

Situation Detection Based on Knowledge Fusion Patterns

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Abstract. With the increasing use of sensors and actuators in technical systems and knowledge-intensive services the need for processing the information captured by these sensors and “making sense” out of it increases. Knowledge fusion is supposed to contribute to this field since it aims at integrating knowledge from different sources. Development of knowledge fusion solutions is a complex task which can be compared to systems and software development. As in other development areas there is a need for efficient development processes which can be supported by reusing solution parts, such as patterns or components. The paper brings together experiences from knowledge fusion sub-system development and from design of knowledge fusion patterns. The main contributions of this paper are (1) a real-world application scenario presenting typical requirements to knowledge fusion systems, (2) application of knowledge fusion patterns from context-based decision support to situation recognition, (3) recommendations from this application case.

Keywords: knowledge fusion, knowledge fusion pattern, situation, situation detection, knowledge logistics.

1 Introduction

With the increasing use of sensors and actuators in technical systems and knowledge-intensive services, like in cyber-physical systems, preventive maintenance or intelligent information logistics, the need for processing the information captured by these sensors and “making sense” out of it increases. Knowledge fusion is supposed to contribute to this field since it aims at integrating knowledge from different sources.

The development of knowledge fusion solutions and systems usually is a complex task which can be compared to systems and software development projects. As in other development areas there is a need for efficient development processes which can be supported by reusing solution parts, such as patterns or components. The aim of this

paper is to bring together experiences from knowledge fusion sub-system development and from design of knowledge fusion patterns. We will analyze applicability and pertinence of knowledge fusion patterns in a past project from civil security and derive recommendations from this analysis for future projects aiming at using fusion patterns.

The main contributions of this paper are (1) a real-world application scenario presenting typical requirements to knowledge fusion systems, (2) application of knowledge fusion patterns from context-based decision support to situation recognition, (3) recommendations from this application case.

The remaining part of the paper is structured as follows: section 2 gives an overview to the field of knowledge fusion and discusses related work. Section 3 presents the application case constituting the frame for this research. An overview to the basic concept of knowledge fusion pattern is given in section 4. Section 5 discusses the applicability of fusion patterns in the given application case and derives recommendations. Conclusions and future work are discussed in section 6.

2 Knowledge Fusion

Techniques for data, information and knowledge fusion from different sensors, services and components have received much attention during the last decade. This section will give a brief overview to the field which starts from data fusion since this often lays the ground for higher level fusion activities, like knowledge fusions.

The process model for data fusion suggested by Joint Directors of Laboratories (JDL) which later became the Data Fusion Group (DFG) is the most popular of the fusion models. First proposed in 1985, the JDL/DFG model was revised several times (see [1] and [2]) due to observed shortcomings [3]. Currently, the levels with the JDL/DFG model are: Source Pre-processing/Subject Assessment (level 0), Object Assessment (level 1), Situation Assessment (level 2), Impact Assessment / Threat Refinement (level 3), Process Refinement (level 4), and User Refinement / Cognitive Refinement (level 5). Through its different levels, the model divides the processes according to the different levels of abstraction of the data to be fused and the different problems for which data fusion is applicable (e.g. Characteristic estimation vs. situation recognition and analysis). The model doesn't prescribe a strict ordering of the processes and the fusion levels, and the levels are not always discrete and may overlap. The model was initially proposed for the military applications but is now widely used in civil domains as well, such as business or medicine. The JDL/DFG model is useful for visualizing the data fusion process, facilitating discussion and common understanding and important for systems-level information fusion design [4].

Other fusion models include the Boyd loop [5], the Waterfall model [6] and the Endsley model [7], which focus on different perspective of the fusion task and propose refined structures or processes. The Omnibus model [8] is an attempt to achieve a unified model by merging different fusion models. It reflects the cyclic nature of the Boyd loop, and carries the finer structure of the Waterfall model, of the JDL model, and of the Endsley model.

Two main groups of knowledge fusion approaches are commonly distinguished: knowledge fusion based on knowledge representation technologies and semantic integration for federated systems. Semantic integration will not be discussed in detail, since it primarily focuses on applications in information systems and database context, i.e. fusing schemata of the information sources. Knowledge Fusion approaches based on knowledge representation techniques, like semantic nets or ontologies, have been subject to research during the last 20 years and resulted in a number of methodology and technology approaches. The most cited and used approaches include the following ones.

The KRAFT [9] architecture for knowledge fusion and transformation: knowledge fusion is defined as a combination of knowledge from disparate sources in a highly dynamic way. In order to do this, data instances need to be associated with knowledge concerning their context, such as how they should be interpreted and how they can be used. Two main kinds of operations are recommended in a distributed knowledge fusion system: knowledge retrieval (to find out everything the organization knows about something) and problem solving (to use the combined knowledge to solve a particular problem). This leads to a number of services required by the system: knowledge location services (to find the relevant knowledge on the network), knowledge transformation services (to translate the knowledge into a common representation language), and knowledge fusion services (to combine and process knowledge).

The Knowledge Supply Net approach KSNet [10]: the goal of the KSNet approach is to complement insufficient knowledge and obtain new knowledge using knowledge from different sources. The technologies involved spans from ontology management and intelligent agents to constraint satisfaction and soft computing. Knowledge as a set of relations, such as constraints, functions, or rules, that can be used by a user or expert in order to decide how, why, where, and what to do with the information in order to meet a goal or a set of goals within a clear context and time. The knowledge fusion process structure has several steps, including translating knowledge from different knowledge sources into a unified form, acquiring knowledge from external sources, select the relevant knowledge producing new knowledge by discovering or deriving it from the existing knowledge, internalization of knowledge, and knowledge fusion management.

The general idea to capture the domain under consideration in a domain ontology, the tasks to be supported in task ontologies being a part of the domain ontology, integration the knowledge sources by using these ontologies and fusing the relevant knowledge on-demand is suitable for the planned project. A commonality between these approaches is that industrial scale application and support by off-the-shelf products so far is quite sparse.

3 Application Scenario

The content of this paper is based on work from the FP7-Security-IP Integrated Mobile Security Kit (IMSK) project⁶. IMSK was addressing the continuously evolving threat of unpredictable terrorist activity, which demands the application of existing and developing technology for the protection of citizens. More concretely, IMSK combines technologies for area surveillance, checkpoint control, CBRNE detection and support for VIP protection, into a mobile system for rapid deployment at venues and sites which temporarily need enhanced security. The project's approach is to design a system (IMSK) that will integrate heterogeneous information to provide a common operational picture. This includes to employ legacy and novel sensor technologies, and to adapt the system to local security forces.

Data, information and knowledge fusion have major roles within the IMSK system. IMSK integrates different kinds of sensors providing observations of the sites to be protected. The data provided by physical sensors, as well as pieces of information provided by human observers and open sources, have to be combined in order to provide an overview of the ongoing situation. Within this work, we are particularly interested in knowledge fusion and fusion of high level information. We decompose the fusion process into several phases of fusion. First, entities of the world are represented using detailed observations provided by different kinds of sensors. This is the attribute fusion phase. Then, the recognized entities are combined and relations among them are observed. The situation fusion phase aims at reconstructing a more global view of the observed situation that contains both the entities recognized in the attribute fusion phase and the relations that have been observed among them by other information sources providing information of a higher level. Both the attribute and situation fusion, rely on the same approach. The two phases differ only by the level of detail of the observations that are processed. Once the representation of an ongoing situation is achieved, the situation recognition aims at deciding whether the ongoing situation is one of the "critical situations" preliminary defined by the end users. Last, the event correlation phase allows for combining the different static critical situations recognized in order to detect the occurrence of complex critical situations. The event correlation phase allows taking into account time and space issues of the critical event detection process.

Several scenarios were defined within the IMSK project that aim at showing the adaptability of the platform to different types of environments and events. One of these scenarios is the protection of VIPs⁷ during an EU summit. The events of the summit take place in three different locations of a city. The participants have thus to go from one place to another one. One of the tasks to be supported is the protection of VIPs when crossing a bridge when going from the congress center to the dinner place. Several sensors are deployed in order to detect CBRN⁸ threats, fireworks, approaching vehicles, etc. Our aim, within knowledge fusion, is to combine observations acquired through the different sensors (and potentially already fused at a low level), with

⁶ <http://www.imsk.eu>

⁷ VIP = Very Important Person

⁸ CBRN = chemical, biological, radiological and nuclear

information coming from other sources. We then have to detect potential critical situations and events, according to the ones that are specified by the end users of the IMSK system. Our example here focuses on the detection of a vehicle approaching a VIP while he/she crosses the bridge. We use the vehicles tracking system observations, the schedule of the summit and observations provided by people on the site.

The requirements to the functionality of a knowledge fusion sub-system derived from this scenario are defined as “capabilities”, i.e. desirable functionalities to be supported by knowledge fusion. Examples for capabilities are:

- Area surveillance: Area control: airspace, Area control: land, Area control: waterways, Protection of public infrastructure, Protection of buildings and Protection of property.
- Command & control (C2): Situation awareness, Decision support, Deployment support and Communication management
- Communications: Emergency communication, secure communication and communication in buildings.
- Access rights: verification of access rights, enforcement of access right restrictions, crowd monitoring, identification if unwanted behavior, VIP assault prevention, identification of wanted people.

4 Knowledge Fusion Patterns

Knowledge fusion patterns were developed to generalize knowledge fusion processes in relation to sources involved in these processes. For this, the knowledge fusion processes ongoing in a context-aware decision support system (CADSS) were investigated [11].

In the CADSS a situation is modeled by a two-level context. Abstract and operational context represent the situation at the first and second levels, respectively.

The abstract context is a non-instantiated ontology-based situation model. This context is created for a specific situation. It captures knowledge relevant to this situation from an application ontology. The ontology combines domain and task knowledge needed to describe situations happening in the application domain.

The operational context is the result of an abstract context instantiation for the actual circumstances. Data and information from various sources (sensors, humans, etc.) is fused within the abstract context structure to produce the operational context. This context is a near real-time schematic picture of the ongoing situation.

The operational context is the basis for decision making. The system supports the decision maker with a set of decisions feasible in the current situation. This set is a result of solving tasks specified in the abstract context as a constraint satisfaction problem.

The investigation of the processes ongoing in the CADSS results in the following knowledge fusion patterns:

Selective fusion: integration of multiple knowledge pieces from various ontologies of different types into a new ontology. The pattern is used for application ontology creation.

Simple fusion: integration of multiple knowledge pieces from a single large multipurpose ontology into a new knowledge piece intended to restricted purposes. The pattern is used for abstract context building.

Extension: inference of new knowledge as a result of knowledge integration. The pattern is used for abstract context building.

Instantiated fusion: fusion of data/information from multiple (possibly, heterogeneous) sources to create a representation that may be used by the CADSS, decision makers, and other humans as the basis for problem solving and decision making.

Flat fusion (see Fig. 1): fusion of knowledge from multiple knowledge sources during problem solving. The pattern is used for generation of a set of feasible decisions.

Adaptation: gaining new capacities/capabilities by units (knowledge sources, source network, actors, etc.) as a result of their adaptation to new circumstances or new scenarios. The pattern is used for adaptation of an existing knowledge source network to new scenarios and for adaptation of decision executives to changing settings.

Historical fusion: revealing new knowledge from hidden knowledge based on the accumulated one. The pattern is used to inductive inference of new relations between the entities presenting in different contexts.

The knowledge fusion patterns are formalized in terms of preservation/change of the structures and autonomies of the initial and target sources, and in terms of the results the knowledge fusion processes produce in the CADSS. The reasons of choice the states for structures and autonomies as a measure are as follows.

Name: flat fusion

Problem: providing the decision maker with a set of alternative decisions

Solution: solving the problems, to which the decision maker has to find solutions in the current situation, as a constraint satisfaction problem

Initial source: operational context

Target source: a knowledge source fusing operational context and the set of alternatives

Autonomy pre-states:	<i>initial source</i>	<i>target source</i>
	non-autonomous	n/a*

Result in CADSS: a new knowledge source of a new type

Result in ontology terms: a new knowledge source representing the result of fusion of the dynamic ontology with the set of alternative decisions

Post-states:	<i>initial source</i>	<i>target source</i>
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Structure:	changed	n/a
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Autonomy:	n/a	autonomous
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Schematic representation: Fig. 2

Phase of CADSS functioning: generation of a set of alternative decisions

* n/a means the source does not exist

Fig. 1. Flat fusion

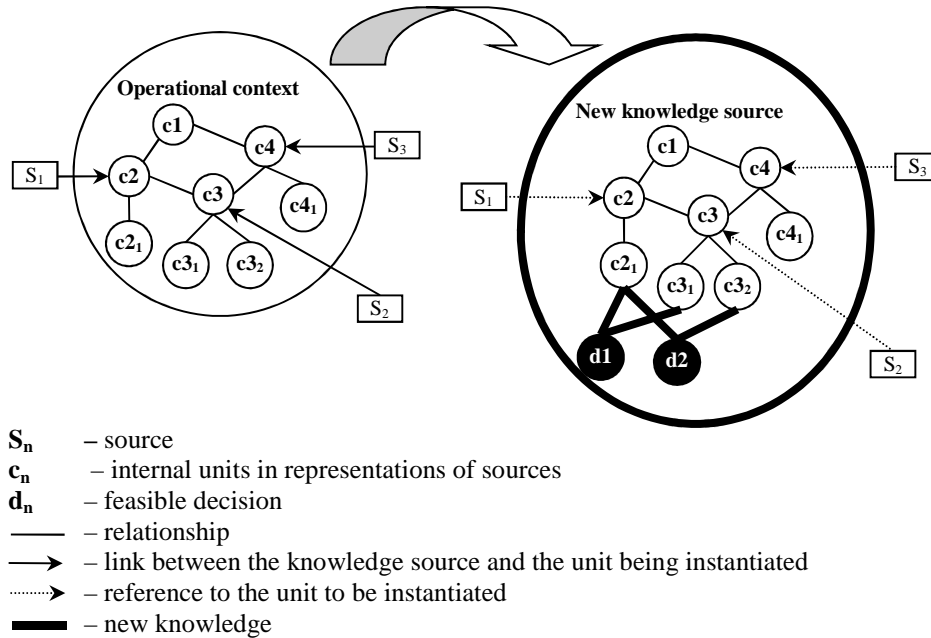


Fig. 2. Flat fusion: schematic representation

Knowledge fusion involves multiple sources in the integration processes. In the context-aware systems integration of data/information/knowledge refers to the process of integration of their conceptual structures. Therefore, source's structure is an obligatory concept taken into account by the integration.

Autonomy creates awareness of the reliability of data/information/knowledge represented in the sources. The CADSS operates in dynamic environments. Information and knowledge represented in the environmental sources that are related to the internal system sources (i.e., the environmental sources and system ones are non-autonomous) are considered to be more reliable than information/knowledge represented in the autonomous environmental sources. An argument in favor of this is any changes in the linked (non-autonomous) environmental sources are reflected in the system sources.

An example of patterns specification is given in Fig. 1; a schematic representation in Fig. 2. Flat fusion pattern is used in this example.

5 Knowledge Fusion Patterns for Situation Detection

Within IMSK, the domain modeling and knowledge representation is based on ontologies [12]. They are used as the core representation paradigm and formalism. The knowledge representation for the fusion module includes two main categories of knowledge: (1) knowledge specifying fusion tasks and (2) knowledge forming the input for these fusion tasks. The fusion tasks to be supported are attribute and

observation fusion, critical situation recognition and event correlation. In this paper, we will focus on situation recognition and the attribute and observation fusion forming the basis for it. An ontology-based formalization of the situation model is available in [12].

Within the attribute fusion, the different features acquired through the various sensors of IMSK are combined so to determine the identity of the objects and entities taking part of the external situation. As opposed to kinematic information (i.e. position, velocity and acceleration), attribute information provide descriptive information about an entity's characteristic or quality. The ID-tag, color, width or acoustic signature on an entity all make plausible attributes. Attributes are, by many means, useful within systems such as IMSK. In crowded spaces, attributes can facilitate a tracker to associate observations to correct tracks. A rich set of attributes can also support in the situational- and behavioral analysis, e.g. by determining the identity of entities, by establishing their relations, and by indicating odd attribute combinations.

The aim of the attribute fusion module is to build a more precise and complete description of the entities taking part in an observed situation. This is made by continuously trying to extend and refine the flora of attributes associated with each entity. For this task, we use heterogeneous sensors and take advantage on their different qualities and the kind of attributes they can deliver. During the situation fusion phase, the focus is on the relations that exist between these different entities. Finding these relations allow having a more coherent representation of the ongoing situation. The representation goes from a set of observed entities to a structured observed situation in which the previous entities take part, with specific roles. When two observations (at least partially) overly, the information fusion sub-processes builds an unique view of the observed object or situation from them. The fusion phase confronts several points of view on the state of an object or a situation. This confrontation leads to a conflict resolution phase. A major stake of information fusion is to automate the conflict resolution phase.

Fig. 3 describes the general information flow used for situation recognition. IMSK smart sensors, fusion modules and open information sources provide information which are captured in observation graphs based on the domain model. These graphs are used for observation fusion and create fused observation graphs. The observation graphs are the basis of situation recognition, which essentially is based on comparison with a-priori defined models of critical situations. In case a critical situation is detected, alerts are generated in the command & control system.

When investigating the use of knowledge fusion patterns for situation recognition in IMSK, the following process was used: we first matched the decision support process forming the ground for knowledge fusion patterns onto the situation recognition flow in IMSK. Afterwards the matching phases were investigated in more detail in order to identify potentially suitable patterns. The potentially suitable patterns then were mapped onto the IMSK ontology in order to finally decide on applicability.

The first step, mapping the decision support process on the situation recognition flow, showed a principal difference in the approaches. IMSK did not explicitly use an abstract context which was adapted and configured for the actual operative situation but rather applied the same application ontology, which was configured for the

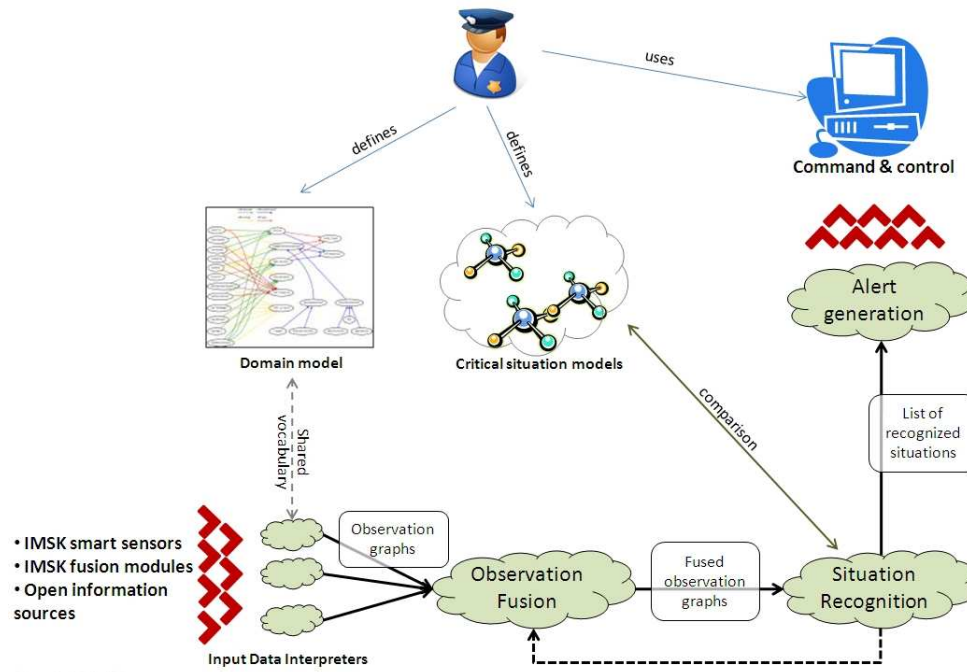


Fig. 3. General information flow for situation recognition

application case under consideration by instantiating it. Although the approaches have similarities, the fundamental difference is that structural changes and extensions as supported by the knowledge fusion patterns addressing the process flow in adapting the abstract context (abstract context creation, refinement and reuse) are not applicable. It should be noted that the use of “context” from decision support systems in IMSK is appropriate, since both event correlation and situation recognition depend on the actual situation of an entity (e.g. the access control sub-systems for the EU-summit).

The knowledge fusion patterns defined for the “operative” part of the decision support system process could be applied even for IMSK. An example is the “flat fusion” pattern presented in section 4. This pattern would be used to create a list of critical situations based on the representation of observations in the knowledge base. In DSS, flat fusion creates a list of feasible solutions for a decision problem. In situation recognition, this “feasible solution” correspond to possible situations.

Other knowledge fusion patterns considered as useful and pertinent for the situation recognition scenario are “instantiated fusion” (for creating a real-time representation of the current situation based on the observations), “historical fusion” (for creating new knowledge based on archived previous critical situations) and “adaptation” (for adaptation of the knowledge base to the detected situation). Fig. 4 gives an overview to the fusion process and usable knowledge fusion patterns in IMSK.

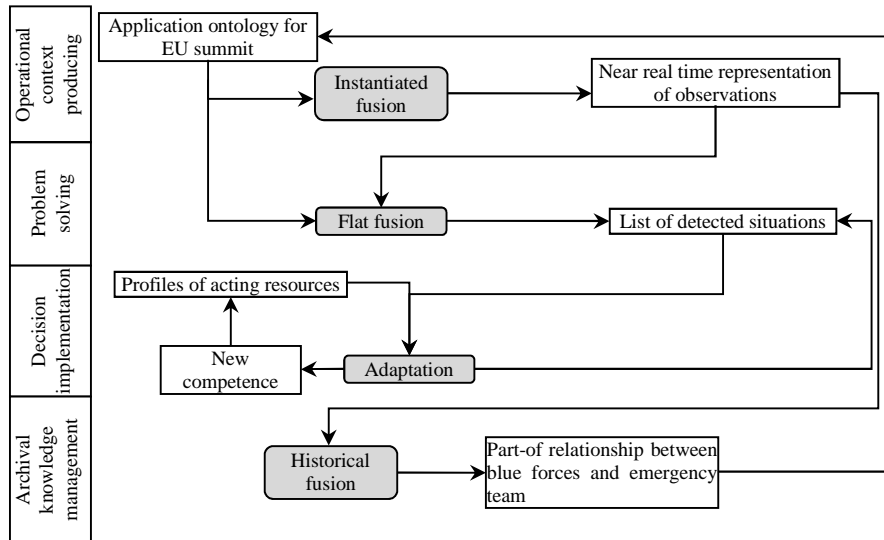


Fig. 4. Usage of knowledge fusion patterns for planning fire response actions

In addition to the use of KF (knowledge fusion) patterns in the knowledge fusion process, we also investigated possible knowledge fusion results [13 – 23]. Potential results enhancing the knowledge base are:

- new knowledge created from data/information. Such knowledge represents information having been processed, organized or structured in a way that may be used by systems and humans as the basis for problem solving and decision making;
- a new type of knowledge. This result means integration of such knowledge that the outcome is knowledge of a radically new type;
- a new knowledge about the conceptual scheme. This result concerns changes in schemes formally representing knowledge. New relations, concepts, properties, etc. appearing in existing schemes are examples of new knowledge;
- a new problem solving method or a new idea how to solve the problem. This is the result of reuse and combining existing knowledge in new scenarios;
- new capabilities/competencies of a unit (a unit that produces or contains knowledge). Like the item above, the new capabilities/competencies are the result of reuse and combining existing knowledge in new scenarios;
- a solution for the problem. This outcome means integration of knowledge from various sources in problem solving, which results to a problem solution;
- a new knowledge source created from multiple sources. This result is a generalization of different knowledge fusion results. It implies origination of a new source to represent the new knowledge.

6 Summary and Future Work

The paper investigated the possibility of KF pattern use in situation recognition using the example of civil security from the IMSK project. The main result was that four KF patterns from the operative part of the knowledge fusion process were found applicable and useful. Based on this insight, we recommend that future projects aiming at the development of knowledge fusion systems for situation recognition should take these patterns into account. We expect this to speed up the construction process of the domain model and the knowledge base. Another result of this investigation is that KF patterns designed for DSS at least on the conceptual level can be transferred to another knowledge fusion purpose: situation recognition.

The main limitation of the research presented here is that it stays on a conceptual level. It would be worthwhile and interesting to develop an actual knowledge fusion solution for situation recognition based on KF patterns. During this development process, the efforts spend would have to be documented and compared to other projects in order to validate whether pattern use really saves efforts.

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