FORMAL TECHNICAL TEXT

MOS-based logic gates do not operate instantaneously because of the way transistor switching works at the physical level; there is a small delay between when the inputs are supplied and when the output is produced called propagation delay. The problem of propagation delay in gates, so-called gate delay, is compounded by the fact that there is also a delay associated with the wires that connect them together. A wire delay is typically much smaller than gate delay but the same problem applies: a value takes an amount of time proportional to the wire length to travel from one end to the other. Although such delays are extremely small, when many gates are placed in series or wires are very long the delays can add up and produce the problem of circuit metastability. Consider for example the XOR circuit developed previously. So far we have taken a static view of the circuit in the sense that we set some inputs and by assuming that all gates operate instantly, compute the output. The picture changes when we take a dynamic view that includes time; in particular, we see that depending on which time period we sample, the circuit can be in a metastable state which does not correctly represent the required final result. Given the labelled XOR implementation in Figure 2.8, Figure 2.11 highlights this effect. We start at time t = 70ns when the circuit is in the correct state given inputs of x = 0 and y = 1. The inputs are then toggled to x = 1 and y = 1 at t = 80ns but the result does not appear instantly given example propagation delays for NOT, AND and OR gates as 10ns, 20ns and 20ns respectively. In particular, we can examine points in the time-line and show that the final and intermediate results are wrong. For example, it takes until t = 90ns before the NOT gates produce the correct outputs and the final result does not change to the correct value until t = 130ns; before then the output is wrong in the sense that it does not match the inputs. One can try to equalise the delay through different paths in the circuit using dummy or buffer gates. A buffer simply copies the input to the output and can also amplify the input in some cases; essentially it is performing the identity function. Since the buffer takes some time to operate just like any other gate yet performs no change in input, one can place them throughout the circuit in order to ensure values arrive at the same time. An example is shown in Figure 2.12. Although the circuit may still enter metastable states, we have tamed the problem to some extent by ensuring that values passing into the two AND gates arrive at the same time. However, even when the effects of propagation delay are minimised it produces a secondary feature that acts as a limit. This feature is the critical path of the circuit, the longest sequential sequence of gates in the circuit that dominates the time taken for it to produce a result. (an excerpt from Daniel Page's *book A Practical Introduction into Computer's architecture*)

LITERARY-TECHNICAL TEXT

Look, it can exist in the Autoverse" ... the obvious response to that will be: "Yes, it can exist—if you put it there by hand—but that doesn't mean it's ever likely to have formed." If we can demonstrate a range of starting conditions that lead to planetary systems with suitable worlds, that will be one less element of uncertainty to be used against us."

Durham had eventually agreed, so she'd taken an off-the-shelf planetary-system modeling program—irreverently titled The Laplacian Casino—and adapted it to Autoverse chemistry and physics; not the deep physics of the Autoverse cellular automaton, but the macroscopic consequences of those rules. Mostly, that came down to specifying the properties of various Autoverse molecules: bond energies, melting and boiling points versus pressure, and so on. Aqua was not just water by another name, yellow atoms were not identical to nitrogen—and although some chemical reactions could be translated as if there was a one-to-one correspondence, in the giant fractionating still of a protostellar nebula subtle differences in relative densities and volatilities could have profound effects on the final composition of each of the planets. There were also some fundamental differences. Since the Autoverse had no nuclear forces, the sun would be heated solely by gravitational energy—the velocity its molecules acquired as the diffuse primordial gas cloud fell in on itself. In the real universe, stars unable to ignite fusion reactions ended up as cold, short-lived brown dwarfs—but under Autoverse physics, gravitational heating could power a large enough star for billions of years. (Units of space and time were not strictly translatable—but everybody but the purists did it. If a red atom's width was taken to be that of hydrogen, and one grid-spacing per clock-tick was taken as the speed of light, a more or less sensible correspondence emerged.) Similarly, although Planet Lambert would lack internal heating from radioisotope decay, its own gravitational heat of formation would be great enough to drive tectonic activity for almost as long as the sun shone.

Without nuclear fusion to synthesize the elements, their origin remained a mystery, and a convenient gas cloud with traces of all thirty-two—and the right mass and rotational velocity—had to be taken for granted. Maria would have liked to have explored the cloud's possible origins, but she knew the project would never be finished if she kept lobbying Durham to expand the terms of reference. The point was to explore the potential diversity of Autoverse life, not to invent an entire cosmology.

Gravity in the Autoverse came as close as real-world gravity to the classical, Newtonian inverse-square law for the range of conditions that mattered, so all the usual real-world orbital dynamics applied. At extreme densities, the cellular automaton's discrete nature would cause it to deviate wildly from Newton—and Einstein, and Chu—but Maria had no intention of peppering her universe with black holes, or other exotica. (an excerpt from Greg Egan’s book *Permutation City*)