Decades ago, researchers figured out that chimpanzees and people share some 99 percent of their DNA sequences, an estimate confirmed recently by the chimp genome project. Counting inversions and deletions, the differences approach 4 percent, but still are similar enough to pose this question: If our DNA is so much like that of our closest evolutionary relatives, why do we look and act so different?

More recently, cloning technology has created genetically identical organisms from a single genome. This lab triumph quickly became a consumer product as bereaved pet owners sought to replace departed animal companions by cloning new ones from their cells. The owners have been disappointed to find that, despite identical genes, their costly human-made cats and dogs do not behave much like the original and may even look rather different.

Explanations for puzzles like these have traditionally been summed up in one ambiguous word: nurture. Researchers will probably be spending much of this century telling us what nurture is. But it’s already quite clear that part of the nurture story—perhaps a big part—is a shifting, heterogeneous collection of molecular processes often lumped under a single heading: epigenetics.

What is epigenetics?

“Epigenetics” is used constantly in papers as if it were a precise term with a definition researchers agree on. They don’t, and their debates are sometimes acrimonious. We’ll use it to mean the study of mechanisms that change gene expression by modifying DNA without modifying its sequence of bases. For some scientists this change must be heritable, either passed along to daughter cells (as in differentiation) or passed along to descendants.

Epigenetics is sometimes compared to software operating on the hardware that is a genome. A more useful metaphor is an analogy to music, devised by Eva Jablonka and Marion Lamb in their seminal Evolution in Four Dimensions. Think of a genotype as a musical score and its phenotype as a specific performance of the score. A score can be copied and transmitted in musical notation, just as DNA is replicated. But the score is interpreted in particular performances, as DNA activity differs from cell to cell. Every performance varies, as in cell differentiation. Individual performances can influence performances by others, just as a cell’s epigenetic patterns are bequeathed to daughter cells. Individual performances also can influence future generations of performers by means of recordings, just as epigenetic patterns can be passed to offspring.

Individual researchers have their own lists of epigenetic mechanisms that can include, for example, self-sustaining loops and prions. We’ll focus on just three of the same three much of the epigenetics literature focuses on: methylation of DNA; modification of histones; and what some say may turn out to be most important of all, noncoding RNA, created from the mysterious DNA formerly known as junk. Don’t be deceived by the separate discussions of these mechanisms. They all interact all the time.

Epigenetic mechanisms may have originated in single-celled organisms to silence invading viruses and parasites, later evolving to become essential for cell differentiation in multicellular organisms. Differentiation and developmental biology were what Conrad Waddington meant when he discussed “epigenetics,” a term he is credited with coining.

Development poses the same puzzle as identical twins or cloned dogs—why don’t identical genomes generate identical outcomes?—except that it occurs in a single organism. With only a few exceptions, the cells in your body all have exactly the same DNA nucleotide sequence. How is it that, in your embryonic days, only some of your cells decided to become brain cells while others chose to be kidney? And how is it that those that decided to become brain cells then stably gave rise to daughter cells that were brain, too, not kidney or any other body cell?

The explanation is clear to Wolf Reik, of the Babraham Institute in Cambridge, United Kingdom. In 2007 he declared flatly, “Development is, by definition, epigenetic.” A DNA sequence turns on at this time and not that one, in this cell and not that one, because epigenetic mechanisms mark it in a particular way that seals its fate and that of its descendants.