Cognitive Cooperation for the Sake of the Human-Machine Team Effectiveness

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SUMMARY

This keynote presents a framework for incorporating cognitive automation into a work system, not only as part of the operation-assisting means but also in terms of cognitive cooperation of a human-machine team operating the work system and thereby taking the high-end decisions of the work process. This framework is based on the experience with successful prototype development of cognitive assistant systems in the flight systems and road vehicle domain. A theoretical framework as shown is important in order to be able to assess work system designs with regard to productivity, i.e. effectiveness and safety.

1.0 INTRODUCTION

Man-machine cognitive cooperation has become reality. There are a great number of prototype systems, which have demonstrated the capabilities of cognitive cooperation. Some references are given for examples concerning the prominent pilot work site in an aircraft cockpit only [Onken et al., 89; Lizza et al., 91,92; Kopf et al., 93; Champigneux, 95; Gerlach et al., 95; Funk et al., 98; Miller et al., 1999; Reising et al., 99; etc.], however, there are many other fields of application. These systems have got artificial cognitive capabilities and thereby allow teaming with human operators as well as with other artificial cognitive systems in order to actively assist the operator in a work process, mainly regarding situation awareness and effective actions with respect to the situational context. The most salient feature of these systems is that they have a great amount of knowledge in common with the human operator to be able to carry out the work tasks, if necessary, even on their own. Most important, they have got explicit knowledge of the prime work system objectives, the key knowledge for a cooperative system to catch up with the intentions of the team mate, for instance the human operator, and to warrant sensible interaction as a team mate. Since prototype systems have demonstrated that cognitive cooperation is technically feasible, the following chapters will not dwell on the technical details of artificial cognitive systems. The focus will rather be on the underlying fundamental ideas about artificial cognitive systems and intrinsic potentials for cognitive cooperation.

Hence, this keynote will dwell on the main properties of artificial cognitive systems, how these properties can be used to improve work system capabilities and to make work processes more productive and more efficient. It will point out that automation in the new setting of cognitive automation will bring about human-machine cognitive cooperation in a way similar to human-human cognitive cooperation [Hoc et al, 1995] and that it can be exploited for more effective coordination between team-mates, humans as well as machines. Approaching this topic from the system engineer's point of view, the structure of the work system and the possible ways to incorporate artificial cognition in the work system have to be discussed first.

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2.0 HOW DOES ARTIFICIAL COGNITION EFFECT THE WORK SYSTEM?

2.1 The Concept of Work System

Taking the system engineer's point of view to find out how artificial cognition can effect human-machine interaction, one should start with the concept of work system. The work system is traditionally structured as shown in figure 1. There are three main work system elements: Operator, work object and operator-assisting means [REFA, 84]. The way the work system functions forms the work process. The work process operates under certain ambient conditions on a given work task, i.e. to achieve a certain time-dependent work result in terms of a transformation of the work object. Thereby, the work process makes use of certain resources (information, material, energy). A work system can only be set up based on a high level work task which stands for itself, i.e. being independently carried out from any other work task, like building a house or flying an aircraft from one certain location to another etc. Thus, performing a subtask like holding speed constant during a certain flight segment, which is obviously only part of a higher level work task, does not form a separate work system. The effectiveness of the work system is determined by the following elements: Operator, operation-assisting means, environmental conditions and resources. The operator is the high end decision element of the work system. It is only this element which determines and supervises within the work system what will happen with the work object in order to accomplish the work task. With respect to the work system concerned, this element operates autonomously. While the human operator and the environmental conditions cannot be changed beyond certain narrow limits, and since the aspect of resource consumption is more or less an economical issue, which is important, though, but not so relevant for the ergonomic design, it makes sense that today ergonomic scientists increasingly concentrate on the improvement of the operation-assisting means, i.e. systematically and ***methodically*** exploiting technology for the sake of a human-centred and efficient work system. In the past, computerized operation-assisting means often have been implemented without use of well-founded methods and theoretical frameworks. This is the reason why the potential of automation for the improvement of the operation-assisting means has been underestimated and misunderstood for a long time, despite increasing its use dramatically, too often not to the delight of the ergonomic scientists. More recently, there are also thoughts about having the high end decision element to operate the work system being extended, not only by humans but also by artificial cognition, which will be taken up later on in this article.

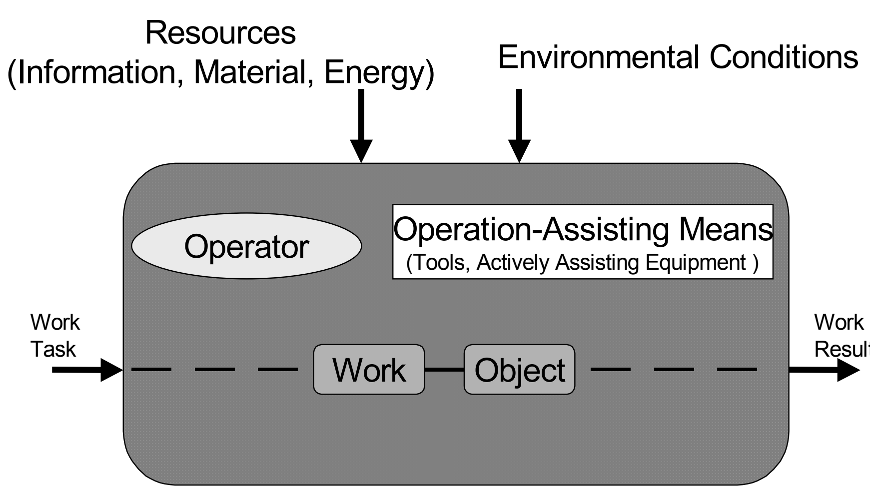

Figure 1: Concept of Work System.

2.2 The Conception of an Artificial Cognitive Unit (ACU)

The conception (model) of an Artificial Cognitive Unit (ACU) will be briefly described in the following. The ACU has got cognitive core capabilities which are of great similarity to those of humans regarding rational reasoning and decision making in order to recognize/identify the encountered situation and to make action plans in order to react properly subject to given objectives. An ACU, though, is not to mimic the processes of the human brain in detail. It rather should be able to generate outputs which could be generated as well by human rational thinking or which, at least, are intelligible to humans.

Figure 2 shows the principal structure of an ACU. The central component is the “body”, the oval core of the ACU in figure 2, which hosts all data used and produced by the artificial cognitive process. The inner part of the body, slightly darker, contains the “a priori knowledge” which is fed into the ACU (or learned), before the process starts. This “a priori knowledge” is the origin of application-dependent behaviour of the ACU. The outer part of the body contains the situational “knowledge” which is created during runtime. This specific kind of dynamically generated and refurbished knowledge results from the ACU-subprocesses, the “transformators” and is called the “cognitive yield”.

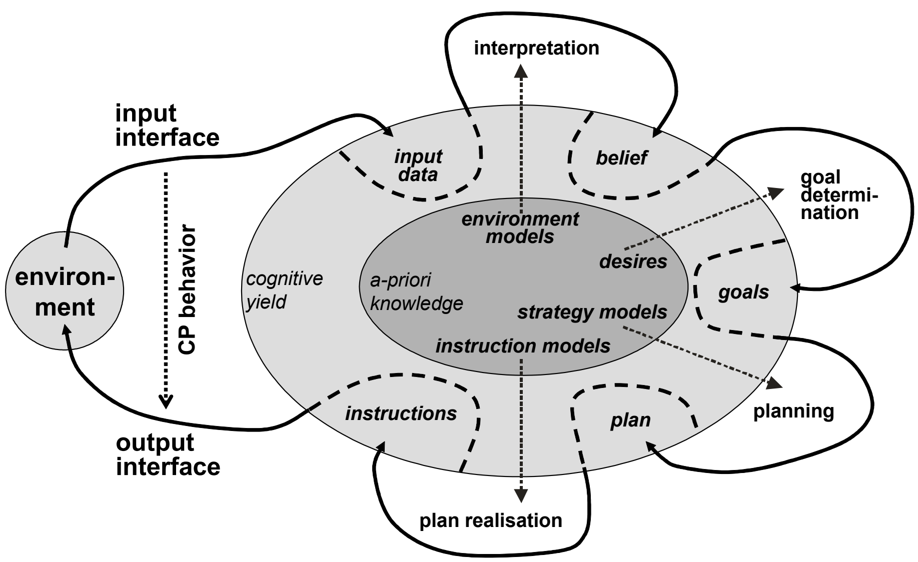

Figure 2: Basic Conception of an ACU.

The transformators are located around the body. They have access to all a priori knowledge and cognitive yield in the body and write their results into designated areas of the body (at the arrowhead). The transformators represent functions according to those of the recognition-act cycle:

- Interpretation (of the situation), mainly based on the input data accessible from sensors and communication interfaces outside the ACU as part of the environment and a priori knowledge about environment models[1],
- Goal determination (including determination of conflicts and opportunities), mainly based on the belief as output of the interpretation transformator and a priori desires,

[1] The a priori knowledge of environmental models might be extended – if wanted – also by introspective models of the ACU itself.

- Planning, mainly based on the determined goals and strategy models and
- Plan realisation, mainly based on the plan how to proceed and a priori knowledge about adequate instructions for the execution units available to the ACU as part of its environment.

The environment represents the world in real the ACU is interacting with. This includes the other components of the work system the ACU belongs to, including human operators and environmental objects, but also other work systems of relevance.

As was already alluded to, also the learning capability can be represented in such a unit, if wanted. It can be imagined in terms of a second layer, fed by the belief and supplementing the a priori knowledge. This is not depicted in figure 1 and will not be further discussed at this point, though.

The ACU represents a computer software, exploiting the computer technology available in order to achieve a cognitive performance level as high as possible. This includes to incorporate all relevant knowledge available about human cognition, but there is not the principal intention to develop an ACU in order to mimic the physiology of the human brain as closely as possible. This would be too specific and limiting regarding the ACU potentials in general. ACU software is available at this point of time, even in terms of an application-independent software [Putzer, 01]. Although this already provides great potentials for improvement of work systems, in particular for more complex systems, there also is, on the other hand, still much room for further performance improvement of the ACU.

2.3 The Two Faces of Automation

In general, automation is a technical resource with the capability to carry out on its own tasks of a work process as determined by the work system designer or the operator. Hence, there is the potential that automation can help to avoid excessive load on the operator, i.e. to keep the load on the operator at an acceptable level. Otherwise, all tasks had to be carried out by the operator alone.

Automation, as it is realistically feasible today, including artificial cognition, can appear in many ways in the work system. Thereby, it might show mainly two faces, each of them with significantly different characteristics [Onken, 01]. In other words, we know of two significantly different levels in automation quality which are possible in the meantime: One of them is what we are used to as the conventional approach (we call it “conventional automation”), as opposed to the “cognitive automation” with characteristics which we are familiar with as those of human team mates.

Level 1 (Conventional Automation)

Conventional automation, whether activated automatically according to design specifications or activated manually by the operator, is predominantly focused on subtasks and accordingly on sub-goals of the work process. The superior prime goals and pertinent tasks are not known by the systems for automation of subtasks. Consequently, these systems work on the basis of observing only a small portion of what is of relevance in a given situation. For example, if the autopilot is activated by the pilot for the subtask “altitude hold”, it is doing its best to comply with this assigned function, even if a high mountain is in its way. The top-level safety goal of avoiding a crash into the mountain is exclusively in the realm of the pilot’s responsibilities. The autopilot doesn’t know of it and will not care.

This conventional concept of having automation functions in the work process like specialists who are good for a particular task but who lack perspective otherwise, was very convenient as long as only simple automated functions were used for simple tasks. It was of no harm that the responsibility load not to violate the top-level objectives of the work process was exclusively on the operator's shoulders. However, in work systems for very complex tasks like those, for instance, for carrying out a demanding fighter mission, increasingly complex "operator-assisting" automation means have to accommodated, correspondingly. With increasing automation complexity, the conventional concept inevitably will lead to overload of the operator at some point, resulting in a dangerous loss of performance. The operator might be unaware of discrepancies between subtask activities of automated functions and the prime goal necessities or of insufficient adaptiveness on his side. This is just the opposite of what was intended by the introduction of automation and is known as automation brittleness, opacity, literalism and clumsiness [Billings, 97]. Figure 3 is showing a simple diagram, illustrating that for the pilot's work site. In fact, conventional automation reduces the demand on the pilot's resources on the average most of the time, but might also generate excessive load – at rare occasions, though – which would not have happened without automation. Many accidents can be accounted to that phenomenon.

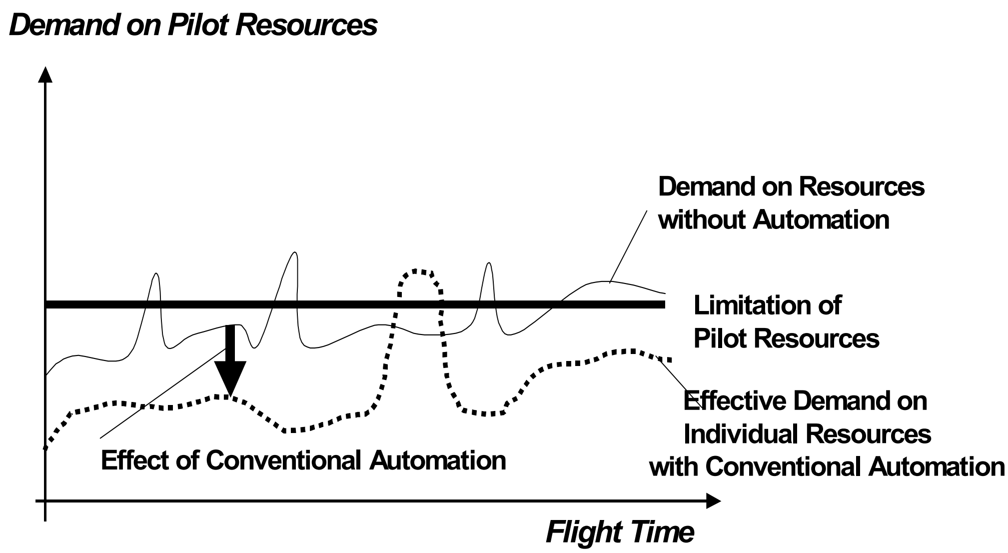

Figure 3: Demand on Crew Resources During Flight Mission.

Level 2 (Cognitive Automation)

As opposed to conventional automation, cognitive automation works on the basis of comprehensive knowledge about work process objectives and goals on all goal hierarchy levels, pertinent task options and necessary data describing the current situation in the work process. Therefore, cognitive automation is prime-goal-oriented. In summary, it stands for artificial capabilities:

- to independently assess and keep ready necessary situation-relevant information about the objectives the human operator is pursuing, about his intents and activities, about the work object and tools, and about the relevant process environment;
- to understand the situation by independently interpreting it in the light of the objectives;
- to distinguish between important and unimportant information, urgent and less urgently needed actions;
- to know which information the operator needs;

- to support necessary re-planning and decision making; and
- to initiate human-like communication with the operator, thereby actively taking care that the operator's situation awareness is evened up with what is detected as conflicts or opportunities by the systems, not to leave him alone with presentations which do not care about what he has understood about the situation and what he actually perceives or does not perceive.

Making use of these capabilities in terms of operation-assisting means in the work system, it has no longer to be the exclusive task of the operator to monitor the process subject to the prime work system objectives. ACUs working on prime work system objectives identical to those of the human operator, that is something the designers of work systems have yet to get used to [Vicente, 99]. Then, a "cognitive" autopilot will see the mountain in front, will know that to proceed stubbornly with altitude hold will end in disaster and it will look for a way around. Consequently, figure 1 can be drawn in more detail making explicit the possible incorporation of ACUs as part of the operator assisting means in the work system (see figure 4).

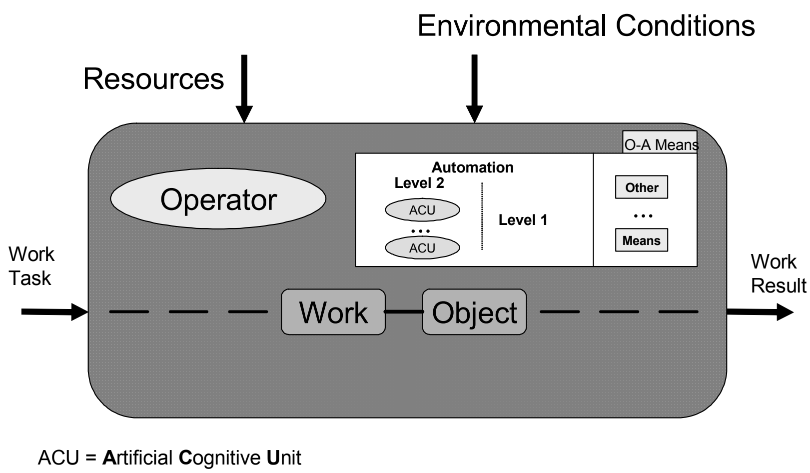

Figure 4: Work System with Cognitive Automation (ACUs) as Part of the Operation-Assisting Means.

This does not mean that cognitive automation is to be used exclusively. Level 1 automation will be incorporated, too, as depicted, and is still very useful, indeed, for low complexity functions, as was proven oftentimes. Cognitive automation on the ACU level, however, is the basis for man-machine cooperation in its real sense. Figure 5 summarizes this discussion in terms of possible productivity gains. One new but not too difficult design question is now, where to work with conventional automation and where to use cognitive automation.

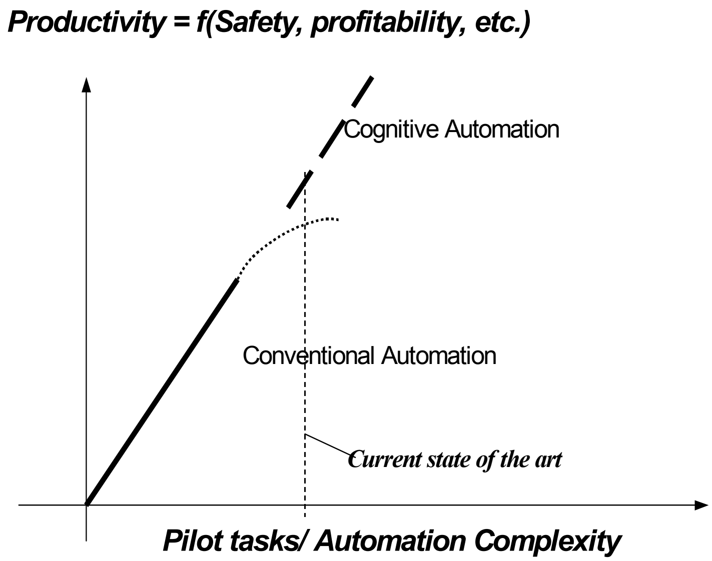

Figure 5: Effect of Conventional and Cognitive Automation on Productivity and Safety.

3.0 COGNITIVE COOPERATION – A BY-PRODUCT OF COGNITIVE AUTOMATION

As opposed to mere interaction, cooperation has particular main characteristics. Cooperating units in a work system (see figure 6) are:

- commonly having access to all information available through sensors, communication and databases;
- appearing as humans and as ACUs as part of the work system[2];
- capable for autonomy but not necessarily working autonomously;
- in general, capable to adopt the roles (i.e. grouping of coherent functions allocated to separate cognitive units) of other cooperating units in the course of the work process, because all are working on common prime work system objectives;
- working rather independently subject to common work prime objectives, thereby possibly starting independent initiatives, usually in terms of communication to even up in beliefs about the situation, goals and decisions and to coordinate roles and authority levels.

This means that cooperating units can appear as assisting means (level 2 automation ACUs) in the work system at a rather low decision authority level, but also as ACUs and human operators in the operator/ACU team (see figure 6) at the high-end authority level for decisions in the work system, which was, so far, occupied by the human operator alone. Basically, each of the cooperating units can (have not to, though) carry out all tasks, which might come up in the course of a work process, but depending on the role and the association with either the operator/ACU team or the assisting means, tasks will be partitioned between them.

[2] In general, also other biological creatures could appear as cooperating units like, for instance, the horse, dragging the carriage and still taking care of avoiding disaster, when the coachman has gone asleep (horse mode).

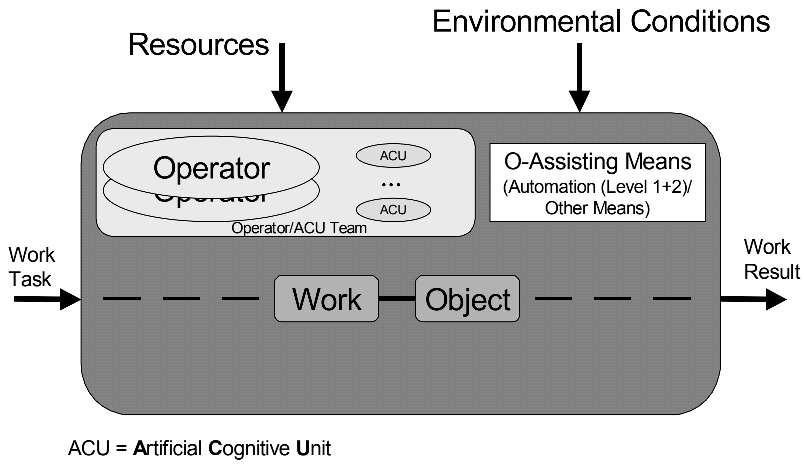

Figure 6: Work System with Cognitive Cooperation (Operators-ACUs).

The cooperating units in the operator/ACU team are normally cooperating under certain complementary roles within the work process. All team members are entitled for full authority (highest in command line) within the respective role to effect the work object (i.e. autonomy). Therefore, autonomy, on principle associated with the operation of a particular work system, is distributed between cooperating operator/ACU team members by roles. A typical example for this kind of cooperation in a human team is the cooperation of the cockpit crew, for instance the TORNADO crew with a pilot and the Weapon Systems Officer. On the other hand, the operation of unmanned systems, for instance, needs that kind of work system setup where ACUs as part of the operator/ACU team have to take over decision tasks at the high-end decision level.

Another consequence using cooperating cognitive units in the work system is the potential that subtasks which do not end up in a direct output to effectors on the work object, might be taken up in parallel by one or more other cooperating units, what is a well known fact in human teams. This potential might be effectively used by both ACUs as assisting means and ACUs working in the operator/ACU team at the high-end authority level. In turn, this leads to the other potential that cooperating units are not bound to a firm allocation of tasks.

Conflicts, in particular decision conflicts between cooperating units in different roles, but also when working in parallel, are always possible. The roles of cooperating units might be overlapping in certain ways and working in parallel under dissimilar strategies in some ways is just so important, because thereby misinterpretations and system errors can be made evident. Conflicts are to be avoided by an authority hierarchy, which, in the ideal case of high flexibility, might be subject to change. Certain circumstances might cause the need for that. For the case of human teams like the pilot crew in a transport aircraft, this is well known under the term “crew coordination” which is to open up some flexibility in the authority allocation to team members in the course of the work process. That can also be exploited in a mixed team of human operators and ACUs. Usually, the human operator’s authority level is above the authority of ACUs, but this has to be carefully investigated for the particular work system case being considered. The principal of higher authority level on the human operator’s side is not necessarily the best solution in all cases. Therefore, flexibility of authority allocation is of great interest, but not easy to implement.

Referring to two examples of prototype systems being referenced earlier, the “Cogpit” project in the UK [Taylor, 01] and the CAMA project in Germany [Lenz, 00; Frey et al., 01] came already rather close to that kind of objective for team coordination. CAMA (Crew Assistant for Military Aircraft) is an assistant for the crew of military transport aircraft, developed and flight tested under contract of the German DoD, and "Cogpit" (Cognitive Cockpit), is a demonstration prototype system of cognitive assistance for the fighter pilot, developed under contract of the British DoD. In particular, the Pilot Authorization of Control Tasks (PACT) framework in the "cogpit" system, providing the necessary and sufficient levels of authority for the task automation manager system is addressing this objective with emphasis. The PACT system has got three primary automation modes, quoting from [Taylor, 01],

" – namely, fully automatic, assisted or pilot commanded – with a further four secondary levels nested within the semi-automatic, assisted mode, which can be changed adaptively or by pilot command. The PACT system uses military terminology for categories of support for Army land forces military operations (At Call, Advisory, In Support, Direct Support) to afford usability and compatibility with military user cognitive schemata and models. It provides realistic operational relationships for a logical, practical set of levels of automation, with progressive operator/pilot authority and computer autonomy supporting situation assessment, decision making and action. Mission functions and tasks, at different levels of abstraction allocated individually or grouped in related scripts or plays, can be set to these levels in a number of ways:

- *Pre-set operator preferred defaults,*
- *Operator selection during pre-flight planning,*
- *Changed by the operator during in-flight re-planning, probably using Direct Voice Input commands,*
- *Automatically changed according to operator agreed, context-sensitive adaptive rules."*

Table 1: PACT System for Pilot Authorisation of Control of Tasks [Taylor, 01]

Primary Modes	Levels	Operational Relationship	Computer Autonomy	Pilot Authority	Adaptation	Information on performance
AUTOMATIC		**Automatic**	Full	Interrupt	Computer monitored by pilot	On/off Failure warnings. Performance only if required.
ASSISTED	**4**	**Direct Support**	Advised action unless revoked	Revoking action	Computer backed up by pilot	Feedback on action. Alerts and warnings on failure of action.
	3	**In Support**	Advice, and if authorised, action	Acceptance of advice and authorising action	Pilot backed up by the computer	Feed-forward advice and feed-back on action. Alerts and warn-ings on failure of authorised action.
	2	**Advisory**	Advice	Acceptance of advice	Pilot assisted by computer	Feed-forward advice
	1	**At Call**	Advice only if requested.	Full	Pilot, assisted by computer only when requested.	Feedforward advice, only on request.
COMMANDED		**Under Command**	None	Full	Pilot	None performance is transparent.

This is an important step to make the operational relationship between cooperating units explicit. From the system engineer's point of view, looking at the main work system elements, the considerations following the scheme as shown in [Taylor, 01] have to be done separately for the element of operation-assisting means and the operator/ACU team.

Consequently, there are two separate tables (see table 2 and 3) for the authority levels of these two work system elements. Only table 3 contains the operational mode of full computer authority in terms of autonomy. In addition, this table shows that the operator/ACU team members are also making use of lower operational modes of cognitive automation in the framework of their roles as part of the team (human team example: cockpit crew).

Table 2: Authority Levels and Corresponding Operational Modes (Operation-Assisting Means)

Primary Modes	Mode Sublevels	Operational Relationship	Computer Authority	Operator Authority	Adaption	Information on Performance ***Operator – ACU***
COOPERATIVE ASSISTANCE (COGNITIVE AUTOMATION)	**3**	**Direct Support**	Action unless revoked	Revoking action	ACU backed up by 0perator	Feedback on action. Alerts and warnings on failure of action.
	2	**In Support**	Advice, and if authorized, action	Acceptance of advice and authorizing action	Operator backed up by the ACU	Feed-forward advice and feedback on action. Alerts and warnings on failure of authorised action.
	1	**Advisory**	Advice	Acceptance of advice	Operator assisted by ACU advice	Feed-forward advice
CALLED ASSISTANCE (COGNITIVE AUTOMATION)		**At Call**	Advice and action only if requested	Full	Operator assisted by ACU only when requested.	Feed-forward advice, only on request Feedback on action. Alerts and warnings on failure of action.
CONVENTIONAL AUTOMATION	**2**	**Direct Support**	Action unless revoked	Revoking action	Computer backed up by operator	Feedback on action. Alerts and warnings on failure of action.
	1	**At Call**	Action if requested	Full	Computer backed up by operator	Feedback on action. Alerts and warnings on failure of action.
NO AUTOMATION		**Operator only**	None	Full	Operator	Performance is transparent.

Table 3: Authority Levels and Corresponding Operational Modes (Operator/ACU Team)

Primary Modes	Mode Sublevels	Operational Relationship	Computer Authority	Operator Authority	Adaption	Information on Performance ***Operator – ACU***
AUTONOMY (COGNITIVE COOPERATION)		**Role Autonomy**	Full	Interrupt	ACUs monitor-ed by other Cognitive units (e.g. operator)	On/off Failure warnings. Performance only if required.
COOPERATIVE ASSISTANCE (COGNITIVE COOPERATION)	**3**	**Direct Support**	Action unless revoked	Revoking action	ACU backed up by other Cognitive unit (e.g. operator)	Feedback on action. Alerts and warnings on failure of action.
	2	**In Support**	Advice, and if authorized, action	Acceptance of advice and authorizing action	Cognitive unit (e.g. operator) backed up by the ACU	Feed-forward advice and feedback on action. Alerts and warnings on failure of authorised action.
	1	**Advisory**	Advice	Acceptance of advice	Cognitive unit (e.g. operator) assisted by ACU advice	Feed-forward advice
CALLED ASSISTANCE (COGNITIVE AUTOMATION)		**At Call**	Advice and action only if requested	Full	Cognitive unit (e.g. operator) assisted by ACU only when requested	Feed-forward advice, only on request.
NO AUTOMATION		**Operator only**	None	Full	Operator	Performance is transparent.

Table 2 also has to take into account the level of Conventional Automation as the lowest authority level of a primary mode using automation.

CAMA is working essentially under the same principals as “Cogpit”, not going beyond the use of ACUs for operation-assisting means, i.e. working in correspondence with table 3. At the time being, this is how far computer authority is driven in the flight domain. This will be different in the application domain of unmanned air vehicles. Slightly different from Cogpit, the operation of CAMA does not include explicit operator selection of authority changes during pre-flight planning. The operator is selecting by doing. Pre-set action defaults are exclusively implemented for advice initiatives subject to certain rules which follow the principal of being as quiet as possible. Emphasis is put on the context-dependent changes of automation level as also provided by PACT in the Cogpit system, which are either initiated by the operator or by the cognitive automation functions. Figure 7 shows the overall pilot scoring of the CAMA flight tests, which somehow underline that cognitive automation in terms of Cooperative Assistance brings about a significant effect.

CAMA increases Flight Safety

Agreed	★★★	★						Disagreed

CAMA increases Mission Effectiveness

Agreed	★★★	★						Disagreed

CAMA increases Survivability

Agreed	★★★		★					Disagreed

Figure 7: Overall Pilot Scoring of the CAMA Flight Tests (4 Pilots).

It turns out that for the purpose of effective authority coordination in a cooperating team the team members should know as much as possible from each other's performance characteristics and behavioral traits. Therefore, modelling of cognitive behavior, in particular of human behavior, has been used in these systems and has become a major field of further research. This will be addressed briefly in the last section of this talk.

4.0 ADAPTIVE OPERATOR BEHAVIOR MODEL

When addressing the conception of ACUs, the content of the 'a priori' knowledge has not been specified in great detail. One aspect, however, not clearly mentioned so far, should be covered at this point for further appreciation regarding cognitive cooperation. It turns out that for the purpose of effective authority coordination in a cooperating team the team members should know as much as possible from each other's performance characteristics and behavioral traits. Therefore, modelling of cognitive behavior, in particular of human behavior, has been used in these systems and has become a major field of further research. These models are to be part of the 'a priori' knowledge containing models of all objects of the world surrounding the ACU and being of relevance concerning the prime work system objectives. These models are, for instance, to be instantiated in the cognitive subprocess of situation interpretation.

Operator models have been developed by use of a wide range of different paradigms, methods and applications. [Jürgensohn, 97] gives a quite comprehensive overview about the actual state of the art. The type of model to look for is a situation- and operator-adaptive model, i.e. modelling the individual operator person, actually working on the work object.

In pursuit of a psychologically plausible model, there has been done relatively little work in this direction. A good starting point is Rasmussen's scheme of three levels of human cognitive behavior: the skill-based, the rule-based and the knowledge-based level [Rasmussen, 83]. Behavior modelling on the rule-based and the knowledge-based level seems to be relatively straightforward on the basis of comprehensive offline interviewing of the operator person, if possible. On the other hand, the probability of incompleteness of the model with respect to work situations not covered by the interviews might still be a problem. Even more difficult is the modelling of skill-based behavior on the basis of verbal interviews.

Therefore, in the following I will address an encouraging approach for online learning of the operator behavior, which offers the chance to achieve the wanted situation- and operator-adaptation of the model which we want for the sake of effective cognitive cooperation. Amazingly, there has been done relatively little work in pursuit of a psychologically plausible model of this kind. Yet, noticeable progress of operator modelling can be stated, for instance in the domain of road vehicle driving, which has to a large extent to deal with the allegedly most difficult part of behavior modelling: Modelling of skill-based behavior. This will briefly be addressed in the following.

The learning process for the driver model, the ACU could adopt, is a rather complex hybrid procedure. For each driving situation in a particular traffic scenario, a priori knowledge can be provided for the rather small number of pertinent candidates of action patterns [Jensch, 78]. The decision process (see figure 8) for one of these candidates/alternatives represents part of the model. The driver's choice is made according to his skill-based situation interpretation, including his individual goals, experiences and anticipations of the behavior of the other traffic participants. This decision model can be learned, for instance, by reasoning on the basis of a case base (see figure 8).

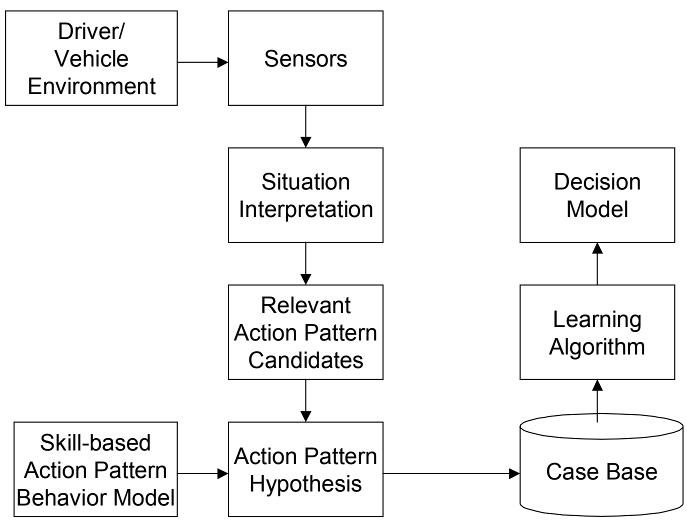

Figure 8: Process of Learning of a Driver-Adaptive Decision Model, Deciding on One of the Situation-Dependent Action Pattern Candidates.

In order to provide the case base, the method of process observation (on-line learning) is used based on the separate skill-based action pattern model which provides the actual "atomic" driver action. This basic part of the driver model is derived by a separate learning process, again using the method of process observation in order to teach the mapping from perception to control actions, the stimulus-response relationship. In order to enable online learning the learning algorithm has to comply with the following requirements. The algorithm must be able to:

- operate with very little a priori knowledge
- extend the knowledge without forgetting that already learned
- allow learning state monitoring

In order to comply with these requirements, for instance general neural regression networks are used for the learning process. General regression neural networks (GRNN) [Specht, 91] are special RBF (radial basis function) networks for linear and nonlinear regression analysis, which approximate an underlying probability density distribution function using the Parzen window method [Parzen, 62].

Two examples of results are briefly discussed, concerning the more fundamental part of learning the skill-based driver action pattern [von Garrel et al., 00]. These are examples for certain driving situations in longitudinal vehicle guidance.

The first example shows a representative result of the behavior of a trained driver model for the two subsequent situations „free driving" and "stopping at a traffic light". A learning algorithm was used as described before. In the training phase for the model, two situation features (speed, relative distance from traffic light) are presented to only one network for the situation "stopping at traffic light". For the situation "free driving" only the feature "speed" is used. As shown in figure 9, the model for acceleration control drives in a stable way in the simulator test run and behaves very similar to the driver.

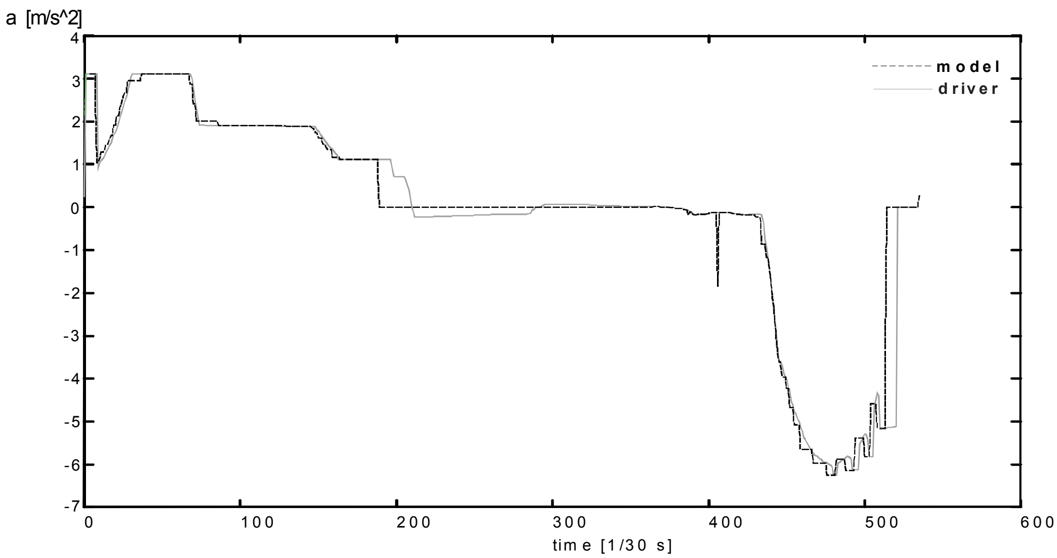

Figure 9: Acceleration Control: Driver Model Performance.

The second example represents a result for the driving context of "car following". The learning algorithm is working on the situation features:

- Headway distance
- Relative speed
- Acceleration of the vehicle in front
- Speed v[m/s] of the own vehicle

Figure 10 shows the driver model performance by comparing the actions for speed control between driver and model in the situational context of "car following" in a 3 minutes simulator test run in an urban scenario. Again, the learning performance appears to be amazingly well. The discrepancies between driver and model are rather small, mostly well within the scatter which is shown by the driver anyway.

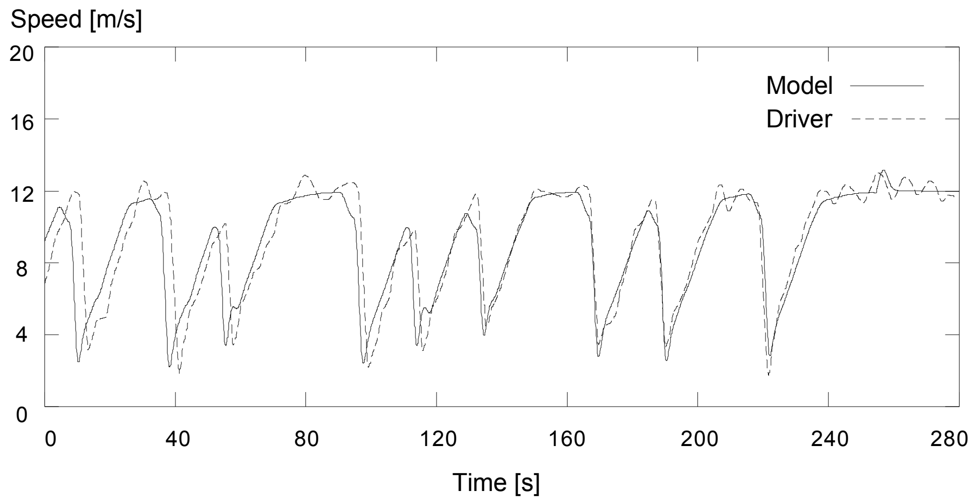

Figure 10: Simulator Test Run with Speed Control in the Situational Context of "Car Following": Driver Model Performance, Comparison Between Model and Driver Behavior.

5.0 CONCLUDING REMARKS

The advances in cognitive engineering technology have brought about means to systematically reflect requirements of human-centered design into clear-cut work system specifications. In particular, the improvement of the operation-assisting means as part of the work system is emphasized on the basis of cognitive automation, a new higher level automation capability.

Prototype systems have already shown – and there is prospect of further considerable extensions and performance improvement – that cognitive automation can indeed provide highly effective cognitive cooperation for the sake of work process productivity and work satisfaction of the human operator.

The success of cognitive cooperation in the work process is highly dependent on the capability of the artificial cognitive units involved to found its activities on a valid model of the human operator. Developments in this area for situation- and operator-adaptive models have, by now, arrived at a very encouraging performance level.

What is not addressed but should be mentioned at this point: The cognitive system approach is also a very powerful means to evaluate the work system performance on an objective basis, also for networks of interdependent work sites. This will help to reveal and clarify where the weaknesses lie of existing work systems and those in development.

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