CJ. W.Grey Walter: Biographical Essay. Encyclopedia of Cognitive Science(2003) 4: 537-539.

Grey Walter
Neuroscience
Biography
autonomous robots#electroencephalography#goal-seeking#nonlinear brain dynamics#scanning
Walter J. Freeman
University of California at Berkeley, USA

An autonomous robot embodies the principles of goal-seeking and scanning that characterize animal behavior. Grey Walter, a physiologist adept in electronics engineering with major accomplishments in early electroencephalography, used his wartime exposure to radio detection and ranging (RADAR) to build a simple 'brain' that endowed his artificial 'turtle' with complex adaptive behaviors.

Introduction

Nobel-winning Sir Winston Churchill in his history of the Second World War wrote a chapter on the "wizards" who had helped Britain win the war in the air by the development and use of radar. William Grey Walter (1910-1977) was one of those young wizards. He used his experience to design and construct a life-like robot with a nonlinear dynamic brain, which offered an existence proof that brains are simpler than many of us have supposed.

Biomedical Engineering

In the decade before the war Grey Walter had already done important work in a field we now call biomedical engineering by his discoveries in electroencephalography (EEG), a medical procedure in which the oscillating fields of electric potential on the scalp and in the brain are measured and interpreted. His first achievement was to identify correctly the source of the alpha rhythm (8-12 Hz). A German psychiatrist Hans Berger in 1929 had discovered brain waves by attaching one electrode to the forehead and another to the back of the head. He used a primitive Fleming electronic 'valve' ('vacuum tube' for Americans, the predecessor of the transistor) to amplify the potential difference. He erroneously inferred that alpha came from the frontal lobes. Walter used his knowledge of the theory of potential, volume conduction, and electronics to triangulate the waves and locate their source in the occipital lobe. He also invented the use of low frequency delta waves (1-2 Hz) to locate brain tumors and abscesses, as well as foci of brain damage that triggered bouts of epileptic activity, then widely known as 'paroxysmal cerebral dysrhythmias'.

After the war he gathered a group of young engineers along with surplus radar, radio, and other electronic equipment to work in a laboratory at Bristol University, which rapidly became one of the world's leading centers for EEG research. One of their achievements was automated spectral analysis of EEG traces. A standard method for EEG analysis since its discovery has been to measure the power in various frequency bands, including alpha and delta, also beta (15-30 Hz) which Berger identified as the carrier of brain information, and theta (3-7 Hz) as well as alpha which he concluded were gating frequencies of packets of brain information. Walter used his skills in analog electronics to conceive a device built by engineers that displayed the frequency content in an EEG trace, even as the trace was displayed with an ink-writing oscillograph, a pen whose fluctuations left a trace on moving paper that became the mainstay of electroencephalographers.

Another notable discovery was a very slow change in electrical potential at and around the vertex of the head, measured with respect to indifferent reference points such as the ear lobes. Walter named this event the contingent negative variation (CNV), because it was seen only after a warning signal had been given to a human subject, who would then plan a possible movement in anticipation of a second signal. German researchers discovered a comparable slow potential in a similar behavioral context, calling it the Bereitsschaftpotential ('readiness potential'). The intriguing aspect of these electrical potentials is that they permit the observer to predict that a subject will make a response within the next half to one second, before the subject is aware of an intention to act. Some psychologists regard this cerebral phenomenon as evidence that intentional actions are initiated before awareness of such actions emerges, and that consciousness is involved in judging the values of actions rather than in the execution of them. Simply put, we learn what sort of person we are by observing not our good intentions but our own actions, which often surprise us.

Walter extended his temporal spectral analysis of time series to spatial analysis by conceiving a bank of amplifiers connected to an array of 22 oscilloscopes. This advance enabled him to show not only the amplitude but the phase difference of each trace of the alpha with respect to the others, by using cinemas of the oscilloscopes. With his 'toposcope' he visualized the spread of alpha waves across the surface of the brain in ways resembling the ebb and flow of tidal waves around the earth. Alpha activity has the peculiarity that it is most apparent when a human subject is at rest with eyes closed, and it disappears when the eyes are opened or if mental arithmetic is undertaken. Walter proposed that the alpha represented 'scanning' by the brain in search of local centers of activity when none was present, and that it stopped when a 'target' was found in the cortex. This 50 year old hypothesis was and still is controversial, but it is still not disproven.

Autonomous, adaptive robots

Walter's greatest achievement stemmed from his wartime experience with electronics (Figure 1). Guided missiles with proximity fuzes then were one of two very active foci of interest, the other being devices for scanning the horizon for targets to be identified and intercepted. The scanning mechanism he helped develop was known as the 'plan position indicator', consisting of the point of light created by an electron beam that moved from the center to the edge of the oscilloscope screen and created a bar like the spoke of a wheel. The spoke rotated counterclockwise at the refresh rate of the screen. A likely radar target appeared as a bright spot, giving its direction and distance. This device is in widespread use today, for example, in ships, submarines, and air traffic control centers. It was the basis for Walter's toposcope when applied to alpha waves.

Walter had a very rich, speculative imagination. The concept of a machine that would define a goal and seek it by scanning resonated with his interest in brains as biological systems that evolved through learning from the consequences of their own goal-oriented actions. He undertook to incorporate these two cognitive operations, goal-seeking and scanning, into an electronic 'toy' that would simulate these most basic characteristics of animal (and human) behavior.

The outcome was fully spectacular, though at the time its significance was not recognized, and his device has been all but forgotten. It was a roving machine so life-like, as he described it in his book, "The Living Brain", that an old lady who felt pursued by it ran upstairs and locked her door.

He named his device *Machina speculatrix* in order to distinguish it from passive devices, such as his earlier conception of *M. sopora* that incorporated Norbert Wiener's principle of stabilization of machine performance by negative feedback ("*Cybernetics*"), and from W. Ross Ashby's '*Homeostat*' that extended the principle of the stability of biological organisms by introducing adaptation through learning. These stable models used what the Harvard physiologist Walter Cannon called "homeostasis", but unlike plants and sessile automata, *M. speculatrix* was continually on the prowl in search of its designer-endowed goal: moderate illumination. His three-wheeled vehicle, which came to be known as "Grey Walter's turtle", had two motors, one for progression by the front wheel dragging the hind wheels like a child's tricycle and one for turning the front wheel. Its drive system, batteries and 'brain' were mounted on a chassis. Above it he hung a carapace from a center pole, so that it could swing inwardly from any direction and contact the chassis. This contact operated a switch, so that if the tortoise hit an obstacle or encountered an incline, it would stop, back up, turn, and eventually move around it or avoid it altogether. This 'receptor' gave the device the sense of touch, information about the direction of gravity, and the means to explore objects in its environment by touch.

He also gave *M. speculatrix* a photocell for sensing light, and designed its circuits to use homeostatic feedback to seek and maintain a moderate level of illumination, which varied with its location and orientation but also with the charge in its two batteries. Its hutch was brightly lit, and when its batteries were fully charged, that level was aversive, so it moved out into its contracted world, continually swinging in cycloid loops first away from the light, then, as its batteries ran down back toward the light in its hutch [Figure 2]. In a single charge cycle it could explore nearly 100 square meters, dealing with obstacles by pushing them aside or going around them, though sometimes straying too far and being found "starved to death" behind a couch. When it regained its hutch it turned itself off and took nourishment from electrical contacts on the floor.

As a means for detecting the internal state, Walter fixed a marker light on the carapace that stayed on when the turning motor was on but went out when turning stopped. When the tortoise encountered its own light in a mirror, it stopped and oriented to its own light, but stopping turned out its light . Then it resumed circling, saw its light again, and stopped. This behavior continued until it had passed the mirror. If it encountered another of its own kind, attracted by the other light, a stately dance ensued of bumping and backing. Walter thought that these behaviors expressed self recognition and recognition of conspecifics.

These complex and not fully predictable behaviors of exploration, negative and positive tropism, discrimination, adaptation to changing internal and external environments, optimization, and stabilization of the internal medium were done with a very simple brain: two miniature valves serving as 'neurons', two mechanical relays, two capacitors, two receptors, and two motors. Walter achieved this by ingenious circuit design. For example, when the tortoise was in search mode, the two valves served as serial amplifiers. When it hit an obstacle, the circuit changed to an oscillator, then called a 'multivibrator', which generated the repetitive backing and butting. He went further with new circuitry, which he called the "conditioned reflex analog" (CORA), to simulate the seven operations he identified in the formation of associative conditioned reflexes. He proposed to embody CORA in a more highly evolved *Machina docilis* ("easily taught") that could learn to go around an obstacle and would then continue to circumvent it after it had been removed. He used *M. docilis* in several prototypic variants to explore different types of memory and the importance of high frequency oscillations, such as the beta activity he had observed in EEGs, for enriching memory stores. His career was cut short by his tragic motorcycle accident, in which he sustained massive brain damage, leading to his death 7 years later.

Evaluation and Summary

The significance of Walter's achievements can be understood by recognizing that these complex adaptive behaviors came not from a large number of parts, but from a small number ingeniously interconnected. His devices were autodidacts that could learn by trial and error from their own actions and mistakes. They remembered without internal images and representations. They judged without numbers, and recognized objects without templates. They were the first free-ranging, autonomous robots capable of exploring their limited worlds. They still provide a high standard of accomplishment. The reason is that, despite major advances in locomotion particularly in simulations of bipedal, quadripedal and hexapedal gaits based on birds, mammals and insects, and despite advances in scanning and navigation that improve robotic comprehension of operating territories, less has been done towards implementation of goal-seeking. The essence of an intelligent machine is that it has within its brain a capacity to conceive desired future states, and it has the degrees of freedom needed to create and adapt its actions in pursuit of those goals in the unpredictable circumstances of the immediate and remote environments. These flexible brain functions that enable simple systems to function in infinitely complex environments are not achieved by rule-driven symbol manipulation, which is at the heart of cognitive science and conventional artificial intelligence. Morover, Walter emphasized analog electronics to simulate neurodynamics at a time when most of his colleagues such as John von Neumann were developing digital computers to implement symbolic logic and deep arithmetic algorithms. His devices were the forerunners of currently emerging machines that are governed by nonlinear dynamics, and that rely on controlled instability, noise, and chaos to achieve continually updated adaptation to ever-changing and unpredictable worlds. He can well be said to have been the Godfather of truly intelligent machines.

Further reading:

Ashby, W. Ross (1952) Design for a Brain. London: Chapman and Hall.
Cannon, Walter B. (1939) The Wisdom of the Body. New York: W. W. Norton.
Churchill, W. S. (1949) The Second World War. Vol. 2: Their Finest Hour. Ch. 4: The Wizard War. Boston: Houghton Mifflin.
Clark, Andy (1996) Being There. Putting Brain, Body, and World Together Again. Cambridge MA: MIT Press.

Freeman, Walter J. (1999) How Brains Make Up Their Minds. London: Weidenfeld & Nicolson.
Hendriks-Jansen, Horst (1996) Catching ourselves in the act: Situated activity, interactive emergence, evolution, and human thought. Cambridge, MA: MIT Press.
von Neumann, John (1958) The Computer and the Brain. New Haven, CT: Yale University Press.
Walter, W. Grey (1953) The Living Brain. New York: W. W. Norton.
Wiener, Norbert (1948) Cybernetics; or, Control and Communication in the Animal and the Machine. New York: Wiley.
Textual history: http://www.uwe.ac.uk/facults/eng/ias/gwonline.html
Illustrations: http://www.uwe.ac.uk/facults/eng/ias/gwarkive.html

Figure 1. Grey Walter at work.

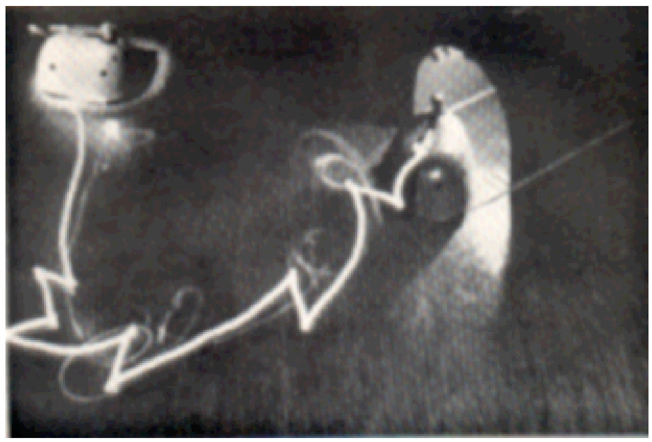

Figure 2. " '... moderation gives place to appetite.' Speculatrix finds her way home." The progress of the turtle about the size of a football is shown by a double exposure and by the trail of light that shows the looping cycloid by which it moved toward the illuminated hutch with its front steering-driving wheel. From Walter (1953, Fig. 15) with permission of the publisher.

Glossary

conditioned reflex - The reaction of an animal (including a human) to a stimulus that does not elicit a response until that stimulus has been followed within about a second by a rewarding or punishing stimulus, such as salivation to a bell after the sound has been paired with food. The mechanism requires cortex in animals, but it does not require consciousness or thought.

contingent negative variation (CNV) - An electrical potential difference measured as a voltage between the top of the head and the earlobes in humans. It rises slowly, starting about a second before a person makes an intentional movement, such as closing an electrical switch at will, and about half a second before the person becomes conscious of his or her own intention to act, indicating that willed actions begin before awareness of them.

cortex - The outer shell of the cerebrum, which in vertebrates has the paired lobes and wrinkled surface resembling a walnut, and which consists of layers of neurons densely packed and interconnected by their filaments called axons and dendrites. All animals with intelligent behavior have some form of cortex; those without any cortex have only conditioned reflexes and homeostatic processes.

electroencephalogram (EEG) - the small electrical potential differences found in and on the cortex and at the overlying scalp and measured in microvolts (millionths of a volt). The potentials fluctuate at frequencies between 0.1 and 100 Hz, so they are commonly known as 'brain waves'. They slow down in deep sleep and speed up on arousal, as well as in dream sleep known as REM for rapid eye movements.

goal-seeking - a form of behavior in which a future state is predicted by conception, imagination, or retrieval from memory. The behavior characterized by flexible and adaptive actions that are shaped and directed by that prediction. All animals show this, as well as some robots such as heat-seeking guided missiles.

homeostasis - a physiological process by which a physical state or chemical concentration in the body is maintained at a constant level called a 'set point' by negative feedback. For example, deviation from normal of body temperature is sensed by receptors in the brain, which trigger reflex panting and sweating if the deviation is above normal, and shivering or blanching to conserve heat if the deviation is below normal. The set point can be changed; for example, it is raised in fever.

multivibrator - an electronic device that has two amplifiers, each connected to the other in such a way as to shut the other one down. In a nervous system the equivalent circuit is known as 'mutual inhibition'. It is a type of circuit that can sustain cyclical behavior such as respiration and locomotion.

scanning - a form of behavior (sniffing, looking, listening, palpating) by which a sensory stimulus is sought or expected, and which is guided by an expectancy of input instead of a future internal state (goal). The search must be broad in the sense of looking everywhere, but narrow in the sense of being specific as to the characteristics of the anticipated stimulus, which implies that the search is guided by memory of past experience, as distinct from a predicted goal or automatic guidance by a set point (see homeostasis).

spectral analysis - a method for breaking down ('decomposing') a complex wave form into frequency bands and measuring the energy in each band. For example, records of brain waves (EEG) are analyzed into the magnitudes of waves in the bands of delta (0.1-2 Hz) theta (3-7 Hz), alpha (8-13 Hz), beta (14-30 Hz) and gamma (30-100 Hz). The same techniques are used to analyze colors in the rainbow, speech, bird calls, whale songs, etc.

stimulus - A packet of energy such as a light flash, sound, touch, smell, or vibration that is usually directed toward just one sense. In the laboratory it is a kind of probe that is brief, precisely located in space and time, and textured in varying degree from simple (light flash) to complex (a face). Its purpose is to control the input to a person or animal while recording a brain state or motor response that is specific to that input, in order to deduce how the brain processes inputs through its various sensory channels.