crowd^{SA} –
Crowdsourced Situation Awareness for Crisis Management[1]

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Abstract

With the enormous rise of social media and ubiquitous mobile access, crowdsourcing applications, where the *"wisdom of the crowd"* helps solving intricate problems, became more and more popular. The tremendous potential of crowdsourcing has been also recognized for emergency and crisis situations by employing *"citizens as sensors"*, allowing *enhance situation awareness* of both, authorities and citizens themselves. So far, crowdsourcing has been mainly used for simple collection and dissemination of crisis information without providing smart processing facilities in order to incorporate crowdsourced information into already existing situational pictures. Going one step further, the goal of our research project *crowd^{SA} (Crowdsourced Situation Awareness)* is to *leverage situation awareness in crisis management* by *enriching situational crisis pictures* assessed on basis of conventional information sources with intelligently sensed crowdsourced information in a *comprehensively traceable manner*. This paper lays out out the vision of *crowd^{SA}* in terms of research goals and associated challenges, extensively discusses related approaches for tackling the challenges and finally sketches out a first system architecture for *crowd^{SA}*.

1 Introduction

With the rapid rise in the popularity of social media (800M+ Facebook users, 400M+ Twitter users) and the emergence of ubiquitous mobile access (5,6B+ mobile phone users)[2], the sharing of observations and opinions has become common-place (2.7B+ Facebook likes/comments per day, 200M+ tweets)[3]. This enables unprecedented access to these social perceptions and the ability for analytics to support a variety of intelligent crowdsourcing applications where the *"wisdom of the*

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[2] http://www.socialbakers.com – in Austria, about 2,7 Mio Facebook users and 80.000 Twitter users
[3] http://thesocialskinny.com/100-more-social-media-statistics-for-2012

crowd" helps solving intricate problems [Naga11]. The spectrum of applications is enormous, ranging from brand tracking and trend forecasting via competitor analysis, opinion mining, and image classification, to event detection and crisis management [Doa11].

Crowdsourcing has been recognized as having a tremendous potential in emergency and crisis situations caused by humans (e.g., mass panic), infrastructure (e.g., power failures), environment (e.g., floods), or a combination thereof, being often characterized by hard predictability, abrupt occurrence, long duration, and wide-area affects [Whit10, Reut12]. Basing on the *"citizens as sensors"* metaphor, the crowd is able to provide – at a micro-level, from various perspectives – either completely new crisis information (e.g., observations, estimations, advices, requests) or evidence for corroborating, extenuating, or disproving existing information [Meie11]. Thus, benefits arise during (i) the pre-crisis phase by detecting unexpected or unusual incidents, possibly ahead of official communications, (ii) the in-crisis phase, by providing rapid information on the evolution of the crisis (e.g., impacts and causes), not available elsewhere due to damaged or simply non-available infrastructures (e.g., sensors), and finally (iii) the post-crisis phase, by enabling some kind of feedback-loop, i.e., performing forensic analysis of crowdsourced crisis information [Came12]. Overall, there is a considerable opportunity in increasing situational awareness of authorities and the preparedness of affected citizens in turn, by sensing, analyzing and aggregating crowdsourced information [Reut12]. This is not least since citizens are an authentic source of crisis information, being intrinsically motivated to contribute, turning community knowledge into emergency intelligence [Pale07].

So far, however, crowdsourcing has been mainly used for simple collection and dissemination of crisis information without providing smart processing facilities to incorporate crowdsourced information into existing situational pictures. Going one step further, the goal of our research project *crowd^{SA} (Crowdsourced Situation Awareness)* is to *leverage situation awareness in crisis management* by *enriching situational crisis pictures* assessed on basis of conventional information sources with intelligently sensed crowdsourced information in a *comprehensively traceable manner*. Crowd^{SA} will build on the results gained in the realm of two of our other reseearch projects, *BeAware*! [BeAw12] and *CSI* [CSI12], [Baum10a], [Baum10b], [Baum12]. These projects focus on proposing a *generic, ontology-driven framework* that supports the development of *situation awareness applications* based on diverse *structured data sources*, facilitating their *perception* and *comprehension* as well as *projection* of possible future situations (cf. Figure 1). crowd^{SA} should complement these efforts by adding appropriate concepts and mechanisms for dealing also with mainly *unstructured* and partly *untargeted content*, stemming from the crowd as well as allowing to *communicate* relevant *situational information to the crowd*.

This paper lays out the vision of crowd^{SA} in terms of research goals and challenges (Section 2), extensively discusses related approaches for tackling these challenges (Section 3) and sketches out a first system architecture for crowd^{SA} (Section 4) and an outlook on future work (Section 5).

2 Research Goals and Challenges of crowd^{SA}

In the following, the vision of crowd^{SA} is detailed in terms of three research goals and associated challenges and illustrated in Figure 1, depicting a first conceptual architecture.

Intelligent Sensing of Crowdsources. The first key research goal of crowd^{SA} – intelligent sensing of crowdsourced crisis information provided by diverse social media channels (notably Facebook and Twitter at a first stage) – leads to the following main challenges.

Sensor Adapters & Tuning. First, adapters are required to realize access to social media channels and to cope with heterogeneity of resulting formats. At the same time, tuning mechanisms are necessary,

for adjusting the sensing[4] of crisis information, supporting the determination of information need (i.e., search terms or concrete questions) as well as checks for relevancy of retrieved results.
Knowledge-based Extraction. Second, the unstructured content (retrieved besides structured metadata) has to be transformed into a structured format, going beyond conventional text processing. Also, crisis ontologies have to be established in order to give "meaning" to the information parts extracted, resulting together with the metadata in so-called crisis objects.

Adequate Enrichment of Situational Pictures. The second goal targets the adequate enrichment of situational pictures with crisis objects and poses the following challenges.
Quality Analysis of Crisis Objects. First, quality analysis is one cornerstone for the acceptance of crowdsourcing in crisis management [Meie11], covering both, validity (aka. accuracy), i.e., the potential truth of observations and orthogonally, reliability (aka. precision), i.e., the degree of consistency between observations over time.
Fusion & Injection of Crisis Objects. Second, the steady stream of information from different channels and users, covering different (complementing, overlapping, or contradictory) perspectives, locations, and evolution stages has to be fused appropriately and injected into the existing situational picture either by extending already assessed critical situations or by instantiating new ones.

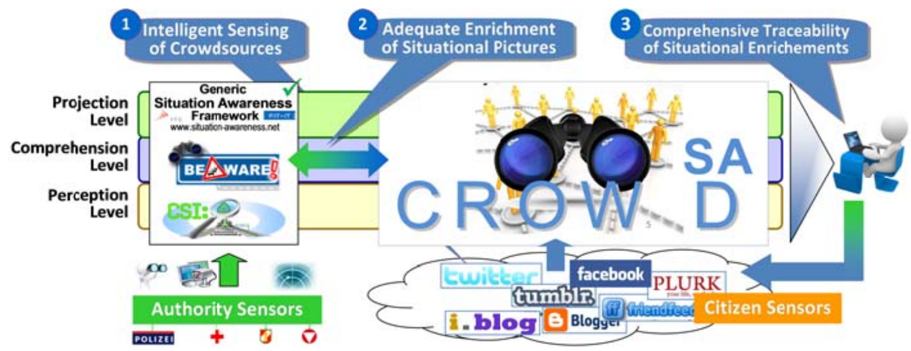

Figure 1: Conceptual Architecture and Key Research Goals of crowd^{SA}

Comprehensive Traceability of Situational Enrichments. The last goal deals with comprehensive traceability of situational enrichments, being the second crucial cornerstone for acceptance of crowdsourcing and thus raising the following challenges.

Provenance Representation & Visualization. First, authorities and citizens should be empowered to scrutinize each part of a situational picture by tracking back its origin all the way down to the social media it stems from, requiring proper representation/visualization of this provenance information.

Oblivious Provenance Generation. Second, for gathering provenance information covering all processing steps across the three levels of situation awareness while leaving them untouched, oblivious provenance generation techniques should be provided.

3 State-of-the-Art

This section discusses, first of all, systems realizing crowdsourced situation awareness for crisis management, before considering further related work along our three research goals, relevant for the

[4] Note that the term "sensing" used should not be mixed up with the term "citizen sensor", whose observations are in fact sensed now. In context of social media monitoring tools, these sensors are also referred to as "listening grid" [Stav12].

challenges targeted in crowd^{SA}. For this, not only concurrent approaches are considered, factoring out the differences to crowd^{SA}, but also complementary ones which could serve as valuable input.

1.2.1 Crowdsourcing Systems for Crisis Management

Although crowdsourcing has been acknowledged in crisis management research and practice, there are currently only few dedicated prototypes available. The system Twitris+ [Naga11], e.g., allows collecting data about a crisis from Twitter (using the twitter search API[5]) and SMS (using Ushahidi[6]). For identifying keywords, "Google Insights for Search"[7] is employed, which compares search volume patterns across specific regions, categories, time frames, and properties. Extraction is done along spatial, temporal, thematic, and sentiment dimensions based on machine learning (ML) techniques and background knowledge. Extracted results can be browsed along the 'when', 'where', and 'what' dimensions, including also widgets for related posts, news, and referenced (Wikipedia) articles. The system ESA-AWTM (Emergency Situation Awareness – Automated Web Text Mining) [Came12] extracts Twitter messages and allows to determine their relevancy based on ML, demonstrated for infrastructure damages from an earthquake. Messages can be visually clustered and de-clustered over time according to similarity of content and forensically analysed, going visually back and forth in time. SensePlace2 [Mace11] provides a simple query panel for retrieving Twitter messages and extracting people and locations, together with a corresponding tweet list, a map showing tweet locations and a history view. The system eStoryS (emergency Storyboard System) [Bell10] is a web mashup for helping people and professionals to create, retrieve, and share information about disasters. It employs the Flickr API[8] to retrieve pictures from its database and arranges them on a map, exploiting the Google Maps API[9]. The system TED (Twitter Earthquake Detector) [Guy10] scans Twitter for previously defined crisis-relevant hashtags, thus requiring intentionally contributing citizens. Relevant tweets are visualized on a map and archived, in order to close the gap of about 20 min¬utes between the first quake and the publication of scientific data.

Summary. The systems discussed focus on situation awareness at the perception level, providing first ideas for information extraction from social media and sensor tuning which could be worthwhile for crowd^{SA}. A further focus is on visual means to facilitate at least the manual comprehension of the provided information by humans using, e.g., visual clustering. There are, however, neither mechanisms for quality analysis, fusion, or traceability nor for automatically assessing or forecasting critical situations.

1.2.2 Intelligent Sensing of Crowdsources

Sensor Adapters & Tuning. The mere access to social media in order to retrieve crowdsourced information is already facilitated, since today's social media use similar technologies for their API's, e.g., HTTP, OAuth[10], and JSON[11], thereby resolving technical heterogeneity [Kaps12]. Basing on these API's, there are a plethora of search engines, either for dedicated social media such as Twitter (e.g., Monitter[12]), or in terms of meta-search engines for various social media like SocialMention[13]. They feature mainly keyword-based, faceted search options that allow analysing what is being said about a subject within unstructured content and sometimes also retrieve structured metadata comprising spatial, temporal, thematic, profile, and attention aspects (e.g., likes). Besides that, there are push-based approaches in terms of social media alerting tools, e.g., BackType[14], allowing automatic alerting as soon as certain pre-defined keywords occur. To cope also with heterogeneity of data retrieved from social media, transformation frameworks in the area of semantic web emerged

[5] https://dev.twitter.com/docs
[6] http://ushahidi.com
[7] http://www.google.com/insights/search/?hl=en-US
[8] http://www.flickr.com/services/api
[9] https://developers.google.com/maps
[10] http://oauth.net
[11] http://www.json.org
[12] http://monitter.com/
[13] http://www.socialmention.com/
[14] http://www.backtype.com/home/alerts

such as Virtuoso[15], allowing to plug in access components for various data sources and to homogenize retrieval results.

For determining the information need, it is of paramount importance to understand the nature of crowdsourced information available in social media during a crisis [Reut12]. Studies analysed, e.g., the geographical distribution of users around the trouble spot, their group membership (individual person, organization, journalist, activist, etc.), their daily social media activity, the number of messages per user as well as responding/forwarded messages and broadcasts. It was shown, that social media experience in a crisis differs from everyday usage [Star12]: Twitterers assume the role of classical media in terms of broadcasting if situational information is not satisfactory and digital volunteers act as information brokers, who collect information from various valid sources, and pass it on [Sutt10]. Additionally, information categories in Twitter messages where detected, used to describe aspects of crisis situations containing location and situation update information [View10].

Knowledge-based Extraction. Conventional, e.g., NLP-based text extraction techniques need to cope with the peculiarities of blog and microblog messages [Naga09]. These include conventions and conversational practices like abbreviations, shortened URLs, user names, hashtags, mentions (depicted by @), improper grammar, lack of context, or re-tweets which could create a statistically significant bias in the corpus to be processed [Naga11], [Feil12]. Therefore, there are first enhanced statistical and learning techniques available that utilize background knowledge and text processing with spatio-temporal-thematic bias [Naga11]. Furthermore, as already mentioned, a particular hashtag-syntax for tweets during crises has been proposed for intentionally contributing citizens, thus alleviating extraction [View2010, Guy2010]. Complementing these techniques, there are already several crisis ontologies available, e.g., for natural disasters in general [Chou11] or forest fire risk management[16], floods and environmental impacts[17] in particular, as well as a metamodel for common properties of crisis situations (i.e., affected environment, treatment, and crisis itself) [Bena08]. Finally, there exist an XML-based messaging standard for sharing emergency information – EDXL (Emergency Data Exchange Language)[18] and a standard ontology for semantic sensors [Comp12].

Summary. Summarizing, besides the mere access to social media channels and the homogenization of retrieved results, there are no dedicated approaches for determining information need and relevancy, except valuable research on the nature of usage of social media during a crisis. There are already first approaches available providing extraction techniques dealing with the peculiarities of microblogs, as well as diverse crisis ontologies which could be valuable input for crowd^{SA}.

1.2.3 Adequate Enrichment of Situational Pictures

Quality Analysis of Crisis Objects. Although there already exist numerous automatic approaches in order to evaluate reliability, trust, influence, and reputation of users delivering crowdsourced information in different domains (cf., e.g., [Doan11]), these are not directly applicable to the domain of crisis management. In crisis management, even data whose reliability and/or validity cannot be determined (as long as this fact is explicitly annotated) can be more useful than having no data at all, especially in an early warning phase, drawing attention to a possible crisis situation. The particular utilization of such information is a question of tolerance for uncertainty, whereby different authorities may have varying levels of tolerance depending on mandate, situation, time, and place [Meie12]. Studies have shown [View08] that false information is prevented from being spread by the collective intelligence of users, who ensure that faulty information is corrected. This means also, that following the principle of the wisdom of the crowd, crowdsourced information becomes more reliable if it stems from different users eventually also through different social media. In this context, re-tweets serve as an evaluation mechanism for important information [Star10]. A mix of strategies to verify

[15] http://virtuoso.openlinksw.com/
[16] http://www.semsorgrid4env.eu/index.php/ontologies/12-fire-ontology-network
[17] http://wsmls.googlecode.com/svn/trunk/local/water/0.4/flood.html
[18] https://www.oasis-open.org/committees/tc_home.php?wg_abbrev=emergency#technical

crowdsourced information is presented in [Meie12] and illustrated in a case study on different verification strategies.

Fusion & Injection of Crisis Objects. A first initial step towards tackling this challenge is undertaken by the plethora of about 200 social media monitoring tools, e.g., Alterian-SM2[19] (cf. [Stav12] for an overview), by tracking certain information over time, thus going beyond one-shot information gathering of social media search and alerting tools. In addition, instead of mere keyword search, they often use at least simple extraction techniques such as sentiment analysis. Furthermore, duplicate detection methods are crucial for fusing crisis objects to explore whether information having, e.g., different origins or reporting times, concern one and the same real-world incident. Especially relevant are approaches able to deal with qualitative data, since citizens are often unable to provide reliable numerical values, making crisis information often highly dynamic and vague. Relevant related work can be found in the areas of geospatial database and moving object trajectories [Baum10b], emphasizing the importance of appropriate similarity measures [Schw08]. Most of the existing work, however, focus on similarity in Euclidian space, only (whereas in our domain graphs, such as road networks, power lines, and communication networks, are heavily used to describe spatial information, too), and lack support for qualitative spatio-temporal information [Baum10b].

Summary. Summarizing, quality analysis of crowdsourced crisis information is still in its infancy, although proposals, such as those of [Meie12] represent a promising starting point for crowd^{SA}. Despite the numerous social media monitoring and duplicate detection approaches, they neither focus on the peculiarities of the crisis domain nor do they consider further processing in terms of enhancing situation awareness. To the best of our knowledge, injection of crowdsources into situational pictures has not been dealt with in literature, although there are valuable approaches available for semantically aggregating sensor data, e.g., [Hens12].

1.2.4 Comprehensive Traceability of Situational Enrichments

Provenance Representation & Visualization. Research on the representation of provenance information [Shet11] primarily focus either on coarse-grained, workflow-oriented approaches, i.e., tracking the process of creating an artifact, or on fine-grained, data-oriented approaches, i.e., tracking from which source elements an artifact has been computed [Tisi09], or on approaches dealing with access and usage of artifacts [Hart09]. The Open Provenance Model (OPM) [More08], e.g., is a generic representation for exchanging provenance information between heterogeneous systems and focuses mainly on workflow provenance. Concerning visualization of provenance information and its retrieval, only few approaches have been published which go beyond simple provenance queries, although it is acknowledged that the amount of information provided by a single provenance query is in general overwhelming for users [Kund10]. Promising approaches are, however, dependency graphs [Davi07] presenting the history of data and based on that, user views for further reducing the information overload [Bito08].

Oblivious Generation. In the domain of crisis management, logging origin and usage of crisis information in an incident log is most often done manually by a so-called “watch officer”, a person at the front line of information processing during a crisis [Came12]. Concerning oblivious generation of provenance information as envisioned in crowd^{SA}, database research has contributed a lot [Tan07], proposing inverse queries and query rewriting, thus generating additional annotation information. In the field of model-driven engineering, Higher-Order Transformations (HOTs) [Tisi09] are used to enhance existing transformations with tracing information between input elements, transformation rules, and output elements.

Summary. Summarizing, we lack an exhaustive provenance model, which comprises all aspects relevant for comprehensive traceability of enriched situations in crisis management and we miss automatic, oblivious generation of provenance information, which has been in prior research only

[19] http://www.alterian.com

discussed for a limited set of query operators. Nevertheless, existing approaches in this area form a proper basis on which the goals followed by crowd^{SA} can build upon.

4 System Architecture of crowd^{SA}

The proposed architecture of crowd^{SA}, which is depicted in Fig. 2, consists of three functional core components for realizing our three key research goals. First, the *CrowdSensor* component is responsible for intelligently sensing relevant crisis information from various social media channels and building up structured, so-called crisis objects. Second, the *SituationEnricher* enhances a situational picture with quality-checked and fused crisis objects, which can be also fed back to the channels to increase preparedness of the crowd. Finally, the *SituationTracer* is a crosscutting component through all three levels of situation awareness, which tracks each part of an assessed or projected critical situation back to its origin. All three functional components interact with the existing BeAware!/CSI prototype via the situational knowledge base. Besides these functional components, there are two further central building blocks. First, the situational knowledge base, which represents the pivotal interface between the existing BeAware!/CSI prototype and crowd^{SA}, contains not only the already developed situation awareness ontology (*SAOntology*, [Baum10a]) and the *StructuredSourceOntologies*, but also the newly to be developed *SocialMediaChannelOntologies*, the *CrisisOntologies*, and the *ProvenanceOntology*. Second, following the philosophy of BeAware!/CSI, the functional components of crowd^{SA} are generic in nature, thus requiring a configuration building block allowing adaptation of the system at each situation awareness level to the requirements at hand (e.g., incorporation of new social media channels or definition of new relevant critical situations).

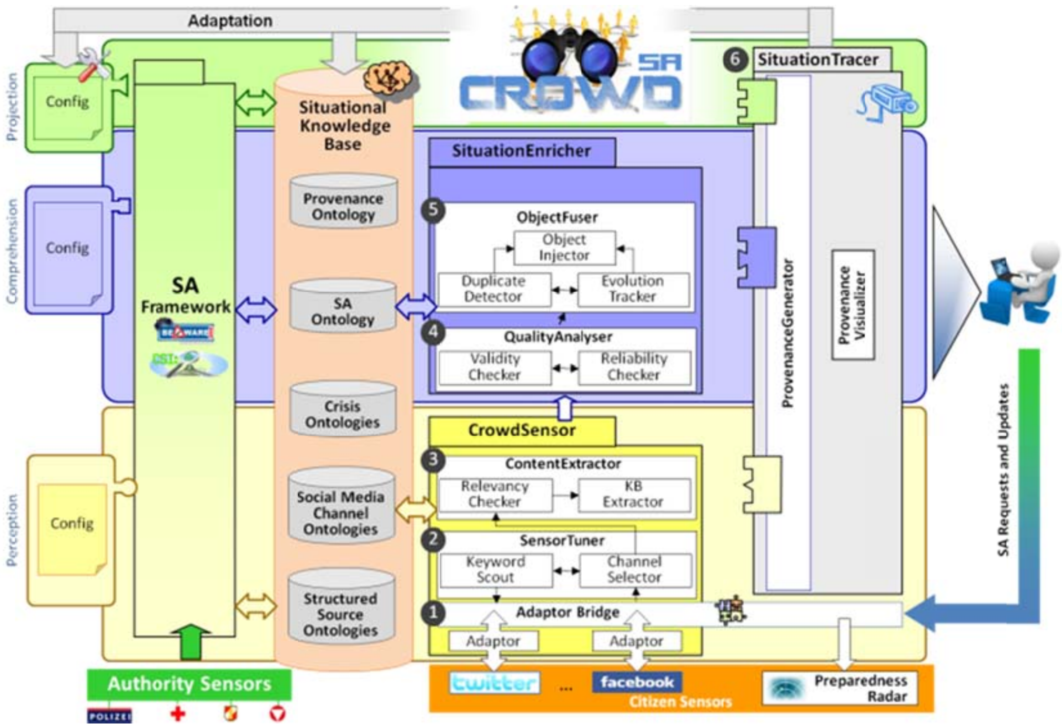

Figure 2: Overall System Architecture

In this respect, for continuously optimizing and improving the situation awareness capabilities of crowd^{SA}, an adaptation feedback loop is foreseen, thereby explicitly using the information tracked by the *SituationTracer* facility.

5 Conclusion

This paper proposed the vision of using crowdsourced information in order to enhance situation awareness in crisis management, discussing research goals and challenges, related approaches as well a first system architecture. Future work will focus on extracting crisis-relevant information from social networks and developing techniques in order to evaluate relevancy and quality thereof.

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