

Beyond MAXWELL & SHANNON: An Engineering View



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Research & Development Center of UPRM
Elect. and Computer Engineering Dept

ICIS Presentation, April 23, 2015



Outline of the Presentation

◆ Introduction

◇ $Math_{fun}\{\text{Science} \longleftrightarrow \text{Engineering} \longleftrightarrow \text{Technology}\}$

◆ Scientific Frameworks: Beyond **Maxwell** & **Shannon**

◇ **Deutsch**: Quantum Information Theory

◇ **Dirac**: Quantum Field Theory

◆ Research Opportunities: **Classical Frameworks**

◇ Shannon's Information Theory

◇ Classical Computation Theory

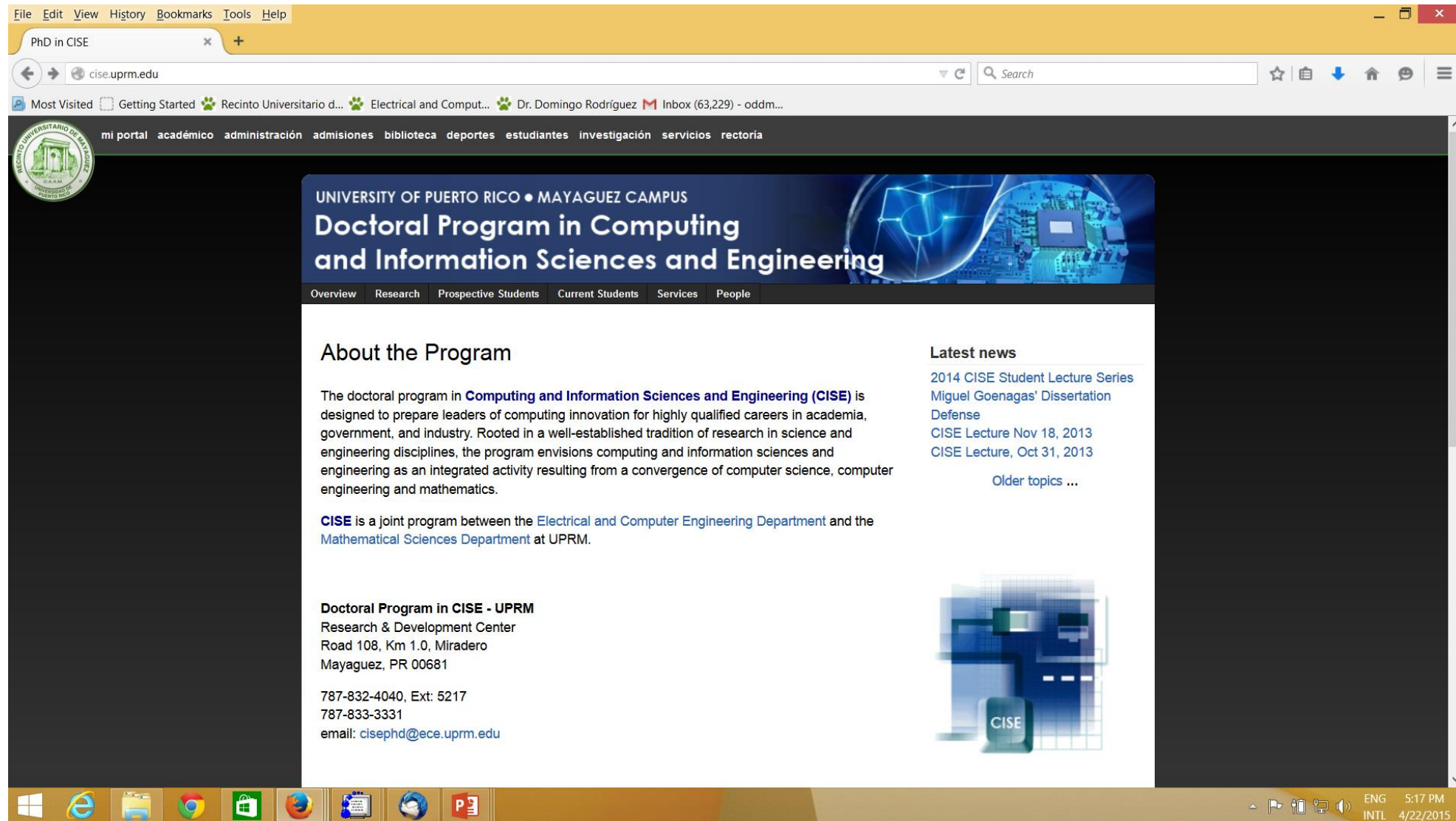
◆ Research Opportunities: **Extended Frameworks**

◇ **Chaitin**: Algorithmic Information Theory

◇ **Shor**: Quantum Fourier Transform

◆ Conclusions

CISE Doctoral Program at UPRM



The screenshot shows a web browser window displaying the website for the Doctoral Program in Computing and Information Sciences and Engineering (CISE) at the University of Puerto Rico, Mayaguez Campus. The browser's address bar shows the URL cise.uprm.edu. The website features a navigation menu with links such as 'mi portal', 'académico', 'administración', 'admisiones', 'biblioteca', 'deportes', 'estudiantes', 'investigación', and 'servicios rectoría'. The main content area is titled 'UNIVERSITY OF PUERTO RICO • MAYAGUEZ CAMPUS Doctoral Program in Computing and Information Sciences and Engineering'. Below the title is a navigation bar with links for 'Overview', 'Research', 'Prospective Students', 'Current Students', 'Services', and 'People'. The 'About the Program' section describes the program's goal to prepare leaders in computing innovation. The 'Latest news' section lists recent events, including a 2014 student lecture series and two CISE lectures. Contact information for the program is provided at the bottom left, and a CISE logo is shown at the bottom right. The Windows taskbar at the bottom of the browser window shows various application icons and system tray information, including the date 4/22/2015 and time 5:17 PM.

File Edit View History Bookmarks Tools Help

PhD in CISE

cise.uprm.edu

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UNIVERSITY OF PUERTO RICO • MAYAGUEZ CAMPUS
Doctoral Program in Computing and Information Sciences and Engineering

Overview Research Prospective Students Current Students Services People

About the Program

The doctoral program in **Computing and Information Sciences and Engineering (CISE)** is designed to prepare leaders of computing innovation for highly qualified careers in academia, government, and industry. Rooted in a well-established tradition of research in science and engineering disciplines, the program envisions computing and information sciences and engineering as an integrated activity resulting from a convergence of computer science, computer engineering and mathematics.

CISE is a joint program between the [Electrical and Computer Engineering Department](#) and the [Mathematical Sciences Department](#) at UPRM.

Doctoral Program in CISE - UPRM
Research & Development Center
Road 108, Km 1.0, Miradero
Mayaguez, PR 00681

787-832-4040, Ext: 5217
787-833-3331
email: cisephd@ece.uprm.edu

Latest news

[2014 CISE Student Lecture Series Miguel Goenagas' Dissertation Defense](#)
[CISE Lecture Nov 18, 2013](#)
[CISE Lecture, Oct 31, 2013](#)

[Older topics ...](#)

CISE

ENG 5:17 PM
INTL 4/22/2015

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.”

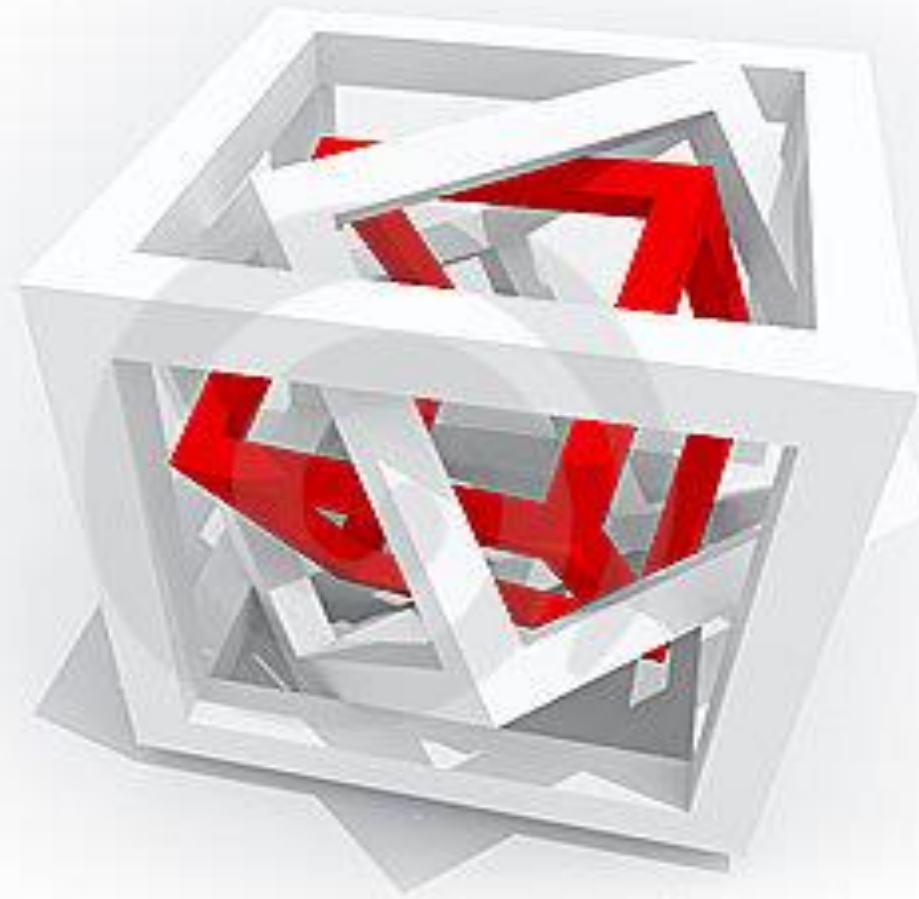
Sponsored Engineering Research at MIT

- ◆ “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

The screenshot shows a web browser window displaying the website for the Department of Engineering Science at the University of Auckland. The browser's address bar shows the URL www.des.auckland.ac.nz/en/about/ourresearch.html. The page header includes the university logo, navigation links like 'Questions? AskAuckland', and a search bar. The main content area is titled 'Department of Engineering Science' and 'Our research', featuring a paragraph about internationally renowned researchers and a list of research areas: Research overview, Bioengineering, Coastal and Marine Science, Fluid dynamics, Geothermal, reservoir engineering and environmental fluids, Intelligent cloud computing, Operations research, Signal processing, Solid mechanics, and Research projects available to students. The right sidebar contains 'INSTITUTES AND CENTRES' (Auckland Bioengineering Institute, Electric Power Optimisation Centre, Faculty of Engineering) and 'Connect with us' (Facebook, Twitter, YouTube). A red 'Apply now' button and a blue 'NZ's Next Top Eng. Scientist' button are also visible. The Windows taskbar at the bottom shows various application icons and the system clock indicating 8:28 AM on 4/22/2015.

Scientific Frameworks

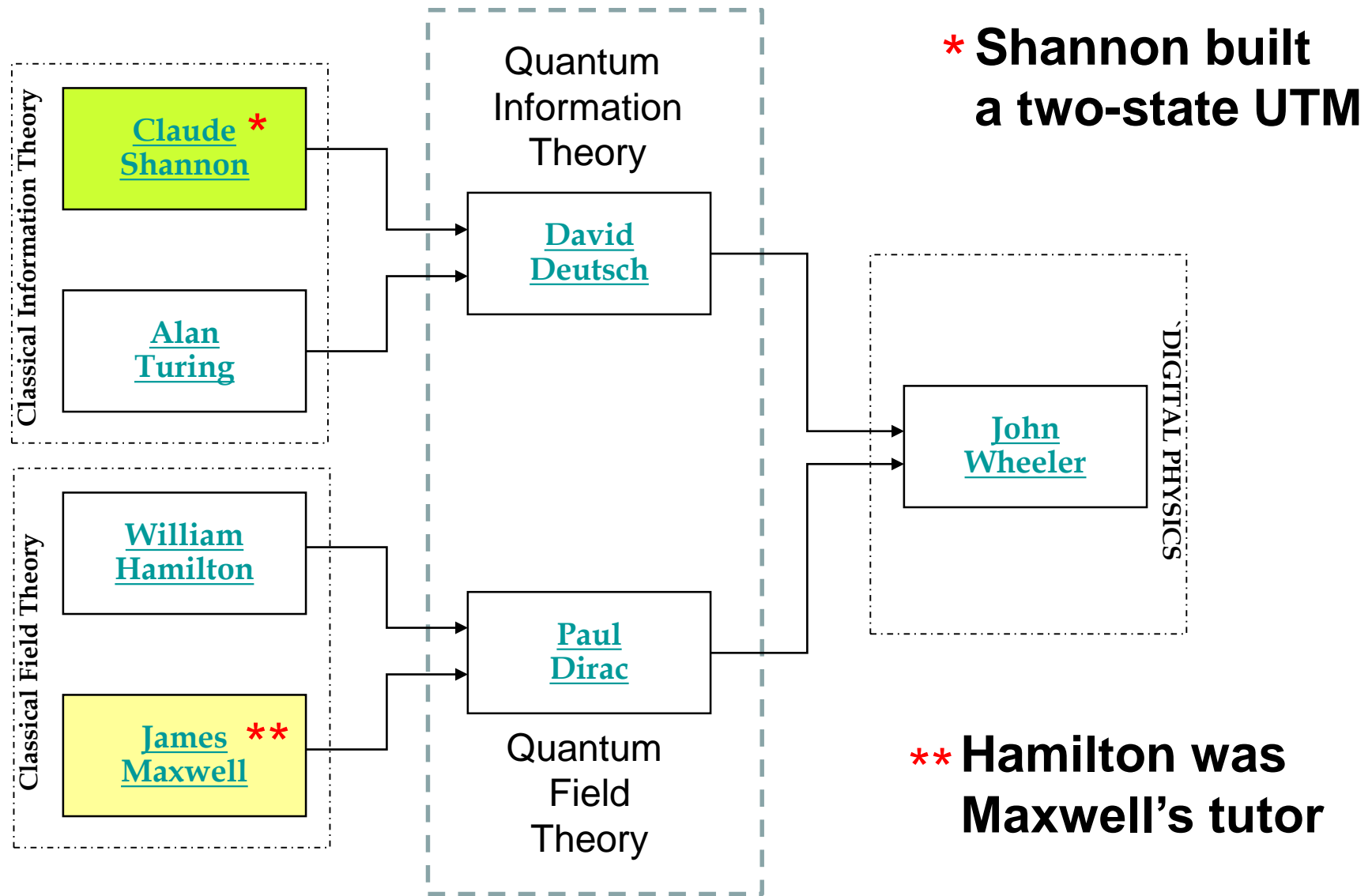


dreamstime.com

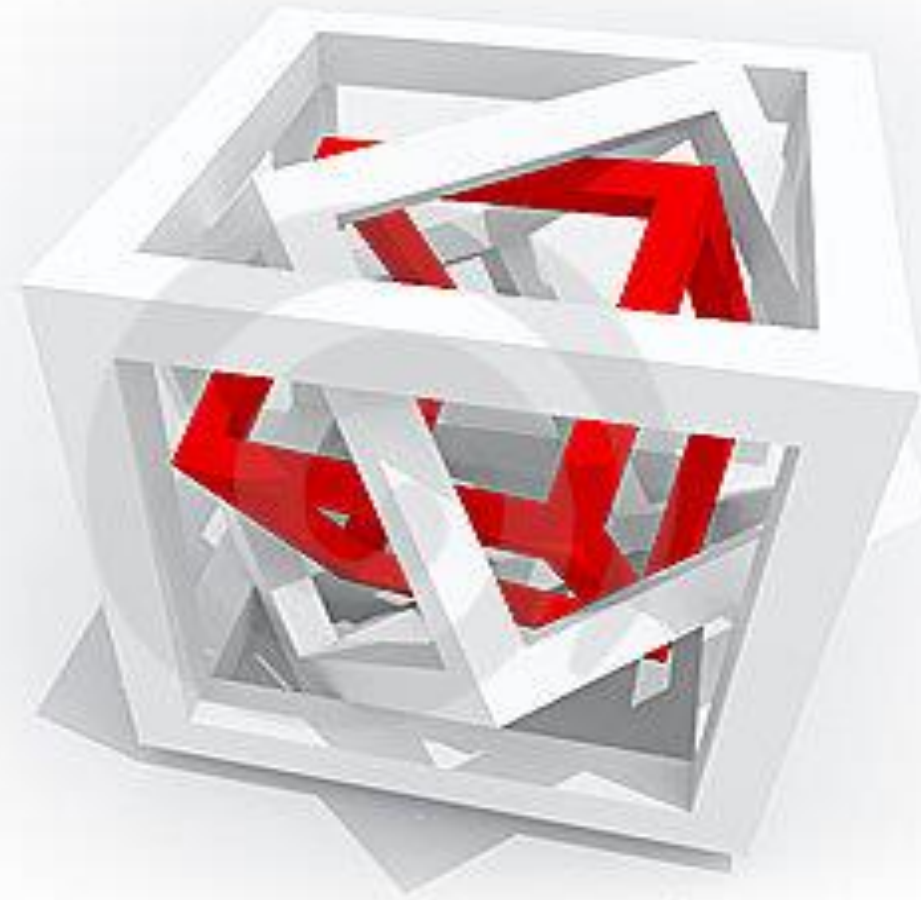
Traub's Modified Four Worlds of IBC

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

Scientific Frameworks: Communication & Computation

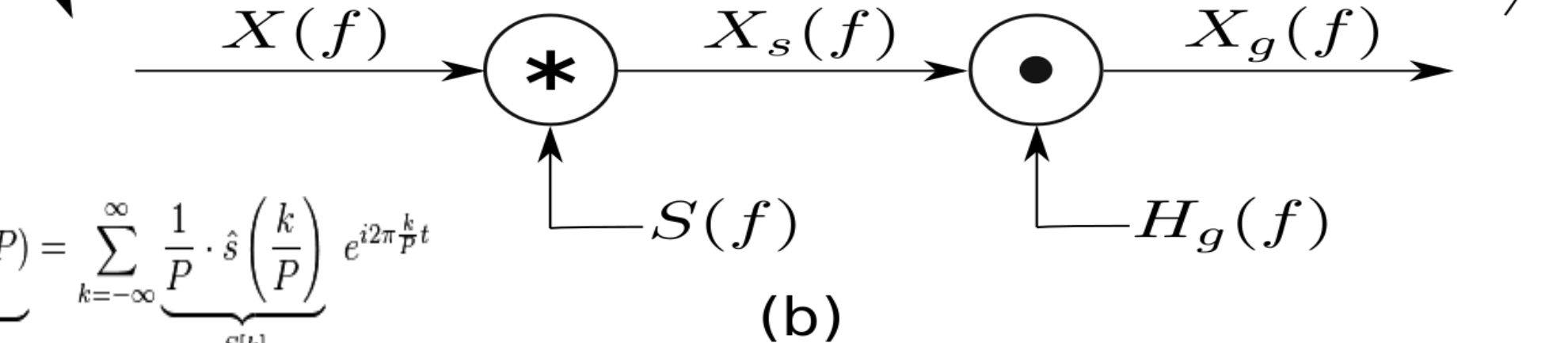
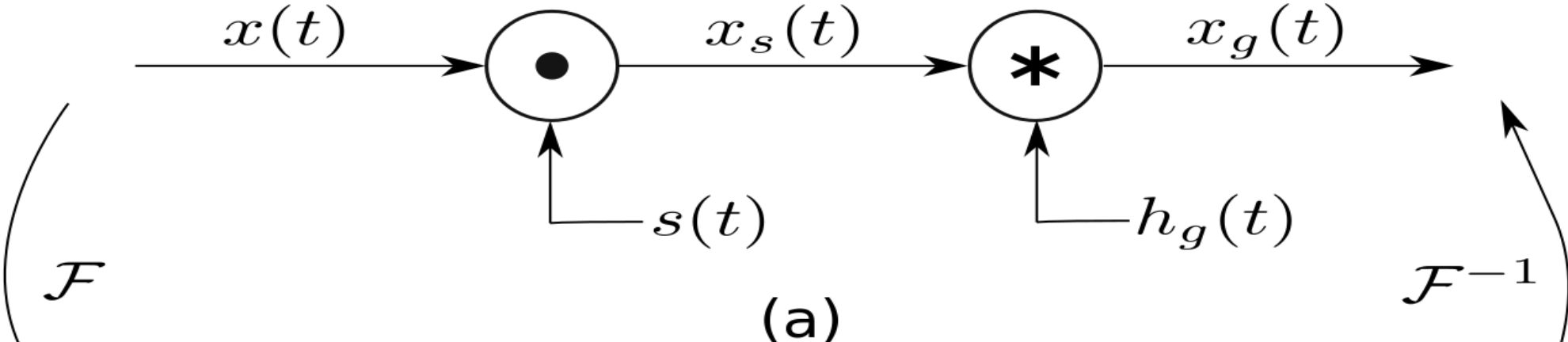


Classical Frameworks



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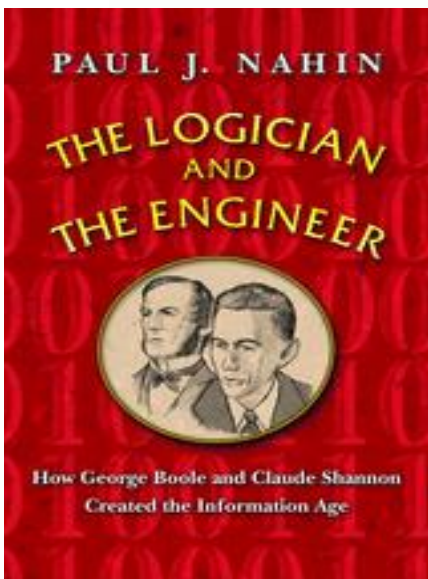
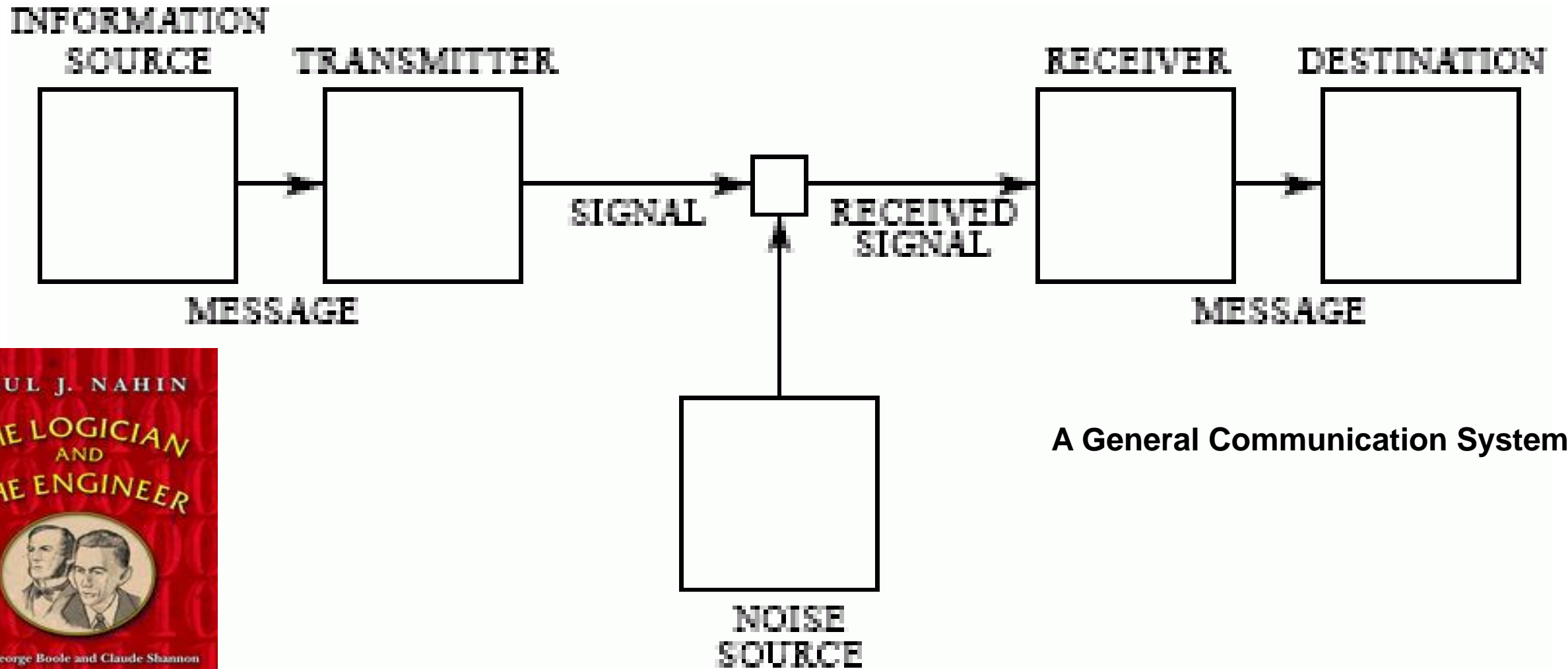
Poisson Summation & Time-Frequency Duality



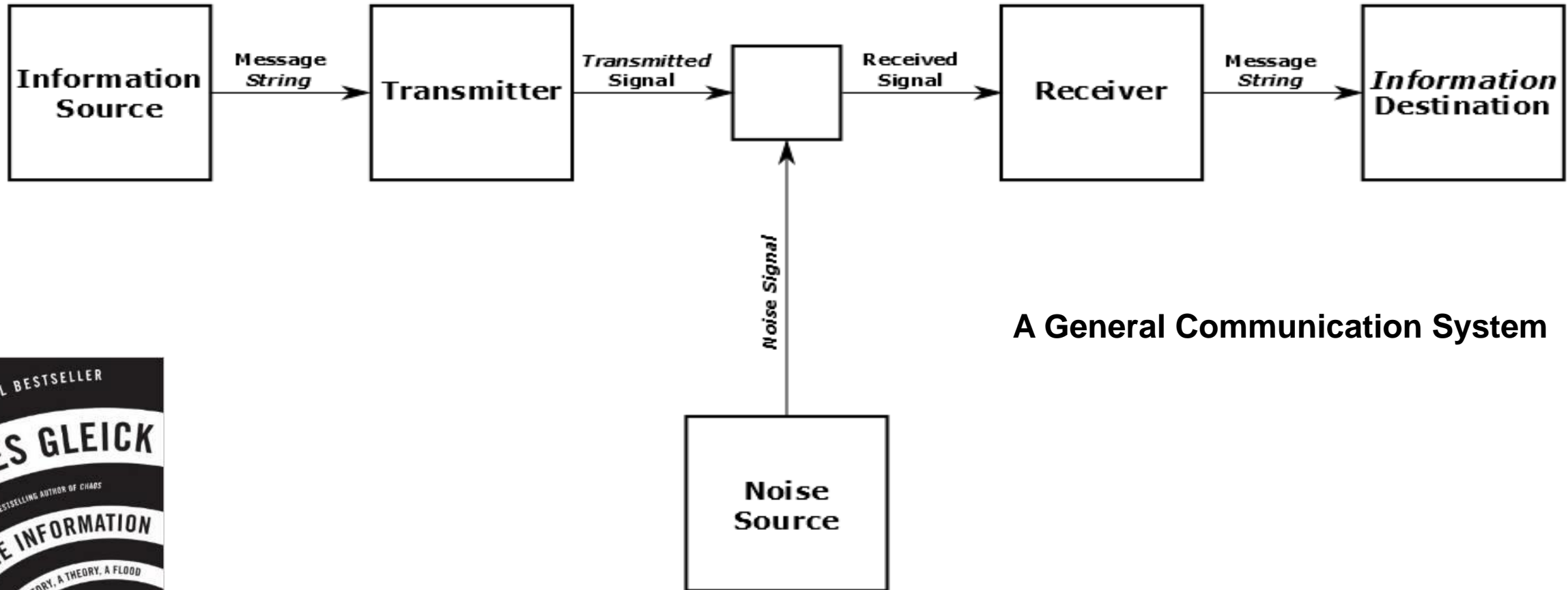
$$\underbrace{\sum_{n=-\infty}^{\infty} s(t + nP)}_{S_p(t)} = \sum_{k=-\infty}^{\infty} \underbrace{\frac{1}{P} \cdot \hat{s}\left(\frac{k}{P}\right)}_{S[k]} e^{i2\pi \frac{k}{P} t}$$

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

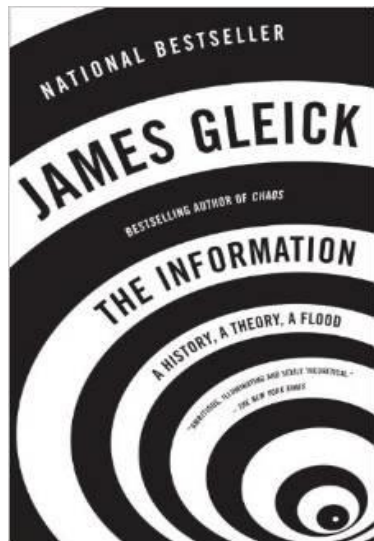
Shannon's Original Diagram (October 1948)



Shannon's Modified Diagram



A General Communication System



“The message is an algorithm”
James Gleick

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**.

SHANNON'S THEOREM: Noisy Channels

$$C = 2B \log_2(1 + (S/N))$$

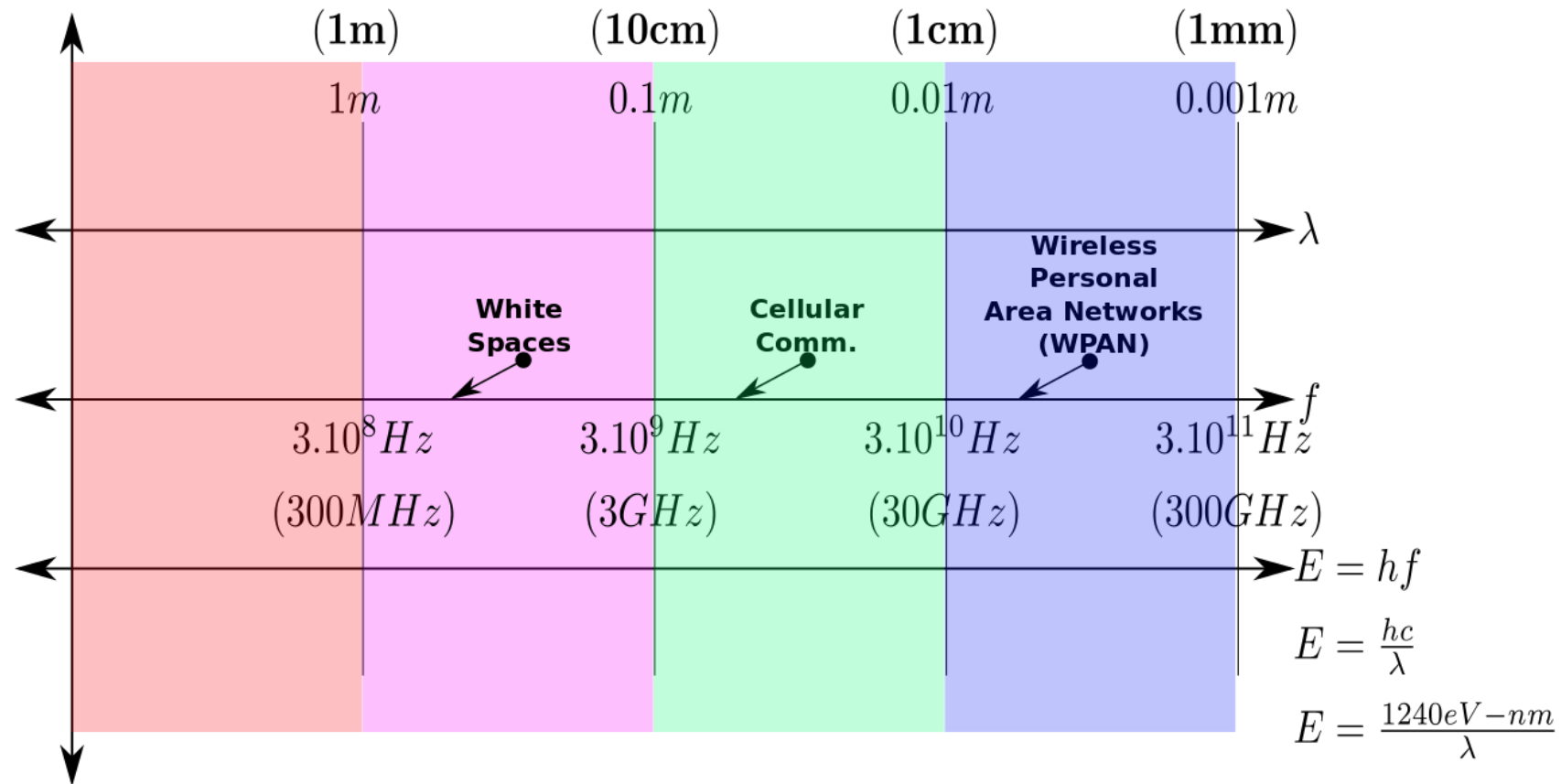
C : channel capacity (bps)

B = channel bandwidth

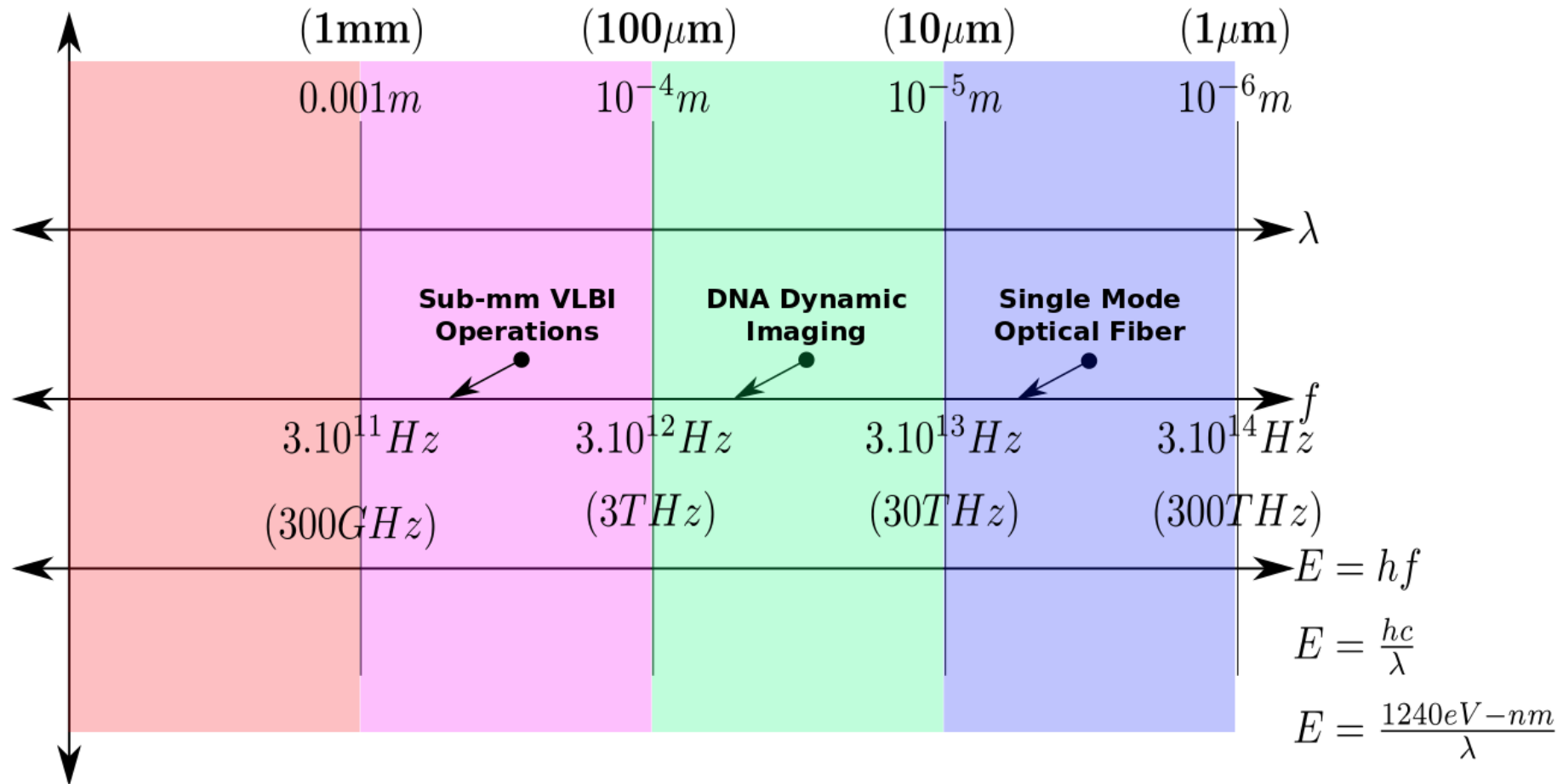
S/N : signal-to-noise ratio

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

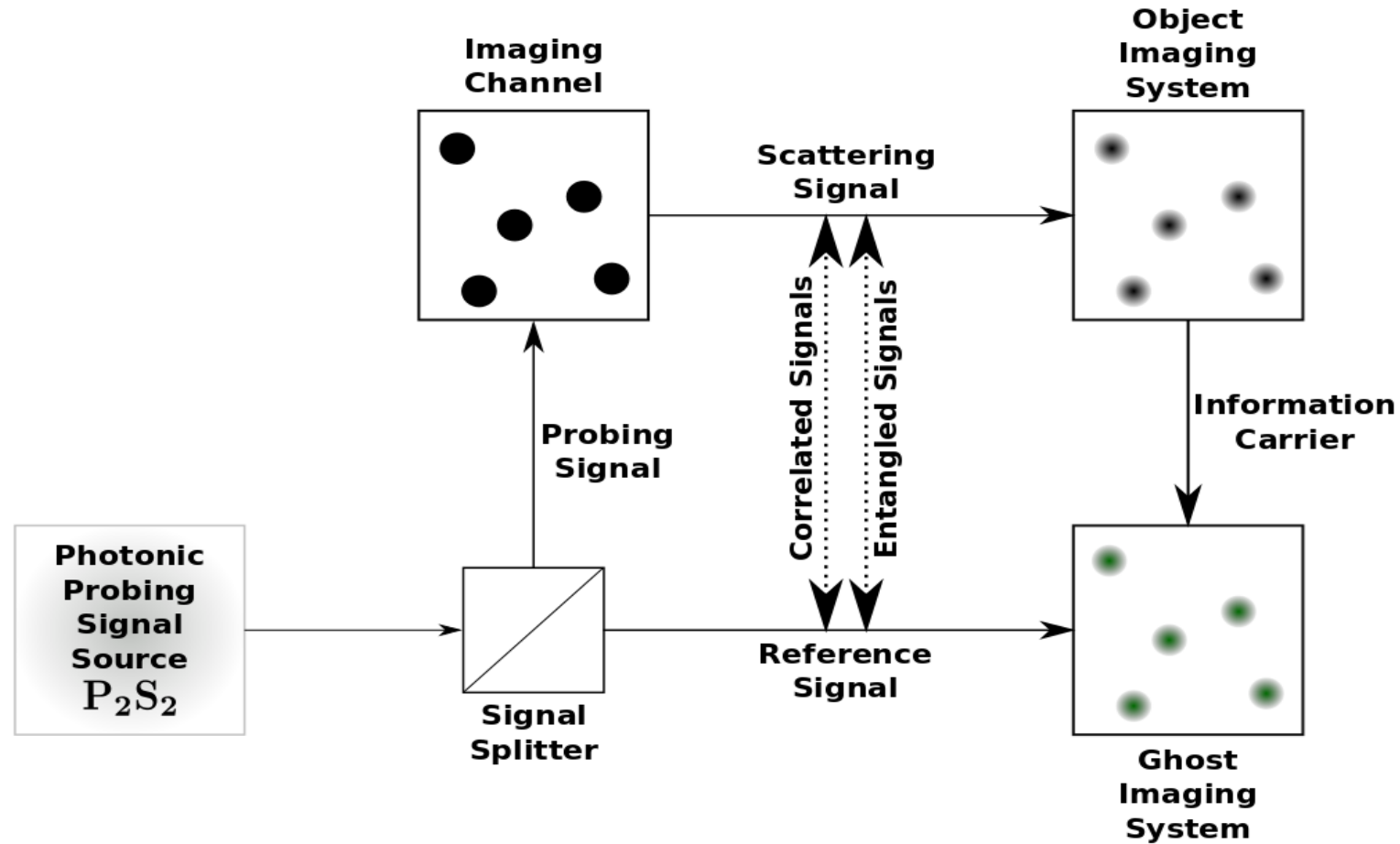
Electromagnetic Spectrum (sub-meter)



Electromagnetic Spectrum (sub-millimeter)



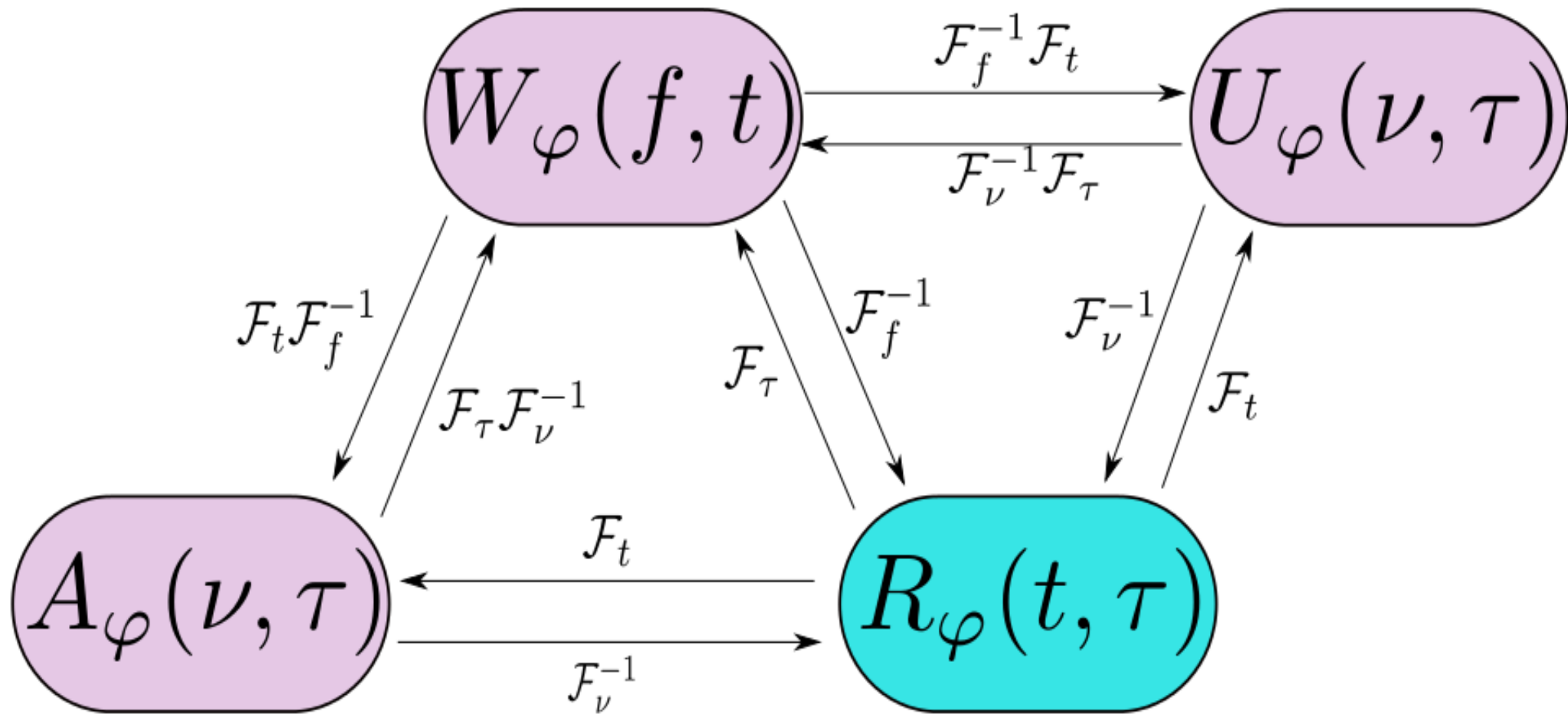
Classical Imaging: Communications Channel



Time-Frequency Operators

$$\varphi \rightarrow \mathcal{O}_{\{\tau, f\}} \rightarrow \psi_{\tau, f} = \mathcal{O}_{\{\tau, f\}} \{ \varphi \}$$

Time-Frequency Representations



A Tutorial on Kronecker Products and FFTs

link.springer.com/article/10.1007%2FBF01189337

Springer Link

Search

Circuits, Systems and Signal Processing
1990, Volume 9, Issue 4, pp 449-500

A methodology for designing, modifying, and implementing Fourier transform algorithms on various architectures

J. R. Johnson, R. W. Johnson, D. Rodriguez, R. Tolimieri

link.springer.com/article/10.1007/BF01189337/lookinside/000.png

A METHODOLOGY FOR DESIGNING, MODIFYING, AND IMPLEMENTING FOURIER TRANSFORM ALGORITHMS ON VARIOUS ARCHITECTURES*
J. R. Johnson,¹ R. W. Johnson,² D. Rodriguez,³ and R. Tolimieri⁴

Abstract. Fourier transform algorithms are described using tensor (Kronecker) products and an associated class of permutations. Algebraic properties of tensor products and the related permutations are used to derive variants of the Cooley-Tukey fast Fourier transform algorithm. These algorithms can be implemented by translating tensor products and permutations to programming constructs. An implementation can be studied in a representative system. This method, AT&T DSP32.

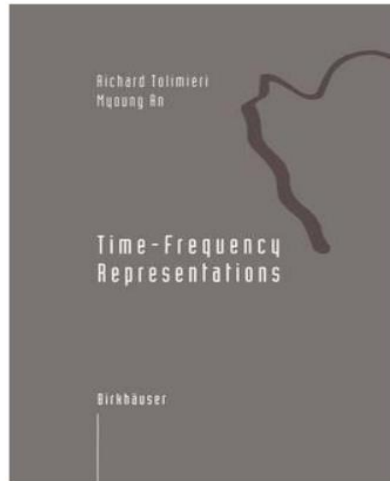
1. Introduction
Shortly after Cooley and Tukey's work on the fast Fourier transform was created and this work was some a method of obtaining variations was conjectured (in production year Pean [13] introduced an introduction to Pean's paper. The formulation was a valuable tool was not taken up at this time due to the great success of the "butterfly" as a teaching and programming device.

* Received June 1989; revised November 30, 1989. This work was performed at the Center for Large Scale Computation, Suite 400, 21 West 43rd Street, New York, New York 10018, USA, and was supported by a grant from DARPA, DC-89-0017.
¹ Department of Computer and Information Science, The Ohio State University, Columbus, Ohio 43210, USA.
² Department of Computer Science, The Graduate School and University Center of the City University of New York, New York, New York 10016, USA.
³ Department of Electrical Engineering, The City College of New York, New York, New York 10031, USA.

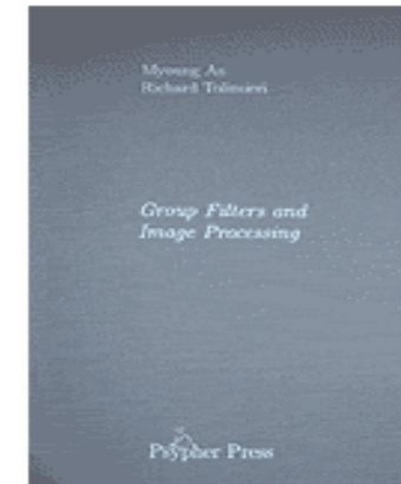
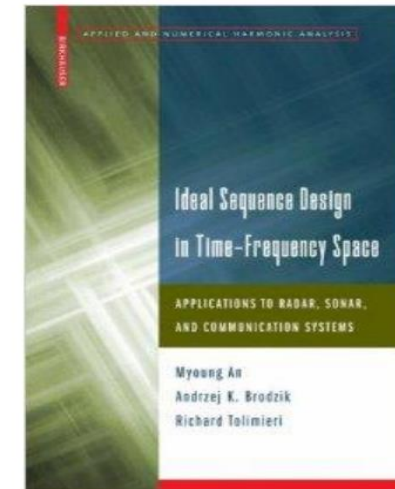
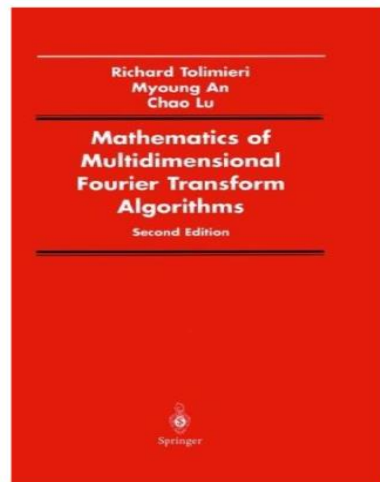
Look Inside

15 Citations

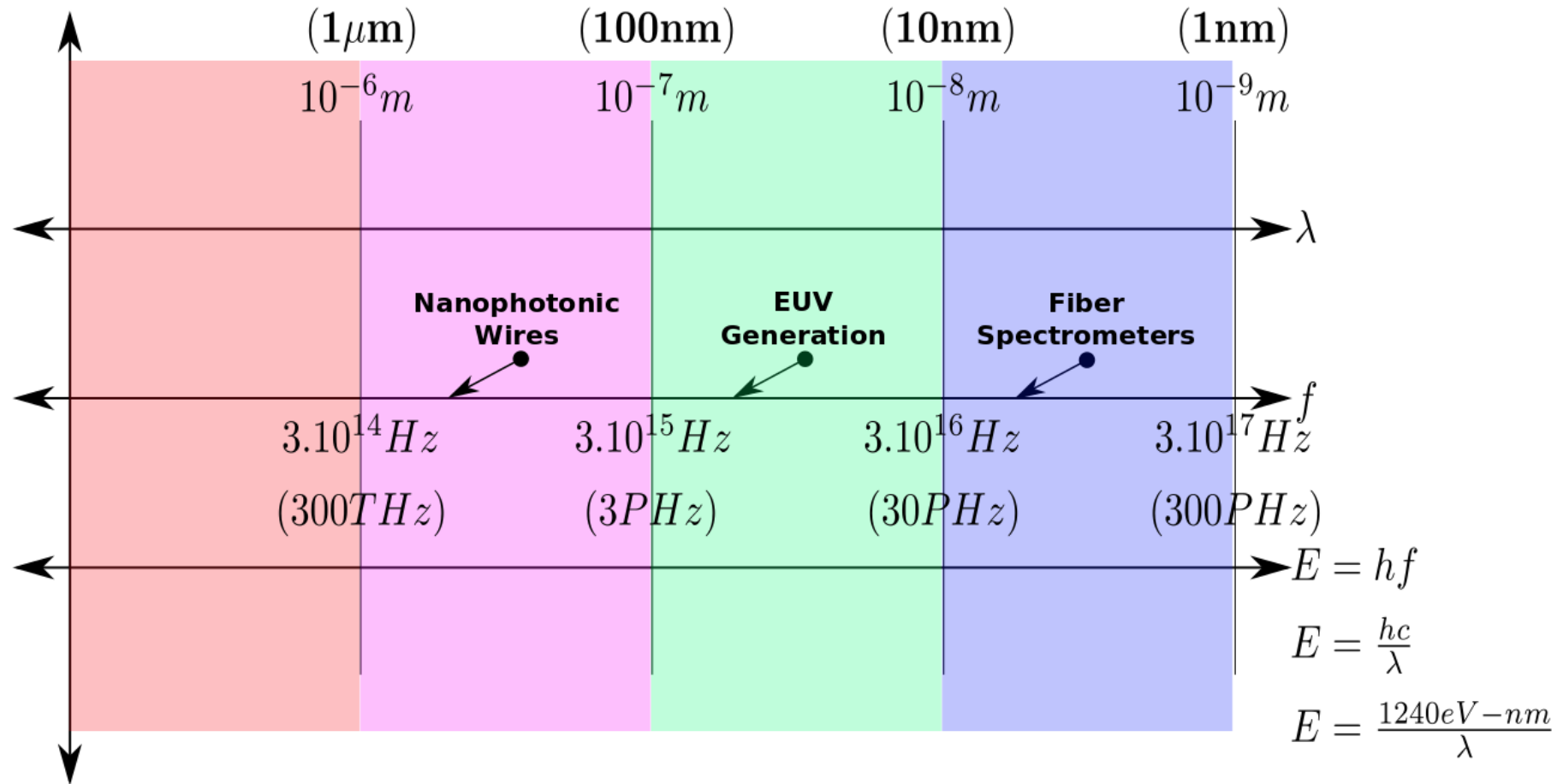
Richard Tolimieri: Principal Scientist at Prometheus Inc.



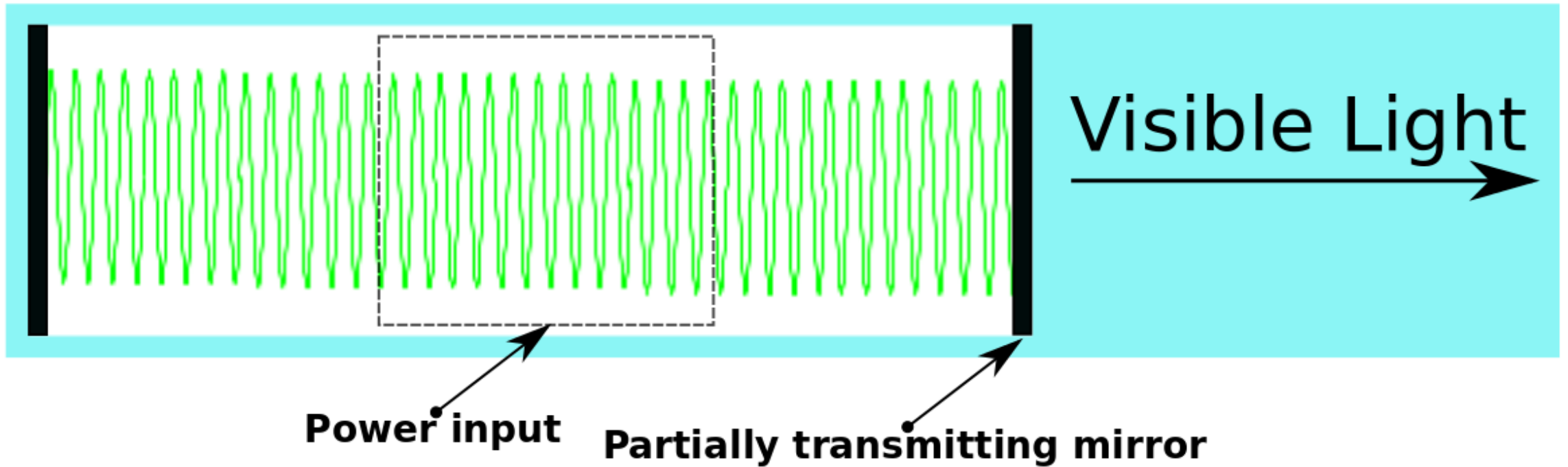
Richard Tolimieri



Electromagnetic Spectrum (sub-micrometer)



Optical Communications

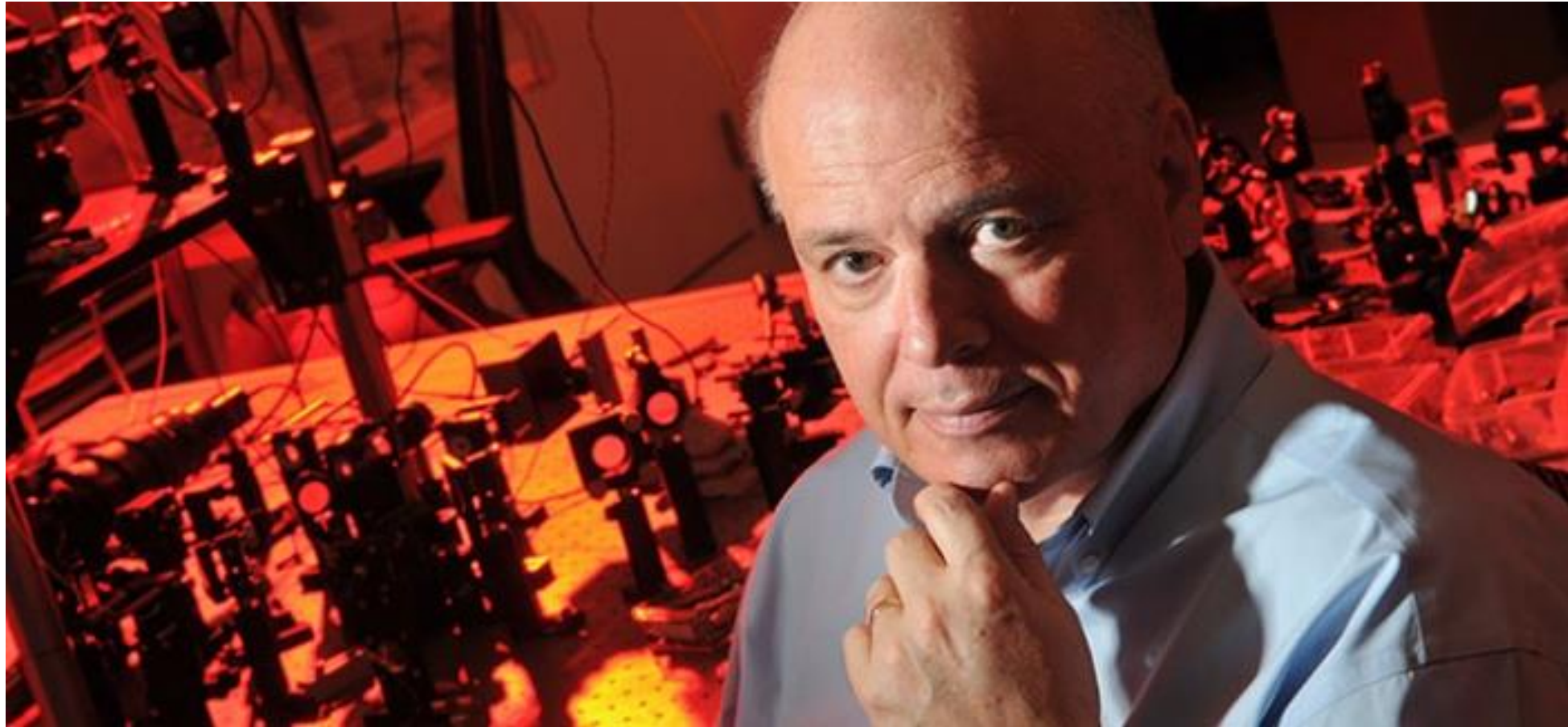


Power input

Partially transmitting mirror

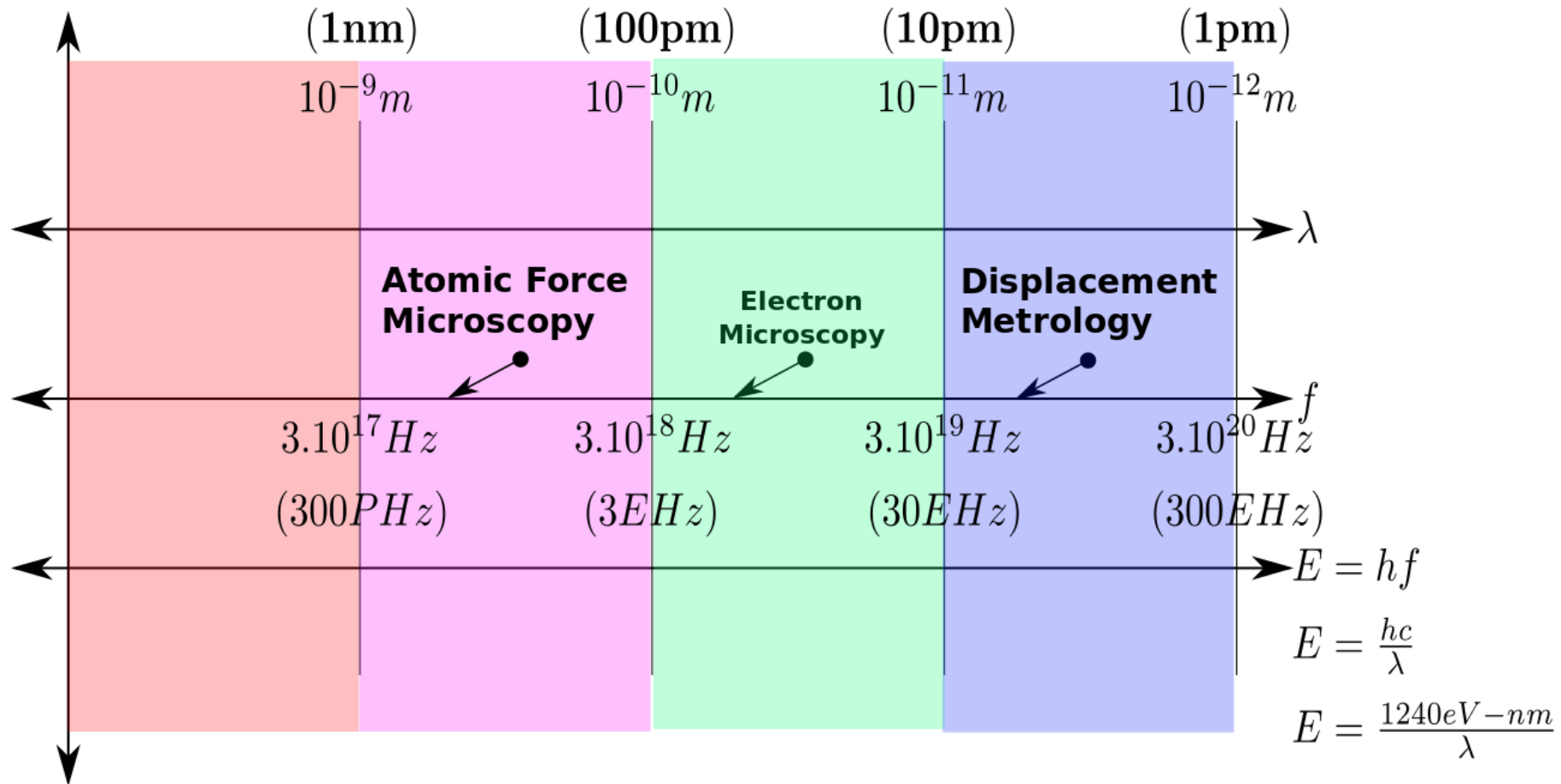
Visible Light

Engineering Science & Technology at Stanford



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

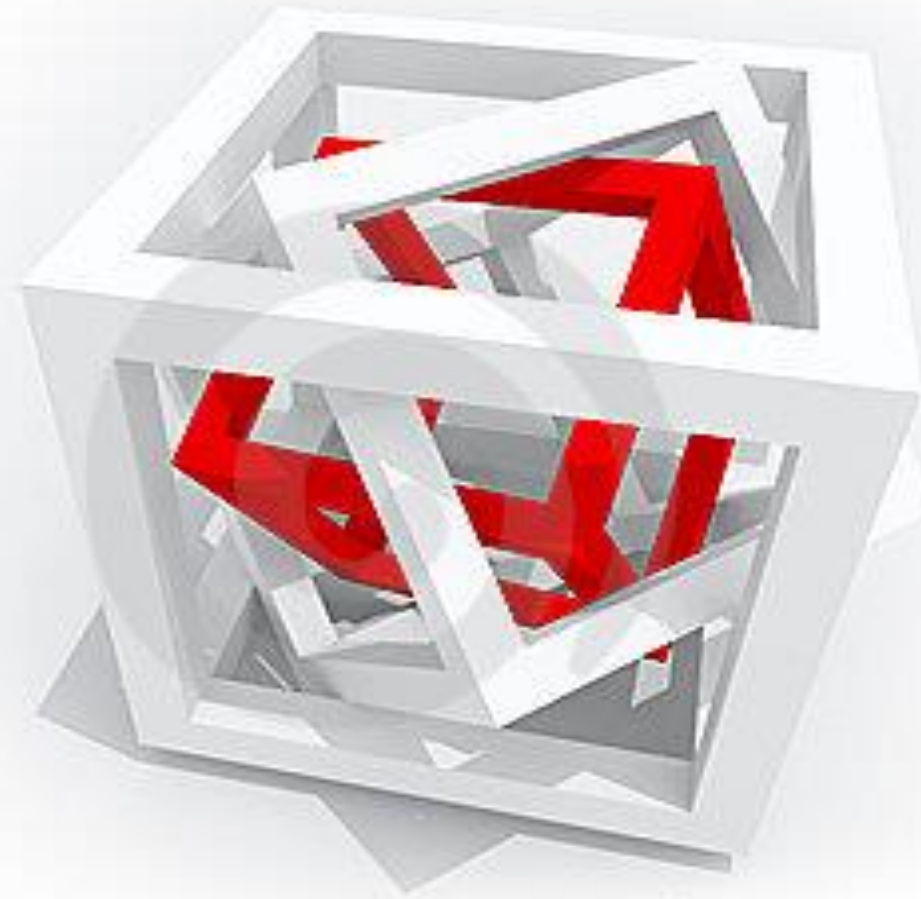
Electromagnetic Spectrum (sub-nanometer)



How small is a nanometer?

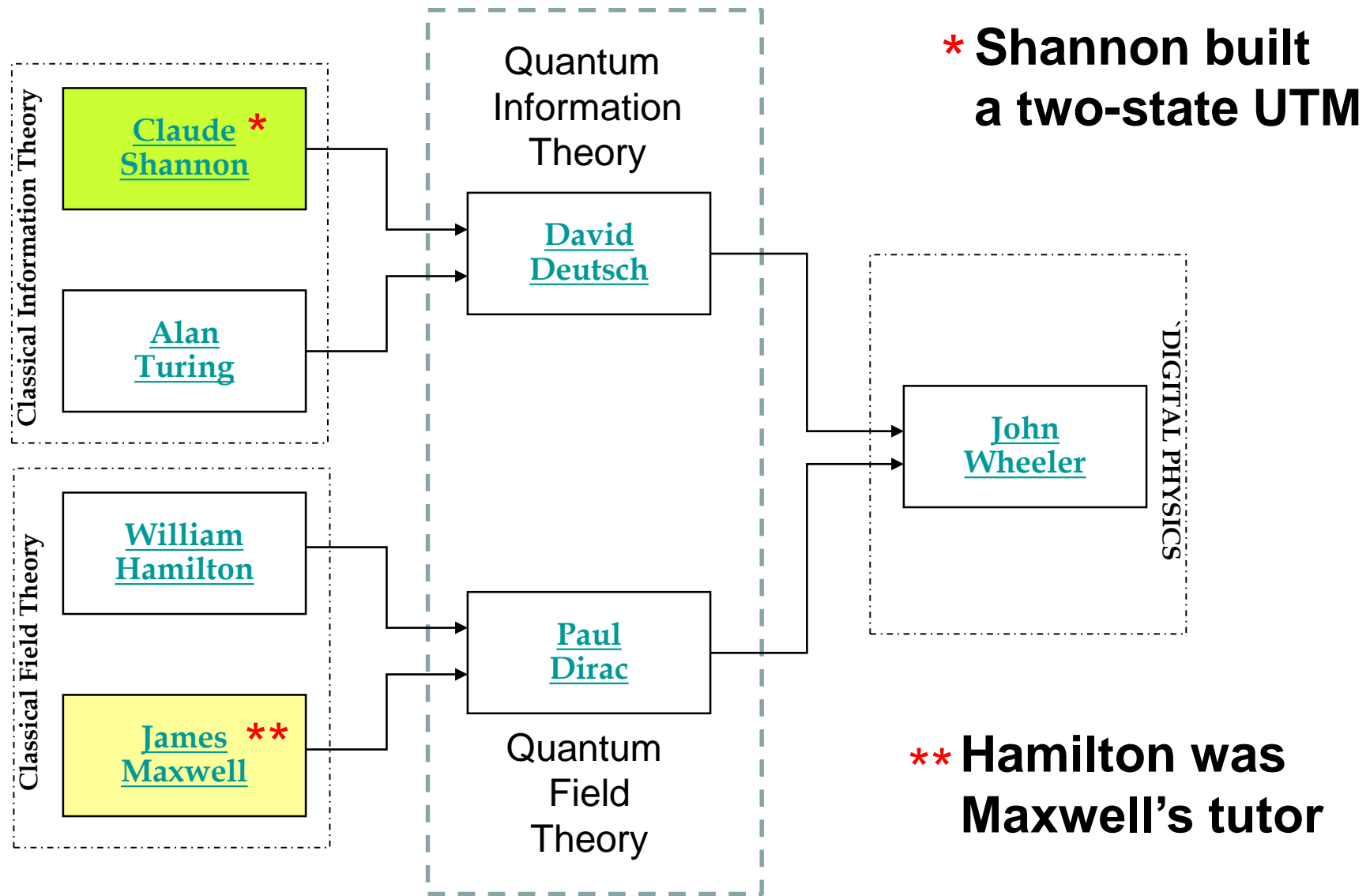
- ◆ 1 meter
- ◆ 10 μm – Size of red blood cell
- ◆ 1 μm – = a millionth of a meter
- ◆ 10 nm – Size of polio virus
- ◆ 1 nanometer – = a billionth of a meter
- ◆ 0.1 nm – Size of the hydrogen atom
- ◆ 1 picometer – = a trillionth of a meter
- ◆ 1 femtometer – = 10^{-15} m, size of a proton

Extended Frameworks

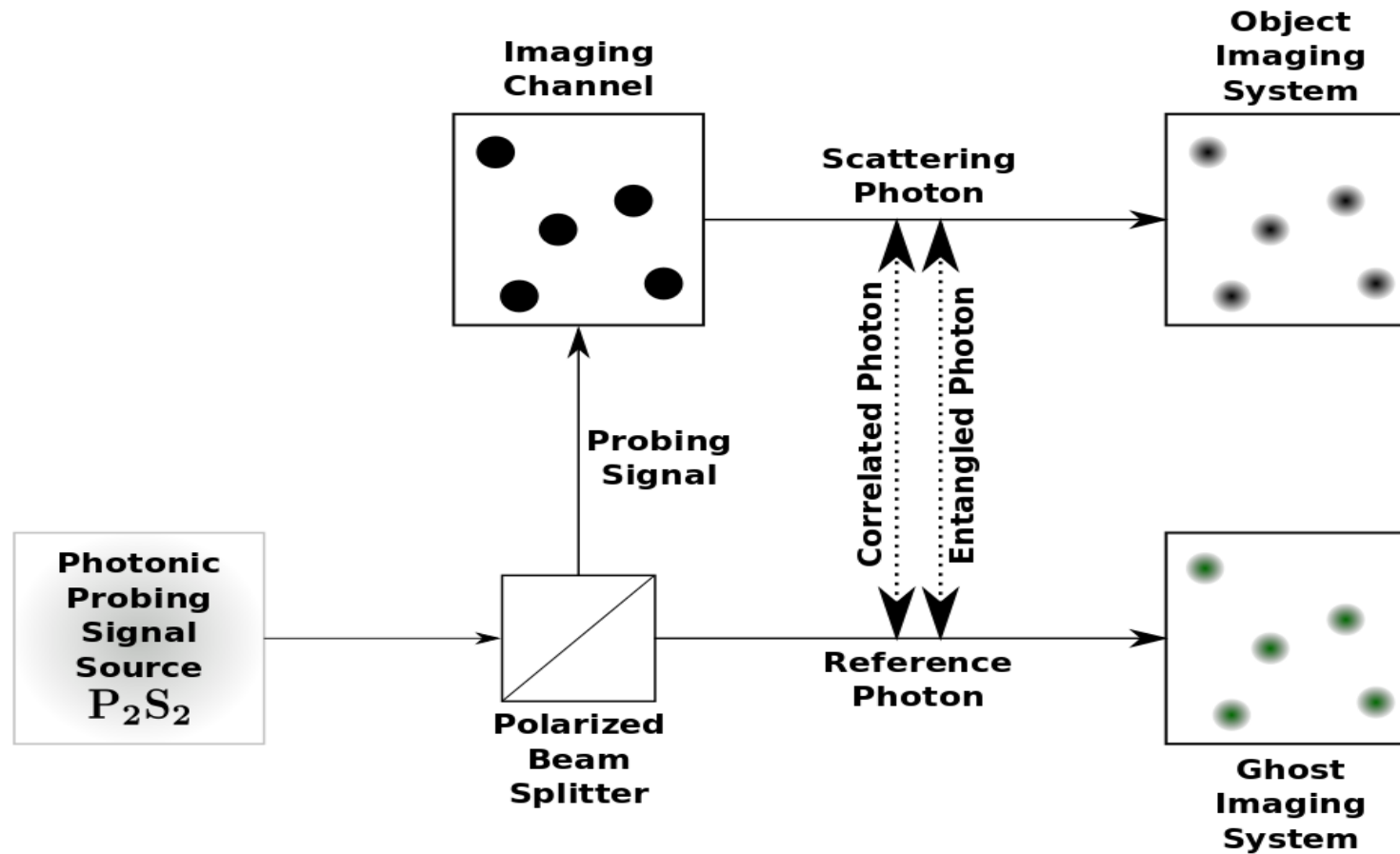


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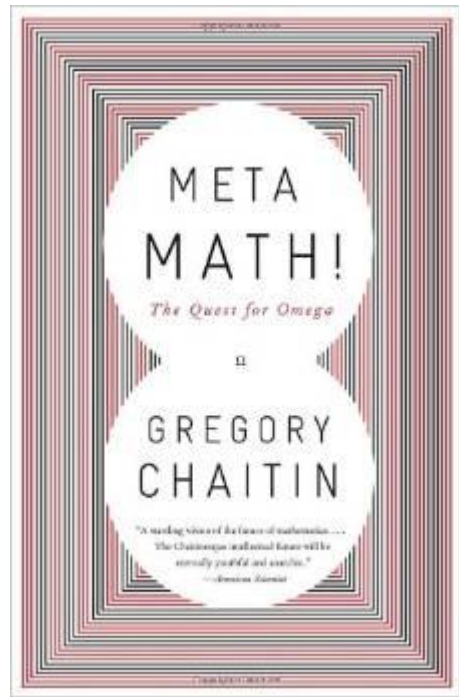
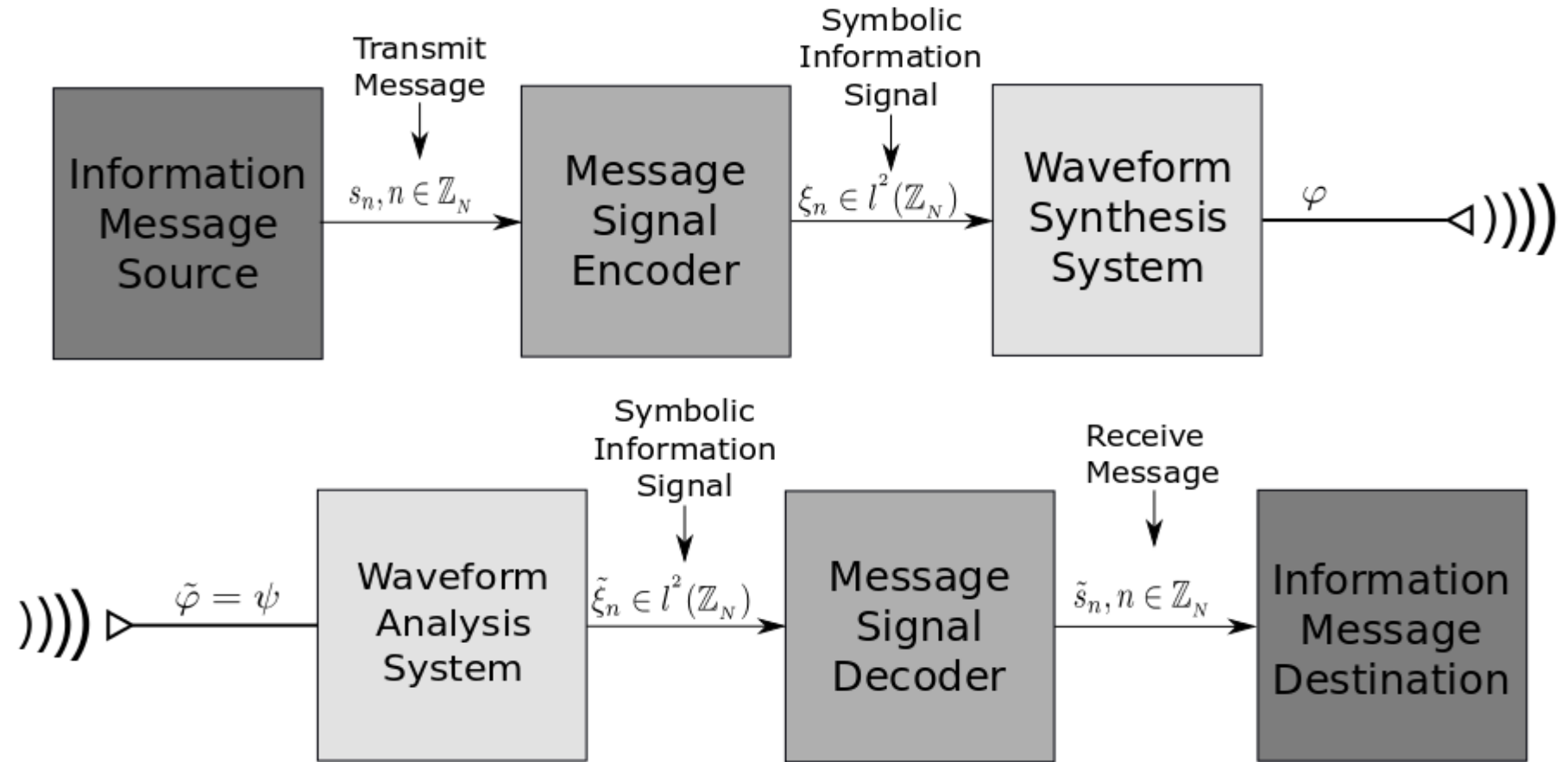
Extended Frameworks: Communication & Computation



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."

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>

CISE Doctoral Program at UPRM

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File Edit View History Bookmarks Tools Help

PhD in CISE

cise.uprm.edu

Most Visited Getting Started Recinto Universitario d... Electrical and Comput... Dr. Domingo Rodríguez M Inbox (63,229) - oddm...

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Latest news

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[Older topics ...](#)

CISE

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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.”



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

