Int. Journ. of Unconventional Computing, Vol. 8, pp. 99–105
Reprints available directly from the publisher
Photocopying permitted by license only

Can a Computer be "Pushed" to Perform Faster-Than-Light?

VOLKMAR PUTZ AND KARL SVOZIL

Institute for Theoretical Physics, Vienna University of Technology,
Wiedner Hauptstraße 8-10/136, A-1040 Vienna, Austria
E-mail: putz@hep.itp.tuwien.ac.at
E-mail: svozil@tuwien.ac.at

Received: April 05, 2010. Accepted: May 10, 2010. Final: September 02, 2010.

We propose to "boost" the speed of communication and computation by immersing the computing environment into a medium whose index of refraction is smaller than one, thereby trespassing the speed-of-light barrier.

Keywords: Optical computation, index of refraction, medium computation, radiative corrections to signalling, quantum field theory

The Church-Turing and the Cook-Karp theses, as well as other, more general limits on computation, are under permanent "scrutiny" (cf., e.g., Ref. [9, p 11] or Ref. [11, p. 5]) by the physical sciences. Some recent issues which have been raised comprise Zeno-squeezed accelerated time scales [57, 26, 16, 34, 51] enabling the construction of "infinity machines" capable of hypercomputation [10, 15, 36], counterfactual computation [32] and cryptography [35] based on quantum counterfactuals [17, 56], as well as the dissipation limits to computation [27]. Here we shall consider the possibility to speed up optical [8] computations and communication by transgressing the speed of light barrier in vacuum. Note that, although the speed of light barrier appears to be a fundamental limit for the transfer of "freely willable" information [40], several ways for "signals" trespassing the relativistic light cone [2], even to the extent of time travel [23, 33, 58, 12, 25], have been proposed. There appears to be a consensus that, just as for quantum correlations featuring (un)controllable non-locality [46] *via* outcome dependence but parameter independence, "signal" signatures beyond the velocity of light limit [31] could be tolerated at the kinematical level [28] as long as they are “benign” and thus incapable of rendering diagonalization-type [9, 48] paradoxes. This means that no paradoxes of self-referentiality, such as the “grandfather paradox” (e.g., by travelling back in time and killing one’s own biological grandfather before the latter has met one’s grandmother), should occur [5].

In what follows we propose to “boost” the speed of communication and computation by “pushing” the computer into a medium whose index of refraction is smaller than one. The speed of communication by light signals varies indirectly proportional to the index of refraction, differing greatly for various forms of media, substrata or “ethers” susceptible of the traversal of light. Quantum field theory allows the index of refraction to become smaller than one, thereby formally indicating a speed of photons exceeding the classical speed of light limit in vacuum.

How can one envisage such a computational substratum? One concrete realization would be the construction of an universal optical computer based on beam splitters [59] capable of rendering arbitrary discrete unitary transformations [41, 63, 50] immersed in a transparent medium occupied by charged fermions. Note that, as optical computers are far more than just photons or beams of light, a necessary requirement for any such computer to properly function would be that the optical components of the computer, such as in particular beam splitters and phase shifters, would work as expected in such a medium.

“Diagrammatically speaking” [21, 44, 52], i.e., in terms of perturbative quantum field theory, a photon, i.e., the “unit quantum of light” associated with a particular mode of the electromagnetic field, travels through the vacuum ether medium [14] by polarizing it through partly “splitting up” into an electron-positron pair and recombining. In solid state physics, this phenomenon gives rise to lattice excitations called *phonons* [49]. The electrons and positrons are themselves subject to higher order radiative corrections involving photons.

Thus, any change of vacuum polarization, such as finite boundary conditions, or increased or decreased pair production, alters the susceptibility of the vacuum ether medium for carrying electromagnetic waves, and thus results in a change of the velocity of light. Historically, this effect has first been studied for magnetic fields [18, 19, 1] and finite temperatures [22]. The first indication of a vacuum polarization-induced index of refraction *smaller than one* was reported by Scharnhorst [42, 29, 43] and Barton [3, 4] in an attempt to utilize the reduced vacuum polarization in the “Casimir vacuum” [30] between two conducting parallel plates. More recently, trans-vacuum-speed metamaterials [60, 62, 53, 61, 47] as well as negative refractive indices in gyrotropically magnetoelectric media [39] have been suggested. It would be interesting to extend these calculations to the squeezed vacuum state by computing the polarization in such an “exotic” vacuum [38].

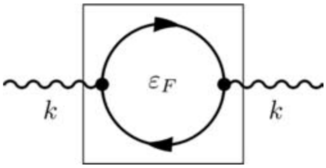

FIGURE 1
Lowest order vacuum polarization diagram.

One of the possibilities which have not been discussed so far is the immersion of the computing environment into a vacuum ether medium “filled” with electrons or positrons. In such an environment, the Pauli exclusion principle would “attenuate” pair creation, thereby reducing the polarization of the medium, resulting in a reduced index of refraction as well as in an increase of the velocity of light.

After regularization and renormalization, the lowest order change to the radiative correction associated with the vacuum polarization (whose Feynman diagram is depicted in Fig. 1) can be written as [37, 20, 44]

$$\Delta\Pi_{\mu\nu}(k^2) = -\left(g_{\mu\nu}k^2 - k_\mu k_\nu\right)\frac{2\alpha}{3\pi}\log\frac{\varepsilon_F}{m}, \tag{1}$$

where m stands for the electron rest mass and ε_F denotes the cutoff associated with the filled electron or positron modes; the calculation assumed $k^2 < m$. Let ϵ_μ stand for the vacuum polarization. Then we can introduce an effective mass term [45, 54, 55]

$$M(k) = \epsilon^\mu \Pi_{\mu\nu}(k)\epsilon^\nu \tag{2}$$

such that the eigenvalue equation is

$$\mathbf{k}^2 + M(k) = (k^0)^2, \tag{3}$$

where $k^\mu = (\mathbf{k}, k^0 = \omega)$; and

$$|\mathbf{k}| \approx \omega - \frac{1}{2\omega}M(k). \tag{4}$$

Thus the index of refraction can be defined by

$$n(\omega) = \frac{|\mathbf{k}|}{\omega} \approx 1 - \frac{1}{2\omega^2}M(k). \tag{5}$$

Hence the change of the refractive index is given by

$$\Delta n(\omega) \approx -\frac{\alpha}{3\pi\omega^2}(\epsilon^\mu k_\mu)^2 \log\frac{\varepsilon_F}{m}. \tag{6}$$

The group velocity is given by [43, Equ. (2)] $v_{gr} = c/n_{gr}$ with $n_{gr}(\omega) = n(\omega) + \omega\,[\partial n(\omega)/\partial\omega]$, which, for transversal waves, turns out to be $n(\omega)$. As a result, the speed of light $c/(1-\Delta n) \approx c + \Delta c$ is changed by $\Delta c = c\Delta n$.

Note that group velocities, like phase velocities and energy velocities, are not in general signal velocities. Thus a group velocity exceeding the vacuum speed of light c does not contradict relativity [7, 13, 8].

Nevertheless, as has already pointed out, this effect can be used to “push” the computer into a domain of faster-than-light computation; with the possibility to decrease its time cycles accordingly. One should keep in mind that at present such a possibility merely remains a theoretical speculation; this hypothetical character being shared with some relativistic “realizations” of hypercomputers. Nevertheless it might be interesting to pursue the possibilities related to temporal quantum field theoretical speedup further, for in principle nothing prevents Δn in Eq. (6) or in other “exotic” vacuum states from approaching one, yielding an unbounded cycle speed, associated with expanding memory requirements [6].

In summary we have discussed field theoretic options for the “speedup” of communication and computation. These are based on the alteration of the polarization of “exotic vacua” and the respective changes of the index of refraction. The speed of light is modified in indirect proportion to the refractive index of the medium it is travelling through. Thus for materials with a refractive index smaller than unity, light travels faster than it does in “normal” vacuum whose index of refraction is associated with unity. Hence, optical computers operating in such an “exotic” medium, if they existed, could compute faster than computers in “normal” vacuum or ordinary materials which have refractive indices equal to or greater than unity. Feasible realization of universal computers utilizing this effect could employ generalized beam splitters capable of realizing arbitrary discrete unitary operators.

We have discussed a general physical framework for “exotic” vacua with indices of refraction strictly smaller than unity. One such vacuum state is responsible for the hypothetical Scharnhorst effect, for which the polarizability of the vacuum “medium” is effectively reduced by the boundary conditions of the electromagnetic field between two conductors (e.g., parallel plates). Another possibility which is introduced here is the occupancy of charged fermionic, in particular electronic, states, which would partially inhibit the pair production of fermion-antifermion (electron-positron) pairs contributing to the vacuum polarization even in lowest nontrivial order of the perturbation series. It should be emphasized that these findings do not represent the possibility to circumvent relativistic causality, nor are they inconsistent with the present formalism of relativity theory or the theory of quantized fields.

REFERENCES

[1] Stephen L. Adler. (1971). Photon splitting and photon dispersion in a strong magnetic field. *Annals of Physics*, 67(2):599–647.

[2] Miguel Alcubierre. (1994). The warp drive: hyper-fast travel within general relativity. *Classical and Quantum Gravity*, 11(5):L73–L77.

[3] G. Barton. (1990). Faster-than-c light between parallel mirrors. The Scharnhorst effect rederived. *Physics Letters B*, 237(3-4):559–562.

[4] G. Barton and K. Scharnhorst. (1993). QED between parallel mirrors: light signals faster than c, or amplified by the vacuum. *Journal of Physics A: Mathematical and General*, 26(8):2037–2046.

[5] John L. Bell. (2002). Time and causation in Gödel's universe. *Transcendent Philosophy*, 3:1.

[6] Cristian S. Calude and Ludwig Staiger. (2009). A note on accelerated Turing machines. CDMTCS preprint nr. 350, 7 p.

[7] Raymond Y. Chiao. (Jul 1993). Superluminal (but causal) propagation of wave packets in transparent media with inverted atomic populations. *Phys. Rev. A*, 48(1):R34–R37.

[8] Raymond Y. Chiao and Peter W. Milonni. (2002). Fast light, slow light. *Optics & Photonics News*, 13(6):26–30.

[9] Martin Davis. (1958). *Computability and Unsolvability*. McGraw-Hill, New York.

[10] Martin Davis. (2006). Why there is no such discipline as hypercomputation. *Applied Mathematics and Computation*, 178:4–7.

[11] David Deutsch. (1985). Quantum theory, the Church-Turing principle and the universal quantum computer. *Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences (1934-1990)*, 400(1818):97–117.

[12] David Deutsch. (1991). Quantum mechanics near closed timelike lines. *Physical Review D*, 44:3197–3217.

[13] G. Diener. (1996). Superluminal group velocities and information transfer. *Physics Letters A*, 223(5):327 – 331.

[14] Paul Adrien Maurice Dirac. (1951). Is there an aether? *Nature*, 168:906–907.

[15] Francisco Antonio Doria and José Félix Costa. (2006). Introduction to the special issue on hypercomputation. *Applied Mathematics and Computation*, 178:1–3.

[16] Jérôme Durand-Lose. (2005). Abstract geometrical computation for black hole computation. In Maurice Margenstern, editor, *Machines, Computations, and Universality, 4th International Conference, MCU 2004, Saint Petersburg, Russia, September 21-24, 2004, Revised Selected Papers*, volume 3354 of *Lecture Notes in Computer Science*, pages 176–187. Springer.

[17] A. C. Elitzur and L. Vaidman. (1993). Quantum mechanical interaction-free measurements. *Foundations of Physics*, 23:987–997.

[18] Thomas Erber. (1961). Velocity of light in a magnetic field. *Nature*, 190:25–27.

[19] Thomas Erber. (Oct 1966). High-energy electromagnetic conversion processes in intense magnetic fields. *Reviews of Modern Physics*, 38(4):626–659.

[20] Richard Phillips Feynman. (Sep 1949). Space-time approach to quantum electrodynamics. *Physical Review*, 76(6):769–789.

[21] Richard Phillips Feynman. (1962). *Quantum Electrodynamics*. Addison-Wesley, Redwood City, CA.

[22] Holger Gies and Walter Dittrich. (1998). Light propagation in non-trivial QED vacua. *Physics Letters B*, 431(3-4):420 – 429.

[23] Kurt Gödel. (1949). A remark about the relationship between relativity theory and idealistic philosophy. In Paul A. Schilpp, editor, *Albert Einstein, Philosopher-Scientist*, pages 555–561. Tudor Publishing Company, New York. Reprinted in Ref. [24, pp. 202-207].

[24] Kurt Gödel. (1990). In S. Feferman, J. W. Dawson, Jr., S. C. Kleene, G. H. Moore, R. M. Solovay, and J. van Heijenoort, editors, *Collected Works. Publications 1938-1974. Volume II*. Oxford University Press, Oxford.

[25] Daniel M. Greenberger and Karl Svozil. (2005). Quantum theory looks at time travel. In S. Dolev A. Elitzur and N. Kolenda, editors, *Quo Vadis Quantum Mechanics?*, pages 63–72, Berlin. Springer Verlag.

[26] Mark L. Hogarth. (1992). Does general relativity allow an observer to view an eternity in a finite time? *Foundations of Physics Letters*, 5:173–181.

[27] H. S. Leff and A. F. Rex. (1990). *Maxwell's Demon*. Princeton University Press, Princeton.

[28] Stefano Liberati, Sebastiano Sonego, and Matt Visser. (2002). Faster-than-c signals, special relativity, and causality. *Annals of Physics*, 298(1):167–185.

[29] Peter Milonni and Karl Svozil. (1990). Impossibility of measuring faster-than-c signaling by the Scharnhorst effect. *Physics Letters B*, 248(3-4):437–438.

[30] Peter W. Milonni. (1994). *The Quantum Vacuum*. Academic Press, San Diego.

[31] Peter W Milonni. (2002). Controlling the speed of light pulses. *Journal of Physics B: Atomic, Molecular and Optical Physics*, 35(6):R31–R56.

[32] Graeme Mitchison and Richard Jozsa. (2001). Counterfactual computation. *Proceedings of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences*, 457(2009):1175–1193.

[33] Paul J. Nahin. (1998). *Time Travel (Second edition)*. AIP Press and Springer, New York.

[34] István Németi and Gyula Dávid. (2006). Relativistic computers and the Turing barrier. *Applied Mathematics and Computation*, 178(1):118–142. Special Issue on Hypercomputation.

[35] Tae-Gon Noh. (Dec 2009). Counterfactual quantum cryptography. *Physical Review Letters*, 103(23):230501.

[36] Toby Ord. (2006). The many forms of hypercomputation. *Applied Mathematics and Computation*, 178:143–153.

[37] Wolfgang Pauli and F. Villars. (Jul 1949). On the invariant regularization in relativistic quantum theory. *Reviews of Modern Physics*, 21(3):434–444.

[38] Volkmar Putz and Karl Svozil. (2004). Quantum electrodynamics in the squeezed vacuum state: electron mass shift. *Il Nuovo Cimento B*, 119:175–179.

[39] Cheng-Wei Qiu and Said Zouhdi. (May 2007). Comment on "negative refractive index in gyrotropically magnetoelectric media". *Phys. Rev. B*, 75(19):196101.

[40] Erasmo Recami. (2001). Superluminal motions? A bird's–eye view of the experimental situation. *Foundation of Physics*, 31(7):1119–1135.

[41] M. Reck, Anton Zeilinger, H. J. Bernstein, and P. Bertani. (1994). Experimental realization of any discrete unitary operator. *Physical Review Letters*, 73:58–61.

[42] K. Scharnhorst. (1990). On propagation of light in the vacuum between plates. *Physics Letters B*, 236(3):354–359.

[43] K. Scharnhorst. (December 1998). The velocities of light in modified QED vacua. *Annalen der Physik*, 7:700–709.

[44] Silvan Schweber. (1984). *Relativistic Quantum Field Theory*. Harper and Row, New York.

[45] Julian Schwinger. (Jun 1951). On gauge invariance and vacuum polarization. *Physical Review*, 82(5):664–679.

[46] Abner Shimony. (1984). Controllable and uncontrollable non-locality. In S. Kamefuchi *et al.*, editor, *Proceedings of the International Symposium on the Foundations of Quantum Mechanics*, pages 225–230, Tokyo. Physical Society of Japan. See also J. Jarrett, *Bell's Theorem, Quantum Mechanics and Local Realism*, Ph. D. thesis, Univ. of Chicago, 1983; *Nous*, **18**, 569 (1984).

[47] A. B. Shvartsburg, M. Marklund, G. Brodin, and L. Stenflo. (Jul 2008). Superluminal tunneling of microwaves in smoothly varying transmission lines. *Physical Review E*, 78(1):016601.

[48] Raymond M. Smullyan. (1992). *Gödel's Incompleteness Theorems*. Oxford University Press, New York, New York.

[49] Michael A. Stroscio and Mitra Dutta. (2005). *Phonons in Nanostructures*. Cambridge University Press, Cambridge.

[50] Karl Svozil. (2005). Noncontextuality in multipartite entanglement. *J. Phys. A: Math. Gen.*, 38:5781–5798.

[51] Karl Svozil. (2009). On the brightness of the Thomson lamp: A prolegomenon to quantum recursion theory. In Cristian S. Calude, José Félix Costa, Nachum Dershowitz, Elisabete Freire, and Grzegorz Rozenberg, editors, *UC '09: Proceedings of the 8th International Conference on Unconventional Computation*, pages 236–246, Berlin, Heidelberg. Springer Verlag.

[52] G. 't Hooft and M. Veltman. (1973). Diagrammar. CERN preprint 73-9.

[53] S. A. Tretyakov. (Dec 2004). Comment on "existence and design of trans-vacuum-speed metamaterials". *Physical Review E*, 70(6):068601.

[54] Wu-yang Tsai and Thomas Erber. (Jul 1974). Photon pair creation in intense magnetic fields. *Physical Review D*, 10(2):492–499.

[55] Wu-yang Tsai and Thomas Erber. (Aug 1975). Propagation of photons in homogeneous magnetic fields: Index of refraction. *Physical Review D*, 12(4):1132–1137.

[56] Lev Vaidman. (2007). Counterfactuals in quantum mechanics. In Daniel Greenberger, Klaus Hentschel, and Friedel Weinert, editors, *Compendium of Quantum Physics*, pages 132–136. Springer, Berlin, Heidelberg.

[57] Hermann Weyl. (1949). *Philosophy of Mathematics and Natural Science*. Princeton University Press, Princeton.

[58] Steven W.Hawking. (Jul 1992). Chronology protection conjecture. *Physical Review D*, 46(2):603–611.

[59] A. Zeilinger. (1981). General properties of lossless beam splitters in interferometry. *American Journal of Physics*, 49(9):882–883.

[60] Richard W. Ziolkowski. (Mar 2001). Superluminal transmission of information through an electromagnetic metamaterial. *Physical Review E*, 63(4):046604.

[61] Richard W. Ziolkowski. (Dec 2004). Reply to "comment on 'existence and design of trans-vacuum-speed metamaterials' ". *Physical Review E*, 70(6):068602.

[62] Richard W. Ziolkowski and Ching-Ying Cheng. (Aug 2003). Existence and design of trans-vacuum-speed metamaterials. *Physical Review E*, 68(2):026612.

[63] Marek Zukowski, Anton Zeilinger, and Michael A. Horne. (1997). Realizable higher-dimensional two-particle entanglements via multiport beam splitters. *Physical Review A (Atomic, Molecular, and Optical Physics)*, 55:2564–2579.