Creating Cool MINDSTORMS® NXT Robots

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PART 1

Look, Mom! No Wheels!

After building your first wheeled robots, you can feel bored. Okay, they're built for precision, you can make them go exactly where you want, at the speed you want . . . but they still use wheels! LEGO itself, planning a new MINDSTORMS line, never thought about a wheeled robot becoming its logo and NXT mascot—months before the product release, the figure of Alpha Rex filled every advertising space. In this first section of the book, you'll discover how to leave the wheels behind and get moving on legs.

CHAPTER 1

Building Biped Robots

I can imagine your impatience—the urge to skip this introduction chapter altogether, and go directly to building the robots that are shown in the next chapters of this part, which are entirely devoted to walker robots. However, you would entirely miss the essentials necessary to understand why the walkers presented in this book actually work; you would miss finding out how to let your robots leave the wheels behind them and get on their own two feet.

This chapter will present the state of the art in LEGO walking biped robots. I'll introduce some basic notions of that branch of physics called statics (balancing forces) to help you develop steady biped robots that do *not* need to use any advanced sensor to balance, such as accelerometers, tilt sensors, or gyroscopes. The stability of those robots is guaranteed only by the hardware configuration.

LEGO Bipedal Walking: The State of the Art

It has been almost ten years since LEGO MINDSTORMS users like you developed various bipedal walking techniques. The numerous biped robots, created fairly successfully during those years, can be categorized as follows:

- Interlacing legs bipeds
- Jerky center of gravity (COG from now on) shifting bipeds
- Smooth COG shifting bipeds

I'll describe these categories in detail, focusing on their level of complexity and the mechanical solutions used, with the help of some visual examples. In the next chapters you'll find the practical examples of this categorization: Quasimodo (Chapter 2) is an interlacing legs biped, *Star Wars* AT-ST chicken walker (Chapter 4) is a jerky COG shifting biped, while the Omni-Biped (Chapter 5) is a smooth COG shifting biped.

Interlacing Legs Bipeds

Robots that fall in the category of interlacing legs bipeds generally use the simplest walking technique. In other words, you must figure out what is the best way to put one foot in front of another. The solution is usually a cam shaft (see Figure 1-4*c*, *d*, and *f*). With the parts provided in the NXT retail set, you can easily build a cam shaft using the holes in the 24-tooth or the 40-tooth gear (see Omni-Biped's legs in Chapter 5). You must attach the legs to an off-center hole to achieve what's called *eccentric motion*. As an alternative, you can use the black 3-long liftarms (as in Quasimodo, Chapter 2).

The particular shape of the feet stabilize a robot of this category (see Figure 1-1*a*)—feet interlace each other (hence the name of this category). Usually, in this kind of robot, the center of gravity is not shifted from side to side. So, you must pay close attention to designing the structure in such a way that the COG projection on the ground always falls inside the area that supports the feet, during each phase of walking. This condition must hold when the feet are on the ground together, but also when one of them is lifted from the ground.

Figure 1-1 shows the various walking phases. In *a*, both feet are on the ground; in *b* and *c*, the right foot begins to step forward and is lifted from the ground, leaving all the weight loaded on the left foot and reducing the support area to only the left foot; in *d* both feet are on the ground again. Next, the process starts again with the left foot leaving the ground and stepping forward.

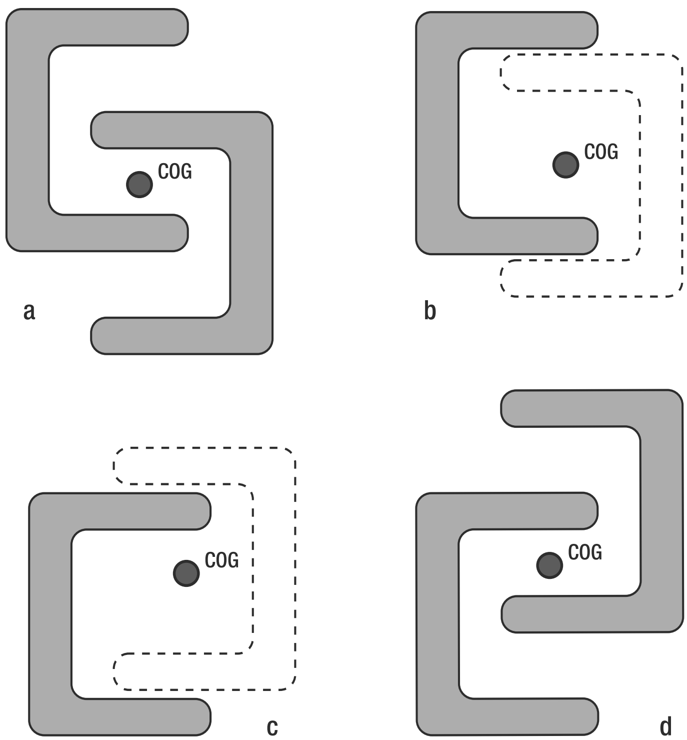

Figure 1-1. *Interlacing legs biped footprints in the various phases of walking*

The preceding approach suffers from the slackness of the LEGO joints: the legs tend to bend inside and the feet do not lift completely from the ground. To solve this problem, you can place a wedge in the inner side of the feet as shown in Figure 1-2*c*, or you can provide your biped with a sort of "hip tendon" made with rubber bands or LEGO parts, as shown in Figure 1-2*d*. All bipeds in nature have similar muscles to keep their equilibrium, so that they can walk steadily.

LEGO veteran users tend to be purists and quite conservative. They might consider it a sacrilege to use non-LEGO parts in your robot building. If you are willing to use rubber bands, you should use original LEGO rubber bands, although it is not the most elegant solution.

However, the best solution is to keep the whole leg frame short and rigid by using cross-bracing. The weaker parts of the leg are usually the moving joints, at the ankle and hip level.

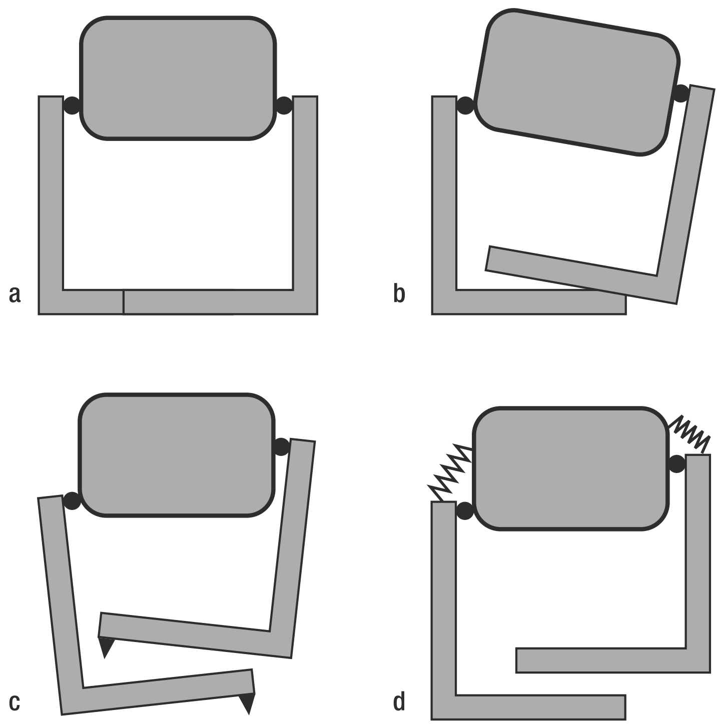

Figure 1-2. *Solving the problems related to LEGO joints' flexible nature*

All this might seem a bit abstract to you, but it will all come clear when you build your own Quasimodo—a biped, and the subject of the next chapter. In Chapter 2, I'll emphasize the defects of this particular walking mechanism and will cover the remedies step by step.

Jerky COG Shifting Bipeds

If you want to get really serious, or if your robot begins to get heavier, you should start thinking about COG shifting. As the term implies, the robot shifts its weight on the foot that remains on the ground, and unloads the other foot that is in the flight phase.

The adjective "jerky" implies that shifting the COG and stepping forward occurs in distinct stages. It also implies that it is done with different motors.

You can accomplish weight shifting while moving the whole mass (RCX or NXT, where most weight resides) from side to side, or by bending the legs at the ankle, knee, or hip level (see Figure 1-3).

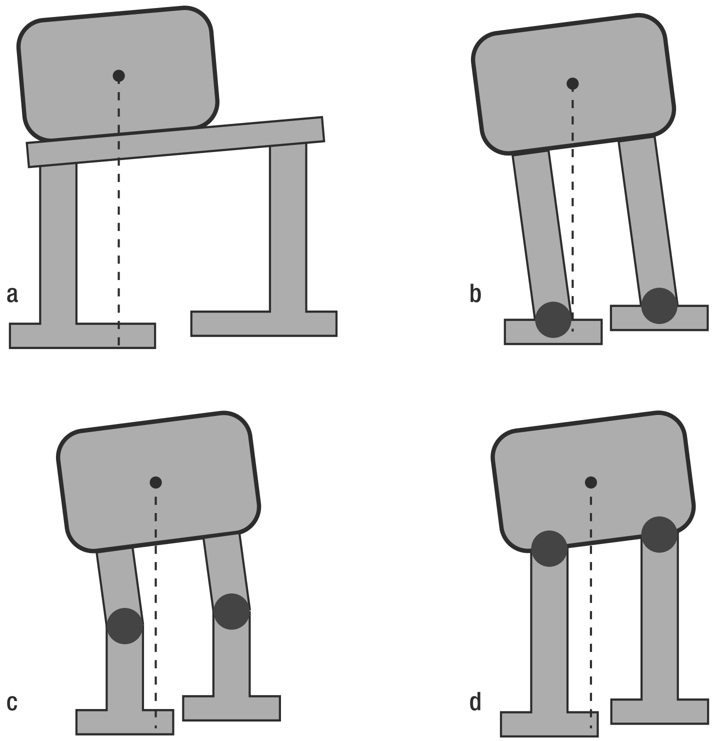

Figure 1-3. *Weight shifting methods*

You can achieve stepping by rotating the legs or *translating* them, keeping them parallel to each other (see Figure 1-4*a*, *b*, and *e*). In these cases, if the feet are moved while they are both touching the ground, the resulting effect is that the robot turns slightly in place. You'll use this feature in the AT-ST biped to make it turn (see Chapter 4).

Figure 1-4 from *c* through *f* shows various stepping solutions. In these pictures, just one leg is shown for clarity: you must attach the hidden one (grayed in *c* and *d*) on the other side of the robot 180 degrees out of phase. For example, in Figure 1-4*c* and *d*, you should attach the legs, on the opposite sides of the robot, at the leftmost position on the cam (the white circle), so that one leg is ahead of the other one. You must apply the same concept when attaching the other leg in elements *e* and *f*.

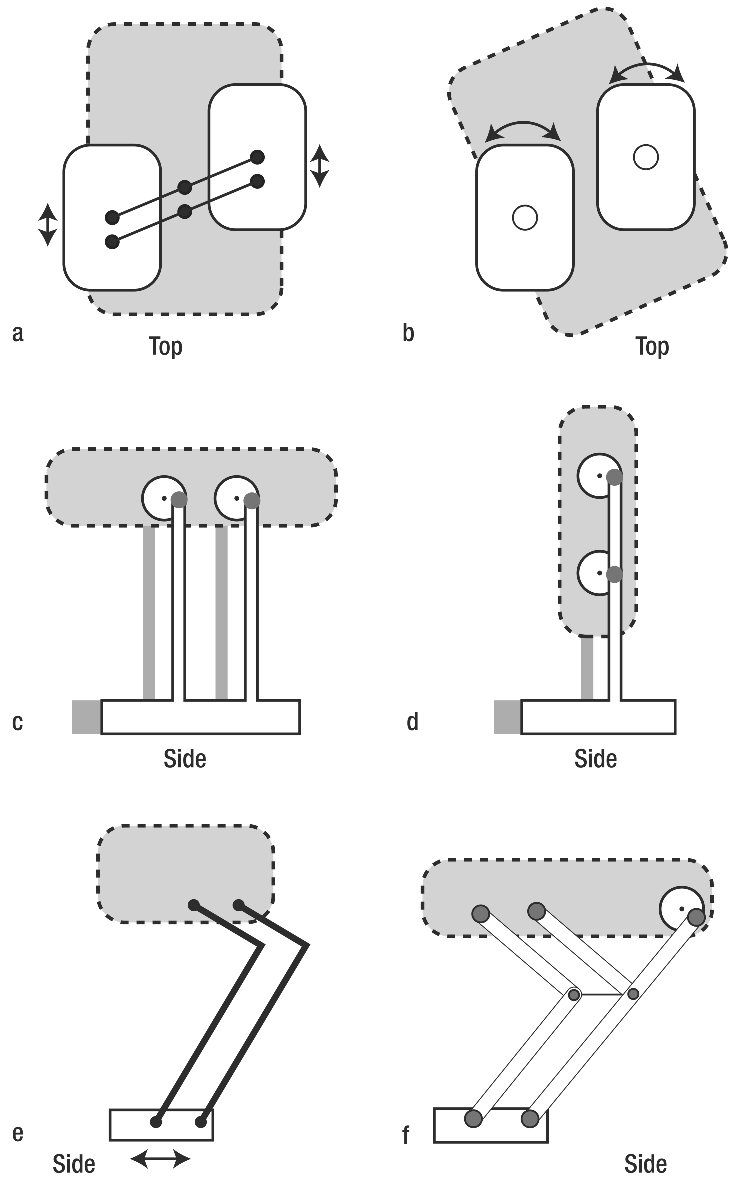

Figure 1-4. *Various stepping methods: a) this top view shows that the legs are translated, keeping them parallel each other; b) another top view where the legs are rotated together; c) side view showing a cammed mechanism keeping the body horizontal; d) a similar side view showing a cammed mechanism with the body kept vertical; e) this side view shows another solution for stepping; f) this cammed mechanism works like the one in c but is better looking.*

As shown in Figure 1-5, many of the bipeds I've built follow this line, such as the Matrix APU (February 2004), the OWL (May 2004), and the RCX-based AT-ST (December 2004). The new NXT AT-ST that you will find in Chapter 4 falls in this category. The dates in parentheses are the construction dates, showing the month in which these creations were published on the Web.

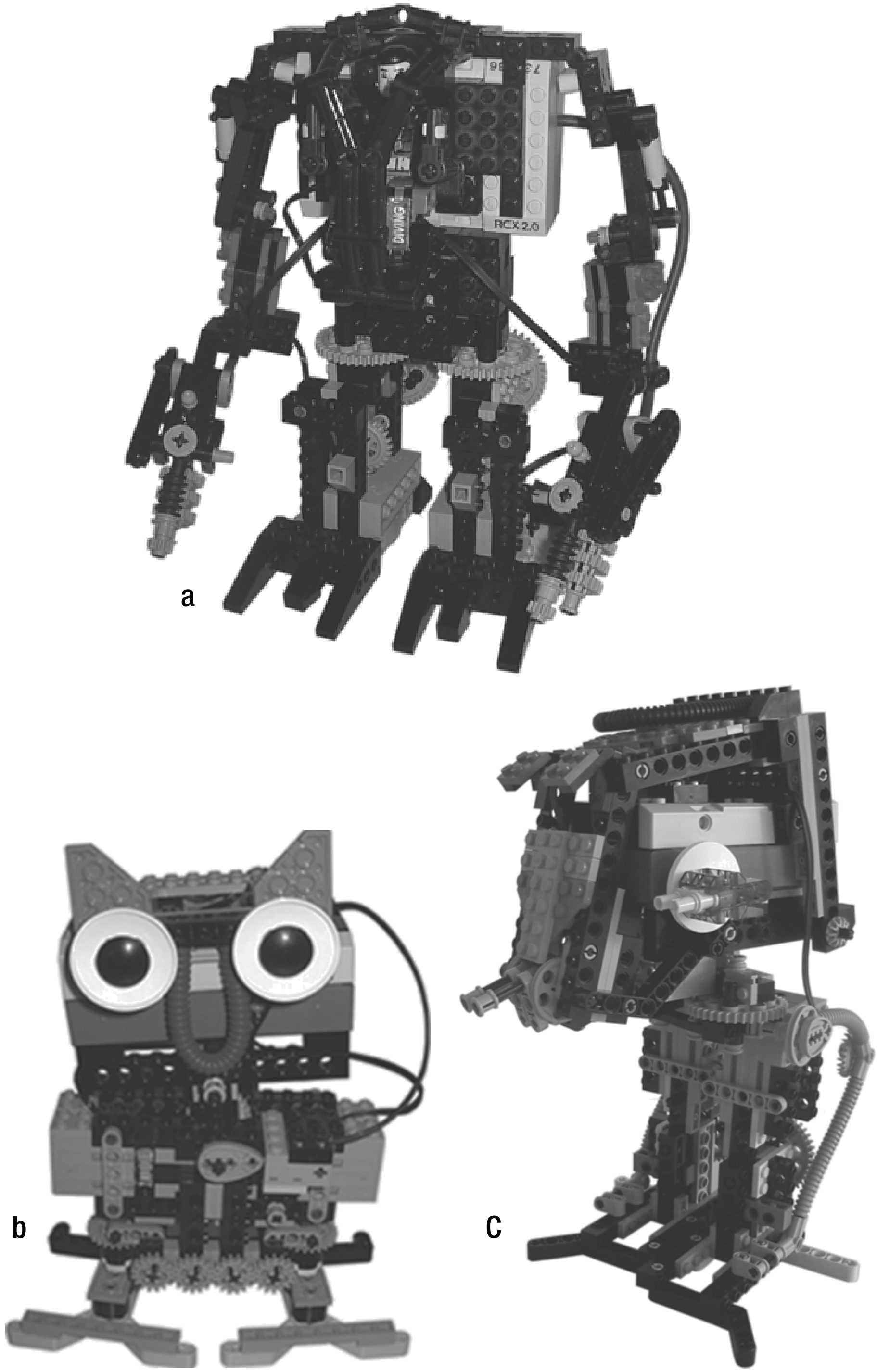

Figure 1-5. *RCX-based jerky COG shifting bipeds: a) Matrix APU, b) OWL, c) AT-ST*

Smooth COG Shifting Bipeds

I prefer smooth COG shifting bipeds due to their speed and smoothness—you probably will, too. They use a single motor to achieve both weight shifting and stepping; hence you need a refined mechanism.

In Figure 1-6, you can see the biped robot that I built in August 2004. This particular robot could only walk straight using COG shifting, and was meant to be a prototype for future bipeds that could also turn.

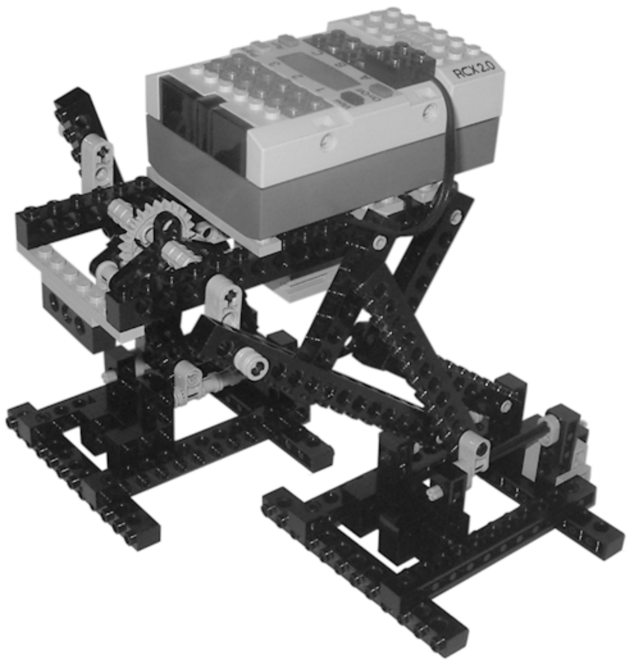

Figure 1-6. *COG-shifting Biped I*

My Advanced COG Biped (dated October 2004), shown in Figure 1-7, features a smooth walking gait and can turn thanks to a motorized rotating ankle. The left foot includes a motor to allow it to turn, while the other foot is built of normal parts (in the Robotics Invention System kit, there were only two motors), trying to balance the other foot's weight. On each foot, a touch sensor lets the robot know which foot is touching the ground.

The robot uses this sequence for turning: when the left foot is lifted from the ground, it is swung outside at a little angle; then the robot steps to load the weight on the foot, to bring it onto the ground. The ankle is then rotated back in its place and the whole robot turns left.

You can repeat this routine as many times as needed to turn in place, and you can modify it slightly to turn in the other direction.

Figure 1-7. *Advanced COG Biped*

Summary

In this introductory chapter, you saw various approaches to bipedal walking. You were shown some startup ideas that might shed light on the mystery of how to develop a biped that not only walks, but can also turn.

To make a biped that walks without resembling a drunken sailor (and that is not at risk of falling down with every step it takes), the clever designer should try to bind the COG projection inside the area supporting the feet. You should do this during every phase of the walking cycle, when both feet are touching the ground and when one of them is in flight phase, leaving the other to support the whole robot's weight. This condition is essential for creating a biped without advanced sensors such as accelerometers or gyroscopes. Such a robot is a static one, because dynamic effects are not taken into account. Stability is guaranteed only by hardware structure, with no need of sensor feedback.

In the next chapters, you'll create three bipeds using all these techniques.