Appendix 4

6.270 1999 Course Notes
MIT 6.270 Course Organizers

Chapter 7: LEGO Design

Chapter 7

LEGO Design

When you're first introduced to the LEGO Technic system, you may be amazed at the number of different kinds of parts you see. There are parts for making moving things — gears, pulleys, axles — as well as parts for making structures. And, at first glance, the function of some of the parts won't be clear.

Once you get into using the LEGO parts, you'll find that they are a powerful way to experiment and play with the design of structures and mechanisms. Unlike the machinist who cuts and drills metal parts, you'll be able to "undo" the things you try out. This means that, also unlike the machinist, you won't have to draw out detailed plans of the finished product before you start trying to make it. You'll learn lots about mechanisms and structures as you play with the LEGO pieces. And you'll learn lots about the LEGO pieces themselves.

In fact, playing with the LEGO pieces is really the best way to learn how to use them. So why should you read this document about using LEGO pieces? Well, quite honestly, if you're the sort of person who likes to learn by exploring things on your own, you might not want to read this document at all. This document might be useful if you're pressed for time and want a shortcut to some of the insights that would otherwise take you a while. It might also be useful if you're a bit intimidated by all the different LEGO parts and would like to see examples of how to use them. This manual isn't a replacement for playing with the LEGO parts though!

If you're not already familiar with the LEGO parts you have, play with them. Make something small. Make something silly. Learning ways to use all the different parts can be fun. Don't worry too much about figuring out what a certain part is "supposed" to be used for – most parts can be used in lots of different ways.

Don't be disheartened if things don't work at your first attempt. Things rarely will, but LEGO parts make it easy to try again in a few different ways.

7.1 The Magic LEGO Dimension

You probably already know that most LEGO bricks come in one of two heights. The short bricks are one third the height of the tall bricks. See Fig. 7.1. But the curse of

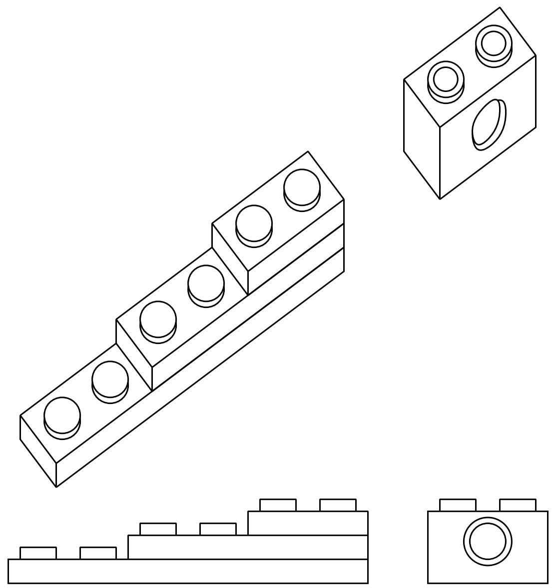

Figure 7.1: LEGO Spacing

LEGO is that neither of these heights is the same the unit of width for the LEGO brick. The curse thwarts efforts to make vertical structures, or geartrains where gears are vertically adjacent.

But armed with the magic LEGO dimension, you can fight back. The ratio of height to width of a tall LEGO piece is 6:5, and, with some creative stacking of LEGO pieces, you can make vertical spacings that are integral multiples of the horizontal spacings. See Fig. 7.2.

7.2 LEGO Gears

Besides the fact that they're just plain cool, why would you want to use gears in your LEGO creation?

You can use gears to translate rotational motion to linear motion (or vice versa), or to transfer motion from one place to another. The main reason for gears, though, is to reduce the speed (thus increasing the torque) of the electric motors.

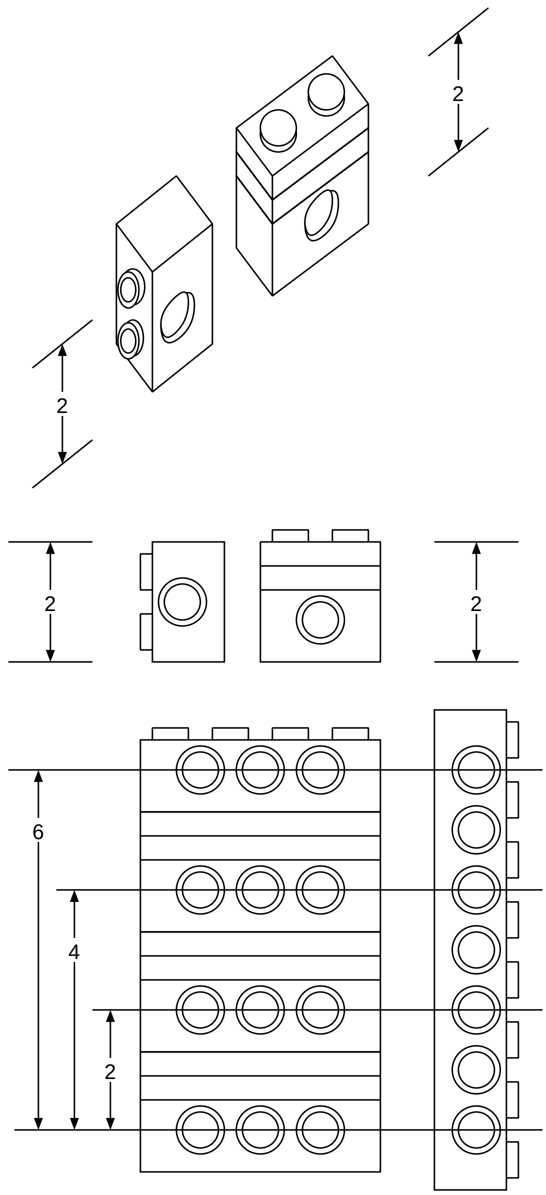

Figure 7.2: Magic LEGO Dimensions

7.2.1 It's all the motor's fault

The little electric motors are really lacking in torque, or, in other words, they can't push very hard. If you try connecting one up directly to a wheel driving your robot around, you'd find the motor too weak to turn the wheel and get your robot to budge one little bit.

But, luckily, even though the motors don't have much torque, they have lots and lots of speed. When you turn your motor on and let the shaft run freely, it probably spins in the neighborhood of 100 to 150 revolutions per second (or 6000-9000 RPM). That's a lot faster than you'd want to drive your robot, anyway! (If your drive wheel is 4 inches in diameter and spins at 9000 RPM, your robot would go

$$\frac{60 \times 9000 \times 4 \times 3.14}{\frac{12}{5280}} = 107 \tag{7.1}$$

miles per hour).

Enter gears. Gears provide you a way to trade speed for torque. You will need to make a gear train to translate a high speed, low torque input into a low speed, high torque output.

Geartrains aren't all that hard to make. But making a really efficient geartrain is an art that takes a while to master. If you're in a hurry and don't have time to discover all the ins and outs of making efficient geartrains on your own, you might be able to make use of the following list of pointers for making geartrains.

7.2.2 Pointers for an efficient geartrain

Use the following gears show in Fig 7.3.

Considerations:

- 16 tooth gear: The 16 tooth gear has a diameter such that it only meshes straightforwardly with other 16 tooth gears. Avoid it.

- 24 tooth crown gear You can make a pretty good right-angle with this gear if you do it right, but it is less efficient than the three good gears. Avoid it.

- Worm gear: I know the worm gear probably seems like the coolest gear you have, but resist the urge to use them if you're trying to make an efficient geartrain! Worm gears are by far the least efficient of the gears you have. Depending on how they are used, they can sap a factor of two or three in energy.

- Pulleys: Pulleys and rubber bands tend to slip when large forces are involved, so if you don't want to lose much efficiency, use them only in the fast-moving parts of the geartrain (since the fast-moving part has the least force). If you

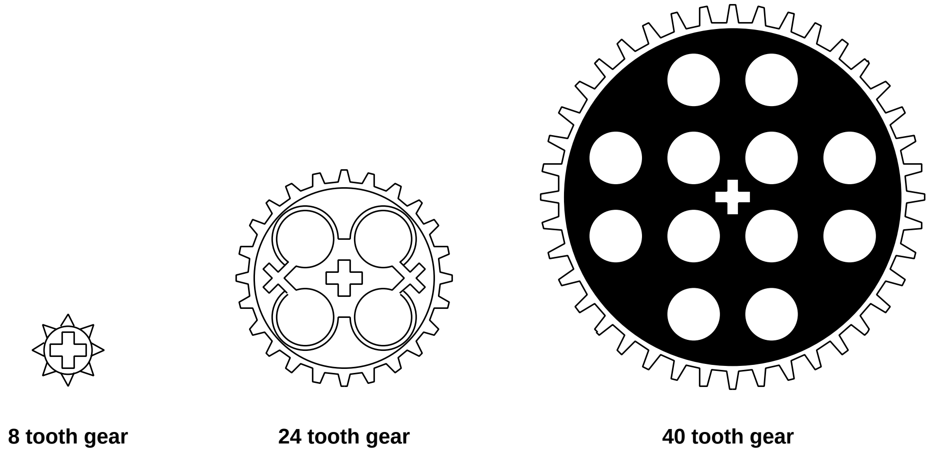

Figure 7.3: Gear Sizing

want your device to be very reliable, you might want to avoid pulleys and rubber bands because the rubber bands can break at inopportune times.

- Chain drive: The chain drive is a little inefficient, but not too bad in the slower stages of a geartrain. There are times when it's invaluable for transferring motion from one place to another. You have to be patient, though – it requires a bit of trial and error to find gear spacing that will work for the chain. If your chain is too loose, it may skip under heavy load, and if it is too tight, you may lose power. Experiment with it. The chains tend to work better on the larger gears.

- Spacing: Try to space the gears from each other by a perfect LEGO horizontal spacing. This is easy to do if you mount the axles horizontally adjacent on a beam. You can also mount gears vertically adjacent if you remember the magic LEGO dimension (1 2/3 vertical = 2 horizontal). Sometimes it is possible to find good meshing distances when the gears are at diagonals, but beware: if the gears are just a little to close together or a little too far apart, the efficiency goes way down.

- Axle supports: Try to have each axle supported by at least two girders as unsupported axles may bend. It's best if the two supporting girders are spaced apart from each other a little bit, but firmly attached to each other by more than one cross-support.

- Try not to have a gear dangling at the end of an unsupported axle. The axles can bend. Either put gears between the girders supporting the axles, or on the outside very close to the girders. If the gear is two or more LEGO units away from the outside of the girders, you may have problems.

- Make sure the axles can slide back and forth a tiny bit. Otherwise, the gears and spacers on the axle are probably pushing up against the girder. This results in surprising amounts of friction which causes the most problem for the geartrain, especially on axles that spin more quickly.

- Gear ratios: Experiment with different gear ratios. The gear ratio determines the important tradeoff between speed and torque.

- Err on the side of too much torque and too little speed. Lots of things can make your geartrain less efficient than when you first tested it. Your batteries might be a bit lower, or a LEGO piece might move slightly to create more friction. And LEGO gears age slightly over time – little bits of plastic wear away and create more friction. So you might choose to design a bit of overkill in the gear train.

7.2.3 How to know if your geartrain is really good

Try backdriving your geartrain. Take off the motor (if it's on), place a wheel on the slow output shaft, and try to turn the wheel. You should be able to make all the gears spin freely from this slow axle. If your gear down is really really good, the gears should continue spinning for a second or two after you let go.

If your geartrain doesn't backdrive, check the following things first:

- Can each axle in the geartrain slide back and forth just a little bit?

- Are the two girders supporting the axles firmly attached to each other by more than one cross-support?

7.2.4 You don't always need an efficient geartrain!

All geartrains don't necessarily need to be efficient! While you may care a lot how efficient your robot drive train is because it has to move the entire mass of the robot, you might not care how efficiently the robot closes its claw or rotates its sensor array to track the opponent.

If you don't care at all about the efficiency of a geartrain, the worm gear allows you to make a more compact geartrain because it gives a faster geardown than do the other gears. (Treat it like having a single tooth in gear ratio calculations! Hooking one up to a 24 tooth gear gives a 24:1 ratio, or a 40 tooth gear gives a 40:1 ratio.)

7.3 Making extremely strong structures

One objection many people have to making things out of LEGO pieces is that LEGO pieces can fall apart. And I think they must fall apart more easily on contest night, too.

Well, believe it or not, it's possible to make a LEGO creations which don't fall apart. Just make use of the **Magic LEGO Dimension** to brace your structures vertically. See Fig 7.4.

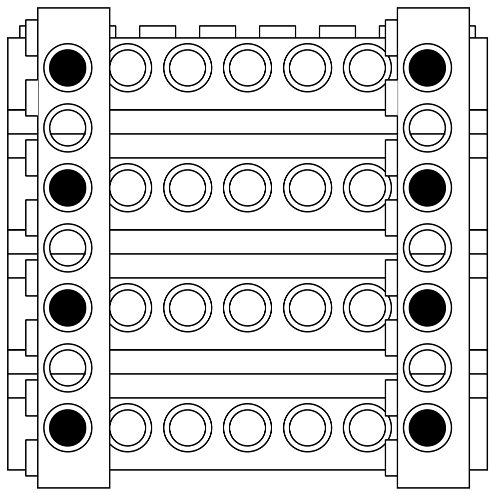

Figure 7.4: Bracing for Success

7.3.1 How to know if your structure is extremely strong

Drop it. If it breaks into a thousand tiny pieces, sorry, it wasn't extremely strong. Advanced LEGO builders can try sledgehammers (just kidding).

7.4 LEGO Challenges

Choose one (or more!) of the following to try and make:

- Make a geartrain with the ratio 135:1
- Make a device to convert rotary motion into a back and forth motion
- What's the largest thing you can build that doesn't fall apart when dropped from waist-level? From shoulder-level?

- Make a car powered by a stretched rubber band. How far can you make the car go?
- Make a ratchet to allow a shaft to turn in only one direction
- Make a catapult or gun capable of shooting a LEGO piece. How can you store the energy to throw the piece? Bonus points if you can hit an organizer or T.A.