

## Chapter 3

### Mechanical and Spatial Thinking: Tools

Chapter 2 shows the nature of the problems faced when trying to support children's learning about mechanical systems and suggests some metrics that can be applied to gauge the effectiveness of any tool we may wish to give children to assist them during the design process. These tools fall generally into two categories: collections of physical pieces that can be combined into objects and software applications that can be used to create virtual objects for later realization as physical objects. Tools in the first category intuitively seem well suited to the task. Physical manipulation of the components provides the opportunity to experience the physical and mechanical properties of mechanisms in a very intimate way. Knowledge gained during the construction of mechanisms, even prototypes, is easily transferred to subsequent mechanisms.

The use of software tools to aid in the design process might seem to have less value. The friction observed as two gears mesh with each other or the interference problems encountered when adding components may not be evident in a virtual assembly. Where a designer might rummage through a box of parts examining and fitting candidate components to a mechanism in progress, the user of design software might not know about all of the components available. A list of difficulties inherent in using software to design mechanisms, especially for children, could go on and on. But software applications can provide significant benefits to children as they create automata when they support the designers' learning in relevant ways.

This chapter presents a representative sample of software applications and construction kits that have been, and could be used to explore mechanical systems. Some of these are aimed

at adult users, while a few specifically target children. In some cases, adult tools have been used by children in the design and construction of contemporary automata and this will be noted when they are examined. The chapter begins with a look at software for designing and evaluating mechanical and physical systems. This is followed by a survey of several popular construction kits that emphasize and encourage the exploration of mechanical systems. The chapter concludes with an overview of both software and construction kits that specifically target the contemporary automata domain.

### **3.1 Design Software for Children**

The landscape of software applications that focus on the design of mechanisms and are intended for children to use is incredibly barren. There are a number of excellent drawing programs for children (KidPix is one example), but these really aren't good choices for creating mechanisms for the same reason that Adobe Illustrator isn't used to create assembly drawings for automobiles. The software that is available for children falls into two general categories: programs that can be used to design objects which can then be constructed and programs that can be used to design purely virtual objects. The former is often limited in the type and complexity of machines that can be built, while the latter can suffer from their inability to be observed and analyzed in the real world. This space of design software is the one for which the MachineShop software was created and the example programs examined here provided much guidance during its development.

#### **3.1.1 LEGO CAD and Derivative Software**

In 1997, CyberToys created a program called LEGO CAD for LEGO Dacta (the educational arm of LEGO Group) and Autodesk (makers of AutoCAD) [24]. Written in Macromedia Director and running on Macintosh (systems 7 and 8) and Windows (95 or 98) computers, it was conceived as a tool for teaching children about simple machines (in the sense of machines that were not complicated rather than the traditional meaning of the phrase). LEGO CAD could render 63 (or 68; the documentation contains conflicting values) different LEGO parts; both traditional bricks

and beams as well as several gears, axles, hubs, chains and other moving pieces found in LEGO Technic kits. These components in particular allowed children to create interesting mechanical objects that could exhibit a wide variety of behaviors. LEGO CAD stored models of each of these elements rather than images and rendered them on the fly as most CAD programs do. Machines built in LEGO CAD looked amazingly like the illustrations that are seen in the directions that accompany LEGO kits (Figure 3.1) and children could then use these pictures as guides when building physical instances of the machines.

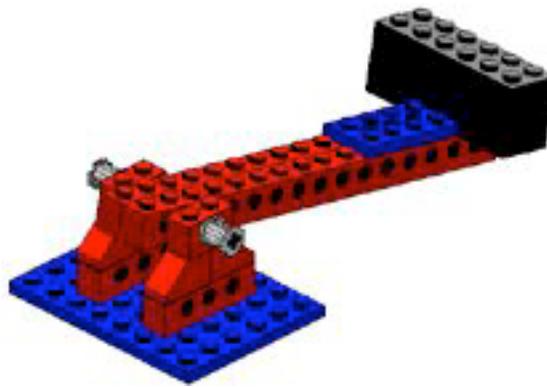


Figure 3.1: Using familiar LEGO elements, children could create simple machines using the LEGO CAD program. These virtual machines could then be assembled from LEGO components and physically manipulated.

LEGO CAD was a surprisingly sophisticated program for its time although it had several shortcomings. The choice of Macromedia Director meant that the program didn't behave quite the same on Windows computers as it did on Macintosh computers. For example, the quality of displayed images was of a higher quality when viewed on a Macintosh than when viewed on a Windows computer. The interface to the software required users to manipulate elements in a 3-dimensional space using the mouse which is a difficult task for a child. Each piece had several attachment points at which it would snap to attachment points on mating pieces. When a piece had a number of these points, it could be difficult to get the desired points to connect, frustrating users. The developers eventually made available a number of work-arounds to make the process easier. And while 63 or 68 pieces may seem like a significant number, it is, in fact,

a very small percentage of the inventory of physical LEGO components available. Users had no mechanism available to them to create additional pieces so were limited to creating within the boundaries established both by the software developers and by LEGO (this is discussed further in Section 3.3.1).

Despite the stated desires of the developers to enhance, expand, and optimize the program, newer versions failed to appear and LEGO CAD is no longer available. But the concepts of virtual LEGO constructions first seen in LEGO CAD still exist in new software from LEGO Group and the open source community. While these tools are not specifically designed for children they are included here because they live in the LEGO domain.

#### **3.1.1.1 LEGO Digital Designer**

In August 2005, LEGO Group released a design environment for LEGO constructions called LEGO Factory [68]. Designers use a freely available software application called LEGO Digital Designer to create 3-dimensional models and building instructions using components chosen from a number of palettes. When finished, users can upload their designs and, if they wish, order the bricks necessary to build their designs. The software clearly shows its LEGO CAD heritage. Users place components into a 3-dimensional view and attachment points are used to connect components (Figure 3.2).

LEGO Digital Designer has a number of features desirable in a design tool for children. By imposing constraints on manipulation and placement of components it helps a new user become productive in a reasonable period of time. The file formats for completed models, while encoded in a binary format and thus not meaningful without the software, are intended to be exchanged and modified by users which should help to create and support communities of practice. The software runs on both Windows and Macintosh computers, making it accessible to a larger audience than if it had been written for just one platform.

LEGO Digital Designer also falls short in some desirable areas. The 3-dimensional interface sometimes makes it difficult to determine one component's relationship to other components or



Figure 3.2: A Mars rover model in LEGO Digital Designer. The palette of components is at the right, file controls are at bottom, view manipulation controls at the lower left, and component manipulation tools are at the left. Model designed by 9 year old *npartist* (real name not given). Image courtesy the LEGO Group.

the base working surface. The control icons are not always meaningful and a new user must rely on descriptive text supplied by placing the cursor over a control and waiting. While LEGO Digital Designer has about 180 components available to users (almost three times as many as LEGO CAD), the majority are blocks and bricks and the number of mechanical components is actually smaller than provided by LEGO CAD. This limits users to doing little more than attaching wheels and tires to their models. There are currently no gears, pulleys, or other motion transmitting pieces available in the software making even simple machines impossible to design.

### 3.1.1.2 LDraw and the Open Source Community

LDraw is an open source CAD program and file format created by James Jessiman and originally intended to generate images of parts to catalog his LEGO collection. Written in 1995, it predates LEGO CAD by two years but does not have the official status enjoyed by LEGO CAD.

Unlike LEGO CAD, the open file format has allowed thousands of adult LEGO users to create both their own files for components but also CAD and viewer programs to work with those files as well as high quality rendering engines to create photo-realistic images of virtual models. Software exists for Macintosh (BrickDraw3D, BrickSmith), Linux (LDGLite), and Windows (MLCad, LeoCAD) computers and is available without charge. A large user community has grown up around these tools [67, 72].

What sets LDraw based programs apart from those produced for LEGO Group is that the needs of the community directly drive development. Any user has the ability to create files for any LEGO component that exists or that can be imagined which can, theoretically, eliminate one of the major shortcomings in the official LEGO products. The community has an oversight process for new part files that helps to assure that files are of consistently high quality and that components described by those files will work together like the physical components do. The LDraw libraries also include a growing number of pieces found in LEGO Technic kits which are especially appropriate for designing mechanisms.

### 3.1.2 The Incredible Machine

In the Incredible Machine (in all of its incarnations) the user is faced with a series of puzzles which can only be solved by creating machines (*contraptions* as they are called in the game) in the style of Rube Goldberg. Through captivating animation and physics modeling, users must attach various mechanical, optical, electrical, and fluid components together in order to achieve the goal of the puzzle.

A simple puzzle is shown in Figure 3.3. On the left, the user must use the pulley and rope provided to connect the two levers in such a way that when the soccer ball (right) is dropped, the basketball will end up in the left hand box and the soccer ball will end up in the right hand box. This is a simple pulley problem in the style of Hegarty [52] with the addition of two levers of the first order to make it interesting. The solution appears on the right.

It's not often possible to make realistic mechanisms with the Incredible Machine, and du-



Figure 3.3: In this Incredible Machine puzzle, the user must connect both levers with the rope and pulley (bottom panel) in such a way that each ball ends up in one of the cardboard boxes. The initial puzzle is shown on the left and a solution is shown on the right.

plicating game contraptions in the real world would be next to impossible. But the variety and ultimate complexity of the machines which are created provides the user with opportunities to experiment and learn that are not seen in other tools. The user can place, rearrange, and test combinations to not only complete the puzzle, but to see how those changes affect the operation of the machine. There are no penalties assessed for wrong solutions so the humorous and intriguing nature of this game encourages users to play and to learn. This has great value in learning to reason about mechanisms and would be a desirable addition to software more appropriate for building physical machines.

### 3.2 Design Software for Adults

While good tools for their intended purposes, none of the tools just described would make good choices for children to use for designing and building automata. Those that do support the construction of physical objects are limited in the kinds and styles of mechanical components that are available for building mechanisms. At the other extreme, being able to design with a large number of components is of little help when there is no adequate way to translate the virtual designs to physical mechanisms. For these reasons students who do build automata as part of

their education are rarely given these tools, even though in other domains or for other activities those software applications can be very useful. The software tools most often used by children to design mechanisms are full-featured applications created for adult engineers and designers such as the ones described in this section.

These tools offer their users the ability to create an almost limitless variety of mechanisms and, in many cases, can help users turn their designs into physical objects. Many of these tools provide sophisticated simulation environments in which the physical properties of material and component can be precisely determined before fabrication. But this power comes at a high price for children. The interfaces are often created with the understanding that users will already be familiar with the domain and the software's approach to the domain. Even for the initiated, the learning curves can be quite steep. Most of these tools are very expensive and require high-end computers to run on, both of which are large obstacles for children, their parents, and their schools. Most of these applications are general purpose and the tools they provide for the creation of simple mechanisms may be difficult to locate, difficult to use, or both. Even a task successfully completed once may be nearly impossible to repeat if the sequence of steps can't be remembered from one use to another. Still, in many cases, there is nothing better available and even a cumbersome tool is better than no tool at all.

### **3.2.1 AutoCAD**

While many proprietary drafting systems had been developed by large engineering and manufacturing firms to link their mainframe computers to their flatbed plotters, AutoCAD was among the first CAD/CAM programs to be released for use by smaller firms and individuals. Created by Autodesk and first made available in December 1982, it quickly gained a following in companies who were keen to realize the benefits it provided both in the research and development and production phases of product development. While AutoCAD was designed to work in ways that were easy for the compass and triangle crowd to embrace, its real power came from its built-in LISP [109] macro language. For the first time, small engineering firms could automate

many of the repetitive drawing and design tasks that had previously been very labor intensive.

The massive feature set of AutoCAD makes it a powerful tool for industry and any survey of contemporary automata will not reveal a single instance that could not be designed with AutoCAD or fabricated from files that AutoCAD could produce. But the hundreds of commands and tools and the thousands of ways in which they can be combined make it a very difficult program to learn<sup>1</sup> and a poor choice for children to use. Still, with the help of an adult knowledgeable in both mechanical design and the use of the software, AutoCAD could be a useful tool for a child.

### 3.2.2 Pro/DESKTOP

Pro/DESKTOP is a 3-dimensional design tool from Parametric Technology that allows users to perform solid modeling parametrically. It found widespread acceptance in industry, sometimes being used alongside its larger CAD/CAM sibling Pro/ENGINEER, but often as the sole CAD/CAM tool in many companies. While not specifically designed for education, Parametric Technology saw this as an opportunity to expand their user base. In 1999, to begin the process, they donated an unlimited license for Pro/DESKTOP to the entire public school system in the United Kingdom for use in the Design and Technology (D&T) component of the curriculum.

This windfall was not all boon, however. D&T teachers found themselves in the position of needing to integrate a tool designed for industry into their classrooms. Most teachers were unfamiliar with Pro/DESKTOP and were forced to make do with whatever training they could receive. While older students had an easier time working with the software, younger students struggled and teachers were forced to find simpler roles for its use. When students in years 5 and 6 are making moving toys or automata [25, 26] they often make use of Pro/DESKTOP, especially when their school owns one or more machine tools that can produce components from the computer files the children create.

D&T teachers almost universally find Pro/DESKTOP to be poorly suited to the purposes

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<sup>1</sup> The author spent six years as a draftsman working with AutoCAD before returning to university and this statement is based on that experience.

for which it is used but can find no better alternatives. To make matters worse, at the time this is being written Parametric Technology is in the process of retiring Pro/DESKTOP since most of its functionality has been gradually incorporated into Pro/ENGINEER. What this means for D&T education remains to be seen, but what is clear is that there is still no tool truly appropriate for these teachers to use.

### 3.2.3 Working Model

Working Model differs from AutoCAD and Pro/DESKTOP in that its purpose isn't to design mechanisms, but rather to understand them. Working Model is a Computer Aided Engineering (CAE) program in which simulations can be run and the data from those simulations analyzed. For the most part CAD/CAM systems are designed to work with components and assemblies at rest and are not particularly well suited to examining those components or assemblies in motion. Working Model allows the user to import 2-dimensional CAD drawings in the standard Drawing Exchange Format (DXF) which can be written by most CAD programs. The user is then able to set those drawings in motion and specify parameters dealing with the simulation environment such as speed, direction, and coefficients of friction. The simulation not only allows the user to watch the mechanism in action, but also provides a variety of output values for such things as force, torque, and acceleration.

Since automata are dynamic objects there are advantages to seeing them move during the design phase, and Working Model provides an environment in which to do this. But do we need simulation, or would simple animation be sufficient? Defining the correct parameters for a simulation and arriving at appropriate values for them can make the initial setup of simulations difficult. Simulations also suffer from difficulties in defining the boundary of the model; deciding what is internal to the simulated environment and what is external to it [133].

### 3.3 Construction Kits

Construction kits are collections of components that are designed to be combined with one another, creating larger assemblies. While the term has become common (software construction kits, homepage construction kits, language construction kits), it is used here to mean sets of physical objects which, when attached or connected together, can be used to create larger objects with more complex structure. It can be argued that these kinds of kits are descended from the *gifts* created by Friedrich Froebel for use in his kindergartens [10] of the early nineteenth century. Certainly he was the first to use this kind of play activity to facilitate learning. As previously mentioned, the use of physical components to construct mechanisms has much to recommend it.

When a child holds, moves, attaches, removes, rotates, inverts, or engages in any other action with a piece she is building knowledge about the process, the domain, and the materials in ways that cannot be duplicated with a computer. This knowledge becomes intimate and its acquisition personal. The things she learns building one structure or mechanism will assist her in building the next. This type of experiential learning begins in infancy and children (and many adults) continue to learn this way. Construction kits take advantage of children's love of building to make the learning all but invisible.

There have been scores of construction kits available to children since Froebel's time. This section will focus on a handful of examples from the last 100 years, all of which could be used to construct the types of mechanisms found in contemporary automata.

#### 3.3.1 LEGO

LEGO Group makes what are arguably the most popular and successful construction kits ever created. The familiar plastic bricks were created in 1958 and incorporated design ideas that LEGO had been using since 1949 in their Automatic Binding Bricks. The building components that LEGO makes are so ubiquitous that rarely does any one refer to them as LEGO bricks, but simply as LEGOs. For the construction of automata this is a distinct advantage. LEGO components are

familiar to many children who need no instruction in their use. This frees them to create stories for their automata to tell and to explore possible mechanisms to help tell those stories.

Because of their popularity, LEGO has segmented their products into families (with some overlap). The bricks, beams, and plates used most often comprise the LEGO System. The mechanical components such as axles, gears, and pulleys along with the special beams and bricks to support them comprise Technic. And the computer controlled robotics sets (which borrow components from both System and Technic) are called Mindstorms.

#### **3.3.1.1 LEGO System**

LEGO System contains the pieces that are most familiar such as bricks, beams, and plates. The variety of pieces available is considerable and they can be used to build anything from a simple house to a full size automobile (Figure 3.4). Hundreds of kits have been released but one of the major draws of System is the availability of large quantities of pieces that have no specific end result in mind allowing the builder to create whatever she wishes. With respect to designing and building automata, System components are primarily of interest for the support roles they can fill. Since all LEGO components are designed to work together, these pieces can be used in structural supports for mechanism components, as general framework components, and as tableau elements and decoration.

#### **3.3.1.2 LEGO Technic**

LEGO Technic sets first appeared in 1977 and were originally called Expert Builder. What differentiated these kits from System is the inclusion of parts specifically designed to provide motion to the static models previously available. Technic kits have overwhelmingly consisted of parts to build vehicles of one description or another. Large collections of parts are not available as they are with System although a number of components can be ordered. The types of mechanisms that can be created with Technic components can come very close to those used in automata. LEGO has created a variety of gears and shafts that can be used directly.



Figure 3.4: A full size replica of a Volvo XC-90 automobile made from LEGO bricks on display at an auto show.

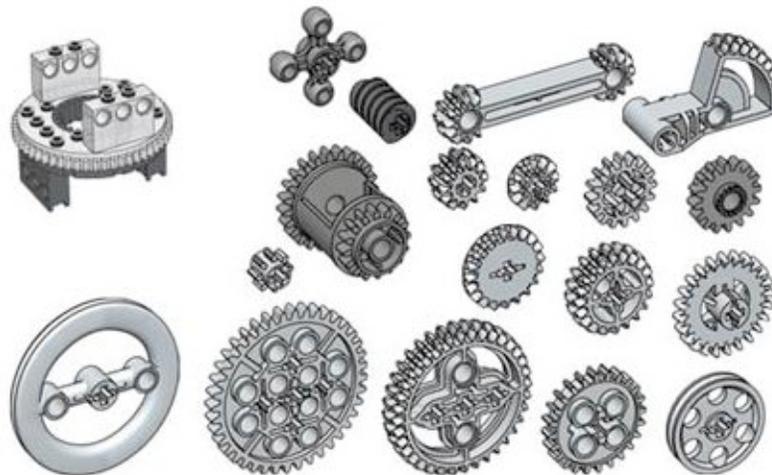


Figure 3.5: A selection of Technic gears and pulleys that can be ordered from LEGO. Note that several of the gears have holes where connectors can be added to create cranks. Drawing courtesy the LEGO Group.

Some of the gears (Figure 3.5) have holes near their edges in which connectors can be added to make cranks, the closest Technic comes to having cams. In addition, the novel beams and connectors used in Technic kits can be used to create levers and cranks. These features make Technic a valuable prototyping environment for automata although several factors make it less

than perfect for final construction. The most serious is the limited selection of parts available<sup>2</sup>. LEGO has decided what sizes and ratios the gears will have, which, in turn, fixes the distances at which shafts and other components can be placed, defining the sizes at which mechanisms can be built.

### 3.3.2 K'NEX



Figure 3.6: The K'NEX gear and crank set can be used to create a number of machines in addition to those shown in the instruction booklet. From left, a Ferris Wheel, an eggbeater, and a bicycle built following supplied plans. Photo courtesy K'NEX.

K'NEX also markets a wide variety of construction kits. The building style is quite different from LEGO in that, rather than assembling bricks and beams into solid shapes, plastic rods of various lengths are snapped together using connector pieces. These connectors allow rods to be connected at angles which are multiples of  $45^\circ$  in the plane of the connector and at right angles to the plane of the connector. Rods and connectors are color coded indicating the length of rods and the maximum angles that connectors can support. Constructions in K'NEX are based

<sup>2</sup> This is a drawback to a greater or lesser extent with all construction kits. One goal of the MachineShop system is to allow users to design custom parts to fit their exact needs rather than working around the parts that are available.

on right isosceles triangles and to make this possible, the lengths of successive rods (taking into account the additional length the connectors add) are at a ratio of  $1:\sqrt{2}$ . These triangles are what gives K'NEX models their structural strength. K'NEX owes much of its style to a much older toy, Tinkertoys [111], but has expanded Tinkertoys capabilities and eliminated many of its shortcomings. K'NEX constructions have a more open feeling than do those made with LEGO and, because there can be significant distances between adjacent pieces, they can be quite large.

Like Technic, K'NEX makes pieces for building machines. Levers, pulleys, wheels, gears, and cranks are all available for inclusion in models (see Figure 3.6) and these can also be useful prototyping tools. In some cases, gears for instance, K'NEX provides more variety than Technic.

### 3.3.3 Metal Construction Toys

Metal construction toys first appeared early in the twentieth century with the introduction of the Meccano Construction Toy System in England in 1901, with Erector Sets following in the United States in 1913 [43]. While Meccano and Erector are arguably the two most successful and well known metal construction toys, they had many imitators and competitors throughout their lives. Temsi, Marklin Metall, Ami-Lac, Stokys, Stabil, Mignon, and Eitech in Europe, Exacto in South America, Steel Tec in Asia, and American Model Builder, Constructioneer, and Metalcraft in the United States all built (or build) similar toys. These systems share a number of common features. They utilize standard systems of reusable metal parts, including perforated strips, girders, wheels, rods, brackets, pulleys, sprockets, gears, electrical parts, motors, and other specialized parts that are attached to one another with screws and nuts. Most systems contain the necessary components for the construction of mechanisms. A #10 Erector set from 1932 is shown in Figure 3.7.

The components in these systems and the building styles they support mirror the explosions in mechanical and civil engineering at the turn of the twentieth century. Skyscrapers and bridges, trucks and automobiles, even the pinnacle of steam power both for transportation and industry are easily modeled with these toys. A.C. Gilbert seems to have been inspired to create



Figure 3.7: An original Erector set from 1932. Erector sets carried number designations and this #10 set was the largest made at that time. Note the variety of wheels, gears, pulleys, and shafts for making moving models. Erector and other metal construction toys are highly prized collector items. The set shown here sold at auction in October, 2005 for \$19,200 US [19]. Photo courtesy Chicago Antiques Guide.

Erector after seeing the catenary towers for the electrification of the New York, New Haven, and Hartford Railroad being constructed from steel girders [128]. This style of construction kit lends itself well to the design and construction of mechanisms and machines both in the variety of ready to use mechanical components and the ease with which frameworks to support and align mechanisms can be constructed.

As with all of the other construction kits mentioned here, metal construction toys are not without flaws. Primary among these is the ease with which the connecting screws and nuts can become lost and the difficulties younger children have in manipulating them. Many times the pieces, beams in particular, are easily bent but not so easily straightened. And a specific drawback

for using these kinds of kits for automata is the virtual impossibility of constructing reasonable looking people and animals with components designed to simulate cranes and Ferris wheels.

### 3.4 Automata Software, Kits, and Resources

The previous sections have reviewed a number of software applications and physical constructions kits that have been or could be used to design and create the mechanisms for automata and, in the process, affect the mechanical reasoning and spatial cognition of the builders. But in all cases these artifacts are general purpose tools for working with mechanisms and machines of many types, not specifically automata. Since automata are the research domain detailed herein, this section will focus on tools which aid the builder in creating contemporary automata (Section 4.1.4). In a number of these examples the intended audience is school aged children, just as MachineShop. It is important to note that all of the examples presented here come from countries with design and technology components in local or national curricula and that little imagination is necessary to see how these would be used to address classroom needs. It also bears mentioning that all of these were assessed as to their strengths and weaknesses and those assessments were used to guide the design of the MachineShop system.

#### 3.4.1 Cabaret Mechanical Theatre

England's Cabaret Mechanical Theatre could be considered the nucleus of the contemporary automata revival [120]. In addition to providing a gallery for the exhibition of automata<sup>3</sup> Cabaret Mechanical Theatre early on offered the works of its artists for sale to the public. The shop soon expanded its offerings to include automata kits (both card and wood) as well as posters, books, and videos to aid neophyte automatists. When design and technology was added to the national curriculum in the United Kingdom, the proprietors, Sue Jackson and Sarah Alexander, found themselves besieged by requests from teachers for help with the new subject matter and a

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<sup>3</sup> Sadly, Cabaret Mechanical Theatre no longer occupies the marvelous space in Covent Garden, London that it did for nearly two decades. The collection currently has no permanent home although representative selections do appear from time to time in traveling or temporary exhibitions.

number of new products joined their automata kits.

#### **3.4.1.1 Automata Kits**

Over the years Cabaret Mechanical Theatre has offered a number of wooden and card automata kits designed by several of the artists whose work is found in the Cabaret Mechanical Theatre collection. The wooden kits are comprised of pre-cut wooden pieces with card, string, and other necessary bits along with simple instructions. These kits range from the very simple to the moderately difficult. The card kits have the pieces brightly printed on stiff card stock with dowels and other parts included. Unlike the pre-cut pieces in the wooden kits, the card pieces must be cut out by the builder before assembly can begin so even the simplest of the card kits is more difficult than the simpler wooden kits. Both kinds of kits require the builder to be able to fit, assemble, and attach pieces as described in the instructions. Building kits such as these is a perfect way to learn many of the necessary skills required to build (but not necessarily design) automata. Since the builder is completing the assembly of a proven design from a master automatist, careful construction (especially with the card kits) will almost always lead to a properly functioning automaton. Figure 3.8 shows an example of an automaton built from a fairly difficult card cutout kit.

The downside of using kits is that little of the design process of the automaton can be discovered during construction. The mechanism and its attachments to the figure or figures of the automaton carry with them none of the design decisions or discarded alternatives that determined what pieces would become the kit. To better understand mechanisms, it is important that the builder be involved in those decisions in order to gain the analytic and comparative skills that are necessary for good design.

#### **3.4.1.2 Cabaret Mechanical Movement**

To provide assistance to novice automata designers, Cabaret Mechanical Theatre published a book designed to help new automatists understand the kinds of movement found in automata,



Figure 3.8: This nefarious feline plies his trade smuggling a shipment of canned tuna in his row-boat. Card cutout kit designed by Keith Newstead. Photo courtesy Cabaret Mechanical Theatre.

learn how components such as cams, gears, and levers can be combined in mechanisms to provide those movements, and how to go about the task of building an automaton [90]. This book is a valuable reference and source of ideas for anyone building automata although younger builders will benefit from having a more experienced builder direct them to the key points in the beginning.

### 3.4.1.3 Designing Kits

To fill the need for an intermediate product between the design oriented *Cabaret Mechanical Movement* and the construction oriented wooden and card kits, Cabaret Mechanical Theatre

created the first of their hands-on kits to help new builders, primarily children, create their own original automata in 1999. This kit was refined in 2002 and a revised version of that kit was introduced in 2005 (Figure 3.9). These kits are a good way for complete novices to gain some experience in both the design and construction of automata. Four movements are supplied to followers by a single-lobed snail cam, a three-lobed triangular cam, a disk, and a crank-slider (see Section 5.1.3.1 for explanations of these components). The builder must choose which of these movements are appropriate for her automaton and attach the necessary pieces which will create the people, animals, or other storytelling elements of the automata.



Figure 3.9: Nearly one hundred pieces can be assembled to make a variety of automata with this Designing Automata kit from Cabaret Mechanical Theatre. Mechanisms are limited to those using cams or a crank-slider. Photo courtesy Cabaret Mechanical Theatre.

This ability to rapidly create an automaton comes at the price of variety in the designs.

While there are a great number of automata that can be built using this kit, focusing on only one kind of mechanical component, the cam, is a serious limiting factor. The alternative would be to add other types of components to the kit, but this could then complicate the process and make the kit less useful for its intended purpose.

#### **3.4.1.4 Interactive CD ROM**

To provide opportunities for younger children to experience building automata, Cabaret Mechanical Theatre produced an interactive, animated CD ROM aimed at children from five to eight years old. Children using the CD can assemble and embellish an automaton using virtual representations of physical pieces from the Designing Automata kit. The CD has a number of frustrating issues. First, it provides even less of an opportunity to experiment with a variety of mechanisms than does the kit. Second, when adding a piece to the mechanism, it is often unclear exactly where the user need to place it in order for it to be added correctly. Finally, this is not an activity that children should be expected to return to again and again such as could reasonably be expected with the Designing Automata kit or the *Cabaret Mechanical Movement* book.

#### **3.4.2 Flying Pig**

Flying Pig is another company in the United Kingdom devoted to the design and creation of contemporary automata [37]. Although primarily existing to sell its line of card cutout automata kits, its website has a number of useful links on mechanisms and their motion, the proper selection and use of tools for building automata, building tips, photos of automata, and a forum for builders to ask questions and exchange ideas. This is one of number of websites (see Appendix D) that automatists of any skill level will find useful.

#### **3.4.3 Software 4 Teachers**

Software 4 Teachers is an organization in the United Kingdom that makes a useful product for builders of automata [107]. Their interactive CD ROM entitled *Automata* contains a wealth

of valuable information. The disc is divided into five sections, each dealing with a set of topics. The first section provides an introduction to automata, spends some time addressing the process of designing, looks at basic properties of movements, and briefly discusses the support structures needed for an automaton. Sections two and three present an introduction to mechanical components showing familiar examples, explaining how best to fabricate them, and showing them used in automata. Section four deals with getting the components to move as they should and spends a little time talking about “the bit on top”. Section five introduces the tools necessary for fabrication and explains how to use them safely. This material is presented through photographs and short video clips supported by textual and audio descriptions. The user is free to explore the material as she chooses using the navigational windows.

#### **3.4.4 MouseWorks**

MouseWorks Canada markets a number of wooden automata kits using simple mechanisms. They also sell a book on automata construction [76]. The first half of the book deals with designing and constructing automata and includes sections on tools, materials, and fixtures. It then presents a number of historically important automata before spending the remainder of the book providing instructions for constructing a number of sample automata. The book is an amalgamation of information readily available elsewhere with some of the illustrations remarkably similar to those in *Cabaret Mechanical Movement* (compare the figures at [76, page 2-4] with those at [90, pp. 53–55]). While the example automata building instructions are good for those learning the craft, the rest of the book is of varying usefulness.

### **3.5 Summary**

The purpose of the MachineShop system is to support children as they design and construct mechanisms for use in contemporary automata. Other software applications can (and often are) used for this same purpose. Of those applications written for children to use in designing mechanisms, some put an emphasis on virtual simulation of the real world and challenge users

to create machines which, though whimsical, could never be built. Others are tightly coupled to some physical construction system (LEGO bricks and components for example) and require users to create with only the components available in the system. No software currently exists that will allow children both a high degree of freedom when designing mechanisms and give them some confidence that those mechanisms can be built to function as intended. While professional CAD/CAM systems can allow that freedom and confidence, they can also be openly hostile and antagonistic to naïve users who can struggle with overly rich feature sets, nonintuitive workflow, and intimidating user interfaces. But in many cases they are the only real option available and children are taught to accomplish only the tasks that they need to accomplish and nothing more. Chapter 5 will examine the ways in which the MachineShop software provides professional power to children.

Software is not the only way to design and experiment with mechanisms. Machines can be built in structured ways using a variety of construction toys or kits. The choice of appropriate construction kits for building the kinds of mechanisms found in automata is a difficult one. Each brand or type of kit has its own strengths and weaknesses and, at least for children, familiarity is often a deciding factor. No construction kit available has the variety of mechanism components that are found in any significant sample of contemporary automata which puts limits on the automata that can be constructed.

Because the design and construction of automata has found a place in some curricula, most notably in the United Kingdom, a number of products are now available that are automata specific. Kits made from wood or heavy card can be assembled to provide construction experience. Software, videos, and books present the problems and solutions of design so that builders can create unique designs. Construction kits whose parts can be used again and again to create any number of automata are now available and a significant number of websites designed to both sell these products and to provide resources to further enhance a new builder's learning have also appeared. This emphasis on contemporary automata will be described in greater detail in Chapter 4.