With these principles, we can now see what it would take for a theory of technology to be an evolutionary theory in a direct sense. Obviously, the evolution of technology is not a biological process since technical artifacts are not biological species. So an evolutionary theory of technology cannot be part of evolutionary biology. Instead, a theory of technology can only be evolutionary in an analogous sense: by assuming that technological change and innovation depend on principles that are strongly analogous to the principles underlying biological evolution. That is, there must be a structural similarity between the two processes through which most or all of the above principles apply to technological change, albeit in a modified form. The more principles apply, the more strongly evolutionary the theory is. The most important principles are the first three, because they are the core principles of evolutionary theory. Theories of technology that employ at least two principles that are analogous to these three core principles may be called weakly analogous to biological evolution, whereas theories that employ all three and at least one of the three peripheral principles may be called strongly analogous.

3 George Basalla's Theory

In his book *The Evolution of Technology*, historian of technology George Basalla presents an evolutionary theory of technological change that aims to explain technological innovation, including the emergence of novel artifacts, and the process by which society makes a selection between available artifacts (Basalla, 1988). Basalla considers his notion of technological evolution to be an "analogy" or "metaphor". He claims "Metaphors and analogies are at the heart of all extended analytical or critical thought." (1988, 3). Basalla holds that metaphors and analogies can be helpful in constructing novel scientific analyses and explanations.

Basalla argues that the proper object of analysis of a theory of technological change is the artifact, since artifacts are normally the outcome of innovative technological activity. He then likens artifact types to species and individual artifacts of a particular type to members of a species (1988, 137). Artifacts are hence to be likened to phenotypes. He claims that variation within artifact types clearly exists: there are many different kinds of hammers, steam engines, or automobiles. There is also a kind of inheritance between artifacts, Basalla claims. That is, artifacts may be followed by subsequent generations of the same artifact, or similar artifacts. The main difference here is that artifacts do not reproduce; they are reproduced by human makers. However, Basalla holds the resulting process of reproduction to be similar to the process of inheritance. Basalla also claims that selective pressures operate on artifacts, and that some are selected to be used and reproduced, whereas others are discarded. He believes that this process of selection can be analyzed with reference of traits of artifacts that make a better or poorer fit to conditions in their environment. He argues that four kinds of factors are involved in the selection of artifacts: economic, military, social, and cultural. These factors do not operate on artifacts directly, but on humans who select artifacts. Their actions are determined by "economic

constraints, military demands, ideological pressures, political manipulation, and the power of cultural values, fashions, and fads." (139). It can hence be said that artifacts have a differential fitness relative to such constraints.

Basalla holds that the mechanism by which new variants of artifacts are created is not the mechanism of mutation and recombination. It is usually a mechanism involving conscious human choices. Likewise, the selection of artifacts is not a blind process, as it also involves human choice. Basalla claims that the selection of artifacts is similar to artificial selection, the selection of phenotypes in animal and plant breeding, and less similar to natural selection. As he claims, "Variant artifacts do not arise from the chance recombination of certain crucial constituent parts but are the result of a conscious process in which human taste and judgment are exercised in the pursuit of some biological, technological, psychological, social, economic, or cultural goal." (1988, 136). It must be admitted that human choices are constrained by economic, military, social, and cultural factors over which human beings do not have complete control. Even so, Basalla holds that the involvement of conscious, goal-directed choices by human beings introduces a disanalogy between technological and biological evolution. Another disanalogy exists, Basalla holds, regarding the notion of species and interbreeding. Artifact types can be combined quite easily to produce new types, meaning that artifact types can interbreed easily, whereas different biological species usually do not interbreed (1988, 137). A final disanalogy between Basalla's theory and the theory of evolution is that there is no unit of reproduction similar to the gene in Basalla's theory; it is artifacts, or phenotypes, rather than genes, and genotypes, that are reproduced.

To sum up, Basalla's theory of the evolution of technological artifacts exploits a number of similarities between biological and technological evolution while also admitting to a number of dissimilarities. Basalla appears to claim that analogous versions of the principles of variation, inheritance, and differential fitness apply to technological evolution, while the principles of genetic reproduction, mutation and recombination, and blindness do not apply. In his theory, technological innovation is hence weakly but not strongly analogous to biological evolution. Inheritance in artifacts is construed as the tendency of successive generations of artifacts to resemble previous generations. Variation and selection are not blind but involve conscious human agents making purposeful choices: choices regarding the creation of novelty and regarding the selection of artifacts.

4 Joel Mokyr's Theory

Economic historian Joel Mokyr has presented an evolutionary theory of technology that does not focus on the evolution of artifacts, as in Basalla's theory, but on the evolution of technological knowledge (Mokyr, 1996; 1998; 1999; 2000a; b). More precisely, he has presented an evolutionary theory of techniques, or technological know-how, mirroring Gilbert Ryle's famous distinction between knowledge "how" and knowledge "that". Mokyr is critical of evolutionary approaches that take artifacts