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Explaining Crisis Situations via a Cognitive Model of Attention

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Abstract: Decision making in critical situations is a complex process. There are many processes to consider. This paper describes a theoretical approach to researching attentional processes and automatic unconscious processes in terms of metacognition. An application of the approach is presented to explain decision making and metacognition as a solution for ineffective cognitive biases during a crisis situation. Evidence is presented from studies on neuropsychology, cognitive control, and cognitive architectures. An application of the recently formulated semiotic methodology is implemented that allows the design of conceptual models of Attention as Action. The formulation of a general model of attentional processes is based on a set of rules. The crisis phenomenon, as the crisis situation trigger, is semiotically described and applied as insight for a crisis information system design that prompts its users toward self-aware internal decision making. The research conducted evidently shows how the approach can explain the design of several cognitive architectures. Pointing toward metacognition as a solution to a crisis phenomenon and cognitive biases, the paper shows that understanding human cognitive and behavioral processes can significantly improve management in a critical infrastructure crisis situation.

Keywords: critical infrastructure; crisis situation; metacognition; decision making; cognitive bias; cognitive architectures

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1. Introduction

With the accelerated development of digital technology, cybersecurity has emerged as a critical concern that is garnering global attention. As cyber threats continue to evolve in sophistication and scale, they pose significant risks to the integrity of sensitive information and the security of critical infrastructures around the world. This escalating threat environment has prompted governments and regulators around the world to increase their efforts in developing and implementing robust cybersecurity policies and frameworks. These regulatory measures aim to strengthen defenses against adversaries in the digital world and ensure the resilience of digital ecosystems against potential attacks. The importance and weight of cybersecurity legislation in 2023 cannot be overstated. With the increasing prevalence of cyber-attacks such as ransomware and data breaches, robust cybersecurity measures are imperative to protect critical information and maintain trust in digital platforms. This large protection ecosystem is very complex and its structure can be confusing. Making decisions to protect it is critical, especially when talking about critical infrastructures.

Metacognitive processes, which include self-reflection and evaluation of one's own thought processes, are important for making informed and strategic decisions. They improve the awareness of crisis managers by pushing them out of their usual thinking and breaking ineffective cognitive biases. That is why the demand arose for providing an explanation of how types of attentional processes lead toward metacognitive processes. Such an explanation can then be integrated into a crisis information system, designing it in a way to prompt the operator to perform metacognitive processes.

The theoretical approach of Attention as Action is presented in this article. The view on the automatic unconscious and attentional processes that it provides is used to explain the interconnections between types of processes by following established understandings from the field of Cognitive Science. Theories of perception and mental imagery [1,2] and established understandings of automatic processes and attention [3] are combined with formulated cognitive architectures like LIDA [4], ACT-R [5], and CogAff [6]. Relations are presented between the Action Cycle Theory, supported by neuroscientific evidence [1], and the experimentally supported cognitive cycle [4]. Research on settled concepts from the Supervisory Attentional System [3] is presented in this work and used to explain the guiding principles of the so-called internal agent. The latter refers to the understanding of the personality that decides which mental resources to direct its attention. Together, the mentioned theories and understandings are integrated into the approach of Attention as Action.

In order for the theoretical approach to be used by researchers and engineers from different spheres, a semiotic internal action representation methodology was designed and presented in this article. It integrates the understandings of the theoretical approach, formulating them into symbols that are used to present theorization and design of concepts from Cognitive Science. This work presents an example of a conceptual model of Attention as Action that is used to explain how a personality experiences a crisis phenomenon.

The Internal Decision Model of Attention is presented in Section 4.2. It uses integrated knowledge from the theoretical approach, the semiotic methodology, and gathered research from Cognitive Science to define general types of attentional processes. Guided by their interconnection, the model proposes an explanation of how an internal agent reaches metacognitive processes. By following established views on metacognitive experiences [7,8] and autonoetic consciousness [9] and supported by evidence on metacognition in decision making [10], the presented model is used to semiotically explain the potential reach of metacognitive experience in contrast to a crisis experience. Supported by the understanding of a cognitive cycle [4] and the Action Cycle Theory [1], types of experiences are defined and viewed as occurring occasionally and circumstantially in specified cognitive stages.

The design of crisis information systems requires an accurate understanding of types of attentional processes and their interconnection. Thus, semiotic representation methodologies, like the one presented in this article, are required to provide researchers with the possibility to design conceptual models that combine several concepts from Cognitive Science. Such models would provide accurate and relevant information in a quick and easily understandable form—conceptual models of Attention as Action. A model of such can serve as a beneficial guide for engineers and developers to make designs of a crisis information system that prompts its users toward metacognitive processes, avoiding ineffective cognitive biases and wrong and rapid decisions.

2. Perception of Critical Infrastructure and Its Disruption

Each person's perception of critical infrastructure can be individual, but there are strict rules about what the term means and how it is defined in each country around the world. In Bulgaria, this is set out in the document "Regulation on the order, procedure and competent authorities for determining critical infrastructure and its objects and assessing the risk to them" [11].

2.1. Critical Infrastructures

A Critical infrastructure (CI) can be found in a social settlement more often than one may think. The U.S. Cybersecurity and Infrastructure Security Agency identifies 16 critical infrastructure sectors [12]. In Bulgaria, 19 critical infrastructure sectors are identified [11]. Each infrastructure, whether public or private, provides us with a specific and characteristic unified experience for our time and we can talk about critical infrastructure.

In this context, if the CI is disrupted, the impact on public life could be significant, both in public and in purely personal terms for the population.

Nowadays, given the geopolitical dynamics, such cyber-attacks against CI are being used as a means of waging a new type of modern warfare. Unlike classical warfare, however, in these conflicts, 'civilians' and businesses/civil, public, and private entities are on the front line as 'legitimate' targets of this type of warfare.

A few famous examples before the war in Ukraine included the attacks on Ukraine's power grid in 2015; the hacking of the Kansas nuclear power plant's business network in 2018; North Korea's attempt to hack the SWIFT network to steal over USD 1 billion; and the notorious 7 May 2021 ransomware attack on the Colonial Pipeline oil pipeline in the United States, which has become the poster child for attacks on critical infrastructure. Let us not forget the bitter Bulgarian experience such as the attack on the National Revenue Agency (NRA), the ransomware attack on Bulgarian Post, attacks on the official websites of a number of Bulgarian institutions, including the presidency website, etc.

The purpose of the attacks may be different. Some are a way to prepare for future conflicts by testing capabilities and defenses, while others are motivated by financial gain, an attempt to steal data, gain remote access or control, or disrupt and degrade services. Often, when an attack by a state-level actor is involved, a "foreign flag" or a combination of self-serving incentives beyond those of the state instigators is used to conceal this fact, in addition to appropriate technical measures. Furthermore, attacks may be the independent activity of cyber criminals who simply want to extract monetary gain or that of hacktivists.

2.2. Disruption of Critical Infrastructure Elements

Critical infrastructure is a very important element of people's lives, so when an incident occurs, its restoration is of particular importance. The disruption of critical infrastructure elements can result in multiple casualties. Making the right decisions to restore it is a complex process that requires effectively influencing the people involved in incident management. This impact can affect their behavior, psychology, attention, and cognitive perceptions in different ways.

In a critical infrastructure incident, stress and strain can affect the mental state of those involved. Stress can lead to panic and rash decisions. It is important to develop and implement techniques to manage the stress and emotional state of the people making these decisions. This can be achieved through training or simulations of crisis situations. Psychological training can help people remain calm and think more rationally at critical moments.

Of particular importance is the cognitive perception of the situation. When a critical infrastructure incident occurs, it is particularly important in decision making as to how a given encounter will be evaluated. This may include processes such as attention, memory, pattern recognition, and situation assessment, which are essential for responding quickly and effectively in moments of crisis. The initial response of the people involved often depends on their automatic unconscious processes. These processes, which include intuitive reactions and recognition of already-known patterns, allow operators to respond immediately. For example, in a cyberattack on a power grid, skilled operators can quickly identify signs of unusual activity and take initial measures to limit the damage. Metacognitive processes involve the awareness and evaluation of one's own thought processes and strategies and also involve an important role. In crisis situations, metacognition helps crisis managers evaluate their own decisions and adjust them as necessary. This self-reflection is important for avoiding the trap of automatic responses that may not be appropriate for any particular situation. For example, after the initial response to a cyberattack, metacognitive processes will assist executives in assessing whether their actions were effective or whether alternative solutions should be sought.

Another interesting cognitive process in crisis management is human attention. Attention should be focused on the most important aspects of the incident, ignoring less important distractions. Effective attention management can be aided by information systems that provide clear and prioritized information. Such systems help operators focus on critical data and make informed decisions quickly.

Proper response models for critical infrastructure incidents are an important aspect of the current research. Determining the correct model is essential and allows operators to identify anomalies and threats based on previous experience and training simulations. Creating realistic simulations and training programs based on cognitive models of perception can significantly improve personnel preparation for real incidents

3. Managerial Decision Making in the Critical Infrastructure System

Decision management is a complex process that can be structured in many ways. Back in 1972, Carlos Llano Cifuentes talked about the management of such processes in his book "Fundamentals of the Managerial Decision-Making Process" [13]. The author focuses on objectivity in the decision-making process. In it, he discusses how managers can balance between subjective evaluations and the need to be objective and unbiased. One of the key components is a proposed systematic approach to managerial decision-making, including problem recognition, generation of alternatives, analysis and selection of the most appropriate solution, and its implementation and control. The approach helps to improve the effectiveness of own decision making by using different methods of risk assessment and management that are critical for successful management.

A few decades later, Frank Harrison [14] also explored this process, looking at it in multiple strands, incorporating insights from psychology, sociology, social psychology, and politics. In his study, the author viewed decision making as a purely quantitative science. Emphasis falls on the process model, focusing on the steps and considerations involved in decision making rather than just the outcomes.

Over time, managerial decision-making processes become more complex and demand deeper understanding and explanation. When it comes to an infrastructure of public knowledge, its processes are very complex and intricate. This also leads to the process where critical infrastructures need to be correctly identified and described and their protection plans need to be spelled out to improve their protection. The European Commission first attempted to assess critical infrastructures in 2008 with the Directive 2008/114/EC [15]. In 2022, this directive was replaced by Directive (EU) 2022/2557 [16], known as the Critical Entity Resilience (CER) Directive, and came into force on 16 January 2023. The directive covers 11 sectors, including energy, transport, banking, healthcare, water, and digital infrastructure. It also provides for the development of national strategies and regular risk assessments to identify critical units and ensure their protection and resilience against a variety of threats, such as natural disasters, terrorist attacks, and other hybrid threats. This is also where management decision making in critical infrastructure is mentioned. Most often, this occurs in the phase of identifying and defining the critical infrastructure elements and their subsequent protection.

Managing decision making in Critical Infrastructures is a complex process. It can also occur in critical situations that do not affect critical infrastructure. Many authors do research on this topic [17–24].

Managerial decision making involves a prior human element. It is for this reason that the question of how people use their metacognitive skills in making complex decisions in high-stakes situations is raised. Metacognition refers to the conscious understanding and management of one's own cognitive processes, such as planning, monitoring, and evaluating one's own thoughts and actions.

Metacognition as a Solution to Cognitive Biases

A cognitive bias (CB) is often described as a systematic pattern of deviation from rationality in judgment. Our team uses the notion that a CB is a cognitive inclination or disposition as described by the Encyclopaedia of Behavorial Neuroscience [25]. A CB can be simply described as a pattern of thinking that is dichotomic to critical thinking. The definition of the latter by the National Council for Excellence in Critical Thinking in 1987 is quite long, but an emphasis can be extracted [26]. Leading statements were considered to be a "... guide to belief and action" that requires skillful conceptualizing, analyzing and

importantly, evaluating information based on empirical sources. This directed us toward the idea that a human may have expertise in a field, but deep analysis of how knowledge can be applied based on observations would require big data. A study on the influence of cognitive bias on crisis decision making presented that experts in the experiment were the least biased group but were still "... significantly affected by anchoring, framing, and bias blind spot" [27]. All of the directions presented in this paragraph point toward the need for an information system (IS) that would be beneficial to the management of CIs. The team of researchers from the presented study propose a design for a "crisis information system" [27]. They describe one of their crisis IS design principles as such that strives toward "debiasing confirmation bias" [27]. They lead us toward another study about decision support systems [28] and claim that in order for the confirmation bias to be debiased, the crisis IS should provide wished information to the decision maker in a balanced way. Such that "... also opposes users' assumptions to mitigate confirmation bias" [27]. Integrated into the crisis IS, such an approach of challenging the user, the expert, would lower the chance of a biased decision.

Metacognition was introduced by John Flavell as awareness and control over one's thought processes that are to be associated with cognitive development and more specifically, with learning [8]. In a parallel ongoing research work of another science project, an understanding was formulated about metacognition as being manifested as a cognitive event. One of the supporting research papers is by Anastasia Efklides, who solidifies the understanding of Flavell's model of Metacognition by providing ideas about offline (1) and online (2) awareness in terms of task fulfillment [7]. The two concepts can be described as personal information-gathering processes about one self's capabilities for a type of task (1) before or after fulfilling a task and (2) during the performance of a task. Metacognitive knowledge and experiences have been compared, with the latter being associated with online and the former with offline awareness [7]. However, both of them can be viewed as phenomena that occur for a short period of time based on already cultivated mental experience. Specifically, metacognitive experiences are related to having a specific feeling at the time and "... a sense that what takes place during the cognitive endeavor is one's own personal, subjective experience..." [7]. Efklides provides further evidence that metacognitive experiences are tightly related to goal and task knowledge by linking them to autonoetic consciousness and episodic memory [7,9]. This may be interpreted as a sign that metacognitive phenomena in general could be narrowly related to the idea of achieving accurate decision making of an expert. Thus, it was demanded that an explanation of experiential nature be provided for experiencing metacognition as such would be important for the design principles of a crisis IS.

Metacognitive abilities can be associated with cognitive biases as they "help people to avoid making the same mistakes twice" [10]. The article by Nick Yeung and Christopher Summerfield presents a solid understanding not only of decision-making but also of post-decisional processing. Their article directs toward the question, "Why are we generally more sure that we are correct than that we have made an error, ...", by providing notions of first- and second-order choices [10]. This can be related to Efklides' idea of metacognitive experiences as such that they occur during the fulfillment of a task as related to its scope [7] but that is also related to already cultivated mental experience.

4. The Approach of Attention as Action

It is common that Cognitive Science reasons about the dichotomic concepts of "intelligent", intentional and explicit processes, and automatic unconscious processes [29]. Related to this comparison, recent work on another parallel ongoing scientific project has brought a new theoretical approach to explaining attentional processes as an action. This approach views an attentional process as a short conscious activity that is performed simultaneously with a process of information provisioning of a targeted automatic unconscious process (AUP). It proposes an understanding of an attentional experience as such that its start and end time points directly correspond to the start and end of the execution of a short

attentional process—an internal action. This is following the understanding of a conscious experience in the Theatre of Consciousness as explained by Baars [30]. In this meaning, the knowledge that an attentional experience holds is based on information provided by the targeted AUP. The latter is viewed as an unconscious processor that generally accomplishes one of the following—organizes sensory input, gathers information from memory, or produces a body action. The provisioning of the information by an AUP occurs in the stage of execution of an internal action that is targeting that AUP. The unconscious processing of the AUP is happening behind the scenes without the personality knowing about it. After processing is performed, an internal event is produced that can be targeted by the personality. This aspect of a personality is referred to as an internal agent.

An attentional process viewed as an action performs observation on the information provided by the targeted AUP in a subjective way and produces conscious knowledge as experience. This corresponds to the explanation by Baars of attention as an internal process that brings unconscious content to consciousness [30]. This means that in a specific moment a content, which can be provided by an AUP, is internally chosen and then attentionally observed. In this manner of thought, a single internal agent undergoes a conscious experience, which is shaped by the information provisioning of a chosen unconscious AUP. This is supported by the "sizable body of evidence" [31], which suggests that "consciousness is the primary agent of such a global access function" [31]. Therefore, a deliberate attentional process can be viewed as a sequence of choices and their corresponding results, i.e., attentional experiences. All of this points to a requirement of a clear understanding of an internal agent that makes decisions on what internal resource to access via a targeted event produced by an AUP and how that resource is attentionally processed via the execution of attentional process as action.

Baars provides the insight that the sensory cortex can be activated "internally as well as externally", which leads to "internal senses" of conscious imagery [32]. Therefore, defining types of attentional processes as actions can be based on attentional experiences as VMI [33]. Furthermore, the interconnection between types of imagery experiences can be sought in order to predict behavior [34]. Internal behavior can be explained by following the modules of the Action Cycle Theory, which Marks supports with neuropsychological evidence [1,34]. The understanding of the interconnection between attentional processes would provide knowledge for formulating predictions on what to expect from the internal behavior of a personality in a specific stage. Thus, it would be beneficial to direct an expert who is undergoing a crisis situation toward proper decision making.

The theoretical approach of Attention as Action can serve as guidance for researchers toward providing explanations of a common internal agent that makes decisions about which AUP to target as a source of information. This leads to the demand of classifying types of attentional actions that are the result of an internal decision to target an AUP. The term internal action (IA) was accepted by our team, to refer to this notion of an attentional process as action. The performance of IA, together with its parallel in-time attentional experience, is viewed as a result of an internal decision that corresponds to a demand for information. On the other hand, the fulfillment of an IA can correspond to one's experience of shifting the focus of attention in terms of the observable objects in the surrounding environment. This is explained by the occurrence of a change in the stream of incoming sensory information [10,35] that lures the attention of the internal agent. All of the provided reasoning resulted in the concluded minimal characteristics of an IA as

1. Being executed by a personality for a short duration without any body movement;
2. Having a parallel to the execution attentional experience, the start and end points of which correspond to the start and end points of that IA;
3. Observation being conducted on unconsciously produced information provided by a targeted AUP.

4.1. The Action Cycle Theory as Underpinning

The work of David F. Marks provides an important dichotomy between visual perceptual imagery (VPI) and visual mental imagery (VMI) experiences [1]. A VPI depends on the present sensory information, whilst a VMI is a "subjective quasi-perceptual experience" that may occur with or without "stimulation of the retinae with light" [1]. In terms of the theoretical approach of Attention as Action, an explanation is added that a VPI is consequential to a targeted sensory event derived from the stream of incoming sensory information [10,35]. Following this idea, a VMI experience could be consequential to either a VPI experience or other previously experienced VMI. If the research focus is directed to the conscious nature of subjective imagery experiences, then it can be assumed that such a VPI or VMI corresponds to the parallel attentional experience corresponding to an IA. Thus, the six modules of the Action Cycle Theory [1] can provide a classification of interconnected attentional processes, which correspond to types of IAs that are classified based on the parallel subjective attentional experience—a VPI or a VMI.

The theoretical approach of Attention as Action follows an idea established by Marks that is described in his relatively recent work on the Action Cycle Theory [1]. The idea that "the system of six modules is activated in the absence of sensory input" [1] led to the view that an IA is a short activity that does not use the sensory information directly but targets an AUP. The latter can rapidly process information provided by the incoming stream of sensory information [10,35] organizing it into a structure. When finished, a sensory event is produced that is or is not targeted by the internal agent. If targeted, a conscious VPI occurs that is due to the execution of an IA. That VPI corresponds to the parallel attentional experience of an IA—characteristic 2. Also, an AUP can gather information from memory and structure it into a mental image in an "automatic and unconscious" way [1]. If the corresponding mental image internal event is targeted by the internal agent, then a product of attention, a conscious VMI, is experienced. The provided reasoning leads to the conclusion that, if a conscious VMI or VPI experience occurs, then an AUP has recently produced information that was offered via an internal event and processed by an IA. The execution of that IA is responsible and analogous in time to the attentional experience, in this manner of thought, a VMI or VPI. Assuming that the unconscious processing of the information by the AUP is finished, if an IA targets that event, the AUP keeps working as an information provider simultaneously during the execution of that IA. This is referred to as the simultaneous characteristic (3) of an IA as such that is executed simultaneously with the information provisioning process of the targeted AUP. A special conclusion is that, if a subjective experience such as a VPI occurs, it means that an AUP was targeted such that it provides perceptual information gathered from the stream of input of sensory information [10,35]. On the other hand, if a VMI occurs, then a memory-related AUP was targeted that shaped the brief conscious experience of a mental image.

4.2. The Cognitive Cycle and the LIDA Model

The idea of the internal agent targeting an AUP can be related to the theoretical approach of the Theatre of Consciousness [30] in a way that the "actor" corresponds to the AUP. The attentional spotlight or the "bright spot" of consciousness [32] is viewed as being directed by someone who guides the performance on the stage—the internal agent. It is important to reaffirm that a conscious experience [30] occurs as a result of the simultaneous execution of an IA and an AUP. The latter is a targeted source of information that is demanded by the internal agent. In a study, Baars concluded with the proposal that multiple networks "cooperate and compete" to solve problems and that they retrieve specific items from immediate memory [32]. Also, it was concluded that conscious contents explained as "brief memories" activate widespread regions of the brain [32]. This is supported by neuropsychological research studies, one of which is by Dehaene et al. [36]. It is shown that the conscious processing of specific visual words additionally activates widespread frontoparietal regions [32,36]. If these networks that cooperate and compete

correspond to AUPs that are targeted by the internal agent, then a classification of processes is demanded that can explain relations between AUPs.

An understanding of a cognitive cycle is established with experimental research using the LIDA model as a cognitive architecture [4]. A single ongoing cognitive cycle starts with stimulus recognition, continues with preconscious and conscious processing, and ends with action selection [4,31]. Baars and Franklin state that "A cognitive cycle is a mostly unconscious process" [31]. If accepting a sequence of AUPs being processed in a cognitive cycle, how is a single execution of an IA related to a single cognitive cycle? Following the idea that an execution of an IA is targeting an AUP as a source of information and that a parallel conscious attentional experience occurs, then the latter can be explained as a learning experience. Put in other words, the conscious attentional experience that corresponds to an IA is an experience of learning. This is supported by the claim related to the cognitive cycle that "conscious content determines what is to be learned" [4], further supported by research on learning [37] and the LIDA model [31]. Baars and Franklin provided a leading direction for understanding learning that is depicted in their conceptual model of LIDA [31], which is supported by experimental research on the cognitive cycle [4]. The learning phases presented with yellow arrows are Perceptual, Episodic, Procedural, and Attentional and can be used to explain corresponding types of IAs.

4.3. Relating the Cognitive Cycle to the Action Cycle Theory

Attentional learning is "learning to what to attend" [38] and allows the personality to use past experiences to predict the future [38,39]. The theoretical approach of Attention as Action uses this settled understanding of attentional learning as a direction toward metacognition. Research was performed to this end, which is presented in the next section. Procedural learning is tightly related to the Schemata module of the Action Cycle Theory [1] this is supported by the definition of the Procedural Memory component of the LIDA model that is also noted as a Scheme Net [4,31]. A relation can be supported between perceptual learning [31] and the Objects [1] module. The latter is coined by Marks as corresponding to either VPI or VMI. This is also supported by the explanation by Baars that the sensory cortex can be activated "internally as well as externally", which results in "conscious inner speech and imagery" [32]. An insight into episodic learning is provided in the LIDA model [31] as tightly related to transient episodic memory. The latter is responsible for the "local associations" component that includes emotional content as cues [4]. This supports the association with the Affect module of the Action Cycle Theory [1], which is scientifically supported by research on autobiographical memory [40].

If learning is viewed as a short activity of remembering the knowledge provided by an experience, then the parallel attentional experience corresponding to an IA is a short experience of learning. This different event-driven view on learning can easily be explained with everyday examples. If a personality is looking at the night sky and suddenly a meteor appears for 1 s, that personality would remember this for years ahead. The fact that the personality observed the fall for 1 s and still remembered it shows that a learning experience has occurred for that or an even shorter duration of time. After some days, the personality might be asked "when did you last see a falling meteor" and might not be able to tell the exact day of the remembered event, but the knowledge of it happening would still be there.

4.4. Directions from the Theoretical Approach

Relations between the unconscious cognitive cycle [4] and the Action Cycle Theory [1] model are now available. The knowledge of the interconnected modules, which correspond to types of subjective imagery experiences, can be used to form new relations with AUPs as such that correspond to the modules of LIDA [31]. Neuropsychological studies can be investigated to provide an understanding of the cognitive processing of a conflict that would further brighten the understanding of automatic processes. An explanation of triggering a process can be sought with the guidance of the study by Norman and Shallice and their Supervisory Attentional System [3]. If a useful semiotic representation technique

is applied, a useful model of Attention as Action can be formulated that explains the occurrence of the cognitive processing of a conflict. This can then be associated with a crisis phenomenon and related to cognitive biases, for which a solution can be provided—the metacognitive processes. The latter can be explained via the theoretical Approach of Attention as Action as internal actions, the probability of execution of which is increased by particular functionalities of a crisis information system.

5. Formulating a General Model of Attention as Action

The Internal Decision Model of Attention (IDMA) applies the concepts of Attention as Action by using the explanations of learning as an experience and as being due to a corresponding execution of an IA, described in Section 4. The IDMA, as a conceptual model, is directed toward explaining the execution of a metacognitive process. This section provides further research on the unconscious networks, called, in terms of the Global Workspace Theory, "contexts" [31,32]. Also, a definition of a special attentional experience derived from sensory information is provided, which is related to the trigger database of the Supervisory Attentional System [3]. An explanation of internal decision making is provided and depicted in terms of time. In order to accomplish a clear understanding of the IDMA, the internal decision making and the semiotic internal action representation methodology have to be explained first.

5.1. Internal Decision Making and the Semiotic Representation Methodology

Explanations provided in Section 4 are depicted in Figure 1. The internal event produced by an AUP is targeted by the internal agent, which leads to the execution of an IA. The parallel attentional experience corresponding to the IA holds knowledge that is shaped by the information of the targeted AUP (stage 2 in Figure 1). Internal decision-making begins with the end of the IA execution; the idea that for some time no internal events occur can be noticed (stage 3 in Figure 1). It is assumed that competition for consciousness occurs in stage 3 until an internal event occurs. The latter may or may not be targeted by the internal agent and if targeted, an execution of an IA will follow continuing with another attentional experience as in stage 2. It is hypothesized that the time of the cognitive cycle [4] corresponds to the sum of the times of stages 1, 2, and 3. However, the time for which internal decision making occurs cannot be specified. A longer duration of internal decision making can be related to attention lapses [41], but further investigation is required.

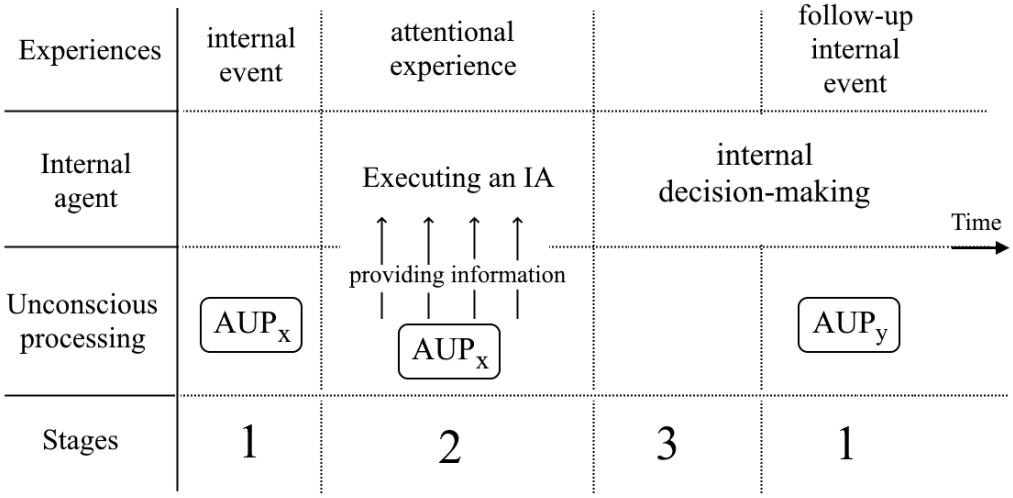

Figure 1. Internal decision making. The abbreviation AUP corresponds to the automatic unconscious process. The letters x and y express assumed types of AUPs.

This basal understanding of internal decision making can be used to explain a chain of processes. This requires a clear specification of semiotic representations that correspond to

definitions of the concepts of Attention as Action. A small table is presented in Figure 2 that shows the applied conceptual model symbols that correspond to the theoretical concepts in the IDMA. The process of body action execution corresponds to the "Action taken" component denominated with nine on the conceptual model of LIDA [4,31].

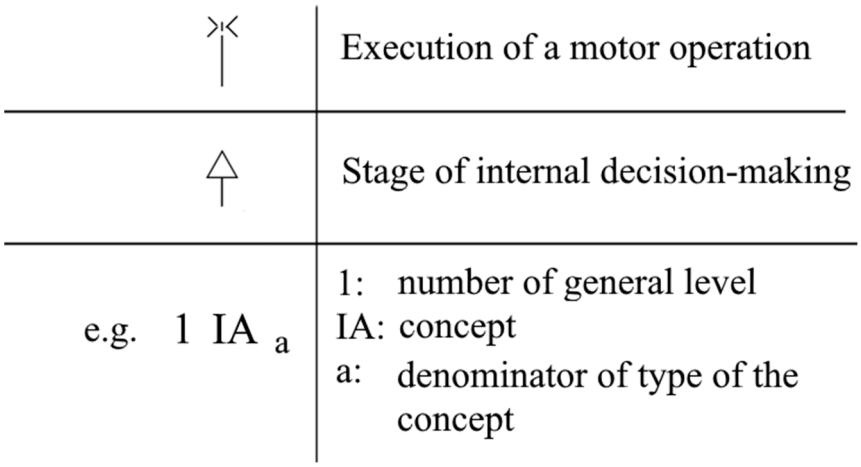

Figure 2. Table of semiotic representations.

5.2. Integrating the Research on Metacognitive Experiences

The demand to understand an attentional process as an action that is fulfilled during a crisis led to the requirement of explaining a metacognitive experience. The theoretical approach of Attention as Action (AaA) and the semiotic representation methodology were used as application and guidance toward formulating relative AUPs. Types of IAs, as explained in Section 4, are classified as corresponding to a targeted AUP. The concepts of VMI and VPI, as formulated by David F. Marks in his Action Cycle Theory [1], served as main guidance for the explanation of the types and the interconnection between the IAs. However, an important note is that the parallel attentional experience of an IA is not viewed as limited to subjective visual imagery, but the idea that the conscious experience can be an inner speech is also maintained [32].

Finally, to all of the provided conjunction of concepts, the understanding of metacognitive experiences [8] as part of the online awareness [7] is added. A metacognitive experience (ME) is described by Efklides as a reflection on "the person's concerns and goals" [20]. As such, it can be stated that an ME is a parallel attentional experience of a special IA. Furthermore, it is hypothesized that in order for such an experience to occur, a preceding attentional experience is required. As an ME can be a cognitive endeavor of "... ideas and beliefs, or feelings" [7], Damasio's Theory of Consciousness can be related [42]. He provides evidence that feelings and emotions differ in the way that the former are a self-perception of the latter [43], which further strengthens the understanding of an ME as a feeling that is a self-observation of a preceding recent attentional experience.

From the provided reasoning, it can be stated that interconnection can be formulated by defining an event that is formed due to an AUP that integrates information from sensory data input. The understanding of a stream of incoming sensory information [35] is used as an underpinning to explain an occurrence of a physical sensory event that is processed by an AUP. This AUP corresponds to the "sensory perceptual structures" formation process as depicted in the conceptual model of the Supervisory Attentional System by Norman and Shalice [3]. This way, the conception of process layers emerges as such, based on a sensory event.

The AUP that processes an SE provided by the sensory stream prompts an internal event, which, when targeted by the internal agent, leads to IA processing. That IA processing can then be defined as part of process layer 1 and its parallel attentional experience corresponds to a VPI. Next, the internal agent can target a follow-up internal event from

either an AUP that is from the same process layer or from the next—process layer 2. If the internal agent targets an internal event of AUP from process layer 2, a corresponding IA from that process layer is going to be executed. The attentional experience is then assumed to be a VMI experience. As such, it is a quasi-perceptual experience [1]—the image that it expresses "occurs in the absence of the relevant object" [1]. From this stage, the internal agent may target another internal event, leading to a VMI experience from process layer 2 or an internal event leading to the special IA. The latter is the metacognitive process as IA that has a parallel attentional experience that is the hypothesized ME itself. The reasoning provided in this paragraph is integrated into the IDMA and can be observed in Figure 3 in the next subsection.

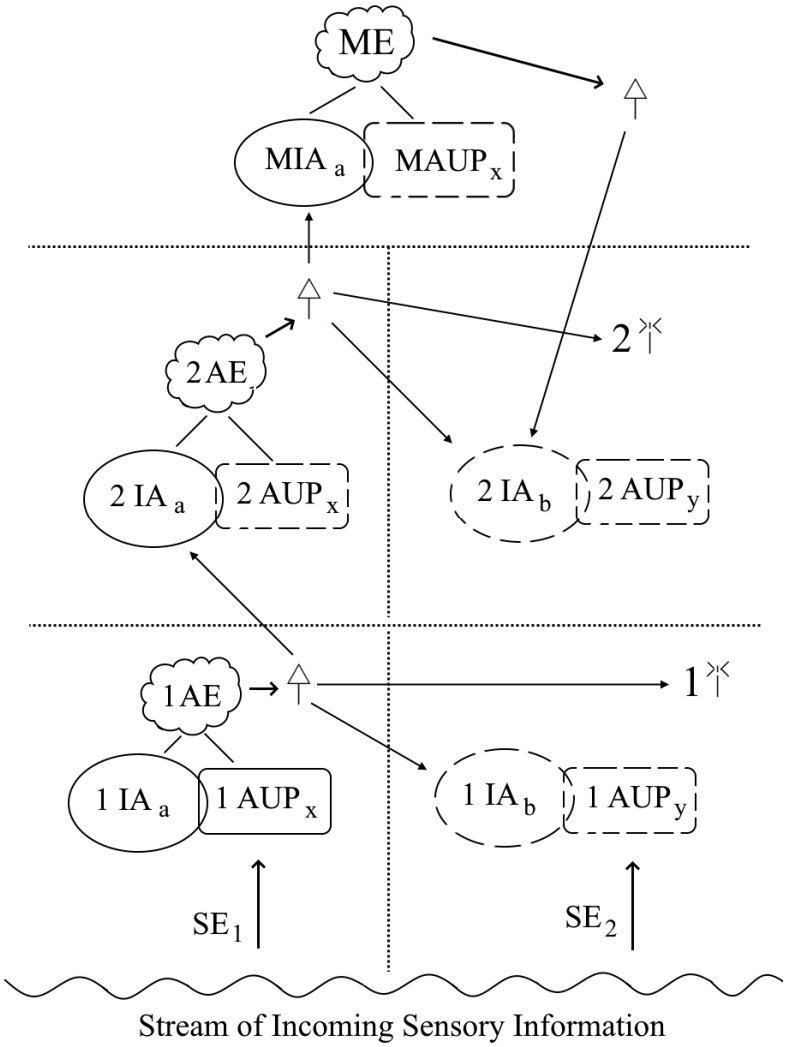

Figure 3. Internal Decision Model of Attention. SE—sensory event, IA—internal action, AUP—automatic unconscious process, AE—attentional experience, ME—metacognitive experience.

5.3. The General Model Derived from the Formulated Rule Set

In order for the IDMA to be applicable as a general model of attentional processes in a crisis information system, a specification of clearly defined rules is required. Such a set of rules can be formulated by following the directions of the AaA approach. A special rule exists in the formulation that integrates the understanding of an ME. It is an addition to the rules based on the concepts provided by the AaA approach. The entire set of rules can be used to develop a system that reproduces internal human behavior. Such a system can be used as a module for a crisis information system with the purpose of predicting internal human behavior. This can serve as a direction toward future research and engineering of a

crisis information system. It can be described as an internal decision-support system that, via monitoring, produces predictions on internal decision making.

The rule set is derived from the provided compilation of understandings of the concepts from the AaA approach, the concept of ME, and the conception of process layers. As a guiding concept of the AaA approach, the rule set is defined and presented as follows. An internal agent may take an internal decision that leads to the following:

1. The execution of an IA in the current process layer (n);
2. The execution of an IA in the next process layer (n + 1);
3. The execution of a motor operation in the current process layer (n);
4. The execution of an IA in process layer 2, if the internal decision-making stage is in process layer 3.

The formulated rule set is semiotically integrated into the conceptual representation of the IDMA in Figure 3. The semiotic representation methodology is presented in Section 5.1 and the defined semiotic table in Figure 2 is applied in the conceptual model of the IDMA. The squares depicted with dotted lines represent separate internal-decision phases. Without the internal decision-making stage, they are hypothesized to correspond to a single cognitive cycle [4,31], as explained in Section 5.1. The metacognitive phase is depicted on top. Figures (ellipses and rectangles) with dashed lines depict processes that are part of an eventual reach to a phase. Ellipses are used for IAs and rectangles for AUPs.

Following the explanation of internal decision making provided in Section 5.1, each targeting of an internal event by the internal agent leads to a new phase (Figure 1). In Figure 3, the internal events produced by an AUP are omitted, but straight directions from the internal decision making to an IA of the next phase are depicted. This means that the IDMA represents only the targeting rules of the internal decision-making process and does not consider types of IAs according to types of attentional experiences. The types corresponding to the subjective imagery experiences of the six modules of the Action Cycle Theory [1] are used to formulate a classification of types of attentional experiences; thus, they define types of IAs.

5.4. Evidence from Theories of Cognitive Control

In his book from 2018 [44], Marks defines a module "voluntary action" that corresponds to the module "Action" in the Action Cycle Theory [1]. In the conceptual model of "The Behaviour Control System" [44], he presents a direct link with consciousness. These links correspond to the three stages in the IDMA sequentially: execution of IA in process layer 2, internal decision making, and then, motor process in layer 2. Marks states that voluntary control is applied when executing actions "Only when there is novelty or special care required" [34]. This leads to the interpretation that an attentional experience as related to a VMI is required in order for a volitional motor process to be executed. This further supports the relation of the "voluntary action" module with process layer 2 of the IDMA. The motor process of layer 1 is yet considered by the IDMA as attentional as it is consequential to internal decision making. However, the motor process of layer 1 is viewed as such that has been implicitly learned or that a schema has been adopted by the personality such that can be applied for the "... selection of the proper body, arm, hand, and finger movements" [3]. In the General Theory of Behavior, this is supported by the link between consciousness and automized action [44].

The Action Cycle Theory by David F. Marks also provides an understanding of a cycle of decision making based on VPI and VMI experiences [1]. The interconnections between types of imagery experiences are neuropsychologically supported by his General Theory of Behavior [34]. The layer 1 AUP processes of the IDMA are related to processes like the perceptual structures forming and the trigger database from the Supervisory Attention System model [3]. Also, the concept of a VPI [1] is considered from general layer 1, as a parallel attentional experience that is a result of the IA and AUP of process layer 1.

An important note is that an experience of an episodic memory that is a conception of the physical world, as observed by senses in the past, is yet again a VMI, as it is currently

not a result of a sensory event coming from the stream of incoming sensory information (Figure 3). Several ordered sensory events can be integrated by the AUP and IA of layer 1 into a VPI of the object, as related to the module Object [1]. Mental imagery experiences of other modules from the Action Cycle Theory model are related to process layer 2 and are deeply analyzed in Section 6.

If a metacognitive experience is a reflection of a goal [7], which is a VMI experience of a goal [1], and the latter is of process layer 2, then the former is of process layer 3. This statement is supported by Marks' article [34] where he references Baars [30] and solidifies the understanding of the "only conscious components of action" [34]. Marks supports the explanation of Baars that an idea or simply a goal as a conscious component of action is "really just an image or idea of the outcome of the action" [30,34]. It is important to acknowledge the claim from Figure 3 that the internal decisions of the general layer of metacognition can only lead to IA execution of process layer 2 and cannot lead to motor process execution. This follows the reflection nature of metacognitive experiences [7,8].

5.5. Evidence from Cognitive Architectures

Considering the Supervisory Attentional System, the triggering database processing as consequent to perceptual structures [3] is tightly related to the "Percept to preconscious buffer" component of the LIDA model [4]. The "possible relational structures" [4] coming from the perception stage are included in the "workspace"—LIDA's working memory. The IDMA links these processes to layer 1 (Figure 3). The local associations component of LIDA includes "... emotional content, as cues" that are stored in long-term memory [4]. This links them to AUPs of layer 2 of the IDMA as the transient episodic memory as an AUP can be targeted by the internal agent with the execution of an IA [4]. This corresponds to episodic learning experience as explained in Section 4.3. The AaA approach follows the understanding provided by Damasio's Theory of Consciousness [42,43] of the dichotomy between emotions and feelings. In simple terms, it can be stated that feelings are conscious reflections of emotions. This further supports the local associations component of LIDA, providing an explanation for episodic learning as a feeling experience that reflects on emotions. Also, this can be related to the Affect module of the Action Cycle Theory and its corresponding VMI [1,34].

The concept of AUP can be related to several scientifically supported understandings of such unconscious automatic processes. The AaA approach allows us to combine several concepts from established cognitive architectures, not only the LIDA model [4,31], for example, but the ACT-R cognitive architecture as well [5,45–47]. A single ACT-R module can be related to the idea of an IA that targets an AUP—a buffer. In this manner of thought, the Manual Control [46,47] module, for example, is the execution of IA after the internal agent has targeted an AUP. The latter has just finished its unconscious work and is providing its information via an internal event (from Section 4) acting like a buffer [32]. Notably, the provision of the information by the AUP is viewed as a process simultaneous to the execution of the IA, but the process that gathers the information before the occurrence of the internal event is unconscious—the internal agent is not aware of its processing. ACT-R's sensory modules (visual and auditory) correspond to the IA being executed as targeting an AUP that organizes sensory data from the SISI [10,35]. Other ACT-R modules can also be explained in a similar way. This means that the theoretical approach of AaA and the IDMA model are applicable in the design of cognitive architectures and provide a new view of unconscious and conscious processes.

Additional support for the metacognitive experience explanation of IDMA can be provided by the CogAff architecture [6]. The meta-management layer as reflective processes [48] can be linked to process layer 3 of IDMA. The alarms are represented in the first layer (from bottom to top) in the figure "Elaborating the CogAff schema" [48]. This corresponds to the idea of sensory events triggering automatic unconscious mechanisms that can reactively produce body action. This is not depicted in IDMA, as it is mainly focused on the conscious processing of information. However, the IDMA still explains

an attentional experience that occurs in process layer 1 that is viewed as awareness of an automatic activity like walking or running. In this manner of thinking the reflective processes from CogAff [48] correspond to AUPs related to body schema information provision [1,49] and the AUP responsible for the sensory data organization. The deliberative "what-if" reasoning corresponds to process layer 2 of IDMA. It is further supported by the understanding of AaA that a VMI of a goal [1] occurs in process layer 2 (from Section 5.3). The planning and deciding of the "what-if" processes correspond to the understanding of mental images of goals and the corresponding Action Cycle Theory module [1].

5.6. Evidence from Neuropsychology

An expert making a decision in a crisis situation would need to apply deliberate attentional control. In their article "Attention to action: Willed and automatic control of behavior" [3], Norman and Shallice define five categories of tasks that require deliberate attentional resources, one of which involves planning or decision making [3]. If it is explained as to when exactly attentional control is applied, then a better understanding of a crisis phenomenon could be provided. Research by Kanske and Kotz supports the system of Norman and Shallice and claims that "dangerous situations trigger a supervisory attentional system" [3,50]. With their experimental methodology, they investigated the ventral anterior cingulate cortex (ACC) of the human brain via Stroop, Eriksen flanker, and Simon tasks. The study evidently supports that the ventral ACC is involved in the integration of conflict related to emotion [50]. They showed that when "target and flanker stimuli are emotional", the duration of the processing of a conflict is shorter [50]. Kanske and Kotz conceived the dorsal ACC as having a main effect of conflict whilst the ventral ACC is activated only by conflict that has emotional stimuli [50]. Botvinick, Cohen, and Carter also view the dorsal ACC as acting like a trigger system for making compensatory adjustments in cognitive control [51]. They also present the aspect of conflict control as a "general monitoring function", which detects "internal states" and signals for a shift of the focus of attention [51]. This was interpreted as tightly related to the idea of presenting an attentional process as action, IA, and the notion of it as a result of an internal decision.

The presented reasoning suggests that conflict processing can be related to the occurrence of a crisis situation. This is further supported by a study from 2024 that observed ACC as responsible for surprise tracking [52]. Another recent study shows that ACC is related to emotions by explaining the latter as a consequence of goal-directed action outcomes [53]. Rolls state that the ACC is involved in "learning actions to obtain reward" [53], which links the ACC to the affected module of the Action Cycle Theory [1] and the local associations component from LIDA such as the incoming percept "including emotional content, as cues" and stores them "in long-term working memory"[4]. This further links to the idea that the ACC is activated when an attention-grabbing emotion is experienced. Such can be a reflection of a crisis situation occurrence. That occurrence in terms of the theoretical approach of AaA is going to be referred to as the crisis phenomenon. The latter as an internal event is further explained in Section 6.

If the occurrence of a conflict trigger produces an internal state that provides the need for a shift of the focus of attention [51], then it can be claimed that the personality has the choice to persuade this shift or to remain focused on its current objective. This aspect of a personality that makes internal decisions of attention shifting corresponds to internal decision making as explained by the AaA approach explained in Section 5.1 and Figure 1. An important note is that an "attention shift" could be viewed as either a top-down process of attention [51] that is related to objects observed via sensory input, or it can mean a change in the internal focus on information. The latter is conceived by AaA as a change in the mode of attention and is explained by the switching of the targeted AUP, as shown in Figure 1. This observation shows that the AaA approach can be useful for explaining cognitive experiences in the field of Neuropsychology.

6. Models of Attention as Action

The IDMA presented in Figure 3 can be used as guidance for defining types of attentional processes. Also, their interconnection can be explained in terms of events that occur in the environment such as the crisis phenomenon. The latter is viewed as an attentional experience of emotion that is a reflection of an event occurring in the surrounding environment that the personality perceives as leading to a crisis situation.

Figure 4 depicts an example of consecutive phases of internal decision making that are made toward the execution of a metacognitive IA. Guided by Figures 1–3, AUP types are depicted via rectangles, while IA types are expressed via ellipses. Starting from process layer 1, guided by Figure 1, an understanding was formulated of an AUP as corresponding to the processes of the trigger database of the Supervisory Attentional System [3]. A VPI [1], as supported by the AaA in Section 4.1, is depicted as a parallel attentional experience of process layer 1. This scenario can interpret the Triggering Process (Figure 4) as such that it corresponds to the matching mechanisms of the striatum [45]. This is supported by what is presented in the ACT-R schematic diagram where the goal buffer is associated with the anterior cingulate cortex (ACC) [45]. This corresponds to the presented in Figure 4 phase 2 where the IA of action outcome (AO) is depicted. The AO also evidently corresponds to the ACC as neuropsychologically supported in Section 5.6 and the study by Rolls [AA]. However, the term goal in the AaA model corresponds to the VMI of a goal as corresponding to the Action Cycle Theory module [53]. Both the local associations and the Goal Context processes are named after the unconscious networks presented in the LIDA model [4,31]. Both of them are recognized as being of process layer 2 as they provide information for the formation of a VMI attentional experience.

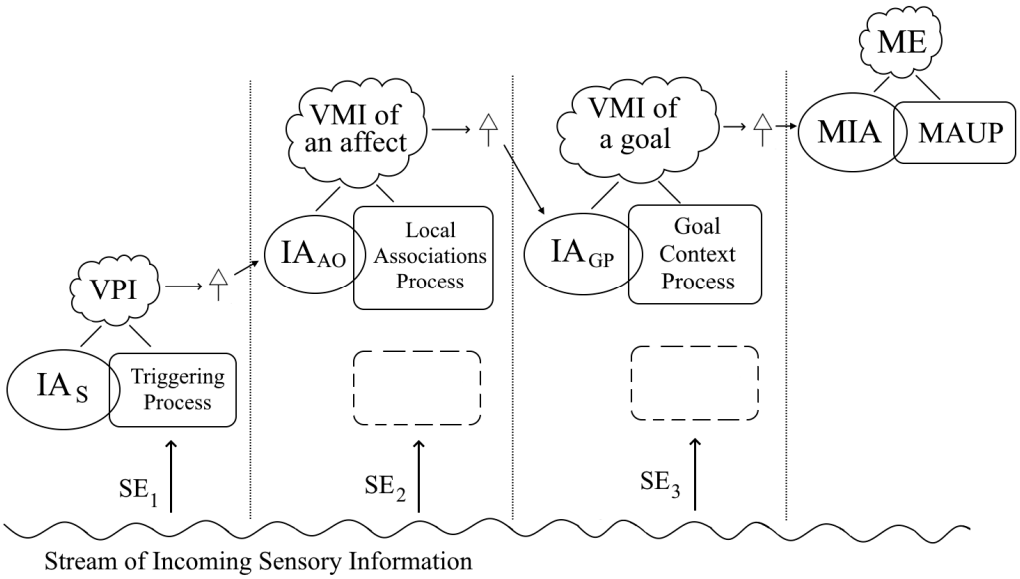

Figure 4. Internal decision making toward a metacognitive experience. Abbreviations as observed from left to right: SE—sensory event, IA—internal action, S—sensation, VPI—visual perceptual imagery, AO—action outcome, VMI—visual mental imagery, GP—goal planning, MIA—metacognitive internal action, MAUP—metacognitive automatic unconscious process, ME—metacognitive experience.

The IA of AO is parallel to a VMI of Affect that corresponds to the module of an Affect of the Action Cycle Theory [1]. This correlates with the interconnectedness between the Object and the Affect module [1] in the case of a conscious VPI experience of an object. Furthermore, the idea that long-term memory is directly related to emotions and feelings is supported by the beneficial effects of the methods of Learning by Feeling [54]. This is further supported by a relatively new study from 2023 that builds an understanding of the episodic structure of memory [55]. The article by McClay, Sachs, and Clewett presents experimental evidence, which suggests that "memory is organized around emotional

states" [55]. That is why our team saw the potential of understanding that an AUP type of local association (Figure 4) provides the basal information on which episodic learning, as corresponding to LIDA [4], is achieved by an IA of AO [53]. This also correlates with the evidence that the VMI of affect has an emotional nature and is parallel to the IA of AO. It can be theorized that an emotion may vary in terms of how big its effect is on the personality. Based on this, it can be argued that each re-experience of a past experience is accompanied by an emotion, but it may simply not hold a strong emotional effect.

A specific type of event in the environment can lead to great stress for a personality as it terminates them from doing an exceedingly important activity, e.g., a medical doctor finding out that the database of the hospital cannot be accessed due to a cyber-attack, so they will not be able to undertake treatment for their patient. Such an occurrence of emotional impact happens in a moment after the sensory information has been processed and realized (attentionally experienced). Our team suggests the admission that this effect happens when the ACC is processing a conflict, using the understanding of Kanske and Kotz as an underpinning [50] more deeply explained and supported in Section 5.6. The suggested results of their experiment that, when the nature of the conflict is emotional, the processing of that conflict is shorter, were applied in the model presented in Figure 5. In the same was as with Figure 4, local associations' AUP is being targeted by a different IA (not AO). That IA of affect (A), as shown in Figure 5, is hypothesized to have a parallel attentional experience of conflict as supported by the evidence on the ACC (Section 5.6). This experience of conflict in terms of the AaA approach is referred to as the *crisis phenomenon* depicted with the abbreviation CP in Figure 5. Its parallel conscious experience is a VMI and is of process layer 2 (guided by IDMA).

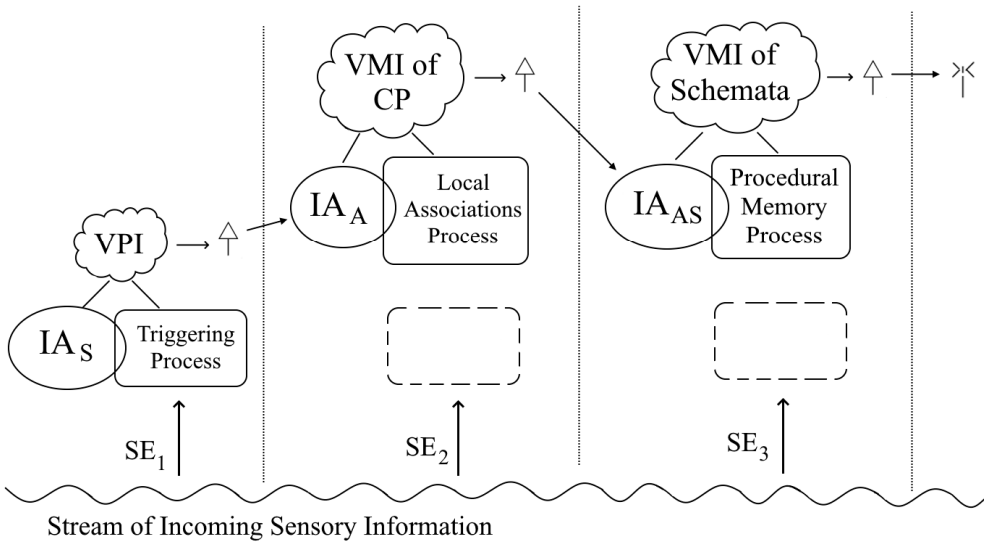

Figure 5. Attention as an action model explaining the occurrence of a crisis phenomenon (CP). Abbreviations as observed from left to right: SE—sensory event, IA—internal action, S—sensation, VPI—visual perceptual imagery, A—affect, VMI—visual mental imagery, AS—action schema.

The faster conflict processing by the ventral ACC [50] can be interpreted as an internal mechanism of the organism to provide a quicker response to a harmful event, by directing the internal agent toward producing a body action, i.e., a motor process as presented in Figure 5 and as corresponding to the symbol from the semiotic table in Figure 2. In order for a body action response to be produced, the internal agent has to pass through the stage of accessing the Procedural Memory AUP. The latter is related to the motor buffer of the ACT-R [5,45–47]. Also, the IA of action schemata that target that AUP corresponds to the motor module of ACT-R. This hypothesis can be further supported by the LIDA model and its Procedural Memory, which is also referred to as a Scheme Net [4,31]. What is more, further relations can be provided with the Schemata module of the Action Cycle Theory [1]

that produces schematic VMI. It can be stated that the AaA approach is severely related to the Piagetian epistemology of schema [56].

The presented reasoning in this section may be brought to the understanding that the crisis phenomenon is related to the fight-or-flight response in the sense that it is an internal event of awareness that a danger is occurring. However, in order for a quicker response to be made so that the danger is avoided, the individual processes the conflict quicker; thus, internal decision-making is made toward action selection processes and quicker body action execution, as shown in Figure 5. The demand for sooner action selection could also be interpreted as leading toward a higher chance of undergoing a cognitive bias. The latter, as defined in Section 4, has bad effects on experts' decision-making [27].

Directions for Crisis Information System Design as a Solution to the Crisis Phenomenon

As metacognition helps people avoid making the same mistake for a second time [10], then it is the solution for debiasing cognitive biases. The depicted internal decision-making pattern presented via the four stages in Figure 4 suggests directions toward debiasing cognitive biases. What is more, the internal decisions toward a metacognitive experience are viewed as opposed to a crisis phenomenon (Figure 4). Based on the AaA approach, the conceptual models in Figures 4 and 5 can be compared. This leads to the observation that instead of undertaking action selection and executing the IA of action schema, the expert who is experiencing a crisis phenomenon will be striving toward the VMI of goals. This way, there would be a higher chance for them to fulfill metacognitive IA, thus experiencing a metacognitive phenomenon instead of leaning toward quick body action responses.

In order for a crisis information system to be designed that directs its users out of the adverse consequences of a crisis phenomenon, a design of monitoring features needs to be accomplished. The IDMA can be applied as a monitoring system. The models in Figures 4 and 5 can be used to predict the eventual internal decision making. An insight is that the alternative of an IA that corresponds to the crisis phenomenon (Figure 5) is the execution of IA as an action–outcome, as guided by the evidence on the ACC [52,53]. This can be interpreted in a way that, in order for the internal agent to avoid the crisis phenomenon, when the system provides information that a crisis is occurring, it needs to also provide positive feedback. Such can be presented after a time of 260–390 milliseconds (the timing of a cognitive cycle) after showing the crisis information to the user. An idea of such feedback is a short animation of a character that produces a goal-directed action that leads to the resolution of the crisis.

7. Conclusions

In today's age of digitalization, critical infrastructures can be subject to multiple attacks. Subsequent incidents and decisions taken are of particular importance for its recovery. It is in the moments when critical decisions have to be made that how one will act is of particular importance. It has been found that cognitive and behavioral theories in the design of crisis information systems can lead to better preparedness and management of CI risks. Based on previous studies and hypotheses, the research demonstrates how the speed and effectiveness of incident responses can be increased and provides new directions for explaining internal decision making. These directions, elicited from the research models of AaA, explain the crisis phenomenon and its opposing resolution—the mental imagery of a goal and the metacognitive internal action. The findings show that cognitive architectures can optimize human–machine interactions, which can lead to improved crisis decision-making management. This can be accomplished by designing systems with cognitive computing for monitoring and for the provision of predictions, preventions, and prompts toward favorable internal decision making.

The project research will continue with the proposal of an artificial intelligence-based model that will help to make correct decisions without asking for human intervention.

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