Abstract—Cyber threat intelligence is a relatively new field that has grown from two distinct fields, cyber security and intelligence. As such, it draws knowledge from and mixes the two fields. Yet, looking into current scientific research on cyber threat intelligence research, it is relatively scarce, which opens up a lot of opportunities. In this paper we define what cyber threat intelligence is, briefly review some aspects for cyber threat intelligence. Then, we analyze existing research fields that are much older that cyber threat intelligence but related to it. This opens up an opportunity to draw knowledge and methods from those older field, and in that way advance cyber threat intelligence much faster than it would by following its own path. With such an approach we effectively give a research directions for CTI.

Index Terms—cyber threat intelligence, research, survey, intelligence, knowledge management, cognitive computing, information fusion, situational awareness

I. INTRODUCTION

For a long time in human history every state that wanted to survive had to know who its enemies are, what are their capabilities, when they intend to do something, where they will do it, why they want to do it, and how they intend to do it. These are so called 5W’s [1]. The enemies, of course, could be the other nation states, different groups of adversaries, but also country’s own citizens. For a long time these kinds of activities were exclusive domain of activity of nation states and was done by secret services of some kind.

But in the late 20th century, and especially in 21st century, with the proliferation of Internet and ever bigger reliance on information technology (IT) companies found themselves basically in the same situation nation states find themselves for centuries. So, companies started to try to obtain data about their threats, and basically, started to perform tasks performed by secret services in order to obtain data about its threats, i.e. 5W’s. Yet, companies are not authorized by law to perform full range of collection activities performed by secret service, nor they have resources to do so. Furthermore, cyber domain has its specifics with respect to domains secret services operate in. So, the two domains were fused thus creating a new intelligence branch, cyber threat intelligence (CTI).

The goal of this paper is to review several of the research fields that the authors identified to have some commonalities with the cyber threat intelligence, but in the same time are much older than CTI, with respect to the use, experience and the body of research. It is the idea that the knowledge accumulated in those other research fields can be applied to CTI in some way. In that way we hope to give some guidelines for advancing cyber threat intelligence much more faster by reusing ideas, methodologies, experiences and other knowledge elements from the other, older, research fields. In that way we aim to fulfill the main objective of this paper, to give research directions in CTI by connecting it to much more mature related fields.

The paper is structured as follows. In the Section II we define the necessary terms, the chief among which is cyber threat intelligence itself. We also give a quick overview of some basic concepts in the cyber threat intelligence. Then, in Section III we briefly review research related specifically to CTI and we also review a related work. The Section IV is about intelligence already done for some time in today’s organizations, i.e. business intelligence and competitive intelligence. Then, in Section V we review some of related fields of research that fully or in part could be applied in order to improve CTI processes and its output. Finally, in Section VI we give conclusions.

This paper builds on presentation given on the Cybersecurity symposium organized by Croatian Ministry of Defense in summer of 2016 on the island of Mali Lošinj.

II. CYBER THREAT INTELLIGENCE

In this section we’ll define what CTI is and also describe few important aspects of the CTI.
A. What is CTI?

To know what CTI is, we have to define it, and we can start with the definitions and descriptions of its constitutive parts contained in the name CTI, i.e. the terms cyber, threat and intelligence. Then we can try to answer the question posed in the title of this subsection, i.e. What is a CTI?

First, the word cyber denotes domain or environment in which everything happens. It’s usually not used alone, i.e. it is used as an adjective. In cases when it’s used alone it is possible from the context to infer what it refers to. There are many possible definitions of the word cyber all of which in basically say the same, cyber is adjective that denotes a special environment. Here is one such definition [2]:

Its inference usually relates to electronic information (data) processing, information technology, electronic communications (data transfer) or information and computer systems. Only the complete term of the compound word (modifier+head) itself can be considered to possess actual meaning.

The definition lists everything that might be considered "cyber"! So, for example, events within a computer system is a cyber world, data while being transferred from source to destination are also in cyber, etc.

Next, the word threat is an umbrella term that includes anything that can make some harm to something. Obviously, what is considered to be threat depends on that something, i.e. who you ask! So, in case of a bank, there is one set of threats, in case of nation state, there’s another set of threats, etc. In conclusion, a very general class of different things can be regarded as a threat, for example earthquake, or negligent person, or an attacker, etc. Consequently, there are lot of definitions of the term threat, e.g. a simple one [3]:

The potential source of an adverse event.

Finally, there is the key term intelligence. One would think that for something done for so long there is agreed upon definition, but the truth is just the opposite! There are multiple definitions, depending whether you look from the consumer or producer side of the intelligence [4], and if you look traditional intelligence applied only for the purpose of the nation state, or the one applied by other entities like different companies.

One modern definition we think is very good and includes not only the intelligence done by governments and militaries, but also by companies, is given by Breakspear [5]:

Intelligence is a corporate capability to forecast change in time to do something about it. The capability involves foresight and insight, and is intended to identify impending change which may be positive, representing opportunity, or negative, representing threat.

This definition places an emphasis on process, rather then on the outcome of this process. There are, of course, definitions that don’t put emphasis on one signal aspect of intelligence, like aforementioned FBI’s one [4]:

Intelligence is:

- Intelligence is a product that consists of information that has been refined to meet the needs of policymakers;
- Intelligence is also a process through which that information is identified, collected, and analyzed; and,
- Intelligence refers to both the individual organizations that shape raw data into a finished intelligence product for the benefit of decision makers and the larger community of these organizations.

To finish with definitions we can now infer from them what specifically CTI is by applying the meaning of words cyber and threat to the word intelligence:

- It is "traditional" intelligence applied in the realm of cyber focusing on threats [6].
- It is a product produced by a process done by an organization, all together called the cyber threat intelligence.
- It is done by companies but also government organizations, and potentially many others that have established process, and produce some product.

It should be also noted that there is a big difference between information and intelligence. This is emphasized in the definition given by Breakspear who explicitly states that CTI [product] involves foresight and insight!

To finish with definitions, let us just say that in the literature it is possible to find two alternative names for Cyber threat intelligence (CTI), threat intelligence [6] and cyber intelligence. Even though not strictly equivalent if we look through the lenses of definitions, usually they are equivalent due to the context in which they are used, i.e. the context provides for "missing" word, either cyber or threat. There is also term security intelligence, but it is a lot more broader that CTI for a simple reason that the word security means a lot more than information security and cyber security.
B. CTI Process

CTI, like intelligence in general, follows a certain process which, as a result, produces output. There are several models that can be found in the literature, for example the most basic steps taken from the traditional intelligence are [7]:

1) Planing and Direction
2) Collection
3) Processing and Exploitation
4) Analysis and Production
5) Dissemination and Integration

The goal of planning and direction is to define overall goals of the intelligence process, i.e. intelligence consumers define what they need. Then in the collection phase raw data is collected. For the collection of raw data traditional intelligence uses many different techniques, like open-source intelligence (OSINT), human intelligence (HUMINT), signals intelligence (SIGINT), and geospatial intelligence (GEOINT), to name a few. But not all of those collection disciplines can be used in CTI by companies or any other entities other than secret services for the reason they are illegal and/or non-ethical. So, for CTI the only available collection discipline is OSINT.

Processing and exploitation transforms raw data into information, and then analysis and production turns information into intelligence, the final product delivered to the intelligence user, which is part of the dissemination and integration steps.

Steps given above are augmented with additional steps that cover the whole process, like feedback step. Additionally, the process is drawn like unidirectional, but there are backlinks that make the process much more iterative with more smaller cycles. There are a number of works analyzing and searching for the optimal process, so we’ll not go into details in this paper.

No matter which exact sequence of steps is taken, it is collectively known as intelligence cycle because steps are usually drawn on a circle with arrows pointing from one to the next step and the last step pointing to the first one. The intelligence cycle is not without its issues, and the collected set of critiques from the literature can be found in [7].

C. CTI Levels

Usually, CTI is divided into three levels, i.e. strategic, operational, and tactical. It is important to emphasize that there is no strict delineation between the three, i.e. there are overlaps and sometimes it might be hard to identify for some activity to which level it belongs to.

At the highest level is strategic cyber threat intelligence. It is closely related to the strategy of the organization and as such its goal is to support it and protect from potential threats. The product of the CTI at this level is for organization’s CEO and the board that sets overall strategy and executes it. At the next, lower, level is operational cyber threat intelligence. The goal of CTI at this level is to identify threats, their tactics, techniques and procedures. All this allows for building better defenses and as such the consumers of this intelligence are CISOs and CIOs [8]. Finally, at the lowest level is tactical cyber threat intelligence. Today it is the most frequently associated with CTI in general, i.e. when people talk about CTI in many cases they actually talk about tactical level and its artifacts [8]. For example, indicators of compromise (IoC), different hash values, description of what malware does and similar are all the products of tactical level cyber threat intelligence.

Note that it is also possible to find four level classification in the literature, i.e. strategic, operational, tactical and technical [9]. Still, the majority of text use three levels and so we adopted that approach, too.

III. CTI Research and Related Work

Research in CTI is currently focused on tactical level, i.e. analysis of malware, creating indicators of compromise, and sharing them. Sharing is done using the STIX of OpenIOC formats for describing the intelligence, and in the case of STIX, TAXII protocol for the exchange of the information. Much less information is available on operational level of cyber threat intelligence. And even less so about strategic intelligence. That doesn’t mean there is no reports covering all the aspects of cyber threat intelligence. Different threat reports published by companies like FireEye, Kaspersky, Sophos, IBM, etc. contain intelligence on strategic, operational and tactical levels, but the emphasis is on tactical and less on operational levels. Furthermore, the information on how the intelligence was collected, processed, etc. is unavailable and probably mainly done automatically on technical level, and manually on all the levels.

As for the similar work to the research reported in this paper, the authors aren’t aware of any. So, this seems to be a promising direction with a lot of opportunity for further, and much deeper, research not yet done by others.

IV. The Three Intelligences

The universe of any company consists of the following stakeholders: (i) customers, (ii) competitors, (iii)
partners, and (iv) attackers. Each one of them interacts with the company on every level (tactical, operational, strategic), and thus influences the state the company will be in short, medium and long term, respectively. For that reason companies developed means of tracking stakeholders and, in a way, predicting what will happen. Competitors are tracked using competitive intelligence (CI), customers, the company itself and other data using business intelligence (BI), and threats/attackers using cyber threat intelligence, (CTI). Partners, if necessary, can be tracked using CI or BI, depending on the exact nature of partnership.

Of the three, CTI is a relative new comer to the game, i.e. BI and CI are practiced for a lot longer time. This means that the two accumulated a lot more knowledge in due time, and due to certain similarities, very likely this knowledge can be applied for CTI as well, advancing it more rapidly than by going through all development/research steps BI and CI went over the years. In the following sections we’ll talk in a bit more details about CI and BI.

A. Competitive Intelligence

Companies are performing competitive intelligence in some form for a long time now, at least 30 years now. The goal of competitive intelligence (CI) is to collect information about competition, analyze it and present managers with actionable data [9]. The CI is especially important today in a highly competitive market where decision makers have to have actionable data in order to properly guide companies and where mistakes and wrong predictions can have disastrous effects. For that reason many companies have established competitive intelligence processes. Furthermore, the fact that this activity exists for a relatively long time, as well as its importance, means that substantial body of knowledge has been accumulated with time.

B. Business Intelligence

Business Intelligence is relatively old activity going back as far as to 1950ties [10] even though the true renaissance the field achieved in 90ties. The goal of BI is to analyze information present withing the company and to extract intelligence (knowledge) that can be used to support decision making by management. The main difference between BI and CI is that former uses internal information, while latter uses external information. For a long time the primary data sources for BI were structured databases, but lately unstructured text is also used due to having vast amounts of it available in comparison to structured data. Furthermore, the advancement of techniques to analyze unstructured data like natural language processing and machine intelligence also helped in that respect.

V. RELATED RESEARCH FIELDS

The business intelligence and competitive intelligence described in the previous section use many methods to analyze and process data. Some of those are described here along with some additional tools that might be used in the CTI. The list is in alphabetical order.

A. Adversarial Reasoning

Adversarial reasoning is subfield of Decision making and its goal is to model and predict how adversarials will behave [11]. This in turn allows one to properly respond to anticipated behaviors. The field of adversary reasoning is relatively old, having first papers appeared in 1992 [11], so in the mean time it is obviously accumulated a lot of knowledge. The main tool of adversarial reasoning was game theory, but that isn’t the case any more. The connection with the CTI is obvious, namely, CTI analyst when analyzing threats has to anticipate threat’s behavior in medium (operational) and long (strategic) time frame.

B. Cognitive Computing

Cognitive computing is a relatively new field but it is a continuation of an old idea of Artificial Intelligence [12]. Namely, the original idea of AI was to mimic human mind in it capacity to comprehend and understand the world. This turned out to be very hard and with the time AI fragmented into multiple subfields each with its own narrow goals. Yet, all of those fields carry a mark of AI and thus AI itself is a very overloaded expression. To avoid all those conotations by using the name AI, Cognitive Computing term was coined. The idea is to use multiple methods in parallel (sequentially) and achieve more complex behaviors than it is possible using only a single method, like deep learning, etc. Since the field is relatively new it is still confusing, and that is the most noticeable by comparing scientific literature like [12] and commercial like [13]. Commercial ones put an emphasis on processing natural language, while scientific ones take a more broader approach. But, either way, the biggest success of cognitive computing to date is IBM Watson [13] which in 2011 managed to beat two of the best players in Jeopardy quiz show [14]. This is a significant success taking into account how hard is for computers to understand ambiguous human language, and to do so quickly. After that success IBM decided
to commercialize IBM Watson and offer it as a cloud service to the customers.

CTI would obviously benefit from cognitive computing in general, and IBM Watson like systems in particular, because they would allow harvesting and understanding a large amounts of data, something that is today very expensive and very hard to achieve, if possible at all.

C. Information Extraction

Information extraction is a research discipline that tries to solve the problem of automated extraction of information from unstructured texts, like documents, Web pages, forums, etc. It grew up from natural language processing, and is developed for over 25 years now [15].

D. Data and Information Fusion

The field of data and information fusion deals with the fusion of information coming from different sources and on a different abstraction levels in such a way to produce new, more complete and better data, information, or decisions, at a level of a human understanding then it would be possible by using the sources separately [16], [17].

Several points are worth emphasizing that connect DIF to CTI. First, there are different models proposed for information fusion which broadly can be grouped by input and output, i.e. input can be either data, features or decisions (from lowest to highest level), while the output can be anything of the same or higher level. For example, if the inputs are features, then the output can be features or decisions. The next point worth emphasizing is the fact that intelligence cycle described in the Section [11B] is only one model proposed for the purpose of information fusion [16]. Others are OODA loop, Waterfall model, the Omnibus model, the Ensley model, and many others. So, the knowledge from DIF can be applied to the specific parts of the CTI cycle, or to the whole cycle in general. Also of interest is that the emphasis on research in the field of DIF is now on high-level fusion. Since the emphasis of current CTI research and practice is concentrated on technical/tactical details it might be inferred that CTI is currently in early stages of development when compared to DIF.

The use of DIF in computer and network security has already been suggested. E.g., Corona et. al [17] review the use of DIF for the purpose of improving intrusion detection.

E. Situational Awareness and Cyber Situational Awareness

The situational awareness (SAW) is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future [16]. The Cyber Situational Awareness (CSAW) is concerned with situational awareness in the cyber space. SAW is dependent on information and DIF so the two are often interrelated in the literature.

Obviously the goal of CTI is to make decision makers aware of threats in cyber space, which in other words, is very similar to cyber situational awareness, though a bit more narrow.

F. Knowledge Management

Knowledge management (KM) is a discipline that provides strategy, process, and technology to share and leverage information and expertise that will increase our level of understanding to more effectively solve problems and make decisions [18]. KM is about managing a knowledge, which is defined in variety of ways, one of which is that it’s actionable information [18]. This is in line with what CTI produces, i.e. CTI from data extracts information and from information produces knowledge. Thus, it is interesting to see what knowledge management is, and what can be (re)used to improve CTI and its processes.

There are a number of reasons businesses use KM [18]. Almost all of which have application for the purpose of CTI, too. Here are just a few with the justification on why they should be used for CTI:

- measure and track value and flow of information – this is a very important issue because when something is better measured, the easier it is to manage it. There is no engineering and science without measurement. This holds for everything, and thus for CTI, too.
- the need to build highly effective virtual teams and reduce cycle times, as well as better customer relationships – again, something very important for today’s organizations that helps the organization to manage and improve its processes, so applicable to CTI, too.
- the need for a better way to share information and knowledge across organizational boundaries and the ability to rapidly respond to queries or crisis – information sharing is a hot topic in information security in general, and in CTI in particular. As can be seen, this is a topic with which KM deals in a
methodological way, so this makes KM very applicable to CTI and Information security in general!

- **the need to retain the knowledge of experts who are retiring** – This is the problem that has every organization with its workforce. Not only when experts are retiring, but also if they leave a company for other job. Keeping their knowledge is very valuable for the continuity of processes done within the organization.

There are other business reasons for using KM in organizations that could be also applied for CTI. But this much is enough to argue that KM is a very interesting field of research with a lot of potential to improve CTI and its processes.

VI. Conclusions and Future Work

In this paper we defined CTI and gave a quick overview of CTI methods and processes. We then reviewed related research fields, starting with business and competitive intelligence and continuing with other related fields. We argued that each research field has something in common with the CTI thus, meaning that CTI can be advanced much quicker by reusing some knowledge from those related fields. If we take into account that each of the related fields is much older (in time frames of information technology) than CTI, then the potential is really big. In that way we showed the potential research directions for CTI.

The work in this paper is just a start since there are much more research topics that has to be done. First, the relation between research fields presented in this paper and CTI can be correlated much deeper, and also there are other fields with a potential to be (re)used in CTI, like knowledge engineering, Ontologies, Uncertainty Analysis/Management, Decision Theory, Critical Thinking, Uncertainty Theory & Reasoning, Big Data, and Cognition.

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