Biography

• Director of the Huawei Mathematical & Algorithmic Sciences Lab
• IEEE and WWRF Fellow
• ERC Grant (2012–2017)
• 20 Best Paper Awards
• 200+ journal papers
2030: Wireless for Intelligent Machines

“G” Waves

- 2G: Mobile for Voice
- 3G: Mobile for Visio-phony
- 4G: Mobile for Internet
- 5G: Mobile for Things
- 6G: Mobile for Machines?
2035: The Internet of Intelligent Machines?
We Are Entering a Hyper-connected Intelligent World

**All Things Sensed**
Sensing the physical world, mapping it to digital signals
Temperature, space, and touch
Sense of smell, hearing, and vision

**All Things Connected**
Data goes online to power machine intelligence
Ubiquitous connections, wide connections, multiple connections, and deep connections

**All Things Computed**
Network integrated AI to power new applications
Digital twins
Digital survival

Broadband  Data center  Cloud computing  Big data  IoT  Artificial intelligence
We Are Entering a Hyper-connected Intelligent World

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Broadband  Data center  Cloud computing  Big data  IoT  Artificial intelligence
Better Perception

Naked Eyes

P30 Pro

Air Quality

Blood Pressure

More Information, Better Service & Experience
Convergence of Wireless Transmissions and Sensing

Spatial Dimension

- Hidden object sensing
  - Calorie: 283Kcal
  - Fresh: ★★★
- Food spectral Sensing and analysis
- Sensing Vehicles

Chemistry

- Terminal Sensing
- Infrastructure Sensing

Biology

- 4D City Sensing reconstruction
  (Traffic control)

Medical

- Analytics
  - Core Cloud
  - Edge Cloud

Terminal Sensing

- Infrastructure Sensing

Core Cloud
**Sensing Assisted Transmission**

**Sensing Assisted PHY**

1. Air Interface Relative sensing

2. Reality mapping and Judging

3. Beam Forming tracking

**Sensing Assisted Network**

1. Environment sensing

2. Infrastructure and traffic reconstruction

3. Network planning and traffic steering
Sensing and Spectrum

TECHNOLOGY

- MM-wave radar
- Lidar
- CT
- MRI
- Thermal imager
- THz

Safety

Size

Accuracy

Integration

Penetration

Efficiency

Tera-THz Extend the Scope of Sensing

Ultra Bandwidth
Molecular Vibration
Non-ionized
Small Size
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Broadband
Data center
Cloud computing
Big data
IoT
Artificial intelligence
The Rise of AI: 1989-2019

2019 Turing Award
The Cost of Understanding
The Limits of Modelling
New Paradigms for Data
AI: Overall outcome of 60 years of development in ICT
Computers and Automata*

CLAUDE E. SHANNON†, FELLOW, IEEE

C. E. Shannon first became known for a paper in which he applied Boolean Algebra to relay switching circuits; this laid the foundation for the present extensive application of Boolean Algebra to computer design. Dr. Shannon, who is engaged in mathematical research at Bell Telephone Laboratories, is an authority on information theory. More recently he received wide notice for his ingenious maze-solving mechanical mouse, and he is well-known as one of the leading explorers into the exciting, but uncharted world of new ideas in the computer field.

The Editors asked Dr. Shannon to write a paper describing recent experiments and speculations concerning future developments in computer logic. Here is a real challenge for those in search of a field where creative ability, imagination, and curiosity will undoubtedly lead to major advances in human knowledge.—The Editor

Summary—This paper reviews briefly some of the recent developments in the field of automata and nonnumerical computation. A number of typical machines are described, including logic machines, game-playing machines and learning machines. Some theoretical questions and developments are discussed, such as a comparison of computers and the brain, Turing’s formalization of computing machines and von Neumann’s models of self-reproducing machines.

* Decimal classification: 621.385.2. Original manuscript received by the Institute, July 17, 1953.
† Bell Telephone Laboratories, Murray Hill, N. J.

INTRODUCTION

SAMUEL BUTLER, in 1871, completed the manuscript of a most engaging social satire, "Erewhon." Three chapters of Erewhon, originally appearing under the title "Darwin Among the Machines," are a witty parody of "The Origin of Species." In the topsy-turvy logic of natural selection, Butler sees machines as gradually evolving into higher forms. He considers the classification of machines into genera, species and varie-
Why now?

**Massive amounts of data** that can be used to train Machine Learning models are being generated, for example through daily creation of billions of images, online click streams, voice and video, mobile locations, and sensors embedded in the Internet of Things devices.

**Computing capacity** has become available to train larger and more complex models much faster. Graphics processing units (GPUs), originally designed to render the computer graphics in video games, have been repurposed to execute the data and algorithm crunching required for machine learning at speeds many times faster than traditional processor chips.

*Key Trend Emerging:* Specially design chips and Hardware for Machine Learning workloads (Tensor Units).

**Machine-learning algorithms** have progressed in recent years, especially through the development of deep learning and reinforcement-learning techniques based on neural networks.
# New Paradigms for Algorithms

|-------------------|-----------------------------|-----------------------------|----------------|---------------------|-------------|------------------------|----------------|-------------------|----------------|----------------|----------------|

- Spectral Methods (FFT)
- Finite-State Machines
- Circuits
- Dense / Sparse Linear Algebra
- Graph Algorithms
- Graphical Models (Tree)
- Monte-Carlo
- Map Reduce
- Structured/Unstructured Grids
- N-Body Methods
- Backtracking and Branch & Bound
- Dynamic Programming

**Examples:**
- Bitwise not: \( \sim x \)
- Bitwise and: \( x \& y \)
- Bitwise or: \( x \mid y \)
- Bitwise exclusive or: \( x \oplus y \)
- Right shift: \( x >> y \)
- Left shift: \( x \ll y \)

**Formulas:**
- \( \pi = \frac{4}{1} \times \frac{4}{3} \times \frac{4}{5} \times \frac{4}{7} \times \ldots \) (Monte Carlo)
- Circle Area: \( \pi r^2 \)
- Square Area: \( s^2 \)
## New Paradigms for Computing

<table>
<thead>
<tr>
<th>Device</th>
<th>Edge</th>
<th>Cloud</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earphone</td>
<td>Always-on</td>
<td>Smartphone</td>
</tr>
<tr>
<td>20 MOPS</td>
<td>100 GOPS</td>
<td>1-10 TOPS</td>
</tr>
<tr>
<td>1 mW</td>
<td>10 mW</td>
<td>1-2 W</td>
</tr>
<tr>
<td>10 KB</td>
<td>100 KB</td>
<td>10 MB</td>
</tr>
<tr>
<td>&lt; 10 ms</td>
<td>~10 ms</td>
<td>10-100 ms</td>
</tr>
<tr>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>N</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Ascend-Nano</td>
<td>Ascend-Tiny</td>
<td>Ascend-Lite</td>
</tr>
</tbody>
</table>
New Paradigms for Networks

Mobile AI: What is the right architecture?
Unified training and inference framework

Consistent Development Experience

Cooperative Training/Inference

Device

Edge

Cloud
New Paradigms for Networks

Current Cloud and AI

- Centralized AI
- AI in Cloud
- Cloud AI
- Core Network
- Edge AI
- Site AI
- Terminal AI

Integrated Cloud, Network & AI

- Core Cloud
- Edge Cloud

L5 Full Scenario (Intent-Driven)
L4 Service Scenario (Autonomy)
L3 Single-Scenario (Conditional Automation)
L2 Task (Partial Automation)
L1 Functionality (Expertise Based)
Smart Communications

Shannon 1.0

1948

Shannon 2.0

2028
1.2. Three Levels of Communications Problems

Relative to the broad subject of communication, there seem to be problems at three levels. Thus it seems reasonable to ask, serially:

**Level A.** How accurately can the symbols of communication be transmitted? (The technical problem.)

**Level B.** How precisely do the transmitted symbols convey the desired meaning? (The semantic problem.)

**Level C.** How effectively does the received meaning affect conduct in the desired way? (The effectiveness problem.)

In

*Recent Contributions to the Mathematical Theory of Communication...*

Warren Weaver, The Rockefeller Foundation
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Better Connection

Information Everywhere

Holoportation & Edge Intelligence (4.62Tbps)

Autonomous / Flying Transportation (4T/day)

Digital Industry and Robotics (<1ms)
New Electromagnetic Channel Models

Reconfigurable Metasurfaces

Metasurface for Nonlinear Manipulation Could Simplify Wireless Communication

Scientists have developed a metasurface that enables efficient manipulation of spectral harmonic distribution, and have proposed a novel architecture for wireless communication systems based on this time-domain digital coding metasurface. According to the scientists, the metasurface could simplify the architecture of communication systems, while yielding excellent performance for real-time signal transmission. Scientists from the State Key Laboratory of Millimeter Waves, the National Mobile Communication Research Laboratory, and the Photonics Initiative, Advanced Science Research Center located in New York make up the team.

(a) Schematic of the proposed BFSK wireless communication system based on the time-domain digital coding metasurface. (b) Experimental scenario of the BFSK wireless communication system. (c-d) The received messages by the BFSK wireless communication system for different receiving angles, showing stable communication abilities. Courtesy of Science China Press.

Optical nonlinear phenomena are typically
From Connected Things to Connected Intelligence

2020

2030
5G is Now
Standardization Timetable

Previous Plan
- 5G Phase 1
- 5G Phase 2
- 5G extension

Accelerating Plan
- Phase 1.1
- Phase 1.2
- Full IMT-2020 NR

Global Launch
- B5G
- 6G
Beyond 5G

2020

- **User experienced data rate:** 1 Gbps
- **Peak data rate:** 20 Gbps
- **Network energy efficiency:** 100 x
- **Mobility:** 500km/h
- **Area traffic capacity:** 10 Mbps/m²
- **Connection density:** 1 Millions/km²
- **Latency:** 1 ms
- **Spectrum efficiency:** 3x

5G++ 2024-2028

- **Peak data rate:** 1 Tbps
- **Jitter:** 0.1 ms (+/- 10 ns)
- **Position:** Δ 10 cm
- **Connection density:** 10/m²
- **Link Budget:** +40 dB

5G+ 2020-2024

6G 2028-2030

- **Peak data rate:** 1 Tbps
- **Jitter:** 0.1 ms (+/- 10 ns)
- **Position:** Δ 10 cm
- **Link Budget:** +40 dB

2030
THANK YOU

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