

# No Silver Bullet

## Essence and Accidents of Software Engineering

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**Fashioning complex conceptual constructs is the *essence*; accidental tasks arise in representing the constructs in language. Past progress has so reduced the accidental tasks that future progress now depends upon addressing the essence.**

**O**f all the monsters that fill the nightmares of our folklore, none terrify more than werewolves, because they transform unexpectedly from the familiar into horrors. For these, one seeks bullets of silver that can magically lay them to rest.

The familiar software project, at least as seen by the nontechnical manager, has something of this character; it is usually innocent and straightforward, but is capable of becoming a monster of missed schedules, blown budgets, and flawed products. So we hear desperate cries for a silver bullet—something to make software costs drop as rapidly as computer hardware costs do.

But, as we look to the horizon of a decade hence, we see no silver bullet. There is no single development, in either technology or in management technique, that by itself promises even one order-of-magnitude improvement in productivity, in reliability, in simplicity. In this article, I shall try to show why, by examining both the nature of the software problem and the properties of the bullets proposed.

Skepticism is not pessimism, however. Although we see no startling break-

throughs—and indeed, I believe such to be inconsistent with the nature of software—many encouraging innovations are under way. A disciplined, consistent effort to develop, propagate, and exploit these innovations should indeed yield an order-of-magnitude improvement. There is no royal road, but there is a road.

The first step toward the management of disease was replacement of demon theories and humours theories by the germ theory. That very step, the beginning of hope, in itself dashed all hopes of magical solutions. It told workers that progress would be made stepwise, at great effort, and that a persistent, unrelenting care would have to be paid to a discipline of cleanliness. So it is with software engineering today.

### **Does it have to be hard?—Essential difficulties**

Not only are there no silver bullets now in view, the very nature of software makes it unlikely that there will be any—no inventions that will do for software productivity, reliability, and simplicity what electronics, transistors, and large-scale integration did for computer hardware.

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We cannot expect ever to see twofold gains every two years.

First, one must observe that the anomaly is not that software progress is so slow, but that computer hardware progress is so fast. No other technology since civilization began has seen six orders of magnitude in performance-price gain in 30 years. In no other technology can one choose to take the gain in *either* improved performance *or* in reduced costs. These gains flow from the transformation of computer manufacture from an assembly industry into a process industry.

Second, to see what rate of progress one can expect in software technology, let us examine the difficulties of that technology. Following Aristotle, I divide them into *essence*, the difficulties inherent in the nature of software, and *accidents*, those difficulties that today attend its production but are not inherent.

The essence of a software entity is a construct of interlocking concepts: data sets, relationships among data items, algorithms, and invocations of functions. This essence is abstract in that such a conceptual construct is the same under many different representations. It is nonetheless highly precise and richly detailed.

*I believe the hard part of building software to be the specification, design, and testing of this conceptual construct, not the labor of representing it and testing the fidelity of the representation.* We still make syntax errors, to be sure; but they are fuzz compared with the conceptual errors in most systems.

If this is true, building software will always be hard. There is inherently no silver bullet.

Let us consider the inherent properties of this irreducible essence of modern software systems: complexity, conformity, changeability, and invisibility.

**Complexity.** Software entities are more complex for their size than perhaps any other human construct because no two parts are alike (at least above the statement level). If they are, we make the two similar parts into a subroutine—open or closed. In this respect, software systems differ profoundly from computers, buildings, or automobiles, where repeated elements abound.

Digital computers are themselves more complex than most things people build: They have very large numbers of states. This makes conceiving, describing, and testing them hard. Software systems have

orders-of-magnitude more states than computers do.

Likewise, a scaling-up of a software entity is not merely a repetition of the same elements in larger sizes, it is necessarily an increase in the number of different elements. In most cases, the elements interact with each other in some nonlinear fashion, and the complexity of the whole increases much more than linearly.

The complexity of software is an essential property, not an accidental one. Hence, descriptions of a software entity that abstract away its complexity often abstract away its essence. For three centuries, mathematics and the physical sciences made great strides by constructing simplified models of complex phenomena, deriving properties from the models, and verifying those properties by experiment. This paradigm worked because the complexities ignored in the models were not the essential properties of the phenomena. It does not work when the complexities are the essence.

Many of the classic problems of developing software products derive from this essential complexity and its nonlinear increases with size. From the complexity comes the difficulty of communication among team members, which leads to product flaws, cost overruns, schedule delays. From the complexity comes the

difficulty of enumerating, much less understanding, all the possible states of the program, and from that comes the unreliability. From complexity of function comes the difficulty of invoking function, which makes programs hard to use. From complexity of structure comes the difficulty of extending programs to new functions without creating side effects. From complexity of structure come the unvisualized states that constitute security trapdoors.

Not only technical problems, but management problems as well come from the complexity. It makes overview hard, thus impeding conceptual integrity. It makes it hard to find and control all the loose ends. It creates the tremendous learning and understanding burden that makes personnel turnover a disaster.

**Conformity.** Software people are not alone in facing complexity. Physics deals

