Beyond MAXWELL & SHANNON: An Engineering View

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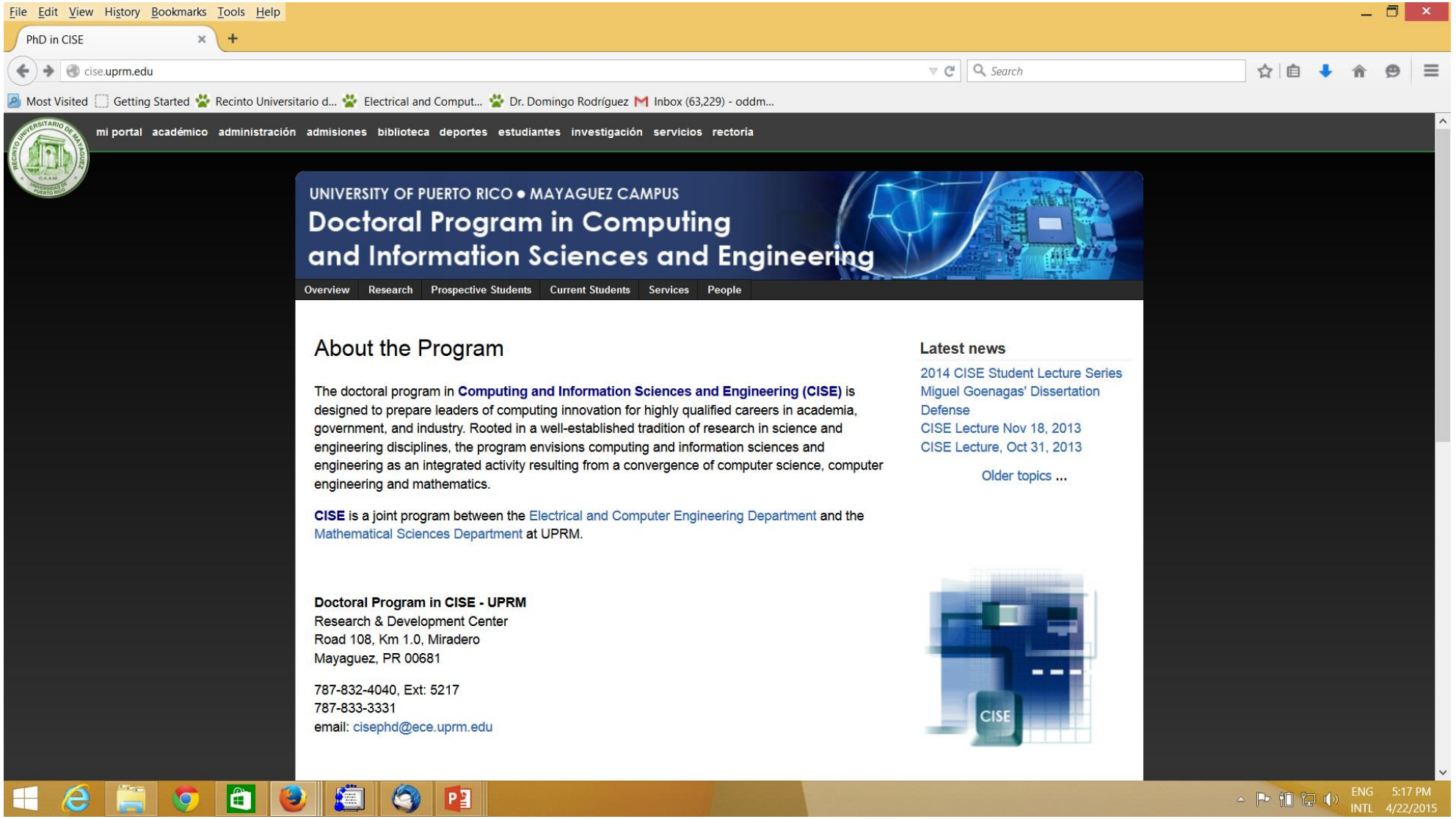
Outline of the Presentation

- Introduction
  - $Math_{fun}$ {Science $\Longleftrightarrow$ Engineering $\Longleftrightarrow$ Technology}
- Scientific Frameworks: Beyond **Maxwell** & **Shannon**
  - **Deutsch**: Quantum Information Theory
  - **Dirac**: Quantum Field Theory
- Research Opportunities: **Classical Frameworks**
  - Shannon's Information Theory
  - Classical Computation Theory
- Research Opportunities: **Extended Frameworks**
  - **Chaitin**: Algorithmic Information Theory
  - **Shor**: Quantum Fourier Transform
- Conclusions

CISE Doctoral Program at UPRM



Institute for Computing and Informatics Studies

Engineering Research Definition

- **Engineering Research:** Seeks and aims to develop theoretical models to further understandings of fundamental mechanisms and inherent attributes of *functional systems* and *physical structures*.

- **Engineering Science:** "Art or science of applying scientific knowledge to practical problems."

- **Engineering Technology:** Engineering use of "the scientific method and material to achieve a commercial or industrial objective."

Engineering Research

- **Engineering** is the **bridge** from science to technology.
- **Challenging opportunities** are manifesting themselves in the area of **engineering research** to strengthen this bridge through new *concepts*, *principles*, and *methods*.

http://famouswonders.com/millau-viaduct-france/

Best Global Universities for Engineering

1. Massachusetts Institute of Technology
2. Tsinghua University
3. University of California--Berkeley
4. Stanford University
5. Nanyang Technological University
6. Georgia Institute of Technology
7. National University of Singapore
8. Zhejiang University
9. Hong Kong Polytechnic University
10. Harbin Institute of Technology

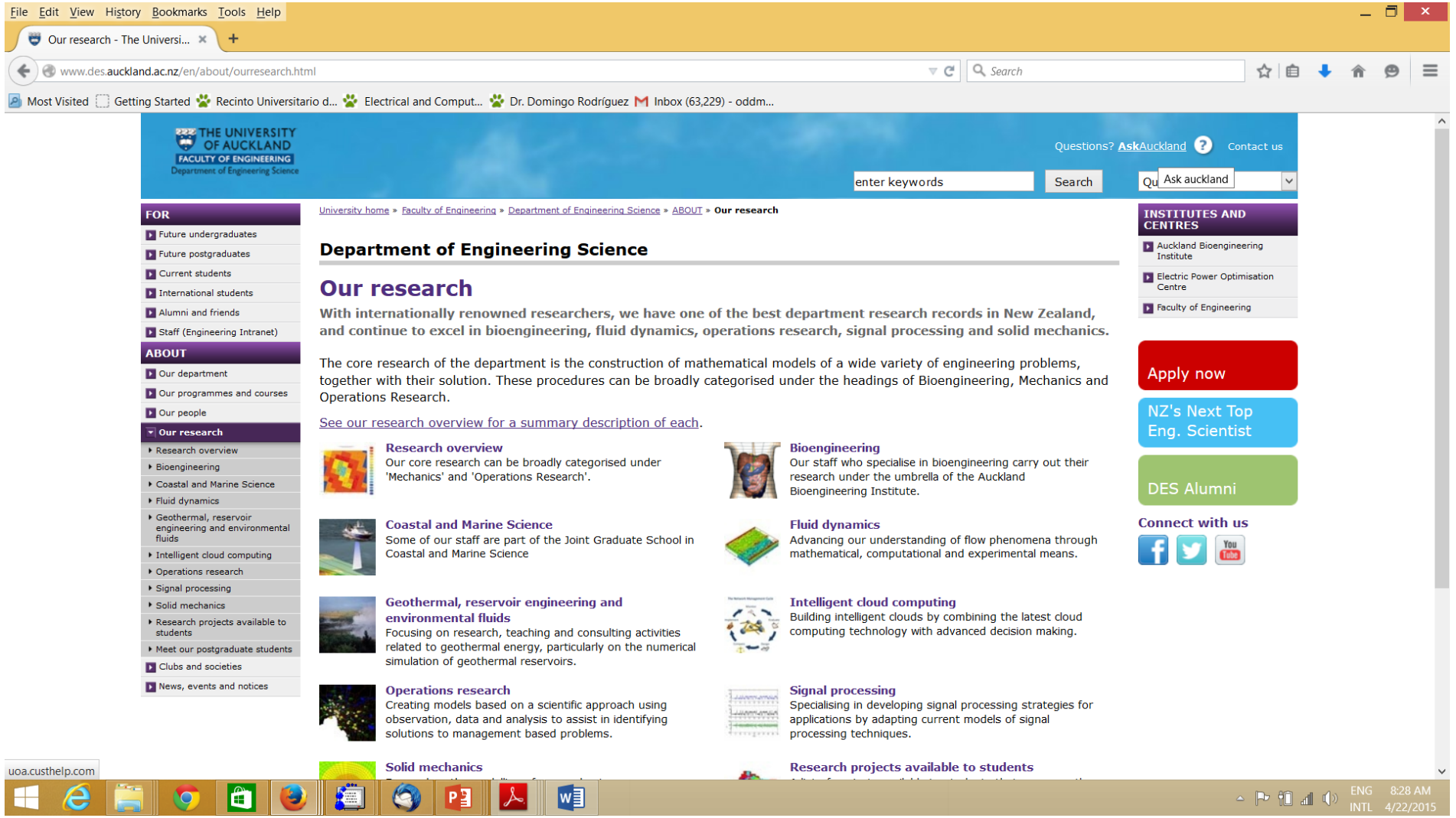
"These well-regarded universities from around the world have shown strength in producing research related to a variety of engineering topics."

http://www.usnews.com/education/best-global-universities/engineering

Sponsored Engineering Research at MIT

- "The faculty, post-docs, graduate students, undergraduates, and other researchers that comprise the **engineering community at MIT** are singularly dedicated to the development of ideas, processes, materials, and devices that will improve the lives of people throughout the world."
- "The School of Engineering's many departments, divisions, labs, and research centers collectively generate more than **$350 million** in sponsored research **every year**—and they define the future of science and technology."

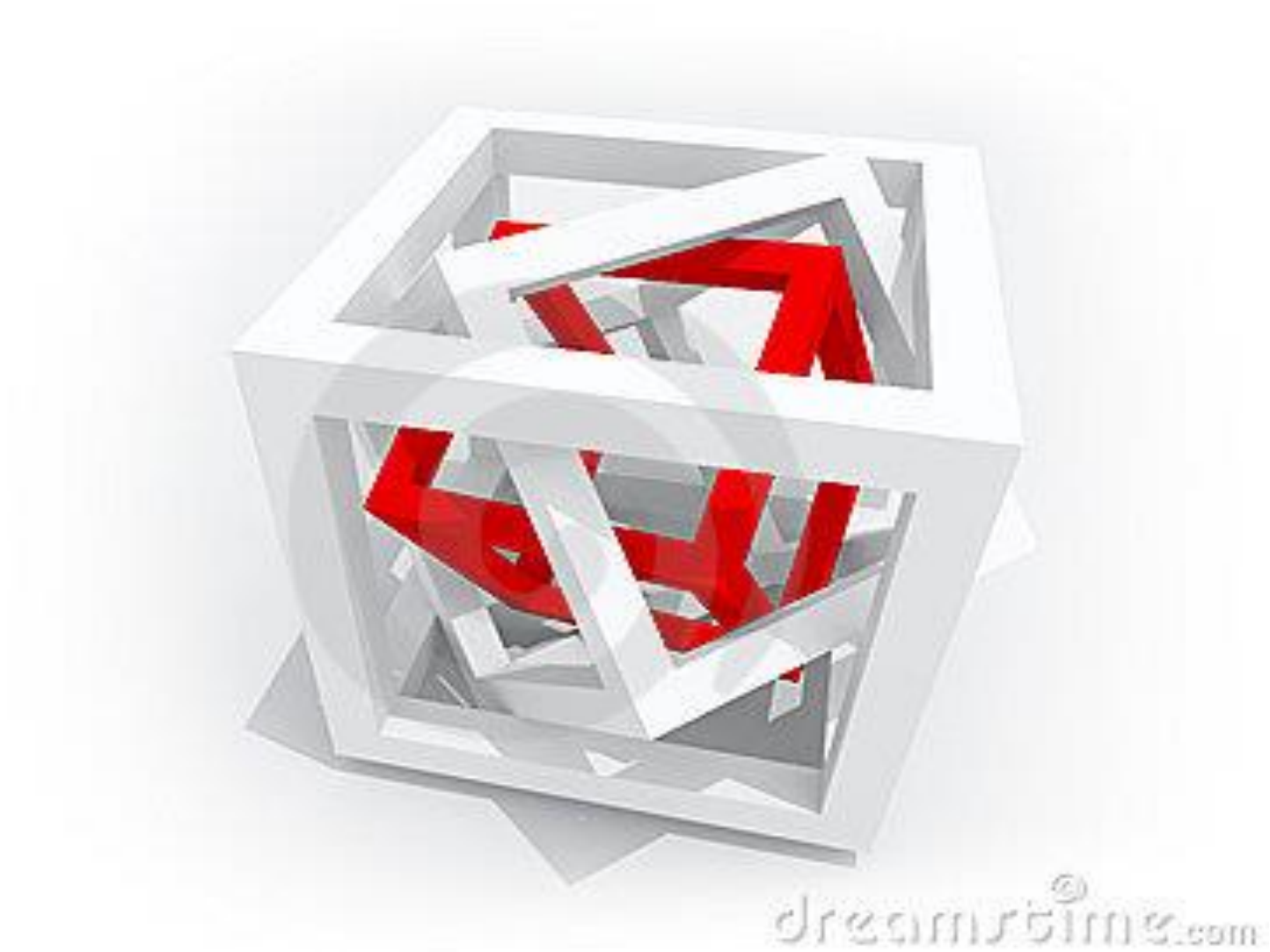
Engineering Science at Auckland – New Zealand



https://www.cs.auckland.ac.nz/~chaitin/complete.html

#173 Best Global Universities

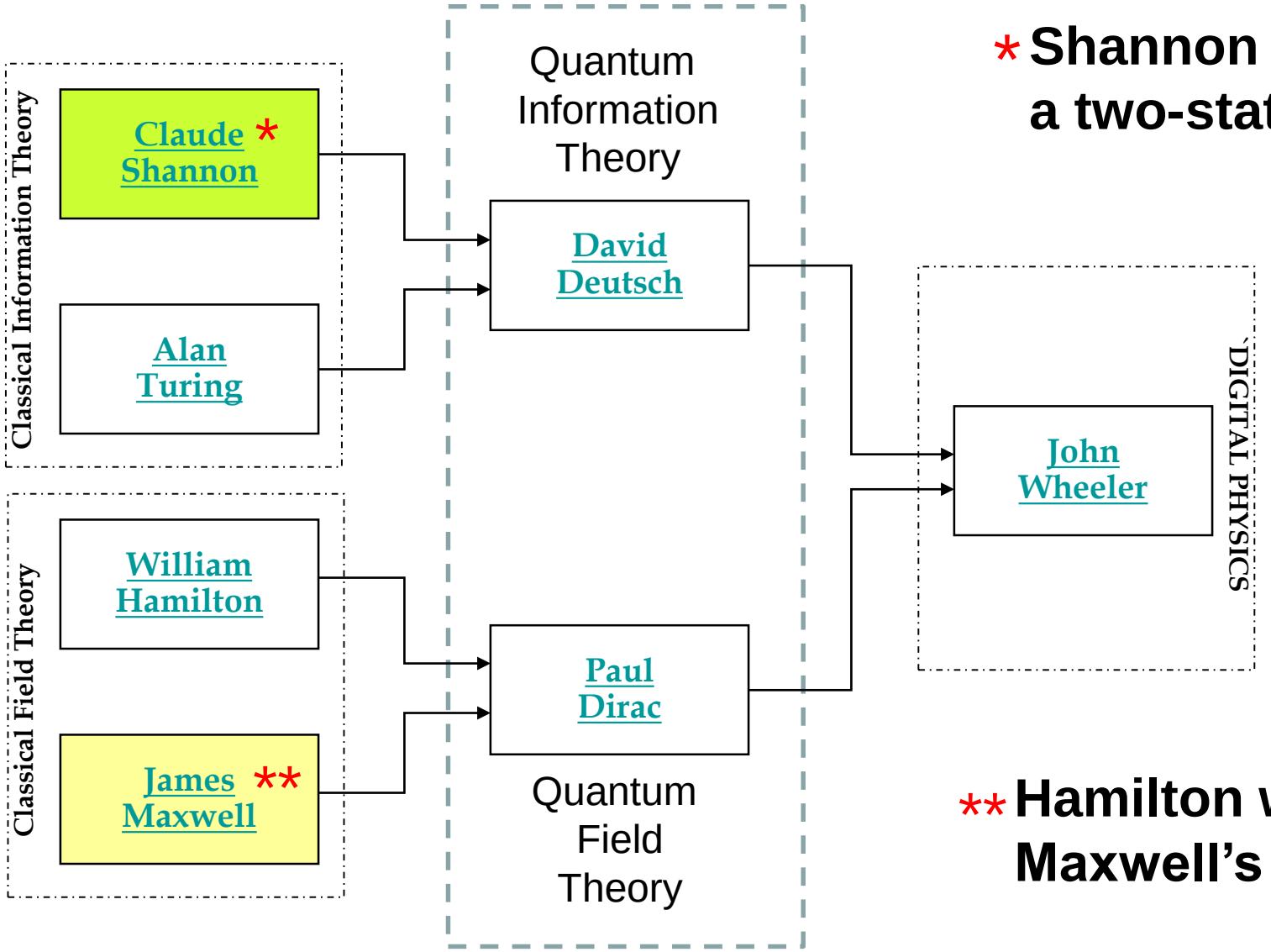
Scientific Frameworks



Traub's Modified Four Worlds of IBC

Physical World Phenomena (Natural)	**Digital World Abstraction (Virtual)**
Mathematical Model (Continuous)	**Computational Model (Discrete)**

Scientific Frameworks: Communication & Computation

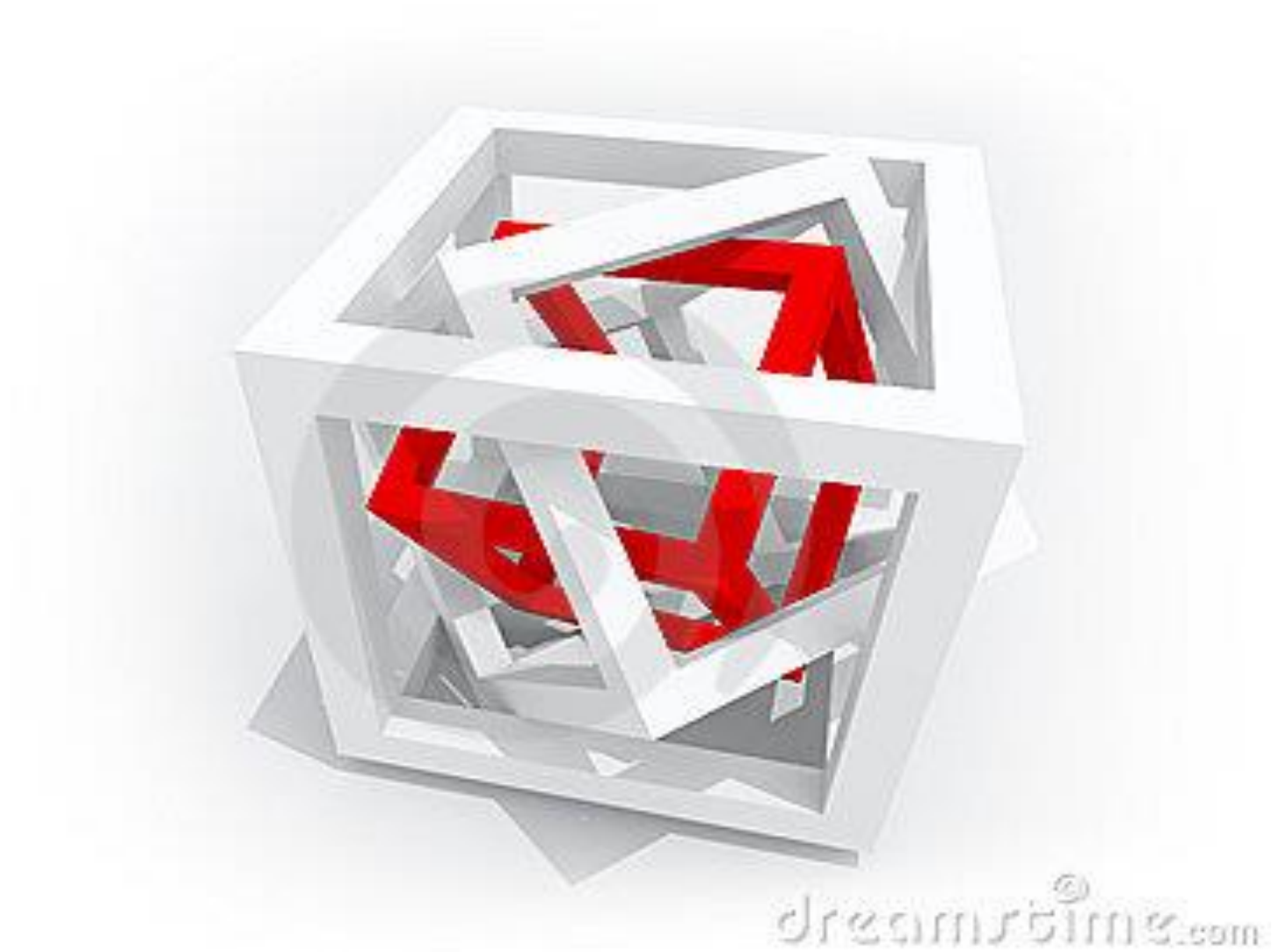


* **Shannon built a two-state UTM**

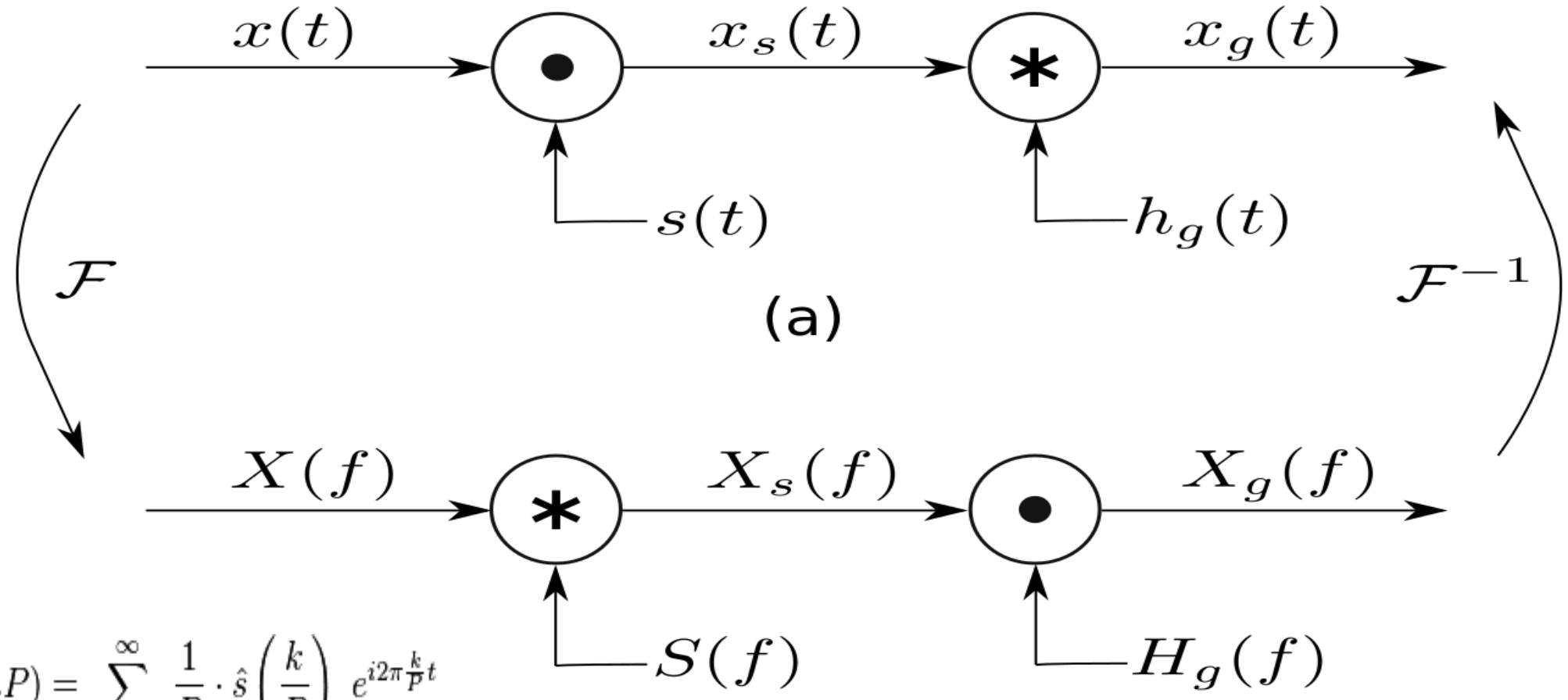
** **Hamilton was Maxwell's tutor**

http://en.wikipedia.org/wiki/Digital_physics

Classical Frameworks



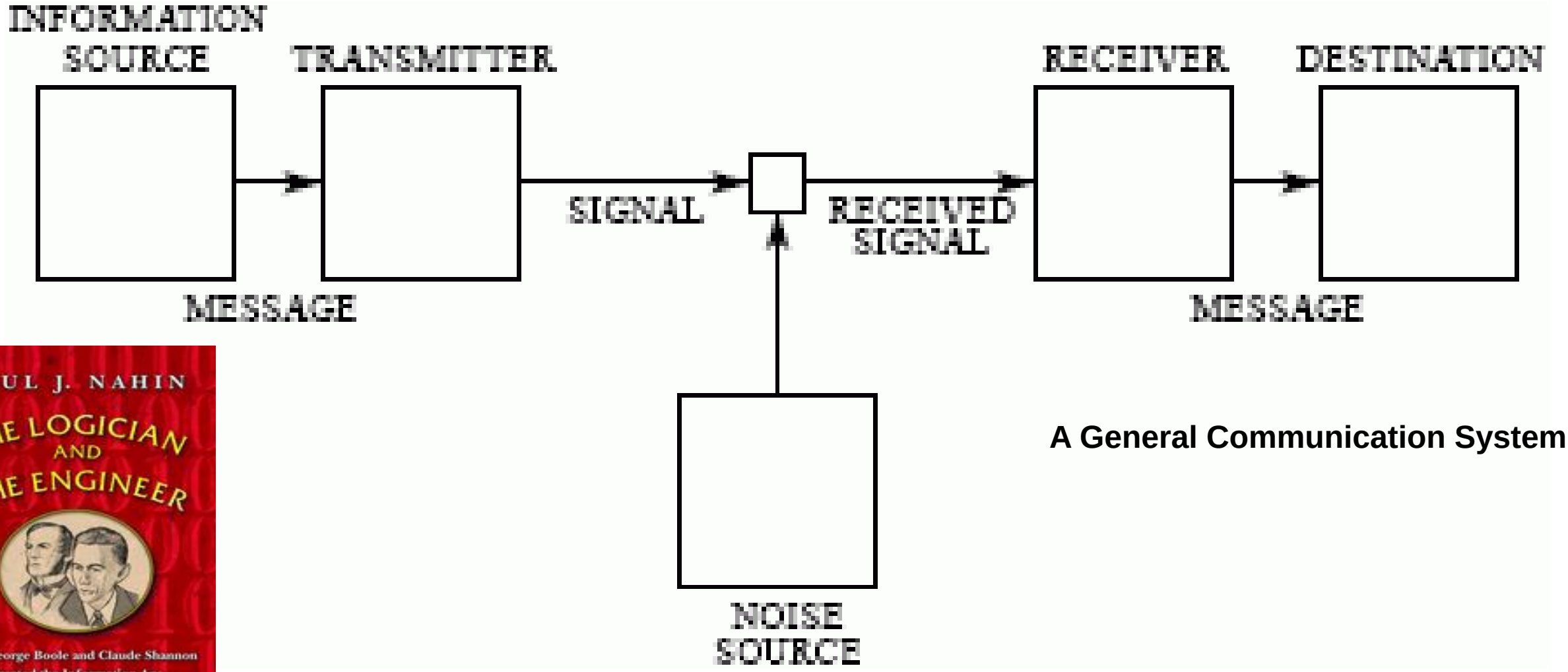
Poisson Summation & Time-Frequency Duality



$$\underbrace{\sum_{n=-\infty}^{\infty} s(t+nP)}_{S_P(t)} = \sum_{k=-\infty}^{\infty} \underbrace{\frac{1}{P} \cdot \hat{s}\left(\frac{k}{P}\right)}_{S[k]} e^{i2\pi \frac{k}{P} t}$$

http://en.wikipedia.org/wiki/Poisson_summation_formula

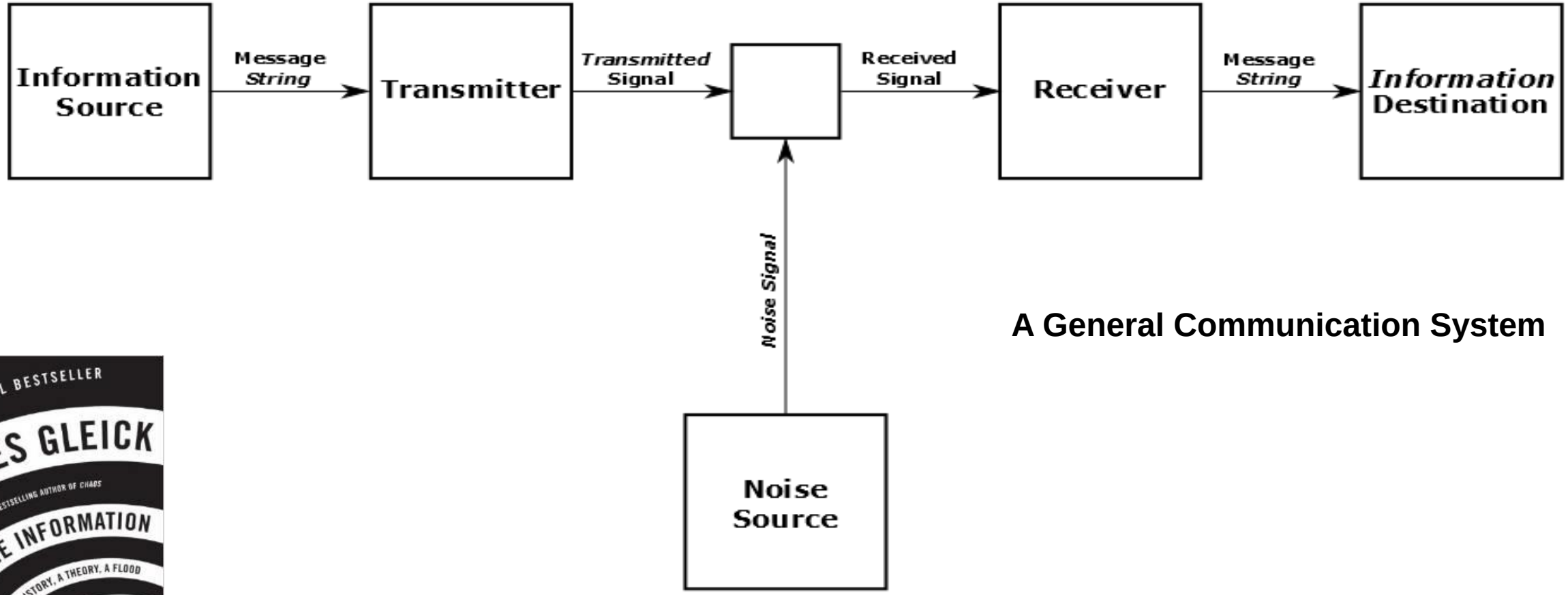
Shannon's Original Diagram (October 1948)



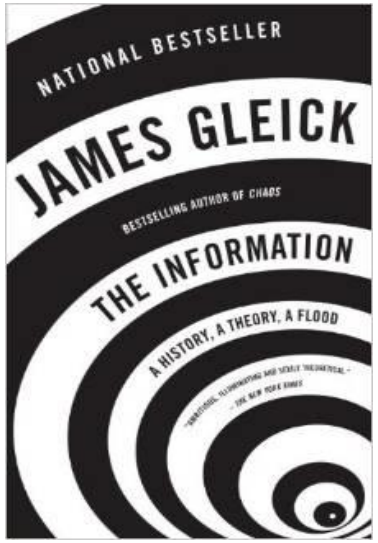
A General Communication System

http://press.princeton.edu/titles/9819.html

Shannon's Modified Diagram



A General Communication System



"The message is an algorithm"
James Gleick

http://en.wikipedia.org/wiki/Information_theory

NYQUIST THEOREM: Noiseless Channels

$$C = 2B log_2 M$$

$$C : channel\ capacity\ (bps)$$

$$B = channel\ bandwidth$$

$$M = 2^L : number\ of\ finite\ states\ in\ a\ symbol$$

Turing's Machine Communication: computation through storage without errors, with communications over a **noiseless channel**.

http://en.wikipedia.org/wiki/Harry_Nyquist

SHANNON's THEOREM: Noisy Channels

$$C = 2Blog_2(1 + (S/N))$$

$$C : channel\ capacity\ (bps)$$

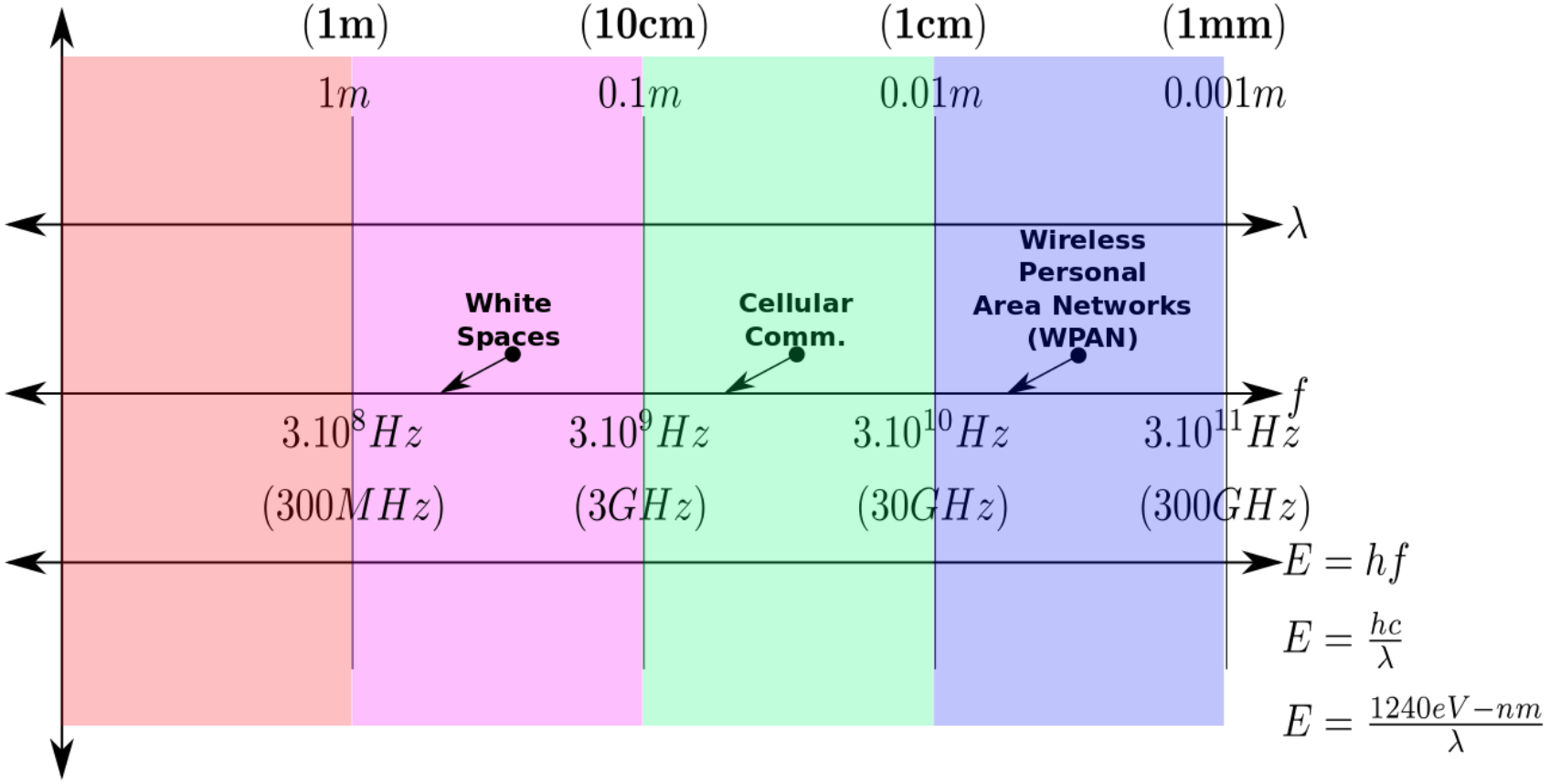
$$B = channel\ bandwidth$$

$$S/N : signal\text{-}to\text{-}noise\ ratio$$

Shannon's Digital Computation: computation and storage without errors, for communications over a **noisy channel**.

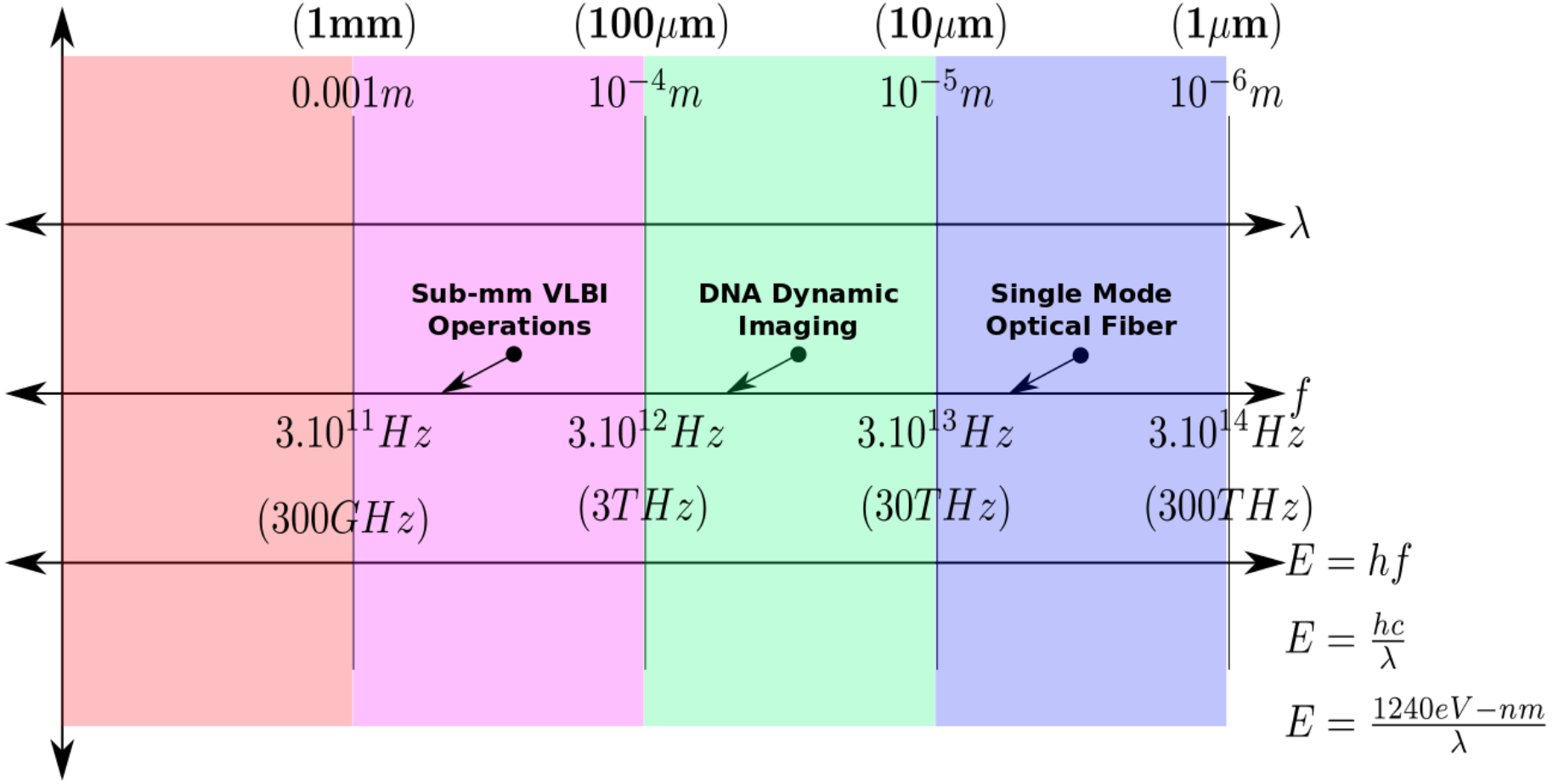
http://en.wikipedia.org/wiki/Channel_capacity

Electromagnetic Spectrum (**sub-meter**)



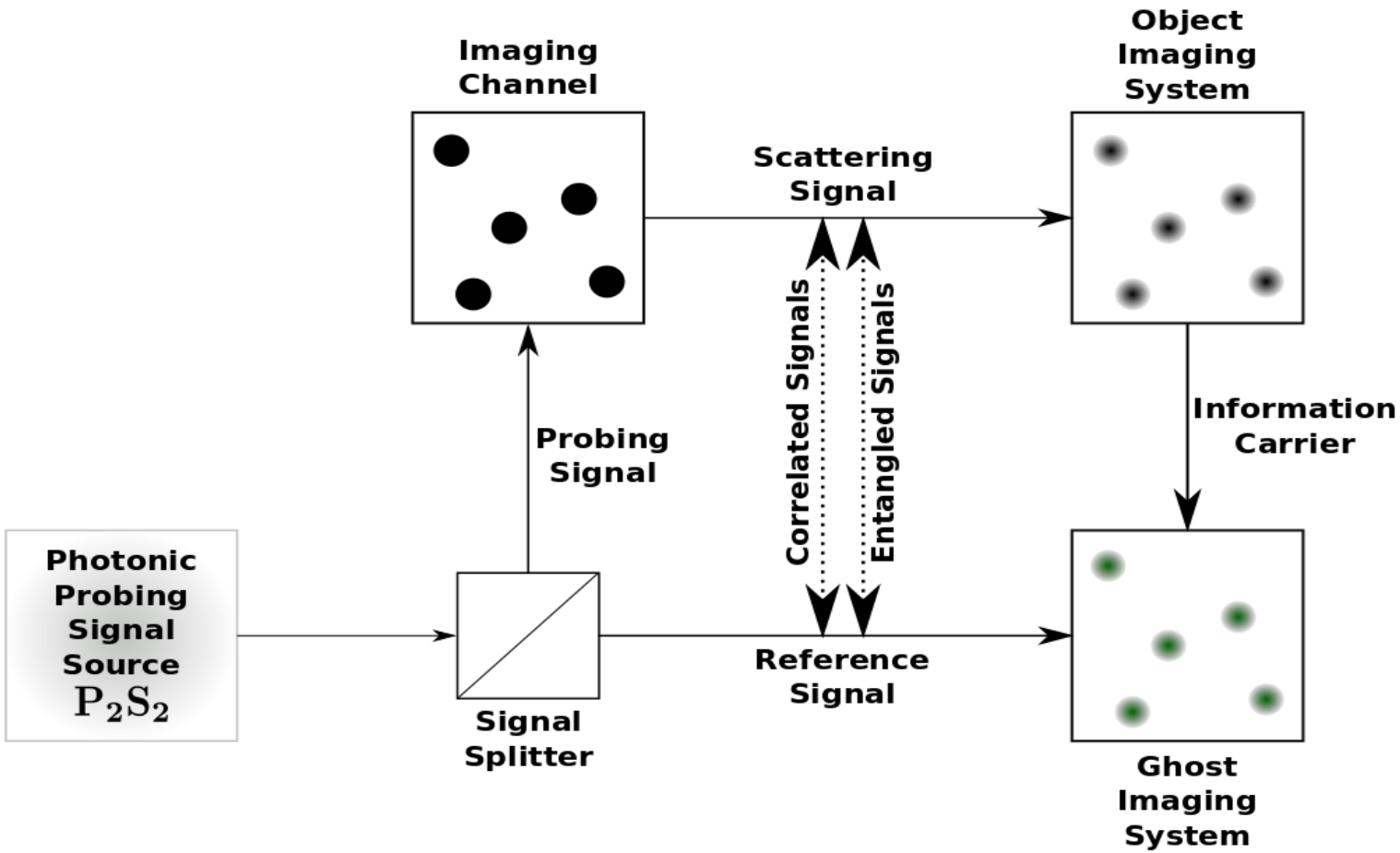
http://en.wikipedia.org/wiki/Electromagnetic_spectrum

Electromagnetic Spectrum (**sub-millimeter**)

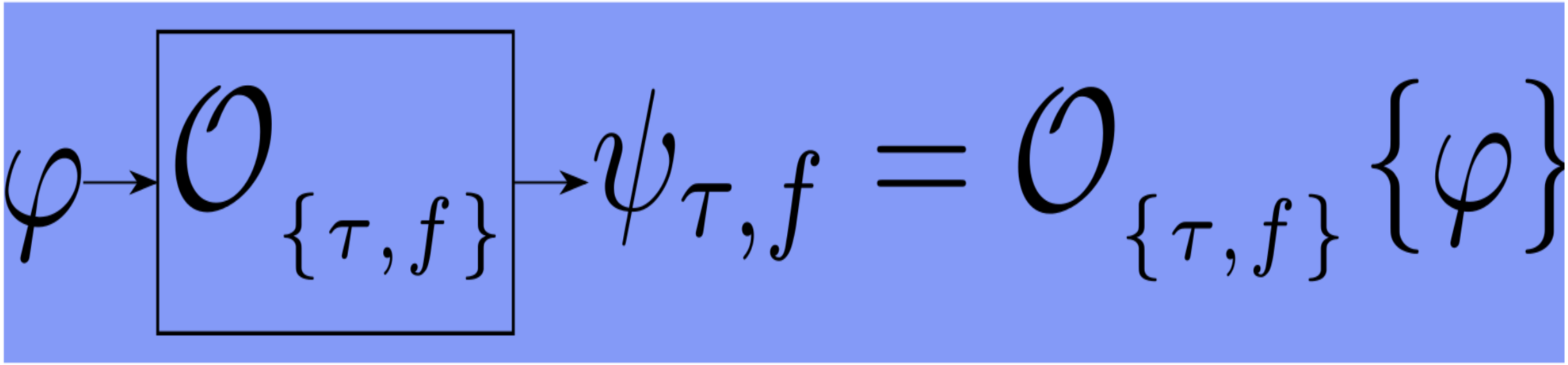


http://en.wikipedia.org/wiki/Electromagnetic_spectrum

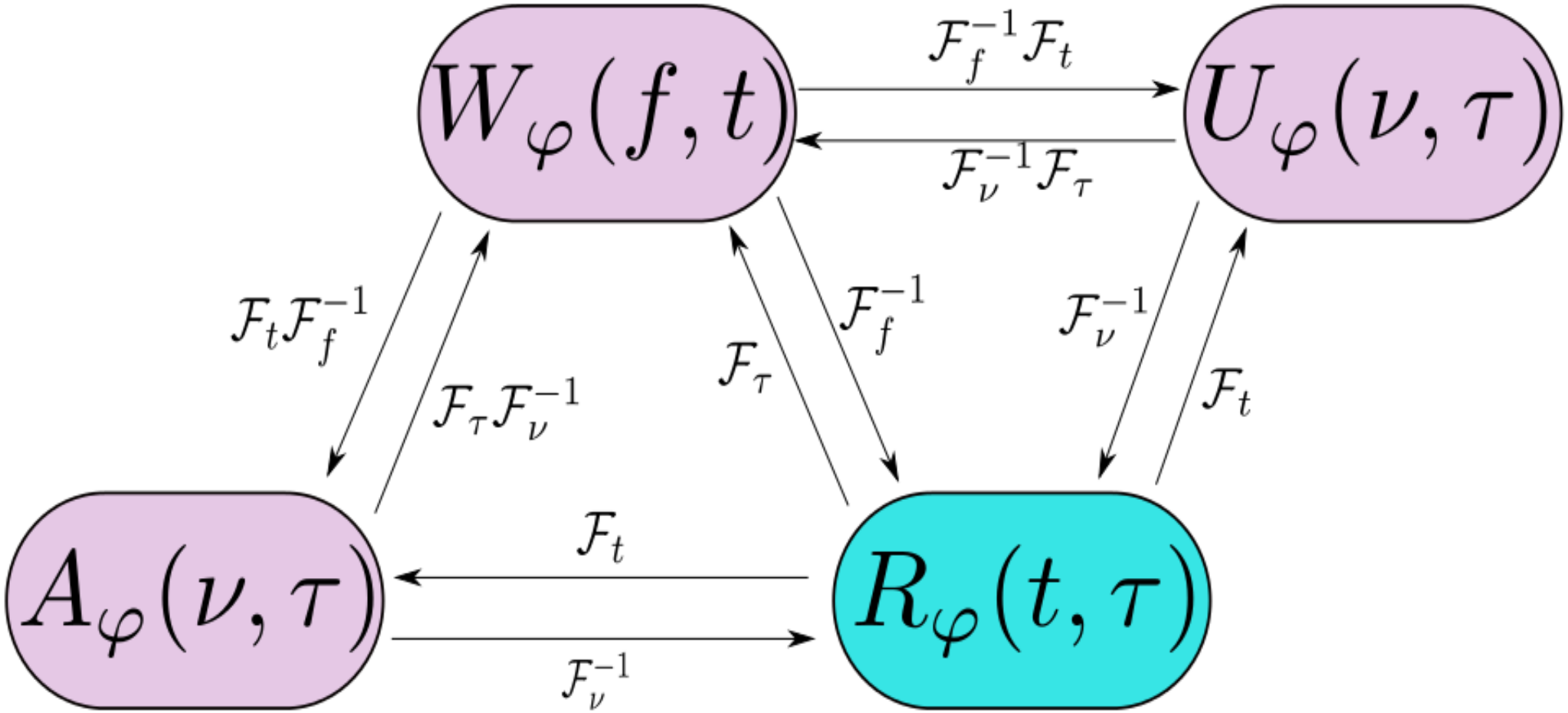
Classical Imaging: Communications Channel



Time-Frequency Operators

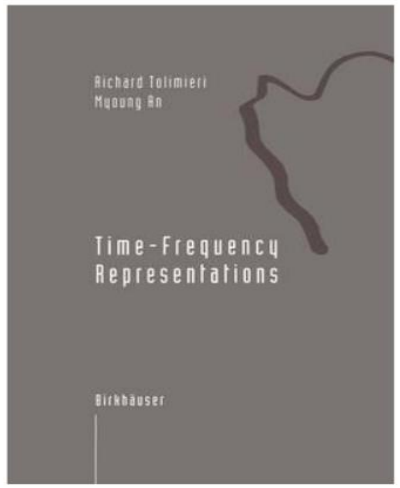


Time-Frequency Representations

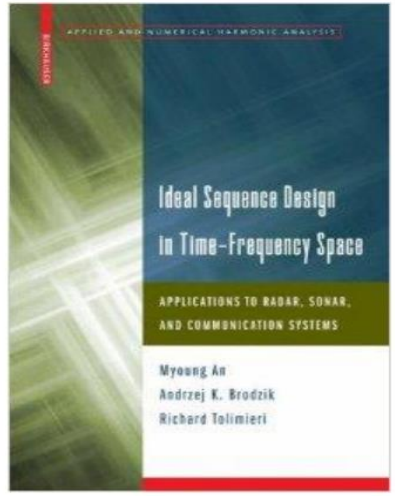


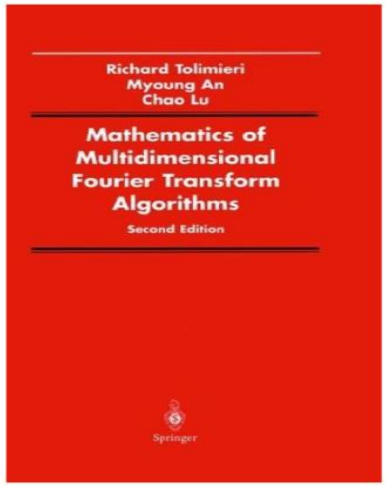
A Tutorial on Kronecker Products and FFTs

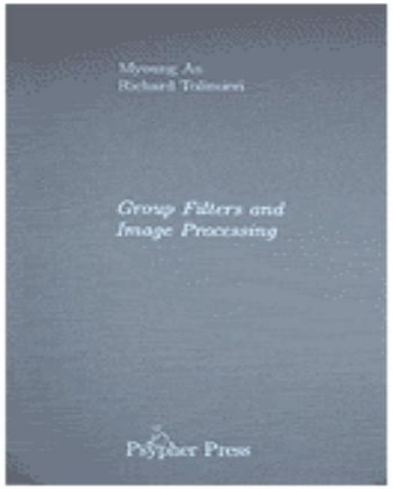
Richard Tolimieri: Principal Scientist at Prometheus Inc.



Richard Tolimieri

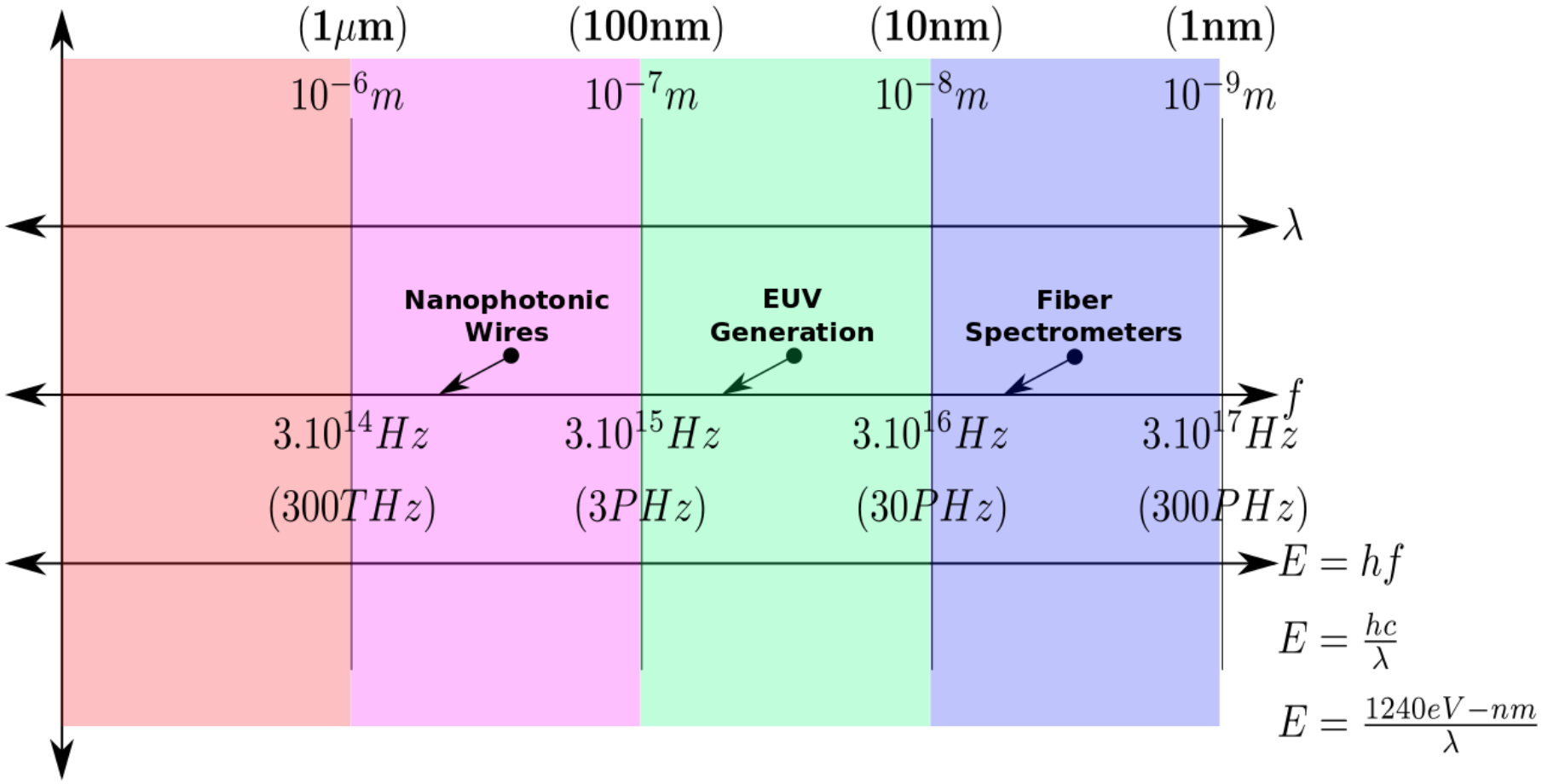






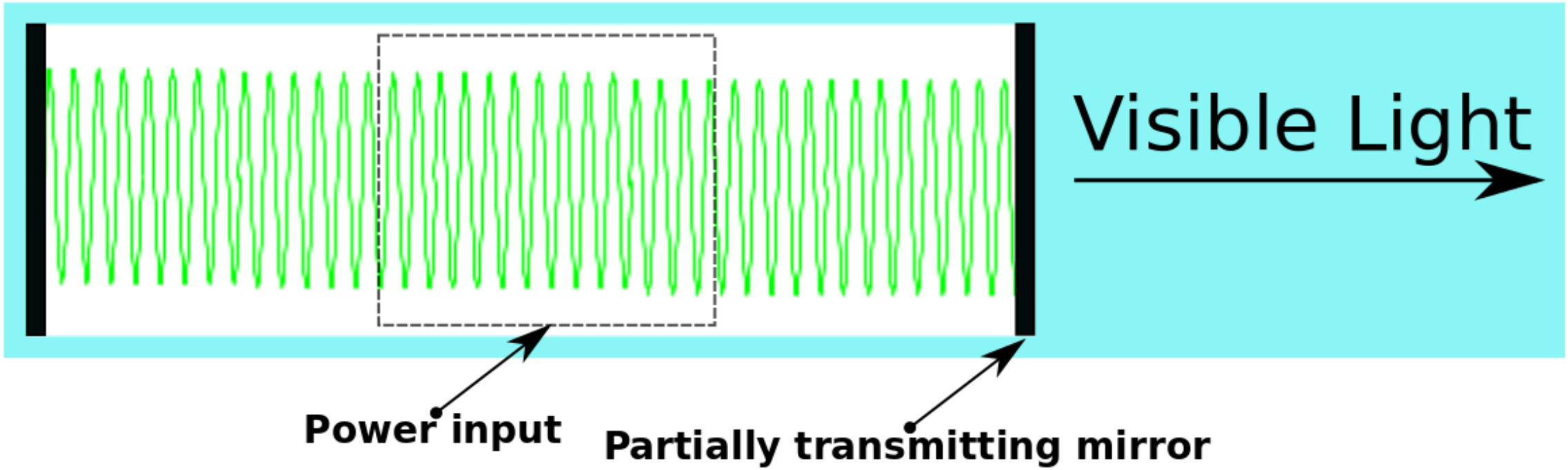
http://www.prometheus-us.com/Scientists/RichardTolimieri.html

Electromagnetic Spectrum (**sub-micrometer**)



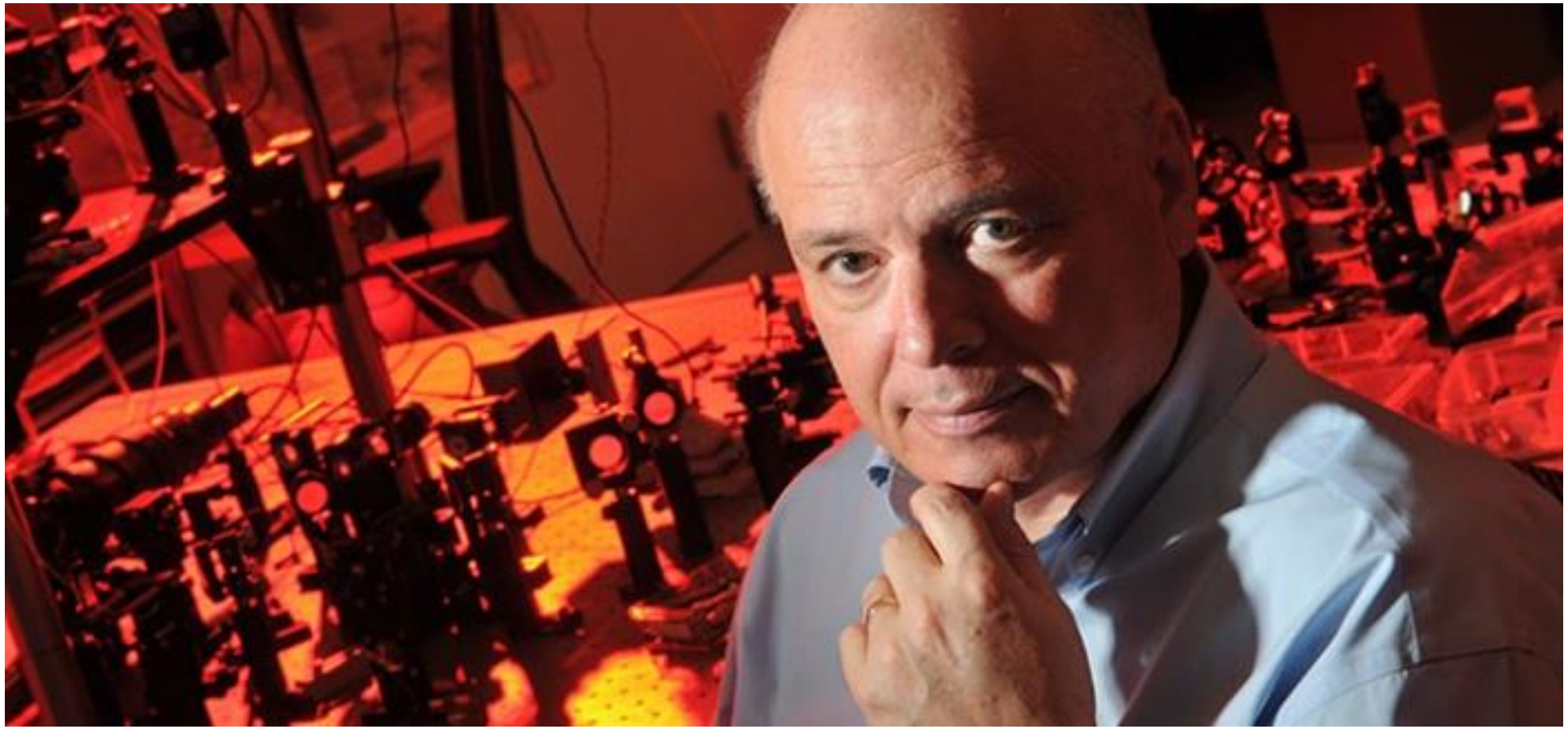
http://en.wikipedia.org/wiki/Electromagnetic_spectrum

Optical Communications



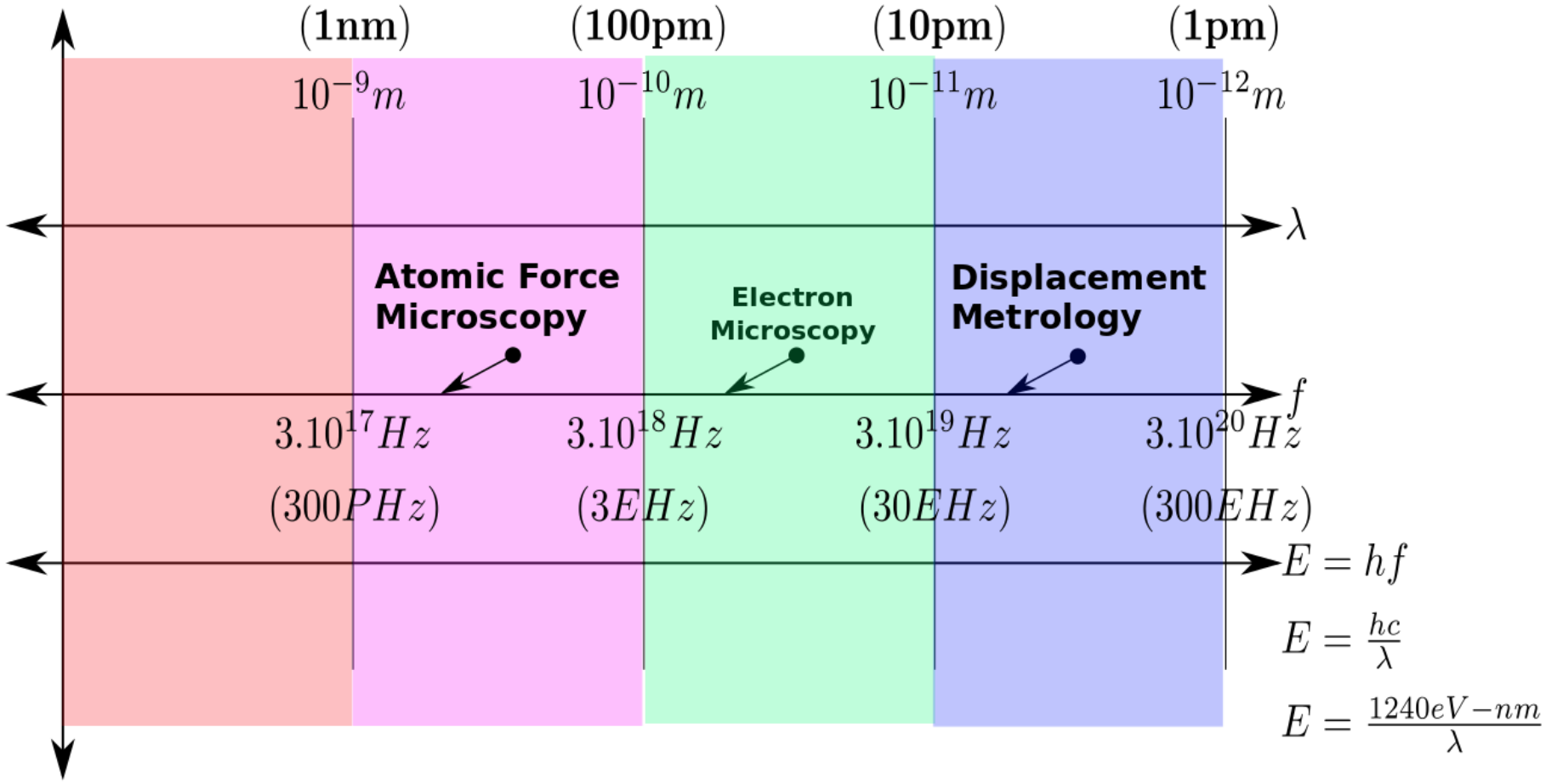
http://research.physics.illinois.edu/QI/Photonics/people/

Engineering Science & Technology at Stanford



http://engineering.stanford.edu/news/stanford-engineers-working-pack-more-laser-beams-data-fiber-optic-strands

Electromagnetic Spectrum (**sub-nanometer**)

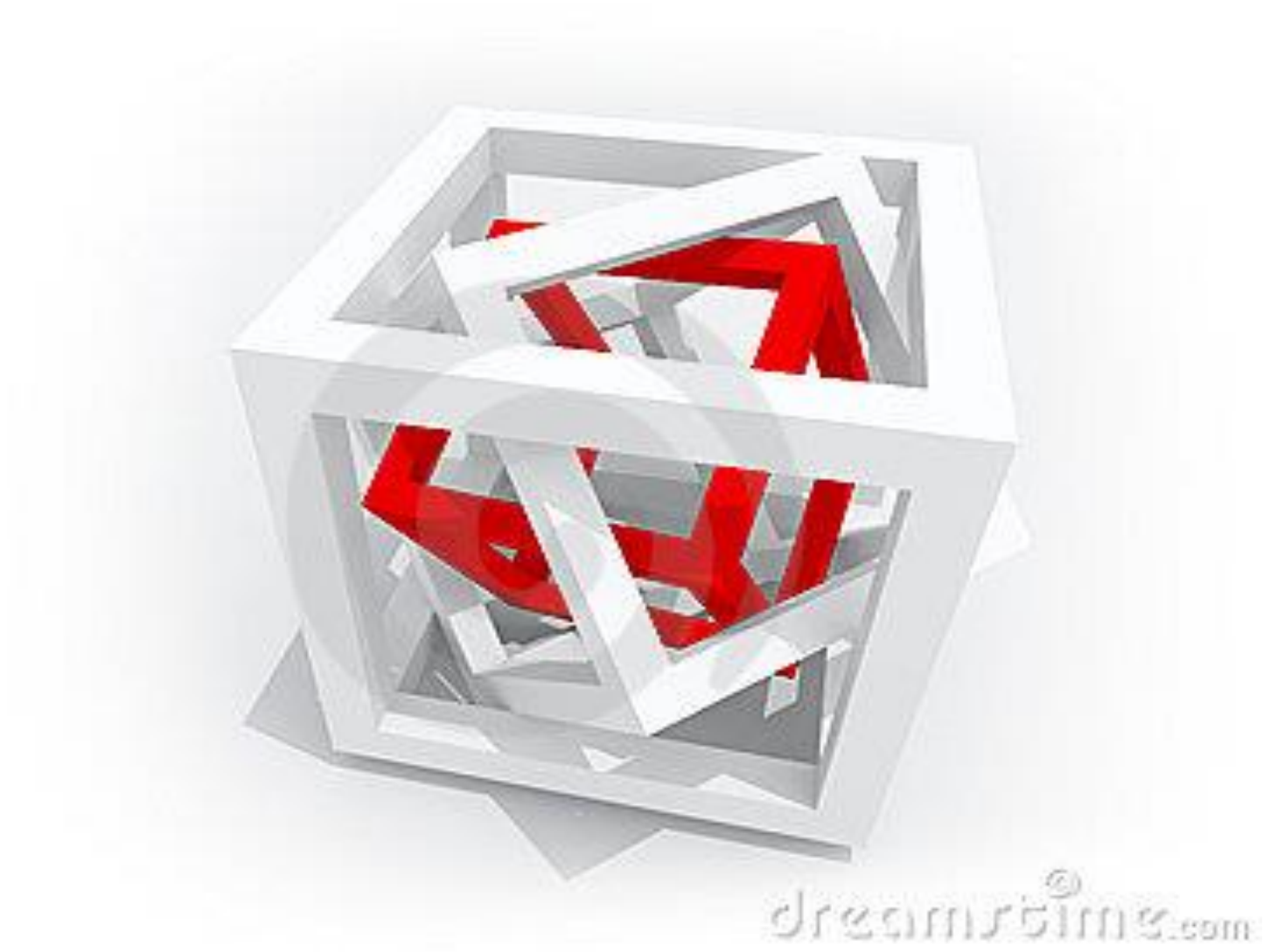


http://en.wikipedia.org/wiki/Electromagnetic_spectrum

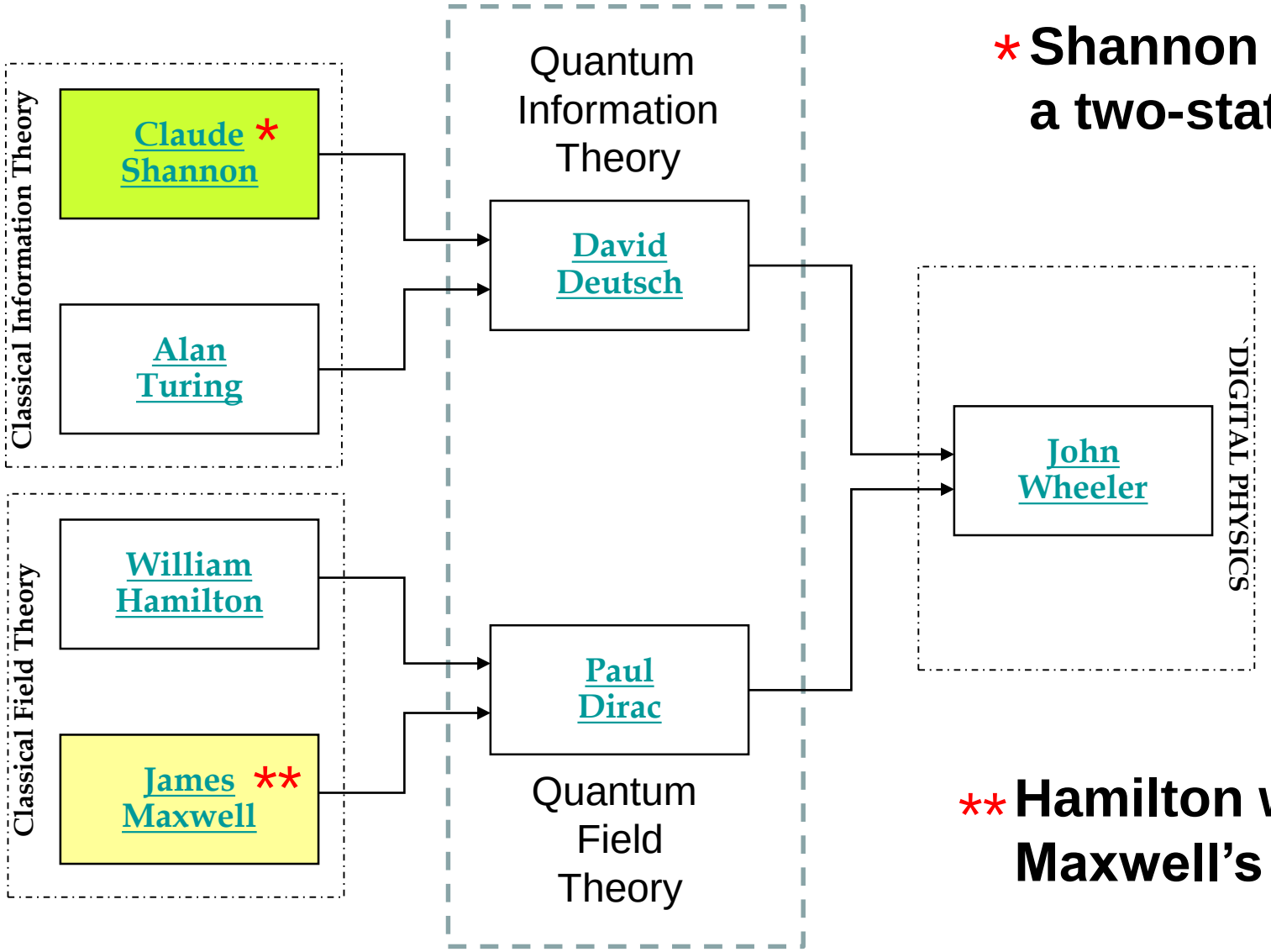
How small is a nanometer?

- 1 meter
- 10 μm – Size of red blood cell
- 1 μm – = a millionth of a meter
- 10 nm – Size of polio virus
- 1nanometer – = a billionth of a meter
- 0.1 nm – Size of the hydrogen atom
- 1 picometer – = a trillionth of a meter
- 1 femtometer – = 10^{-15} m, size of a proton

Extended Frameworks



Extended Frameworks: Communication & Computation



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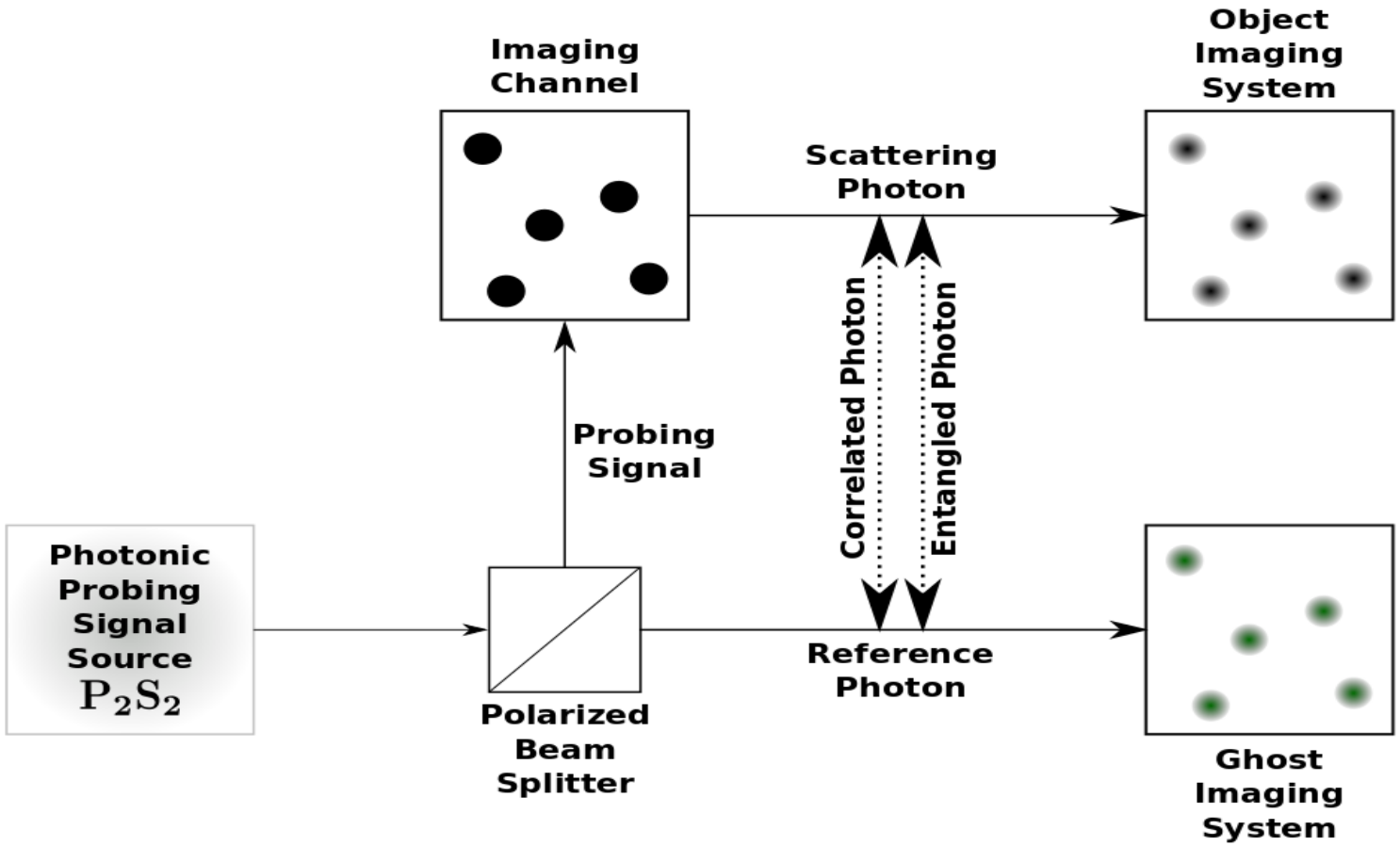
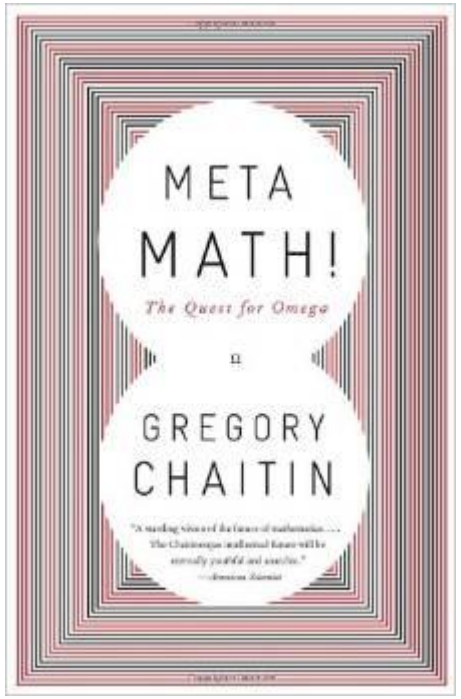
** Hamilton was Maxwell's tutor

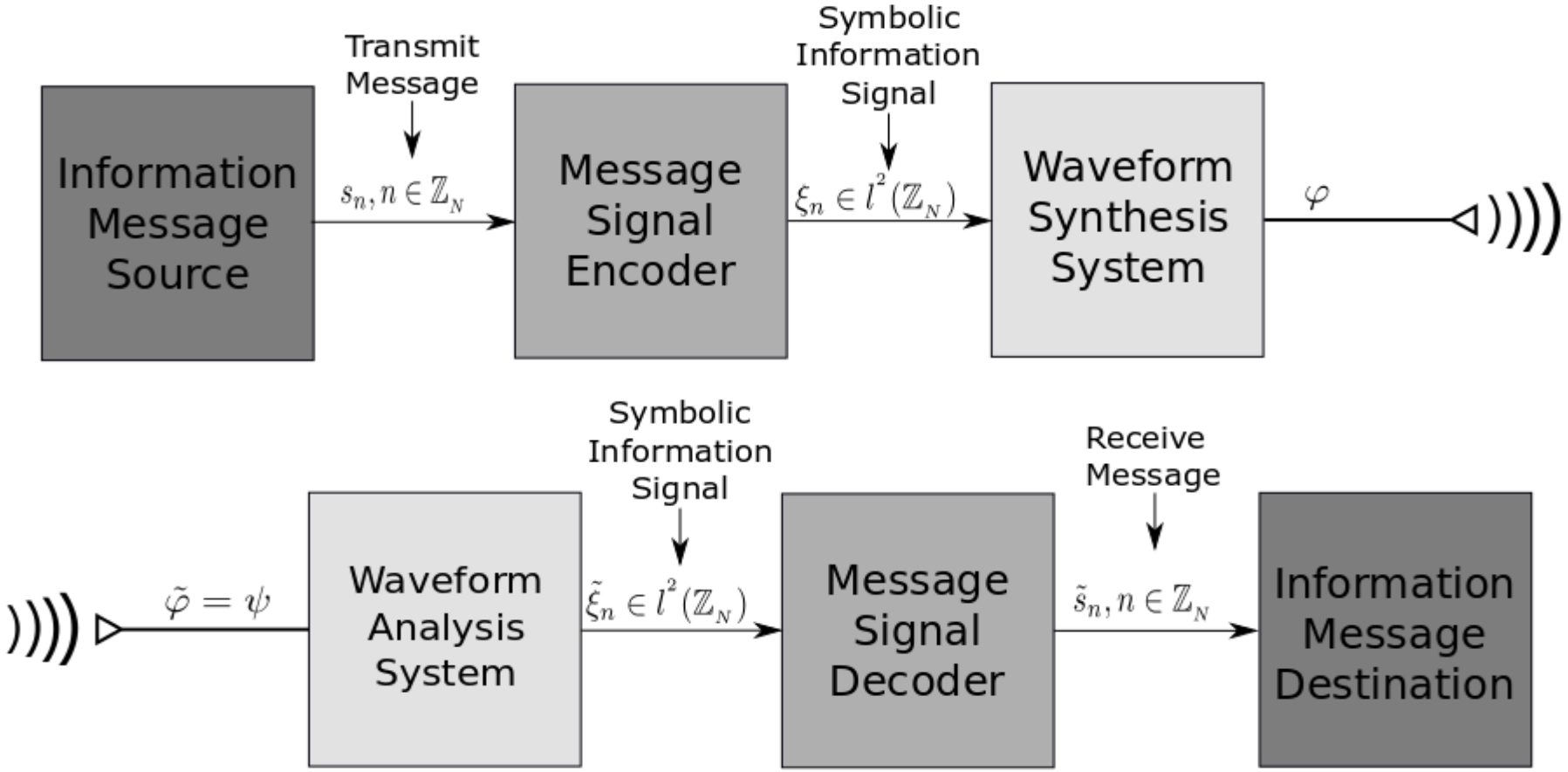
http://en.wikipedia.org/wiki/Digital_physics

Quantum Imaging: Communications Channel



Proposed Model of a Communication System





Algorithm Information Theory: it is "the result of putting Shannon's information theory and Turing's computability theory into a cocktail shaker and shaking vigorously."

http://en.wikipedia.org/wiki/Algorithmic_information_theory

Information – Processing – Automation

- **Information** is defined as any *distinguishable physical entity* conveyed from one point to another in *spacetime*.

- **Processing** is defined as a *sequence of operations* acting on a particular entity. An operation, in turn, is defined as a *functional action*; that is, an action with a purpose.

- **Automation**, as an engineering concept, is defined here as the design of *programmed techniques* to reduce human labor and other physical resources, while enhancing desired *distinguishable attributes* in a production process.

Automated Information Processing

- It is the study of theoretical and empirical aspects of *information carrying entities* termed **signals**.
- The **theoretical aspects** of AIP deal with the automated processing of abstract entities.
- The **empirical aspects** of AIP deal with the treatment of physical signals using *computational operator methods*.

"Innovation through Automation"

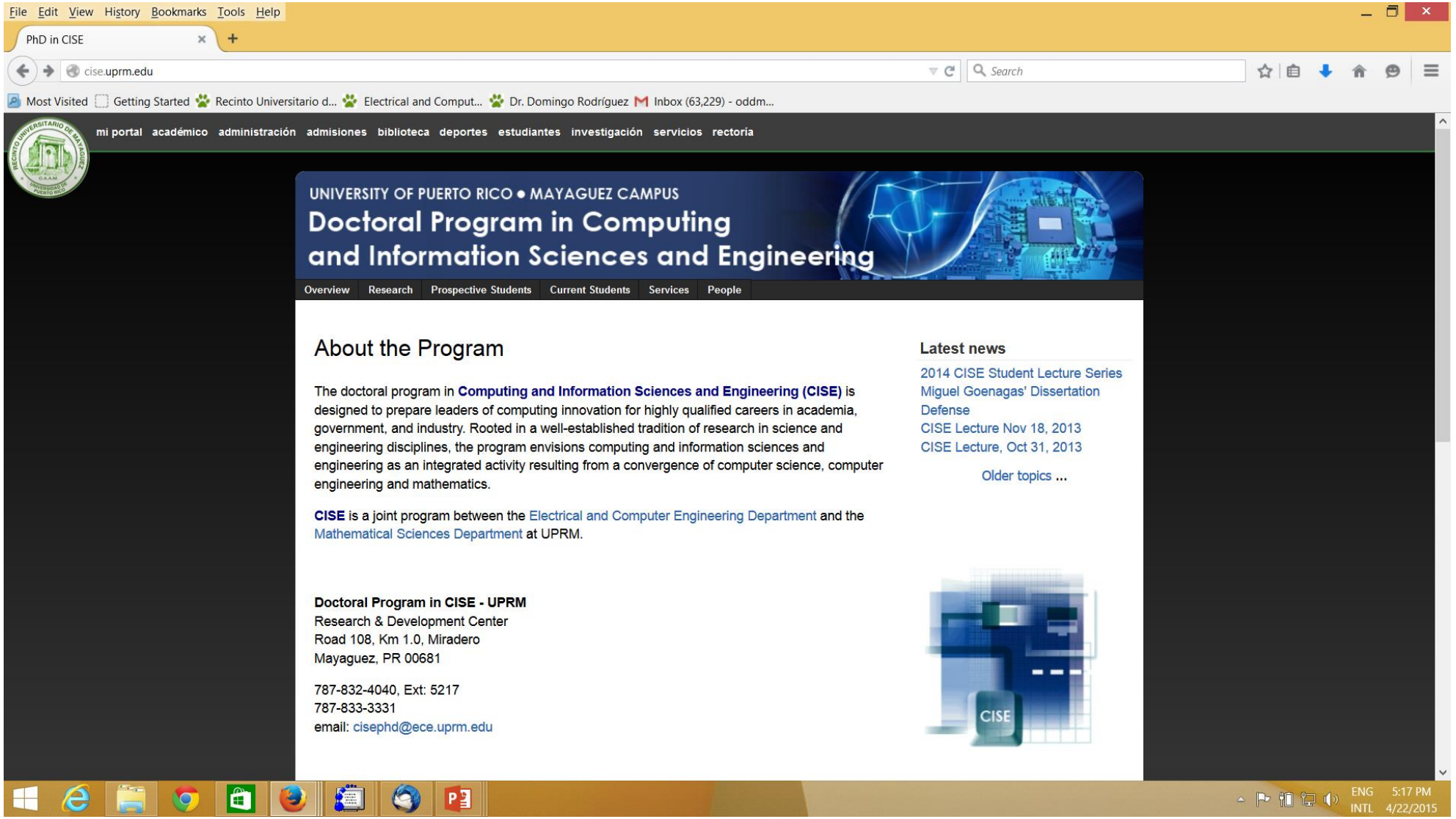
General Electric's Global Research Center - Niskayuna

GE Automation 2015: https://www.youtube.com/watch?v=wjmFrqyPnKc

GE Automation 1955: https://www.youtube.com/watch?v=Vp6eFGvVV8s

http://www.geglobalresearch.com/

CISE Doctoral Program at UPRM



Institute for Computing and Informatics Studies

Niccolò Machiavelli – The Prince… (1469-1527)

"It must be considered that there is nothing more difficult to carry out, nor more doubtful of success, nor more dangerous to handle, than to initiate a new order of things. For the reformer has enemies in all those who profit by the old order, and only lukewarm defenders in all those who would profit by the new order, this lukewarmness arising partly from fear of their adversaries, who have the laws in their favour; and partly from the incredulity of mankind, who do not truly believe in anything new until they have had the actual experience of it."

http://www.design.caltech.edu/erik/Misc/Machiavelli.html

Conclusions

- **Extended Scientific Frameworks**
  - **Quantum Information Theory**
    - **Universal Quantum Computer**
  - **Quantum Field Theory**
    - **Quantum Mechanics Principle of Least Action**
- **Challenges and Opportunities**
  - **Quantum Computation**
    - **Shor's Algorithm (Quantum FFT) & Grover's Algorithm (Quantum Search)**
  - **Quantum Communication**
    - **Quantum Cryptography & Quantum Ghost Imaging**

THANK YOU

DISCUSSION