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A service-oriented architecture for ensemble flood forecast from numerical weather prediction

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SUMMARY

Floods in mountainous river basins are generally highly destructive, usually causing enormous losses of lives and property. It is important and necessary to develop an effective flood forecast method to prevent people from suffering flood disasters. This paper proposed a general framework for a service-oriented architecture (SOA) for ensemble flood forecast based on numerical weather prediction (NWP), taking advantage of state-of-the-art technologies, e.g., high-accuracy NWP, high-capacity cloud computing, and an interactive web service. With the predicted rainfall data derived from the NWP, which are automatically downloaded, hydrological models will be driven to run on the cloud. Judging from the simulation results and flood control requirements offered by users, warning information about possible floods will be generated for potential sufferers and then sent to them as soon as possible if needed. Moreover, by using web service in a social network, users can also acquire such information on the clients and make decisions about whether to prepare for possible floods. Along with the real-time updates of the NWP, simulation results will be refreshed in a timely manner, and the latest warning information will always be available to users. From the sample demonstrations, it is concluded that the SOA is a feasible way to develop an effective ensemble flood forecast method. After being put into practice, it would be valuable for preventing or reducing the losses caused by floods in mountainous river basins.

1. Introduction

Mountainous regions, where the natural conditions are extremely complicated, account for nearly two-thirds of the total land area in China. In such regions, high-intensity rainstorms occur frequently during the flood period, which can lead to serious flood disasters and cause enormous losses of lives and property to the inhabitants living in the villages at the riversides or near the outlets of rivers (Caruso et al., 2013; Mazzorana et al., 2013; Ruiz-Villanueva et al., 2013; Shi and Wang, 2015). According to the statistic, there are 29 provinces, 274 prefecture-level cities and 1,836 county-level cities that suffer from flood disasters in China, covering an area of 4.63 million km^2 and involving 0.56 billion people. The key prevention and control area is 0.97 million km^2, involving 0.13 billion people, among which 74 million people suffer a direct threat (Chen, 2010). Specifically, the death toll caused by flash flood disasters accounted for two-thirds of the total death toll caused by all flood disasters every year in China before the 1990s; the percentage has risen to 80% since 2000. Approximately 4,000 people, accounting for 90% of the death toll caused by all flood disasters, were dead or missing in the flash flood disasters in 2010. This indicates that the situation of flood prevention and control will still be severe in the future; more technical and financial support should be provided for these flood-prone regions. Consequently, it is important and necessary to develop an effective flood forecast method to prevent people from having to suffer flood disasters.

Generally, traditional methods for flood forecast include the following two types. The first type comprises those methods based on critical rainfall, including the static and dynamic critical rainfall methods (Carpentera et al., 1999; Georgakakos, 2006; Liu et al., 2010). It is supposed that floods and some secondary disasters (e.g., debris flow and landslide) may occur in a river basin when the rainfall during a certain time interval reaches a certain amount or intensity (i.e., the static critical rainfall). Because the saturated degree of soil or the antecedent precipitation index has an

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important effect on the formation of floods, the critical rainfall should not be constant; thus, the dynamic critical rainfall method has been developed. Overall, the critical rainfall methods are easy to use, with no need for rainfall–runoff calculation; however, they cannot reflect the spatial variation of rainfall, making their applications in flood forecast limited. In contrast, the second type, which is applicable for river basins with sufficient, observed hydrological data, comprises those methods based on critical streamflow computed by using an empirical approach or hydrological models (Liu et al., 2005; Nayak et al., 2005; Cane et al., 2013; Moreno et al., 2013). Comparing simulation results against the flood control requirements, warnings concerning floods can be made early, if needed. Due to its high forecast accuracy, this type of method has been widely used; however, limited by the demand for massive observed data, it seems to be useless for river basins with poor data quality, especially for ungauged river basins.

China has dealt with the task of flood prevention and control for a long time. Moreover, more attention will be paid to floods in the future, and the construction of automatic weather stations, county-level data processing centers and early warning systems will be carried out in the near future. A number of provinces in China have set up their own flood warning systems; however, there are still gaps between the requirements for flood warning and reality. For example, a typical process of a flood warning system below the county level includes several levels (e.g., county, town, village, group and family). The rainfall and hydrological regime is reported to the superior level by level, and the warning information is sent to the inferior level by level as well. Although such a process is in accord with the status quo in China, the lengthy information transmission may considerably affect the efficiency. Thus, it is important and necessary to develop a high-efficiency method for flood forecast.

To this end, this paper aims to propose such a flood forecast method. Currently, numerical weather prediction (noted as NWP hereafter), at the global scale, has developed rapidly with the development of science and technology (Demeritt et al., 2007; Pappenberger et al., 2008). Furthermore, service-oriented architecture (noted as SOA hereafter) has been successfully applied in a wide variety of fields (Erl, 2005; Bell, 2008; Linthicum, 2009); however, the application of SOA for ensemble flood forecast cannot be found in the literature. As a result, this paper proposes the general framework of an SOA for ensemble flood forecast based on the NWP for the first time, taking advantage of the high-accuracy NWP, high-capacity cloud computing and an interactive web service. On the one hand, NWP is introduced to increase the forecast lead time; on the other hand, SOA is introduced to improve the forecast efficiency. In this study, the major challenges in developing such a flood forecast method are (i) automatically downloading and updating the predicted rainfall from the NWP in real time, (ii) implementing multiple scenarios for flood forecast at the same time by using high performance computing (noted as HPC hereafter) job scheduling, and (iii) transferring warning information efficiently by using an interactive web service. Due to these state-of-the-art technologies, this method would be useful for preventing or reducing the losses caused by flood disasters in mountainous river basins after being put into practice.

2. Methodology

A conceptual framework of the SOA for ensemble flood forecast based on the NWP, combining the advantages of the high-accuracy NWP, high-capacity cloud computing and an interactive web service, is proposed in this paper (Fig. 1). In the following, the basic structures of the SOA, NWP, hydrological model used for ensemble flood forecast, HPC job scheduling used for multiple scenarios, and interactive web service used for information transfer will be introduced in detail.

2.1. Service-oriented architecture

Service-oriented architecture (SOA) is essentially a software design methodology based on structured collections of discrete services that collectively provide the complete functionality of a complex application (Erl, 2005). Each service is a well-defined, self-contained set of functions and built as a discrete piece of code, which makes it possible to reuse the code by changing only the interactions of a certain service with other ones rather than the code of the service. Moreover, services communicate with each other closely, involving either simple data passing or complex coordination (Bell, 2008, 2010). Hence, SOA is considered as the infrastructure supporting communications between services, and some connecting services are required. Currently, web service, a set of protocols enabling services to be published, discovered and used in a technology neutral form, seems to be the most feasible way for developing the SOA (Benslimane et al., 2008). By using a web service, a service consumer (e.g., the user client) can send a request message to a service provider (e.g., the cloud server), and then the service provider can return a response message to the service consumer as soon as possible (Linthicum, 2009). It is worth noting that the SOA is an architecture not only of services, as seen from a technology perspective, but also of policies, practices and frameworks, by which we can ensure that the right services are provided and consumed.

As shown in Fig. 1, the cloud server and user client are regarded as the two primary systems in the SOA. Data collection and management, hydrological simulation, flood forecast and early warning are achieved on the cloud server; meanwhile, messages of flood control requirements from different users and flood early warnings from the cloud server are transferred between the cloud server and user client by using a web service in a social network. Fig. 2 presents the flowchart of the SOA for ensemble flood forecast based on the NWP, and the details are introduced as follows.

First, the NWP data are downloaded automatically, in real time, from websites that provide relevant data and then stored in the database on the cloud server (see Section 2.2 for details); moreover, flood control requirements are provided by users on the clients and stored in the database as well. Second, a physically based hydrological model, the Digital Yellow River Integrated Model (noted as DYRIM hereafter) (Wang et al., 2007, 2015; Li et al., 2009a,b), is adopted to compute the streamflow by using the NWP data; the simulation results are also stored in the database. Third, judging from the comparison of the simulation results against the flood control requirements from different users, flood early warnings are generated, if necessary; in addition, along with the real-time updates of the NWP data, the simulation results are refreshed in a timely manner so that the latest early warnings are always available. Finally, by using a web service, the flood forecast and early warning system on the cloud server can send warning information to the potential sufferers. Moreover, users on the clients can also run the DYRIM on the cloud server by themselves at any time to acquire the simulation results within the forecast lead time of the NWP data so that better preparation can be made for the possible flood disasters. Overall, it is clear that such a process of flood forecast and early warning is quite different from the current process and is useful to the potential sufferers, affording them much more response time for flood disasters.

2.2. Numerical weather prediction

Normally, numerical weather prediction (NWP) can be divided into two categories: single NWP and ensemble NWP. The single