By PETER NAUR, *recipient of ACM's 2005 A.M. Turing Award*

Computing Versus Human Thinking

In this presentation I shall give you an overview of my works from the past fifty years concerning the issue given in the title. Concerning this title I invite you to note particularly the middle word, 'versus'. This word points to the tendency of my efforts around this theme, to wit, to clarify the contrast between the two items, computing and human thinking. This tendency of my work has found its ultimate fulfilment in my latest result, which is a description of the nervous system showing that this system has no similarity whatever to a computer.

It is ironic that my present award lecture is given under the title of Turing. As a matter of fact, one part of my work concerning computing and human thinking has been an explicit critique, or rejection, of the ideas of one prominent contribution from Alan Turing—his presentation of what is known as the Turing Test [56, 31-1986] (References appended by the year refer to works authored by the present author.)

Such rejection of notions currently held to be well established has been an important component of my efforts. Indeed, I have found that a large part of what is currently said about human thinking and about scientific and scholarly activity is false and harmful to our understanding. I realize that my presentation of some of these issues may be offensive to you. This I regret, but it cannot be avoided.

DESCRIPTION AS THE CORE ISSUE OF SCIENCE AND SCHOLARSHIP

The tone of critique and rejection of established ideas has its roots in my earliest activity, from its very beginning more than fifty years ago. Already in my work in astronomy, around 1955, a decisive item in my awareness came from Bertrand Russell's explicit rejection of any notion of *cause* as a central issue of scientific work. As pointed out clearly by Russell, science as pursued by astronomers is concerned, not with causes, not with logic, but with *description* [53].

When about this time I got into computing, into the work on establishing the programming language Algol 60 [2], I saw the crucial issue to be description.

Consequently my principal contribution to this work was the development of a new form of description, continuing the work of John Backus [1], and the application of this form to describing the programming language adopted by the Algol committee. This new form of description was an indirect critique against the form of description employed in the earlier version, so-called Algol 58. It was first presented in a working document to the Algol 60 conference in Paris in January 1960 [8-1960]. The discussions leading to Algol 60 were later described by Perlis [51] and in [24-1981].

Compiler Design

During the following years I got mostly engaged in the design of compilers for Algol 60. My main contribution was the design, together with Jørn Jensen, of the Gier Algol compiler [9-1963]. The success of this design rested directly on taking the primary issue in the design of a compiler to be, not syntactic analysis, but storage allocation. The Gier Algol compiler had 9 translation passes. During execution the translated program was held in a paging system.

Some of the techniques of the compiler were described separately in [10-1965, 12-1965, 15-1966].

Techniques of Programming and Program Description

In the following years I entered the discussions of the problems of programming of computers and on establishing computing as an academic subject. I suggested that the most proper designation of such a subject would be, not computer science, but *datalogy,* that is the study of data and data processes [13-1966, 16-1968]. This was adopted by Copenhagen University, where the field under that designation was established in 1969. I presented the subject in textbook form in [20-1974].

In the papers [14-1966], [18-1969], and [22-1976], I presented programming techniques aiming at enhancing the programmer's understanding of the program he is constructing. In [14-1966] I suggested that one main issue is the question of *description of algorithms and programs* and propose that the description in terms of a programming language be supplemented with what I call general snapshots, that is *descriptions in the form of statements of relations holding between the values of the relevant variables at definite points of the program*. With the aid of such snapshots formal arguments and proofs concerning the values of the variables will be possible, but far more important, general snapshots are invaluable as aids to the human reader. In [18-1969] I described a discipline, programming by action clusters, that help the programmer's understanding by making relations concerning the variables hold invariantly throughout the program text. In [22-1976] I described how formulating the program as an interpreter of control records may enhance both the efficiency and the programmer's understanding of certain common types of programs.

One use of general snapshots is demonstrated in a later work in which I apply them to Turing's universal machine [55, 37-1993]. As a result I found several programming errors in Turing's program.

Problems of program development were brought forward particularly during the Conference on Software Engineering in October 1968 and in the report on that conference to which I, together with Brian Randell, contributed as editor [17-1969].

During the following years the discussions became centred particularly on ideas of so-called structured programming and on claims for so-called formal specifications of programs. I contributed to this discussion with empirical studies of the programming activity and of such formalizations that may be found in the mathematical literature and in program specifications as they have appeared in publication, including a formal description of Algol 60 [19-1972, 23-1981, 25-1982, 26-1983, 30-1985]. By these studies I succeeded in demonstrating that the claims for the advantages of formal specifications as a tool to human programmers are unjustified.

As a major result of these studies I described programming as a human activity: theory building [27-1985]. By this description the core of programming is the programmer's developing a certain kind of understanding of the matters of concern.

Descriptions of Mental Life

My work on the programming activity led me directly to a consideration of related aspects of mathematics and natural languages, and thus of psychological and philosophical issues of human thinking [11-1965, 21-1975, 34-1989].

In this context I had occasion to examine a number of newly published works on such topics as machine or artificial intelligence and cognitive science, by contributing reviews of works on such topics to the *Computing Reviews* [28-1985, 29-1985, 32-1988, 33-1989, 38-1993].

Through this reviewing activity I found confirmed time after time that present-day authors argue about mental life from totally defect, confused cognitivist notions, in terms such as 'consciousness', 'knowledge', 'language', 'intelligence', 'concept', that denote nothing clearly, and moreover that William James's insight into human mental life as presented in his *Principles* *of Psychology* [5] is unknown. I gradually came to realize that the whole field of psychology, which supposedly is concerned with mental life, during the twentieth century has become entirely misguided into an ideological position such that only discussions that adopt the computer inspired form of description of mental life is accepted, while any other form, including the form developed by William James in his *Psychology,* is rejected as inadmissible and unpublishable. So as to clarify this extraordinary situation of psychology I engaged from 1986 into a series of studies.

In one study I subjected Turing's paper on the so-called Turing Test [56] to a thorough critical analysis [31-1986], resulting in a conclusion by which Turing's whole argumentation is invalid, the basic reason being that Turing argues from a fallacious notion of thinking, as something done by somebody or something. This notion is contradicted by what William James [5] states as the first fact of psychology, to wit, that thinking is something that goes on.

Knowing

Under the influence of my recurrent experience that the argumentation in recent discussions related to human knowing is defect, I decided to carry out a more systematic study of the significance of formalization, logic, and rules, in discussions of human thinking, linguistic activity, computing, and scientific/scholarly activity. The result was two papers, [39-1994, 45-2000], and a book titled *Knowing and the Mystique of Logic and Rules* [42-1995].

In this book human knowing is examined as it emerges from classical empirical psychology, with its ramifications into language, computing, science, and scholarship. While the discussion takes empirical support from a wide range, claims for the significance of logic and rules are challenged throughout. Highlights of the discussion:

- Knowing is a matter of habits or dispositions that guide the person's stream of consciousness;
- Rules of language have no significance in language production and understanding, being descriptions of linguistic styles;
- Statements that may be true or false enter into ordinary linguistic activity, not as elements of messages, but merely as summaries of situations, with a view to action and reaction;
- In computer programming the significance of logic, proof, and formalized description, is incidental and subject to the programmer's personality;
- Analysis of computer modelling of the mental activity shows that in describing human knowing the computer is irrelevant;
- In accounting for the scholarly/scientific activity, logic and rules are impotent;
- A novel theory is presented: scholarship and science have *coherent descriptions* as their core.

Another major conclusion of the studies was that the works by William James [5] and Otto Jespersen [6, 7] are superior to any other accounts of human thinking and linguistic activity, while they are ignored by cognitivist psychologists.

Science and Scholarship

In parallel with writing the book on *Knowing* [42-1995] I discussed the place of computing in relation to other fields of science and scholarship, in two articles [35-1990, 41-1995, English version 43-1996]. In these articles I argued that as far as the activity of science and scholarship is concerned, computing makes sense as a *form of description*, while issues of logic or method are irrelevant.

This was confirmed in an empirical study of the use of formal descriptions in the programming activity [37-1993].

Other issues of science and scholarship imposed themselves upon my attention in the form of ideological suppression of scientific discussions of computing and human thinking, not only in psychology but also in the recent computer literature. Such suppression is illustrated by the following three incidents. *Communications of the ACM*, November 1995, brought an article by the psychologist G. A. Miller: *WordNet: A Lexical Database for English*, describing a so far unsuccessful project to develop a computer program that supposedly processes natural languages as people do. Miller describes language in terms of words, word senses, and linguistic contexts. By this manner of describing the linguistic activity he gets stuck. He says that 'Choosing between alternative senses of a polysemous word is a matter of distinguishing between different sets of linguistic contexts in which the word form can be used to express the word sense' and then concludes that 'How people make such distinctions is not well understood.'

But this impasse arises merely from Miller's inadequate description of the linguistic process. Talking of verbal 'word senses' given by 'sets of linguistic contexts' is an impossible way of describing human linguistic activity. Choosing between alternative senses of a polysemous word does not arise when people speak. The action of each person engaged in the conversation consists of the continuous changes in the person's thought object. What each word means appears in each person's stream of thought, by the associations coming in the situation from that person's habits. Typically the meaning of a word is ephemeral, entirely a matter of the particular conversation taking place. This is obvious for such common words as 'the', 'he', and 'she'.

In response to this article I wrote a letter to the editor of the *Communications of the ACM*, pointing out the defects of Miller's approach. This was refused by the editor. This made me resign from my membership of the ACM. I later included the text of the letter in [50-2005] section 3.3.

In the second incident, also in 1995, I was given the book by B. von Eckardt: *What is cognitive science?* by *Computing Reviews* for review. I wrote a review that indicated the failure of the author to argue for the field, pointing out in detail how the author is committed to confused notions both of science, mental life, and computing. My review was rejected by the editor of the *Computing Reviews.* I later had it published in *The Computer Journal* [40-1995]. This ended my contribution of reviews to the *Computing Reviews*.

As the third incident, the article [43-1996] titled *Computing As Science* was rejected by the editor of the *Communications of the ACM.*

Philosophy as Presumption

After writing the book on *Knowing* [42-1995] I decided that at least part of the ground of the decay of psychology lies in the philosophical influence. The result was an *Antiphilosophical Dictionary: Thinking—Speech—Science/Scholarship*, published first in a version in Danish [44-1999] and then in English [47-2001]. In this I carry through a critical analysis of pronouncements, allegedly philosophical, by some of the best known philosophers, such as Descartes, Bertrand Russell, Martin Heidegger, Gilbert Ryle, and Ludwig Wittgenstein. Through these analyses I establish that what is said by philosophers about human mental life is void of empirical support. The overall conclusion of the work is that philosophy is an ideology of presumption, harmful to science and scholarship, while the descriptions by William James of mental life and by Otto Jespersen of the linguistic activity, although unsurpassed in their insight are unknown to philosophers.

This work I supplemented with an empirical study, carried out together with Erik Frøkjær, of the importance or otherwise of philosophical locutions in scientific and scholarly work [46-2000]. The study is based on pronouncements from 80 scientists and scholars from a variety of fields, all professors at Copenhagen University. These pronouncements confirm that the influence of philosophy on science and scholarship is confusion.

The Ideological Decay of Psychology

Subsequently I decided to lay bare more explicitly the *ideological decay of psychology* during the twentieth century. A major issue of such an undertaking is to select the literature sources that may rightfully be claimed to represent present day psychology. In the first version of my study, in Danish, I choose *Den Store Danske Encyclopædi* [3]. The first version of my work on this subject was published under the title *Psykologi i videnskabelig rekonstruktion* [48-2002].

In October 2003 I decided to produce an English version of this work. Since the Danish source of the first version obviously would be inadequate in an English version, I chose instead the *Oxford Encyclopedia of Psychology* [4] and *Penguin Dictionary of Psychology* [52] as the sources of present day psychology. The work was published under the title *An anatomy of human mental life—Psychology in unideological reconstruction—incorporating The Synapse-State Theory of mental life* [50-2005].

In this book the anatomy of mental life is presented primarily in carefully selected, rearranged and annotated quotations from William James's *Principles of Psychology,* in terms of four themes: *habit, the stream of thought, association,* and *acquainting*. Additional original presentations: *sign habits and language, creative thinking,* and *the activity of art*. It is argued in detail that William James's *Principles of Psychology* from 1890 is a supreme scientific contribution of mankind, on a par with Newton's *Principia.*

The presentation is justified by the *ideological decay of psychology* during the twentieth century, as it was brought about by the activity of what is called the *American-psychology-enterprise*. The decay is documented by detailed, critical analyses of 51 articles in the *Oxford Encyclopedia of Psychology,* by 63 authors, and of articles in the *Penguin Dictionary of Psychology.* Most of the articles examined are found to be marred by fallacies, mostly ideological. As conclusion on the situation of the activity of the American-psychology-enterprise around year 2000:

- The discussions of the phenomena of mental life are dominated by invalid ideologies: behaviorism and cognitivism, resulting in a confusion by which there is no clear common understanding of the terms being used and a failure to account for the life experience had by anyone.
- The psychotherapy practised is quackery on a

continental scale.

- The academic activity consists of confused ideological skirmishes and laboratory experiments with slight relevance to human life, while the quackery performed by the psychotherapeutists is ignored. In the attitude to and handling of psychotherapy the American-psychology-enterprise of year 2000 is as general medicine was around the year 1800.

The Synapse-State Theory of Mental Life

The work on the *Anatomy* [50-2005] gave me the occasion, in November 2003, to look closely at Charles Sherrington's *The Integrative Action of the Nervous System* [54]. This immediately told me where in the nervous system one finds the plasticity that James states very clearly must be the neural ground of habits, to wit: in the synapses. And so the way was open to a neurophysiological description of the nervous system, which I have called the Synapse-State Theory [49-2004].

The Synapse-State Theory of mental life is grounded empirically partly in mental life as it is known to anyone and partly in neurophysiological insight into the nervous system as this was established around 1910.

Mental life is experienced at all times by anyone, but only a genius such as William James has been able to describe it coherently, as he presents it in his *Principles of Psychology* [5]. James mainly describes experiences and actions as they are know to anyone. In addition he describes certain neurophysiological features as they have been established empirically in experiments with frogs.

First of all, the most prevalent feature of our experiences and actions are *habits.* And James immediately points out: habits are grounded in *the plasticity of the nervous system.* This is a central matter in my theory. Side by side with habits James describes *instincts,* which are, as it were, the origin of habits.

And next comes the great phenomenon: *thinking goes on.* This is what James calls *The Stream of Thought, of Consciousness:* we experience *thoughts* and *feelings.* More in detail: at any moment we experience a *thought object.* A thought object is complicated. It has certain cores that have faint *fringes.* When one thinks about any definite topic there will be a thousand other things in the stream of thought: the fringes.

The cores are the anchor-points of the stream of thought, which James calls *concepts* but which I prefer to call *acquaintance objects.* We can know that we think of the same as at earlier occasions—but the *thought* about it, what is in the fringe, is never the same. I can think of my mother. This I have been able to do my whole life. My mother is an unchangeable acquaintance object in my life. But each time I think of my mother the thought is different. But I know that it is the mother with whom I am acquainted I think of.

2005 A.M. Turing Award—Peter Naur

"For fundamental contributions to programming language design and the definition of Algol 60, to compiler design, and to the art and practice of computer programming."

The thought objects are changing incessantly. There are some important circumstances about the changes. One of them concerns *attention.* That is a concentration within the thought object towards an acquaintance object, at any time, of short duration. Our attention jumps back and forth within the thought object. This happens within a time scale of about one second.

Then there is another, rather different way in which the changes take place, namely what James talks about as *the specious present.* This concerns that whatever we think about at a certain moment contains in weak form what we thought about a few seconds before. It is a kind of tail to the acquaintance object presently in the attention, within a time scale of 20 or 40 seconds, in such a way that what we thought of 20 seconds ago is still there, getting gradually weaker.

Attention and the specious present combine in a circumstance of the changes of the stream of thought that James describes by distinguishing what he calls *substantive* and *transitive parts* of the stream of thought. In transitive parts the attention is directed only towards such acquaintance objects in the thought object that have been the objects of the attention within the latest specious present, without being directed towards any other acquaintance object. James compares it with a bird in flight. The transition to a substantive part happens when the attention is directed toward an acquaintance object from the fringes. This will be experienced as a result of the previous process and thus as a resting point in the stream of thought. Here the bird perches.

An acquaintance object which is called forth to the attention from the fringes is one that has been habitually connected to one or more of the other acquaintance objects in the thought object by being excited at the same time. This kind of habitual connection between the acquaintance objects is denoted *association.*

Within this activity there are special processes, *sensation* and *perception*. In perception something sensed directs the attention to an acquaintance object.

Further there is *recall* and *memory*. Memory is recall—through associations—of an acquaintance object that is associated to something in the past. What James calls memory has no relation to what is called memory by modern cognitivists.

The understanding of *time* builds upon the specious present and associations.

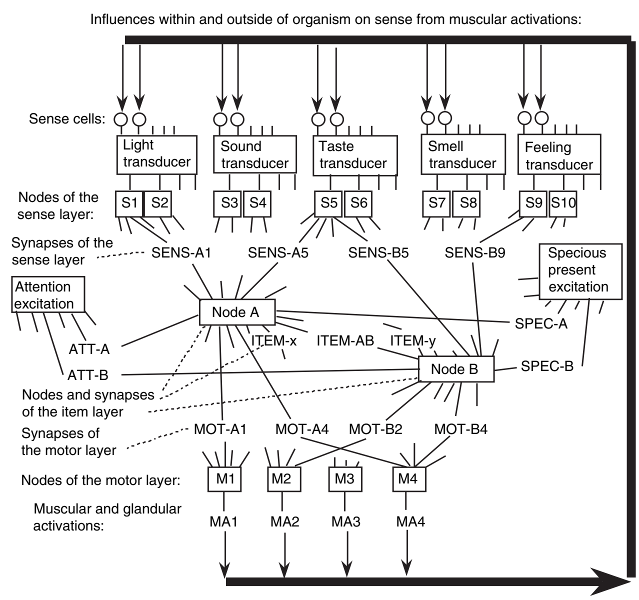

Figure 1. The Synapse-State description of the nervous system.

Actions, instinctive and *voluntary*, are controlled by the thought objects. In this context William James gives much attention to the physiology: neurons and impulses, sense cells, muscles and glands. He particularly stresses a general property of the neurophysiology: *summation of impulses*. That which releases an action within us may be various impulses. And it may be such that each of these impulses by itself is insufficient to make the action happen. If then two of these impulses occur simultaneously they are added together, and then the action is released.

So much about mental life as it is known to all of us and described by William James. We do not have go further into it, it is well known, we just have to read William James. That no present day psychologist knows anything about it is another story.

The other main source is Charles Sherrington: *The Integrative Action of the Nervous System* [54], which presents fundamental empirical studies, particularly of dogs—dogs scratching themselves, for example—how that happens. By these studies Sherrington has found that the paths of neural excitations, the *neurons,* are connected by what he calls *synapses*. The synapses are plastic in the way they transmit the neural excitations. By Sherrington's researches the synapses come in several different forms and they are influenced by drugs.

All this is the empirical basis.

This leads to my theory—description—of *the central nervous system*, shown in Figure 1. The nervous system consists of three kinds of things: *synapses, neurons*, and *nodes* where the neurons meet. The activity of the nervous system consists of excitations. Excitations are transmitted along the neurons, through the synapses, and are summed and distributed in the nodes. This function of the nodes embodies the *summation of impulses.*

Structurally I have occasion to talk of five different layers: (1) *item-layer,* (2) *attention-layer,* (3) *specious-present-layer,* (4) *sense-layer*, (5) *motor-layer*. All this may be seen in Fig. 1.

In the figure the item-layer is in the center, the attention-layer is to the left, the specious-present-layer to the right, the sense-layer is at the top, closely connected to the *sense transducers,* and the motor-layer is below, connected to muscles and glands. Each of these layers has its own synapses having different properties. The nodes are shown within boxes, the neurons are lines, and the synapses are identified as ITEM, ATT, SPEC, SENS, or MOT.

Let us start at the center, the *item-layer*. With its synapses this embodies the long term habits of our organism. In other words, all what is there through many years of our life, more or less prominently. It consists of nodes where the neurons join in large numbers. The figure shows two nodes: Node A and Node B. Of such nodes there are roughly 100,000. Each such node is connected to every other through a path consisting of a neuron, a synapse, and a neuron. One of these paths is shown in the figure: Node A, neuron, ITEM-AB, neuron, Node B. Such a connection with a synapse connects every pair of nodes in this layer. Thus there must be of the order of 10 thousand million synapses. These synapses have that plasticity which embodies all the long term habits of our mental life.

In the figure I have suggested the many neurons that connect to each node—each node has many short lines. From each node there are about 100,000 of them, since they should connect to 100,000 others. The nodes are the neurophysiological embodiments of the *acquaintance objects*.

The plastic properties of the ITEM-synapses are such that in the newborn individual they have low conductivity. But the moment the two nodes to which a synapse is connected are both excited, the synapse becomes conductive. It will develop every time the two connecting nodes are excited, getting more conductive in a plastic way. In this way the two nodes become *associated*, with the effect that whenever one of them gets excited the other one becomes excited as well since the synapse connecting them will conduct the excitation. And it will conduct in both directions. If no re-excitation takes place the synapse will slowly, gradually over years, lose the conductivity again.

This is how it happens in the item-layer.

Attention-layer: Each node in the item-layer has one connection, through one attention-synapse, to a common node, denoted *Attention excitation.* So ATT-A and ATT-B are two attention-synapses. But their properties are entirely different those of the synapses in the item-layer. An attention-synapse, for example ATT-A, works such that if the connected node, here Node A, gets excited beyond a certain level of strength—and this may happen through its connection to and excitation from nodes of the sense-layer, such as S1 and S5, or from other nodes in the item-layer with which it is associated, e.g. Node B—if this excitation rises to a certain level it will excite the attention-synapse ATT-A, with the consequence that this synapse becomes conductive for a duration of about one second and conducts a strong excitation from the Attention excitation into Node A. This will influence the summation of impulses in that node. If Node A is already strongly excited and then in addition receives excitation from the attention-synapse ATT-A, it will have extra strength. This is the impulse that—as we say—attracts the attention. At this moment the attention sits in Node A.

When the synapse ATT-A has delivered this impulse—it lasts only about a second—it will cease the excitation, and may be assumed to be tired after this action. Probably it will have to recover for perhaps 20 or 30 seconds before it is ready to act again.

So much about the attention-layer.

Specious-present-layer: each node in the item-layer is connected to just one specious-present-synapse, which I denote SPEC. Every SPEC-synapse is connected to a common node denoted *specious-present-excitation*. These synapses work somewhat like the attention-synapses, but slower. Normally they will have no conductivity, so no excitation will come through from the specious-present-excitation. But when their connected node becomes excited above a certain level—perhaps because the connected attention-synapse has delivered an impulse—the specious-present-synapse gets excited and will then conduct an excitation from the specious-present-excitation into the same node, and this extra excitation will gradually fall off within a time scale of about 20 seconds. This means that there may be a handful of these synapses, perhaps 5 or 10, that are all at some stage of falling off in their excitation. They form a queue of nodes that have been strongly excited within the latest minute or so.

So much about the specious-present-layer.

Now for the *sense-layer*. It has a number of nodes, of which only a few are shown: S1, S2, ..., S10. Each such node gets excited from one of the senses. There is a certain transformation of sense impulses in the sense transducers, different for each sense, and the resulting impulses are sent to the nodes. From each such node there is a connection through a synapse to every one of the nodes in the item-layer. We see a few of them: SENS-A1, SENS-A5, SENS-B5, and SENS-B9. These synapses again are plastic. In the young individual they will have only low conductivity. But by being excited from both sides simultaneously they gain in a conductivity which is higher in the direction towards the node in the item-layer, and lower in the opposite direction. Whenever we have a sensation there will therefore be a tendency that certain of the item-nodes become excited. When having a sensation of something specific a whole number of the nodes S1, S2, ..., S10—there may be hundreds of them—will receive an excitation. And if from each of the hundred there is a conductive synapse into one particular item-node, this node by summation of the impulses will become strongly excited. When this excitation is strong enough to excite the attention-synapse of the node, this is called *perception* of the corresponding acquaintance object.

What is embodied in the node may for example be the acquaintance object of my mother. Certain impulses make me think of my mother, that is make my mother come forth in my stream of thought. It may be sense impressions, but it may also be many other things and combinations of things.

The conductivity in the opposite direction, from ITEM-nodes to SENS-nodes, is a matter of imagery. When we think of something we get a faint image in our stream of thought, by the excitations in the opposite direction. But the image is faint and blurred. It is blurred because there is no strict relation between the set of impulses that excite the ITEM-node and the nodes in the sense-layer.

A very important matter should be said: the excitation of the nodes in the sense-layer, S1, S2, ..., S10, that is where the *experience* happens. That is what we see, hear, smell, taste, feel. Whenever one of these nodes is excited we experience it in the stream of thought.

So much about the sense-layer.

Finally about the *motor-layer*. It has a number of nodes, M1, M2, ..., each of which may excite a muscle or a gland. Each of these nodes is connected through a synapse of a special kind, a MOT-synapse, to every node in the item-layer. This is where the activation of muscles take place, depending on whether certain synapses have been made conductive, again plastically, and again with a long term plasticity, but with a shorter time scale than in the case of the ITEM-synapses—I believe they are here to be reckoned in weeks or months, where in the item-layer it a matter of years. The training of a muscular action decays quite rapidly. When in playing the flute one has trained a particular muscular figure, it takes no more that a week before it it noticeably deteriorated. It is a matter of the MOT-synapses.

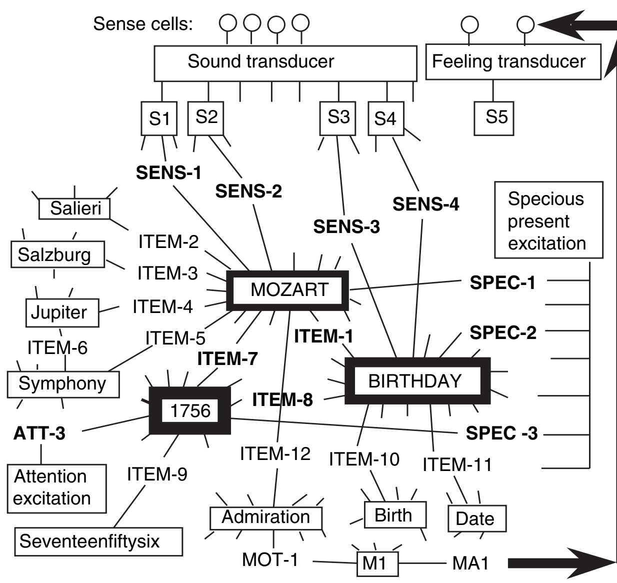

Figure 2. Excitation pattern: When was Mozart's birthday?

But again it is so that the conductivity of the active synapses is increased by training.

So much about the motor-layer.

Finally Fig. 1 turns the attention to a general, important matter, with the thick black arrow that shows influences from muscular activations to sense cells. This is a phenomenon that William James points out very clearly, that all what we call *feelings* and *emotions* is a matter of the muscles having sense cells in them. When we feel something the primary phenomenon is that certain muscles are activated. And then, in the muscles, anywhere in the organism, there are sense cells that are influenced by the activity. This is a very important process that happens all the time, that we in this way experience, feel, the state of our own body. That is what is indicated by the thick line.

It may also be a muscular action which one picks up visually, for example a movement of the hand. One sees the movement. The impulse goes the same way.

This connection is a decisive circumstance in the way our *movements* are controlled from the nervous system.

As illustration I will show a picture of a typical pattern of excitations. Fig. 1 showed permanent connections. Fig. 2 shows some of the synaptic connections and nodes that are excited at a certain moment, and by bold type and thickness of the frames around the nodes shows the relative strengths of the excitations of some of those connections and nodes. The moment is one at which the person has just been asked: When was Mozart's birthday? While hearing that question spoken a large number of the person's auditive sense cells have become excited, and these excitations have been transferred by the Sound transducer into a large number of nodes of the sense layer, whereby they have come into the person's stream of thought as sounds. Moreover, while hearing the word 'Mozart' a number of nodes such as S1 and S2 that are connected to the node MOZART through synapses that have high conductivity, SENS-1 and SENS-2, have been strongly excited. These many excitations will have been combined by summation into the node MOZART, with the consequence that the attention and specious present synapses of that node have become excited. A few seconds later these excitations still linger on in the synapse SPEC-1 that keeps the node MOZART excited for the duration of the specious present. This process by which the node MOZART has become strongly excited from the nodes of the sense layer is know as *perception*. In quite a similar manner, the hearing of the spoken word 'Birthday' and the attendant excitations of nodes and synapses such as S3, S4, SENS-3, and SENS-4, has led to the perceptional excitation of the node BIRTHDAY.

The strong perceptional excitations of the nodes MOZART and BIRTHDAY will immediately have become transferred through conductive synapses (embodying *associations*) into a large number of other nodes, that at this moment will form the fringe of the thought object. Only a very few of these fringe nodes are shown in the figure: by association with MOZART: Salieri, Salzburg, Jupiter, Symphony, 1756, Admiration; by association with BIRTHDAY: Birth, Date, 1756. Any of these nodes may through conductive synapses in the motor layer excite muscular or glandular activations. Thus the node Admiration through the synapse MOT-1 and the node M1 activates a muscle MA1 that in its activation influences sense cells that in their turn by exciting the node S5 produce the experience of a feeling of admiration in the stream of thought.

The node 1756 will become excited from both MOZART and BIRTHDAY and so will excite its attention synapse, ATT-3, and its specious present synapse, SPEC-3. And so as the result of hearing the question 'When was Mozart's birthday?' spoken the node 1756 will become strongly excited.

It should be made explicitly clear that the identifying labels put on the nodes in Fig. 2, such as MOZART, BIRTHDAY, and 1756, are there merely for purposes of description. In the nervous system the nodes of the item layer are all alike and only distinct by the states of their connected synapses. For example, the node MOZART is distinct by virtue of the states of such synapses as SENS-1, SENS-2, ITEM-1, ITEM-2, ITEM-3, ITEM-4, ITEM-5, ITEM-7 and ITEM-12. The spoken, sounding word 'Mozart' is attached to the node MOZART only by the states of synapses of the sense layer, such as SENS-1, SENS-2, and others, that become excited when the word 'Mozart' is sensed in hearing, as explained above.

Likewise, the person's pronouncing of a word attached to a node in the description is a matter of conductive synapses connected to such nodes in the motor layer that when excited will activate muscles of articulation and vocalization. In Fig. 2 ITEM-9 connecting to 'Seventeenfiftysix' may be such a synapse.

In summary, according to the description of Fig. 2 the response in the person's stream of thought to the question When was Mozart's birthday? is a matter of (1) the person having nodes, embodying acquaintance objects, of 'Mozart', 'birthday', and '1756', and further (2) that the synapses connecting them, ITEM-7 and ITEM-8, have in the person's past been put into conductive states. The response involves neither any kind of 'language processing', nor any 'memory' container. What is sometimes called 'short term memory' is a matter of nodes of the item layer that are excited for the duration of the specious present by their SPEC-synapse, such as MOZART, BIRTHDAY, and 1756, in Fig. 2.

How this form of description may account for all the features of mental life is a longer story, of which I have written a series of articles, one about *the stream of consciousness,* one about *sensation and perception*, one about what William James calls *memory,* which is something entirely different from what modern psychologist call memory, and I am working on an account of *instinctive* and *voluntary actions*. I have tried to have these articles published in journals, so far without any success. The present presentation, when published in the *Communications of the ACM*, will in fact be the first presentation of the Synapse-State Theory of mental life to appear in a journal.

So I am clearly at the beginning of that twenty year period that it usually takes to have a scientific breakthrough accepted.

Conclusion

And so, as the conclusion of this discussion of the theme given in the title: Computing presents us a form of description. This form is very useful for describing a great variety of phenomena of this world, but human thinking is not one of them, the reason being that human thinking basically is a matter of the plasticity of the elements of the nervous system, while computers—Turing machines—have no plastic elements. For describing human thinking one needs a very different, non-digital form, as demonstrated by the Synapse-State Theory.

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