ACT-R in the military

A systematic review of Adaptive Control of Thought - Rational, a cognitive architecture, in the military

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Abstract

This paper provides an overview into the use of ACT-R as a cognitive architecture in the military. ACT-R stands for Adaptive Control of Thought - Rational. It is a cognitive architecture, a framework for a human like AI program, that models the human mind. In this paper its use will be examined in the military. Through this literary survey an overview will be created of the military's usage of ACT-R. The overview will answer the questions in which applications the military uses ACT-R and why they use ACT-R. It will bring understanding to the people of how ACT-R is used in the military. It will also give insight into where their tax money is being spent on. For the military an overview will come in handy in case ACT-R gets outdated. They will know what programs will need an update. The overview consists of three parts. A robotics operator manager, a test to determine the value of an officer managing multiple robots. The creation of intelligent tutoring systems for ship navigation and aircraft recognition. A supporting tool for analysts to help determine the value of information.

1 Introduction

Today we live in a time of war and technology.[1] Therefore the military plays a big role into our lives everyday. The military makes use of the technologies we have nowadays, for example it makes increasingly more use of robotics[1]. They also use cognitive architectures, as you will see in this paper, which "specify the underlying infrastructure for an intelligent system" [2].

Cognitive architectures are infrastructures for programs that model the human behaviour or thoughts. Their goal is to model the human mind to ultimately be able to make a human like AI. The system should act as a human and therefor, make similar mistakes in similar settings.[3]

ACT-R is an example of a cognitive architecture. ACT-R stands for Adaptive Control of Thought â Rational. Its main focus is to model human behaviour [2]. It is adaptive, meaning it will act based on the knowledge it has and when it has developed more knowledge it may handle differently in the same situation. It has a long-term memory and a short-term memory; with those it will develop itself with every cycle.[2]

ACT-R is one of the cognitive architectures used in military applications (e.g. [1]). The military is very important due to the ongoing wars in the world. We entrust the military with the lives of many to fight on the battle field. To minimize the risk of loss of life, soldiers need to be prepared and trained. The military uses ACT-R as an infrastructure to build training, tutoring and simulations upon. Currently there does not exist an overview of the applications of ACT-R in the military.

Such an overview is needed; We also live in a time where people are sceptical of and distrusting in technology. An overview will help people understand how ACT-R is used in the military and with this understanding I hope to create more trust in the military by the people. It is also needed from the other point of view; what if ACT-R becomes outdated? An overview will help to easily know what programs need to be updated. Another reason is that we are funding military research with more money and ACT-R is one of the expenses . Taxpayers want to know how their money is spent and if it is well spent. Creating this overview will help give insight into this. This systematic review will try to answer the following questions.

[1] At the time of writing there are wars in Gaza and Ukraine.

In which applications does the military make use of ACT-R? And why is ACT-R used in these applications? To create the overview we need these questions. The "which" will give us an answer to where ACT-R is in use. The why will explain to us the need for ACT-R in those applications.

I will give some background information in chapter 2 through relevant works. In section 3 I will discuss the method I used to gather relevant scientific papers; this includes searching databases and creating inclusion and exclusion criteria. Furthermore, I will discuss the results in section 4. This will be followed by a chapter on responsible research. Chapter 6 will be a discussion of my research including limitations. The paper will end with my conclusions.

2 Background

Related works in this field include the work of Anderson about ACT-R[4] an Maher and Orlando about cognitive architectures in the military[5].

2.1 An integrated theory of the mind

Anderson explains in this article how the theory of ACT-R works for version ACT-R 5.0. They think that is the best possible theory for a cognitive architecture with as goal to explain how each module of the mind works. ACT-R 5.0 has modules separated each with their own information processing sort. It is composed of the following modules; visual, manual, declarative, and intentional. Each of these modules has their own buffer. The system cannot process all information at once, but only respond to information in the buffer. The buffer storage is limited to a chunk, a single declarative unit of knowledge. The visual module and manual model play a big role in tasks in which participants are screening a computer screen and clicking a mouse. ACT-R works with cycles of approximately 50 ms, every cycle the buffers from each module is updated. The cycle represents the iterative brain cycle from cortex to basal ganglia. The perceptual-motor system does not implement real sensors or motor control. It mimics the timing of perception and action, the output of the visual model and the input of the actions. It allows for easier implementation. ACT-Râs visual system has a visual-location module and a visual-object module, the latter is concerned with properties of an object and the first is concerned with spatial locations of objects. The series of steps the system has to go through is tracked by the goal module. After receiving the information and the action that needs to be taken. The steps of the action are put into the goal buffer so the system will do every step neatly in the right order. The declarative memory module consist of factual information and the procedural memory consists of patterns of information. The Anti-Air Warfare Coordinator is a coordinator that checks the intent of the incoming aircrafts. It determines their type (e.g. commercial airplane) and their intent. Decisions the AAWC needs to make, need to happen quickly. To determine the underlying process the AAWC goes through, an ACT-R model is made. While this research explains the ACT-R model and gives a military application for the ACT-R model. It only mentions one possible use of ACT-R in the military. [4]

2.2 Reducing war fightersâ cognitive burden

The Mission Engineering process is applied to reduce the burden on war fighters. They create three parts, the Semantic Data Models, Cognitive Architectures, and Knowledge Graphs.

The CA creates an understanding of how to create ME standard system and it locates the cognitive loads in the organization. The CA maps out how data turns into information and finally becomes knowledge. It is an important tool to detect the burden and to reduce it. This paper explains our need for cognitive architectures in the military. It does not give an insight into the current applications. It shows what it can be used for and what it does but does not provide us with an example. [5]

3 Methodology

In this section I will present the methodology used for this study. It will contain how I selected the literature used in this systematic review. I followed the steps from[6]. First I identified the inclusion and exclusion criteria. To find the literature I created queries and ran those through multiple databases. Then I screened the titles and abstracts of the papers to see if the paper should be included in the review or excluded. After this I obtained my papers, followed by selecting the papers to be included in my review based on the full text. From there on the data extraction took place.

3.1 Inclusion and exclusion criteria

To only include relevant papers, I created inclusion and exclusion criteria. My inclusion criteria are covered by my query; the record should have ACT-R as a subject and a military focus. My exclusion criteria are non-English papers and papers that do not focus on the United States Army. If they fit into one of these categories they will not be included into my research. I chose to only include literature that conducted their study on the US army instead of other nations and their armies. I opted for this since the use of cognitive architecture models in the army could differ widely per nation and every nation also has a different military strategy so it is possible they would not use cognitive architectures in the same way. I opted for the US army as it is a large nation and there were enough papers to conduct a literary survey on. For the cognitive architecture I opted to only include ACT-R due to time constraints. This project is carried out in 9 weeks, this led to me having to make choices. I chose ACT-R as it was the one I found the most papers about in my general search.

3.2 Literature searching in databases with queries

I searched the following databases to acquire my literature: the ACM Digital Library, IEEE Xplore, Scopus and Web of Science. I included Scopus and Web of Science, because they are large multi-disciplinary databases, which therefore contain a lot of literature. IEEE stands for Institute of Electrical and Electronics Engineers and ACM stands for Association for Computing Machinery. Since this paper has a Computer Science and Engineering focus, I consulted these databases. With the inclusion and exclusion criteria I created a list of keywords to help build the queries for each database. Those keywords consisted of ACT-R and military. For ACT-R I included the full name of the architecture, Adaptive Control of Thought â Rational, instead of only the acronym. To get more results on military I added some synonyms. The list of keywords can be found in TableâŠ below.

Table 1: Number of results per query

ACT-R	Adaptive Control of Thought - Rational
Military	Army, Navy, Air Force

I created the query for Scopus and adapted this query to fit in all databases. These queries can be found in the appendix. For the results of the queries in the database consult TableâŠ . This query is used to receive only papers and articles which mention the application of ACT-R in the military, for example how they utilize ACT-R in their project of building a tutoring system for naval ship navigation. The queries resulted in 44 papers, and 34 after removing duplicates.

Table 2: Number of results per query

Scopus	28
IEEE	7
WoS	7
ACM	2

3.3 Literature Selection

To select my literature I first removed the 10 duplicate records. After this I removed any non-English papers, this was only 1 paper. The resulting 33 records went through an abstract and title screening. Based on titles, authors and abstracts I excluded irrelevant papers. This resulted in having only 13 papers left for my full text screening.

3.4 Availability

From the 13 papers left to analyse, 3 were unfortunately unavailable. Therefore, I cannot include them in my analysis and results. I had requested them, but due to time constraints they were not delivered in time for this research paper. This leaves me with 10 papers to include in my full text-screening.

There were 10 records that underwent a full-text screening. During the process of abstract screening a few papers were included which ultimately were not relevant for my research. For this process, I read the papers abstract, introduction, conclusion and the headers of every section. Based on that I included or excluded the records. The 4 papers that were excluded based on the full text and the reason of exclusion can be found in the table below.

After the literature selection process, I still had 6 papers left to include in my literary review. A PRISMA diagram can be found in figure 1. It shows how many papers were included or excluded during this whole process.

3.5 Full text screening

During the process of abstract screening a few papers were included which ultimately were not relevant for my research. The papers that were excluded based on the full text and the reason of exclusion can be found in the table below.

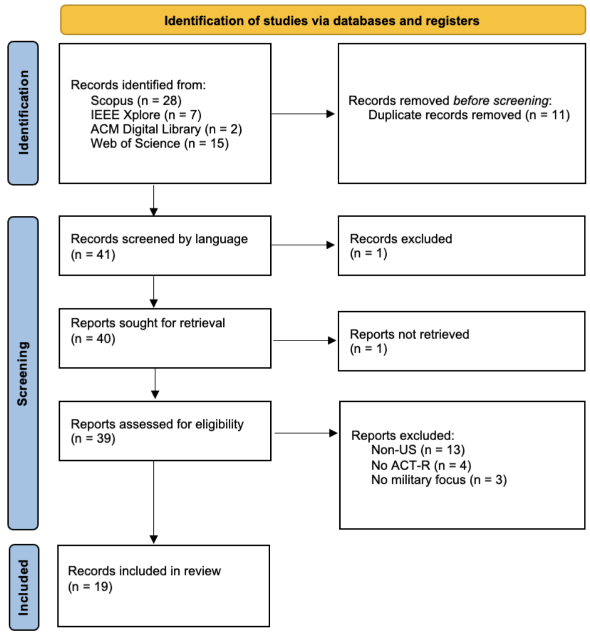

Figure 1: adapted PRISMA diagram

Table 3: Excluded papers based on full text screening

1.	Enhancing autonomy with trusted cognitive modeling	The paper
2.	Expanding a standard theory of action selection to produce a more complete model of cognition	The paper
3.	From domain specific languages to DEVS components: Application to cognitive M and S	ACT-R
4.	Using cognitive models to design dynamic task allocation systems	ACT-R is

Paper 1 and 2 mentioned the military in their abstract or keywords but during screening showed a lack of relevancy. Paper 1 mentions that autonomous TODO finish sentence. Paper 2 TODO include the reason for exclusion. Paper 3 was also not relevant for this literary review. Paper 4 had a relevant outlook on the military but was in fact not about ACT-R, they mentioned ACT-R as a future research option. This is still interesting, but not if relevance for this literary review.

3.6 Data Extraction

The relevant papers included only 6 records. To answer my research questions, I focussed on the section where the paper explained the ACT-R based model they created to answer their own research questions and I focussed on their goal of the ACT-R based model. To answer my research question as to why they chose ACT-R I focussed on the parts where they motivated their choice for ACT-R. â

4 Results

The data extraction led to three different applications; a supporting tool for analysts to value information, determining the value of a robotics operation manager, and improving tutoring systems. The results can be found in the table below.

Table 4: Results

Supporting tool for analyst to determine the value of information
Improving tutoring systems: visual aircraft recognition
Improving tutoring systems: Ship navigation manoeuvres
ACT-R to model a Robotics Operator Manager

4.1 Supporting tool for analyst to determine the value of information

Military decisions need to be made quickly due to time constraints and they need to be based upon relevant information. The volume of information is increasing, therefore so is the cognitive load upon information analyst. To create an assisting method for the analysts, the US Army Research Lab (ARL) needs to understand how the analysts perform on a cognitive level. To examine this the ARL created an ACT-R model. The value of information (VoI) depends on the reliability of the source [2] and the possibility that the content of the information is true [3]. Combined, this gives the information a rating, which leads to a ranking following ARLs fuzzy associative memory (FAM) model. The ARL expanded their FAM model after experimenting with the value of information interaction and combination as relevant additional information affects the value of the initial information. ARL will create a model to modify users at a novice level and the model will perform the tasks to determine the VoI. It will follow the cognitive process of a novice user. The ARL aimed at creating an ACT-R model that can simulate the process of an analyst. This model will receive information and it will determine the information rating. The system will determine an applicability value, based on the information ranking. When set, the computer will provide the next information element. The model repeats the process of rating the information. It has been given a relationship between the two information elements. With this relation the model determines a new applicability value. This process is repeated for all combinations. The ACT-R model has a similar result as the analysts and can therefore mimic the analystâs behaviour sufficiently. ACT-R can support the intelligence analyst in determining the VoI, resulting in a lower cognitive load on the analyst. [7][8]

4.2 Improving tutoring systems: visual aircraft recognition

It is important that soldiers can quickly recognize an aircraft before engaging. With a tutor they can be trained for to identify each aircraft as friendly, neutral, or hostile. With the increase in unmanned air systems as well as fratricide, VACR is becoming more important.

[2] This is ranked from A to E (reliable, usually reliable, fairly reliable, not usually reliable, and unreliable) [7]

[3] This is ranked from 1 to 5 (confirmed, probably true, possibly true, doubtfully true, improbable)[7]

The training consists of a classroom session and a computer training. Development of a smart tutor is the goal of this research. ACT-R is commonly used for smart tutoring systems; it can simulate the student and their thought process. Tracking errors allows the tutor to give feedback and hints at the perfect time. In this project ACT-R simulated and predicted the studentâs behaviour, which helped create the tutoring system. It showed the most successful attributes for the tutor, since it could mimic students and their learning process for every attribute of the tutor. [9]

4.3 Improving tutoring systems: Ship navigation manoeuvres

The Conning Officer Virtual Environment (COVE) trains officers to manoeuvre the ship (e.g. placing the ship at the docks). To avoid risks and costs paired with these manoeuvres in real life, COVE is used to train students. However, an expert needs to oversee the whole process and give feedback. A system with an intelligent tutor and expert performance through a cognitive model is supposed to unburden the instructorsâ workload. ACT-R was chosen for this model as the model needed to simulate human performance. The goal of the model is to be able to provide feedback and support the intelligent tutor. The model is trained by multiple experts and therefore needs to be adaptive and accept multiple paths to the same manoeuvre. It also needs to ensure the manoeuvre is being completed successfully through monitoring the behaviour of the student. To develop the model, feedback from experts to students using COVE was analysed. This pointed to the most important factor to the manoeuvres according to the human experts. The timing of the feedback was monitored as to be post action; students must be able to make errors. Experts were asked to provide insight into their ways of completing manoeuvres. Via headtracking it was established that experts alternate their attention during tasks between the environment and ship status indicators. This is also implemented into the model, that way the tutor can give feedback to the student if they are not alternating enough. The model as part of a tutoring system must be adaptive to errors and different behaviour from the students as opposed to the âperfect expert behaviourâ. Less than optimal solutions should also be considered correct to some degree. This calls for human cognition as well as the need for scanning, since a human cannot get multiple information sources as opposed to a computer. [10]

4.4 ACT-R to model a Robotics Operator Manager

Operations are more frequently involving robots in the military. These can be deployed in dangerous situations (e.g. bomb disposals). Humans are required to be involved when a robot is deployed for the human-robot interaction (HRI). Controlling the robots can come at the cost of a higher mental load which is a trade-off for performance. It is not possible to let the robots do everything autonomous since they are still prone to making errors. The goal is to have one human, an officer, control multiple robots, a Robotics Operator Manager (ROM). The initial Model was an EE (Engineered Explosive) detection ROM managing two robots planning gout a convoy path. The most important cues for EE detection were implemented in the model that underwent the test phase. During the test phase participants were asked to play the role of a ROM in EE detection, through a computer interface. During the test phase two independent variables were tested; limited bandwidth and time constraints. The final model was implemented in ACT-R to finetune the parameters of the model until its results are close to the empirical data from the test phase. The final model underwent changes to multiple parameters; the details can be found in [BRON]. ACT-R has as a goal to represent empirical data, so it was a logical choice for this model. In this experiment they are using the results from the test phase to improve the Initial Model so it will generate accurate results. The final model should be a viable simulation. [1][11]

5 Responsible Research

In this project we practice responsible research. I will discuss the risk of bias towards the US army and towards ACT-R. Ethical considerations will be mentioned as well as reproducibility.

5.1 Risk of bias

Due to the chosen exclusion criteria, exclude non-US and non-ACT-R papers, there has been a little bias in my research. It is not a bias that has risen to the surface due to my personal beliefs, but due to time constraints. Since they are not subjective but objective it is still reproducible and thus not a problem. The research paper now only considers how the United States utilizes ACT-R as a cognitive architecture. Their biases and the limitations of ACT-R give my paper a bias towards applications in which ACT-R can be utilized. For future research I recommend to include multiple nations and cognitive architectures, this should eliminate these biases.

5.2 Ethical considerations

The ACT-R model is used to optimize the military. One could argue how ethical it is to optimize warfare as it may result in loss of life at the other side. Aside that, confidentiality is a sensitive subject in the military. One could consider whether creating an overview of research in the United States military is ethical since it makes it easier for opponents to get insight into the U.S. military and their operations. However, since all papers used were open to the public, the risk can be neglected. Along with that, there were only 6 papers included in this literary review, so the risk is limited.

5.3 Reproducibility

I have done a systematic literature review. For this it is important to document every step very clearly. The research should be reproducible. I have documented every step as well as the inclusion and exclusion criteria. In the appendix the queries can be found for each database that I have used, as well as the date on which I have consulted the databases. In the appendix/results a table can be found with the name of every excluded paper and the reason for exclusion. Every step taken is mentioned in this article and therefore the research should be reproducible.

6 Discussion

In the discussion I would like to address the limitations of my research and their effect on this research. First, I will discuss the limitation I put on the nations, then I will discuss my choice of architecture and I will also discuss the access I had to papers as well.

6.1 Only applying ACT-R in the military to the United States Army

As mentioned before, I only included papers that were discussing the ACT-R cognitive architecture in the U.S. army. This excludes a large sum of papers about the ACT-R framework in the military. I have chosen to apply the research only to one nation due to time constraints, but also due to the fact that different nations may utilize the cognitive architecture in a different way. I wanted to create a simple overview for one nation and I chose the U.S. for this overview. I chose the U.S because it is along with China and Russia the biggest military force at this point in time ADD SOURCE. Russia was not present in the database searches, and the U.S. was more represented than China.

6.2 Only including ACT-R as a cognitive architecture in the military

Due to time constraints my research could not include too many factors. I therefore concluded I had to narrow my research to apply only to one cognitive architecture. I chose ACT-R of this family of architectures because of its simulation properties and the value of simulation to the army. I therefore concluded I should choose ACT-R as the main focus of this research.

6.3 Availability of literature due to time constraints and access

In the discussion I would like to address the issue of unavailability of literature. With very limited time it is hard to gain access to papers which are not openly accessible. I have requested the full texts form the authors, but I have not received any reply yet. I also have limited resources due to being a student at the TU Delft. The TU Delft grants access to multiple databases and resource platforms, but it cannot give access to all databases and all the papers in those databases. I therefore had to exclude papers that could have had interesting additions to this paper. All excluded papers and the reason for their exclusion can be found in the appendix.

6.4 Confidentiality in the military

I have chosen to do my research on cognitive architectures in the military. Since the military is an institute in which confidentiality is very important, it is possible that not all research is disclosed to the public. Especially not to the foreign public. This may have impacted the number of papers that were available to me, a Dutch student.

7 Conclusions and Future Work

7.1 Conclusion

The results give us 3 applications. The military uses ACT-R as a supporting tool for analyst to calculate the VoI. ACT-R is also utilized to improve tutoring systems, by simulating students and their learning process. The military can test different tutoring strategies and ACT-R helps in selecting and perfecting the best one. Lastly the ACT-R is used to see if a Robotics Operator Manager is feasible and if it has an added value. ACT-R is chosen in all cases because it can simulate human behaviour and their cognitive process. While the overview is incomplete due to availability constraints, it does give us a good insight into how the military utilized ACT-R. It allows the taxpayers to see that the military is using ACT-R to simulate empirical data so their models can be more accurate and will therefore lead to more safer technologies, leading to less loss of life.

8 Future work

To gain more insight as to how the military is using cognitive architectures, I recommend doing a more extensive literature review. In this more extensive review it is interesting to include other architectures and to compare them. Another recommendation is to include multiple nations and to compare the difference in utilization of cognitive architectures between different countries. This gives a more extensive overview as to where cognitive architectures can be applied in the military.

A Queries

A.1 Scopus

TITLE-ABS-KEY ((("act-r" OR "Adaptive control of thought â rational") AND (military OR army OR navy OR "air force")))

A.2 IEEE Xplore

("All Metadata":"ACT-R" OR "All Metadata":"Adaptive control of thought â rational") AND ("All Metadata":military OR "All Metadata":army OR "All Metadata":navy OR "All Metadata":"air force")

A.3 Web of Science

("act-r" OR "Adaptive control of thought â rational") AND (military OR army OR navy OR "air force") (Topic)

A.4 ACM Digital library

[[Abstract: "act-r"] OR [Abstract: "adaptive control of thought â rational"]] AND [[Abstract: military] OR [Abstract: army] OR [Abstract: navy] OR [Abstract: "air force"]]

B Keywords

TODO create nice table.

B.1 Initial search

Cognitive architectures Military | synonym army

B.2 Final Search

ACT-R | Adaptive Control of Thought - Rational Military | Army, navy, Air force

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