Al Oppenheim, DSPG MIT

General Research Interests and Style:

New algorithms for signal processing

Applications to speech, oceanography, video, communications, sensor networks, radar, sonar etc. etc.

- traditional
- speculative directions motivated by metaphors from physics and biology
- "Solutions in search of problems."

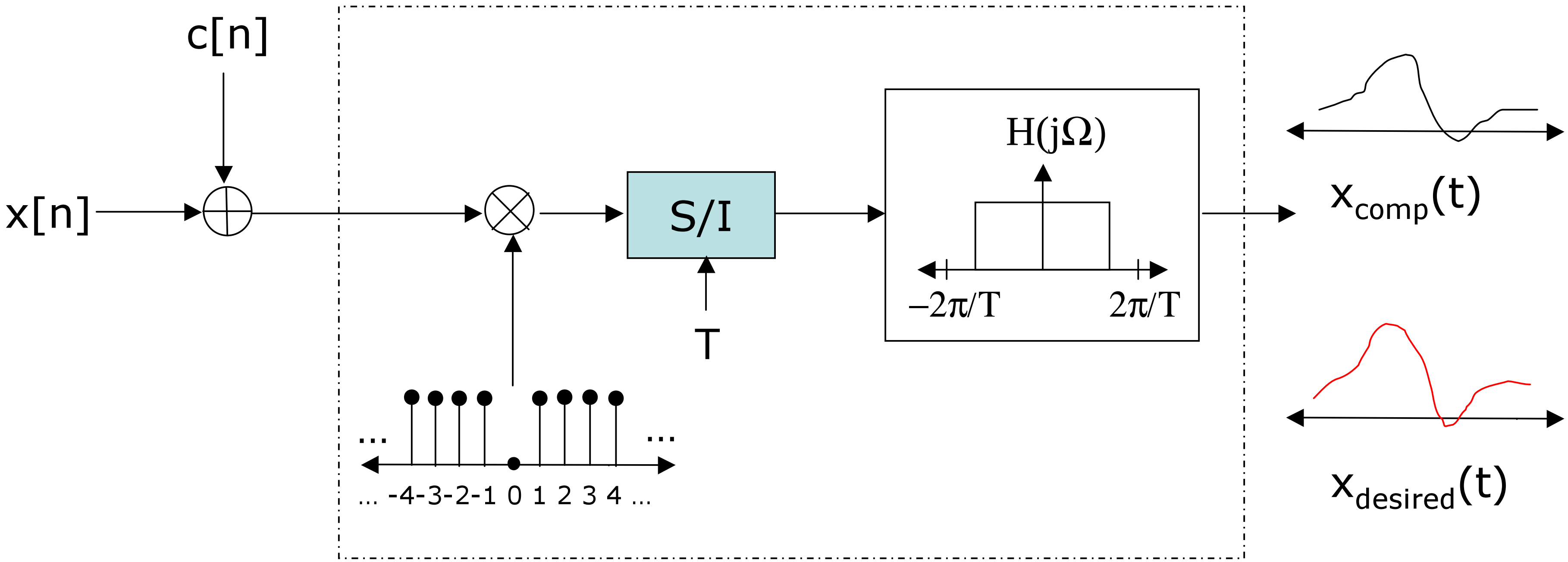
Some Research Themes

- **Sampling Theory and Signal Representations**
- **Signal Modelling**
- **Some “New” Mathematics For Signal Processing**
- **Biological Signal Processing**
- **Various applications**

Multirate and Nonuniform Sampling

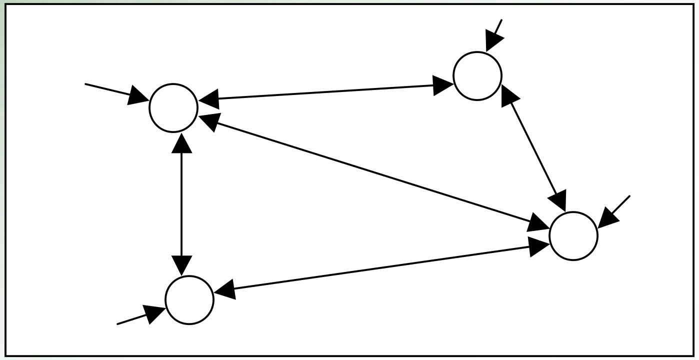
- Efficient reconstruction from nonuniform samples
- Data-dependent Sampling
- Sine wave sampling
- Efficient sample rate conversion
- The “missing pixel” problem

Compensation for Faulty D/A Converters



- Choose c[n], such that c[0] = -x[0]
- Choose c[n] to minimize reconstruction error
- Desire finite length solutions

Distributed Signal Processing



Processor Networks:

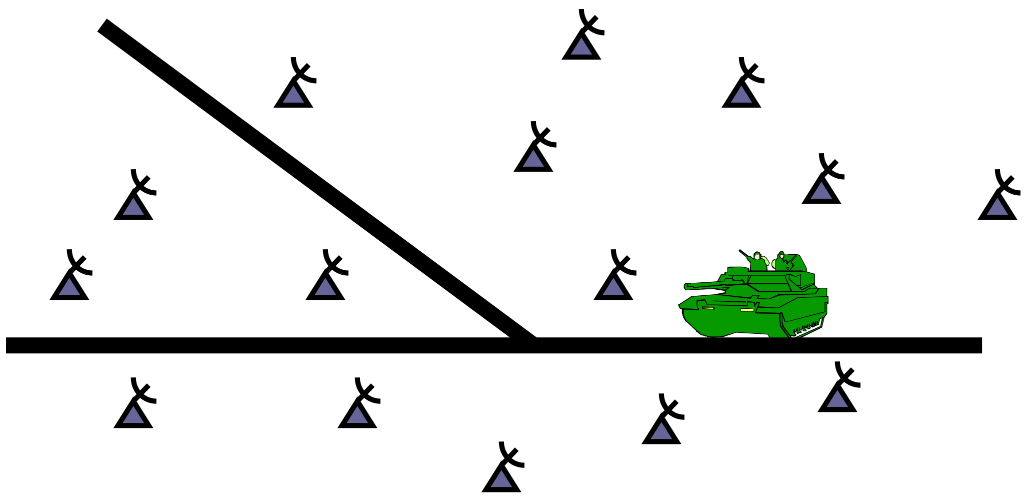
- **Nodes sense, route, and process signals**
- **Cooperation between nodes accomplishes pre-defined signal processing task**

Challenges for Efficient Algorithms:

- **Inter-node communication more costly than local computation**
- **Nodes communicate asynchronously**

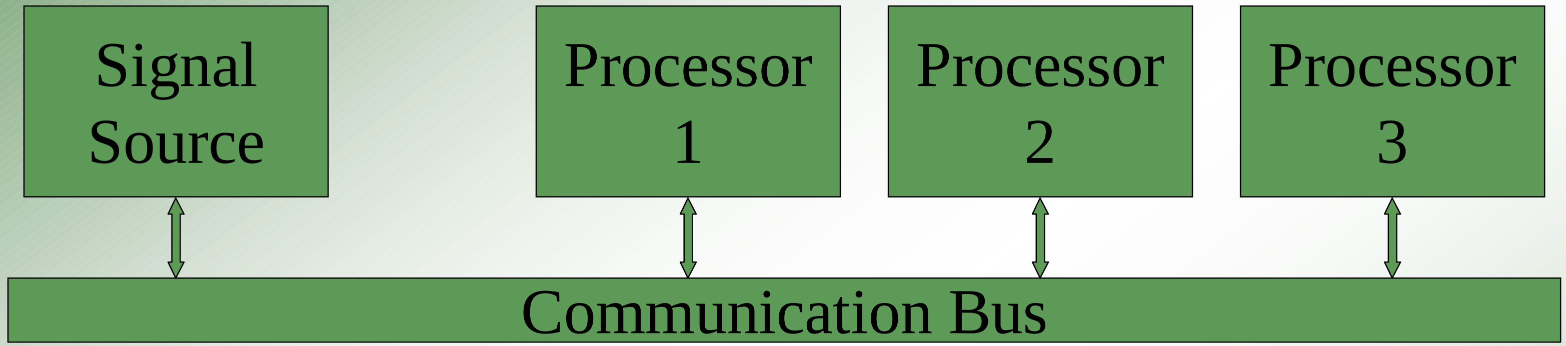
Charles Sestok & Alan Oppenheim

Distributed Sensor Networks



- **Sensors connected with wireless communications collaboratively detect, track, and classify targets in the environment.**
- **Communication cost can limit the network's signal processing capability.**
  - **RF circuitry consumes valuable battery power.**
  - **Shared communication bandwidth limits data flow rates.**
- **In dense networks using thousands of simple nodes, position information may be unavailable to selection algorithms.**

General Hardware for Distributed Signal Processing



Hardware for Distributed Signal Processing

- **Signal Source represents processors' input data**
- **For LTI signal processing, local processors contain adders, multipliers, and memory**
- **Inter-processor communication over broadcast bus**

Measure bus clock cycles per output sample to determine communication complexity of an algorithm

Example: Distributed Computation of a Discrete Fourier Transform

Communication Requirements:

- Direct Computation - N bus clock cycles
  - Communication structure is completely parallel
- FFT - approximately N/2 log N bus clock cycles
  - Each stage of butterfly computations requires N/2 bus cycles to exchange data between processors
- Communication parallelism of direct computation is well-matched to broadcast communication bus

Processor Load:

- Direct Computation - 1 multiply per bus cycle
- FFT- 1 multiply per N/2 bus cycles
- Lack of communication parallelism in FFT prevents efficient utilization of the processors

My Favorite Folk Theorems

- **Anything's optimum if you pick the criterion correctly**
- **Just because it's optimum doesn't mean it's good**

- **speculative directions motivated by metaphors from physics and biology**

- **“Solutions in search of problems.”**

Some Examples of Algorithms based on Nature as a Metaphor

- **Cellular automata**
- **Simulated annealing**
- **Fractals for coding, modulation, and scene generation**
- **Chaotic dynamics**
- **Solitons**

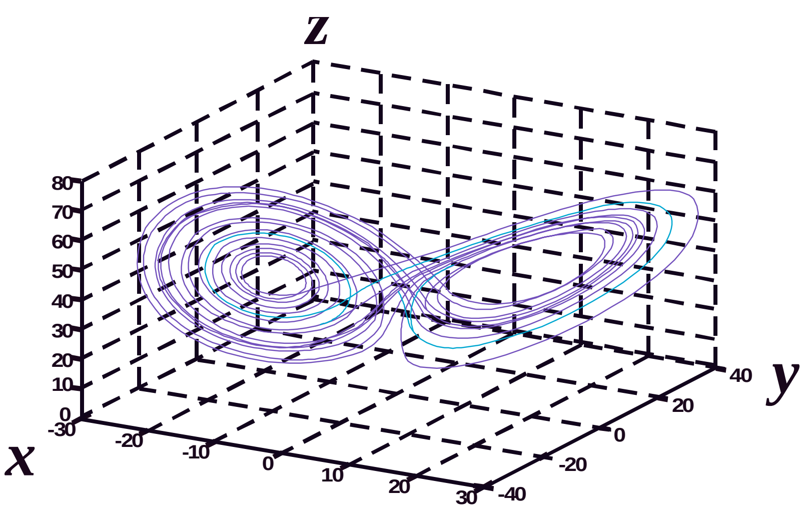
Chaotic Signals and Systems

-
- **Nonlinear Dynamical Systems**
  x(t) = F[x(t), u(t), t]

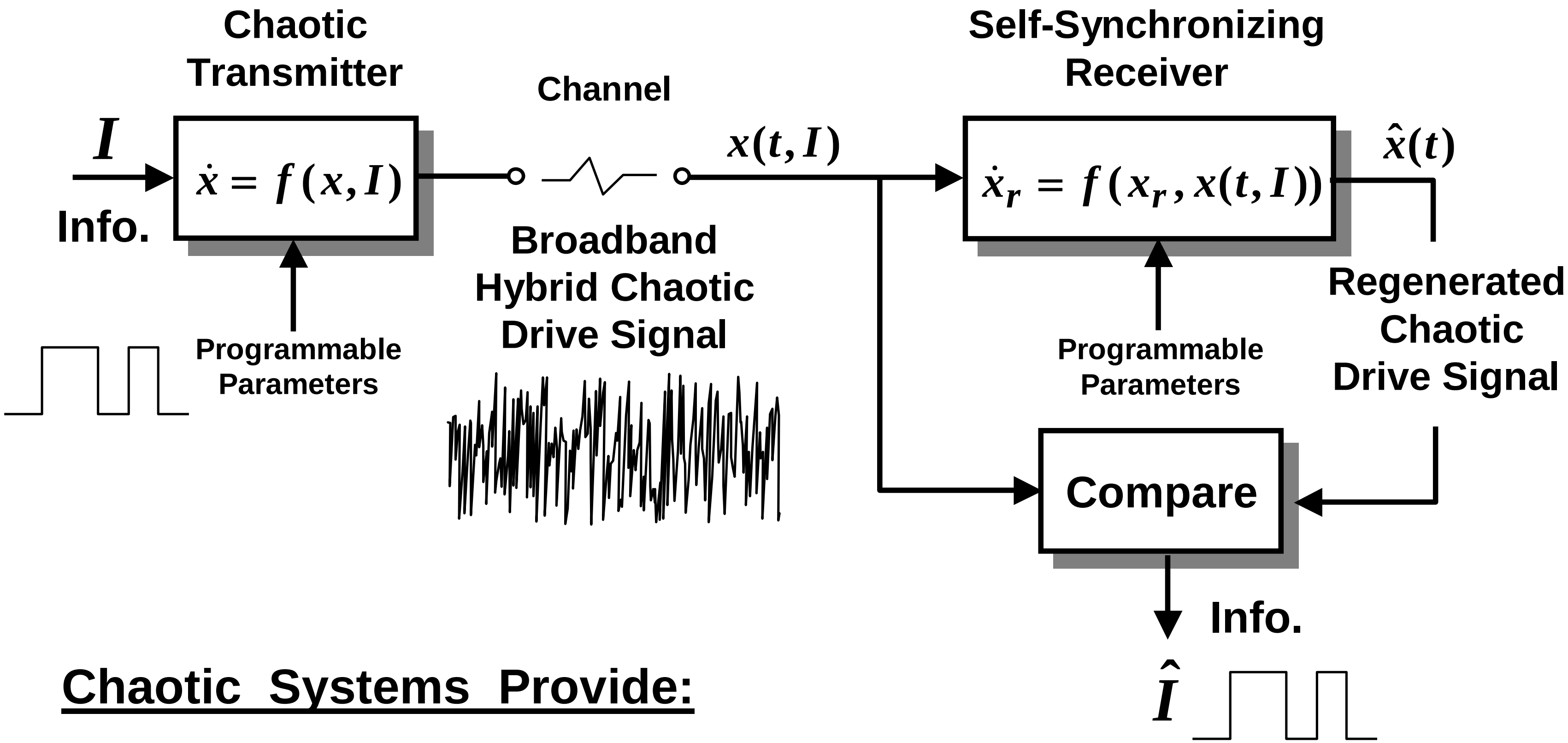
Deterministic & SDIC $\Leftrightarrow$ Chaotic Behavior

Lorenz System

$$\dot{x} = \sigma(y - x)$$
$$\dot{y} = rx - y - xz$$
$$\dot{z} = xy - bz$$



Chaotic Communication Concepts

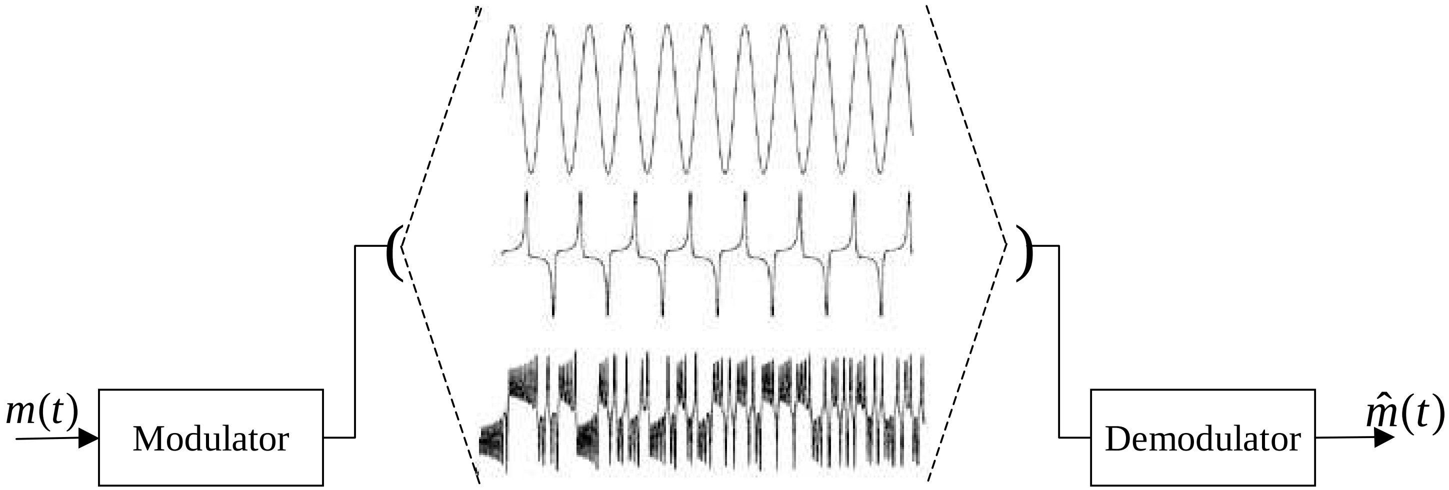


<u>Chaotic Systems Provide:</u>

- **A Wide Variety of Broadband Waveforms**
- **A Class of Self-Synchronizing Receivers**

Kevin Cuomo, Alan Oppenheim, Steve Strogatz

Generalized FM

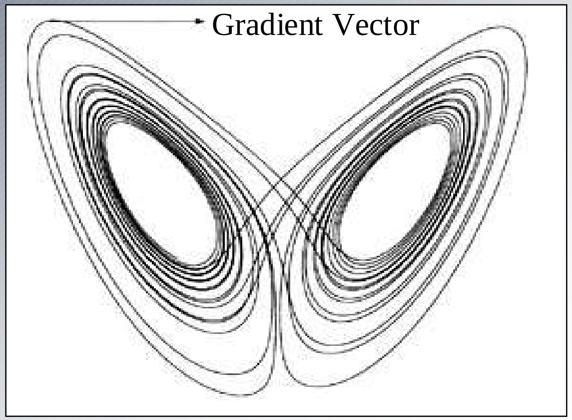


- Carrier waves are generated by dynamical systems that have:
    1. A periodic, almost periodic, or chaotic attractor,
    2. A known exponentially convergent observer.
- FM is a special case.

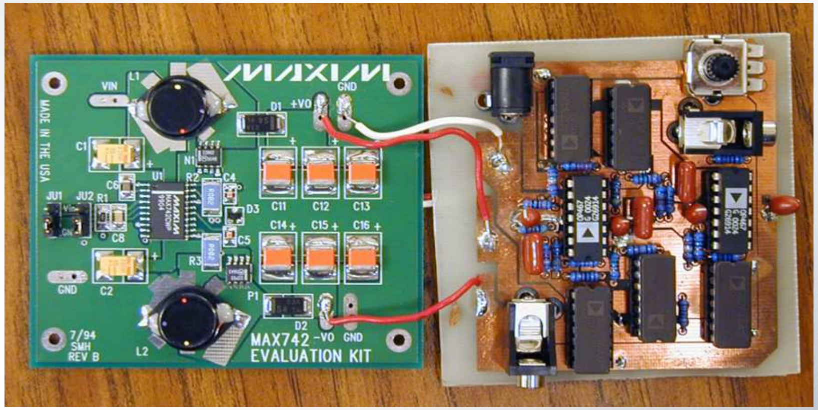
Generalized Frequency Modulation

(Torres, Oppenheim and Rosales)

The Lorenz System (Chaotic)



Circuit Implementation



Dynamical System Equations:

Without Modulation

$$\dot{x}_1 = \sigma(x_2 - x_1)$$

$$\dot{x}_2 = rx_1 - x_1x_3 - x_2$$

$$\dot{x}_3 = x_1x_2 - bx_3$$

With Modulation

$$\dot{x}_1 = (\omega_c + \beta m(t))\sigma(x_2 - x_1)$$

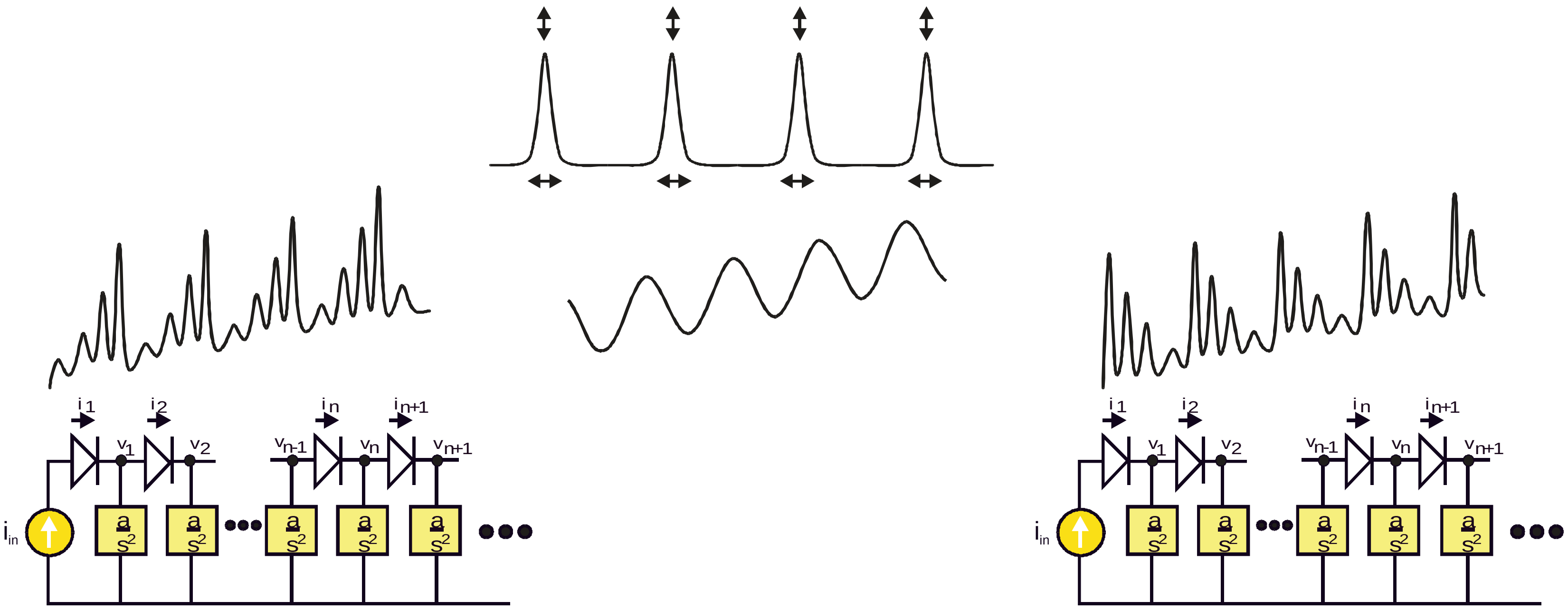
$$\dot{x}_2 = (\omega_c + \beta m(t))(rx_1 - x_1x_3 - x_2)$$

$$\dot{x}_3 = (\omega_c + \beta m(t))(x_1x_2 - bx_3)$$

Soliton Multiplexing

- **Modulate time-separated solitons with OOK, PAM or PPM**

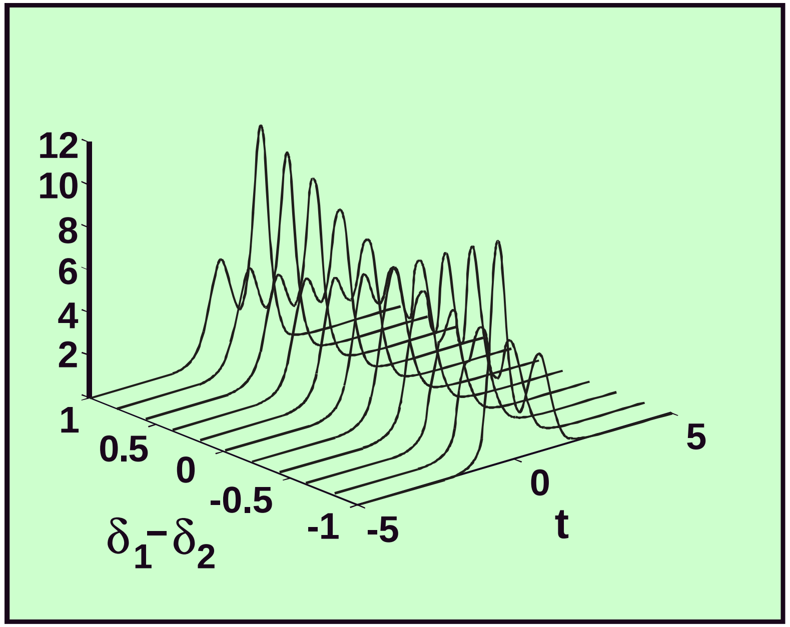
  Multiplex individual solitons together using Toda lattice

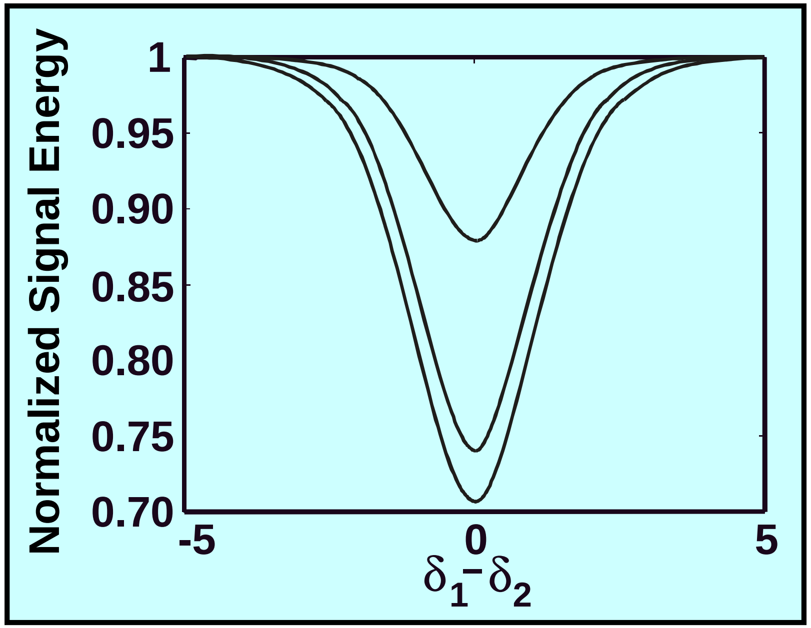


Multiplexing **Demultiplexing**

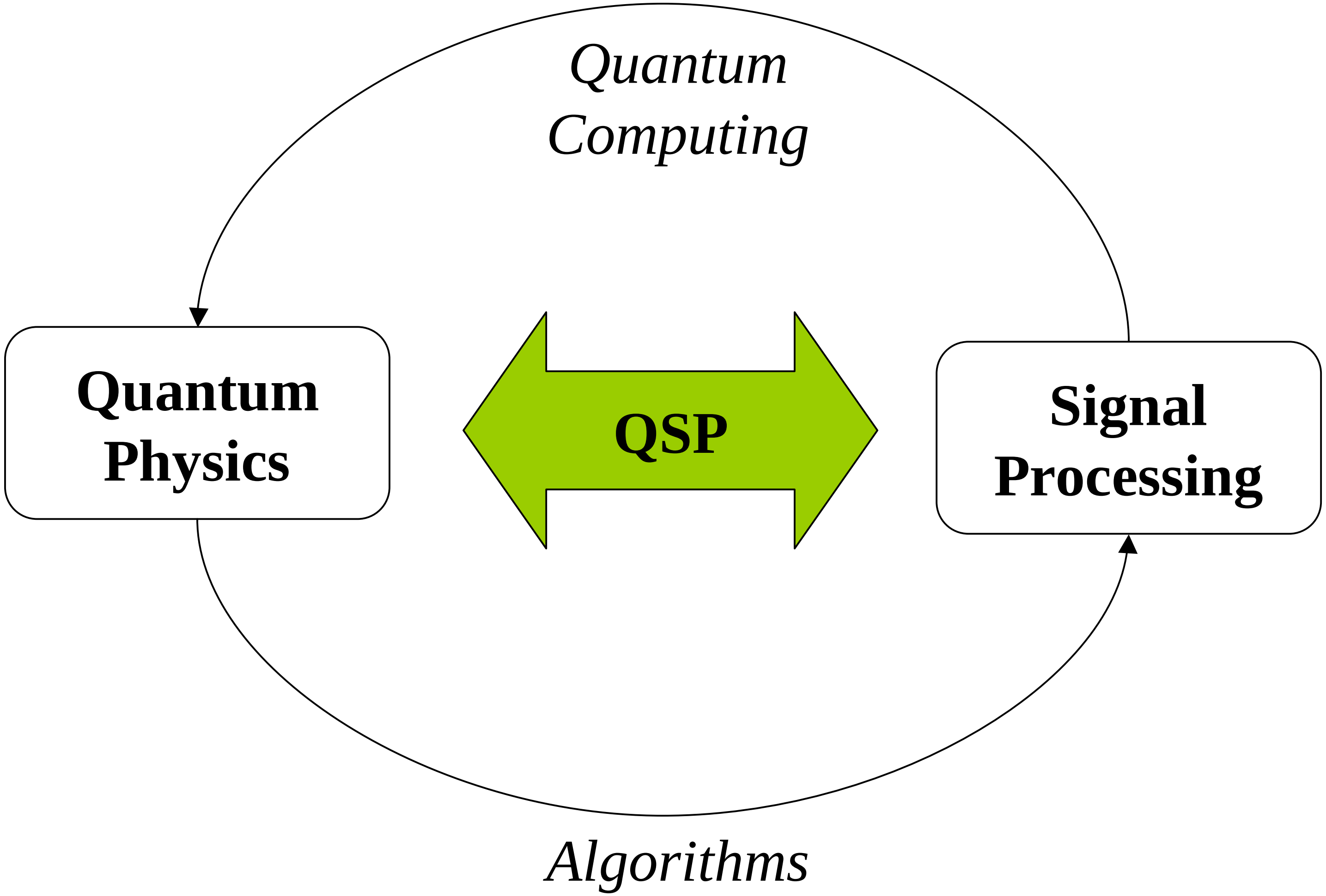
Low-Energy Signaling

Signal Energy Minimized by Multiplexing





Quantum Signal Processing



Quantum Signal Processing

Quantize: 1. To subdivide into small but measurable increments
2. To calculate or express in terms of quantum mechanics

Merriam-Webster's Collegiate Dictionary, Tenth Edition, 1998

- QSP borrows from the principles of quantum mechanics and some of its interesting axioms and constraints
- QSP is not constrained by physics

Quantum Mechanics

- **Measurement of the system: probabilistic outcome M(x) with probabilities dependent on the state x**
- **Consistency of the measurement: repeated measurements on a system yield the same outcomes M(M(x))=cM(x)**
- **Determinate states: states for which M(x) is determinate i.e. not probabilistic**
- **Various other constraints imposed by the physics**

  $\Rightarrow$ **Measurement "collapses" the system into a determinate state**

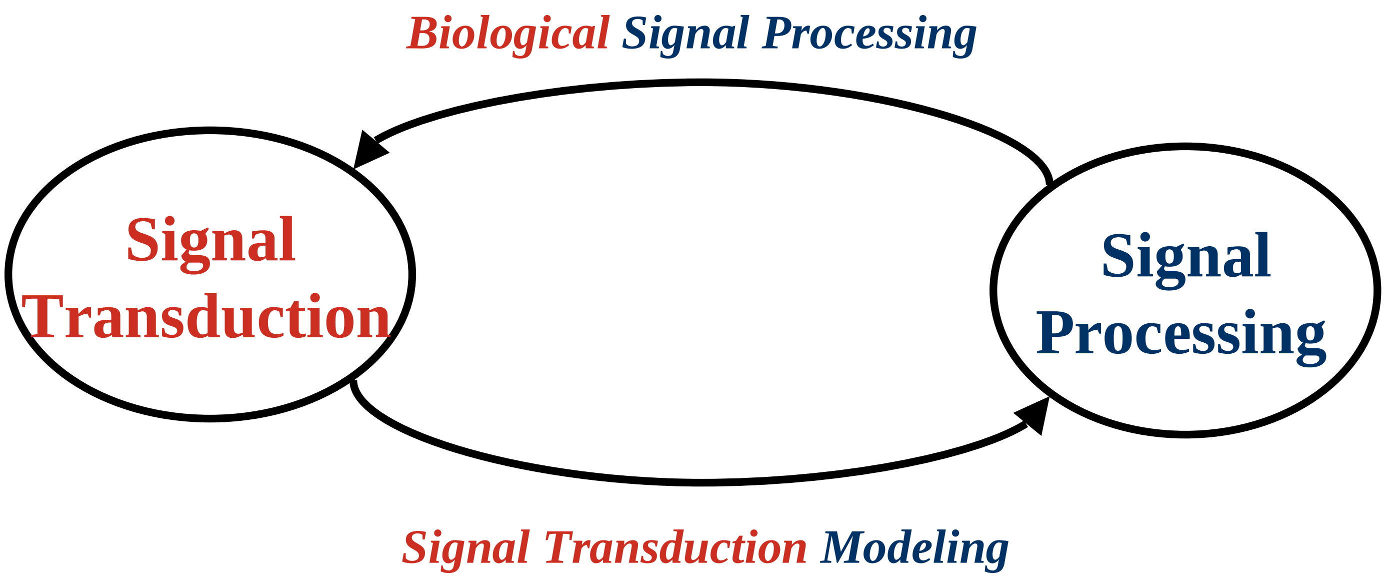
Quantum Signal Processing

The QSP framework has led to interesting new results in:

- **Quantum detection**
- **Matched filter banks**
- **Multiuser detection**
- **Sampling theory**
- **Frames**

Y.C. Eldar and A.V. Oppenheim "Quantum Signal Processing "
***IEEE Signal Processing Magazine*, November 2002**

Biological Signal Processing



Objectives

- Formulate underlying principles governing biological signal transduction pathways using signal processing theory.
- Develop signal processing algorithms inspired from signal transduction pathways.
- Exploit biological hardware to perform signal processing.

How are stream processing and signal processing related?

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Yesterday I thought I had a guess

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Today I’m confused about the definition

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Today I’m confused about the definition

The day after tomorrow I’m looking forward to understanding it better