DIGITAL PHYSICS

Edward Fredkin

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6.895 Digital Physics

(New)

Prereq.: Permission of Instructor

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An inquiry into the relationships between physics and computation. 6.895 is appropriate for both computer science and physics students. Models of computation based on systems that obey simple physical laws and digital models of basic physical phenomena. Tutorial on conventional digital logic. Information, communication, memory and computation. A formal model of computer circuitry, conservative logic, will be used to model computers at various levels of complexity from simple logic gates to processors, memory, conventional computers and Turing machines. Questions about reversibility and about the conservation of information during computation. Minimum energy requirements for a *unit* of computation. Generally reversible iterative processes. Tutorial on some areas of the quantum mechanics. Digital time and space. Universal cellular automata. Digital model of the zero-dimensional Schrodinger equation. Proof of the conservation of probability in the digital model. Three dimensional digital Schrodinger equations. Digital Newtonian mechanics. Digital determinism. The laws, physical constants and experimental tests of digital physics. Atomism. Questions of the ultimate nature of reality. Metaphysics and cosmogony.

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LECTURE OUTLINE FOR 6.895, DIGITAL PHYSICS

1. *Introduction and Overview; the Atomic Theory of Everything*

   Definition of the subject, "Digital Physics". The historical progress of atomism. Atomism carried to a conclusion. The connections between physics and computer science. Why it is desirable to have laws about computation, information and communication. Why computation may shed some light on physics. Why physics may help us to understand computation. Computation as a process that obeys laws of physics. The informational nature of the most fundamental of questions. Unresolved paradoxes of cosmogony, physics and metaphysics. The philosophical goal; an ultimate explanation of some natural phenomena. Overview of the material to be covered. Texts, notes and bibliography.

2. *Information*

   Information as a means of representation. Information as a means of communication. Information as part of a process, a computation or a mechanism. A lot about the <u>bit.</u>

Spin, the perfect bit. The definition of physical communication and physical memory. Why physical communication and physical memory are the identical process. The ultra concreteness of information.

3. *Using The Concept of Information*

Gaining additional understanding of physical phenomena by looking at information flow. The amount of information in a volume of space-time. The amount of information passing through an area of space-time. The amount of information that can be obtained from an experiment. The use of coding. How much information can be coded by a pair of particles. The relationship between the amount of information in a representation and the amount of information in the system that interprets the representation. The impossibility of getting away with fewer than the necessary number of bits. Why the assumption that finite volumes of space-time can only represent finite numbers of bits is reasonable. The notion that the bits must be there, somewheres, to represent the states of a system.

4. *Computation Tutorial -- I*

Computation modelled as finite state machines, Turing machines, automata, cellular automata, Boolean algebra, digital logic, iterative processes and conventional computers. Conventional digital logic. Historical perspective. Standard gates, flip-flops and ways of interconnecting them. Garden of Eden configurations and reversibility. Incremental microscopic reversibility vs global reversibility. Inverse function forwards in time vs inverse function backwards in time. Universality, simulation and the speed-up theorem.

5. *Computation Tutorial -- II*

More on conventional digital circuitry. Precise view of the role of fan-out, fan-in, propagation delay, energy requirements, energy dissipation and wiring. Roles played by memory and communication in conventional digital logic. Computation as a physical process.

6. *Conservative Logic -- I*

The basic elements of conservative logic; the wire and the gate How one constructs gates and flip-flops. Other elementary circuits. The rules for wiring circuits of conservative logic. Why circuits of conservative logic are reversible. General requirements for reversible circuits. Generalized conservative systems.

7. *Conservative Logic -- II*

Circuits of medium complexity. Carnot's argument about heat engines applied to conservative logic. Measuring the minimum energy requirements for a computation. Why conservative logic generates "garbage". How to get rid of "garbage".

8. *Conservative Logic -- III*

The Turing machine and the general purpose computer built of conservative logic. The concepts of universality and simulation reiterated in the context of conservative logic. The use of conservative logic as a measure of computational complexity. All finite processes may be modelled exactly by reversible systems. The law of conservation of information.

9. *Conservative Logic -- IV*

Energy requirements for computation. Why old arguments about the value of the minimum energy required for computation are invalid. The nature of a computation that proceeds without any dissipation of energy. The possibility of practical ways to build computers that use essentially no power. The one example of a computer that dissipates no energy. Thermodynamics quickly revisited. What happens to fundamental processes of nature when time runs backwards.

10. *The Charming Circle*
The origin of the charming circle. The derivation of the equations. Properties of the iterated difference equations. Why the radius is "constant". Why the process is reversible in the face of truncation and round-off. Why information is not lost even though it is thrown away.
11. *Generally Reversible Iterative Processes*
How to make any process into a reversible process. The Garden of Eden problem. Why the total memory required to convert an irreversible process to a reversible one has a factor of four as its upper bound. Reversible digital Newtonian mechanics. Why F=MA can be restated as:
$S_{t+1}=[F_t/M+2S_t]-S_{t-1}$ which simply states that the future position, S_{t+1}, of a mass, M, is a function of the forces acting on it and its previous positions.
12. *Quantum Mechanics Tutorial -- I*
Feynman, volume III, chapters 1, and 2.
13. *Quantum Mechanics Tutorial -- II*
Other parts of volume III. Questions, paradoxes and mysteries. Classical Schrodinger and Hamiltonian equations. Stern-Gerlach results. Understanding spin from an information point of view.
14. *Digital Time and Space*
A general discussion about time. The nature of the direction of time. The relationship between time and space. General properties of space-time. Digital time, the automata model of time. Digital space. How a finite space wraps around. The cellular automata model of space-time. Real and imaginary time. Absolute time. Absolute orientation. Absolute velocity. More on digital Newtonian mechanics.
15. *The Zero Dimensional Digital Schrodinger Equation*
The nature of the quantity computed by the digital Schrodinger equation. Properties of the equation in terms of physical reality. The long term behavior of such equations. The half step integration. Properties of the digital amplitudes. The definition of the probabilities. The conservation of the probabilities.
16. *Derivation of the Digital Schrodinger Equation*
The conventional forms of the Schrodinger equation. The source of the equation. The meaning of the amplitude. The difference form of the differential equation. The effect of the quantization of the amplitudes. The further atomization of the digital equation.
17. *Digital Schrodinger Equation -- III*
Derivation of the difference form of the equations. A careful look at the nature of time in the difference form. The half-step method applied to the amplitudes. Reformulation of the amplitude calculation into two time steps. The consequent change in the method of calculating the probabilities from the new "amplitudes". Multiplying one side of the equation by minus one and iterating just one equation. Why swapping the real and the imaginary parts of the amplitudes causes time to go backwards. Why amplitudes are complex numbers. Treating space and time more symmetrically by computing the spatial updates one axis at a time.
18. *Digital Schrodinger Equation -- IV*
The results of simulating the Digital Schrodinger equation in three dimensional space. The return to the approximate initial conditions. Why conservation of probability and the discreteness of the amplitudes guarantees that the amplitudes for a particle cannot continually spread. A process that computes a future with a probability chosen properly from the present amplitudes. The digital Dirac equations.

19. *Digital Determinism*

Digital determinism. One way determinism. Why computation is more backwards determined than it seems. Systems with short range non-deterministic behavior whose long range behavior is determined. Unknowable determinism and the speed-up theorem. Exact models of non-deterministic systems. Exact, microscopic models of random behavior.

20. *An Interpretation of the Digital Probability Amplitude*

The nature of the digital amplitudes. Why they are sufficient to represent all of natural phenomena, given the structure of digital space-time. How the basic quantities of physics are represented. The relation between digital amplitudes and the probability amplitudes of quantum mechanics. Fields and particles.

21. *The Laws of Digital Physics and The Physical Constants*

Information is conserved -- all fundamental processes are reversible. Physical memory and physical communication are the same process. All fundamental processes must be universal. Space and time and all quantities that exist in space and time are discrete or digital. The unit of length. The unit of time. Determination of the units of length and time. Reasons for the existence of particular stable particles. The determination of half-life. The laws of digital Newtonian mechanics.

22. *Experimental Tests of the Theory of Digital Physics*

Looking for angular quantization in astronomical data. Time quantization in short decay times. Experimental determination of angular quantization. The importance of using a narrow band source. The effects of the motion of the source and the motion of the receiver. The masking effects of most kinds of averaging. The determination of the metric orientation. The determination of the velocity of a system through the metric.

23. *Atomism and the Absence of Continuity*

Zeno's paradox about the arrow in flight. Zeno's paradox about Achilles and the tortoise. The calculus. Geometry, the point and the line. Patterson's lions and Christians problem. Continuity and information content. Why dispensing with real continuity, as opposed to mathematical continuity, poses no great loss. The differential equation as an approximation to the true difference process.

24. *Digital Metaphysics and the Ultimate Nature of Reality*

A restatement of great metaphysical questions in terms consistent with our new digital concepts. The nature of mind, perception, brain, sensation, knowledge and consciousness. Questions about unobservable phenomena. Hidden variables. The effect of the observer on what is observed. Miracles.

25. *Digital Cosmogony and Cosmology*

On the origin of the universe. The laws of our universe. Other possible consistent sets of laws. What there might have been before there was time. The nature of the machine that runs the information process that is our digital universe. Why it is true that that machine is computing our future as fast as is possible. Possibilities about the nature of the place in which that machine exists. In the prebegining there was the computer, it was loaded with the initial conditions, the start button was pressed and then there was the begining.

26. *Summary and Critique*

There will be a general summary and critique of the material presented.