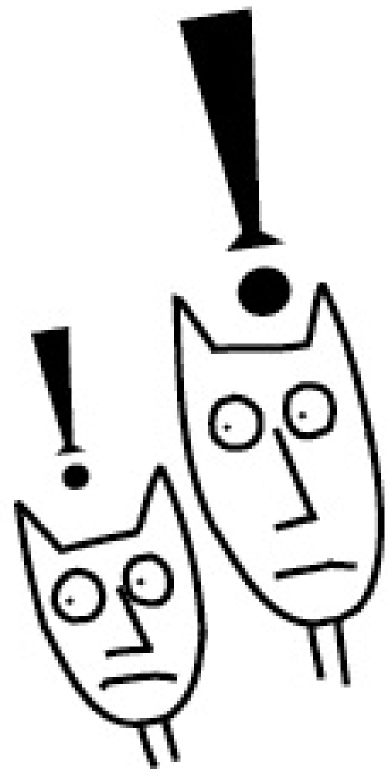
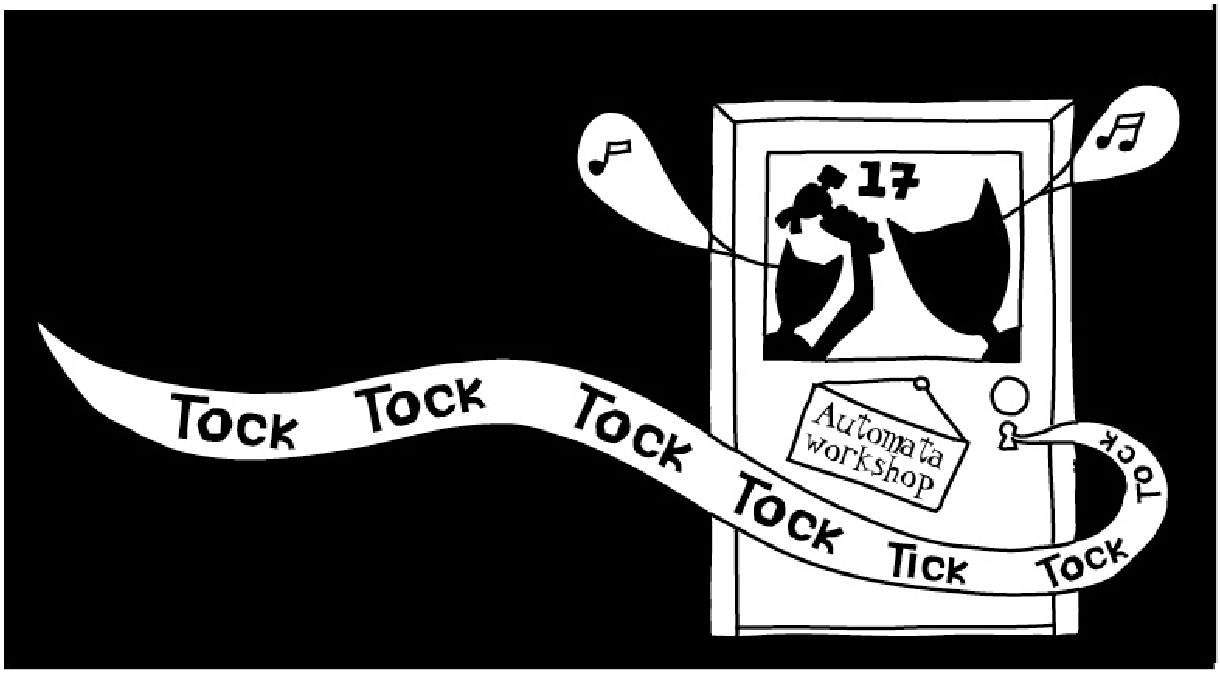



Everybody who makes automata makes mistakes. The trick is to learn from them.

The End

Making things move is a frustrating business even for people who are very good at it but if you enjoy it, don't stop.



Bibliography

Recommended Reading

When I first wrote this section I said it should be entitled Possible Reading because there were so few useful books on automata or making mechanisms. Fortunately the situation has improved a lot since 1998. It's also much easier to find out of print titles now so this list has been enlarged to include "new" books, with apologies for retaining some things that might be harder to find. Please let us know about anything we've missed for future updates. Here's a link to the book shop on our website.

Design and Technology

Books aimed at schools have sections on mechanisms, control and construction methods. For example, **Collins CDT – Technology**. Collins Educational. London. 1988. ISBN: 0 00327 434 9.

There are lots of books with "How Things Work" in the title. Obviously, the older editions have more mechanical devices. For example, **How Things Work 1** (based on Wie Funktioniert das? Germany 1963). Granada. 1972. ISBN 0 586 08095 3 (1982).

Mechanics and Mechanisms

Making Things Move: DIY Mechanisms for Inventors, Hobbyists and Artists by Dustyn Roberts. Tab Electronics. 2011. ISBN: 0071741674. This is a large and wonderful thing and a great next step from here.

There are lots of very technical books which are full of vector diagrams and mathematics that are not terribly useful for this sort of work. You may find very old books which are more fun. For example, **The Mechanic's Friend** by Archibald Williams. Thomas Nelson. No date, no ISBN. I guess it was printed in the ‘50’s. It has lots of practical information. You may never find a copy but I encourage you to look for similar things.

There are also some reprints of old books on mechanisms. For example, originally printed in 1868 is **507 Mechanical Movements** by Henry T. Brown. Lindsay. 1984. ISBN: 0 91791 425 2 The publishers, Lindsay, also printed other books of interest but are no longer in business. See ISBN: 9650060219 for another reprint. See also, the website where some of the mechanisms have been animated: 507movements.com

A book that is still available is **Basic Machines and How they Work**. Dover. 1971. ISBN: 0 48621 709 4. It’s rather strange because it was produced by the Bureau of Navy Personnel (USA) so it has lots of diagrams featuring sailors doing mechanical things.

Paper Engineering

Paul Spooner’s book of seven card cut-outs, **Spooner’s Moving Animals**, (Virgin - Abrams in the USA - 1986. ISBN: 0 86369 175 7) also has Paul’s view on the history of automata and his philosophy of ‘Rough Automata’. Even if you don’t make the cutouts, it’s still worth buying for the words and pictures. This was followed by **Red Roger** (Bellew Publishing. 1988. ISBN: 0947792082) which is a beautifully illustrated children’s story with only one cut-out and then, the **Museum of the Mind** (Bellew Publishing, or Abrams. 1992. ISBN: 0951872508) from which you can make a 14-inch high paper head with various mechanical scenes in place of the brain.

Paper Models that Move by Walter Ruffler (Dover, 2011 ISBN: 0486477932) contains 14 models to cut-out and use to entertain your friends. If you like card cut-outs, we have lots of individual models in our web shop.

Robots

There are build your own robot books that tend to cover electronics and servo motor technologies. There are also more general books which often have sections on the history of automata. For example, **Robots: Fact, Fiction + Prediction** by Jasia Reichardt. Thames and Hudson. 1978 ISBN: 0 50027 123 2.

Animatronics

This book on the work of Jim Henson's Creature Shop shows the application of mechanics in the film industry. **No Strings Attached** by Matt Bacon. Virgin. 1997. ISBN: 1 85227 669 X.

Automata and Mechanical Toys

There are quite a few books on mechanical toys but most of them tend to be aimed at collectors so they have very little mechanical detail. The most practical one I've found is **Mechanical Toys (How Old Toys Work)** by Athelstan & Kathleen Spilhaus. Robert Hale. 1989. ISBN: 0 70903 857 7.

This is the most well known book on the history of automata. It's currently out of print but it shouldn't be impossible to find a copy: **Automata and Mechanical Toys** by Mary Hillier. Bloomsbury Books. 1976. ISBN: 1 87063 027 0 (1988).

As well as the history of automata, this book does include sections on tools and materials as well as making projects based on a 12 Days of Christmas theme: **Automata and Mechanical Toys** by Rodney Peppe The Crowood Press Ltd. 2002. ISBN-10: 1861265107

Some of the most famous examples of old automata can still be seen operating. The Jaquet-Droz automata are housed in the Art and History Museum, Neuchatel, Switzerland. They also sell the book, **Androids–The Jaquet-Droz Automatons** by Roland Carrera, Roland. Scriptar SA. Lausanne. 1979. ISBN: 2 88012 018 7. This has the history of the machines as well as lots of detail on the restoration of The Musician.

Paul Spooner's **A Day at the Butchers** (2004. ISBN: 095287299) is a catalogue produced to coincide with the exhibition of the same name. It includes a text by Geoff Nicholson and over 30 pictures of Paul's machines and drawings. It can be purchased from our website: Cabaret Mechanical Theatre.

Kinetic Art

Jean Tinguely was the most significant kinetic artist. **A Magic Stronger than Death** by Pontus Hulten and Jean Tinguely. Thames and Hudson. 1987. ISBN: 0 50027 489 4.

Other areas to check are Toys, Puppets and Crafts.

The Back Cover

Making Automata is hard. Making other sorts of three dimensional objects can also be hard, but the extra dimension of movement seems to add a disproportionate amount of difficulty.

For most people, especially those untrained in engineering skills, getting to the point where making mechanical devices is easy, can be a long and frustrating task. Then again, there are many people who have a sound understanding of engineering but can’t even draw a horse.

These things can be learnt. This book does not teach you how to draw a horse, but it does remove the mystery that surrounds the world of mechanisms and the business of making things move.

Cabaret Mechanical Movement contains a lot of theory but it’s also packed with practical tips and ideas for making your own automata, moving toys or mechanical sculpture.

This book is published by Cabaret Mechanical Theatre, a museum that pops-up all over the world to delight its visitors with witty examples of the automata makers art.

You can find out more about CMT on our website: www.cabaret.co.uk

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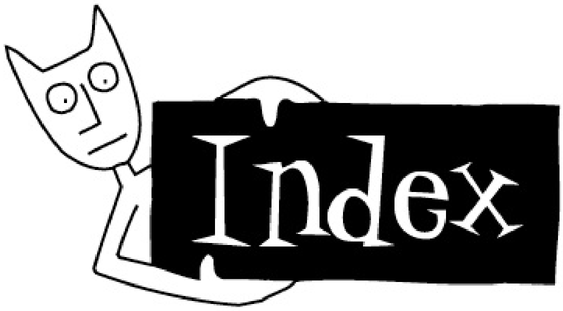

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