# History of TOD™ and Tissue Computing

*"The Age of Tissue Computing has Arrived™"*

Brought to you by BCM Industries

Tissue Operating Device (TOD™) is the world's first mass produced, commercially available, Tissue Computer with networked neuron processing. This TOD™ family of tissue driven data processors offers from 16 million to 5 billion neuron powered processing and data storage options. BCM Industries (BCM) is accepting orders and reservations for delivery of all nine TOD™ Models.

This Article, with References, provides an introduction and overview to the arising Age of Tissue Computing. Over the next decade, Tissue Computing will impact every aspect of everything. For a limited insight to this impact, see the Article: "TOD™ Processing Applications."

TOD™ production slots for 2023 may fill fast. If you have questions or a serious purchase interest, do not delay, contact a BCM Sales and Support representative. For additional purchase data see the Article: "Nine Available TOD™ Models."

By imbedding a Tissue Computer, the nine TOD™ Models provide users with near blinding processing speed, and throughput, massive data storage capacity, and lighting neuron fast data transfers. Conventional digital computers with chips and motherboards, no matter how enhanced, will never achieve the levels of performance of a pure Tissue Computer.

All digital chip processors and memory devices are performance limited by the physical constraints of the chip and motherboard architecture. Furthermore, digital systems do not possess the intrinsic capabilities to learn or rapidly process complex data. [1] [2] [3]

The TOD™ embedded Tissue Computer, has no chips, no motherboard, but delivers a massive and expandable learning capacity, and extremely complex data processing capabilities. The TOD™ Model 5120 delivers the application program 5 billion neurons, 5% of the neurons in a human brain, in a single rack mounted Model.

In response to the growing market demand for user access to neuron processing services, IBM, Intel, Graphcore, BrainChip, and others are offering special chip performance enhancements for selective parallel processing applications.

## Concept of Tissue Computing

During 2019 and 2020, both Intel and IBM announced the limited availability of neuron processing on a chip. They are called neuron chips; however, they are actually "artificial" neurons on a chip. With these new neuron chip advancements, Intel and IBM moved society into the period of "Artificial Neuron Computing." Two years later BCM has advanced into real neuron processing - "The Age of Tissue Computing." [4] [5 [6] [7] [8] [9]

Although in certain applications these Intel and IBM enhanced artificial neuron chips can deliver significantly improved performance, ultimately these artificial chips still have the performance limitations resulting from the physical time and space issues of a chip operating with a motherboard architecture.

Throughout 2020, we continued to observe an ever-increasing number of users with applications needing blinding processing speed, massive computational throughput, near infinite data storage capacity, and lighting fast data transfers. The ultimate successful solution is to leap from digital processing to the neuron processing age.

For the successful transition to neuron processing BCM recognizes the need to provide a family of neuron processors that are affordable and offer to customers a complete range of both general purpose and specific applications. This public neuron processor release needed to address the needs of commercial, education, business, military, and scientific users. This is similar to IBM's approach to releasing the IBM 360 family of digital mainframe computer systems delivered beginning in 1965.

The TOD™ Tissue Computer consisting of millions of active neurons residing in a medically sterile, pristine, protected operating environment, must totally avoid chips and motherboards. It must deliver high-performance processing and storage capabilities in a stand-alone neuron populated tissue structure in a pure, environmentally controlled, self-sustaining container.

In addition, for a successful transition, the Tissue Computer must deliver rapid and seamless transfers of data and intelligence between the internal neuron processing nodes within the tissue processing structure and be capable of receiving and processing high volumes of externally supplied intelligence and data from many types of external sensors and data sources.

This new Tissue Computer must offer all these functions and services under direction and management from a user or application program originating from an external digital computer or device. In addition, the total package must be commercially affordable, meaning all components must be mass producible at low unit production costs and operate dependable, with minimal service intervention for years.

**Creation of TOD™**

In response, BCM initiated Project TOD™ to design, manufacture, and commercialize a Tissue Computer, which included significant, digitally programable, neuron processing capabilities. The ultimate success of Project TOD™ was assured because BCM had already acquired or created all the individual components and elements needed to produce the required Tissue Computer.

The BCM team have decades of experience and skills in all forms of tissue engineering, cell growth, tissue population management, and related tissue computing engineering and technologies, including low-cost mass production of extremely high-density neuron populated tissue structures.

With completed development and recent clinical trials of the Autologous Regenerative Tissue Replacement (ARTR™) organ repair tissue implant process, BCM is arguably a world leader in many areas of advanced tissue engineering. BCM is possibly the only company in the world with the customized manufacturing capabilities to reliably mass produce tens of millions of tissue structures (TC Disks), each populated with up to one million highly active neurons.

This special tissue manufacturing capability is key to producing the required volume of affordable Tissue Computers for rapid flooding of the world markets with TOD™ units. This supports the proclamation that "The Age of Tissue Computing has Arrived™."

**TOD™ Configuration**

As illustrated in Figure 1, TOD™ includes three major components: a Tissue Computer, a Management Computer, and a TOD™ configured laptop computer. For details regarding these components and specifics on the Tissue Computer (TC) processing features, and array architecture, see the Article: "TOD™ Design Production and Service"

TOD™ is commercially offered as a family of general and special purpose neuron processing Tissue Computers. As presented in Table I, the TOD™ family is offered in nine unique Models offering from 16 million to 5 billion neuron powered processing and data storage options.

The TOD™ Model 16 is the smallest, delivering 16 million neurons from a standard sized desktop or floor tower. The next size, the TOD™ Model 48, delivers up to 48 million neurons in a larger floor version or a rack mounted configuration.

The largest TOD™ Model offered, the 5120, can provide a maximum of five (5) billion neurons. Although potentially possible, BCM has not addressed the networking of multiple TOD™ Model 5120 units to obtain larger programable pools of available neurons.

Initially all available TOD™ Models are configured for fixed operations. However, BCM is developing mobile-ruggedized versions of some models. To address this availability time-delay, BCM suggest users requiring mobile-ruggedized versions purchase or lease a fixed operations model, and later swap the fixed Model for a new ruggedized version.

Of the three TOD™ components the Tissue Computer was of course the key development challenge. It had to be an extremely reliable neuron processor constructed of continually nurtured tissue disks (TC Disk), able to be massively populated with neurons. The tissue structures were required to be assembled into processing arrays. The design had to address modularity, an expandable neuron processor architecture, and all internal data transfers had to be over tissue cords (TC Cord), also heavily populated with neurons.

The neuron processor architecture was required to be contained in a medically sterile environment assuring tissue growth and survival, with minimal support for a period of up to seven years.

These tissue creation and assembly capabilities are what BCM has perfected to deliver ARTR™ organ repair tissue implants. The greatest challenge was to deliver a safe and dependable operating environmental for the tissue array and millions of neurons for up to seven years with limited customer participation.

As is apparent, the TOD™ and the Tissue Computer design, architecture, and operations are completely different from the traditional von Neumann digital computer architecture that employs a separated CPU and memory structure, used in digital computers and devices. This new Tissue Computer interfaces with digital computers, but there is no other similarity. Both TOD™ and the Tissue Computer design are totally "Think out of the Box" designs.

**Neuron Processor Performance**

Over the last decade, major computer manufacturers, universities, research organizations, and governments have committed significant resources to advance neuron processing technologies. In 2019 and 2020, both Intel and IBM achieved success in creating an "artificial" neuron chip. [4] [5 [6] [7] [8] [9] [10]

A brief comparison of these currently available Intel and IBM offered neuron processing units, along with the nine TOD™ Models are presented in Table II. The available Intel processors and their neuron capacity are the Pohoiki Beach, 8 million, and the Pohoiki Springs 100 million. The available IBM processor is the TrueNorth, with 64 million neurons.

In contrast, BCM has developed and offers a true neuron processor. TOD™ is available in a family of nine Models, with neuron processing capacities from a low of 16 million in a desktop tower, to 5 billion neurons in Model 5120, the largest rack configuration.

With these new neuron processors, Intel and IBM have demonstrated and validated: (a) digital computers can manage and control the system and application processing using millions of neurons, or artificial neurons, (b) both system operations software and application programs are available or can be developed to utilize these neuron processing capabilities, and (c) neuron processing is both functionally and physically real and the future of processing.

In the TOD™ Tissue Computer design BCM choose to totally avoid the use of chips and motherboard, and instead addressed neuron processing as a standalone, neuron-only Tissue Computer. Because this standalone tissue approach is basically replacing the Intel and IBM “artificial” neurons on a chip, with an actual neuron populated tissue architecture, all the above validations (items (a) thought (c) above), apply directly and fully to TOD™ and the Tissue Computer.

Measuring performance of neuron processing is dependent upon many factors, including the task call sequencing, and processing structure imposed by the operating system and the application program.

However, as a general reference on the performance improvements available from neuron processing, Intel reported their “artificial” neuron processing chip, Loihi, enables users to process information up to 1,000 times faster and 10,000 times more efficiently than CPUs for specialized applications.

How does one comprehend and relate to one thousand times faster? It means a processing task that requires 1,000 seconds (16.7 minutes) on a fast digital computer can be performance in one second on a properly setup neuron processor such as TOD™.

**TC Disks and TC Cords**

The Tissue Computer includes one or more processing arrays. These arrays are assembled from two unique BCM proprietary tissue structures: the TC Disk and the TC Cord. Both the Disk and the Cord are designed and manufactured by BCM using a proprietary collagen scaffolding interactive sequential build and a highly repetitive neuron population embedding process. [11] [12] [13]

The TC Disk addresses all neuron processing and memory activities. Specifically, the Disks function as individual independent neuron processors. The TOD™ system including the programmable Tissue Computer architecture allows individual TC Disks to be programmed and combined into larger neuron processing arrays.

Each TC Cord is an individual segment of the Tissue Computer internal neuron data network. The TC Cord network addresses data transfers and data networking functions for all Tissue Computer internal data and intelligence transfers.

To view the TC Cord networking of TC Disks in the processing arrays and the size and shape of a TC Disk, ready for insertion into a TC Disk populated array in a Tissue Computer, see the Article: “TOD™ Design Production and Service.”

Special TC Cord ports, with embedded or attached data format and data form translator capabilities are employed to transition neuron data into other data forms. BCM is developing plug-in data ports to accept directly sourced data in these formats: digital, optical, audio, video, RF, Inferred, thermal, and seismic. Many of these data format translation technologies and capabilities are currently being developed by BrainGate, Synchron, Neuralink, and others. [14] [15] [16] [17]

Although the TC Disk and TC Cord devices each have different tasks and roles to perform and are physically distinctly different, they are both constructed with neuron populated tissue.

**Installation, Operations, and Maintenance**

All TOD™ Models are sold under a one-year full replacement warranty. That warranty includes the customer on-site delivery and complete professional installation by a TOD™ Support Team. The on-site team assembles, connects, evaluates, and performs full system tests to assure each delivered TOD™ Model fully meets or exceeds all performance standards.

Complete installation is a part of the full TOD™ warranty and support package received with each TOD™ purchase. It is provided to purchasers located in all accessible populated locations around the Globe. Under the warranty and any extensions, this Tech Team Global service coverage also applies to all required on-site warranty service activities.

The TOD™ Tissue Computer includes millions of active neurons. To survive and successfully perform requested processing tasks, these neurons require a conducive sterile environment, controlled temperature and humidity, energy, and other services. The Tissue Computer is constructed to address and provide this operating environment and the required services.

**Utilities, Tools, and Application Programming**

Two of the TOD™ system components are digital computers: the Management Computer and a TOD™ configured laptop computer. There are many general-purpose and specialized digital programming utilities, tools, and application programs available to address these digital segments of the TOD™ system configuration.

Because TOD™ includes the first commercially available Tissue Computer and offers users direct programming access to millions of neurons, one might assume there are no existing and available software utilities, tools, or application programs to operate, manage, and leverage the massive performance capabilities available from TOD™.

That presumption would be incorrect. For more than a decade a growing community of scientist, engineers, and application developers have been building and using software that is focused on neural networks and neuron processing.

The result is that many of the software utilities, tools, and application programs required to manage and control TOD™ are currently available, and many are open source. These programs are either directly TOD™ compatible, or with modification can become a part of the TOD™ and Tissue Computer software users' library.

In addition to many open-sourced groups and communities, IBM and Intel have been joined by Qualcomm, Oracle, Microsoft, Google, and others in offering education and training in neuron processing and coding. To learn more about neuron processing software and the open-source communities, see the Article: "Programming and Controlling a Tissue Computer." Available upon request. [4] [5 [6] [10] [11] [12] [13]

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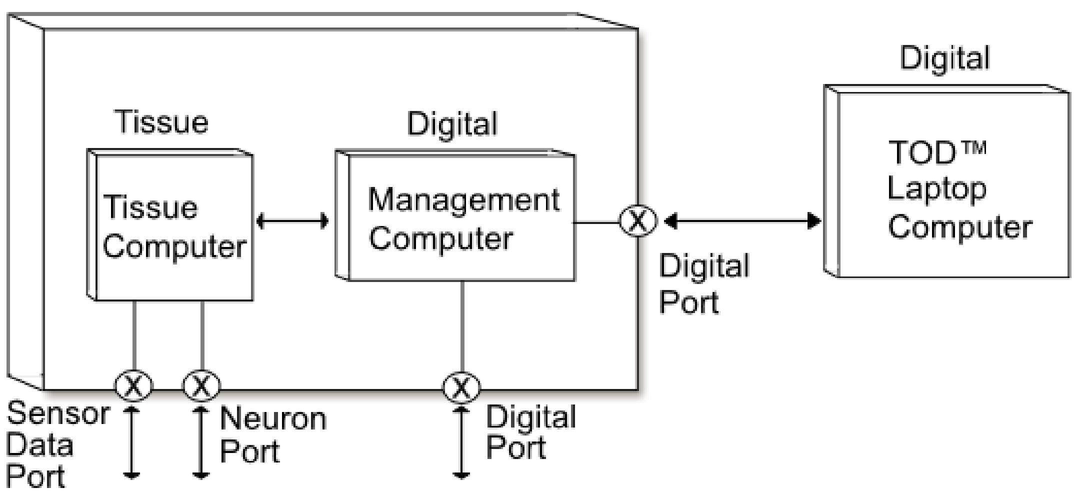
**Figure 1**

**TOD™ System Configuration**



## Table I

# Commercially Available TOD™ Models

| TOD™ Model Number | Max Neuron Capacity (1) (2) | Number of TC Disks | Number of TC Arrays (3) |
|---|---|---|---|
| TOD™ 16 | 16 million | 16 | 1 |
| TOD™ 48 | 48 million | 48 | 3 |
| TOD™ 64 | 64 million | 64 | 4 |
| TOD™ 96 | 96 million | 96 | 6 |
| TOD™ 192 | 192 million | 192 | 12 |
| TOD™ 480 | 480 million | 480 | 30 |
| TOD™ 1024 | 1 billion | 1024 | 64 |
| TOD™ 2048 | 2 billion | 2048 | 128 |
| TOD™ 5120 | 5 billion | 5120 | 320 |

Notes: (1) The actual number of neurons present at any given time will vary due to many factors that affect neuron birth, death, and growth rates. BCM cannot therefore guarantee the number of neurons in any specific TC Disk. However, every BCM manufactured TC Disk has the potential to hold and deliver up to one million neurons.
(2) TC Disk neuron population density is established by tissue and other factors. The human brain has 100 billion neurons in a volume of 1500 cc, or 91.5 cubic inches. Each TC Disk is approximately 2x2x0.5 inches or 2 cubic inches, establishing a maximum capacity of one million neurons per TC Disk.
(3) The Model 16 Tissue Computer planar array has 16 TC Disks in a 4x4 array. The Model 48 cubic array has 48 TC Disks in a 3D structure of a 3 deep 4x4 array. The 3D structure of the cubic array is the bases for all Tissue Computer architectures in the larger TOD™ Models.

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## Table II

# Available Neuron Processor Systems

| Max Neuron Capacity | Intel- Neuron Processors | IBM- Neuron Processor | BCM- TOD™ Model Number |
|---|---|---|---|
| **Up to 20 Million** | Pohoiki Beach<br>8 Million | | Model 16<br>16 Million |
| **Up to 75 Million** | | | Model 48<br>48 Million |
| | | TrueNorth<br>64 Million | Model 64<br>64 Million |
| **Up to 150 Million** | Pohoiki Springs<br>100 Million | | Model 96<br>96 Million |
| **Above 150 Million** | | | Model 192<br>192 Million |
| | | | Model 480<br>480 Million |
| | | | Model 1024<br>1 Billion |
| | | | Model 2048<br>2 Billion |
| | | | Model 5120<br>5 Billion |

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## Appendix A

# Reference Data

BCM is active in moving concepts and research from the lab to commercial production for profit. BCM advancements in tissue engineering, cell growth management, neuron processing and neuron data networks are occurring at an accelerating rate and are therefore far ahead of peered reviewed research literature.

This reference data provides a starting point for further research. Parties seeking additional data, validations, or expanded discussions should contact BCM.

**[1] The computational efficiency of biological neural processing systems**

While Moore's law has driven exponential computing power expectations, its nearing end calls for new avenues for improving the overall system performance. These authors see new alternative brain-inspired computing architectures that promise to achieve the flexibility and computational efficiency of biological neural processing systems

Point: These authors present the problem of digital processing limits and provides a vision for biological neural processing systems. BCM has accepted this challenge and is accepting orders for TOD™, with commencing mass production and commercialized delivery scheduled for late 2022 or early 2023.

Source: Bottom-Up and Top-Down Neural Processing Systems Design: Neuromorphic Intelligence as the Convergence of Natural and Artificial Intelligence (2021)

https://arxiv.org/pdf/2106.01288.pdf

**[2] The Need for Neuron Processing**

Conventional digital processors are limited in processing speed and memory bandwidth. Their performance is inefficient and slow due to the number of required data transfers and energy demanding data movements. Furthermore, they do not possess the intrinsic capabilities to learn or deal with complex data which is available from a neuron processor.

Point: In response, BCM applied established technologies and years of tissue engineering experience, a superb scaffolding construction, cell growth and management manufacturing platform to develop TOD™ which includes a digitally managed and controlled Tissue Computer. Using a BCM developed TC Disk and TC Cord volume tissue production facility, BCM is prepared to commercially deliver neuron processing capabilities to everyone in nine different Models, including a desktop tower.

Source: 2022 Roadmap on Neuromorphic Computing and Engineering

https://arxiv.org/ftp/arxiv/papers/2105/2105.05956.pdf

**[3] Artificial Neural Network**

Over the past decade a large variety of hardware has been designed to exploit the inherent parallelism of the artificial neural network models. Despite the tremendous growth in the digital computing power of general-purpose processors, neural network hardware has been found to be promising in some specialized applications, such as image processing, speech synthesis and analysis, pattern recognition, high energy physics, and others.

Point: To address large processing applications, the computer industry and users are keenly aware of the finite capabilities of a digital processor. They are seeking a solution and aware neuron processing is the likely answer. BCM has responded with TOD™ and can attest a digital controlled and managed neuron processor offers a viable solution.

Source: Neural Networks in Hardware: A Survey

http://apt.cs.manchester.ac.uk/intranet/csonly/nn/NNHSurvey.pdf

**[4] Intel Moves to Neuron Processing**

Intel Labs' second-generation neuromorphic research chip, codenamed Loihi 2, and Lava, an open-source software framework, will drive innovation and adoption of neuromorphic computing solutions. Enhancements include-

Up to 10x faster processing capability
Up to 60x more inter-chip bandwidth
Up to 1 million neurons with 15x greater resource density
3D Scalable with native Ethernet support
A new, open-source software framework called Lava
Fully programmable neuron models with graded spikes
Enhanced learning and adaptation capabilities

Point: Intel, a major player in new chip development and manufacturing, is producing artificial neuron processors, controlled, and managed by a digital motherboard and digital software. With these chips, Intel has validated the success of digital-neuron data and intelligence exchange, and established software utilities, tools, and application programs to operate in a neuron processing environment.

The BCM development of TOD™ is commercially and technology consistent with the neuron processing advancement efforts by Intel. The difference is TOD™ uses a Tissue Computer for neuron processing and is not constrained by the corporate need to produce a processing chip that resides on a digital motherboard.

Although Intel chips are artificial neuron processors, the software developed to operate and support these chips is likely directly portable to TOD™ providing usable utilities, tools, and application programs

Source: Loihi 2:  A New Generation of Neuromorphic Computing

https://www.intel.com/content/www/us/en/research/neuromorphic-computing.html

Source: Taking Neuromorphic Computing to the Next Level with Loihi 2 Technology Brief

https://www.intel.com/content/www/us/en/research/neuromorphic-computing-loihi-2-technology-brief.html

**[5] Intel 8 million-neuron neuromorphic system**

During July 2019, Intel announced that an 8 million-neuron neuromorphic system comprising 64 Loihi research chips, codenamed Pohoiki Beach, was available to the broader research community. With Pohoiki Beach, researchers can experiment with Intel's brain-inspired research chip, Loihi, which applies the principles found in biological brains to computer architectures. Loihi enables users to process information up to 1,000 times faster and 10,000 times more efficiently than CPUs for specialized applications like sparse coding, graph search and constraint-satisfaction problems. This 2019 effort was followed by Pohoiki Springs, an improved version of Pohoiki Beach.

Point: Pohoiki Beach is a research community accessible computer, there is no data indication it is  a commercially available system at an affordable price. Intel linked 64 Loihi research chips together, each with 125,000 neurons, to obtain an 8 million-neuron processor. In contrast TOD™ uses real, "not artificial," neurons to deliver neuron processing. At a low cost just $600,000, TOD™ Model 16, in a standard desktop tower the smallest commercially offered TOD™ Model, delivers the user 16 million neurons. These Intel efforts added validation the TOD™ Project and increased the volume of neuron processing software available for Tissue Computers users and the neuron application developer community.

Source: Intel Newsroom Post - Intel's Pohoiki Beach, a 64-Chip Neuromorphic System, Delivers Breakthrough Results in Research Tests

https://newsroom.intel.com/news/intels-pohoiki-beach-64-chip-neuromorphic-system-delivers-breakthrough-results-research-tests/#gs.lzowcq

**[6] Intel 100 million-neuron Pohoiki Springs Cloud service**

During March 2020 Intel announced Pohoiki Springs, its latest and most powerful neuromorphic research system providing the computational capacity of 100 million neurons. The cloud-based system will be made available to members of the Intel Neuromorphic Research Community (INRC), extending their neuromorphic work to solve larger, more complex problems. Pohoiki Springs is a data center rack-mounted system and is Intel's largest neuromorphic computing system developed to date. It integrates 768 Loihi neuromorphic research chips inside a chassis the size of five standard servers.

Loihi processors take inspiration from the human brain. Like the brain, Loihi can process certain demanding workloads up to 1,000 times faster and 10,000 times more efficiently than conventional processors.

Point: The points presented in Reference [5] for Pohoiki Beach, apply. Note the largest commercially available TOD is Model 5120, which delivers up to 5 billion neurons, in a rack configuration that can be installed in any data center site a customer desires.

In competition with the Intel Pohoiki Springs cloud service, TOD™ Model 96 delivers up to 96 million neurons, and the Model 192, up to 192 million neurons. Both are offered commercially for purchase and can be installed at any customer site. In addition, both the Model 96 and Model 192 offer software programming conversion of each Model into a Full Dup Real-Time Parallel Processing configuration.

The Intel reported size and performance data on both Pohoiki Beach and Pohoiki Springs cloud service totally validates that computer chips, no matter how enhanced, on a digital motherboard will ever achieve TOD™ levels of performance.

Source: Intel Newsroom Post - Intel Scales Neuromorphic Research System to 100 Million Neurons

https://newsroom.intel.com/news/intel-scales-neuromorphic-research-system-100-million-neurons/#gs.m6m007

**[7] IBM Builds 64 Million Neuron Processing Computer System**

The IBM TrueNorth Neurosynaptic System can efficiently convert data (such as images, video, audio, and text) from multiple, distributed sensors into symbols in real time. Powered by a 64-chip array of the IBM TrueNorth Computer will feature an end-to-end software ecosystem designed to enable deep neural-network learning and information discovery. The system's advanced pattern recognition and sensory processing power will be the equivalent of 64 million neurons.

Point: IBM, producer of the original IBM 360, with the creation of artificial neuron processor chips has moved into neuron processing. Like Intel, it appears IBM corporate management cannot visualize data processing without chips and motherboards.

However, development of the TrueNorth Computer has validated at least four areas of interest to BCM and TOD™. Their efforts have validated: (a) digital and neuron data and interfaces can successfully exchange intelligence and data, (b) a digital processor and associated system and application software can successfully direct tasks, and manage the operations of a single and an array of neuron processors, (c) software operating systems, utilities, tools, and application programs can be created to maximize the capabilities and features available from neuron processors, and (d) artificial neuron processor chips on a motherboard, no matter how enhanced, will never achieve the levels of performance available from the TOD™.

Source: Next Big Future: US Air Force buying IBM 64 million neuron computer

https://www.nextbigfuture.com/2017/06/us-air-force-buying-ibm-64-million-neuron-computer.html

**[8] IBM Creates Artificial Neurons**

IBM scientists have created artificial neurons and synapses using phase change memory (PCM) that mimics the brain's cognitive learning capability.

Point: The beginning of the establishment of artificial neuron chips computing era. This technology resulted in the development of many neuron processing coding utilities, tools, and application programs which are applicable to TOD™ operations.

Source: IBM creates artificial neurons from phase change memory for cognitive computing

https://www.computerworld.com/article/3103294/ibm-creates-artificial-neurons-from-phase-change-memory-for-cognitive-computing.html

**[9] IBM and Neural Networks**

Neural networks reflect the behavior of the human brain, allowing computer programs to recognize patterns and solve common problems in the fields of AI, machine learning, and deep learning.

Point: The support of neural networks by IBM has resulted in more awareness in neuron processing and aid in more independent development of neuron processing software. This is a major benefit to TOD™.

Source: IBM Cloud Education

https://www.ibm.com/in-en/cloud/learn/neural-networks

**[10] Artificial Neuron Chips Successes and Challenges**

Being able to wrap a common deep learning framework on top, scaling it across multiple high core count chips, and providing a useful programming interface are all keys of bringing a research product into the mainstream.

In other words, scaling any chip without taking a performance hit is a tough problem but these chip company designers have cobbled together some code that automatically routes the best spot for data on each chip, and trying to assure the data transfer between each is fast, not an easy task on a motherboard.

Being able to wrap a common deep learning framework on top, scaling it across multiple high core count chips, and providing a useful programming interface are all keys of bringing a research product into the mainstream.

Some of the leaders chasing this artificial neuron approach include IBM, Intel, Graphcore, BrainChip, and others.

Point: All these companies pursuing artificial neuron chips have recorded development successes, but more importantly they have technically and scientifically established the ability to marry digital processing with neuron processing and produce positive results. This group has also created the foundational software utilities, tools, and application programs for a library of software to support the continuing growth in neuron-based processing applications and to support and operate TOD™.

Source: A Rare Peek into IBM's TrueNorth Neuromorphic Chip

https://www.nextplatform.com/2018/09/27/a-rare-peek-into-ibms-true-north-neuromorphic-chip/

Graphcore is a British semiconductor company that develops accelerators for AI and machine learning. It aims to make a massively parallel Intelligence Processing Unit that holds the complete machine learning model inside the processor.

Source: Graphcore website

https://www.graphcore.ai/

BrainChip is a global technology company that is producing a groundbreaking neuromorphic processor that brings artificial intelligence to the edge in a way that is beyond the capabilities of other products.

Source: BrainChip website

https://brainchipinc.com/

**[11] Collagen- Material of Choice for TC Disk and TC Cord Production**

With its wide distribution in soft and hard connective tissues, collagen is the most abundant of animal proteins. Natural collagen can be formed into highly organized, three-dimensional scaffolds that are intrinsically biocompatible, biodegradable, non-toxic upon exogenous application, and endowed with high tensile strength. These attributes make collagen the material of choice for tissue engineering applications

Collagen by virtue of its ubiquity, low immunogenicity, and ability to be molded into strong, biocompatible scaffolds are accessible, persistent, and versatile. Moreover, collagen-based materials are adroitly at the interface of natural and synthetic macromolecules.

Point: BCM has years of experience using bovine collagen in all types of tissue engineering applications, including tissue construction of TC Disks and TC Cords.

Source: Collagen-Based Biomaterials for Wound Healing

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8408697/pdf/in_vivo-35-2541.pdf

**[12] Nerve Tissue Scaffolds and Successful TC Cord Network Assembly**

Nerve Tissue scaffolds have been constructed and successfully used to repair severed spinal and nerve cords with digital nerve gaps exceeding 3 cm in length.

Point: Validation of collagen scaffolding in the construction of TC Cords, the successful merging of existing and newly created nerve tissue, and the successful interfacing and data-intelligence transfers between newly connected and cell merged nerve tissue. These results demonstrate the ability for BCM to construct, and for TOD™ to successfully operate a TC Cord network within the Tissue Computer

Source: Peripheral nerve repair and reconstruction

https://pubmed.ncbi.nlm.nih.gov/24306702/

**[13] Nerve Tube Imbedded Collagen Scaffolding Delivers Neuro Functionality**

Collagen scaffolding structures can successfully provide neuron pulse transfer functionality in nerve conduit tubes. They have established a stable and as a long-lasting primary structure demonstrated superior quality and sufficient cytocompatibility.

Point: Research and medical science has validated nerve conduit with imbedded collagen scaffolding, heavy populated with neurons (nerve cells), will move neuron data through the nerve conduit and provide robust service and survivability. Nerve conduit with imbedded collagen scaffolding, heavy populated with neurons is the definition of a TC Cord.

Source: In Vitro and Ex Vivo Analysis of Collagen Foams for Soft and Hard Tissue Regeneration (2021)

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8408697/pdf/in_vivo-35-2541.pdf

**[14] BrainGate Demonstrates Wireless Neuron to Digital Data Transfer**

This event was a demonstration of high-resolution broadband recording from multiple implanted microelectrode arrays using a wireless intracortical BCI in human subjects.

Point: Validation of a third-party digital-neuron data transfer device. These types of data transfer technologies are an integral part of the operations of the Tissue Computer and TC Cord network interfacing with a digital device.

Sources: Researchers demonstrate first human use of high-bandwidth wireless brain-computer interface

https://www.brown.edu/news/2021-03-31/braingate-wireless

Home Use of a Percutaneous Wireless Intracortical Brain-Computer Interface by Individuals with Tetraplegia (2021)

https://ieeexplore.ieee.org/document/9390339

**[15] BrainGate2 Decodes Neural Signals**

A brain-implant system trained to decode the neural signals for handwriting from a paralyzed man enabled a computer to type up to 90 characters per minute with 94 percent accuracy.

Point: Validation of a third-party digital-neuron data transfer device. These types of data transfer technologies are an integral part of the operations of the Tissue Computer and TC Cord network interfacing with a digital device.

Source: Brain-Computer Interface User Types 90 Characters Per Minute with Mind (2021)

https://www.the-scientist.com/news-opinion/brain-computer-interface-user-types-90-characters-per-minute-with-mind-68762

Source: BrainGate2: Feasibility Study of an Intracortical Neural Interface System for Persons With Tetraplegia

https://www.clinicaltrials.gov/ct2/show/NCT00912041

**[16] Synchron Demonstrates Neuron to Digital Data Transfer**

A patient implanted with the Stentrode brain computer interface successfully messaged the world on social media directly through thought using an implantable brain computer interface.

Point: Validation of a third-party digital-neuron data transfer device. These types of interfacing and data transfer technologies are an integral part of the operations of the Tissue Computer and TC Cord network interfacing with a digital device.

Source: Business Wire/Via AP (12-27-21)

https://warroom.org/2021/12/27/synchron-announces-first-direct-thought-tweet-hello-world-using-an-implantable-brain-computer-interface/

**[17] Neuralink Interface to Directly Control Digital Devices**

The Neuralink app is planned to allow direct control of an iOS device, keyboard, and mouse directly with the activity of the brain, just by thinking about it. Animal studies have been successful. Elon Musk reports approved user availability to be late 2022.

Point: Validation of a third-party digital-neuron data transfer device. These types of data transfer technologies are an integral part of the operations of the Tissue Computer and TC Cord network interfacing with a digital device.

Source: Neuralink website

https://neuralink.com/approach/

**[18] Qualcomm Neural Processing**

The Qualcomm Neural Processing SDK provides tools for model conversion and execution as well as APIs for targeting the core with the power and performance profile to match the desired user experience. The Qualcomm Neural Processing SDK supports convolutional neural networks and custom layers.

Point: Another large digital company in the neuron processing environment and a potential source for neuron processing utilities, tools, and application programs.

Source: Qualcomm Developer Network

https://developer.qualcomm.com/software/qualcomm-neural-processing-sdk

**[19] Oracle and Neuron Data Bases**

Oracle 18c Database brings prominent new machine learning algorithms, including Neural Networks and Random Forests.

Point: Oracle has focused on Neural Networks but many of these developed application programs, data base structures and tools are applicable to TOD™ and Tissue Computers.

Source: Understanding, Building and Using Neural Network Machine Leaning Models using Oracle 18c

https://developer.oracle.com/databases/neural-network-machine-learning.html

Source: Concepts - Neural Network

https://docs.oracle.com/en/database/oracle/oracle-database/18/dmcon/neural-network.html#GUID-C45971D9-A874-4546-A0EC-1FF25B229E2B

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