the moon waxes and wanes, making its way through the hooded sky in a chilly haze. Projectiles leave the cannon's mouth and sail upward until they reach their apogee and then smoothly and without interruption turn themselves around and return to earth. In all of this, a sense of seamlessness predominates, almost as if the sun, the moon and the cannon's weighed charge were being carried by the same river carrying consciousness itself, their differences in speed or direction subordinated to similarities in the very nature of the process.

Newton's intelligence was abnormally sensitive to the nuances of continuity; he thought in great languid movements, his mind turning to flows and fluxions, things changing smoothly; he was able apparently to see geometrical shapes deform themselves continuously, as when a circle is flattened to become an ellipse. And he was one of the first of the great mathematicians to subject the experience of continuity to the discipline of number.

Curiously enough, the concept of continuity does not itself figure in his thought. It is the presumed background, playing even in this case the role that it plays elsewhere. Newton never succeeded in forcing his own powerful sense of continuity into consciousness. The mathematical tools that he made his own would come to make complete sense only against a background clarified two hundred years later, by mathematicians such as Cauchy, Weierstrass, Dedekind, Kronecker, and Cantor, who knew what Newton had done and could see where the edge of his self-consciousness had ended.

Newton's characteristic mental motion was a smoothly executed slide in which he would gain purchase somewhere amidst the ordinary numbers and then, with a tremendous

Binomial Thm,

burst of acceleration, take off for points beyond. The binomial theorem offers a striking example both of the force of his mathematical intelligence and its natural trajectory. The theorem addresses a simple problem: if two numbers are added, and their sum is then raised to some power—$(a + b)^2$, or $(a + b)^3$, say—what then the result? Mathematicians before Newton knew how to compute $(a + b)$ to arbitrary integral powers. What they lacked, those mathematicians, was a way of expressing their knowledge in a single line of concentrated code.

Enter now Isaac Newton, but twenty-four, newly retired to the countryside, never clean, never personally scrupulous. There is ink in the crotch of his fingers. Books on the table in disorderly stacks in Latin, Greek, French, and English, the heaped and careless treasure of European learning. The windows are closed, the air unmoving, the bed unmade, Newton's disheveled linen piled in a corner of the room and the remains of supper congealed on a pewter plate left standing on the top of a walnut armoire. I believe the chamber pot has not been emptied. Newton moves from his bed to his chair, entwines his long fingers, stares into space, and then when the gust of his thought has blown through his mind, bends over and grasping the ink-dipped quill in hand, begins to cover a new sheet of parchment with small crabbed numbers.

That concentrated line of code emerges:

$$(a + b)^n = a^n + na^{n-1}b + \frac{n(n-1)}{2!}a^{n-2}b^2 + \ldots + nb^{n-1} + b^{n*}$$

*There is only one unfamiliar symbol here, and that is 2! Read "two factorial," it signifies the product of two and one. By the same token, 5! = 5 × 4 × 3 × 2 × 1. And ditto for all the rest.

But there is more. The binomial theorem covers all cases in which expansion proceeds by an integral exponent. The theorem makes no provision for negative or fractional exponents. It is here that the sturdy door of the familiar opens to reveal entirely a new prospect beyond, a modest enlargement of an expression's scope engendering a subtle and profound reassessment of the strategies for its expansion. Where before, a single finite formula carried its weight no matter the numbers, now the requisite formula must be expressed in *infinite* terms, the prosaic world of symbols and signs exploding outward.

Newton's enlargement of the binomial theorem made use of mathematical expressions known as *infinite series.* An infinite series is just what the term might suggest, a series of numbers that goes on forever. Consider thus $(1 + x)^n$, where $n = \frac{1}{2}$, and $x = 0.1$. The symbols embody a request for the square root of 1.1. But no strictly finite formula suffices for the computation at hand. Instead, there is this:

$$(1 + x)^n = 1 + nx + \frac{n(n-1)}{2!}x^2 + \frac{n(n-1)(n-2)}{3!}x^3 + \ldots + \frac{n(n-1)\ldots(n-r+1)}{r!}x^r + \ldots$$

an *infinite* operation conveyed by finite means. The sums in the series are evaluated one after the other and the value of $(1 + x)^n$ given in stages: $1 + \frac{1}{2}(0.1)$, $\frac{1}{8}(0.1)^2$, and on and on. The further the expansion, the better the approximation to the square root of 1.1.

This is in itself exciting, rather like watching an unsteady series of images snap suddenly into focus and then as they move along the projector's ratchets reveal an unsuspected scene; but an infinite series does more than simply convey the

mathematician from step to step. As the partial sums accumulate, they may well acquire a limit, a number toward which they are tending. If so, that number is assigned to the series as its sum, this completing the domestication of the infinite. The expansion of an infinite series offers the mathematician slices of the truth; its limit brings the mathematician the truth itself.

This Newton knew and understood, of course; he was a master of infinite series. But the concept of a limit, like so much else, Newton could not define. Nor could anyone else. And this, too, is an aspect of his own occluded self-consciousness, for the definition of a limit required mathematicians to undertake a profound and concentrated two-hundred-year meditation, the concept of continuity itself finally emerging into definition like the sun finally moving from behind dark clouds.

If in all this, I have left the discussion shrouded in myth and metaphor, this is only because it is thus that when loitering in the seventeenth century I found it.

* * *

IF NEWTON WAS fortunate in studying mathematics when he did, he was fortunate again in possessing a scientific inheritance that was brilliant, penetrating, and short. Using instruments more powerful than any known to the ancient Greeks, Tycho Brahe, Johannes Kepler, and Nicolas Copernicus had studied the heavens with unheard of patience. Their research had given the community of natural philosophers what they had never possessed—precisely organized data represented in quantitative terms.

Infinite series

NEWTON RETURNED to Cambridge having confirmed his genius to himself. Had Newton been entirely as myth describes him, he might have remained a gem whose luster shown only from the ocean floor. He used the singularities of his personality to wonderful effect. By 1667, Newton had collected his thoughts on infinite series in a long manuscript—*On the Analysis of Infinite Series.* It did not contain Newton's complete account of the calculus, but it did demonstrate a magnificent mastery of infinite series. Had it been known, it would have made Newton's reputation. The manuscript came into the hands of John Collins, an enthusiastic mathematical amateur, and a man of instinctive generosity. Collins took it upon himself to circulate the manuscript to men prepared to appreciate it. The precise details of these exchanges are now lost, but when he was quite certain that word of the manuscript would have had its desired effect, Newton, understanding intuitively that a whisper is often more suggestive than a shout, withdrew it from publication.

When sometime later Isaac Barrows, who had once taught Newton mathematics, determined to resign the Lucasian professorship at Cambridge in order to pursue theological studies, he understood that only one man at the university might succeed him. It was thus that in his twenty-seventh year, Newton became a professor of mathematics at Cambridge University. He was free to do as he pleased and to think as he would.

The days follow, then the weeks, and the years, the low flat English light breaking apart the night, birds in the trees, the countryside, even in Cambridge, spreading its early morning fragrance through the streets and gardens of the university. Newton rises at six, disheveled, splashes water from a bowl on his fingertips and wrists, and after pausing to look

from his window at the breaking day, repairs immediately to his blackened desk where without interruption he continues to chase a thought he had chased the night before, writing in his neat clear hand, the last traces of sleep utterly gone, his mind free, focused, flexible, racing calmly. His roommate, John Wickam, enters his chambers and nods. The two men have little need to chatter. Newton rises and fetches his gown and together, somber as two shades, they descend the narrow staircase and exit their chambers into the morning light. Tea and coarse bread or some horrid English porridge for breakfast. A slow sedate meditative walk back to chambers, the sun now ascending into the eastern sky, Newton pausing by the gravel where he can see the very diagrams he had inscribed weeks before, carefully preserved by fellows already mindful that Newton's diagrams were the effusions of a genius that they could not fathom and had no wish to disturb.