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Strategic Systems of the Future (SSF)

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Strategic Systems of the Future (SSF)

-Some Long Term Research Challenges

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Strategic Systems of the Future (SSF)

- **ASW**: SSBN, SSGN and SSN Security
- **Unmanned Systems**: *undersea, surface, ground, aerial and space*
- **Directed Energy Weapons & Counter Measures**
- **Quantum Computing the Game Changer?**
- **ADM Cebrowski's Network Centric Warfare:** *Tactical networks, cyber and economic systems*

The ASW Challenge: Stealth & Detection

"***Submarines*** *and* ***mines*** *are the biggest threat to any sea control mission. We must take them very seriously. To have dominance at sea, we better be good at anti-submarine and mine warfare."*

- *ADM Gary Roughead.*

Two Driving Research Themes

- Fundamental problem of *accurately detecting and classifying* submarine and mine signatures.

- Fundamental problem of *avoiding detection*, *counter measures against detection*, and *stealth*.

Scientific Focus

There is a need for improving the understanding of:

- the generation
- radiation
- propagation
- Scatter and
- detection

of a variety of ***signal types:***

- acoustic,
- chemical,
- optical,
- electromagnetic,
- hydrodynamic and
- radiological

associated with a submarine's operation.

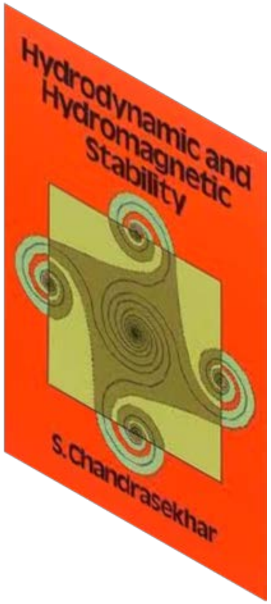
Reference:

I. ***Scientific American***, March 1988: “The Non-acoustic Detection of Submarines”, by Tom Stefanick.

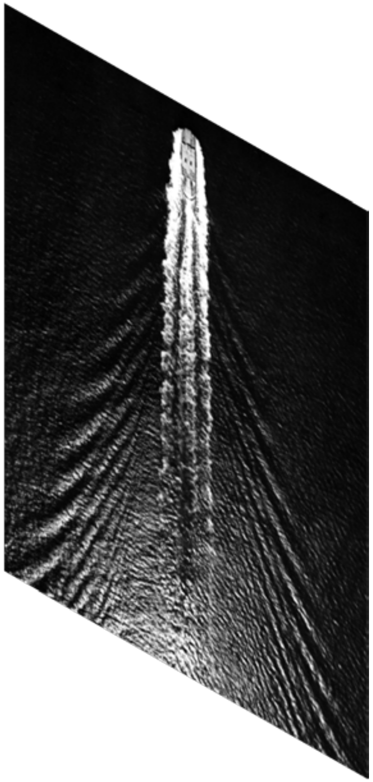
II. ***Scientific American***, February 1981: Advances in Antisubmarine Warfare”, Joel S. Wit.

Modern Advances in Estimation and Control of Coupled Hydrodynamic, Acoustic and Electromagnetic Fields

- Nonlinear filtering and estimation of hydrodynamic disturbances, temperature anomalies and magnetic field deflections.
- Physics based control of aero/hydrodynamic configurations.
- New insights in search and detection of randomly moving targets with randomly distributed sensor networks.
- New insights in detection theory of sonar equation with modern advances in stochastic processes.
- New insights in to obstacle avoidance in surface, undersea and aerial scenario.



Real Time Estimation of Hydrodynamic Anomalies



Surface Anomalies:
- Bernoulli humps,
- Kelvin waves,
- Surface wakes.

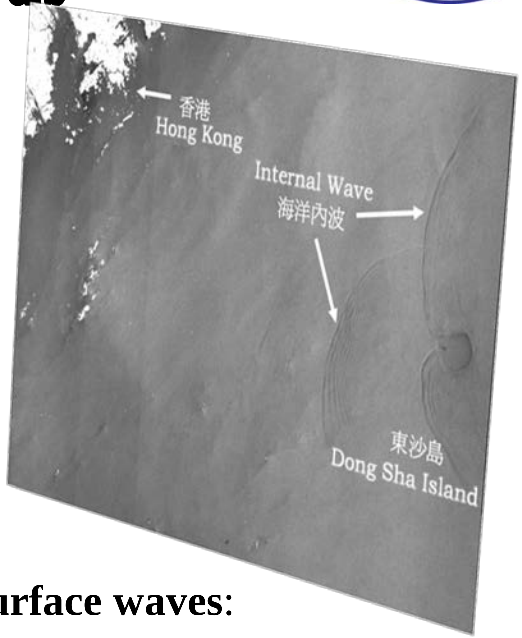
Internal Anomalies:
- Vortex structures,
- Wakes,
- Internal gravity waves.

Real Time Estimation of Hydrodynamic Anomalies-Model Hierarchy

- **Models for surface and internal waves****-Walter Munk, Joseph Keller, John Miles.
- **Fully nonlinear model**: Density dependent Navier-Stokes equation.
- **MHD Models with density dependence**: geomagnetic field interaction with hydrodynamic anomalies.
- **Coupled hydrodynamic, thermal and species transport system**.

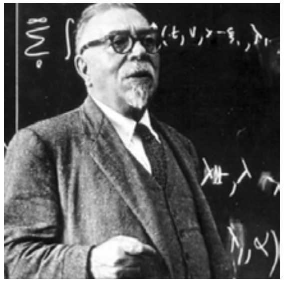
** C. Garrett & W. Munk, “Internal Waves in the Ocean”, *Annual Review of Fluid Mechanics*, 1979.

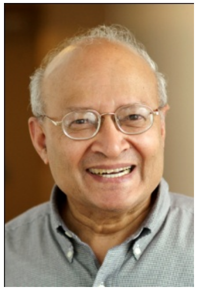
Real Time Estimation of Hydrodynamic Anomalies-Estimation Methods



- **Quickest detection methods** (change detection)
- **Bayesian methods**
- **Kalman filters (linearized hydrodynamic fields)**
- **Fully nonlinear filters for hydrodynamic anomalies, internal and surface waves**:

Initial groundwork done in the papers of S. S. Sritharan -Need to specialize the "abstract theories" of Fujisaki-Kallianpur-Kunia, Zakai equation, White Noise filter of Kallianpur-Karandikar to problems of fluid dynamics and nonlinear wave propagation


Avoiding Detection & Stealth: Physics Based Control of Hydrodynamic Anomalies

- Fluid dynamic **shape optimization** is a passive means of minimizing wake (includes surface roughness and other passive control methods).
- It has been demonstrated theoretically* and computationally** that **it is possible to suppress vortex shedding by active feedback control**.
- Controller design utilizes linear or locally linearized Navier-Stokes equation with suction and blowing on the boundary for example (or rotation if flow past cylinder).
- Long term perspective is very promising with **tremendous potential to actively manage in real time the wake behind surface and submerged vessels.**

* *Papers of S. S. Sritharan and others.*

** *Substantial literature on computational flow control.*

Search of Randomly Moving Targets with Randomly Distributed Sensor Networks.

- **Search theory has its roots in Naval Operations Research** (Bernard Koopman) –stationary target, moving searcher or moving target, stationary sensor.

- Modern search theory can be built using recent advances in stochastic processes to deal with **multiple moving targets and mobile sensor networks.**

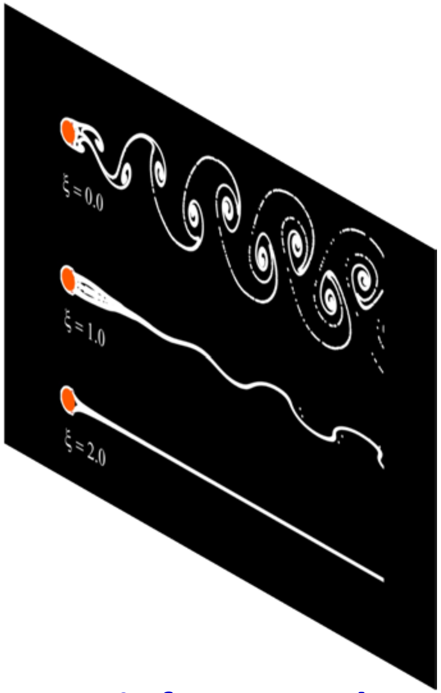
- **Bayesian methods can be used to devise search and detection of swam of undersea unmanned systems with sensor networks.**

- Combination of Bayesian and model based methods will **combine modern advances in stochastic-probabilistic and control theoretic methods.**

New Models for Sonar Equation with Modern Advances in Stochastic Processes.

- Classical **“sonar equation” and related Lambda-Sigma processes**, etc classify **detection and loss of contact by calculating “exit probabilities”** (or level crossing probabilities).
- Modern developments in stochastic processes can be used to devise sophisticated “sonar equations” and other detection models.
- Improvements to sonar models need to be worked out to **incorporate sonobuoy oscillations and signal/noise correlations**.
- A **“network counterpart” of sonar equation** can be obtained for detection of multiple undersea vessels using sensor networks.

Unnamed Systems: *undersea, surface, ground, aerial and space*

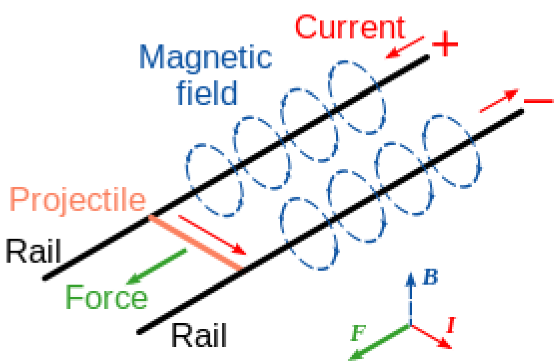


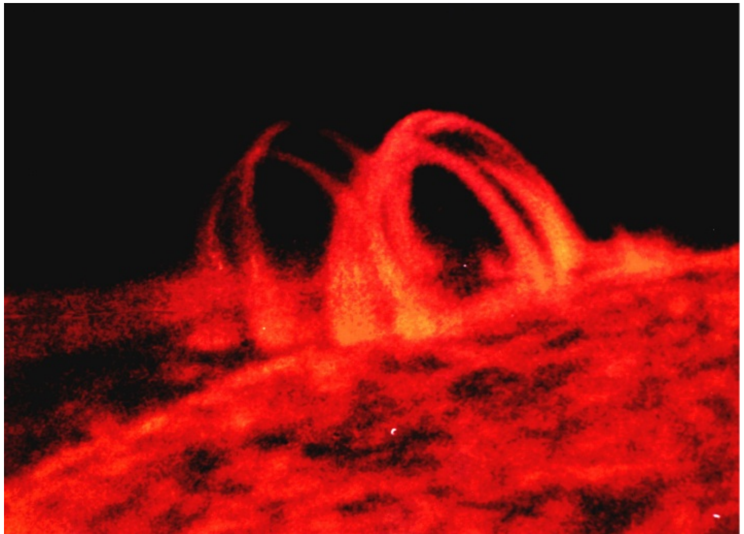
U.S. Air force Academy simulation

- **Autonomy**
- **Flow Control**
- **Combustion Control**
- **Control of ionized gases**
- **Estimation of turbulence and plasmas**
- **Search of multiple agents with moving sensor networks**

The Lorentz Force

J x B

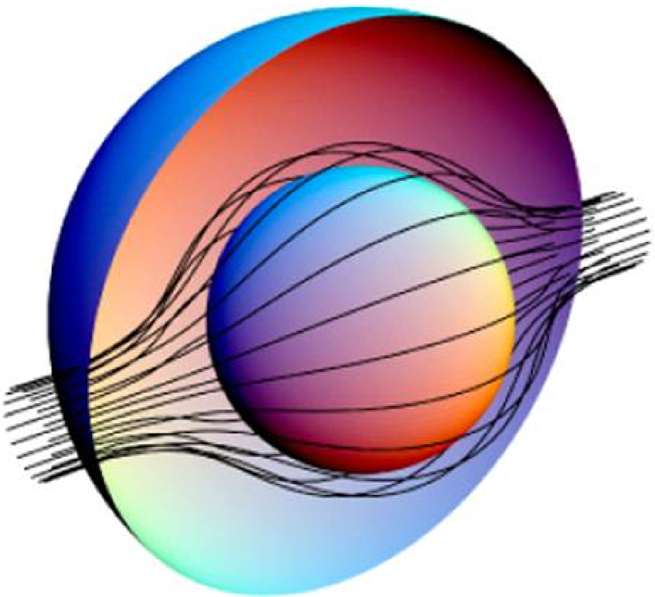


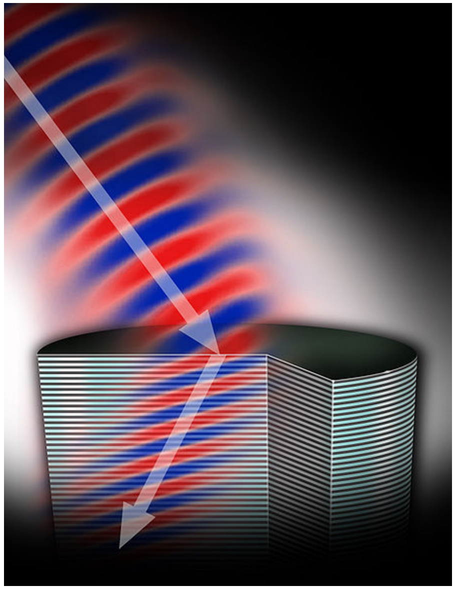


Directed Energy Weapons & Counter Measures

- Electromagnetic Cloaking
- Free Electron Lasers

Electromagnetic Cloaking





U. Leunhardt and T. G. Philbin, *General Relativity in Electrical Engineering*, 2006.

Maxwell Equations:

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{J} + \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t}$$

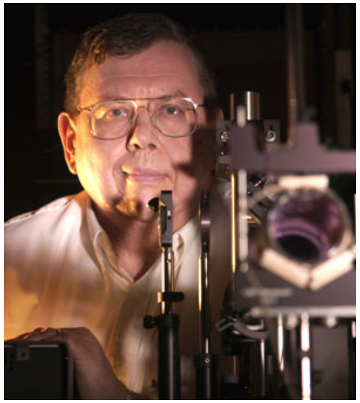
$$F_{\alpha\beta} = \partial_\alpha A_\beta - \partial_\beta A_\alpha$$

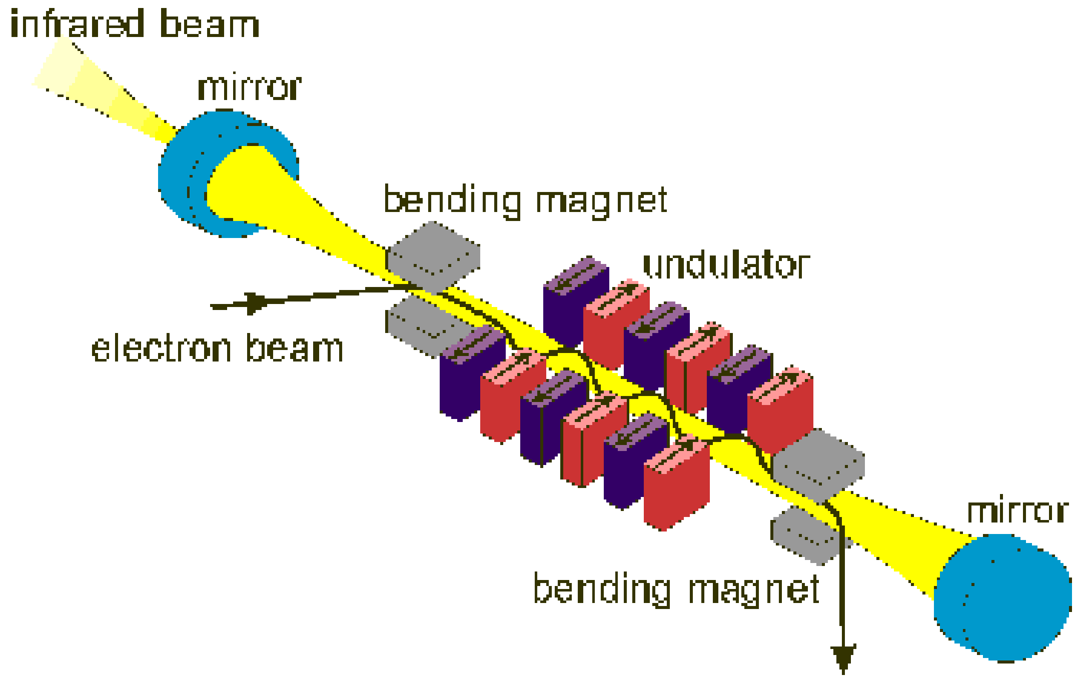
$$\mathcal{D}^{\mu\nu} = \frac{1}{\mu_0} g^{\mu\alpha} F_{\alpha\beta} g^{\beta\nu} \sqrt{-g}$$

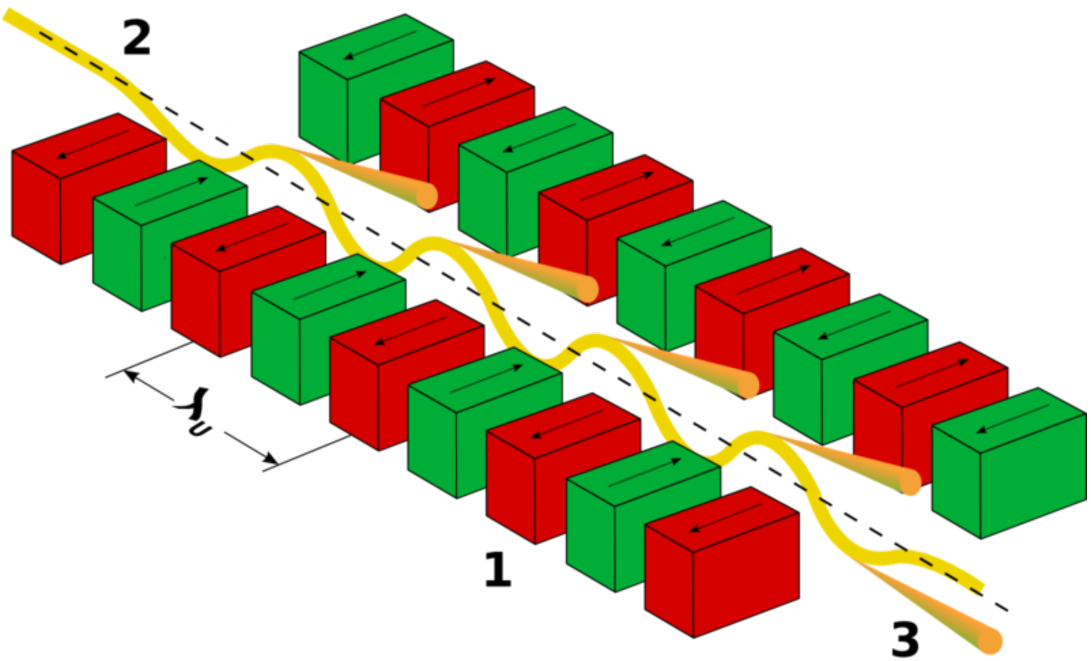
$$J^\mu = \partial_\nu \mathcal{D}^{\mu\nu}$$

$$f_\mu = F_{\mu\nu} J^\nu$$

Free Electron Laser (FEL)







- H. Motz and M. Nakamura, 1959.
- J. M. J. Madey, 1971.

System Science for FEL:

- Control and estimation theory for Quantum Electrodynamics?

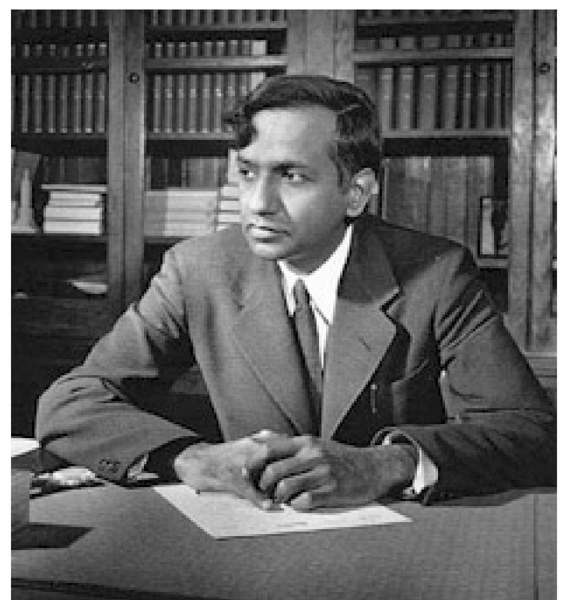
- System Engineering for optimal and scalable design of undulators?

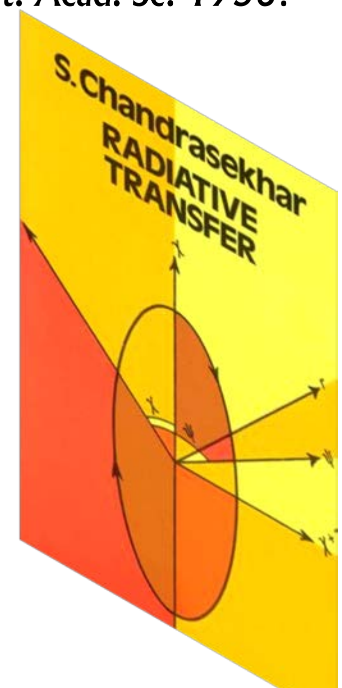
Detection of Laser Attack

- How can we rapidly detect Laser & Microwave Weapons Attack?

$$X(\mu) = 1 + \mu \int_0^1 \Psi(\mu') \left[\frac{X(\mu)X(\mu') - Y(\mu)Y(\mu')}{\mu + \mu'} \right] d\mu' \quad (9a)$$

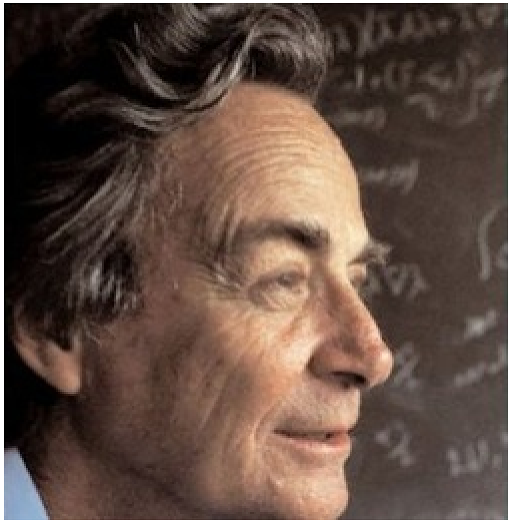
"The Searchlight Problem" S. Chandrasekhar, Proc. Nat. Acad. Sc. 1958.





Quantum Computing

- **Shor algorithm**
- **Grover algorithm**
- **Quantum Error Correction**
- **Quantum Fourier Transform**
- **Entanglement**



Classical bit: $|0\rangle$ **or** $|1\rangle$

Qubit: $a\,|0\rangle + b\,|1\rangle$ **with** $a^2 + b^2 = 1$

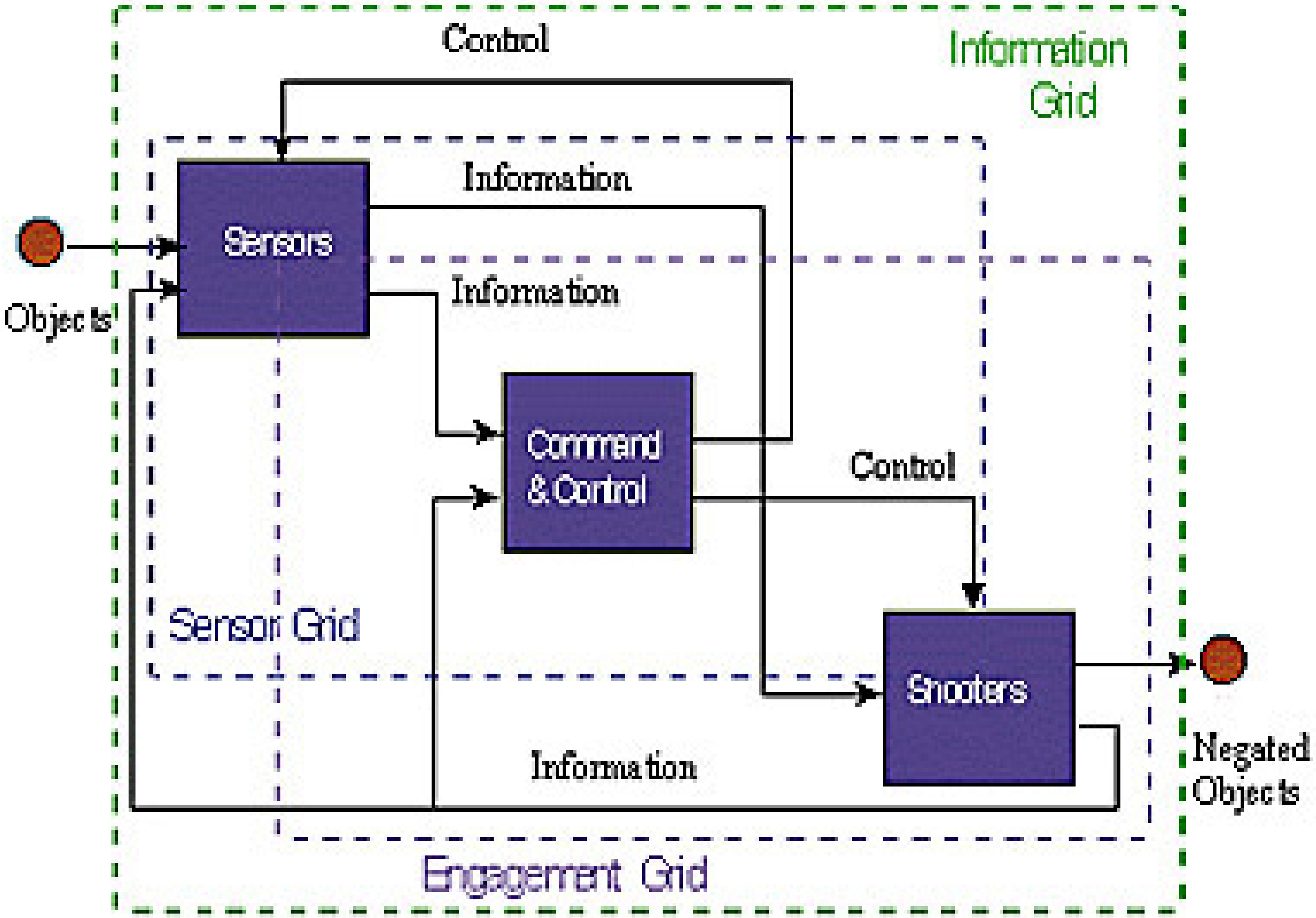
R. P. Feynman, "Simulating Physics with Computers", Int. Journal of Theoretical Physics, Vol. 21, 1982, pp. 467-488.

Nolan R. Wallach, "Quantum Computing and Entanglement for Mathematicians, Lecture Notes in Mathematics, 2008.

ADM Cebrowski's
Network Centric Warfare (NCW)

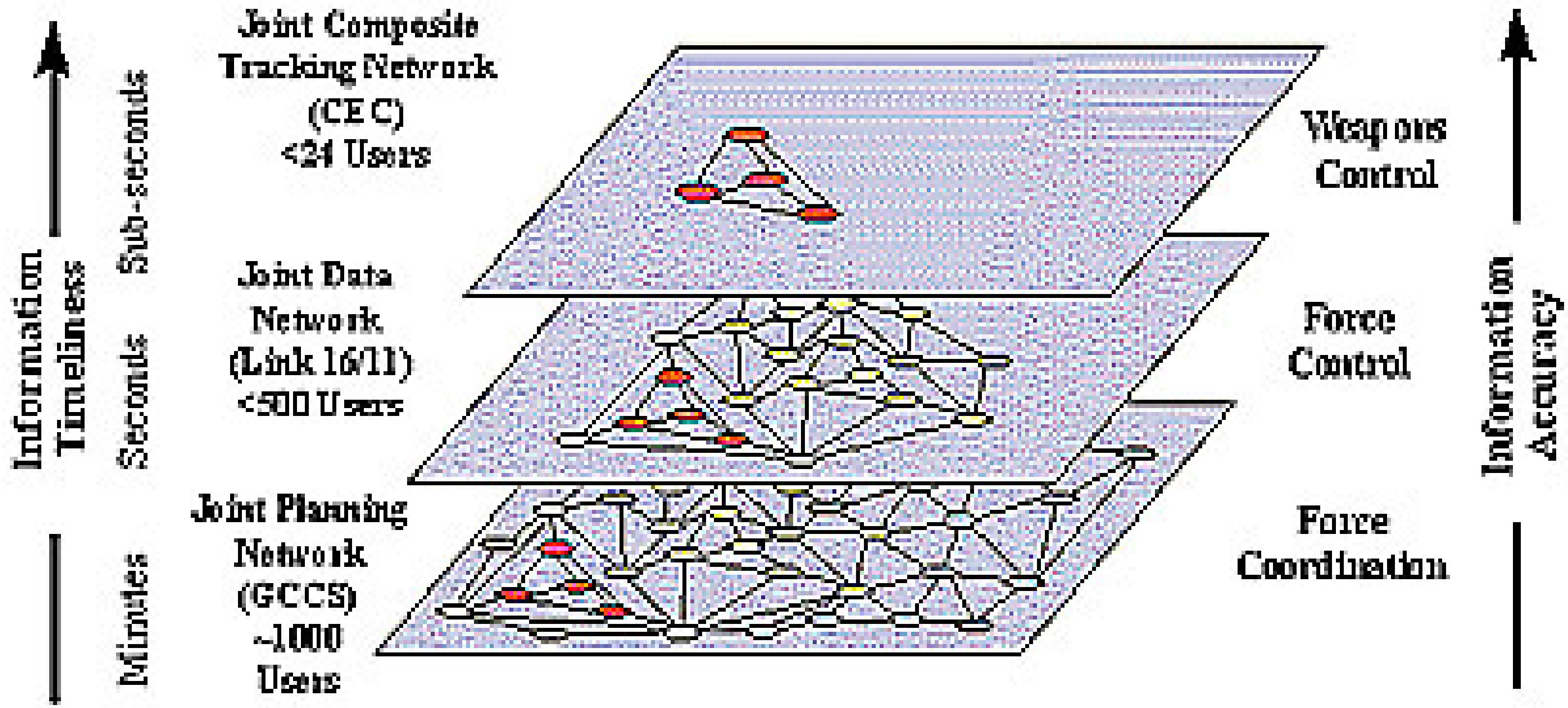
Tactical networks, cyber and economic systems

- **Autonomous cyber defense system**
- **Autonomous unmanned systems control using mobile sensor network**
- **Autonomous tracking of financial network, high frequency and algorithmic trading.**


Control
Information
Grid
Information
Sensors
Information
Objects
Command
& Control
Control
Sensor Grid
Shooters
Information
Negated
Objects
Engagement Grid

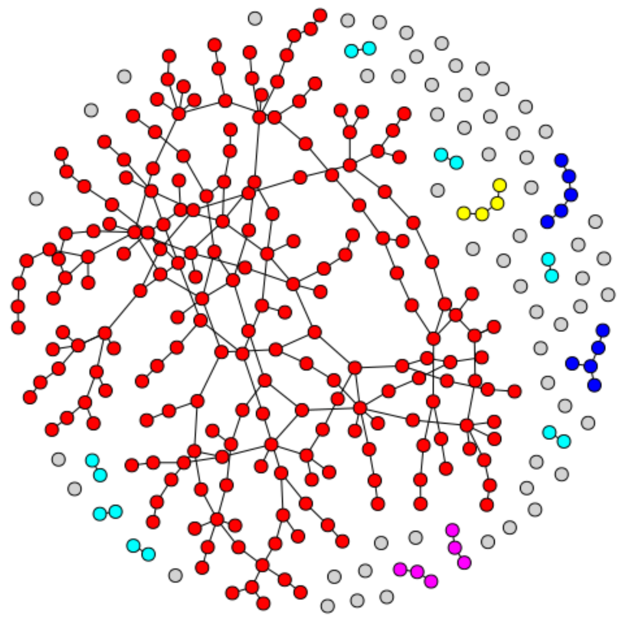
Sensor / Content

Shooter / Transaction



CEC: Cooperative Engagement Capability
GCCS: Global Command and Control System

A Mathematical Theory for NCW?
Random Graph Dynamics



- **Erdős–Rényi**
- **Power Laws**
- **Small worlds**
- **Giant Components**
- **CLT & LDP**
- **Random walks on random graphs**

$$p = 1 \Big/ \binom{\binom{N}{2}}{m}$$

Key Message

- **Control science to Impact**: *fluid dynamics, electromagnetics, quantum electrodynamics,* etc. (ASW, Unmanned systems, DEW)

- **Random graph dynamics:** *models for designing C4ISR Networks, cyber, economic/financial networks, etc.*

- **Advances in stochastic and signal analysis methods and quantum computers:** *will test vulnerabilities and enhance stealth (DEW, ASW, Unmanned and Cyber systems)*.