Management support systems: Towards integrated knowledge management

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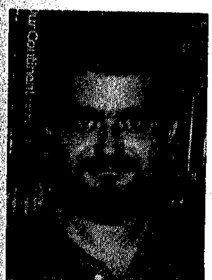

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Humans do not apply formalistic scaffolds of fixed rules of 'knowledge' to integrate the a priori given objective world of data 'out there': they do not compute the world. Regardless of some 'knowledge'-modeling assumptions, just the opposite is true: humans use their subjectively perceived world of turbulent circumstances to bring forth (create, recreate and adapt), again and again, *knowledge* as an autopoietic network of relations through which they coordinate their actions. Such knowledge brings (through language) coherence and coordination to the otherwise turbulent and chaotic world of human action. Knowledge is not 'processing of information' but a *coordination of action*. As a consequence, any management support system (DSS, AI, ES, etc.) claiming knowledge as its purpose or its base, cannot be of the symbolic computation type à la Simon.

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'The central question of all social sciences: how the combination of fragments of knowledge existing in different minds can bring about results which, if they were to be brought about deliberately, would require a knowledge on the part of the directing mind which no single person can possess.'

Fridrich A. von Hayek

Introduction

We are witnesses to the accelerated movement from the traditional electronic data processing (EDP) and management information systems (MIS), towards decision support systems (DSS), expert systems (ES) and artificial intelligence (AI), and their more integrated and enterprise-wide versions like management support systems (MSS).

This rapid transition is neither artificial, nor temporary, and certainly not insignificant. It represents and reflects fundamental and all-powerful shift in human–technological concerns from data and information towards knowledge and wisdom. This shift is accompanied by the most profound reorientation in management, decision making and organization of work [24]. While data and information are piecemeal, partial and atomized by their very nature, knowledge and wisdom are 'holistic', related to and expressed through systemic network patterns, integrative by definition.

Example. Consider the task of baking bread. *Data* are like basic elements: atoms and molecules of starch, H_2O, bacteria of yeast, etc.; no trace of 'bread' anywhere.
Information is like ingredients: flour, sugar, water, spices; still no trace of the intended outcome (but one cannot make a beer out of it anymore). Having all such ingredients does not imply that a *knowledge* of how to make bread exists: one can still end up with a tasty crust, black cinder or gluey mush. Knowledge involves relations: recipes and their contextual interpretations. Further, having the know-how for making bread does

not imply that one actually *should* make bread and why. *Wisdom* goes beyond knowledge because it allows comparisons (judgments) with regard to know-what and know-why. It is a long way from data to wisdom. (There is one additional step beyond wisdom: *enlightenment* – enriching the still value-free wisdom by the dimension of 'truth'.)

The above analogy illustrates how and why management-related human concerns were bound to shift from the data processing of the past all the way to the knowledge acquisition of today: from specialization to integration.

To manage wisely implies knowing *why* to do something; to manage effectively implies knowing *what* to do; to manage efficiently implies knowing *how* to do it (and to 'muddle through' implies nothing and having 'lots of data' around).

A scheme of progression from data to knowledge (and wisdom) is summarized in table 1. In table 1, each higher level is meant to subsume the lower one: that is, in order to act wisely, it is still necessary to have knowledge, information and data about the task.

Observe also that while data and information (being components) can be generated per se, i.e., without direct human interpretation, knowledge and wisdom (being relations) cannot: they are human- and context-dependent and cannot be contemplated without involving *human* (not machine) comparison, decision making and judgment.

Remark. Taxonomy of table 1 is meaningful only from a vantage point of individual or group. In the world of human interactions (society), such classification would be much more complicated. Even data, for example, are not simply objective facts 'out there' which would be the same for all people and equally 'given' to all individuals. Data for some are information to others, one person's knowledge is the other person's data, and so on. This leads to a continuous and interdependent (even circular and self-producing) creation and re-creation of data, information, knowledge and wisdom in human societies. Such processes lead to the *autopoiesis of social systems*, which contrasts with the static concepts of 'equilibrium analysis', 'economic man' or 'perfect markets'. Social autopoiesis has been treated separately [20].

An important related problem was stated by F.A. Hayek [4,5] as follows:

> 'The economic problem of society is not merely a problem of how to allocate 'given' resources – if 'given' is taken to mean given by a single mind which deliberately solves the problem set by these 'data'. It is rather a problem of how to secure the best use of resources known to any of the members of society, for ends whose importance only these individuals know.'

The first problem is represented by Linear Programming while the second one by the design of De novo approach. Also these issues have been treated separately [23].

At least in the most developed economies of Japan and U.S., we are now traversing the path from information to knowledge. Technology is rapidly becoming *teknowledgy*.

In this paper we stress the coordinative and integrative nature of knowledge and the need for developing the 'integration-friendly' and knowledge supportive systems.

Knowledge

What is knowledge?

Remark. In our context we cannot use such typical definitions and analyses of knowledge as for example those employed by M. Foucault [2]. The English 'knowledge' translates

Table 1
Taxonomy of knowledge.

	Technology	Analogy	Management	Metaphor
Data	EDP	*Elements*: H_2O, yeast bacteria, starch molecules	Muddling through	KNOW-NOTHING
Information	MIS	*Ingredients*: Flour, sugar, water, spices, fixed recipe for bread only (OR/MS type)	Efficiency (measurement + search)	KNOW-HOW
Knowledge	DSS ES, AI	Choose among different recipes for bread	Effectiveness (decision making)	KNOW-WHAT
Wisdom	HSM MSS	Why bread and not croissant?	Explicability (judgment)	KNOW-WHY

the French '*connaissance*' and '*savoir*'. The following is their usage due to Foucault:

'By *connaissance* I mean the relation of the subject to the object and the formal rules that govern it. *Savoir* refers to the conditions that are necessary in a particular period for this or that type of object to be given to *connaissance* and for this or that enunciation to be formulated.'

Such definitions are not useful. The dictionary-type tautological 'definitions' (*connaissance* = a particular corpus of knowledge, *savoir* = totality of *connaissances*) seem to be Foucault-opposites and even less illuminating.

Knowledge should refer to observer's distinction of 'objects' (wholes, unities) through which he brings forth from the background of experience a coherent and self-consistent set of coordinated actions.

Through the operation (or process) of distinction, individual pieces of data and information (components, concepts) become connected with one another (i.e., organized) in a network of relations. Knowledge then is contained in the overall organizational pattern of the network and not in any of the components (or their simple aggregates or collections).

This emerging network of relations in turn determines which and how additional components are brought forth ('produced', interpreted) from the background. Network organization is therefore necessarily circular (organizationally closed), self-maintaining and self-producing. Its components (but not the network as a holistic entity) are subject to external (or internal) structural perturbations and they 'excite' and 'inhibit' each other throughout the network in a simultaneous (or parallel) fashion. Knowledge is a self-producing and self-maintaining network of relations which are being continually re-created under perturbations. Knowledge is an autopoietic (self-producing) system. For reviews and foundations of the necessary autopoiesis consult for example [8,17,18].

Knowledge cannot refer to a 'given and fixed' set of objects 'out there', which are to be simply 'captured', represented or modeled. This old idea of symbolic computation (associated with the names of H. Simon, A. Newell, N. Chomsky or M. Minsky) – the idea that knowledge and mental processes involve structures of symbols and transformations of symbolic expressions – is properly artificial and mechanistic: quite suitable for artificial intelligence, but unrelated to human intelligence. Consequently, the resulting static or 'representative' knowledge systems are of limited long-term usefulness in terms of *human* knowledge support (see also [11]).

People do not simply 'compute their way through' a given objective world: knowledge refers to the *process* of active network configuration and reconfiguration of our human world of objects and their relations.

The set of coherent actions brought forth through the operation of distinction is coordinated by and in language. Language must be an integral part of *any* knowledge system model, not as 'processor of information' but as a 'coordinator of action'. The study of language as a means for effective coordination of human action has so far been neglected.

Just about the only exception is to be found in the work of Maturana [9] who defines language as a 'consensual coordination of consensual coordinations of action', also implying the ever important concept of a dialogue (or conversation). Knowledge systems must be conversational, not just mechanistically interactive.

Because the *objects of knowledge* are not given and fixed a priori, but are repeatedly brought (and 're-brought') forth through the described operation of human distinction, their definitional boundaries cannot be crisp and sharp. Consequently, the language which we use to coordinate our knowledge-derived actions must appear to be 'imprecise and fuzzy' from any information-processing perspective. In reality, however, such fuzzy language is not only adequate, effective and 'precise' for the purposes of action coordination – it is necessary.

Knowledge and ambiguity

Human perception, knowledge and understanding do remain effective even in spite of incomplete, ambiguous or fuzzy pieces of information. This is the consequence of the fact that knowledge is autopoietic relational pattern and not particular component(s).

A network of distributed but interconnected components (that excite and inhibit one another in a parallel fashion) is capable of dealing with the ambiguity and fuzziness of components (both internal-constitutive and external-perturbational).

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Network *structural flexibility* and *openness* to *multiple sources* of perturbations (information), while maintaining the organization of relations, is an effective way of dealing with the 'incoming' ambiguity (see also [11]).

The requisite factor flexibility and source multiplicity has been difficult to simulate with Simonian symbolic computation. By concentrating on the ambiguity and fuzziness of network *components* we lose the sight of the whole and thus by definition miss the phenomenon of knowledge. Traditional efforts to transform the (information) source ambiguity into 'crisp' mathematical symbolism does not help the problem. Abstracting from the source ambiguity entirely and simply re-transforming the traditional 'crisp' symbolism into the 'fuzzy' one ('fuzzification' of the fuzzy sets theory) is quick and expedient, but remains components-oriented and therefore poor model of knowledge [19]: humans do not deal with information ambiguity through its symbolic computation and re-computation. They deal with ambiguity through evolving an autopoietic *network* of relations interconnecting the pieces of information.

Because knowledge is a network and because this network is self-producing and self-maintaining, no 'central information processing' is needed. From this vantage point, fuzziness and ambiguity of concepts (building blocks of knowledge) is necessary.

Any complex system can be self-organizing and self-coordinating *only* if there is an overlap between its components. This 'overlap', this meshing of 'fields of vision', allows for communication and propagation of 'in-formation' [in the sense of indentation, perturbation] to take place over the network. Only through such overlaps of meaning can 'parallel processing' take place. Destroying, removing or narrowing such fields of overlap reduces system's ability for self-coordination. Crisp and non-overlapping concepts can only be coordinated through a central processing agent, as in machines for sequential computing.

Vagueness, blurring, ambiguity, indefiniteness, fuzziness, etc., are not simplistic deficiencies or imprecisions to be tinkered with by expeditiously self-appointed manipulators of symbols; rather, *they are grand strategic innovations of human mind allowing for knowledge to emerge, persist and expand in an autonomous and autopoietic fashion*.

Jan Christian Smuts, father of *holism*, was also the first to recognize the importance of 'concepts and their fields of ambiguity' [12, pp. 16–19]:

> 'We have to return to the fluidity and plasticity of nature and experience in order to find concepts of reality. When we do this we find that round every luminous point in experience there is gradual shading off into haziness and obscurity. A "concept" is not merely its clear luminous centre, but embraces a surrounding sphere of meaning or influence of smaller or larger dimensions, in which the luminosity tails off and grows fainter until it disappears. Similarly a "thing" is not merely that which presents itself as such in clearest definite outline, but this central area is surrounded by a zone of intuitions and influences which shades off into the region of indefinite. The hard abrupt contours of our ordinary conceptional system do not apply to reality and make reality inexplicable.'

Smuts also did not miss the communicative-propagative role of ambiguity, especially in the study of causation. The cause–effect connection, for example, has to be treated as a whole situation where the fields of 'cause' intersect with those of 'effect', one passing into another gradually and often imperceptibly. Reducing both participating aspects into crisp, disconnected and opposing forces makes it immediately impossible to understand how one passes into another in *actual* causation.

Cause and effect are interlocked and mutually influence each other through the interpenetration of their two fields. Without this, no simultaneous, parallel or self-coordinated action would be possible. The 'crisp' and isolated concrete thing (or concept) could never come into real contact or into active (or creative) relations with any other thing (or concept), *but for its field of ambiguity*. There would be no knowledge, the real world of matter and life would be (and perhaps it is becoming) quite unintelligible and inexplicable. The world to us would be a mere collection of *membra disjecta*: scattered data and barren pieces of information.

It is only in man-made artificial contrivances (like sequential machines), the products of abstract, computing and symbol manipulating intelligence, that no ambiguity of meaning is allowed and precision, exactitude and crispness are in fact necessary. Why should we try to mold the autopoietic reality of matter and mind to such artificial imagery?

Both expert and common experience perpetuate the confusion between data, information, knowledge and wisdom. Yet the distinction is crucial and knowledge *is* about human ability to make distinctions, choices and decisions. We can *have* data or we can *have* information, but we do *not* have knowledge: we know or do not know. Data and information are parts and pieces of different levels of aggregation, but knowledge refers to the intended whole (which in itself can be a part of something). Wisdom then involves comparability of different wholes and the explicability of their choice or preferences.

Such conceived notion of knowledge allows humans to face novelty, to deal with the unexpected, to engage creative faculties, intuition and common sense. It is therefore this creative process and the ability of 'bringing forth' which has to be amplified, enhanced and supported by our modeling efforts.

Objects of knowledge

Objects of knowledge are distinguishable entities (unities, systems) brought forth from their background either as *wholes* or as *composites*. The wholes are characterized only by properties imparted through the operation of distinction which brought them forth. No components are distinguished. Composites are brought forth through additional applications of (nested) operations of distinction: their components and their relationships are distinguished in relation to the whole they integrate.

Thus the wholes and their composites are related and differentiated only by the number of levels of distinction applied. One can see that it is observer's discretion whether to bring forth an object of knowledge as a whole or as a composite. Any component can itself be brought forth as a whole. The reality of objects of knowledge is thus being continually constructed, degraded and re-constructed by human observers.

To speak of knowledge, the distinction itself (whole or composite) would be insufficient: it must be accompanied by some 'empirical test' – it must bring forth a coherent set of actions. Knowledge that is not manifested through (some) set of actions would not be distinguishable as knowledge.

Composite objects of knowledge can be distinguished at two separate levels: in terms of their *organization* and in terms of their *structure* (see for example [8,9,17,18]).

Organization refers to general relations between the components that define a composite in terms of its class identity. Changes in organization result in changes of object class identity.

Structure refers to actual or specific components and relations that characterize a composite as a particular unity (system) of its kind. Changes in structure do not alter object class identity as long as the organization is maintained.

Example. Consider a well-known system: an automobile. Its *organization* is characterized by such relationships among wheels, transmissions, engine, steering and braking components that define it as a member of the class of automobiles. Because of its organization we can bring forth (recognize) the system as automobile. Its *structure* is then a particular realization (or manifestation) of its organization: specific materials (metals, wood, plastics, rubber, ceramics), actual spatial positioning (engine in front or in back, steering wheel on the right or on the left), and particular connection (front wheel drive, rotary engine, turbo, fuel injection).

By changing the organization we obtain something else than automobile (motorcycle, boat, carriage). By changing the structure (while preserving organization) we get different kinds of automobile (sedan, coupé, Porsche, my car).

Observe that the anthropomorphic notions of 'purpose', 'input', 'output' and 'function' are not necessary here: as a matter of fact they refer to a different and non-intersecting domain of discourse.

Observe further that the same organization can manifest (reveal) itself through a large variety of structural embodiments. A composite exists only through its structural embodiment: through components and their relationships. As long as object organization is preserved it can undergo a history of structural changes without the loss of class identity. It is also conceivable that different organizations could manifest themselves in relatively indistinguishable structures.

To know an object of knowledge (in the sense of bringing it forth from its background) can occur at two levels: (1) one can know the particular and specific by bringing forth object structure; (2) one can know the general, the identity class itself, by bringing forth object organization.

At the first level only a 'surface knowledge' of the particulars is involved; at the second level also the 'deep knowledge' (see for example [1,3,10,14]) is engaged. Observe that in order to to deal with the unexpected, novel and unprecedented, one has to know the organization, the identity class of a system in question; knowing its structure alone would be insufficient.

Any 'expert' system (either contrived or human) operating on system structure alone ('surface' knowledge) cannot be considered as dealing with (or even mimicking) human expertise, knowledge or related phenomena. Any 'expert' system of the production type, where a unit of 'knowledge' is represented by an IF–THEN rule, operates on a structure level only and can work only for the specific problem solving in a very narrow domain.

Such system is based on the assumption of Simonian symbolic computation. It presupposes that human cognitive skills are composed of rules that can be represented symbolically in the form, 'if this, then that'. But modeling of knowledge must involve organization of autopoietic networks of interrelated concepts, not simply symbolic representations of schemata and rules (see also [11 and 16]). Such would not be an *expert* system.

Human experts are characterized by their knowledge of system organization (identity class, 'deep' knowledge) which allows them to approach a variety of new, unique and unprecedented problems. People who cannot do that are rarely considered experts.

Example. Take the famous fire control expert Red Adair. Each fire, blow-out or explosion is unique in terms of all or most of their structural dimensions. Using a 'knowledge base' of the IF–THEN flat structure would call for an almost immediate disaster and would get Red Adair out of the expert business very soon. Red Adair, as any true expert, must work with two- or even more-layered hierarchy of knowledge. His expertise is rooted in this knowledge of system organization allowing him to face novelty and deal with it effectively.

Human experts use the underlying organizational knowledge in dealing with a variety of structural problem manifestations under different conditions and circumstances. In order to model *human* expertise, 'a multi-layer hierarchy model should be applied to organize a knowledge base in order to achieve highly flexible and powerful expert systems' [14].

In dealing with man-made mechanical artifacts, an expert model would likely be effective with a two-layer knowledge base. However, 'expertise' applied to natural and biological (especially living) systems is likely to encounter complex types of organization, particularly the autopoietic ones, and three or more levels may be required. In dealing with human systems, any expertise is by definition multi-layered, encompassing not only organization and structure, but also the purpose and value systems at the highest levels.

Men, models or machines operating with only one-level IF–THEN 'knowledge' rules remain useful in performing the necessary mechanical routines and carrying out predetermined (even though perhaps simply 'branching') problem-solving steps in repetitive situations.

Modeling knowledge

One possibility of representing the relationship of both organization and structure of objects of knowledge is to combine ISA and PARTOF relations in constructing the appropriate knowledge base [14].

For example, statement 'an automobile is a (ISA) physical object' connects the knowledge object with a particular identity class. An ISA arrow is directed from AUTOMOBILE to PHYSICAL OBJECT. Next, 'engine is a part of (PARTOF) an automobile' represents components and their relation to the whole. An PARTOF arrow goes from ENGINE to AUTOMOBILE. One can also write: 'an automobile has parts (HASPARTS): engine, steering, body, etc.' with HASPARTS arrows directed from AUTOMOBILE to individual parts (ENGINE, STEERING, BODY, etc.).

All components connected by HASPARTS arrows must be included in a single 'frame' of slots (components), all identified by unique frame and slot names. The contents of identity class frame 'Automobile' can then be 'inherited' by for example frame 'Porsche'. Concrete and specific (structural) components are the values of 'frames': LENGTH, WIDTH, WEIGHT, CAPACITY, etc.

Example (simplified from Ueno [14]). Assume that a knowledge object AUTOMOBILE consists of only four subsystems: BODY, ENGINE, STEERING and ELECTRONICS. Among the principal objects of knowledge are for example PORSCHE X, PORSCHE, AUTOMOBILE and PHYSICAL OBJECT which are connected hierarchically by ISA arrows. By using additional RELATIONS, like INCLUDES, TOGETHER, FRONTOF, etc., we can show that BODY holds ENGINE and STEERING subsystems, or that ENGINE and ELECTRONICS subsystems work together, and so on.

All structures are defined around all principal objects at each level of the hierarchy. The relationships between AUTOMOBILE and its components (BODY, ENGINE, STEERING and ELEC-

TRONICS) are 'inherited' by PORSCHE and then by PORSCHE X: a particular, specific automobile.

For example component BODY has subcomponents of its own: FLOOR, CARDOOR, ENGINE SPACE, TRUNK, etc., while for example CARDOOR has WINDOW, HANDLE, and so on.

Each 'frame', like AUTOMOBILE, BODY, or PORSCHE, consists of at least six items. In addition to its name, it contains also a pointer FRAME to another 'frame', predicates PR, numerical values NV, and other information such as text TX and LISP-function LP. For example, representing the network of relations among components is achieved by a set of predicates defined as the value of a RELATIONS slot in the frame. The representation of functions and procedures can be defined and written in such languages as LISP or PROLOG.

In table 2 we present the example of frame-based representation (partial) of three of our principal objects.

The outlined knowledge system for expert management support must have both ability and capacity to generate its own internal organizational and structural diversity in response to particular distinctions decided upon and brought forth by the *user*. It has to be capable of 'growing into' a particular task while in use. Simply feeding an assortment of a modeler's pre-fixed conceptions to a 'novice expert' would be a waste of time – and of knowledge.

The goal is to make the 'experts' better and transform them into experts. The goal is not to make even more 'experts' out of the multitude of 'novices'. Such short-sighted strategy could misfire and even 'experts' transformed into 'novices' as a consequence.

Table 2
Example of frame definitions in knowledge system 'Automobile'.

Frame: AUTOMOBILE		
ISA	FRAME	PHYSICAL OBJECT
HASPARTS	FRAME	BODY, ENGINE, STEERING, ELECTRO
RELATIONS	PR	(INCLUDES BODY, ENGINE), (TOGETHER ENGINE, ELECTRO), ...
LENGTH	NV	(200–500)
WIDTH	NV	(130–200)
WEIGHT	NV	(300–5000)
CAPACITY	NV	(2–50), (D4)
Frame: BODY		
ISA	FRAME	PHYSICAL OBJECT
PARTOF	FRAME	AUTOMOBILE
HASPARTS	FRAME	FLOOR, ENGINE SPACE, TRUNK, ...
RELATIONS	PR	(FRONTOF, ENGINE SPACE, FLOOR), ...
Frame: PORSCHE		
ISA	FRAME	AUTOMOBILE
LENGTH	NV	165
WIDTH	NV	169
WEIGHT	NV	1140
CAPACITY	NV	4

Allowing 'experts' to become experts requires broadening and expanding of their expertise, not narrowing it down. When an expert becomes too specialized (knows a lot about too little) he ceases to be an expert: he becomes unable to deal with any sort of novelty. 'Support' systems which require and enhance such deeper specialization then effectively destroy knowledge which would be the prerequisite for expertise.

Trends toward narrower specialization of experts did take place in the society. The task of supportive expert systems should be to counteract such expertise-destructive trends, not to amplify them even further. We do not want to make existing 'bad' experts more efficient in whatever they are doing; we want to help bring about new and 'different' experts, more effective in what needs to be done.

In other words, expert systems should be *high technology* bringing forth a new support net of relations, not simply a *technology* which preserves the old technology support net [22].

Observe that so-called 'knowledge explosion' (also 'information explosion' or 'information society') are misnomers limited to the structural ('surface') knowledge only. Organizational or 'deep' knowledge is *not* as explosive as it may appear, if it is 'explosive' at all. Even today we can aim for a 'renaissance man', especially with the help of expert systems constructed to move in the direction opposite of specialization, towards reintegration of knowledge, overcoming specialization, negating the 'experts' themselves.

Division of labor

Any task can be progressively broken down into a number of subtasks and operations. As long as all these subtasks are performed by a single worker or automated machine, there is no need to speak about the division of labor. It is sufficient to refer simply to the *division of task*.

This task disaggregation makes possible *parallel* processing of subtasks and therefore translates directly into increased productivity. In order to realize parallel (rather than serial) processing of subtasks, they have to be carried out by *different* workers or machines: now labor too has become divided and we speak of the *division of labor.*

Remark. Machines do not strictly perform labor, only humans do. One can profitably distinguish between human labor and machine 'labor'. Our usage of 'labor' is not based on such distinction and is employed only in the sense of 'carrying out the task', whether by human, by machine or by both in interaction (human system). If a hundred workers controlled by a supervisor were fully replaced by a hundred machines controlled by a supervisor, the division of human labor would be reduced in a 100:1 ratio but the number of specialized subtasks to be performed would stay the same. The problem of supervision remains.

The division of task and labor is accompanied by disaggregation, division and distribution of knowledge necessary to carry out the overall task. The knowledge of the task becomes divided and distributed among different production agents (humans and machines): it is appropriate to speak of the *division of knowledge*.

Example. When a person (or machine) produces a chair from cutting the proper wood to selling it at the fair, that person possesses (or a machine contains) a full contingent of the requisite task knowledge. The task is divided, but the labor and knowledge are not. As the labor itself becomes divided, each person (or each machine) possesses or contains only a portion of the overall knowledge. Knowledge becomes distributed: nobody (or nothing) individually knows how to make a chair any longer.

Also, by 'knowledge contained in the machine' we do and must mean the knowledge necessary for carrying out the task and *not* the knowledge which goes into making that machine.

Traditional economist's concept of 'division of labor' thus effectively hides at least three important, separate and relatively distinct dimensions: division of task, division of labor and division of knowledge.

When we divide a system into its components, whether mentally or physically, we have to uncover, postulate or design an overall controlling or coordinating organizational principle. It might be fine to break a living organism into myriads of tiny cells and then study the cells *very* carefully: but what is being learnt about the organism? Economic and social systems are 'social organisms' and their integrative principles should be of eminent concern [20].

We divide the task into a thousand of subtasks. It is then appropriate to ask: How difficult and how costly is it to assure that the coherence of their proper sequencing, scheduling and interaction is maintained? We divide the labor among a thousand of 'partial' workers (or machines): How difficult and how costly is it to maintain their coordination, motivation and functioning? We divide the knowledge into a thousand of tiny bits: How difficult and how expensive is it to maintain its necessary integration, storage and update as a whole?

The answer to all three questions is: progressively more difficult and progressively more expensive.

When the complexity, difficulty as well as costs implied by further divisions become too large, we have to turn, by necessity, in the direction of *reaggregation* of labor and *reintegration* of knowledge. Observe that the underlying division of task itself is not as crucial; it is the way the subtasks are carried out (in parallel, in series, by machines, by men) which is of importance.

Examples. Regardless of the underlying division of task, single worker (as well as a single machine) must carry out the subtasks sequentially (at least at the current levels of scientific advancement). Productivity can be increased by employing a multitude of such singly-acting production agents as is described in fig. 1.

Observe that no division of labor or knowledge is involved and no task coordination is needed. Workers are their own managers and coordinators. Only if subtasks are distributed to *different* workers (or machines) they can be carried out in parallel or simultaneously. A case of such division and distribution of labor and knowledge (comparable to the previous situation) is presented in fig. 2.

Note the emergence of the coordinative function and appearance of Manager (M). If we assume some limits on human coordinative faculties (here manager can coordinate at most 5 other people), then further division of labor requires corre-

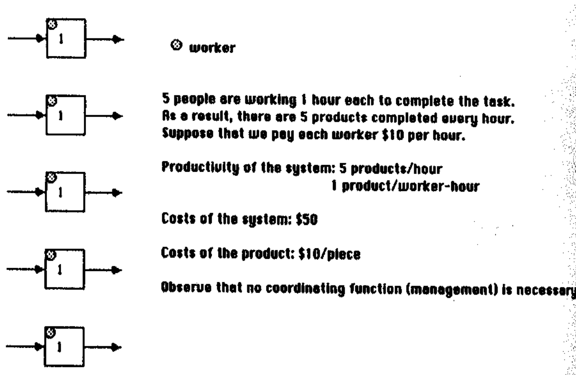
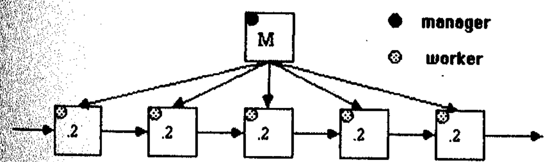


Fig. 1. No division of labor and knowledge, no need of coordination.



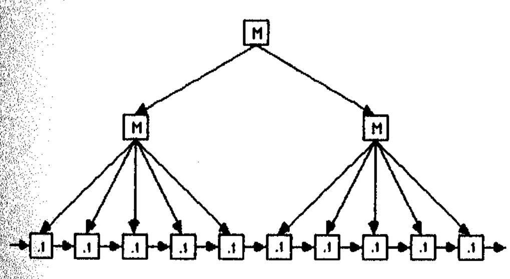
The task was divided into 5 subtasks. 5 people are working on subtasks of 0.2 hours each. Productivity of the system: 5 products/hour and 1 product/worker-hour. Because of lower skills, workers are paid $5 per hour. Coordination (manager) is necessary, say at $25 per hour. Total costs of the system: $50. Costs of the product: $10/piece.

Fig. 2. Division of labor and knowledge, emerging need of coordination.

sponding growth in the coordinative hierarchy. It can be shown that under proper ceteris paribus conditions, the rate of growth of the requisite coordinative hierarchy would be at least as large as the rate of growth of the differentially distributed subtasks to be coordinated. In fig. 3, the emergence of such management hierarchy is represented.

At the same time we have purposefully induced conditions when the increased productivity would not be accompanied by lower costs. Progressive division of labor can lead to higher productivity and cheaper products only as long as a set of very specific conditions is satisfied. Even if the growth rates of management salaries were equal to those of workers' wages (which they are not!) the cost of coordination and management would ultimately have to exceed the gains in productivity. (The productivity gains themselves are subject to diminishing returns and we have not even mentioned the increased complexity and diminished effectiveness of coordinative functions.) Overall, we postulate a 'maximum economic level of the division of labor', as it is shown in fig. 4.

Originally, one person performs a whole task: e.g., making clothes from hunting for the animal



The task was further divided into 10 subtasks. 10 people are working 0.1 hour each. Productivity of the system: 10 products/hour and 1 product/worker-hour. Three managers are needed for coordination. If workers and managers are paid as before, the ($5)10 + ($25)3 = $125, total cost of the system. Cost of the product $12.5/piece.

Fig. 3. Emergence of coordinative hierarchy (management) and social memory (storage of knowledge).

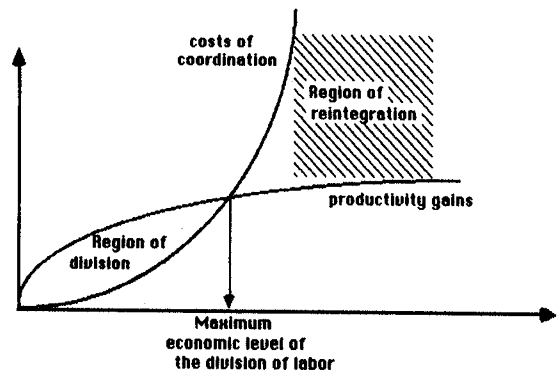


Fig. 4. The crosspoints: maximum economic level of the division of labor.

to sewing., As the process of division of labor sets in, more people are becoming involved and their tasks progressively more specialized. Coordinative agents and leaders (precursors of today's management) soon emerge. As markets grow, the division of labor and specialization grow correspondingly. It almost appears (as it did to Adam Smith) that barring the size of the market there are no limits to the process of division of labor.

But there are limits: not only labor but also human knowledge is becoming divided and distributed in the process. Coordination becomes more difficult, more costly and more complex. Markets continue to grow and press for ever higher productivity, but further division of labor simply 'cannot deliver': the process slows down and ultimately must reverse itself.

Division of knowledge

Any process of the division of labor is accompanied by the parallel process of the division of knowledge. Usable knowledge now rarely exists in its concentrated or integrated form: it has become dispersed into bits of incomplete and often contradictory pieces possessed by separate individuals.

This problem of the Division of Knowledge, first recognized by F.A. Hayek [4,5], leads to formulating the really central problem of economics as a social science (i.e., not as a 'wilted branch' of physics):

How the spontaneous interaction of a number of people, each possessing only bits of knowledge, brings about a state of affairs which could be brought about by deliberate direction only by somebody who possessed the combined knowledge of all those individuals.

Example. No single individual possesses the requisite knowledge of building a space shuttle. Yet the space shuttles get built. How? Where is the complete and requisite knowledge 'stored' and how? In order to deal with the problem of increasingly atomized and widely distributed knowledge, humans have evolved, quite spontaneously, complex coordinative hierarchies of management and command. It is these hierarchies which in their totality represent the requisite '*social memory*', the way of 'coding and storing' human knowledge about wholes.

We show that although the phenomena of the division of labor and division of knowledge are interrelated, and circularly form the consequence of one another, the division of knowledge goes beyond that of labor.

Remark. Knowledge should not be confused with 'skill' – as we have mentioned earlier. While 'skill' refers only to system structure or 'surface' knowledge to be used in specific trade and under specific circumstances, knowledge involves also system organization or 'deep' knowledge. Only the knowledge of organization allows humans to deal with novelty and thus provides the required capacity of foresight and prediction. It is only in this sense that we shall understand knowledge in our context: the notion of 'skill' is not relevant as it can be readily acquired by lower-level machines or *golem-like* 'workers'.

According to Hayek [4,5] the economic problem of society is mainly one of rapid adaptation to changes in particular circumstances of time and place. It follows, quite naturally and inescapably, that important decisions must be left to those who are *familiar* with these circumstances, who know directly of the relevant changes and of the resources immediately available to meet them.

Such problem CANNOT be solved by first gathering all relevant data and information, then communicating all this 'knowledge' to a central agency which, after properly integrating all and everything, issues its orders and sets to communicate them back to the points of their origin. This is how centrally planned societies and enterprises are organized. The problem must be solved by some form of decentralization, like for example the very effective *distributed autonomy* of Bat'a [21], to ensure that the crucial knowledge of the particular circumstances of time and place will be properly and promptly used by the system.

But the individual 'on the spot' (anywhere in the hierarchy and least of all at the top) cannot act solely on the basis of his intimate but still limited and atomized knowledge of the facts of his immediate surroundings. There is still the problem of communicating *to him* the additional information which allows him to fit his decisions into the whole pattern of changes of the larger economic system.

It is at this point where *Management Support Systems* (MSS) are needed most. Their task is to allow one individual's limited 'field of vision' to sufficiently overlap with other individuals' limited 'fields of vision' so that through such *interlinkage* an 'interflow' becomes possible and relevant information is communicated to all system participants. To support the aggregation of all 'fields of vision' for the purpose of communicating the aggregates in the management hierarchy would be hopeless; to support further narrowing of individual 'fields of vision' would amount to a 'white-collar crime'.

Knowledge-based MSS can be characterized as systems with distributed intelligence: they facilitate autonomous coordinability of increasingly decentralized subsystems which can state and adapt their own objectives. There is no need for a central managing mechanism (hierarchy) or agent (manager). Instead, individual ability/capacity declarations, contractual negotiations and circular communication are allowed to take place over the local area network. Such autonomous coordinability of decentralized system with proper fault-tolerance, on-line maintainability and on-line expandability was achieved on a large scale by Bat'a-system [21] in the pre-computer era; it is now being studied more formally in connection with modern parallel computing systems [6,7,13].

Reintegration of knowledge

If one person starts performing subtasks *previously carried out by two persons, or if one person starts controlling two instead of one machine, or even if one machine starts performing functions previously* done by two machines – we can be sure that no further division of either labor or knowledge is taking place. The process of reintegration has started.

The process of labor and knowledge reintegration is a natural and gradual consequence of the preceding process of the division and distribution. In fact, they are both interrelated parts of an even broader and all-encompassing meta-process.

These two apparently and fundamentally different responses (division and integration) to the same stimulus (growth of marked demand) cannot be characterized as a 'cycle' or 'wave', nor as a 'revolution' or 'transformation', not even as a 'metamorphosis' or 'growth'. The most fitting seems to be Giambattista Vico's conception of *corsi e ricorsi* in the evolution of social systems [15].

Any real origin in human affairs – and the process of division of labor is of a real origin – must meet with a real end. After each *corso* there follows a different and yet organically related *ricorso*. There is always a course and recourse, outswing and rebound, disaggregation and reaggregation. The dual process of *corso e ricorso* should not be taken apart: it is a whole, a self-organizing and self-renewing whole. The success spawns failure and growth is also a decline. Every *corso* in human affairs is self-binding and self-limiting, transforming itself, gradually and at first imperceptibly, into its inevitable *ricorso*.

The *corso* of the division of labor is an old process, an *ancient régime* initiated concurrently with the emergence of human history. It has been expanding, exploding and spreading itself until today. Only now, at the very end of the twentieth century, the first manifestations of its *ricorso* can be observed. It is the longest of all long economic 'cycles'.

As the division of labor and knowledge progressed, the specialized efficiency of 'partial' manual and knowledge workers was continually enhanced by dedicated and single-purpose machines. These are possibly complex machines designed to perform a small or narrowly defined task as quickly and as efficiently as possible. A worker becomes an operator and thus a necessary attachment to the machine. Worker supports and enhances the machine, not the other way around.

Conclusion

'Integration' is now rapidly becoming a byword of the newly emerging, high-technology & knowledge-based management systems. Machines are becoming universal or multipurpose, workers multifunctional, and managers (at least some) aspiring 'renaissance men'. Job and functional rotation are increasingly common at all levels of the hierarchy, quality circles and teamwork are mushrooming and education replaced training. Hierarchies are becoming flatter and workers are becoming managers (even officially so at the now defunct People Express). Autonomy, participation and self-management are replacing the traditional 'managements' by objectives, motivation. control and reward.

Knowledge is being reintegrated: people are learning broader, not narrower tasks; workers are being rewarded according to the number of tasks they can carry out; machines are designed for multifunctionality; products are redesigned with sharply decreased number of parts. Management support systems are now capable of creating, storing, maintaining and expanding knowledge as well as supporting the knowledge process of humans.

Integration of individual subtasks reduces the complexity of user interfaces to systems. Modern MSS must be autonomously coordinable, based on distributed (*un*centralized) intelligence, parallel and thus fault-tolerant, on-line maintainable and on-line expandable, object oriented, capable of synchronous and asynchronous message passing and broadcasting – as was so inadequately argued in this paper.

It would be a waste if current 'expert' systems should remain on the level of simple IF–THEN rules operating on a unidimensional PART-OF 'database of facts'. For promoting further enhancement of specialization and narrowing of expertise at the times of gathering forces of universal reintegration could amount to a case of white-collar 'crime' of producing unnecessary human golems.

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