back of the cab. I don't know how to look at these cases. My feeling is that they don't matter. There are two ways we might try. We can try to explain that each one is itself composed of symmetrical components that are smaller. Thus, for instance, the splash guard over the front wheel is made of a symmetrical square box, which houses the oil mechanism, and a segment of a circle, which goes around the wheel. Of course, the multiple composition of the two has distorted the square box so that it isn't perfectly symmetrical. But anyway, a few asymmetries here and there are quite all right. What matters is that the maker *tried* to make each part symmetrical wherever he could, and a few times he missed. This is a more accurate statement of the process that was happening here. These symmetries are quite different from the pixels of a photograph. The pixels in the photo are symmetrical, but trivially small. The components I am showing you in this locomotive are quite large. What is remarkable is that most of the relatively larger pieces of the locomotive are almost symmetrical, or at least distortions from symmetry made under a continual attempt to be symmetrical.

In the locomotive we see a continual striving for symmetry, which is abandoned only in those cases where there really is no other way. We see exactly the same in an industrial warehouse. And in a piece of machinery where the asymmetry is really essential, we feel an equal grace: For instance, a modern jet fighter has wings, tail, which are symmetrical in the large, but not symmetrical in themselves.

In many beautiful ancient buildings we see such a conglomeration of symmetries, too: It is this which creates their peacefulness. Many ordinary 20th-century things also had the same: For instance, a cement yard, or an oil refinery. In such 20th-century industrial structures, we often find the same loose agglomeration of symmetries (page 477). But many more recent *designed* modern structures (buildings and other things) possess an immense number of asymmetries — and *there* the overwhelming feeling is that the asymmetries are arbitrary, not forced by *necessity*.

6 / SYMMETRY, SIMPLICITY, AND JUST WHAT IS REQUIRED

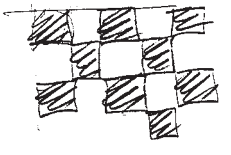
The crux of the central connection between symmetries, simplicity and necessity lies in the following. Very often, when we look at something, we have an immediate, intuitive sense of its rightness or wrongness. This sense of rightness or wrongness most often comes directly from the symmetries we see and our sense about these symmetries.

The essence of this rightness or wrongness hinges on the issue of necessity. There is an intimate and fundamental connection between arbitrariness, necessity, and symmetry, which says, in a nutshell, this. *Everything in nature is symmetrical unless there is a reason for it not to be*. When this law is violated, we feel that something is unnatural, and that is the way in which symmetry plays such a fundamental role.

Let me give an example. Imagine you are looking at the sky one day. Suppose suddenly you were to see a cloud which is perfectly square. Without even thinking, you would know that it was not a natural cloud. You would know it must have been made by an airplane, or by some other non-natural process. You know this instantly, within the first tenth of a second. Why is this so? It is because you have an immediate familiarity with clouds as symmetry structures. Although clouds are loose and asymmetrical, still their characteristic form, the quality which makes them clouds, is a definite symmetry structure *of a certain type*. If we were to see a square cloud, we would be seeing a different kind of symmetry structure, and we would know, at once, that it was artificial. We would know it cannot have come about as a result of the normal cloud-making process because the cloud process does not produce that *kind* of symmetry structure.

This example shows that the symmetry structures in the world are very close to us. We perceive them instantly and subconsciously, without even knowing it. This mode of perception gives us an intuitive sense of which symmetry structures are appropriate or not appropriate in various situations. When we see the square cloud, we instantly register that something is "wrong". Our sense of what is right and what is wrong thus depends on subtle and detailed awareness of the kinds of symmetry structures which are appropriate and natural in various different situations.

Here is another example. A few years ago, a student showed me a drawing of a proposed



Student's checkerboard plan. It has too many symmetries (between buildings and gardens) to be the plan of an apartment building

apartment house design which he had drawn. It had the form of a checkerboard. He told me that the black squares were apartments, and the white squares gardens. Immediately, without hesitating or even thinking, I said, "It must be wrong". He was quite taken aback. "How can you say that so fast? You haven't even looked at the drawings yet".

"No," I said, "but I already know it must be wrong. In a checkerboard there is a symmetry between the black squares and the white ones, they are the same size and the same shape. But gardens and apartments are *unlike.* There could not be a natural structure, in which two things which are so different in their nature, could have exactly the same form. So I know this design must be wrong, before I even examine it."

Each thing in the world is subject to various influences. It has various degrees of similarity and difference compared with other things, according to its situation. And in itself also, it has various degrees of similarity and difference. This is what we call its symmetry structure. Symmetry is a precise way of talking about similarities.

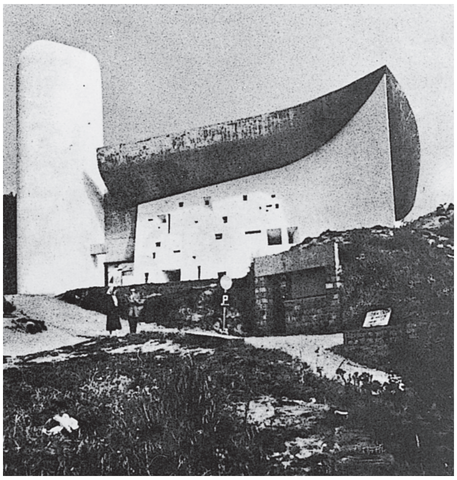
We observe that in any thing, there must be just the right amount of similarity and difference. Its internal degrees of similarity and difference must match, exactly, the degrees of similarity and difference which it experiences in the world.

When we make something which is just right, we have hit the degree of similarities and differences — its internal symmetries — just right. On the other hand, when we are wrong we can also always analyze the wrongness of what we have made in terms of symmetries. Either the symmetries are less than the situation requires. Or the symmetries are more than the situation requires. To understand the idea that the symmetries in a structure are "just right," consider, for example, the flow of electricity in two parallel wires. Other things being equal, the current will flow equally in the two wires. Why is this? If we want to, we can invoke some rule like Ohm's law or the principle of least action, to show why the wires carry the same current. But the deepest explanation, the most profound one, is simply this: There is no reason for the two wires to carry different currents, because the situation is symmetrical. Therefore, they carry the same current. In the absence of any reason, things distribute themselves symmetrically. Asymmetries occur only where there are reasons powerful enough to generate them.

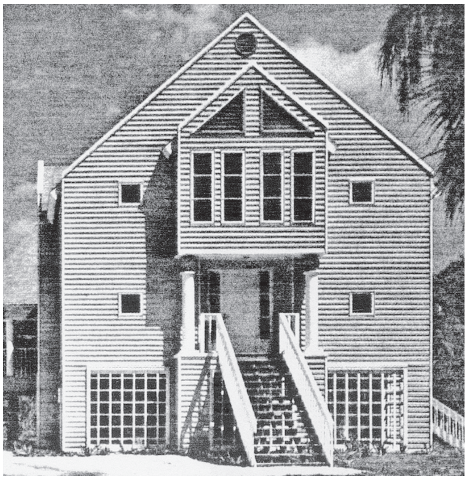
In general, a harmonious structure — and the simplest structure — is one whose internal similarities and differences correspond exactly to the degrees of similarity and difference that exist in its conditions. That is the best definition of simplicity. Consider the shape of a bubble. When we have a soap bubble floating in the air, it roughly has the shape of a sphere. Although we can give various sophisticated mathematical explanations for this fact, there is one very simple explanation, more fundamental than all the oth-

Vermeer, Woman pouring milk,

College buildings, Christopher Alexander and Hajo Neis, 1987



Early 20th century: not enough symmetries. Everything had to be asymmetrical, in order to be modern. Le Corbusier, Ronchamp.



Late 20th century: too many symmetries. Postmodernism, like neoclassicism, tended to put in toomany symmetries, more than were appropriate for a given situation.

An unusual building, odd, yet strangely natural. Not influenced by either modernism or postmodernism, although quirky, this building has the number of symmetries about right.

ers. It is simply this. The air pressure on the inside of the bubble presses out with equal force in all directions. The same is true of the air pressure outside the bubble, pressing in. It presses with equal strength all over the bubble. Under these circumstances the bubble must take on the form of a sphere, because a sphere is the only volume-enclosing shape whose surface is the same at every point.

Suppose you saw a bubble in the shape of a

Even simpler. A system of local symmetries, relaxed and well-adapted to its circumstances. Here the number of symmetries is just right.

cube. You would know, right away, that something was wrong because a cube has too many differences in it. Mainly, the corners of the cube are different from any other points and the edges are different from the middle of the sides. Such a structure could only come about under circumstances where the forces or processes also had a comparable level of complexity, where the pattern of forces somehow gave rise to eight points which were "special." Since you know the forces in a bubble aren't like that, you know the bubble can't take on the form of a cube.

We can express this idea, in the most general way, by saying that things which are similar must be similar, and things which are different must be different. Or I can put it more precisely: The degree of similarities which exist in a structure must correspond exactly to the degree of similarity of the conditions there, and the degrees of differences which exist in a structure must also correspond to the degrees of difference in the conditions there.

This is a profound idea, which — I believe — no one has so far managed to express in a fully mathematical way. If it could be expressed precisely, it would be the rule from which everything, all form, derives.

Let us come back to architecture. A building which is perfectly made, and perfectly simple, is one in which the symmetries correspond exactly to what is required — neither more, nor less — just as we see in nature. Please look at the four pictures on pages 472–73. In the first period of the modern movement, when Ronchamp was made, architects and designers were very much afraid of symmetry. Everything had to be asymmetrical in order to be modern. So, generally, things had *too few* internal symmetries to be perfectly natural. We wince when we see these structures because the symmetries feel wrong.

Now, in the present period of so-called postmodernism, the pendulum has swung the other way. Postmodernists, as neoclassicists used to do, put in *too many* symmetries, more than are appropriate for a given situation. So we wince when we see them because in this case, too, we can feel the wrongness of the symmetry structure at once.

Making a thing whose symmetries are ex actly right is extraordinarily hard. It means, that we have to be so simple that all the necessities are in perfect balance. Simplicity is the state in which all structure is removed, except exactly that structure which is required.

7 / THE IDEA OF A NATURAL SYSTEM OF SYMMETRIES

To understand the idea of "only what is required" further, let us consider what we might call a natural system of symmetries.

Here, for instance, is a Chinese brush painting of bamboo. The twigs and branches hanging down form symmetries. But the symmetry we see in the tree is very gentle. The leaves are not perfectly symmetrical. They are approximately symmetrical. The clusters of twigs and leaves hanging down form local bundles which are almost, but not perfectly, symmetrical. The tree itself is not perfectly symmetrical. Yet it has a

Branches of a bamboo tree: depicted in a Chinese brush painting: natural symmetries.