The interdependence of different levels of scale in a structure has been extensively developed in systems theory and complexity theory, with significant recent applications to computer science and biology. The general properties of hierarchical systems (also called layered systems) can be summarized as follows. These rules apply to any discipline that deals with complex structures, and according to the thesis of this Chapter, also to architecture. My terminology is that a lower scale has the smaller units, and the higher scale has the larger units.

1. Units on a particular scale have their own type of interaction, which is independent of those in the other scales. Each scale has to be strongly defined before different scales can be combined to create a whole.

2. Higher scales result from constraints (expressed in terms of the higher scale) being imposed on lower scales. Many small units combine to make up a big unit (on a higher scale).

3. The interdependence of scales is only one-way: a higher scale requires all lower scales in order to function, but not vice versa. Large pieces depend on their small components.

4. Interaction across scales leads to correlations among all the different scales, and this process generates a coherent whole. Connecting different scales creates a system.

5. Emergent properties add new properties of structure to a complex, organized system, making it greater than the sum of its parts. The interactions among all the different pieces add something new to the whole.
Life generates hierarchical systems as observable organic structures. Computer programs are hierarchical information systems with distinct, interconnected scales that have to cooperate. The increasing complexity of man-made systems has made it necessary to organize them internally in some practical manner, simply in order to understand them. As a consequence of their complexity, these totally artificial entities have evolved a structured hierarchy that has many common features with natural forms, showing how the underlying rules are the same.

The significance of a unit in a complex structure is clarified as we view it from different scales in the scaling hierarchy, trying to grasp its organizational role in the whole. The need for any given unit may not be fully understandable on its own scale: it could be a necessary component supporting the structure on a higher scale. In an organized structure, every scale in the hierarchy contributes, with the downward dependence of larger on lower scales, yet the total effect is an effect of the system. A complex system does not depend solely on any single scale; neither can any scale be neglected or eliminated. Each scale has its own particular goal, which is indirectly supporting the organization of the whole.

The complex whole represents something not found in the isolated parts alone. A hierarchy links units together in ways they could not achieve on their own. When units of one scale combine to form the next-highest scale, a new and in some ways unexpected component of the total structure emerges; this is referred to as an "emergent property". Those units combine into something not explainable in terms of the lower scale. A more encompassing whole includes the contributions of all the lower scales, while adding its own organizational principle.

This point is really at the heart of my thesis, and links architecture with the new science of nonlinear phenomena. The assumption of nearly all nineteenth century mechanistic physics is that a complex system could never be more than the sum of its parts. In the last few decades, however, we have discovered a score of important phenomena that have emergent properties: properties of the system as a whole which cannot be traced back to any of its isolated constituent parts. That is, many complex systems are irreducible. This Chapter argues that the greatest architectural achievements are in fact characterized by emergent properties. Thus, my discussion is aimed at understanding what is happening in a great building that has achieved emergent properties so that it can be successfully applied to new structures.

Since it is impossible to guarantee positive emergent properties, it is also impossible to impose them in design. And yet, in architecture, the emergent properties, as experienced from the finished whole, establish our primary response to a building. Emergent properties that result from the interaction of all the components in unanticipated ways can result either in a positive effect (the awe experienced inside a Cathedral) or a negative effect (a piece of complex software that does not function as expected). Top-down design misses emergent properties, yet they are the most important component of great architecture. We need to recognize that our design capabilities are limited to the lower orders in the
hierarchy of scales, and the overall effect is largely outside our control. We experience order from all the scales coming together, but can neither rigidly design this higher order, nor entirely quantify it. I believe that the scaling ideas outlined here provide a basis for positive emergent properties, by making them possible and facilitating their emergence.

All lower scales are necessary for the higher scales of a hierarchical system to work (hierarchical system property number 3, above). In plant physiology, this explains the effect of a herbicide. A chemical blocks the working of a lower scale, and that is sufficient to sabotage (and kill) the organism. Similarly, a lower-scale bug crashes a big computer program. The same might be said of viruses and germs for the animals. In architecture, this principle implies a fundamental role for details. If a lower scale is lost, this sabotages the emergent properties.