Fire Alerts on the Geospatial Semantic Web

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Abstract. CSIR is a South African research institution with broad and extensive experience in the domain of fire, ranging from policy work to basic research into fire and ecology. One of the more visible fire-related applications that CSIR has been involved in is known as the Advanced Fire Information System (AFIS), a joint initiative with Eskom, the South African electricity utility. The application utilises results from remotely sensed data to infer fire occurrence and trigger alarms to Eskom operators based on proximity of fire events to Eskom infrastructure, notably transmission lines and towers.
This paper describes the Meraka Institute (African Advanced Institute for ICT – a National Research Centre affiliated with CSIR) view of the future of AFIS. Meraka intends to migrate AFIS from a narrowly focussed, 'black-box' application to one servicing users in multiple fire-related scenarios. Future AFIS versions would be based on an open framework of geospatial web services, ontologies and software agents. We aim to draw upon the deep organisational knowledge of fire and fire processes that is held by CSIR and its partners to produce a system that can supply highly tuned, meaningful and customised fire alerts to users. We hope to evolve AFIS from a single use application into an agent-based platform enabling rapid development and deployment of new fire-related applications through concept-based queries of data and knowledge repositories. We believe that AFIS is representative of the evolution that many geospatial applications on the web may have to follow, from being tightly coupled, software dependent applications, through being loosely-coupled, web service and standards-oriented applications to a point where they provide geo-information to the semantic web.

Keywords wild fire, monitoring, service-oriented architecture, geo-information, sensor web enablement, ontologies

1 Introduction

1.1 Background

In southern Africa, fire is perceived ambiguously. There is a tension between fire as a crucial process in certain ecosystems and fire events as a threat to infrastructure and life. In both cases though, spatio-temporal awareness of fire likelihood, fire occurrence and fire behaviour is key to appropriate intervention.

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1.2 Intentions

This paper describes the Meraka Institute (African Advanced Institute for ICT – a National Research Centre affiliated with CSIR) view of the future of AFIS. Meraka intends to migrate AFIS from a narrowly focussed, 'black-box' application to one servicing users in multiple fire-related scenarios. Future AFIS versions would be based on an open framework of geospatial web services, ontologies and software agents. We aim to draw upon the deep organisational knowledge of fire and fire processes that is held by CSIR and its partners to build a system that can supply highly tuned, meaningful and customised fire information to users. We present AFIS as representative of the evolution that many geospatial applications on the web may have to follow, from being tightly coupled, software dependent applications, through acting as loosely-coupled, web service and standards-oriented applications to a point where they provide geo-information of different kinds to the semantic web.

1.3 Structure

This paper will discuss the current AFIS architecture and use cases before describing our view of a web-service oriented AFIS as a precursor to a semantically rich, configurable, agent-based decision-support framework. We describe this as a flow from geo-information dead-ends through to a point where geo-knowledge is easily available, retrievable and re-usable. We wish to present ideas on where we believe ontological representation of geo-information may be beneficial in forthcoming AFIS versions, with particular reference to the web service interface layer. We show that the process of semantically enriching the service-oriented architecture followed by the eventual implementation of AFIS as an ontology-driven agent-based system, provides a possible pattern for similar semantic enrichment of other applications currently using closed/service-oriented GIS systems.

2 AFIS 1: Geo-Information Dead-End

AFIS 1 is an example of the kind of system Chang and Park (2006) describe as a complete Internet-GIS application. It is complete in that a large proportion of the application logic, data and server components exist on a single machine, dependent on the software architecture of a single commercial vendor. It is a strongly use-case bound system and even when distributed data is utilised, these data are poorly described and the interpretation of them is hard-coded into the system.

AFIS 1 has a simple set of use cases: it is required to alert users to the existence of fire events near to infrastructure; it needs to archive fire events; and it needs to allow access to this archive for web-based query and retrieval of fire event information. Data from two kinds of remote sensors are used for fire detection. AFIS 1 assumes that a fire event exists if a "hotspot" is observed. Hotspots are pixels that appear with a higher temperature relative to their neighbouring pixels. The MODIS instrument on the Aqua and Terra platforms provides hotspot detection at approximately six-hourly intervals at a scale of roughly one hectare. The SEVERI sensor aboard Meteosat-8 provides a high temporal resolution (fifteen minute) for hotspot detection, but coarse spatial resolution (five hectare). MODIS and SEVERI specific algorithms are deployed at the ground receiving station to extract hotspots. Their deployment is 'black-box': data from the sensors comes in, processing takes place and hotspots are generated into text files. Each hotspot record contains positional, time and other attributes.

The first use case is executed – SMS alerts are generated off these hotspots and sent to appropriate users. The files are sent via FTP to hotspot client machines. One of these machines is responsible for the other AFIS use cases. A software component listens for changes to the FTP directories. When new files are added, the component parses the files and archives the records into an ESRI ArcSDE database according to sensor. These records are then served up to the Internet via an ESRI ArcIMS Image Service. There, fires can be queried and visualised in a spatial context.

Certainly, there can be little complaint about the hardware and software performance of the system. It has remained stable and upright over long periods of time, serving data about thousands of fire events. Issues arise however, if a closer inspection is made of the data generation process.

Firstly, each point in the system relies on the understandings and interpretations of a human – the "coder-in-the-loop" problem. For example, hotspots are generated into a text file with little metadata, certainly none that a machine could process. Second, there is a reliance on a particular software bus to deliver data. Text files are picked up, parsed and entered into ArcSDE by software containing ESRI MapObjects. ArcSDE can be accessed by applications either natively or via adapters, but when data delivery takes place via ArcIMS, one is limited to utilising certain clients to gain access to the data. Interoperability would be better addressed by adherence to open standards based interfaces. Thirdly, and importantly, information arising from the system reaches dead ends.

This stems from the strongly use-case driven nature of the system - it is enough to visualise hotspots in a software client (as part of a map image) or to send off a SMS message to particular clients. Little further value can be extracted from AFIS by other applications, and the components cannot easily be re-used. Human users are the only agents that can make sense of AFIS outputs.

3 AFIS 2 : Networks of Geo-Information

AFIS 2 addresses the issues raised above through its design as a loosely coupled, web services based system, adhering to current and emerging Open Geospatial Consortium (OGC) standards, especially those concerned with Sensor Web Enablement (SWE). Sensor Web Enablement is an OGC initiative that extends the OGC web services framework by providing additional services for integrating web-connected sensors and sensor systems. SWE services are designed to enable discovery of sensor assets and capabilities, access to these resources to allow data retrieval, subscription to alerts, and tasking of sensors to control observations (Botts et al., 2006).

The SWE initiative has developed draft data model specifications for modelling sensors and sensor systems (SensorML), modelling and encoding observations from such systems (Observations and Measurements, Transducer Modelling Language) and describing processing chains to process observations (SensorML) (Botts, 2005, Cox, 2005). The SWE initiative makes strong use of loosely coupled web services in its architecture, creating a framework where sensor-related data can be discovered, explored and accessed. The architecture is designed to create abstraction from the sensors themselves towards generic interfaces that can be consistently understood. SWE provides four types of web services: Sensor Observation Service (SOS) (Na and Priest, 2006), Sensor Alert Service (SAS) (Simonis, 2006), Sensor Planning Service (SPS) (Simonis, 2005) and Web Notification Service (WNS) (Simonis and Wytzisk, 2003).The SOS provides a standard interface that allows users to retrieve raw or processed observations from different sensors, sensor systems and observation archives. The SAS provides a mechanism for posting raw or processed observations from sensors,process chains or other data providers (including a SOS) based on user-specified alert/filter conditions. The WNS provides a standard interface to allow asynchronous communication between users and services and between different services. A WNS is typically used to receive messages from a SAS and to send/receive messages to and from a SPS. The SPS provides a standard interface to sensors and sensor systems and is used to coordinate the collection, processing, archiving and distribution of sensor observations. Discovery of OGC and SWE services is facilitated by the Sensor Web Registry Service - an extended version of the OGC Catalog Service.

These draft specifications provide semantics for constructing machine-readable descriptions of data, encodings and values, and are designed to improve prospects for plug and play sensors, data fusion, common data processing engines, automated discovery of sensors, and utilisation of sensor data (Moodley, et. al., 2006).

The main functions of AFIS 2 can be enumerated as: provide fire alerts, populate a hotspot archive and allow access to the hotspot archive. AFIS will generate fire alerts that are enriched through analysis of supplementary data such as wind stress (direction and speed) and current fire danger index.

Figure 1 illustrates the AFIS 2 cycle. This starts with the corrected data from the MODIS and SEVERI sensors. The corrected data is then passed through several sensor dependent algorithms, which produce hotspots. These hotspot detections or events are advertised at and published to an OGC Sensor Alert Service (SAS), essentially an event pushing service. Consumers interested in hotspots register at the SAS providing subscription parameters including observation filters and thresholds which may be used to focus the alerts to the consumer's needs. In AFIS 2, it is envisaged that hotspots are low level alerts. Further value needs to be added before users of AFIS receive fire alerts. As such, the subscribers to hotspot alerts are archival database feeders and additional processing chains, though end-users could make use of these alerts too.

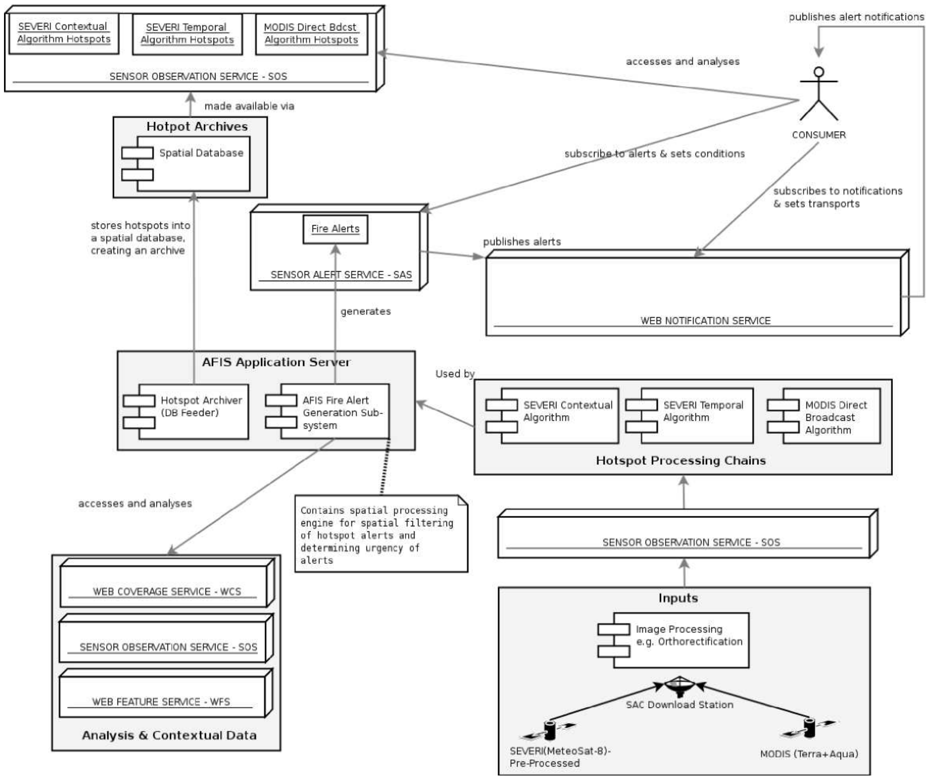

Fig. 1. AFIS SWE concpetual architecture

In AFIS 2 , when hotspots are detected, a database feeder software entity and a fire alert generation entity receive alerts from the SAS. The former is tasked with storing these hotspots into an archival database , which is then exposed to the Internet through an OGC Sensor Observation Service (SOS). This service would allow consumers to explore hotspot history and hotspot attributes in greater detail. Meanwhile, the fire alert generation entity is registered with the SAS, to which end-users subscribe and provide their filter and threshold conditions. The fire alert generation entity then performs contextual and spatial analysis on the hotspots, attaching attributes to hotspots, including wind stress, fire danger index and intersection with features of interest. In the case of an Eskom Employee responsible for a set of transmission lines, the alert filter would state that hotspots within his jurisdiction are of interest, but only if the fire danger index is high, the wind is blowing in the direction of the lines and the hotspot is within 1000 metres of a line. In order to perform these kinds of analysis, the fire alert generation entity consumes data from other OGC services, for example a Web Coverage Service that outputs an updated wind stress surface dataset (generated from a weather station SOS) and a Web Feature Service that contains features of interest. In the Eskom case, features would be transmission lines and towers, as well as jurisdiction areas. The new alert is thus a hotspot alert passed through spatial and contextual analysis chain and enriched with attributes that can be used for filtering and information purposes. The alert is raised at a high level SAS that consumers (including end users) subscribe to. The consumer could also register at a OGC Web Notification Service (WNS), providing details about the medium through which alerts would be received (e.g. SMS). The end user may choose to act on the alert or analyse it further, perhaps even using the SOS that exposes the hotspot database.

The migration to Sensor Web Enabled service-oriented architecture for AFIS makes the current data sources available via standard OGC SWE service model interfaces, and ensures that the data is encoded in the OGC SWE and other data model formats (i.e. O&M, SensorML, GML). This would facilitate the incorporation of AFIS 2 process chains and generated data into a wider network of geo-information, where they would be available for discovery and re-use in other fire-related scenarios. This is a significant departure from AFIS 1, where no concern for re-use was incorporated. An advantage of the service orientation of AFIS is that services may be interchanged. Improved or different algorithms for detecting hotspots can be placed behind a service facade and added to the pool of services that could be utilised by AFIS. AFIS 2 is a move away from using the Internet to serve maps, towards using the Internet to produce knowledge.

4 AFIS 2.x: Towards an Intelligent System

Our current implementation of the service-oriented fire-alerting system still suffers from many of the problems inherent in the “black box” application that we started with. The application is still narrowly focussed on hotspot provision, and any spatial reasoning ability (for instance, the composition of spatial and threshold filter conditions) resides in the hard-coded application logic. However, the use of the SWE services (including the registration of these services with a public registry service) will allow internet users to dynamically discover these information offerings, opening up the possibility of other applications being able to utilize these offering to realize different end-user requirements. Note that the visualization of historical data in a geographic context now involves the convolution of at least two services, namely the WMS and the SOS, because the hotspot data provided by the SOS must be mapped onto an image served by the WMS. This increases the technical complexity required by the client program, but allows for the historical data to be queried and retrieved independently of the final image, removing the need for manual image interrogation, and opening the door to automated geospatial reasoning.

However, despite the information offerings of the services-based AFIS application being available over the internet, the usefulness of such information offerings is debatable, since end-users still face problems when attempting to discover OGC service offerings. Service discovery is done by using one or more OGC Catalog Service (CS-W) instances. These catalogues will contain information harvested from the capabilities document of each registered service. The catalogues in the OWS-3 test bed include the ability to allow catalogue searches based on the phenomena captured by the observations, as well as the GML names and descriptions used in observation offerings (Na and Priest, 2006).

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Problems of semantic heterogeneity can arise with respect to the keywords used in observation offerings or phenomena descriptions (Lutz and Klein, 2006). For example, AFIS may provide a “hotspot” offering, which would not be returned by a query requesting ”fire” information. The integration of SWE services into a semantic service framework allows better matches between requester needs and provider offerings. We would like to provide a “semantically enabled AFIS” by linking the descriptions of the service characteristics to the concepts and processes described by various relevant domain ontologies.

In order to construct our set of fire-related ontologies we would leverage the deep understanding of fire processes as they occur in southern Africa, which is vested in the CSIR, and integrate, where useful, with work that has been undertaken in building fire ontologies elsewhere (e.g. BACAREX - de la Asuncion, et.al., 2005). These ontologies would be grounded by higher ontologies e.g. SUMO (Niles and Pease, 2001) and NASA SWEET (Raskin, 2006) - which will be part of the expanded AFIS application. We are researching OWL-S as a mechanism for the semantic enrichment of the workflows/ processes of our current architecture. Our starting point will be the Sensor Alert Service, which provides basic alerts to users, but is limited in the filters it allows on the advertised alert offerings and relies on end-user interpretation of sparse alert notifications in order to relate the alert back to the original query. We can make this service far more useful (in the AFIS context), by providing a semantically enriched proxy layer to mediate client, sensor and service interaction.

The initial semantic enrichment of the SAS will enhance AFIS usability in the following ways:

1. The advertised alerts will be described such that users interested in fire events can easily determine whether the particular events highlighted by the alert are relevant to them. Hence, the attributes of particular fire events (including wind stress, fire danger index and intersection with features of interest) must be unambiguously and clearly described.
2. Different user profiles will be provided so that clients can subscribe to alerts based on conditions relevant to a particular type of user. These subscriptions will be presented in a way that allows non-expert users of the system to easily construct individually customised alert profiles e.g. A local tower controller will need to be alerted to all fires in his/her area of responsibility, but a national controller will only want to be alerted to fires that pose a significant threat to the national infrastructure or that require reconfiguration of the electricity supply chain.
3. Alert notifications received from the system will contain enough information for the user to respond rapidly and appropriately without needing to map alert identification numbers back to a particular subscription process.

Since the spatial characteristics of fire events are central to the determination of the relevance of the event to an alert subscriber, geosemantic annotation of the service offering will be crucial. This will enable semantically aware applications to become cognisant of the service and use the service and domain ontologies appropriately to reason about fire processes and occurrences.

We note that this semantic SAS is application specific. In order to facilitate data reuse across multiple scenarios, we would need to expose hotspot information before application level processing takes place. Alert-based applications would likely be composed of layered SAS's, with each layer exposing attributes more specific to a given use case. A low level semantic SAS only exposes very generic fire attributes, e.g location, time of detection and brightness temperature. Value could be added at a second level by inserting likely direction of spread and fuel conditions. Application level attributes including proximity to specific infrastructure would reside at a third level semantic SAS. The types of ontologies supporting the attribute descriptions would also become less abstract with each semantic SAS layer. Existing upper ontologies (SWEET, SUMO) would be used to conceptualise location, time and phenomena such as brightness temperature. Mid level ontologies relevant to general properties of vegetation fires would allow us to describe that wind speed and direction, for example, play a crucial role in fire spread behaviour. Domain level ontologies would provide the knowledge detail necessary for describing attributes pertinent to an application. In another vein, the lower level semantic SAS's would be of less interest to end users, but the higher level SAS's would be significantly more useful to them.

5 AFIS 3: Geo-Information on the Semantic Web

The future AFIS application will use an open, web-resident architectural framework currently under development – the Sensor Web Agent Platform (SWAP) (Moodley, et. al., 2006). This framework fuses Web Services with another promising distributed architectural paradigm, namely Multi Agent Systems (MAS). A Multi Agent System includes both the agents and the infrastructure that supports their interactions (Luck, McBurney et al, 2005) ex Moodley & Kinyua 2006) . Some of the architects of SWAP are currently working on a MAS, MASII, that extends the standard architecture defined by the Foundation for Intelligent and Physical Agents (FIPA, 2002). MASII uses the standard components of the FIPA MAS architecture, namely, User Agents (representing end-users), Service Agents (representing service providers), and a Directory Facilitator that allows registration of service agents for discovery by user agents. Both user agents and service agents communicate using ACL, and both may be consumers of non-agent services that can be discovered via a service registry as needed.

In addition to these components, Moodley and Kinyua (2006) propose the introduction of Adaptor Agents. Adapter Agents maintain the ontology infrastructure used within the system, as well as maintaining an application catalogue that contains descriptions of current applications in the MAS. User Agents must periodically access the application catalogue to be aware of changes in the application offerings in the MAS. Each application may have its own specific ACL, ontology(ies) and visualisation tools. Adaptor Agents are responsible for packaging and maintaining these in the form of downloadable user adaptors. These can be downloaded by user agents, installed locally, and presented to the end user as a new application. The SWAP leverages the infrastructure services provided by Multi Agent Systems to deliver new applications to the end-user. One of these applications will be the next-generation AFIS system.

As described in Moodley et al, (2006), the SWAP abstract architecture has a three tiered structure, comprising a Sensor Layer, a Co-ordination Layer and a Decision layer. These are shown in Fig. 2, and can be described, with special reference to the AFIS 3 architecture, as follows:

Sensor agents reside in the Sensor Layer. They encapsulate individual sensors, sensor systems and archived observations. For AFIS, these sensor agents must encapsulate the SEVERI observations off the Meteosat-8 platform. The agents will also serve live or archived versions of these observations. The data from the Meteosat-8 sensor agent then forms the input into the second, Co-ordination layer, via the work flow agent. By reasoning with the application ontologies, the work flow agent determines which inputs are required to satisfy user queries. For AFIS 3, we expect to use a non-contextual hotspot detection algorithm that requires information about the expected background temperature

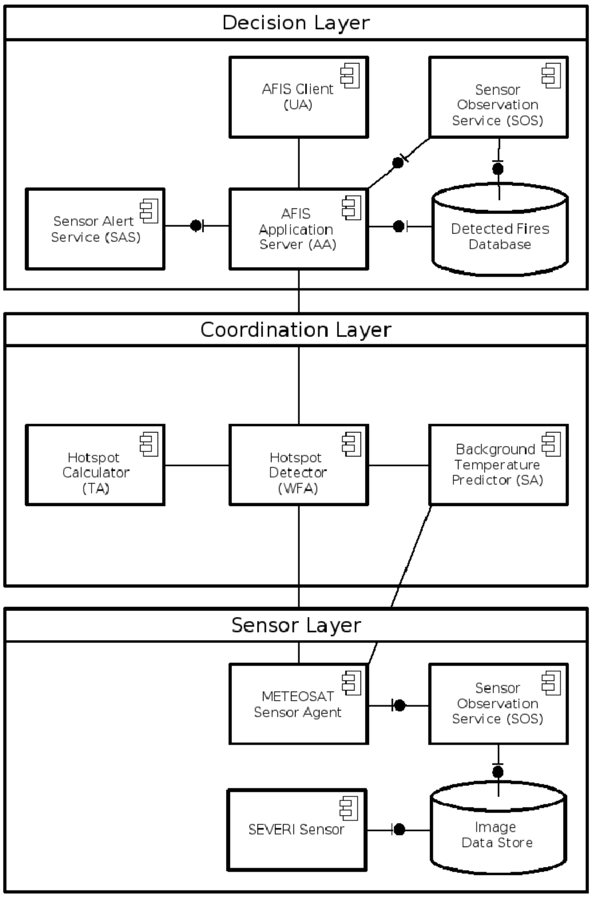

Fig. 2. SWAP AFIS architecture

of a pixel. The work flow agent will therefore, in addition to the sensor data, retrieve the expected background temperature information from a simulation agent, the Background Temperature Predictor. The work flow agent then tasks the tool agent, a Hotspot Detector, to detect hotspots based on the two inputs (i.e. observed and simulated data). The detected hotspots form input from the Co-ordination Layer into the AFIS application agent in the Decision Layer. The Decision Layer also contains the AFIS client, acting as the user agent. The combination of the AFIS application and client agents will allow users access to the full functionality of the AFIS system, including providing the ability to specify alerts in the system.

The various agents that make up the open system are not tightly coupled – the sensor, simulation, tool and work flow agents will be available for use by other applications. Ontologies will provide explicit descriptions of all components within SWAP i.e. sensors and sensor data, simulation models, algorithms, applications, and processing chains. Work flows for combining these components for use by software agents will also be ontologically described (Moodley, et. al., 2006).

A number of research questions must be addressed before SWAP can be fully realised. These include questions relating to the internal model of agents, communication between agents and between agents and non-agent services, message structure and message payload structure, framework for building ontologies, how to handle contradictory knowledge, how to integrate different types of ontologies into the agent paradigm, maintenance of ontologies, data fusion, dynamic configuration of process chains and appropriate agent development framework (ibid.).

Further work would focus on the issues raised by Worboys 2005 and Cole and Hornsby 2005. Alerts can be seen as noteworthy events – happenings or activities requiring intervention; we wish to be able to reason with these events or, in Worboys' terms, occurents. The processes and agents that instigated these occurents and the results (in the form of processes and occurents) of these events are of interest to us. The utility of AFIS could be enhanced if we could, for instance, reason about environmental conditions becoming conducive to particular kinds of fire or about the likely behaviour of a fire that has been detected. This could allow for better preparedness as well as sustained and adaptive management of fire events as they unfold in non-linear fashion (Annoni, et. al., 2005). We need to move beyond feature-based representation of geo-information to a situation where knowledge enriched/contextualised geo-spatial events are but one of the possible types of meaningful content generated by applications such as AFIS.

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